MBMG 238

UPPER TETON AQUIFER STUDY
FINAL PROJECT REPORT

GEOLOGY AND HYDROLOGY OF THE BURTON BENCH AND TETON VALLEY AQUIFERS

by

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Abstract

Sand and gravel deposits on the Burton Bench and in the Teton River Valley between the City of Choteau and the Rocky Mountain front occupy 6 distinct topographic levels. The oldest (level 6) deposits are pre-Illinoian and possibly late Pliocene in age. Level 5 deposits are probably early illinoian in age based on erratic and glacial till exposures. Levels 3 and 4 are most probably late Illinoian deposits because Canadian shield erratics rest on their surfaces at altitudes as high as 3,970 feet above sea level. A problem with the late Illinoian interpretation of the level 3 and 4 deposits results from their apparent continuity with deposits emanating from the base of the late Wisconsin alpine Teton River terminal moraine to the west. To date, the problem is unresolved but could be explained by the superposition of the Wisconsin Teton River moraine on older, Illinoian age morainal deposits. Levels 1 and 2 represent Wisconsin erosion and deposition in the Teton River drainage.

The Burton Bench aquifer north of Choteau in the Farmington-Agawam-Bynum area contains approximately 300,000 acre feet of water in storage. The aquifer has been characterized by high water table conditions in its recharge and discharge zones and by relatively deep water tables in its middle (storage) zone. Ground water generally flows eastward following the topographic slope of the land surface. Recharge to the aquifer is derived from ditch leakage and deep percolation through flood irrigated fields and results in seasonal water table fluctuations in the recharge zone of up to 10 feet. The Ralston Gap, previously thought to be an important source of recharge to the aquifer is relatively unimportant compared to the amount of water derived from leaking ditches and flood irrigated fields. Discharge from the aquifer is by drains, springs, and sub-irrigated fields in the topographically lower parts of the aquifer east of Farmington, along Spring Coulee, along Foster Creek, and along portions of Muddy Creek.

Water level data for the study period did not show upward or downward trends indicating long-term increasing or decreasing storage in the aquifer. However, examination of flow patterns and seasonal water level changes in the aquifer points to a problem with water use. The use of leaky irrigation ditches and flood irrigation of fields for decades has lead to an artificially high water table in the Burton Bench aquifer. The high water table has enlarged the area of ground-water discharge east and north of Farmington by causing subirrigated fields, and springs to occur. Drains have been dug, individuals have appropriated water from the springs and drains, and subirrigated lands have been utilized to grow grass for feed. These uses require specific water levels at or near altitudes of those at the present time. Any activity in the aquifer which lowers the altitude of the water table in the discharge zone of the aquifer can adversely affect these rights. If the water-level dependent water rights in the discharge part of the aquifer are respected, little new development which potentially could lower water levels in the discharge zone should be. If, however, the means of diversion for the water-level dependent rights are converted to those which are not so dependent on specific water levels, much additional development of the aquifer could occur.

The Teton Valley aquifer lines the floor of the Teton River Valley between the City of Choteau and Rocky Mountain front 20 miles to the west. The sand and gravel deposits generally are 20 to 30 feet in thickness but are greater than 50 feet thick in the vicinity of Spring Hill. Water flows generally down-valley

more or less parallel to the Teton River. Recharge to the aquifer occurs through down-valley subsurface flow and from leakage from the Teton River during periods of high flow. Water levels in the aquifer fluctuate seasonally but no upward or downward trends in the water table were noted during the study period.

The most apparent problem in the Teton River Valley aquifer is its susceptibility to contamination, specifically in the vicinity of Choteau where the aquifer provides water to the citizens of the town. It is recommended that the City of Choteau take steps now to protect the quality of water in the Teton River Aquifer so that its needs and uses are not threatened in the future.

Upper Teton Aquifer Study

Final Project Report

Introduction

The Upper Teton Aquifer Study resulted from a continuing history of water rights conflict in a portion of western Teton County, Montana. By 1984, numerous hearings and several court cases had pointed out the need for a general groundwater of an area north of the City of Choteau locally known as the Burton Bench. A groundwater study of the Burton Bench area was expected to provide information to both water users and water managers about how aquifers in the area functioned helping alleviate existing and future water-use problems within the study area. The City of Choteau had also periodically expressed concern about the reliability of its water supply and one goal of the project was to address some of the concerns of the City of Choteau about its water-supply.

In February of 1984 a meeting was held at the Teton County Courthouse for people and agencies interested and concerned about the water problems of the area. State agencies attending the meeting included: the Montana Department of Natural Resources and Conservation (DNRC) to provide information regarding administration of water rights; and by invitation of DNRC, the Montana Bureau of Mines and Geology (MBMG) to provide technical advice. During the course of the meeting, the Department of Natural Resources suggested that one way to resolve some of the water use problems might be to obtain State of Montana Water Development Grant funds for the purpose of studying the groundwater systems of the Choteau area. The DNRC also suggested that one local entity which could apply for such funds would be the Teton County Conservation District (TCCD). The TCCD was interested in sponsoring an aquifer study and contacted MBMG for help in carrying out the work. Subsequent to the February 1984 meeting, several other meetings between the TCCD and the MBMG were held and an application to DNRC resulted for Water Development funds. The original proposal suggested that coupled with the groundwater study a study of surface water, primarily irrigation water distribution systems, be made within the study area. In April of 1985 the 85'th Montana Legislature approved a reduced version of the project through the Water Development Grant Program which included studying only the groundwater within the proposed project area. The Upper Teton Aquifer Study officially began July 1, 1985.

In addition to the $99,996 grant awarded to the Teton County Conservation District from Water Development funds, the Montana Bureau of Mines and Geology contributed approximately $24,000 in in-kind services to the project as a subcontractor to the conservation district. Originally scheduled to end on June 30, 1987, the Upper Teton Aquifer Study was extended an additional year to allow collection of additional geologic, test drilling, and water-level data. The final completion date for the project is June 30, 1988.

The basic goals of the Upper Teton Aquifer Study were to:

1. Identify aquifer parameters for major aquifers within the study area including: aquifer geometry; hydraulic conductivities; storativity; recharge-discharge boundaries; and quality of groundwater.

2. Build a baseline set of groundwater data including information from water-well inventories, lithologic logs, aquifer test analysis, and water-level measurements. The information obtained during the study period was to be used to prepare a hydrogeologic analyses of the data collected during the project period.

In addition to the general goals outlined above, the Ralston Gap area (see Figure 2 for local place names used in this report) was of particular interest to many people in the study area because of a perception that much recharge to the Burton Bench aquifer may be derived from that area. Because of the local interest, the MBMG made a special effort to quantify probable recharge to the Burton Bench Aquifer derived from underflow through Ralston Gap.

Another secondary goal for the project was to use the information gained during the study for the education of local citizens regarding general concepts about groundwater, its movement, and how those concepts apply to local conditions within the Study area. To accomplish this task, a public meeting was held in Choteau on October 5, 1988. At the meeting the most significant results of the Upper Teton Aquifer Study were presented. Also, questions from the public about the information and interpretations derived during the study were answered. This report contains the detailed data and interpretations resulting from the completion of the study.

Description of the Study Area

The Upper Teton Aquifer Study is located in central Teton County approximately 50 miles north-northwest of Great Falls, Montana. Figure 1 shows the location of the study area within the state of Montana. The boundary of the study area is irregular and is shown on Figure 2. The study area includes most of Townships 24 to 26 North and Ranges 4 to 6 West. The eastern boundary of the study area is arbitrarily defined as the eastern edge of the U.S. Geological Survey's 15' Choteau topographic quadrangle or 112 degrees west longitude. The southern edge of the study area is marked by the topographic break along the southern edge of the Teton River Valley exclusive of the Deep Creek drainage and

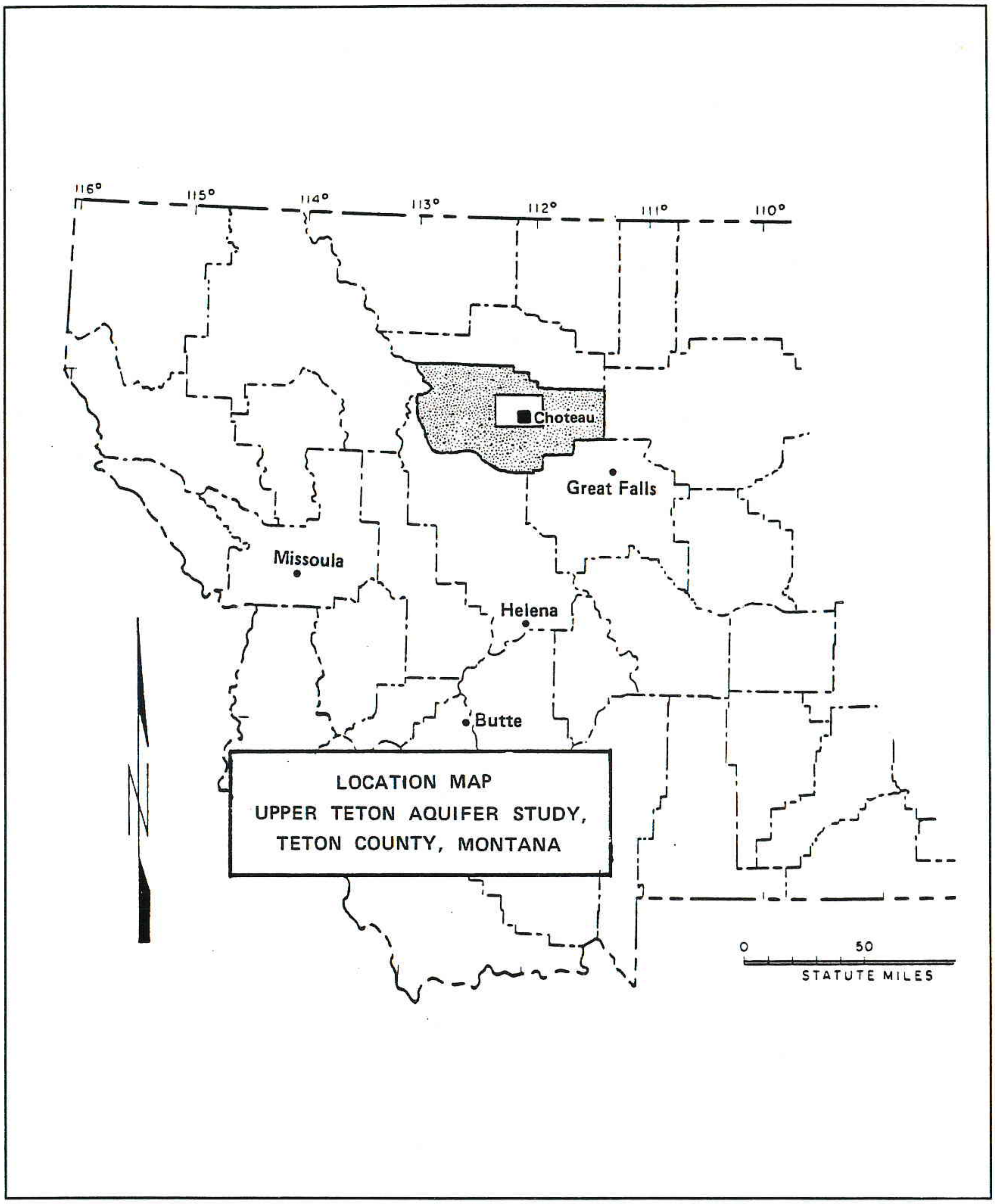

Figure 1: Location of the Upper Teton Aquifer Study within the State of Montana.

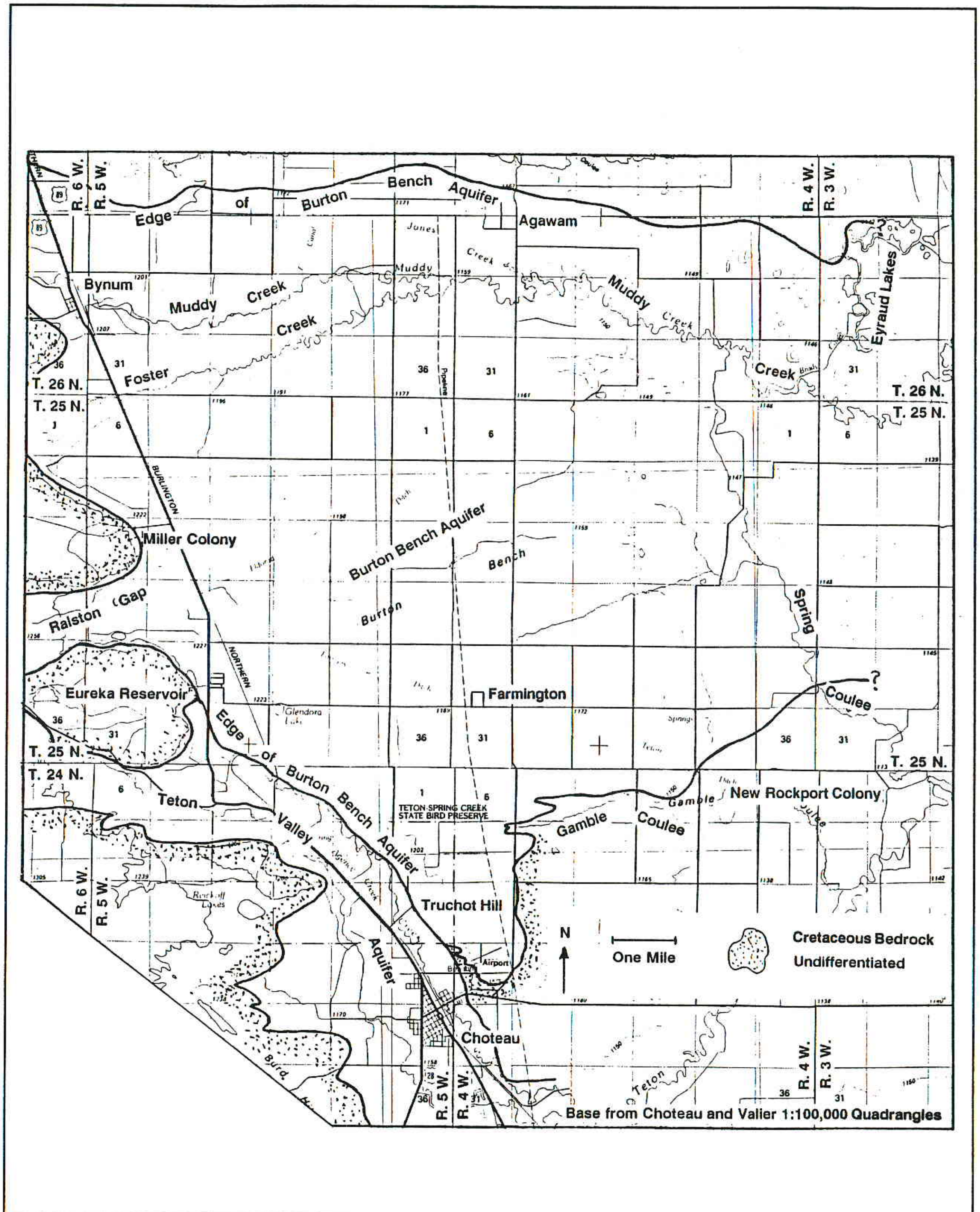

Figure 2: Local place names within the Upper Teton Aquifer Study.

extends to the northwest from about the City of Choteau to about the vicinity of Eureka Reservoir. The southern boundary also extends northeast from the vicinity of the City of Choteau to 112 degrees west longitude. The western boundary extends north from Eureka Reservoir to a point approximately 2 miles northwest of the town of Bynum. The northern boundary extends east-west to a point approximately 1 mile north of Eyraud Lakes. The study area covers approximately 280 square miles and contains most of the area known as the Burton and Agawam Benches, the alluvial valley of the Teton River, and the towns or settlements of Choteau, Bynum, Farmington, Miller Colony, New Rockport Colony, and Agawam. Work on the Upper Teton Aquifer Study was concentrated within the formal study area but excursions outside of the study area for reconnaissance purposes were made eastward to Collins, Montana and westward to the front of the Rocky Mountains to help provide additional data about the geology of the area.

The Upper Teton Aquifer Study area contains two major gravel aquifers divided on the basis of geologic and hydrologic boundaries. The two major gravel aquifers are the Burton Bench aquifer located north of the City of Choteau and the Teton Valley alluvial aquifer extending up the Teton River Valley from Choteau to the vicinity of Eureka Reservoir. In addition to the major aquifers, several minor aquifers contained in sandstones of the basal Eagle Formation in the western portion of the study area exist but were not studied. The locations and areas of the two major aquifers are shown on Figure 2.

Land Description System

Locations of points of interest such as wells, springs, and geologic features will be described by the use of Township, Range, Section, and Tract. The land description system is that used by the Water Resources Division of the

U.S. Geological Survey and a complete example of the land description system is included as Appendix A.

Acknowledgements

Many people have worked together to make the Upper Teton Aquifer Study successful. Foremost are Dale Johnson, Ruth Makin, and District Conservationist John Streich, who all worked hard to assist as much as possible during the course of the study. Cooperators including Cecil Cole, Bert Guthrie, Jim Hamilton (City of Choteau), Bill Leys, Jesse Malone, Walt Malone, Lyle Otness, Ron Otness, and Daryl Stott all allowed access to their land. Many other individuals allowed access to their wells for water-level monitoring and/or water sampling. Use of these wells was critical to the success of the project. Thomas J. Osborne and Roger A. Noble contributed their efforts in managing some of the field work early in the project. Their efforts are well appreciated. Finally, Ike Hitchcock made this project successful by completing one of its most difficult tasks. Ike faithfully measured all of the observation wells on a regular basis for almost 3 years which provided some of the most valuable data derived from the study. Without his effort much less information would be available to document water level changes in the Burton Bench and Teton Alluvial aquifers.

Basic Data

Basic data collected during the Upper Teton Aquifer Study are presented in Appendices at the end of the report. Short descriptions of each type of data, why and how it was collected, and some of its implications are included below.

Static Water Level Data

Hydrographs of static Water level data collected during the Upper Teton Aquifer Study are presented in appendix B. Water levels were determined by measurement with a steel tape of the distance from a predetermined point on the land surface to the water level in the well. Luepold and Stephens type F and digital recorders were also used to monitor water levels more intensively in selected wells. Figure 3 is a map detailing the locations of wells for which there are hydrographs. A number keying the location of the well to the hydrograph appears on the map and is matched by the appropriate hydrograph in Appendix B.

Water level change versus time data as illustrated in the hydrographs is important because it the method most often used to measure changes in groundwater storage within an aquifer. Rises in water level indicate that an aquifer is storing more water than previously; declines in water level indicates that an aquifer is storing less water than previously. By measuring water levels at many points in the aquifer, general knowledge of whether different areas of an aquifer are gaining or losing water can be obtained.

Hydrographs for the Upper Teton Aquifer Study are plotted as altitudes of water above sea level rather than distance to water below land surface. The shape of the hydrograph is the same regardless of which method is used to plot the data. Distance to water below land surface is easily calculated from the hydrographs by subtracting the altitude of the water in the well from the altitude of the land surface at the well site. For Example; on the DNRC/ANDERSON hydrograph (Number UTSWL9 on the map) a water level of 3,849 feet above sea level occurs just before December 31, 1985. Distance to water below land surface at that time was 1.0 feet found by subtracting 3,849 (the altitude

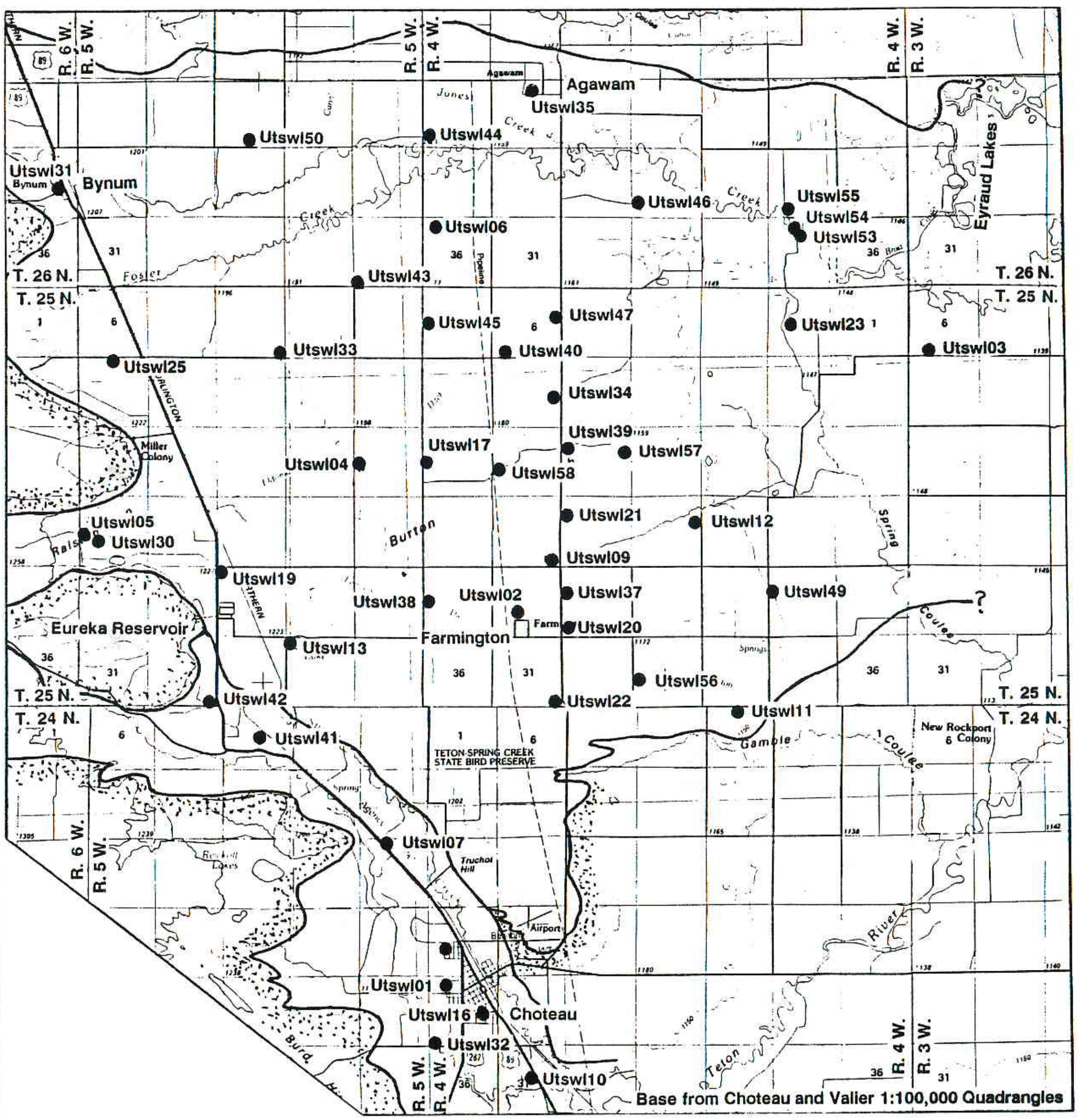

Figure 3: Map of Hydrograph Locations in the Upper Teton Aquifer Study.

of the water in the well) from 3,850 (the altitude of the land surface). Each hydrograph was constructed as nearly as possible to cover a range in time from July 1, 1985, when the Upper Teton Aquifer Study project started, to December 31, 1988. Similarly, water level ranges for most of the hydrographs is 10 feet. Consistency in axis scales aids in comparing hydrographs from different wells. However, water levels in some wells in the study area move more than 10 feet annually and where this is the case, the axis scales on the hydrographs have been adjusted accordingly.

Four water level recorders are still operating within the study area and are being maintained by the Teton County Conservation District. The recorders are located at the TCCD/MBMG/LEYS well (Number UTSWL4); TCCD/MBMG/COLE well (Number UTSWL58); and the TCCD/MBMG/MALONE W. well (Number UTSWL57) in the Burton Bench aquifer. The fourth recorder is installed on a well drilled for the Upper Teton Aquifer Study in the northwestern portion of the City of Choteau. The recorder was not installed until October 1988 and no records are available for inclusion in the report.

Aquifer Test Data

Data obtained from the 8 aquifer tests conducted during the Upper Teton Aquifer Study are contained in appendix C. Information related to pumping rate, water level, and time, obtained during each test are presented in tabular form for each well involved. Consequently, because many of the aquifer tests involve observation wells, 16 sets of aquifer test data are included in the appendix. Tables 4 and 5 on pages 105 and 141 summarize results of the aquifer testing program. Figure 4 is a map showing locations of the various aquifer tests conducted during the Upper Teton Aquifer Study.

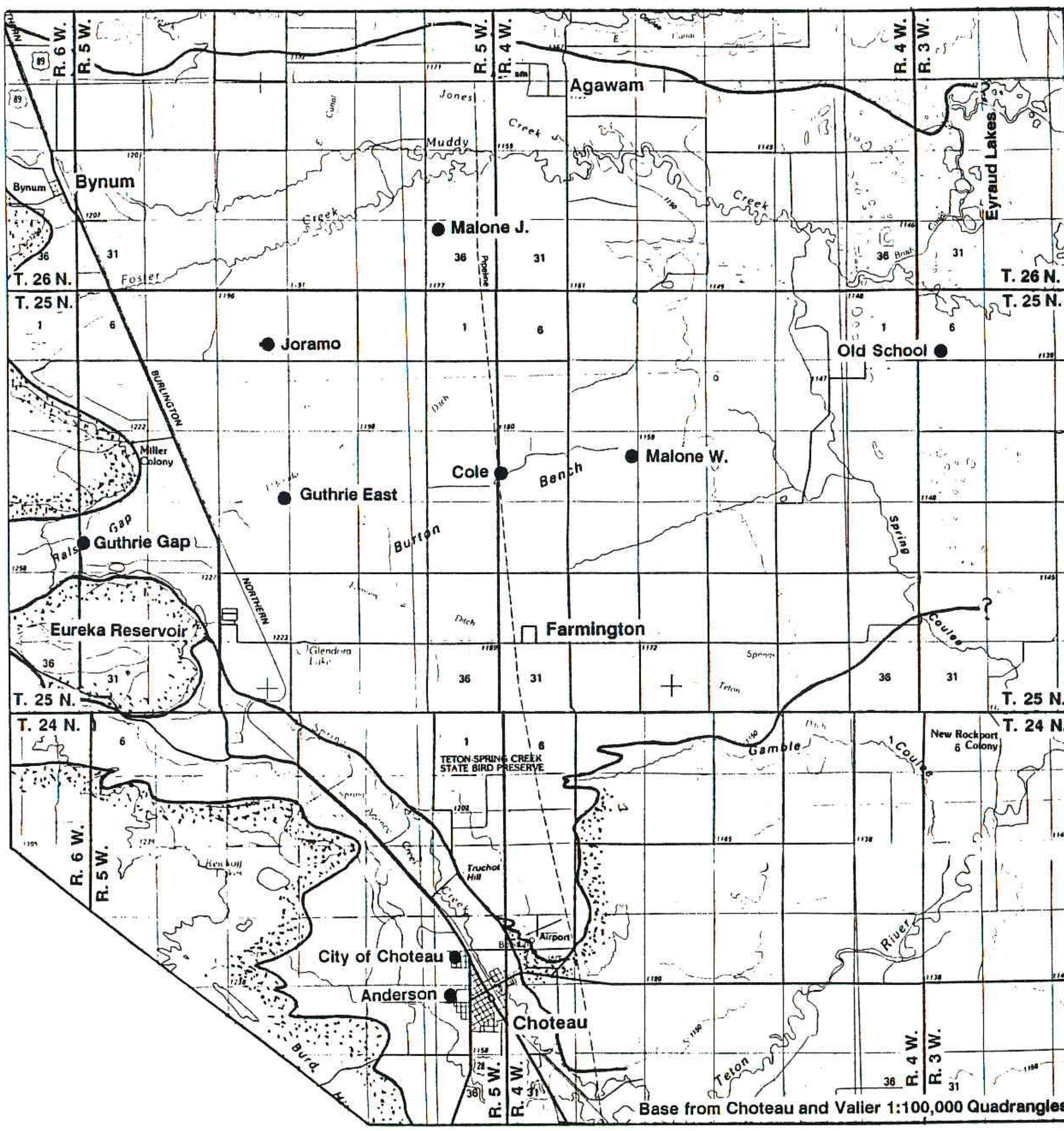

Figure 4: Map of aquifer Test locations for the Upper Teton Aquifer Study.

Data from the aquifer tests are plotted in various forms depending on the type of test and on hydrogeologic conditions found at each site. Constant discharge tests were evaluated using Theis leaky aquifer type curves for artesian conditions and Newman delayed yield type curves for water table conditions. In some cases, aquifer test data were evaluated using both Theis and Newman type curves for purposes of comparison. Step discharge tests were conducted on some pumping wells which did not have associated observation wells. Step discharge test data were evaluated using a method derived by Birsoy and Summers (1980) which accounts for changes in pumping rate during the test and allows all of the step discharge data to be used for calculation of aquifer characteristics. Definitions for terms related to aquifer hydraulics such as transmissivity, hydraulic conductivity, storativity, and specific yield are contained in Appendix C.

Water Quality Data

Appendix D contains both water quality information collected during the Upper Teton Aquifer Study and water quality information which existed in Montana Bureau of Mines and Geology files prior to the study period. Figure 5 is a map of locations for water quality analyses on the Burton Bench and in the Teton Valley aquifer. The analyses are arranged by township, range, and section within the Teton Valley and Burton Bench aquifers. The section for the Teton Valley aquifer contains 5 analyses all collected during the study period. The Burton Bench portion of the appendix contains 36 analyses of which 31 were collected during the project period and 5 came from bureau data files. The analyses provide a profile of water quality in the Burton Bench and Teton Valley aquifers during the project period.

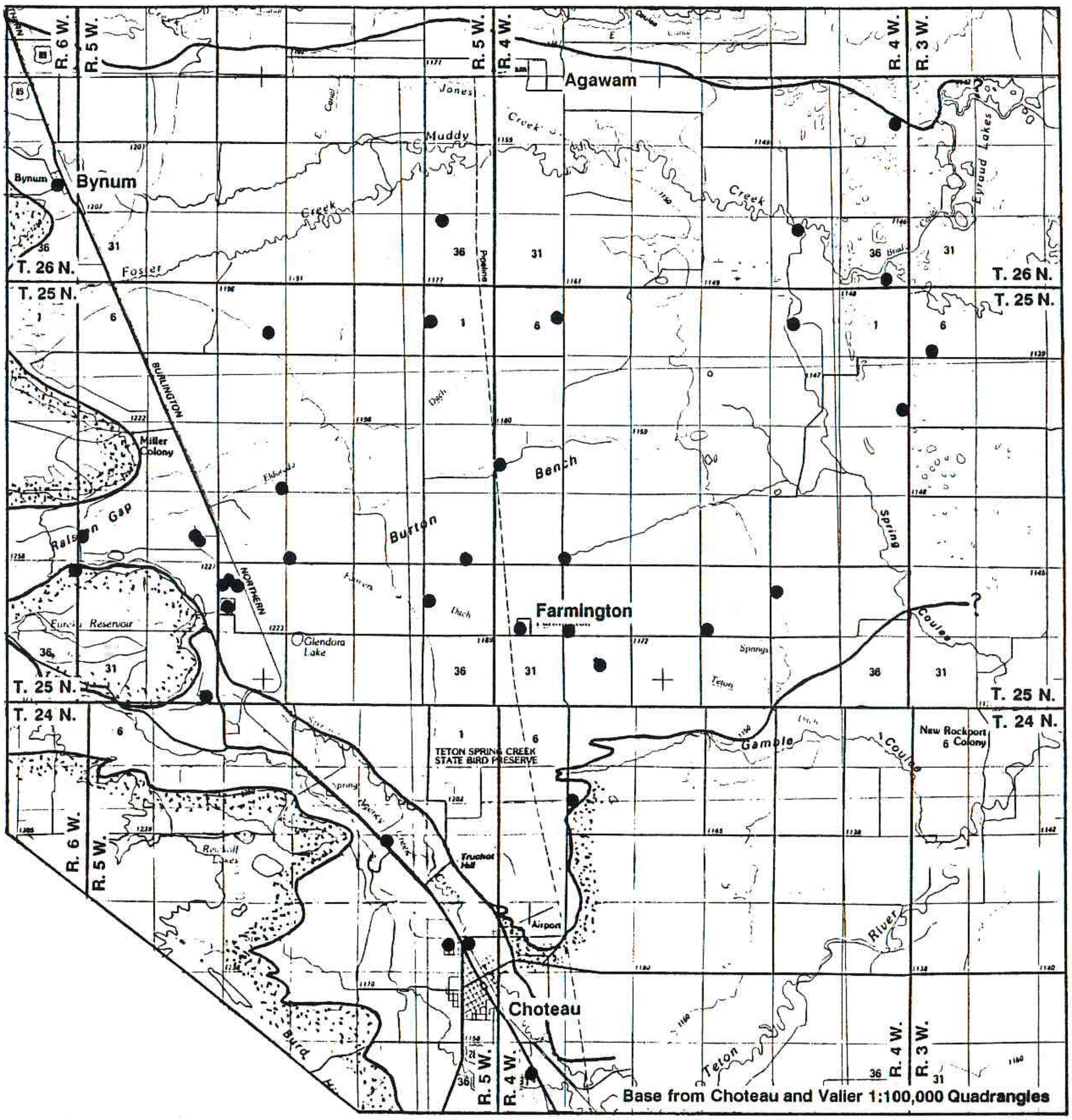

Figure 5: Map of water quality analyses locations for the Upper Teton Aquifer Study.

Drilling Results

During the Upper Teton Aquifer Study 24 drill holes were constructed to provide data about the geology and hydrology of the study area. Appendix E contains lithologic and construction logs for these wells. Drill hole locations for the aquifer study are contained on Figure 6. Well drilling provided data regarding depth to bedrock for the Burton Bench aquifer, provided points to measure static water levels, and points to conduct aquifer tests in both the Burton Bench and Teton Valley aquifers.

An observation well within the study area was drilled for one or more of the following reasons.

1) The well was necessary to provide lithologic and depth to bedrock information about a portion of the study area.

2) The well was necessary to provide a site at which aquifer testing could be conducted within the study area.

3) The well was necessary to provide temporary or long term sites for measurement of water levels in the aquifer.

Approximately 50% of the wells (13 of 24) were drilled with the Montana Bureau of Mines and Geology's auger drill rig and served mostly purposes 1 and 3. Most wells drilled with the auger rig were in the Ralston Gap Portion of the Burton Bench aquifer where 10 holes were drilled and cased with 2 inch diameter PVC casing. These wells were points where water level information on the Ralston Gap portion of the Burton Bench aquifer could be collected.

One production well and two observation wells were also drilled with the auger drill at a site selected within the City of Choteau to meet purpose number 2. The production well was used for a long term constant discharge aquifer test

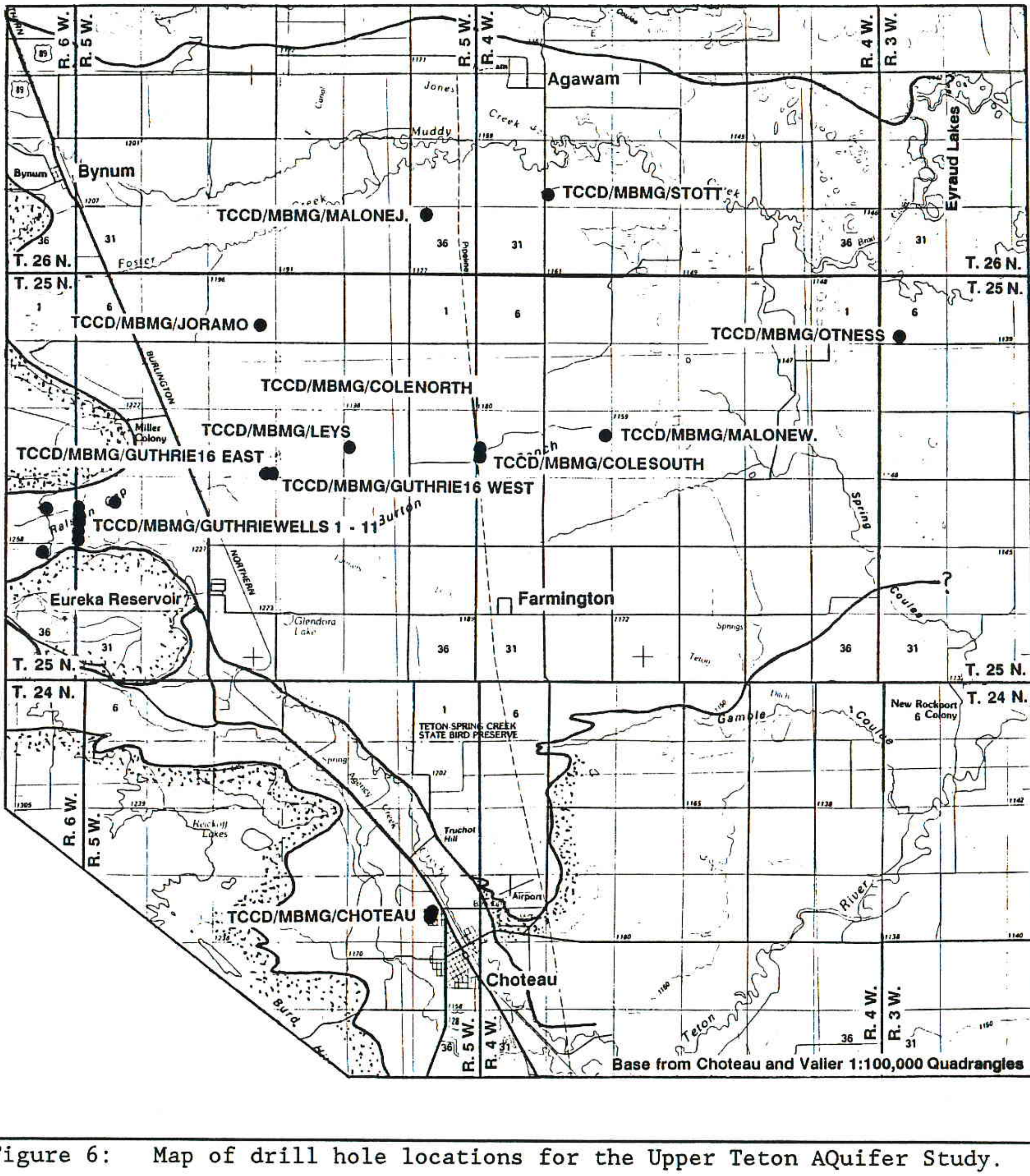

Figure 6: Map of drill hole locations for the Upper Teton AQuifer Study.

of the Teton Valley aquifer. A water level recorder has been installed at one of the observation wells at the City of Choteau site for long term monitoring of static water levels.

All but one of the remaining wells (10 of 24) were drilled with the Montana Bureau of Mines and Geology rotary drill rig. The wells drilled by the MBMG served all three purposes listed above with three exceptions. The Cole South well and the Guthrie East well, were drilled only to be observation wells for the Cole North and Guthrie West wells during aquifer tests. The Leys observation well was drilled to provide lithologic and static water level data only and was completed with 2 inch diameter casing.

One well was drilled under contract with a commercial driller. The Old School/Otness observation well required setting and grouting of surface casing for which the bureau did not have the proper equipment. The Old School/Otness observation well was drilled near an existing unused well to create a pumping well- observation well pair for aquifer testing purposes.

Climatic Conditions

The area contained in the Upper Teton Aquifer Study is semi-arid receiving approximately 11.3 inches of precipitation annually. Annual precipitation data for the Choteau airport, obtained from the National Weather Service are shown on Figure 7 and monthly precipitation data for the years 1985 through 1988 are shown on Figure 8. Annual precipitation since 1948 varies from lows of between 5 and 6 inches in 1960 and 1973 to highs of approximately 18 inches in 1964 and 1974. The average precipitation over 40 years is 10.99 inches per year. Removing some of the higher frequency variations (see Figure 9) in the annual

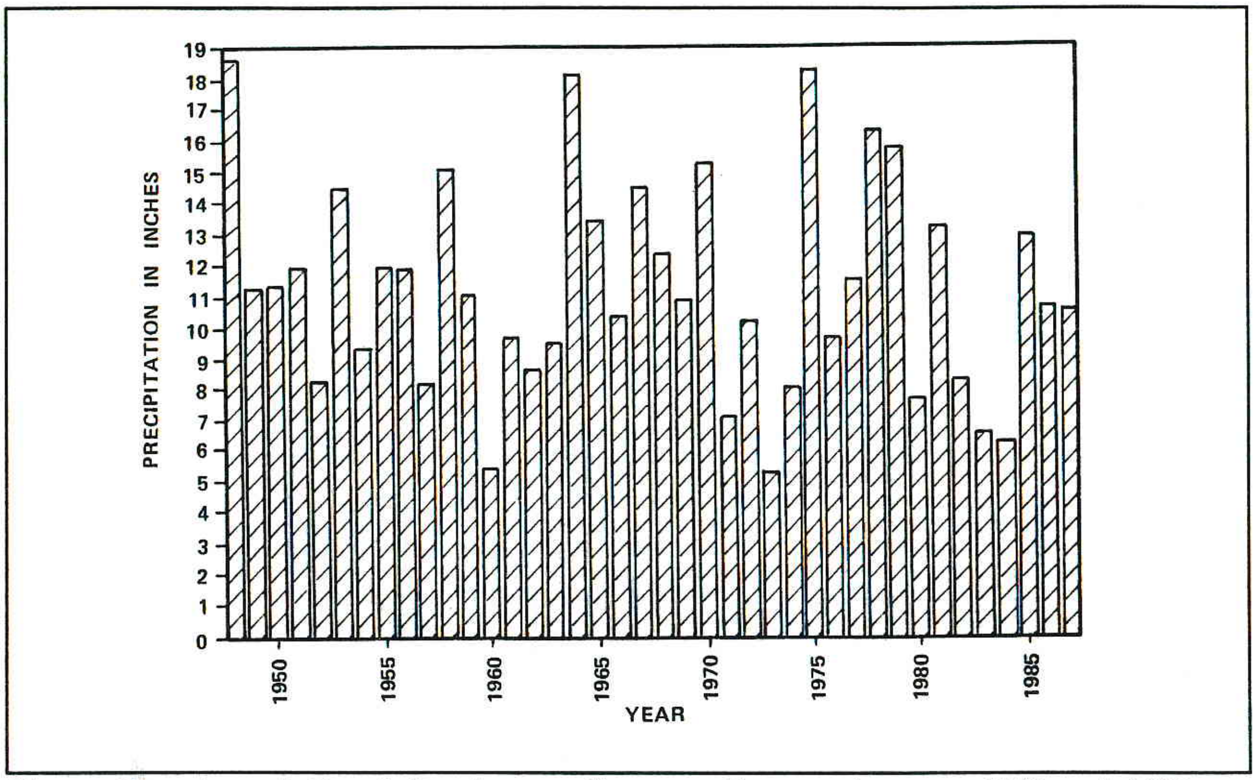

Figure 7: Annual Precipitation at Choteau, Montana between 1948 and 1987.

precipitation by using a five year moving average, a well defined wet-dry cycle with a period of about 10 years can be seen. Figure 9 shows that the wettest periods in the last 35 years were between 1963 and 1968 and between 1976 and 1978.

The Upper Teton Aquifer Study area, according to Figures 9 and 10, is in a prolonged portion of the dry side of the cycle. This is shown by Figure 10 which compares the precipitation in any one year against the 40 year average precipitation by accumulating each year's departure from the average precipitation and plotting the cumulative departure versus time. Each wetter than normal year adds to the departure, each dryer than normal year subtracts from the departure. The wet-dry cycle in the data is apparent in this illustration also. The cumulative departure of precipitation from the long-term

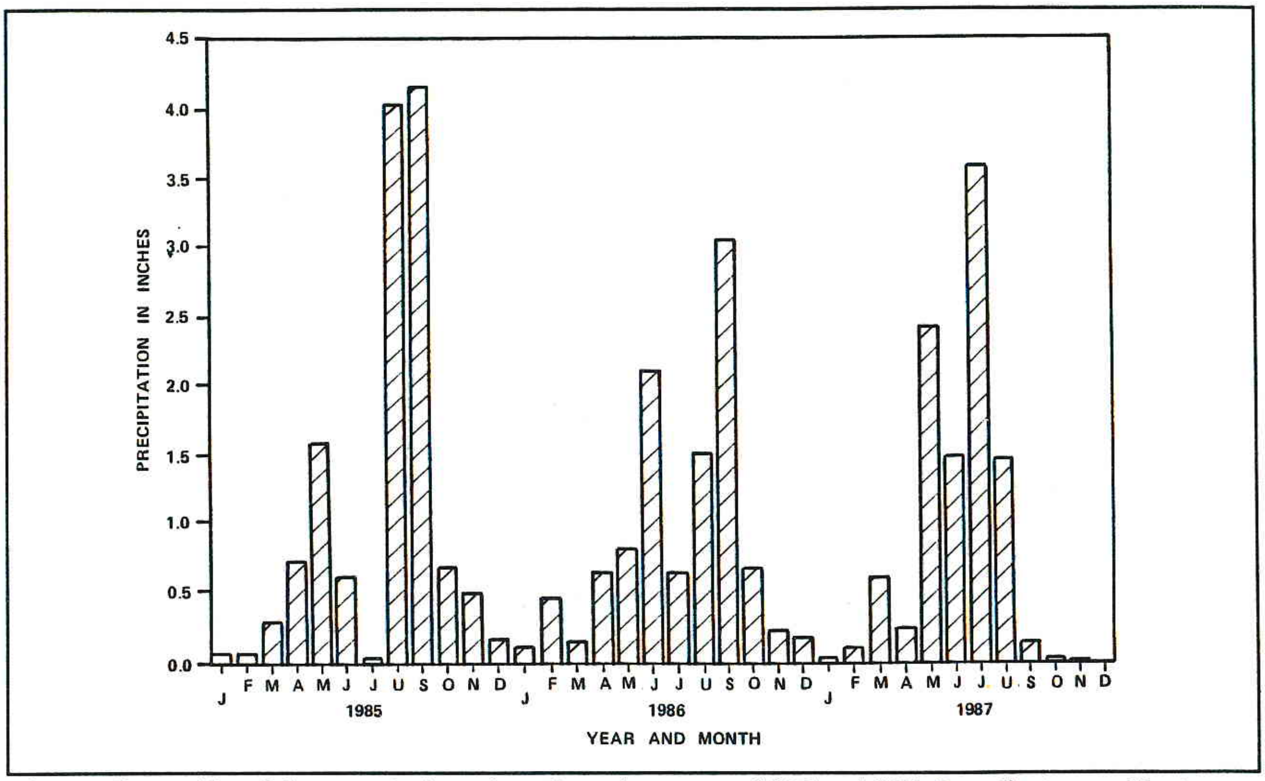

Figure 8: Monthly precipitation for the years 1985 - 1987 for Choteau, Montana.

average has been negative since about 1981 and has declined to a point in 1986 where the cumulative departure is 0.0 inches of precipitation. The prolonged dry period indicates that the wet-dry cycle seen in the preceding 20 years may be undergoing modification. Figure 11 is a plot of daily precipitation versus time for the period of the study and shows that the summers of 1986 and 1987 were wetter than the summer of 1988. Only precipitation occurring after July 1, 1985 is shown on the chart so no judgement can be made about the summer of 1985 from these data. The highest daily rainfall occurred in July of 1987 and produced almost 1.8 inches of water at Choteau. Rainfall events greater than 1.0 inch in intensity occurred 5 times during the study period and events of at least 0.5 inch 20 times. Precipitation events with intensities of less than 0.1 inches occurred numerous times. Seasonal variation of precipitation during each year of the study period is shown on Figure 11. The daily precipitation chart can be used to compare precipitation during the project period against water level changes on hydrographs.

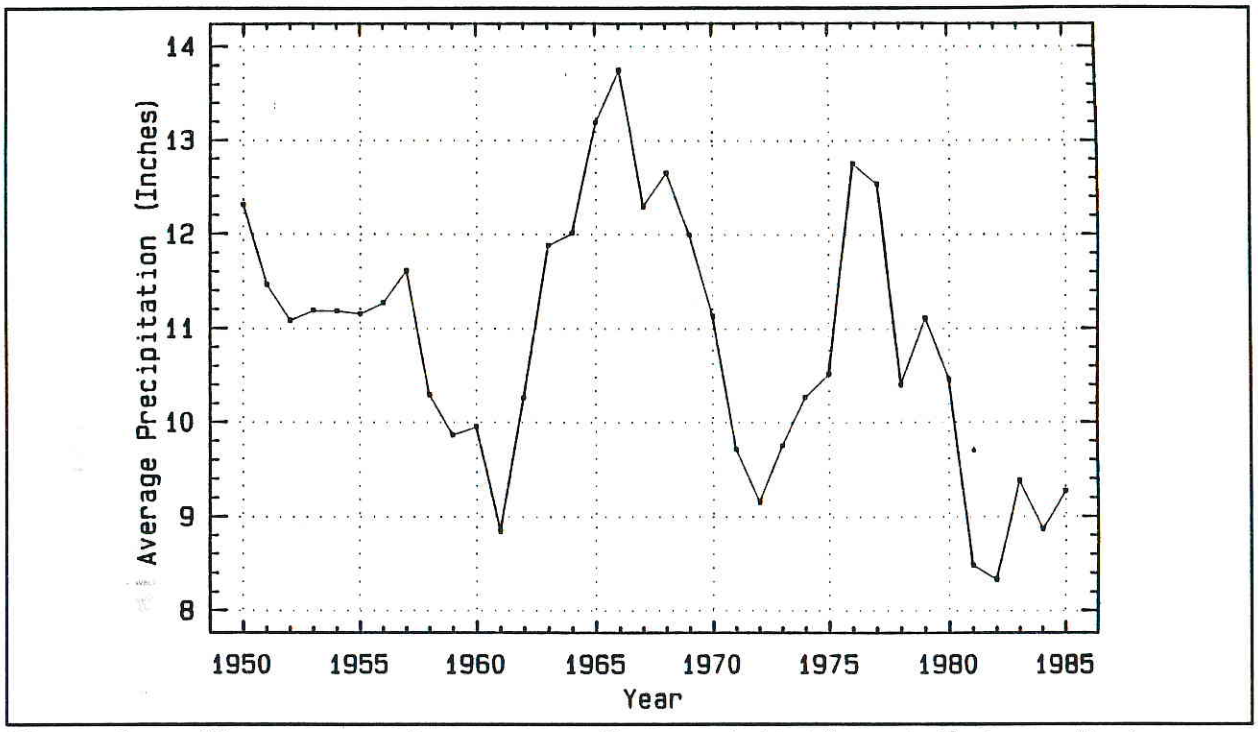

Figure 9: Five year moving average for precipitation at Choteau, Montana.

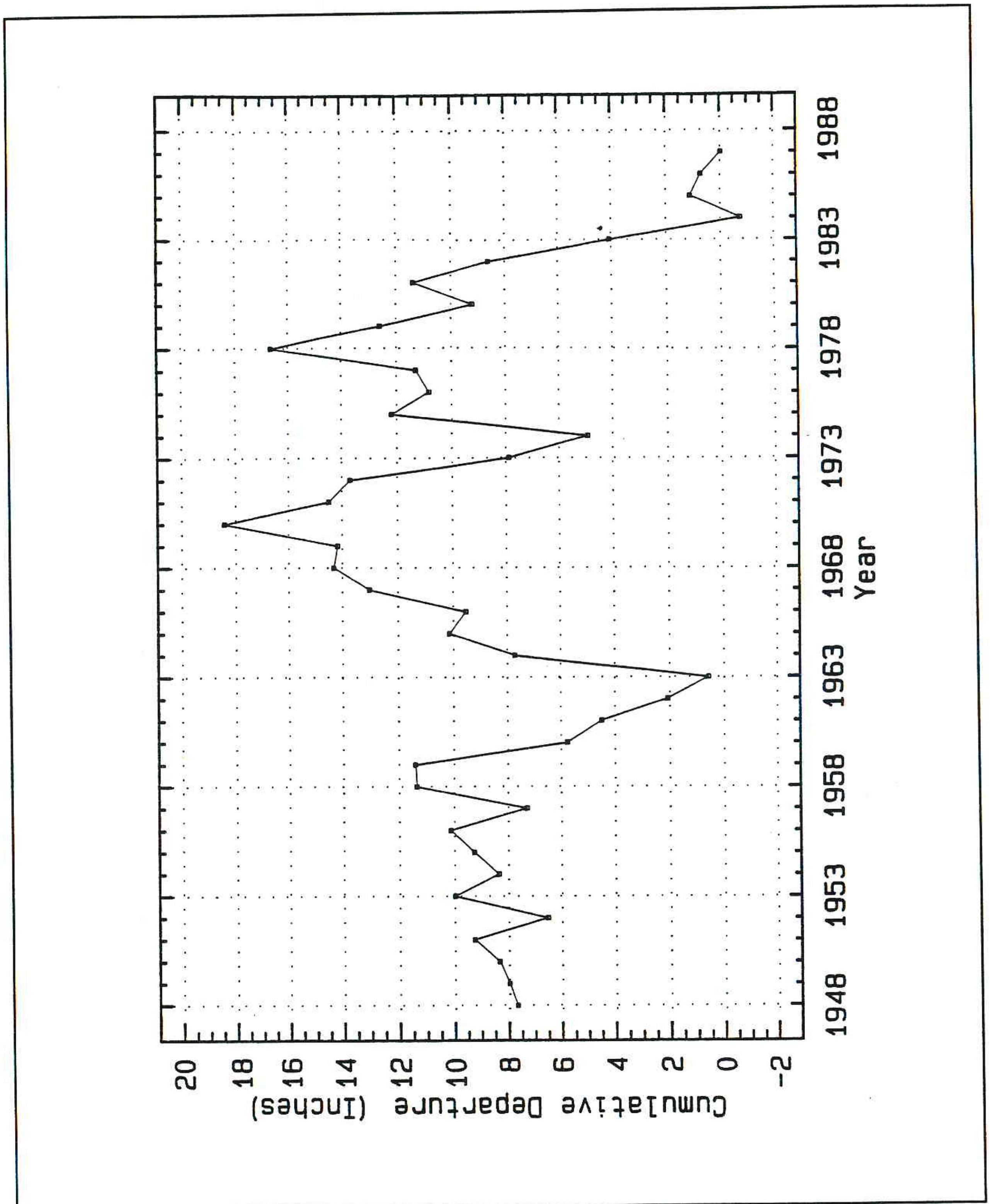

Figure 10: Cumulative departure from normal for the years 1948 - 1988 for precipitation at Choteau, Montana.

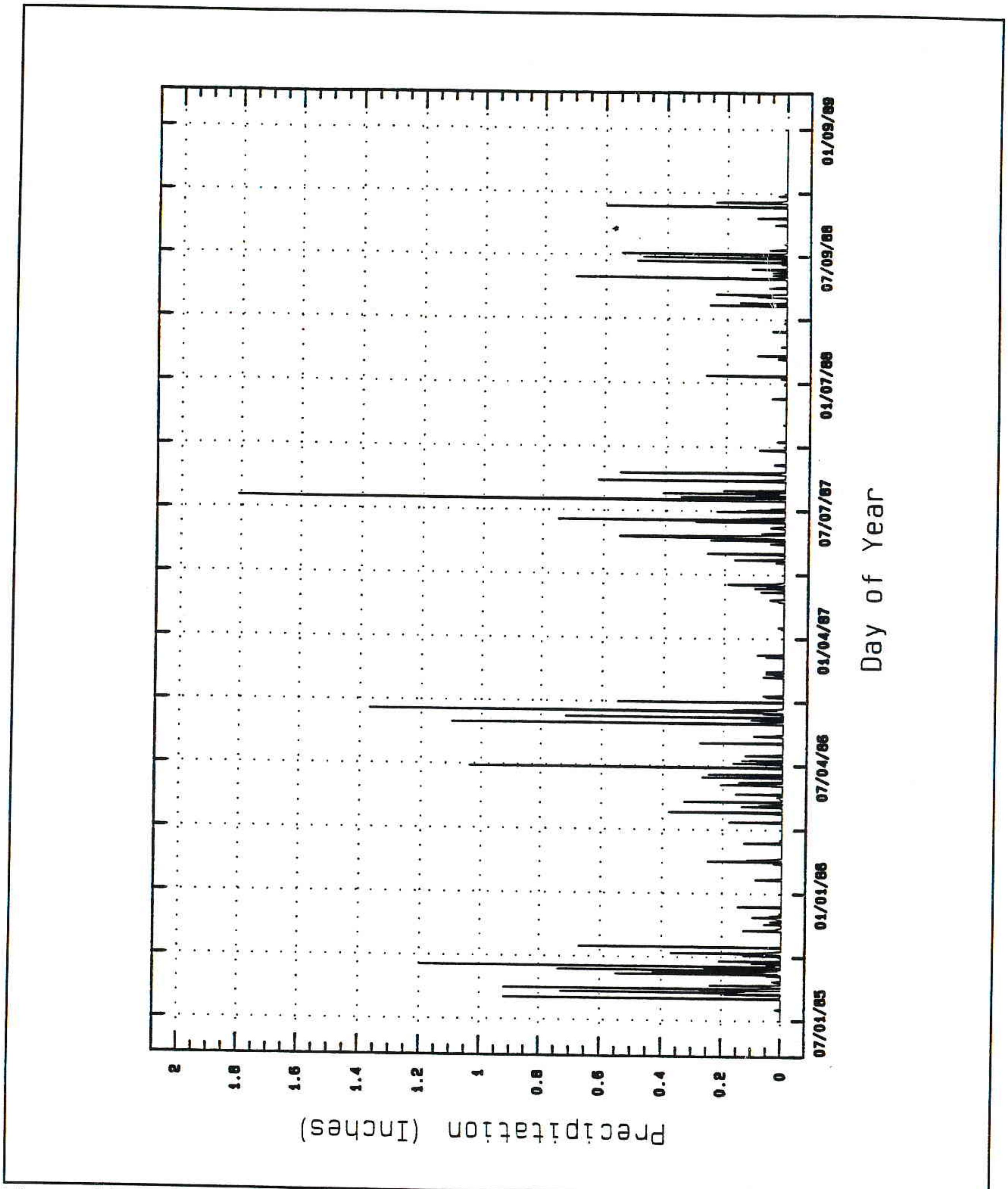

Figure 11: Daily Precipitation at Choteau, Montana, between July 1, 1985 and December 31, 1988.

Previous Work

Geology

Few workers have attempted to discuss the surficial geologic deposits of the project area. Alden (1932) published a large paper on the physiography and glacial geology of eastern Montana and in it discussed the surficial geology of the study area. Alden produced his major work during the period of strong influence of the Davisian cycle of Geomorphic development, a cycle which culminated in the creation of the peneplain -- an extensive area of little or low relief which was crossed by large sluggish rivers. A peneplain would remain in existence until geologic uplift or another similar mechanism would cause the rivers to entrench themselves and begin to dissect the peneplain. Alden viewed most of the gravel capped uplands in Montana and southern Canada as remnants of now dissected peneplains and mapped the gravel deposits of the Burton Bench as his number 3 or youngest major erosional surface. Alden also mapped the western edge of the continental ice sheet which crosses the eastern portion of the Burton Bench, and the morainal deposits of the Teton River glacier where it exits from the mountain front about 25 miles west of Choteau. Alden did not discuss the thickness or the lithologic makeup of the gravel deposits forming the Burton Bench.

Chalmers (1968) described in much more detail the Quaternary glacial geology in the vicinity of Choteau, Montana, including the Burton Bench area. Chalmers attempted to define deposits of the "Bull Lake" substage of the Wisconsin glaciation in the Teton River Valley by mapping glacial, alluvial, and lacustrine sediments in the area. Chalmers concluded that most of the Burton

Bench was an alluvial fan comprised of "Pinedale" glacial outwash derived from the Teton River glacier, that the Teton River had been diverted through the Ralston Gap (see figure 2) to deposit the alluvial fan, and that below about 3,890 feet above sea level, the Pinedale fan was covered by glaciolacustrine deposits or glacial till from continental glaciation. No attempt was made by Chalmers to differentiate between different geomorphic surfaces occurring on the Burton Bench. Chalmers presented no data regarding the general thickness of the outwash deposits on the Burton Bench or their subsurface eastward extent and did not attempt to describe the hydrogeology of the area.

Nimick etal (1983) described the hydrogeology of the Pine Butte Swamp approximately 25 miles west of Choteau and in doing so described some of the Pleistocene geology of the Teton River Valley in that area.

Mudge etal (1983) have produced the most recent geologic mapping for the Choteau area. They mapped the Burton bench area as "older" undifferentiated gravel of Pleistocene or even late Pliocene in age. Mudge etal mapped the alluvial valley of the Teton River as "recent" alluvium including glacial outwash deposits of "Bull Lake" and younger in age. Therefore, Mudge etal considered the Burton Bench area to be covered by gravel deposited prior to the "Bull Lake" substage.

Hydrogeology

Relatively little work has been completed on the hydrogeology of the Upper Teton Aquifer Study project area. Fisher (1909) discussed both the Burton Bench and Teton River Alluvial aquifers. He noted that wells at Choteau obtained water from three distinct horizons in the alluvial deposits at 7, 27, and 48 feet below land surface. Fisher stated that the water quality was similar at these levels to that of the Teton River. Regarding the Burton Bench, Fisher (1909) observed that before irrigation ditches crossed the Burton Bench, water was found near the base of the gravel deposits capping the bench. In 1909 after a number of years of irrigation development water was generally found only 10 to 12 feet below land surface over much of the Burton Bench area. Calvert, in a section written for Fisher's 1909 paper, described the "Muddy Creek Artesian Basin" which lies northeast of the Burton Bench. Water quality in the basin was described as good by Calvert after examination of about 20 artesian wells. Wells were described as ranging in depth from 16 to 100 feet below land surface. Most wells were augured by hand through what was described as overlying "impervious lacustrine clay". Recharge for the artesian basin was postulated to be underflow though the Ralston Gap.

Norbeck (1976) completed the most detailed overview of the hydrology of the Burton Bench prior to the Upper Teton Aquifer Study. Static water level data were collected for a approximately one year, some water quality data were collected, and the effects of pumping a large irrigation well drilled in the artesian portion of the aquifer were analyzed.

Norbeck suggested that the aquifer was recharged by infiltration of snowmelt, precipitation, and irrigation water in the western portion of the aquifer. Groundwater, according to Norbeck, moved downgradient towards the east and discharged in part into Muddy Creek in sections 35 and 36 of Township 26 North, Range 4 West. Other areas of discharge included the upper portions of Spring Creek and areas east of the study area. Norbeck concluded his report with a series of questions that needed to be answered prior to being able to determine the amount of water that could be safely developed from the aquifer.

The questions included data needs for the areal extent of the Burton Bench aquifer, thickness variation data for the aquifer, hydrologic data for the aquifer, recharge-discharge data for the aquifer, and boundary conditions for the aquifer.

Geology of the Upper Teton Aquifer Study

A complete discussion of the geology of the Upper Teton Aquifer Study Project Area would necessarily include a complete description of all of the bedrock formations of the study area. Mudge etal, 1983, showed that bedrock formations under the surficial deposits included the Virgelle Sandstone, Telegraph Creek Formation, and the Mowry Shale all of Cretaceous age. The Telegraph Creek Formation and the Mowry Shale are non-aquifers in the study area and were not included in the aquifer study. The Virgelle Sandstone, which outcrops in the vicinity of Ralston Gap, does provide water to a few wells and may play some role in recharge to the Burton Bench aquifer. However, little data for aquifers in the Virgelle Sandstone were collected and no conclusions regarding these aquifers were drawn.

Post Tertiary geology of the project area is related to two primary geologic controls: lateral migration of the Teton River while carrying sand and gravel from front range of the Rocky Mountains; and encroachment of continental glacial ice on the study area from the east and northeast. Combination of these two controlling factors created situations where large amounts of sand and gravel were deposited both on the Burton Bench and in the Teton River. Older surficial deposits (Pre-Pleistocene) are related to streams and rivers which flowed away from the western front of the Rocky Mountains.

Geomorphology and Geology

The Upper Teton Aquifer Study area and its vicinity contain landforms which when evaluated provide much information regarding its surficial geology. Erosional and/or depositional surfaces; the Ralston Gap, a large wind gap in the western portion of the study area; the Burton Bench alluvial fans which are important because they contain aquifers; the Teton River Valley and its gravel deposits; alpine glacial landforms; continental glacial land forms; and glaciolacustrine deposits are all features of the study area which when evaluated can contribute to the understanding of the surficial geology.

Erosional and/or Depositional Surfaces

The study area and the vicinity of Choteau contains numerous erosional and/or depositional surfaces, analysis of which help explain the history of the area's surficial geology. The surfaces include: High-level gravel capped benches which stand 500 to 700 feet above present stream levels; mid-level benches which stand 300 to 400 feet above present stream levels; and low-level benches which stand from 10 to 120 feet above the Teton River.

High-Level Benches: Alden (1932) and Chalmers (1968) noted and mapped gravel covered benches (Alden's Number 1 Bench) which stand up to 700 feet above the present level of the Teton River. The benches are covered with 15 to 30 feet of coarse, poorly stratified sand and gravel that contains large amounts of red and brown quartzite. The highest gravel capped surfaces above the present erosional level of the streams were correlated by Alden to the "Flaxville" surface of north-central Montana. None of the highest surfaces occur within the study area but the 7-mile hill area, located in Sections 24 and 26 of Township 23 North, Range 5 West a few miles south of Choteau, was considered by Alden to be "Flaxville". Other "Flaxville" surfaces occur north of the study area on the upper portions of the Pendroy Bench and about 10 miles east of Choteau on the Teton Ridge. Chalmers (1968) noted that all of the "Flaxville" surfaces in the vicinity of Choteau dip to the northeast and are not aligned with present drainages indicating that streams depositing gravels now capping the high-level surfaces may have been flowing northeastwardly.

Mid-Level Benches: Alden (1932) also mapped a series of mid-level benches 300 to 400 feet above the present erosional level (Number 2 Bench). Chalmers (1968) mapped several surfaces with in the Upper Teton Aquifer Study area which she tentatively correlated with Alden's Number 2 bench or terrace. Chalmers (1968) speculated that the flat topped hills north and south of the Ralston Gap in Sections 18 and 30 of Township 25 North, Range 5 West may be remnants of remnants of the mid-level surfaces but noted that they were virtually devoid of sand and gravel deposits being mostly bare bedrock. West of Choteau and west of the study area Chalmers (1968 page 27) mapped argillite, quartzite, and limestone gravel caps up to 20 feet in thickness on hills locally known as Teton Buttes in sections 15, 22, and 23 of Township 24 North, Range 6 West. The gravel caps are about 500 feet above the present erosional level of the Teton River. Farther west in sections 15 and 24 of Township 24 North, Range 7 West two other gravel capped buttes exist which Chalmers also correlated with the mid-level benches. The upper surfaces of these un-named buttes are about 400 feet above the Teton River.

Low-Level Benches: Photogeologic interpretation and cursory field examinations show that a number of lower altitude benches associated with the present Teton River exist between Ralston Gap and the terminal moraine of the Teton River glacier in the southeast corner of Township 25 North, Range 8 West. Detailed examination indicates that similar surfaces are also present on the gravel deposits which cover much of the Burton Bench. A brief discussion of the erosional and/or depositional surfaces of the Teton River between the mountain front and the Burton Bench is warranted because their evaluation will help explain the geology of the gravel deposits on the Burton Bench. Plate 1 illustrates geomorphic features of the study area that are discussed in this report.

The highest altitude and presumably oldest of the low-level surfaces (Number 6 on Plate 1) occurs in portions of sections 17 and 18 of Township 25 North, Range 8 West and is approximately 120 feet above the present river level. The bench is elongate in an east-west direction and dips towards the east-southeast at about 40 feet per mile. Chalmers (1968) did not map this surface as being underlain by gravel but a short field visit to the bench showed that the surface is underlain by about 40 feet of coarse limestone/dolomite sand and gravel in Section 19 A of Township 25 North, Range 7 West. The largest remnants of the bench are isolated by lower altitude erosional levels and by lower altitude bedrock exposures to the east. The most likely correlative surface on the Burton Bench is the highest altitude gravel capped surface (Number 6 on Plate 1) at Truchot Hill covering portions of Sections 11, 12, and 13 of Township 25 North, Range 5 West. The gravel capped surface on Truchot Hill is approximately 100 feet above the present level of the Teton River and is east-west in largest dimension. The altitude and location of the number 6 surface shows that the gravel under the surface could not have been deposited by a stream flowing through Ralston Gap. A measurement of imbrication in the gravel underlying the number 6 surface at a gravel pit in Section 19 BB Township 24 North, Range 5 West confirms that a stream flowing from a bearing of North 80 degrees West deposited the gravel. A stream aligned along the present valley of the Teton River above the City of Choteau probably deposited the number 6 level gravel. The number 6 surface on the Burton Bench has been eroded on its northern margin by upper tributaries of Gamble Coulee.

Approximately 50 to 60 feet above present river level, the next highest erosional level (Number 5 on Plate 1) extends from beneath the northern edge of the Teton River moraine in Sections 23 and 24 of Township 25 North, Range 8 West. Near the mountain front, the number 5 surface is entirely north of the number 6 level and dips approximately 50 to 60 feet per mile in an east-west direction crossing sections 15, 16, 17, and 18 of Township 25 North, Range 8 West and Section 13, Township 25 North, Range 9 West. A second remnant of this surface also exists on the north side of the upper reaches of Blacktail Creek. The northern remnant is narrower and much more dissected than the larger southern remnant. Chalmers (1968) described this surface as being "Bull Lake" in age and underlain by poorly, sorted, weakly cemented, limestone gravel. Blacktail Creek occupies a valley incised into the number 5 surface and in part represents glacially related erosion because the valley appears from beneath the distal edge of the Teton River Moraine in Section 23 of Township 25 North, Range 8 West. Meltwater from the Teton River glacier apparently flowed down this valley into the basin which is now occupied by Bynum Reservoir.

The largest remnants of level number 5 have been truncated on their eastern ends by erosion caused by Blacktail Creek and its tributaries but several smaller remnants are also east of Blacktail Creek in Section 23 of Township 25 North, Range 7 West. The eastern most remnant of the number 5 level, west of Ralston Gap, is a long narrow finger of gravel covering a hill in Sections 21, 22, and 23 of Township 25 North, Range 6 West. A gravel pit in Section 21 CCB of Township 25 North, Range 7 West exposed 8 to 10 feet of coarse limestone/dolomite sand and gravel on Virgelle Sandstone bedrock. The gravel deposit at the location of the pit is about 50 feet above the present erosional level of the Teton River.

East of Ralston Gap the number 5 surface may be represented by the second highest altitude gravel capped surface on the Burton Bench (See Plate 1). Level 5 on the Burton Bench appears to originate on the southern margin of the Ralston Gap and in Sections 33 and 34 of Township 25 North, Range 5 West. Within the Gap much of level 5 has been removed by erosion. The northern edge of level 5 extends from Section 28 of Township 25 North, Range 5 West to near the town of Farmington in Section 30 of Township 25 North, Range 4 West and extends southward to its boundary with erosional level Number 6. The southern portions of level 5 on the Burton Bench are located such that they probably were not deposited by a stream flowing through the Ralston Gap. There may have been a concurrent channel of the Teton River developed in the vicinity of Eureka Reservoir and the present channel of the Teton River which provided a path for the deposition of the level 5 gravels.

Two closely related surfaces (Levels 3 and 4 on Plate 1), approximately 10 to 15 feet above the present river level in Sections 28 and 29 of Township 25 North, Range 7 West, are the surfaces which cover the northern one half of the Burton Bench and many of the gravel deposits in the Teton River Valley between the Teton River moraine and the Ralston Gap. Level 4 is slightly higher in altitude and is differentiated from level 3 by its topographic position and the less fresh appearance of surficial depositional features such as braiding marks. In the west half of Section 30 Township 25 North, Range 6 West the level 4 surface has a thick well developed soil zone in silt deposits. Braiding marks reflecting individual stream channels on the level 4 surface are subdued by the development of the thicker soil. In the same section, the level 3 surface has a poorly developed soil and braiding marks are strongly visible. Level 4 has been cut out and mostly replaced by level 3 deposits between the Teton River moraine and the Ralston Gap.

Level 4 remnants are completely missing from the Ralston Gap area but are again present on the Burton Bench covering a portion of the bench approximately 1.5 to 2 miles in width between Ralston Gap and Montana highway 220. Chalmers (1968) considered both surfaces 3 and 4 to be outwash from the "Pinedale" glacial event. On the Burton Bench, level 3 and 4 surfaces are 30 to 40 feet above the present level of the Teton River.

Level 3 is the largest surface on the Burton Bench and is in the form of an asymmetrically developed alluvial fan inset into the higher altitude level 4 surface (Fullerton, 1988, written communication). In Section 17 ABBB of Township 25 North, Range 5 West the level 3 surface is covered by about 3 feet of light brown silt which is very calcareous at it's base and which contains numerous pebbles from the underlying gravel. The alluvial fan landform is best developed north and east of Ralston Gap where it nearly coalesces with a smaller alluvial fan called the Bynum Fan in the vicinity of the upper reaches of Foster Creek.

Distinct erosional levels of the Teton River above Ralston Gap that are lower in altitude than erosional levels 3 and 4 also exist. The lowest erosional level consists of the recent floodplain of the Teton River at or only a few feet above the present channel of the river. The second distinct level includes areas of the Teton River Valley which are slightly higher in altitude than the immediate floodplain but which are clearly separated from erosional level 3. Higher Teton River erosional surfaces (>2) are characterized by weakly to strongly developed braiding marks observable on aerial photographs. The lower surfaces (below levels 3 and 4) show meander scars rather than braiding marks indicating a change in river morphology related to decreased bed loads and less discharge from the stream system in post glacial time. Erosional levels below level 3 are not recognized in the Ralston Gap or on the Burton Bench, indicating that the lowest erosional levels of the Teton River postdate deposition on the Burton Bench.

A recent (post-glacial ?) diversion of the Teton River (Fullerton, 1988, written communication) through the Ralston Gap is indicated on aerial photographs by a channel with strong well defined braiding patterns clearly cross-cutting level 3 braiding marks. On the land surface, the post-glacial diversion channel gravels are under weakly developed soils in comparison to level 3 surfaces. The post glacial diversion originates in Sections 26 and 27 of Township 25 North, Range 6 West extending eastward through the Ralston Gap onto the level 3 alluvial fan (see Plate 1). The northernmost position of the post glacial diversion is in Section 2 of Township 25 North, Range 5 West where traces of the channel are approximately 1 mile in width. The post glacial diversion was probably of temporary nature because it is inset only 2 to 3 feet into the level 3 surface on the Burton Bench. The erosional scarp at the head of the post glacial diversion is less than 5 feet in height near the Teton River indicating that the diversion has been occupied by the river in very recent time and that little down-cutting of the Teton River Valley has occurred since the end of the diversion.

The Teton River channel downstream from the Ralston Gap becomes progressively more entrenched into the southern edge of the Burton Bench. The south edge of the valley also has numerous tributaries entering it which appear to be graded to the present river level. The north side of the valley between Eureka Reservoir and the City of Choteau is a young lightly vegetated scarp which has apparently been formed since the end of the last glacial stage. Below about Section 4 of Township 24 North, Range 5 West the valley is approximately 1 mile in width and is flat bottomed. Gravel deposits in the valley generally show meander type scars and features. Erosional levels 1 and 2 exist in this portion of the Teton River Valley but become almost indistinguishable from each other below the vicinity of Eureka Reservoir. Approximately 2 miles above Choteau, the Teton River Valley abruptly widens to about 3 miles. This portion of the valley appears to be filled with alluvial deposits and several small tributary valleys to the Teton River may have also been filled in their lower reaches.

A couple of miles below Choteau, the Teton River makes an abrupt northward bend and begins to follow a path aligned with Deep Creek. A few miles further downstream in Section 23 DCCC of Township 24 North, Range 4 West, where the Dutton Highway crosses the Teton River, the Teton River is cutting into Cretaceous age Colorado Shale bedrock. The altitude of Bedrock at the Dutton Road crossing is approximately 3,690 feet above sea level and is the current base level for the Teton River drainage above this point.

Ralston and Eureka Gaps

A wind gap located in Section 19 of Township 25 North, Range 5 West is known as the Ralston Gap and was formed by repeated diversions of the Teton River through the area of the gap. The Ralston Gap is approximately 0.7 mile in width at its narrowest point and has been incised approximately 200 feet into Cretaceous age Virgelle Sandstone bedrock. Drilling data collected from 11 drill holes within the Ralston Gap shows that it contains approximately 11 to 15 feet of alluvial sand and gravel fill (see Figure 16).

One mile south of the Ralston Gap in the northern portions of Sections 31 and 32 of Township 25 North, Range 5 West is the much smaller less well developed Eureka wind gap now occupied by Eureka Reservoir. Evidence for the development of the Eureka Gap by flowing water includes: its position approximately parallel to the Ralston Gap and the Teton River; the position of the upper end of the Eureka Gap within the erosional complex leading into the Ralston Gap; the presence of sand and gravel sitting on Virgelle Sandstone bedrock in the wind gap along the south side of Eureka Reservoir in Section 36 DAAA of Township 25 North, Range 6 West; and the presence of sand and gravel deposited on the level 5 erosional surface in Sections 33 and 34 Township 25 North, Range 5 West. The lowest altitude in the Eureka Gap occurs at its eastern end and is approximately 4,140 feet above sea level.

Evidence for Eureka Gap sand and gravel deposited on the level 5 erosional surface is found in a gravel pit located in Section 33 BBCC of Township 25 North, Range 5 West where approximately 22 feet of coarse limestone/dolomite sand and gravel are exposed. The bottom 20 feet of the exposure is sand and gravel of the number 5 level the upper foot of which contains a well developed vertical frost heave zone similar to those seen in exposures at the City of Choteau landfill and other exposures of the number 6 level gravels. Overlying the frost heave zone, is approximately 2.5 to 3 feet of non- frost heaved Eureka Gap limestone/dolomite gravel.

Between the lower end of the Eureka Gap and the Eureka Gap gravels is the upper end of the Spring Creek Valley. Spring Creek occupies the only sizable incision into the erosional scarp along the northern edge of the Teton River Valley between the City of Choteau and Eureka Reservoir. The valley of Spring Creek is cut approximately 40 to 60 feet into the Burton Bench and it is difficult to explain the development of this small valley. Most likely, the upper valley of Spring Creek in Section 32 of Township 25 North, Range 5 West was formed as a plunge pool when water flowing through the Eureka Gap became diverted into a more deeply incised valley now occupied by the Teton River. This means that the valley now occupied by the Teton River would have to be older than the development of the Eureka Gap. Given the closeness of the Teton River Valley to the Eureka Gap, it would seem that capture of the discharge through Eureka Gap would have been soon after its development and that only thin and aerially limited deposits of Eureka Gap gravels would be found on the number 5 surface.

Burton Bench Alluvial Fans

Chalmers, 1968, interpreted the sand and gravel deposits on the Burton Bench as being a single alluvial fan deposited during the "Pinedale" stage of the alpine glaciation by the Teton River flowing through the Ralston Gap. As noted earlier it is clear that the level 6 gravel and portions of the level 5 gravel deposits, were not deposited through the Ralston Gap. The level 3 and 4 surfaces are strongly related to the Ralston Gap. Both dip eastwardly and northerly (number 3 only) from the mouth of the Ralston Gap at a relatively constant rate of 60 to 80 feet per mile. All of the small stream channels on surfaces 3 and 4 also lead upstream to the Ralston Gap and the lower edge of the landform is more or less asymmetrically arcuate around the Ralston Gap. The level 3 and 4 surfaces form a distinct, well developed alluvial fan.

A separate alluvial fan is located in Sections 30 and 31 of Township 26 North, Range 5 West in the vicinity of the Town of Bynum. The Bynum fan was deposited by Muddy Creek apparently during the late Wisconsin ("Pinedale") glaciation. The toe of the Bynum fan almost coalesces with the toe of the Ralston Gap fan in the vicinity of Foster Creek in Section 6 of Township 25 North, Range 5 West. Well logs for wells within the town of Bynum indicate that the maximum thickness of the Bynum Fan is approximately 20 feet.

Well log data are not complete enough to provide the level of detail necessary to positively differentiate erosional scarps correlative with surficial scarps between levels in the subsurface of the Burton Bench but does provide good estimates of gravel thickness and bedrock altitude in different portions of the Burton Bench. Plates 2 and 3 are bedrock surface altitude and gravel thickness maps generated for the Burton Bench. The maps provide a general idea of the shape of the basin in which the Burton Bench gravels have been deposited and a general idea of their thickness at different places on the Burton Bench. In addition to the two maps, two cross sections constructed from drill hole data available on the Burton Bench, assist in visualizing the gravel deposits.

Bedrock Surface Under: The overall shape of the basin into which the Burton Bench gravel deposits were deposited is that of several valleys the largest of which is more or less aligned along Foster and Muddy Creeks. The buried "Foster Creek" valley extends from the headwaters of Foster Creek in Section 1 of Township 25 North, Range 6 West northeastwardly towards the townsite of Agawam in Section 30 of Township 26 North, Range 4 West. The trend of the valley from Agawam is easterly towards the vicinity of Eyraud Lakes in Section 30 of Township 26 North, Range 3 West. The shape of the valley is not presented in detail because of the sparseness of well log data but it is apparent that the lowest bedrock altitudes within the study area are found along the approximate axis od the valley. The valley represents a geomorphic feature which has been subsequently covered by the deposition of some of the Burton Bench gravels.

Smaller tributary valleys in the central portions of the Burton Bench may have contained streams flowing northward into the larger valley. Consequently, the bedrock surface under the Burton Bench gravel deposits would be irregular reflecting the presence of the tributary valleys.

The remaining portions of the buried bedrock surface is not defined enough to show detail because of the non-uniform distribution of well log data. However, some of its more important aspects can be distinguished. One important feature is the steepness in the east-west direction of the bedrock-gravel contact in the western portion of the Burton Bench. The bedrock surface altitude in the mouth of the Ralston Gap is approximately 4,020 feet above sea level in Section 19 Township 25 North, Range 5 West. Approximately 2 miles to the northeast, in Section 16 DDDD of Township 25 North, Range 5 West, the bedrock surface altitude is 70 feet lower at about 3,950 feet above sea level representing an average slope of the bedrock surface of about 35 feet per mile. East of Section 16 in Township 25 North, Range 5 West the dip of the bedrock surface steepens abruptly as shown by the depth to bedrock in the TCCD/MBMG/LEYS drill hole (see Appendix E for log) in Section 14 BCCC, Township 25 North, Range 5 West. The test well encountered bedrock at an altitude of 3,780 feet above sea level. The bedrock altitude difference between the Section 16 wells and the LEYS well represents an eastward-northeastward dip to the bedrock surface of about 90 feet per mile. East of the LEYS well the dip in the bedrock surface appears to flatten out to a slope of approximately 40 feet per mile decreasing yet more in the eastern portion of the Burton Bench to 20 to 25 feet per mile.

The variation in slope on the bedrock surface in an east-northeast direction is important to the deposition of the Burton Bench gravel deposits because it provided a place for deposition of sediment while the river attempted to bring it's bed to grade. Because the bedrock slope is irregular and the slope of the land surface (east-west) is relatively constant, the resulting thin-thick-thin characteristic of the Burton Bench gravel deposits ultimately is an important control in the hydrology of the aquifers which have developed in the deposits. It also shows that the Teton River while flowing through Ralston Gap did not have time to erode the underlying bedrock to "grade" indicating the "temporary" usage of the Ralston Gap by the Teton River.

A second buried valley is shown on Plate 2 in Sections 1, 2, 11, and 12 of Township 24 North, Range 5 West. The valley can be seen in outcrop a numerous locations in section 11 and is represented by thick sequences of sand and gravel tightly cemented by secondary calcium carbonate, and by low bedrock altitudes. The Depner well in Section 1 of Township 24 North, Range 5 West penetrates the margin of the valley. The valley is entrenched into the level 5 surface and probably represents a channel of the Teton River cut after deposition of the level 5 and 6 gravels but prior to glaciation of the area.

A probable ridge in the buried bedrock surface is shown in Sections 33, 34, and 35 of Township 25 North, Range 5 West. Data supporting the bedrock ridge are found in 3 wells located in sections 33 and 34 and in the topographic relationship of the level 5 surface to the level 4 surface. The evidence is scant but the presence of a bedrock ridge in this location helps explain the deposition of the level 5 gravel deposits and the apparent greater age of the level 5 gravels relatively to the level 4 gravels.

<u>Thickness of Gravel Deposits</u>: The gravel thickness map (Plate 3) for the Burton Bench shows the result of the variation in the bedrock surface on the deposition of the Burton Bench gravels. Bedrock surface variation is the primary

factor in the thickness of the gravel deposits because the land surface is relatively smooth on the burton Bench.

Thickest gravel deposits on the Burton Bench are located more or less symmetrically around the mouth of the Ralston Gap. A band of gravel which is greater than 40 and as much as 75 feet in thickness extends from Sections 1 and 2 of Township 24 North, Range 5 West in a concave westward curve to Sections 5 and 6 of Township 25 North, Range 5 West. The pattern shown by the thickest gravels on the Burton Bench is consistent with the interpretation of the geomorphology of levels 3 and 4 of the land surface as being alluvial fans.

The southern tip of the thicker zone includes fill in the buried valley in Sections 1 and 2 of Township 25 North, Range 5 West. Two east-west finger like zones of gravel greater than 20 feet in thickness are found in the eastern portions of the Burton Bench. The northern finger probably represents deposits in the lower reaches of the pre-alluvial-fan drainage system in the buried valley mapped on Plate 2. The southern finger-like zone may represent tributaries to a second portion of the pre-alluvial-fan drainage system. The bedrock Surface map (Plate 2) shows this valley system based primarily on outcrop data in Sections 11 and 12 of Township 24 North, Range 5 West. Between the two buried valleys, an area occurs where sand and gravel deposits are less than 20 feet in thickness covering a broad bedrock high which is probably the remnant of a drainage divide between the two valley systems.

A well was drilled during the aquifer study in Section 6 CDCD of Township 25 North, Range 3 West on the bedrock high to provide a point for testing in this portion of the aquifer and also to provide lithologic information for the gravel deposits in this area. It was unknown whether or not sand and gravel deposits in this portion of the study area originated from the west or from the east.

Deposits originating from the east would be derived from meltwaters of the various continental glaciations of north-central Montana and would contain continental glacial erratics such as Canadian Shield fragments and well rounded brown quartzite clasts derived from erosion of quartzite rich (Flaxville related) gravel deposits northeast of the Burton Bench. Deposits originating from the west would not contain these lithologies. Examination of the well cuttings from the TCCD/MBMG/OTNESS drill hole (see Appendix E for log) showed that sand and gravel at this location occurred under 84 feet of glacial till deposits and consisted almost entirely of limestone/dolomite clasts derived from the mountain front to the west. The uppermost cuttings from the gravel deposits contained a few fragments of schist and gneiss derived from the Canadian Shield, but cuttings from deeper in the well did not contain the erratics. Apparently, a small thickness of continental glacial outwash is resting on Burton Bench sand and gravel deposits at this location.

Water well log and drill hole data available prior to the study for the Burton Bench show mostly sand and gravel deposits with only small amounts of clay and silt as distinct beds. Drilling conducted during the Upper Teton Aquifer Study supports the general well log interpretation that little clay occurs as distinct beds in the gravels of the Burton Bench. However, drilling data from 3 drill holes in the central portion of the Burton Bench may also have penetrated gravel deposits separated by thin zones of fine-grained material. These gravels may have been deposited in tributaries of the drainage system (see Bedrock Surface above) existing on the Burton Bench prior to the transportation of sand and gravel into the area through the Ralston Gap.

In the TCCD/MBMG/LEYS drill hole located in Section 14 BCCC of Township 25 North, Range 5 West, coarser larger diameter gravel was noted below a depth of 49 feet under a thin (approximately 1 foot) zone of yellow clay represented in drill cuttings by a couple of balls of clay. In Section 4 DBDD of Township 25 North, Range 5 West the TCCD/MBMG/JORAMO observation well encountered a thin clay or sandy zone at approximately 45 feet below land surface. Above the possible clay zone, drill cuttings consisted of small fragments of limestone/dolomite gravel approximately 0.75 inch in longest dimension all of which had been broken by action of the drill. Below the clay zone, cuttings ranged from 0.75 to 2 inches in longest dimension but were almost completely unbroken by the drill and were being washed from position by the drill bit. Some of the unbroken pebbles had less than 1 millimeter thick calcium carbonate rinds on one side (presumably the lower). The calcium carbonate rinds are similar to those found in soil zones in near surface environments and could have been deposited by downward percolation of precipitation or other water in the "C" zone of a soil. An unconsolidated, slightly cemented formation is indicated by the condition of the cuttings and may represent a gravel deposit separate from the gravels placed by transportation through the Ralston Gap. In Section 18 CBBB of Township 25 North, Range 5 West both of the TCCD/MBMG/COLE drill holes encountered a clay zone approximately 3 feet in thickness at a depth of about 45 feet below land surface. A bit sample gouged at 46 feet below land surface in the southern well and brought to the land surface by pulling the drill string, consisted of calcareous, light-gray clay with some gray sand and silt which caused the sample to disintegrate easily in water. The clay was also slightly mottled with limonitic staining. Above the clay zone, cuttings from the Cole wells were approximately 0.75 to 1 inches in longest dimension and were mostly broken by the drill bit. Below the clay zone cuttings were approximately 0.75 inch in longest dimension but were almost completely unbroken by the action of the drill. Again, the difference between the drilling characteristics of the gravel deposit above the clay zone and below the clay zone may indicate that two gravel deposits may be present at this location.

In addition to the wells described above, a few wells in the northern and eastern portion of the Burton Bench area encountered two gravels separated by as much as 45 feet of fine grained deposits. In an oil and gas test well drilled in Section 31 DCC of Township 26 North, Range 3 West, 5 feet of gravel was encountered at 60 feet below land surface. The drill log for this well reports 45 feet of clay before an additional 15 feet of gravel between 110 and 125 feet below land surface. The thickness map (Plate 3) shows thicknesses of the lower gravel in this area of the Burton Bench because it is most likely to be related to the Ralston Gap derived sand and gravel deposits to the west. Upper gravels in these wells are relatively thin and are probably outwash derived from the continental glaciations.

Geologic Cross Sections: An west-east cross section (A-A' on Plate 4) originating in the Ralston Gap and extending in an east-northeast direction approximately 12 miles to the TCCD/MBMG/OTNESS well in Section 6 of Township 25 North, Range 3 West serves to illustrate the eastward slope of the land surface and the variation in thickness of the Burton Bench gravel deposits. The line of the cross section is shown on both Plates 2 and 3.

Section A-A' illustrates the thin-thick-thin characteristic of the Burton Bench gravel deposits. In the Ralston Gap the gravel deposits are approximately 10 to 15 feet in thickness. In the central portion of the Burton Bench the gravels are up to 70 feet in thickness but again are only 15-20 feet in thickness in the eastern third of the section. The eastward slope of the land surface on section A-A′ is broken by hummocky topography of the late Wisconsin glacial till on the eastern end of the section. The cross section clearly shows the onlap of glaciolacustrine and glacial till deposits on the gravel deposits. Glaciolacustrine and glacial till deposits provide the "impermeable" cap for the artesian portion of the Burton Bench aquifer.

Continuity of the Burton Bench gravel deposits east of the Burk Number 1 oil and gas test in Section 11 of Township 25 North, Range 4 West is probably as shown on section A-A′. However, distance from the Ralston Gap and other areas through which gravels were transported to the Burton Bench area coupled with the relative thinness of the gravels raises the possibility that the gravels are not laterally continuous east of the east end of section A-A′. The gravels in the section are shown as being continuous because cuttings from the TCCD\MBMG\OTNESS well shows that gravels at that location were derived from western sources; water quality data for these wells shows that the water is low in dissolved solids and is similar to water a few miles to the west; and the short distances between control points on the eastern end of the cross section.

However, gravel deposits east of the study area and east of the east end of section A-A′ have not been shown to be laterally continuous with the Burton Bench gravel deposits. Many unknowns exist in the area between the east edge of the Upper Teton Aquifer Study and the town of Collins, Montana. Close examination of cutbanks along Muddy Creek and the Teton River between the study area and Collins associated with a more complete well inventory and better geologic mapping will be necessary to sort out problems regarding the true eastward extent of the Burton Bench gravel deposits.

A second cross section (B-B′ on Plate 4) drawn in a south-north direction across the central portion of the Burton Bench allows illustration of the gravel thicknesses and the bedrock altitudes in this direction. The cross section begins in the Teton River Valley and extends approximately 12 miles northward to the vicinity of Agawam in Section 18 of Township 26 North, Range 4 West. The cross section extends through the thickest portions of the Burton Bench gravel deposits and cuts across surfaces 6, 5, 4, and 3 on the Burton Bench. It is clear from this cross section that because the thickness of the gravel deposits is large relative to the small altitude differences between topographic surfaces, 3 and 4, correlative bedrock erosional scarps to these topographic scarps are not likely to be present. The topographic scarp between levels 4 and 5 may be reflected in the subsurface by an erosional scarp. Level 5 gravels are probably older than level 4 gravels and erosion occurring during the interval between their deposition is represented in the bedrock scarp. The high altitude bedrock of Sections 33, 34, 35, and 36 of Township 25 North, Range 5 West appears as a ridge because of the presence of the buried valley in Sections 11 and 12 of Township 24 North, Range 5 West.

A second important feature of the cross section shows that bedrock altitudes in the vicinity of Muddy Creek on the north end of the section are approximately 50 feet lower than bedrock altitudes in the Teton River Valley below Truchot Hill.

Teton Valley Gravel Deposits

Gravel deposits in the Teton River Valley between the City of Choteau and the vicinity of Eureka Reservoir are not as well known as gravel deposits on the Burton Bench. Fewer wells exist in the Teton River Valley located so that interpretation of the data can be used to describe the deposits. Wells are often older and records for these wells are sketchy. Most wells in the valley that do have usable information about their construction are located in or near the city of Choteau and only a few wells are scattered both up and down valley from the town. Bedrock altitudes under the city of Choteau range from about 3,770 to about 3,810 feet above sea level. Contours on a map shown in Figure 12 show that the bedrock surface is valley shaped and appears to be aligned along the present valley of the Teton River.

Descriptions of drill cuttings made during the drilling of the City of Choteau 6 inch test well showed that in Section 24 CBCB of Township 24 North, Range 5 West the valley fill deposits are composed of limestone/dolomite sand and gravel derived from the mountains to the west. Most clasts were pea- to marble size with the exception of a bouldery zone approximately 2 feet above the gravel-bedrock contact. The Teton Valley gravel deposits are approximately 20 feet thick at the location of the drill hole. The bedrock formation was the Colorado Shale.

Thicknesses of the Teton Valley gravel deposits appear to increase upstream from Choteau, to about the vicinity of Eureka Reservoir. Above Eureka Reservoir in the Teton River Valley a few well logs indicate that gravel deposits are approximately 30 feet thick. The average thickness of the Teton Valley gravel in sections 23, 24 and 25 of Township 24 North, Range 5 West near the city of Choteau is 21 feet based on 16 well log reports. The gravel is only 15 feet thick in a well in Section 25 CCCC of Township 24 North, Range 5 West and 29 feet in a well reportedly drilled in Section 24 DBAA of Township 24 North, Range 5 West.

Upstream from Choteau a well reportedly drilled in Section 14 BDA of Township 24 North, Range 5 West penetrated 36 feet of sand and gravel above bedrock and a well drilled in Section 10 BCBA of the same township penetrated

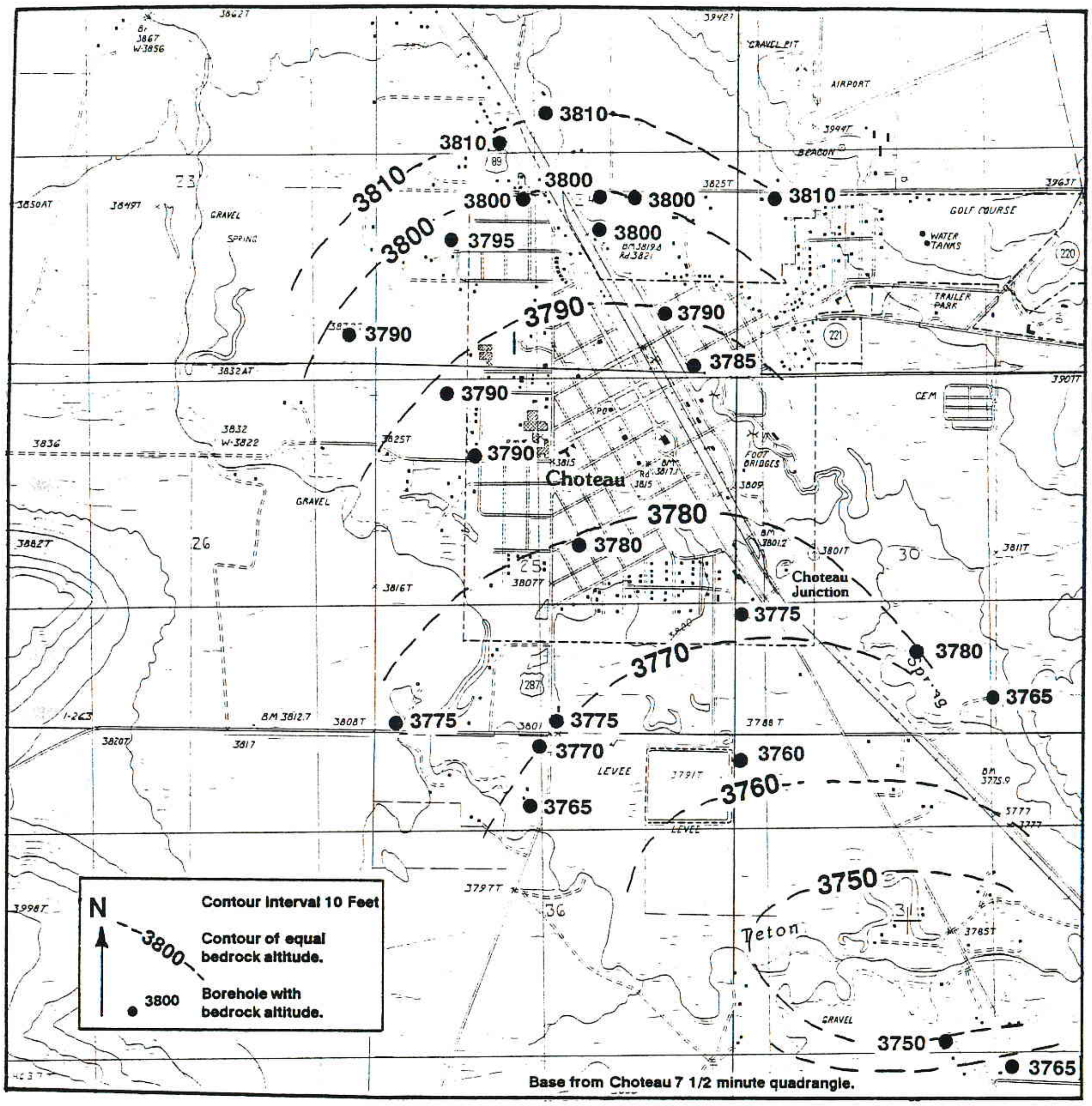

Figure 12: Bedrock surface altitudes under the City of Choteau, Teton Valley aquifer.

31 feet of sand and gravel. In Section 4 DBB of Township 24 North, Range 5 West a well owned by the Newman Ranch was completed in gravel at a depth of 27 feet indicating that the gravel deposits are greater than 27 feet in thickness at this location. In Section 32 DDDA of Township 25 North, Range 5 West another well owned by the Newman Ranch penetrated 53 feet of gravel and did not encounter bedrock at a depth of 57 feet below land surface.

Alpine Glacial Landforms and Deposits

No alpine glacial landforms are found within the Upper Teton Aquifer Study area. The nearest alpine glacial landforms are approximately 9 miles west in the southwest quarter of Township 25 North, Range 8 West where the breached terminal and lateral moraines of the late Wisconsin advance of the Teton River Glacier (Chalmers, 1968; Nimick etal, 1983) (see Plate 1) are found. The moraines are well developed, have a maximum height of 170 feet (Nimick etal, 1983), and are symmetrical with the mouths of the south and north forks of the Teton River. Well developed outwash plains (levels 3 and 4 on Plate 1) extend from and originate within the moraine. Chalmers (1968) presented some evidence that earlier advances ("Bull Lake") of the Teton River glacier may have extended possibly as far east as the City of Choteau. However, if that was the case, no glacial landforms related to the advance have been recognized.

Continental Glacial Landforms and Deposits

Landforms related to two advances of continental glacial ice are preserved within the Upper Teton Aquifer Study area. The border of the late Wisconsin ice is marked along the eastern edge of the study area by a topographic change from the gently eastward sloping surfaces of the Burton Bench to the knob and kettle undulatory surfaces of the late Wisconsin glacial till. The provisional western edge of the late Wisconsin ice is shown on Plate 1. The altitude of the late Wisconsin till margin is approximately 3,760 feet above sea level on the Burton Bench. Fullerton (written communication 1988) suggested that the limit of the late Wisconsin till as illustrated above is provisional because the actual edge of the till sheet is obscured by deposits of the late Wisconsin Glacial Lake Choteau.

An earlier advance of continental glacial ice also caused deposits of glacial till and glacial lakes to occur in the Upper Teton Study area. Late Illinoian Heron Park till (Fullerton and Colton 1986), present on portions of the Burton Bench, shows that late Illinoian ice extended some distance farther westward than did the late Wisconsin ice. The margin of the late Illinoian till has been modified or removed by post glacial erosion or by deposition of materials on the till by the late Illinoian glacial lakes Great Falls and Choteau, or the late Wisconsin glacial lake Choteau, and has not been clearly defined. Chalmers (1968) reported that Canadian Shield erratics found in the vicinity of Choteau airport indicated that continental ice may have reached this portion of the Burton Bench. Fullerton (1988 written communication) stated that late Illinoian ice reached an altitude of approximately 4,000 feet above sea level on the Burton Bench based on continental glacial erratic locations and a reported exposure of thin discontinuous remnants of Heron Park Till south of Glendora Lake in Section 34 CCC of Township 25 North, Range 5 West.

Examination of exposures of gravel deposits on the Burton Bench determined that the extent of the late Illinoian continental ice may not have been as far westward as Fullerton has suggested. Evidence supporting the lower altitude for the ice margin was obtained from examination of exposures of surficial materials on levels 5 and 6 of the Burton Bench. Complicating the determination of the ice edge altitude is the presence of continental glacial erratics at altitudes higher than the altitude of the till margin.

Figure 13 shows locations of Canadian Shield erratics on the Burton Bench provided by Fullerton (written communication 1988) as well as locations of erratics found during the Upper Teton Aquifer Study. The highest altitude on the Burton Bench at which Canadian Shield erratics have been reported is approximately 3,980 feet above sea level in Section 2 BB of Township 24 North, Range 5 West, but this locality is 10 to 20 feet higher than other known erratic locations. Examination of this locality during the aquifer study did not produce erratics but the field in which the site is located is being actively farmed and the erratic could have been removed. Careful examination of the road side west and at higher altitude than that of the section 2 locality failed to locate any erratics. Borrow pits along east-west roads on the Burton Bench at altitudes up to 4,000 feet above sea level were also examined for continental erratics but none were found above altitudes of about 3,960-3,970 feet above sea level.

Numerous Canadian Shield erratics have been found on levels 5 and 6 of the Burton Bench but several groups of erratics have been found on the level 3 surface at altitudes between 3,920 and 3,950 feet above sea level in Sections 3, 4, and 14 of Township 25 North, Range 5 West. If it is assumed that the Canadian Shield erratics were deposited directly by glacial ice, a probable maximum altitude of the late Illinoian ice on the Burton Bench would be about 3,950 to 3,980 feet above sea level and that level 3 and 4 surfaces are older than the Illinoian glaciation. However, evidence that the Canadian Shield erratics occur in place in glacial till on western portions of the Burton Bench has not been found. Exposures of greater than 10 feet of limestone/dolomite

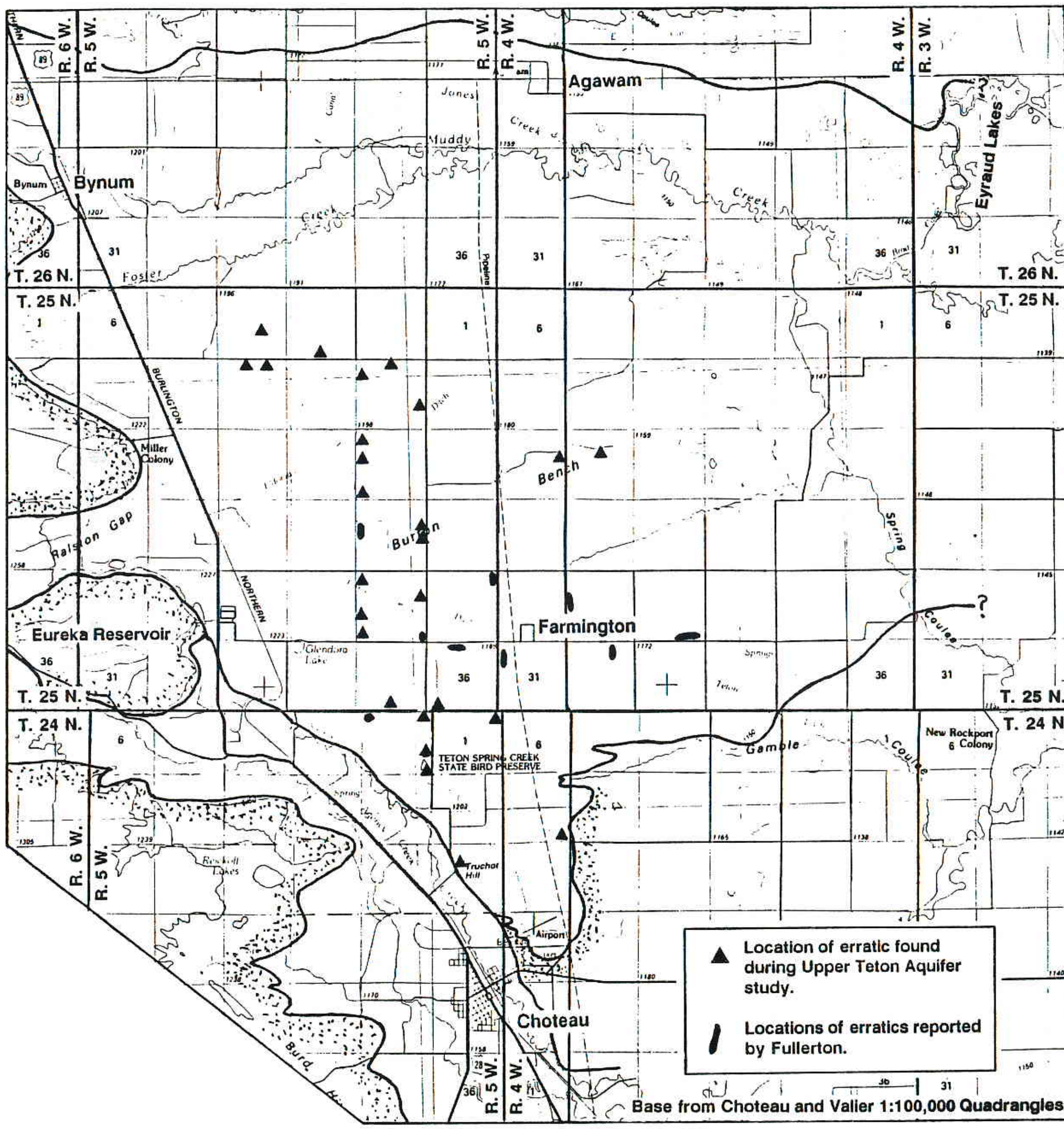

Figure 13: Locations of Canadian Shield derived continental glacial errattics on the Burton Bench.

gravel occur in a pit just west of the Choteau airport in Section 19 BBC of Township 24 North, Range 5 West at a land surface altitude of 3,940 feet above sea level. The upper 2 to 3 feet of the gravel contains well developed frost convolutions where pebbles have been vertically oriented suggesting that the gravel probably was present prior to the Wisconsin glaciation. Above the gravel is 0 to 3 feet of light brown silt and fine sand. The silt deposit displays a weak to moderate horizontal (bedding) parting, weakly developed vertical jointing, and contains a few pebbles of limestone/dolomite. The silt is very friable, has low density, does not have the appearance and texture of glacial till, and more nearly resembles loess. The horizontal parting characteristic implies that the material may also have been deposited in water. Because the "silt" could possibly be continental glacial till referenced by earlier workers it was carefully examined for presence of continental glacial erratics. After examination of all the silty zones exposed in the gravel pit (over 100 feet laterally), no continental glacial erratics were observed.

Similar silt deposits on levels 5, 6, and 3 of the Burton Bench have also been observed at other locations. At the Choteau city dump in Section 18 DDDD of Township 25 North, Range 4 West (altitude 3,940 feet above sea level) approximately 3 feet of silty sand occurs over about 18 feet of sand and gravel. Careful examination of the long trenches on the west edge of the dump, where approximately 1,000 feet of exposure exists, failed to produce any glacial erratics in place in the silt. The gravel at the dump is also extensively convoluted by frost action in the upper 3 feet. A roadcut in Section 3 BBC of Township 24 North, Range 5 West (altitude 3,990 feet above sea level) exposed 15 feet of gravel mantled by 1 foot of brown silt. In a railroad grade cut in Section 11 DAAA of Township 24 North, Range 5 West (altitude 3,955 feet above sea level) 0 to 3 feet of light brown silt rests on more than 3 feet of frost convoluted gravel. Careful examination of the silt over a lateral distance of about 60 feet did not produce any Canadian Shield erratics. An abandoned railroad cut in Section 33 DDB Township 25 North, Range 5 West (altitude 4,015 feet above sea level) exposed 0 to 3 feet of white-brown horizontally laminated, vertically jointed silt resting on approximately 5 feet of frost convoluted gravel. Examination of the silt showed some pebbles from the underlying gravel but no Canadian Shield erratics. In a gravel pit in Section 17 ABBB of Township 25 North, Range 5 West (altitude 4,005 feet above sea level) 3 feet of brown calcareous silt overlie 13 feet of sand and gravel. In Section 7 DDDD of Township 24 North, Range 4 West (altitude 3,900 feet above sea level) a small gravel pit exposes a similar silt deposit resting on sand and gravel. The silt is light brown, friable, contains a few pebbles from the underlying sand and gravel, and is 0 to 1.5 feet in thickness. In this pit the upper 4 feet of the gravel deposit is convoluted by frost action. On the land surface in the adjacent plowed field, numerous Canadian Shield erratics can be found but careful examination of the entire exposure of the silt in the gravel pit produced no Canadian Shield erratics.

It is possible that coincidence of Canadian Shield erratics sitting on the surface of fine grained silt deposits may have created confusion regarding the origin of the silt deposits. The friable, low density, horizontally laminated, and weakly columnar characteristics of the silt deposits resemble windblown or eolian loess or thin lacustrine deposits more than they do glacial till. Because many of the surficial deposits previously identified as glacial till on the Burton Bench could be silt deposits, it is not certain that the late Illinoian ice extended onto the bench as far as previously thought. Chalmers, 1968 documented a change in soil type from "sandy and gravelly" to "gumbo" at an altitude of approximately 3,900 feet above sea level on level 5 of the Burton Bench and attributed the change to either the presence of glaciolacustrine deposits or glacial till on the Burton Bench below that altitude. Fullerton (1988, written communication) provided some corroborating evidence by noting that late Illinoian ice reached an altitude of about 3,900 feet above sea level on the north flanks of the Teton Ridge a few miles east of the study area. Evidence to date supports an altitude of approximately 3,900 feet above sea level for the western extent of late Illinoian ice on levels 5 and 6 of the Burton Bench.

If Canadian Shield erratics located above 3,900 feet above sea level on the Burton Bench were not deposited directly by glacial ice then an alternative mode of emplacement is necessary to explain their presence. Movement of the erratics to their present locations by man is one mechanism which accounts for their specific locations. However, too many erratics are found on the Burton Bench to have been brought to the bench from other areas. The erratics are most often found in the corners and along the edges of fields and are probably within 0.25 mile of where originally deposited. Additionally, several sets of erratics were found on level 3 of the Burton Bench within newly farmed fields and these rocks had not been transported by man.

Glacial till and outwash gravels of continental origin were observed at the eastern end of level 6 on the Burton Bench at an altitude slightly below 3,900 feet above sea level. Along a county road between Sections 8 and 17 of Township 24 North, Range 4 West glacial till, a small outwash channel, and sand and gravel deposits containing Canadian Shield erratics occur within 1.5 miles east of Montana highway 220. Glacial till from Section 16 BAA of Township 24

North, Range 4 West is yellowish brown (5Y7/2 - dry), slightly sandy, and contains a few quartz and quartzite erratics. No jointing, staining or lignite clasts were observed in the till. The till is thin and discontinuous and was removed from the county road borrow pit during construction of the road. Weathered Cretaceous Colorado shale is exposed in the borrow pits and the glacial till is exposed away from the road in the fields. The till at this locality is at an altitude of approximately 3,870 feet above sea level.

Borrow pits along a county road between Section 31 of Township 25 North, Range 4 West and Section 6 of Township 24 North, Range 4 West were examined for glacial till up to an altitude of 3,900 feet above sea level. Exposures along the road were poor but no till was observed. Glacial till was observed in a ditch bank in Section 30 DDDD of Township 25 North, Range 4 West at an altitude of about 3,870 feet above sea level but not in the same ditch bank in Section 30 DCCC of the same township at an altitude of 3,880 feet.

Glaciolacustrine Deposits

Associated with both the late Wisconsin and Illinoian westward upland advances of the continental ice, were glacial lakes in the vicinity of Choteau which intermittently formed and drained. The two lakes most closely related to the Upper Teton aquifer study area were lakes Choteau and Great Falls.

Fullerton, 1988 (written communication) reported that from evidence in the Helena Valley and elsewhere, the late Wisconsin glacial lake Great Falls reached an altitude of approximately 3,720 feet above sea level and therefore did not cover the area of Choteau. Late Wisconsin glacial lake Choteau impounded meltwater from alpine glaciation to the west and accepted overflow from Glacial Lake Cutbank and other lakes to the north. The late Wisconsin glacial lake

Choteau reached an altitude of approximately 3,820 feet above sea level (Colton and Fullerton 1986) and spilled into the late Wisconsin glacial lake Great Falls through the Cliev channel in Sections 4-6 Township 22 North, Range 2 West. The Cliev channel has a present day maximum altitude of approximately 3,820 feet above sea level, is sharply cut, and does not appear to have suffered from extensive refilling from land sliding etc. If the base of the Cliev Channel can be used to estimate the altitude of the late Wisconsin glacial lake Choteau, then the lake extended westward on the Burton Bench to about 2 miles east of Farmington. In the Teton River Valley the late Wisconsin glacial lake Choteau would have extended up-valley as far as the City of Choteau.

In Section 36 of Township 24 North, Range 5 West, where U.S. Highway 287 crosses the Teton River at an altitude of 3,790 feet above sea level, approximately 7 feet of dark gray to black silt and clay overbank or lacustrine deposits are exposed. The silt is massive and does not show well developed laminations or other horizontal structure. The silt deposit is banded but the banding appears to be based on organic material content and is not related to varves or other common structures in glaciolacustrine deposits. About 1.5 feet above stream level (and 6 feet below land surface), the silt overlies a 0.3 foot thick deposit of white powdery volcanic ash. The ash has been identified (Chalmers, 1968) as Mt. Mazama ash which is approximately 5,600 years in age. The volcanic ash rests on greater than 1 foot of dark gray clay with red-brown mottling. The volcanic ash shows that the silt deposits are not likely related to glacial lake Choteau because it and the deposits over it are too young. However, the clay deposits on which the volcanic ash rests could possibly be deposits of the late Wisconsin glacial lake. Similar deposits in the Teton River Valley were not observed above an altitude of about 3,800 feet above sea level.

Nearby well log data show that the silts and clays are underlain by coarse sand and gravel deposits of the Teton River Valley. Approximately 0.5 mile downstream the silt deposits thin to only a few feet in thickness and are lying on sand and gravel deposited by the Teton River.

Other possible deposits related to the late Wisconsin glacial lake Choteau occur on the Burton Bench. In Section 29 B of Township 26 North, Range 4 West at an altitude of approximately 3,780 feet above sea level, Muddy Creek is cutting into massively bedded silt deposits similar to those previously described at the highway 287 locality near Choteau. The material is light to dark gray, non-jointed, non-laminated, and fractures into large blocks. However, the silt does not show the banding noted at the Highway 287 locality. Approximately 3 feet below the land surface, volcanic ash occurs which has tentatively been identified by stratigraphic position as Mt. Mazama Ash. Below the volcanic ash are silt and clay deposits that may have been deposited in the late Wisconsin glacial lake Choteau. In Section 28 B of Township 26 North, Range 4 West, at an altitude of about 3,780 feet above sea level in a stream cut formed by Muddy Creek, another more complete exposure of possible late Wisconsin lake beds occurs. At this locality 2.6 feet of pinkish white, friable, volcanic ash occurs 1.5 feet below land surface. Above the volcanic ash is silty sand in which the modern soil zone is developed. Below the volcanic ash is 3.3 feet of olive-drab, blocky, slightly fissile, orange-brown mottled clay. Below the clay is 2.3 feet of dark gray green sand containing abundant snail shells. The sand contains weak bedding and the bottom 1.3 feet sand is black apparently from organic matter. Below the sand zone is slightly sandy clay, mottled as above. The clay also contains snail shells. The clays and sands underlying the volcanic ash are probably deposits related to the late Wisconsin glacial lake Choteau.

The greatest thicknesses of glaciolacustrine deposits observed during the Upper Teton Aquifer Study were some of those previously described by Chalmers, 1968. The exposures are located along the north edge of Section 4 Township 23 North, Range 4 West in cutbanks and slump scarps in the south edge of the Teton River Valley. At these locations 40 to 50 feet of well bedded silts and clays are overlain by sand and gravel deposits. No bedrock was observed at the base of the exposures but mass wasting at the base of most outcrops obscured their toes. The thickness of the lake related deposits in this area is attributed to filling of a preglacial valley which is now being re-excavated by the Teton River. The Teton River Valley is aligned with that of Deep Creek downstream of Section 5 of Township 23 North, Range 4 West and appears to have entered a more deeply incised older valley at that location. The older valley contains sediments from late Illinoian and late Wisconsin lakes that occupied the region.

During the late Illinoian glacial maximum, proglacial lakes developed in the Choteau area in much the same manner as they did during the late Wisconsin maximum. Fullerton (written communication 1988) stated that the late Illinoian glacial lake Great Falls reached a maximum altitude of approximately 4,000 feet above sea level based on strand lines in the Helena Valley. At this altitude, the glacial lake was continuous from Choteau, to Great Falls, to the Highwood Mountains, and up the valley of the Missouri River to the Helena Valley. As the late Illinoian glacial lake Great Falls drained (Fullerton 1988, written communication), the water level fell below upland areas such as the Greenfield Bench and the remnants of the late Illinoian glacial lake Great Falls became separate lakes. The late Illinoian glacial lake Choteau probably formed at this time and was about the same size as the late Wisconsin lake which later formed.

It is most likely that continental glacial erratics on the Burton Bench above altitudes of about 3,900 feet above sea level were deposited by rafting of the erratics on icebergs in a glacial lake. Because the late Illinoian lake reached altitudes high enough above sea level to deposit the continental erratics as high as 3,970 feet above sea level, it is the most probable lake to have deposited the erratics. Two problems occur with this hypothesis. First, continental glacial erratics would be expected to occur within and below the silt deposits which are located on the various surfaces of the Burton Bench. At this time continental erratics have not been located in these two stratigraphic positions on the Burton Bench. Secondly, if erratics found on Burton Bench levels 3 and 4 were deposited within a late Illinoian glacial lake, the sand and gravel deposits and the level 3 and 4 surfaces would have to be late or pre- late Illinoian in age. A late Illinoian or earlier age for these deposits and surfaces was postulated by Richmond (unpublished data reported by Fullerton, 1988, written communication) but has not otherwise been previously proposed. If the Burton Bench level 3 and 4 surfaces were late Illinoian in age it would imply that the present valley of the Teton River would be related to the late Wisconsin glaciation. However, this interpretation is difficult to support when level 3 and 4 surfaces on the Burton Bench are traced back to the apparent late Wisconsin Teton River Moraine near the mountain front.

Pleistocene Geologic History

From the information presented above, a geologic history for the Burton Bench and the Teton River Valley between the city of Choteau and the mountain front can be partially derived.

The oldest sand and gravel deposits related to the Teton River are the level 6 deposits (see Plate 1 for locations of surfaces and levels described in this section). The level 6 deposits probably represent Teton River channel positions probably as early as the late Pliocene but definitely older than at least late Illinoian. Late Illinoian till does not cover the level 6 surface because the altitude of the surface is above 3,900 feet above sea level on the Burton Bench. Canadian Shield erratics, probably brought to the area during the late Illinoian glaciation and deposited in the late Illinoian glacial lake Great Falls, rest on the Burton Bench portions of the level 6 surface at altitudes as high as 3,970 feet above sea level. The level 6 surface must have been continuous through the area of Ralston Gap and Eureka Reservoir at altitudes high enough to correspond to remnants of level 6 surfaces west of Ralston Gap. After gravels related to the level 6 surface had been deposited, level 5 deposits were placed along the north side of the level 6 surface at lower altitude; leaving the level 6 surface as a terrace in a valley. Level 5 surfaces and related gravel deposits were deposited by the Teton River through a now removed valley slightly south of Eureka Reservoir. Somewhat later in time, the Ralston Gap may also have been used to deposit some level 5 gravels but if so, most have been removed from the gap area by later erosion.

The level 5 gravels are better preserved than the level 6 gravels and cover a much more extensive area. The antiquity of the level 5 surfaces is shown in the vicinity of Bynum reservoir (see Plate 1) where they are truncated by erosion and are partially isolated by topographic reversal. On the Burton Bench, an age at least as great as late Illinoian is shown by the presence of Illinoian age till and erratics on the level 5 surface below altitudes of 3,970 (for the erratics) and 3,900 (for the till) feet above sea level.

At the end of the period of deposition for the level 5 surface the Teton River may have been diverted from the area. Where its channel was is not clear but several possibilities exist. The most likely is that entrenchment of the Teton River occurred in a valley more or less aligned along the present river valley upstream from Choteau connecting with the truncated end of the buried valley exposed in Section 11 of Township 24 North, Range 5 West. It is also possible that the river occupied the valley now containing Willow Creek in Section 12 of Township 24 North Range 5 West and was a tributary to what is now Deep Creek.

After the level 5 surface gravels were deposited, erosion by tributaries to the Muddy Creek drainage removed the softer more easily erodible bedrock along the north side of the level 5 valley. The coarse gravel caps on the level 5 and 6 surfaces protected the soft cretaceous bedrock from erosion resulting in topographic reversal and the older stream valleys became an upland. A tributary valley to the buried valley now partially occupied by Deep Creek (or the Teton River) may have also developed along the southern edge of the number 6 level more or less aligned with the present valley of the Teton River. Smaller tributary valleys entered the larger tributary to Deep Creek and these valleys are still preserved as small drainages entering the south side of the Teton River Valley in Sections 16, 21, and 28 of Township 24 North, Range 5 West.

After the late Illinoian glaciation and after late Illinoian glacial lakes Great Falls and Choteau had drained, erosion in the Muddy Creek drainage system on the north side of the Burton Bench continued. The Ralston Gap, which may have formed during deposition of level 5 gravels remained but may have not been used by the Teton River during the interglacial period between the Illinoian and Wisconsin glaciations. It is unclear where the Teton River flowed during this interim period. It is possible that the river flowed down the valley of the North Fork of Willow Creek into the Deep Creek drainage but it is also possible that the river may have occupied a valley more or less aligned along its present valley and may have been the primary agent of erosion along the south side of the number 6 surface. Support for this hypothesis is found by the presence of a gravel terrace approximately 3,860 above sea level in Sections 29 and 32 Township 24 North, Range 4 West on the north side of the Teton River Valley below Choteau. This terrace is too low in altitude to be related to the level 5 and 6 surfaces on the Burton Bench.

During the Wisconsin glaciations, the Teton River again deposited sand and gravel through the area of Ralston Gap. Level 3 and 4 surfaces on the Burton Bench and in the Teton River Valley west of Ralston Gap were created during this period at the expense of the pre-existing level 5 surface. The Ralston gap was widened and deepened removing remnants of level 5 deposits and level 4 gravels were deposited in the form of an alluvial fan into the basin which had been formed north of the level 5 gravel deposits.

Because the Ralston Gap was being widened and deepened during the deposition of the sand and gravel, the bedrock high holding the Teton River above the basin into which it was depositing its load was being lowered. This caused removal of level 5 deposits from the Ralston Gap and deposition of gravels at altitudes no higher than those of level 4. Continued erosion in the Ralston Gap area created erosional scarps between the level 3 and level 4 surfaces. Finally, the level 3 alluvial fan surface present today over most of the Burton Bench was formed. Support for this hypothesis includes the overall thickness of the sand and gravel deposits on the Burton Bench and the apparent lack of erosional scarps in the subsurface because of the thickness of the gravel deposits. The level

3 and 4 surfaces on the Burton Bench are correlative with the level 3 and 4 surfaces at the foot of the Teton River moraine which is considered to be Wisconsin in age (Chalmers, 1968; Nimick, 1983).

At the end of the Wisconsin glaciation, the Teton River continued to downcut and migrated southward in its valley between Ralston Gap and the Teton River moraine. At some point the river reoccupied or occupied a preexisting tributary valley to Deep Creek. The new valley represented a more favorable path for the Teton River as the river system entrenched itself into the continental till east and north of Choteau between Choteau and Collins, Montana. Down cutting of the new valley formed the present valley of the Teton River between Choteau and Eureka Reservoir creating the smooth very young scarp present along the north side of the valley.

The Teton River reoccupied the Ralston Gap for a short period either at the end of the late Wisconsin glaciation or more probably since the glaciation. The river cut a shallow channel into the level 3 surface (see Plate 1) but soon migrated southward again into its present valley.

The proposed geologic history as outlined above seems to fit most of the facts as now understood for gravel deposits in the Teton River drainage above Choteau, Montana and on the Burton Bench. The most serious problem with the interpretation regards the presence of continental Canadian Shield erratics on the level 3 and 4 surfaces. If the surfaces date from the late Wisconsin glaciation, there appears to be no agent for deposition of the glacial erratics. If the surfaces date from the late Illinoian glaciation, the presence of glacial lake Great Falls provides an agent for the deposition of the erratics but calls into question the age of the Teton River Moraine because the level 3 and 4 surfaces are traceable directly to the distal edge of the moraine. One explanation could be that the late Wisconsin and earlier Illinoian alpine moraines are superimposed and that levels 3 and 4 are in fact Illinoian in age. Levels 2 and 1 would represent late Wisconsin outwash and reworkings of older Illinoian age outwash. The presence of continental glacial erratics on levels 3 and 4 of the Burton Bench gravel deposits is presently unresolved and must wait for additional field work and information before the locations of the erratics can be explained.

Hydrogeology of the Upper Teton Aquifer Study

Introduction

Thick and permeable gravel deposits are the media in which the major aquifers of the Upper Teton Aquifer Study area have developed. The two major aquifers: the Burton Bench aquifer; and the Teton Valley aquifer will be discussed separately because throughout the study area they are completely isolated from each other. Recharge to both aquifers comes from the Teton River drainage system and from direct infiltration of precipitation, but their hydrogeologic aspects are separate. Topographic differences between the two aquifers caused by recent erosional history, ditch leakage as a source of recharge to the Burton Bench aquifer, and the presence of nearly impermeable Colorado Shale under the aquifers allows the hydrogeology of the two aquifers to be isolated from each other. The most surprising finding about the Burton Bench Aquifer is the large annual water level changes recorded in wells in the west-central portion of the aquifer. The most striking finding in the Teton Valley Aquifer was its relatively high transmissivity reflecting the better sorting and flushing of fines from the sands and gravels aquifer in a stream deposited environment versus an alluvial fan depositional environment.

Burton Bench Aquifer

The Burton Bench aquifer will be discussed in terms of static water levels and recharge, storage, water quality, and aquifer test data derived during the study period. A special emphasis will be placed on describing the hydrology of the Ralston Gap area because of its strategic location at the up-gradient end of the recharge zone of the Burton Bench Aquifer. Relatively little emphasis will be placed on the artesian portion of the aquifer because hydrostatic control comes from the west and changes in the hydrogeology of the western portions of the aquifer will ultimately have effects on the artesian zone. A section on summaries and conclusions will end the discussion of the Burton Bench Aquifer and the data gathered in the study will be placed into perspective regarding water use.

Static Water Levels and Recharge:

Static water level data (the distance below land surface that water stands in a well) has provided information about how groundwater recharge occurs in the Burton Bench portion of the study area and links recharge in the Burton Bench aquifer to leakage from irrigation ditches and field losses from flood irrigation. Water-level, combined with aquifer test data, also provide evidence that subsurface recharge to the Burton Bench aquifer through Ralston Gap (see figure 2 for location) is not as important as previously thought (Fisher 1909) when compared to the amount of recharge derived from irrigation ditch or field leakage.

Water levels were obtained from a set of observation wells defined in the early stages of the aquifer study and measured monthly throughout the study period. Hydrographs for each well are contained in Appendix B. Locations for the monitored wells are shown in Figure 3.

Water level information is important because it provides insight into the amount of water in storage in an aquifer at the point of measurement. Water level information obtained at different times shows whether an aquifer at that location is gaining water in storage (rising water levels) or losing water from storage (falling water levels). Figure 14 is a schematic drawing of an aquifer showing the relationship between water levels in observation wells and the amount of water in storage.

A summary of water level measurements (converted to altitudes) appears on

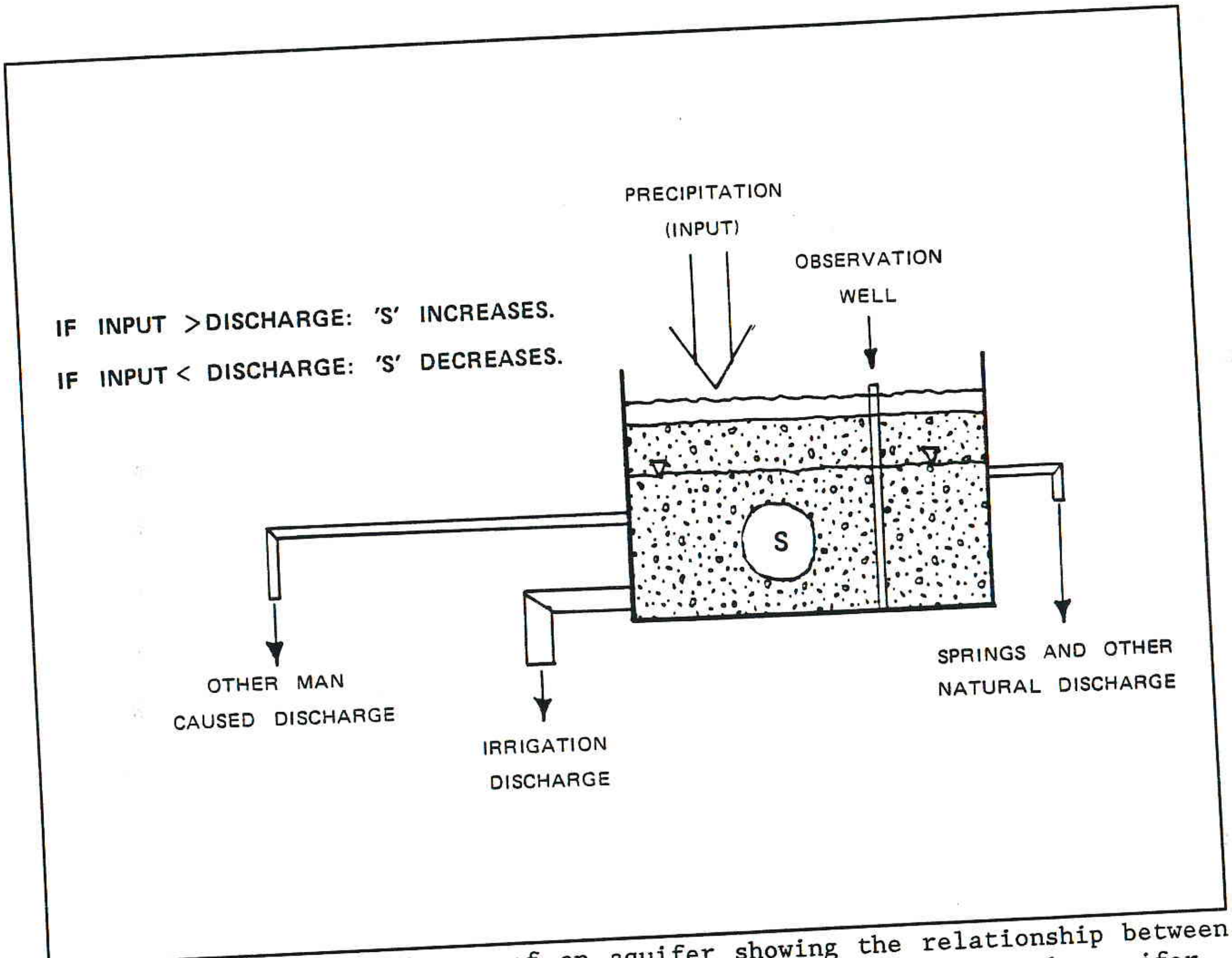

Figure 14: Schematic diagram of an aquifer showing the relationship between static water level and the amount of water stored in the aquifer.

Plate 5. Highest water level altitudes are in the vicinity of Glendora Lake and the Ralston Gap. Lowest water level altitudes are in the eastern portion of the Burton Bench aquifer. The slope of the water table varies from 60 to 70 feet per mile in the southwestern portion of the aquifer to approximately 20 feet per mile in the central portion of the aquifer. Because groundwater flows down

gradient, lateral movement of water in the subsurface is generally eastward as shown by the flow lines drawn perpendicular to contours of equal water level altitude on Plate 5. The flow lines indicate that water in the Burton Bench aquifer flows from west to east and from southwest to northeast. Water discharges from the system through numerous seeps, springs, and groundwater drains east of Highway 220 where the land surface intersects the water table and by groundwater flow laterally through the artesian zone to the east.

Plate 5 is a snapshot of the configuration of the water table in the Burton Bench aquifer taken at the time the measurements of the water table were made. Water tables are dynamic and the shape of the surface changes with time. While Plate 5 illustrates directions of groundwater flow, it tells little about the relative importance of different areas regarding recharge to the aquifer. Evaluation of water level information in respect to time provides clues regarding sources of recharge to the aquifer.

Selected hydrographs from Appendix B serve as examples for the water level change discussion and are included on Figure 15. Wells Utswl 5, Utswl 4, Utswl 2, and Utswl 37 generally illustrate types of water level change in different portions of the Burton Bench aquifer. The wells are correctly positioned in time relative to each other and water level changes are drawn to the same scale. Utswl 5, Utswl 4, and Utswl 2 are traces provided by continuous water level recorders and Utswl 37 is based on monthly measurement for the summer of 1986 when the well was measured weekly. More detail on the movement of the water table is available for this portion of the Utswl 37 record and is shown by the more jagged portion of the record. The four hydrographs in Figure 15 illustrate a general decrease in annual water level movement downgradient in the Burton Bench aquifer.

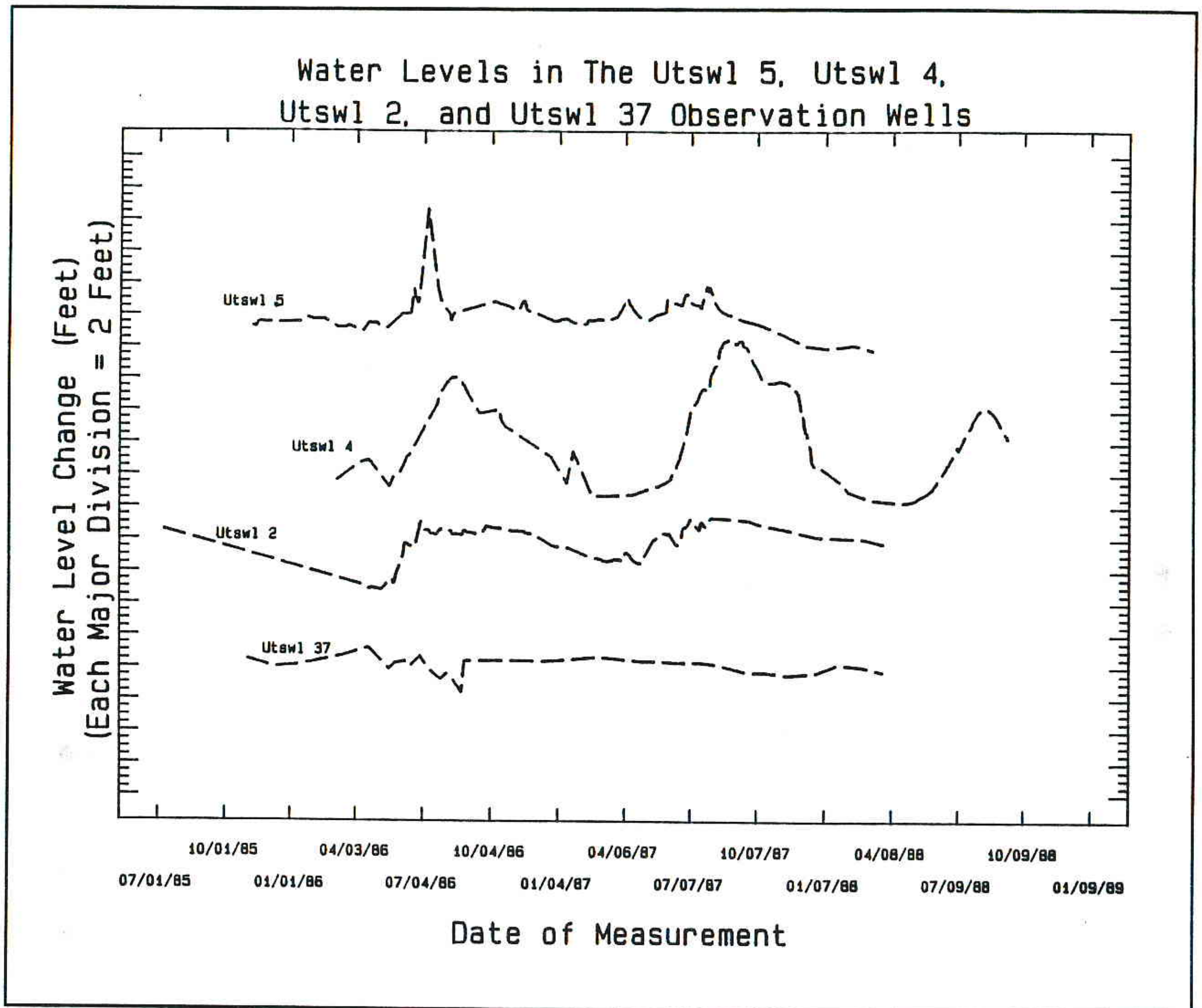

Figure 15: Selected Hydrographs for the Burton Bench aquifer.

Utswl 5 is located within the Ralston Gap. Water levels in this well are approximately 8 to 9 feet below land surface. With one exception, water level fluctuations are less than 2 feet in magnitude. The sharp upward peak in July 1986 reflects response of this well to flooding of the field in which it is located and is apparently unusual. In general, water level measurements in UTSWL 5 show that water levels within the Ralston Gap are relatively constant on an annual basis varying approximately 2 feet over the period of record. Confirmation of the lack of movement of the water table is provided by water level measurements in 11 other wells located within the Ralston Gap which are summarized in Table 1.

Utswl 4 is located approximately 3.5 miles northeast of Utswl 5. Water levels in this well are 45 to 50 feet below land surface and fluctuate between 6 and 10 feet annually. Water levels begin rising in the well in May-June of each year, peak in September, and fall to a low the following February and March. The annual variation of the water table at this location appeared consistent over the course of the study period. Large fluctuation of water levels in this well, only a few miles down-gradient from the relatively constant Utswl 5 observation well, indicates that water level fluctuation in Utswl 4 is not dependent on water level changes in the Ralston Gap and consequently, not dependent on groundwater flow though the gap.

UTSWL 2 is located just north of the town of Farmington (see Figure 3). Water levels are approximately 10 to 11 feet below land surface. Annual water level change in this well is similar to that in UTSWL 4, but the range of movement is much less and the water level peaks are less well defined. UTSWL 2 rises from its low point in March and April to peak in July and August of each year. Water level movement ranged between 3 and 4 feet in 1986 and 1987.

UTSWL 37 is located approximately 0.75 mile east of UTSWL 2. Water levels are approximately 3 to 4 feet below land surface. The movement in the water table in UTSWL 37 is similar to most wells measured in the eastern and artesian portions of the Burton Bench aquifer where water levels are relatively stable and vary less than 1 foot over the period of record. Reasons for this stability are twofold. First, UTSWL 37 lies near a discharge zone for the Burton Bench aquifer. Springs, seeps, and other wet areas in the vicinity of this well control the water table by increasing in discharge when water levels start to rise. Secondly, a groundwater drain located on the west side of Highway 220 intercepts some groundwater when water levels are high. Water level peaks seen in the UTSWL 2 are removed by discharge to surface water limiting the movement of the water table.

Because groundwater flowing through the Ralston Gap is one source of recharge for the Burton Bench aquifer and because of its strategic location at the up-gradient end of the aquifer, specific attention was paid to the Gap during the aquifer Study. Eleven wells were drilled in the Ralston Gap to explore the groundwater potential of the Gap and to determine geologic and lithologic relationships. A north-south cross section across the Ralston Gap based on 7 of the wells was drawn along the west side of Section 19 of Township 25 North, Range 5 West for the purpose of better understanding the geology of the gap and to estimate a saturated cross sectional area for the Gap. Other wells (4 in all) in the Gap were drilled both up- and downgradient from the cross section. The up- and downgradient wells provided points where groundwater levels could be measured and the hydraulic head downgradient through the Gap could be estimated. Altitudes for the cross sectional wells and the downgradient well were determined by leveling from a benchmark in Section 21 CC, Township 25 North, Range 5 West. Altitudes for up-gradient wells were estimated from topographic maps. Water level measurements on the 11 wells were made between 2 and 6 times during the course of the project. Lithologic logs for the wells are contained in Appendix E.

The cross section of the Ralston Gap is presented in Figure 16 and shows that the valley is relatively wide in comparison to its fill. A line representing the average depth to water in the Ralston Gap wells is also shown in Figure 16. Standard deviations on the average water level for the wells ranged

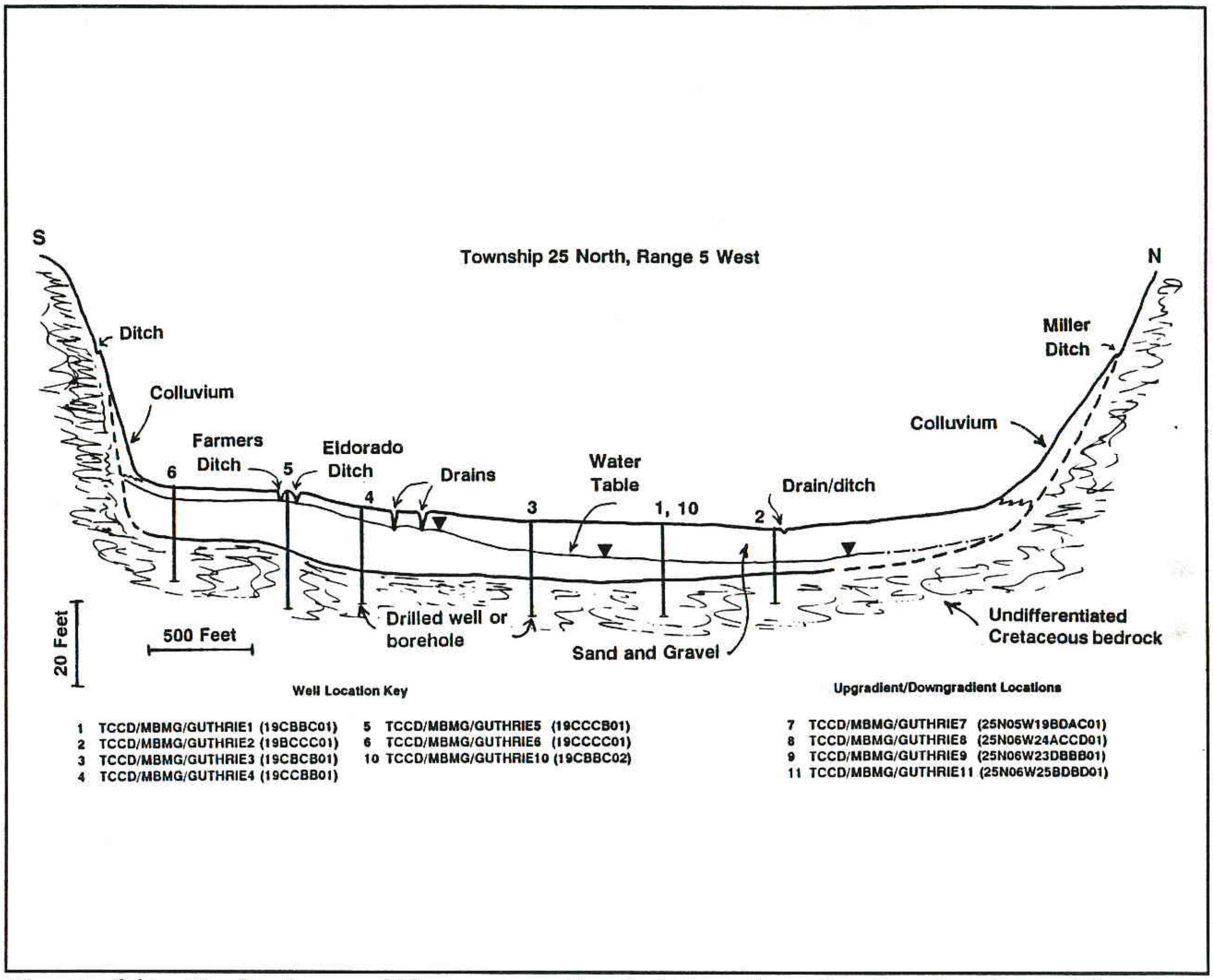

Figure 16: Geologic profile across the Ralston Gap, Burton Bench aquifer.

from 0.2 to 0.8 foot but generally were less than 0.5 foot. Water level measurements for the Ralston Gap are summarized on Table 1. A water level recorder (UTSWL 5 on Figures 15 and 17; see Figure 3 for location) was operated in the Ralston Gap for much of the project duration. Examination of the record for this recorder indicates that water levels were generally stable in the Gap during the project period supporting the conclusion that subsurface flow through the Ralston Gap is relatively constant.

The water table shows the influence of the Farmers and Eldorado ditches in the southern portion of the profile. Water levels are only a few feet below the land surface in the vicinity of the ditches and become progressively farther below the land surface in the northern portion of the section. Groundwater appears to be mounded on the south side of the Ralston Gap due to leakage from these two ditches and a third ditch which traverses the south valley wall.

Groundwater drains crossed by the line of the section are shown on Figure 16 appropriately scaled to the section. Drains just north of the irrigation ditches intersect the water table and supply water to the Guthrie irrigation systems. The "drain" north of the northernmost well in the section appears to be perched above the water table and is not obtaining water from the groundwater system at the line of the profile. Water in this drain is supplied by interception of higher water table areas west of the line of the profile.

Table 1

Static water level altitudes in Ralston Gap Observation Wells
(Altitudes are in Feet above Sea Level)

Well Number	1	2	3	4	5	6	7	8	9	10	11
Land Surface Altitude	4081.02	4079.78	4081.92	4084.62	4089.30	4090.43	4061.93	4094.83	4130	4081.12	4110
SWL/Date											
07/24/86	4072.78	4071.07	4074.33	4081.59	4086.33	4087.50	4059.45	4091.44	4124	4072.80	4106.6
08/26/86	4071.85	--	4074.68	4081.59	4085.85	4087.20	4059.46	4091.04	4124	--	4105.8
10/10/86	--	4071.73	4073.68	4081.59	4086.33	4087.07	4059.95	4091.08	4123	4072.17	4105.1
12/03/86	4072.95	--	--	4081.82	4085.66	4087.22	--	4091.31	4124	--	4106.0
02/06/87	4071.33	--	--	4081.63	4085.66	4087.59	--	4091.13	4123	--	4106.0
04/23/87	4071.80	--	--	4081.64	4085.56	4087.08	--	4091.39	4124	--	--
06/18/87	4073.4	--	--	4082.23	4086.66	4087.94	--	--	--	--	--
Average	4072.35	4071.40	4074.23	4081.73	4080.01	4087.37	4059.62	4091.23	4123.7	4072.49	4105.9
Standard Deviation	0.8	0.46	0.51	0.23	0.45	0.30	0.28	.020	0.52	0.45	0.54

(Dates are given in Month/Day/Year Format)
(Locations for wells are shown on Figure 16)

Using Figure 16, the saturated cross sectional area in the Ralston Gap is approximately 27,300 square feet if the valley is actually shaped reasonably close to that shown in the cross section and based on the "average" water table altitude and shape. Hydraulic conductivity values for the Ralston Gap were determined by a constant discharge aquifer test on a well drilled for that purpose in Section 19 CBBC, Township 25 North., Range 5 West. Hydraulic conductivity for the Ralston Gap is about 3,500 gallons per day per square foot of saturated area. Downgradient hydraulic head based on water level measurement in Guthrie wells 9 and 7 is about 0.006 (no units). Using Darcy's law (Freeze and Cherry page 16) a discharge through the line of the cross section can be calculated and was determined to be approximately 573,000 gallons per day. Conversion of this figure to acre feet per day yields a value of 1.75 which when extrapolated for one year yields an annual subsurface flow through the line of the profile of about 640 acre feet per year.

As a potential source of recharge for the Burton Bench aquifer, the Ralston Gap provides a reasonably steady contribution of approximately 640 acre feet annually. If major changes in the water level occurred, the cross sectional area on the profile would change giving rise to fluctuations in the discharge as estimated by the Darcy equation. Because water levels in the Gap fluctuate much less than those only a few miles downgradient (UTSWL 4, Figure 15) water level changes in the vicinity of UTSWL 4 can not be explained by groundwater flow through the Ralston Gap. Another source of recharge must be determined for the Burton Bench aquifer which can account for the annual fluctuations in the water table noted in observation wells such as UTSWL 4 and UTSWL 2. Sources of water available for recharge other than that flowing through the Ralston Gap include direct infiltration from precipitation and leakage of irrigation water from ditches and fields.

Water level changes in UTSWL 5, UTSWL 4, UTSWL 2, and UTSWL 37 are matched with precipitation measured at the Choteau airport on Figures 17 and 18. Minor water level peaks in UTSWL 5 may be related to periods of precipitation as recorded at the Choteau Airport. For example, short duration water level changes correspond or shortly follow precipitation events of 1 inch or greater during the summer of 1987. Water level changes in response to specific precipitation events exhibit quick rises as recharge from rainfall or snowmelt infiltrates to the water table followed by a more gradual decline as water is transmitted by the aquifer away from the area of recharge and the rate of infiltration declines.

At first glance UTSWL 4 (Figure 17) also appears to respond favorably to precipitation events. Water levels make major advances upward during or shortly after the majority of precipitation occurs in each year of the record. However, water level change in UTSWL 4 is much longer in duration and much larger in amplitude than those of UTSWL 5. The rise in water level is abrupt and steady and does not exhibit the same short term aspect as water levels in UTSWL 5. If water level changes in UTSWL 4 were related only to precipitation, water levels rose up to 10 feet over a period of months whereas they rose less than 2 feet over a period of weeks in UTSWL 5 in response to the same amount of precipitation.

UTSWL 2 (top Figure 18) also shows influence from the precipitation which occurred during the period of record but the influence appears to be superimposed over larger scale and longer term water level fluctuations. Variations of less than 0.5 feet in the water level trace appear to correlate with precipitation events of approximately 1 inch. During both years of the record for UTSWL 2,

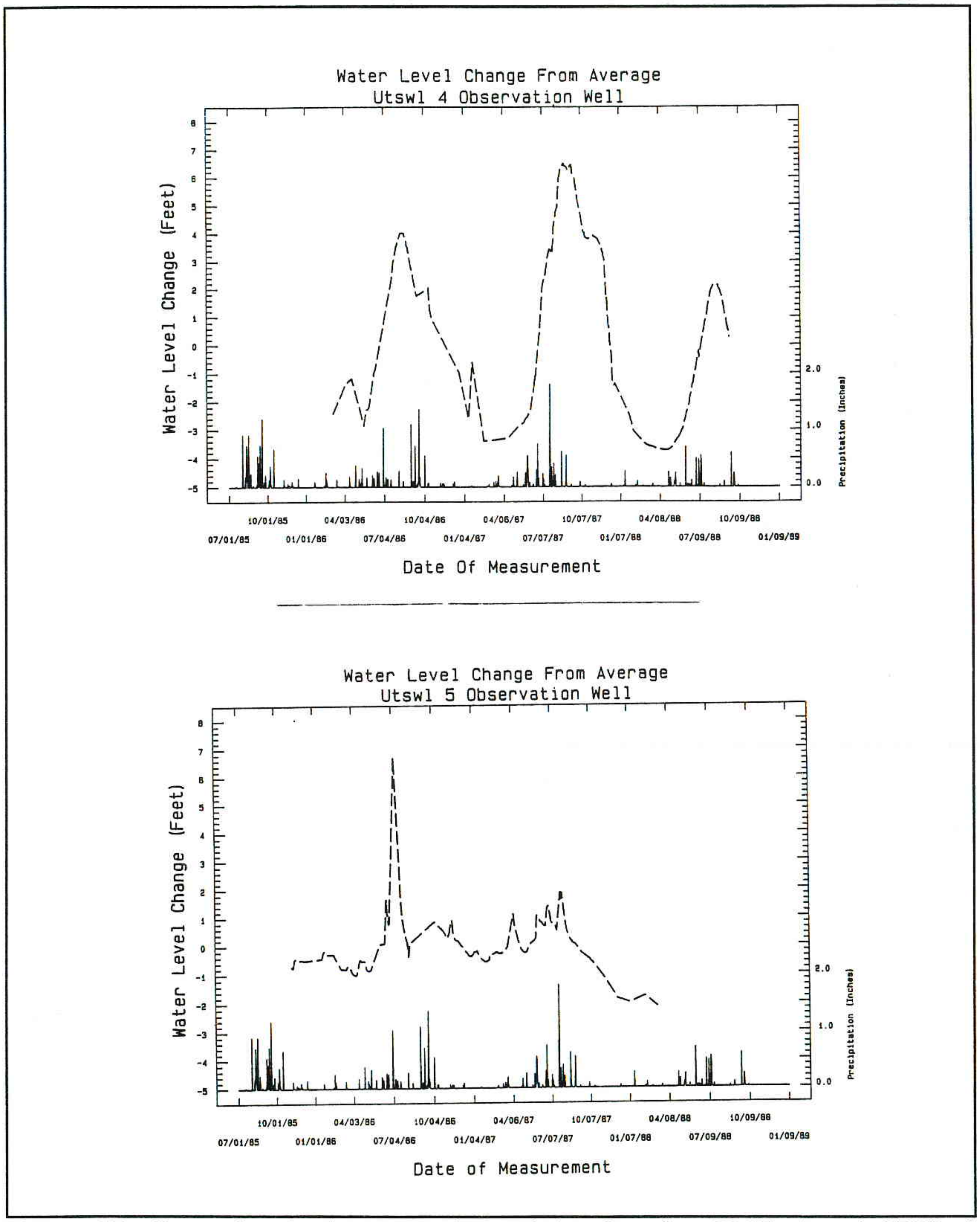

Figure 17: Water level changes and precipitation for UTSWL 4 and UTSWL 5 observation wells, Burton Bench aquifer.

major upward movement of the water table began prior to major precipitation events of the spring and summer season.

Water level and precipitation data for UTSWL 37 are shown in the lower portion of Figure 18. Very little correlation between water level changes and the timing of precipitation events appears on the chart. Part of the lack of correlation may be caused by the monthly measurement frequency where small short term movement of the water table could not be recorded by the observer. However, the lack of correlation may also be because UTSWL 37 is located at an altitude low enough so that Illinoian glacial ice may have over-ridden its location. The till left by the ice could provide a lowly permeable cap for the aquifer eliminating or reducing the affect of precipitation on the aquifer at this location.

Data measuring the influence of annual precipitation on the Burton Bench aquifer were not obtained during the Upper Teton Aquifer Study. However, if 5 percent of the annual precipitation (0.046 feet of water) infiltrates the land surface and becomes recharge to the Burton Bench aquifer over that portion of the aquifer through which recharge occurs (49,000 acres), approximately 2,300 acre feet of water would be derived from the precipitation. The actual amount of water in the Burton Bench aquifer derived from precipitation is undetermined but a figure of 5 percent of the annual precipitation provides a reasonable estimate resulting in a volume of the correct order of magnitude. If infiltration is 7 percent of the annual precipitation, the amount of water would be 3,100 acre feet annually. If the percentage is less, the amount of water available as recharge would be less. Approximately 2,300 acre feet annually 3.5 times the amount of water available to the aquifer through underflow in the Ralston Gap.

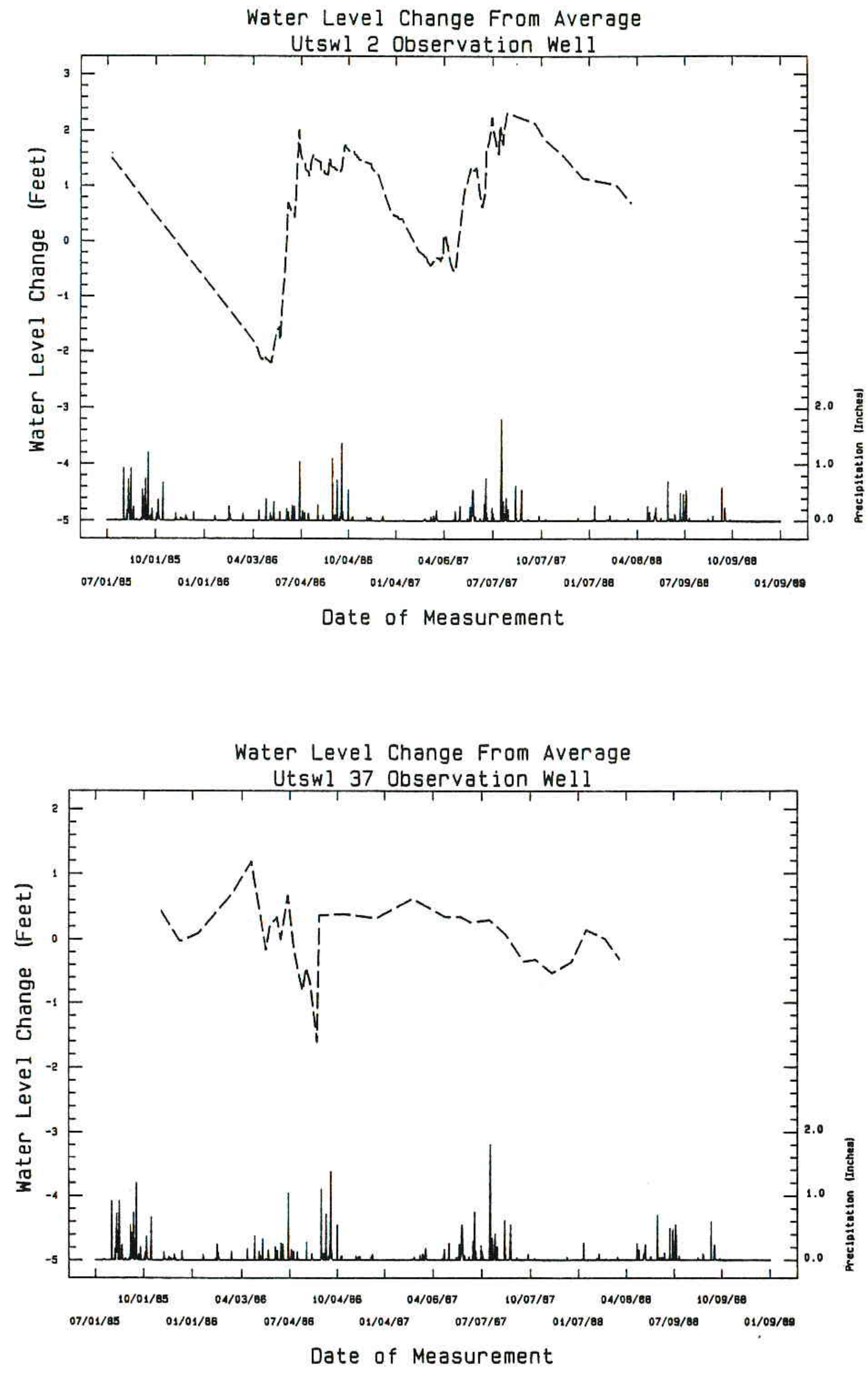

Figure 18: Water level changes and daily precipitation in the UTSWL 2 and UTSWL 37 observation wells, Burton Bench aquifer.

Leakage from irrigation ditches and flooding of fields is the third identified source of recharge to the Burton Bench aquifer. Influence of irrigation water leakage on the aquifer is best seen by evaluating water level records to determine where water levels rose and fell during different time periods. Water level change maps for the Burton Bench aquifer were constructed for 6 month intervals beginning with measurements made in January 1986.

Net water level changes between January and July of 1986 are shown in Figure 19. During the period, water levels rose between 1 and 5 feet in portions of the Burton Bench aquifer generally west of Farmington. Water levels in two wells east of Farmington also rose 6 and 8 feet respectively. A narrow arcuate zone beginning just north of Farmington and extending to the northeast either underwent no net change for the period or declined between 1 and 2 feet.
Water level changes for the succeeding July 1986 - January 1987 period are shown in Figure 20. Water levels dropped between 2 and 5 feet in a large area northwest of Farmington between Farmington and the Ralston Gap. Water levels also dropped between 1 and 6 feet in an area east of Farmington. However, water levels in the vicinity of Farmington and in a narrow irregular band between Farmington and Agawam rose from 1 to 3 feet. Comparison between Figures 19 and 20 shows that water levels in the western up-gradient portions of the Burton Bench aquifer generally fell during the July-January period, but water levels in the downgradient areas near discharge zones generally rose. An exception is an area east of Farmington where water levels fell.

A third water level change map is shown in Figure 21. The map shows net water level changes in the Burton Bench aquifer for the period between January and July 1987. During this period, water levels in a northeast band across the central portion of the aquifer fell between 1 and 5 feet while water levels

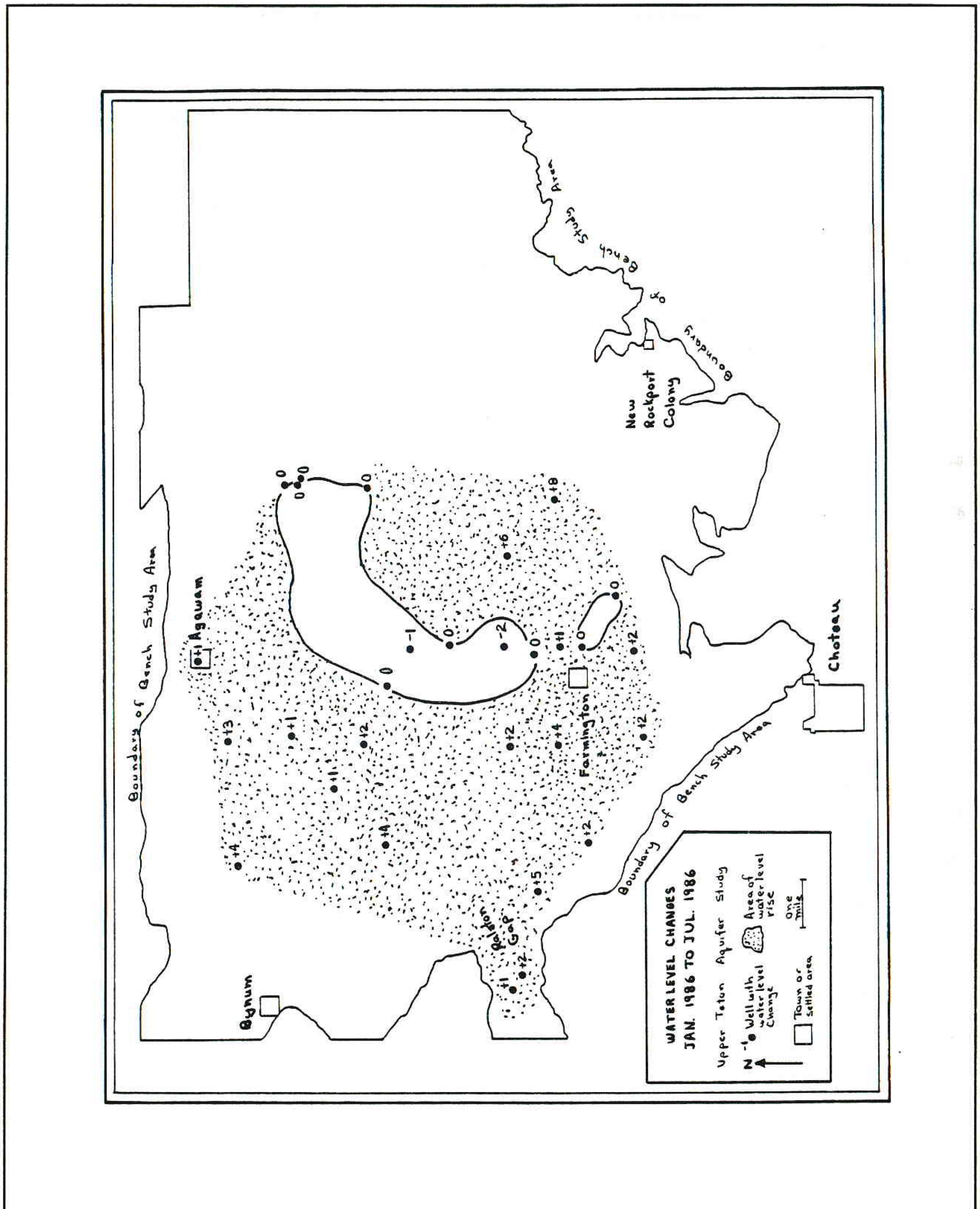

Figure 19: Water level changes between January and July 1986, Burton Bench aquifer.

elsewhere rose. Comparison of water level changes for this time period with those of the previous 6 months shows that the sense of motion of the water table is again reversed. Water levels fell in areas of the aquifer in which they had previously risen, and rose in areas where they had previously fallen.

Figures 19, 20, and 21 illustrate a general pattern of movement in the water table of the Burton Bench aquifer during the aquifer study. Water levels rise in the western portions of the aquifer during the spring and summer months and fall in the late summer and winter periods. Water levels in wells near and north of Farmington often rise during the winter months and fall during the summer months. The pattern of water level movement in the Burton Bench aquifer can not be explained by a reasonably constant but relatively small subsurface flow through Ralston Gap and also can not be explained solely by precipitation. Precipitation may provide up to 2,300 acre feet per year of recharge to the aquifer but in some wells the annual upward fluctuation of the water table begins prior to the receipt of major spring and summer precipitation events. Additionally, water level changes in portions of the aquifer likely to receive like amounts of infiltration from precipitation respond with large differences in water level change.

Tying water level change information together with the water table information shown on Plate 5, water level change information as shown on the hydrographs in Figures 17 and 18, and groundwater flow through the Ralston Gap leads toward a source of recharge for the Burton Bench aquifer that fits the following criteria.

1. The majority of recharge water to the Burton Bench aquifer does not flow into the aquifer through subsurface flow through the Ralston Gap because relatively stable water levels in the Gap do not indicate that groundwater flow changes substantially through the Gap on an annual basis. Water levels farther east in the

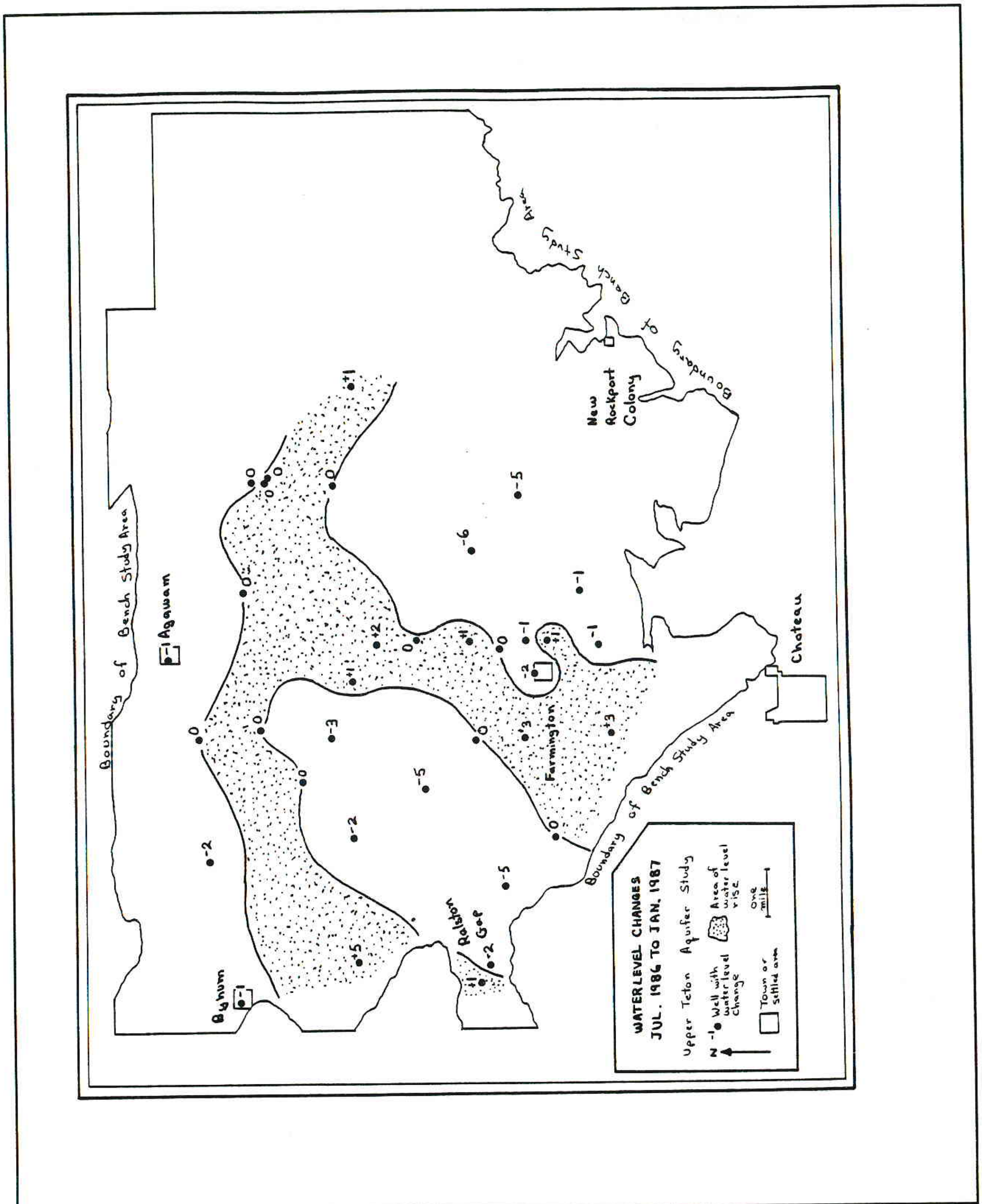

Figure 20: Water-level changes between July 1986 and January 1987, Burton Bench aquifer.

aquifer show major fluctuations related to recharge.

2. Direct infiltration of precipitation does not create large annual fluctuations in water levels based on evaluation of hydrographs.

3. Recharge occurs primarily in the western portion of the aquifer in the spring and summer of each year based on net water level changes in that portion of the aquifer.

A source of water that meets the criteria listed for the primary source of recharge to the Burton Bench aquifer is leakage from irrigation ditches and through fields that are flooded for irrigation. The recharge is present at the correct time of the year and in the correct areas of the aquifer to be a good source of recharge based on the data previously reviewed. Approximately 115 miles of unlined irrigation ditch have been constructed in a 35 square mile area bounded by the Teton Ditch on the south, bedrock hills outside of the aquifer on the west, Foster Creek on the north, and Montana Highway 220 on the east. Figure 22 is a map showing the larger ditches but smaller ditches and laterals are not shown. Examples of the amount of ditch loss for two irrigation districts on the Burton Bench are provided in records provided by those companies. The Farmers ditch loses an average of 28 percent of the water turned out from the reservoir based on records between 1980 and 1987. Average losses for the 1980-1987 period were 1,950 acre feet per year. The Eldorado ditch, based on 1987 records, lost about 22 percent of its water or 4,370 acre feet of water. Ditch losses from these two companies could account for approximately 6,300 acre feet of water being potentially available to the Burton Bench aquifer annually. No information detailing where ditch losses are greatest or how much of this water may be lost prior to reaching the Burton Bench is available. The potential recharge also does not include losses due to deep percolation through fields that are flood irrigated or from other ditch systems.

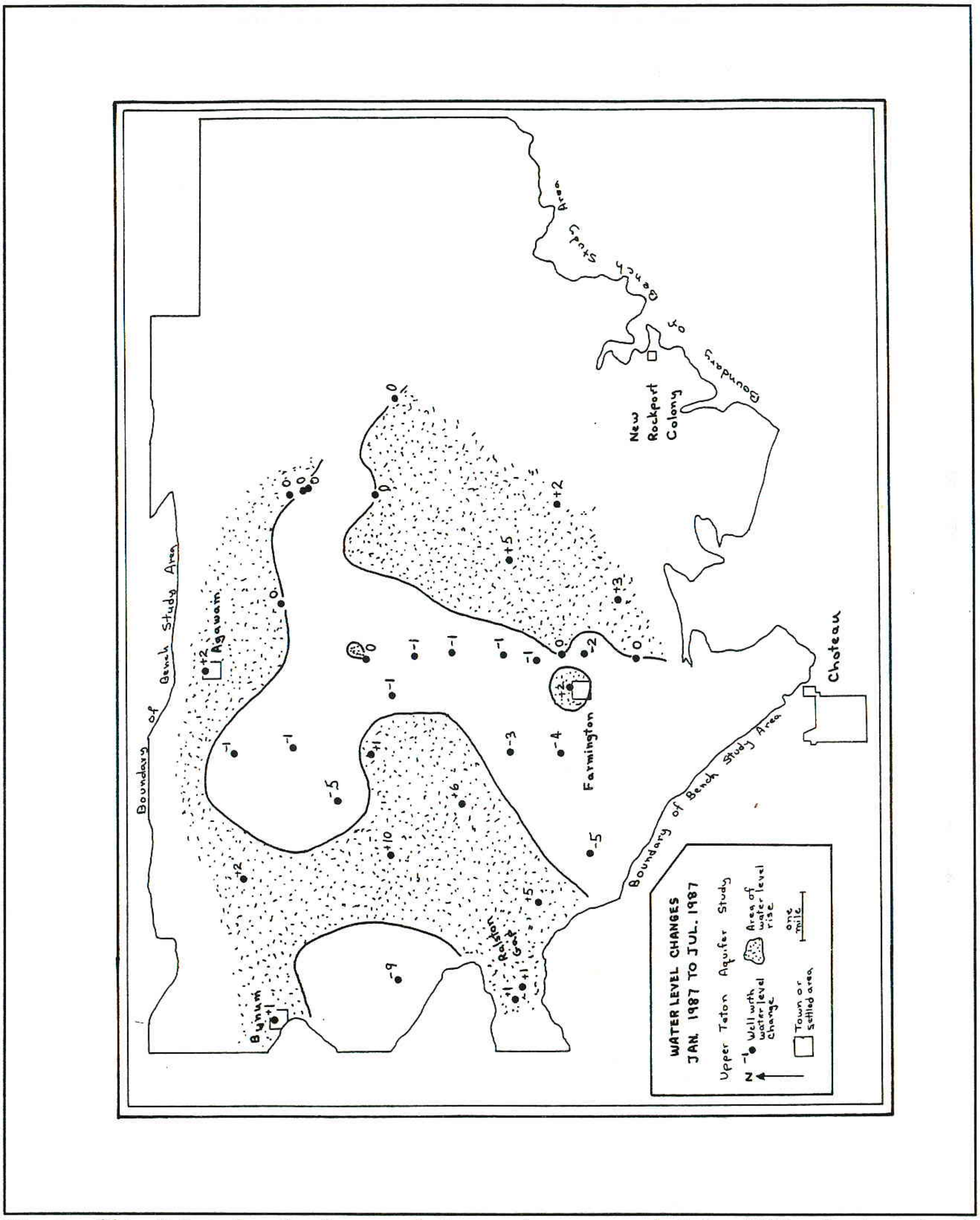

Figure 21: Water level changes between January and July 1987, Burton Bench aquifer.

Of the three potential sources of recharge to the Burton Bench aquifer, ditch and associated leakage through flood irrigated fields may be the largest. Ditch losses are at least 10 times the amount of water estimated to flow through the subsurface in Ralston Gap and approximately 2.7 times the amount of recharge that can be expected through infiltration of precipitation. Observations by Fisher (1909, page 67) confirm the importance of ditch and field leakage.

> "Before irrigation ditches had crossed the Burton Bench water was obtained at a depth corresponding to the thickness of the gravel, but the water plane has been gradually rising under the influence of irrigation until now an abundant supply is found at 10 to 12 feet below the surface."

Data derived during the Upper Teton Aquifer Study confirm Fisher's observation that irrigation practices provide most recharge water to the Burton Bench aquifer. Leaky ditches which traverse miles of unconsolidated sand and gravel and flooded fields in the western up-gradient portions of the aquifer have created an un-naturally high water table in the Burton Bench aquifer which has been in place for a period of time long enough for local citizens to become accustomed to its presence. The high water table has created wet areas and springs in the downgradient discharge portions of the aquifer which have been appropriated by different users. The appropriation of the discharge water is one of the major water use problems in the Burton Bench aquifer effectively preventing additional development of the aquifer.

Water in Storage:

The geometry of the Burton Bench Aquifer is best illustrated in Plates 2 and 3. Thickness of the gravel deposits in the southern and central portions of the Burton Bench west of Farmington (see Plate 3) relative to the thinner gravel deposits of the Ralston Gap and areas east of Farmington plays a critical

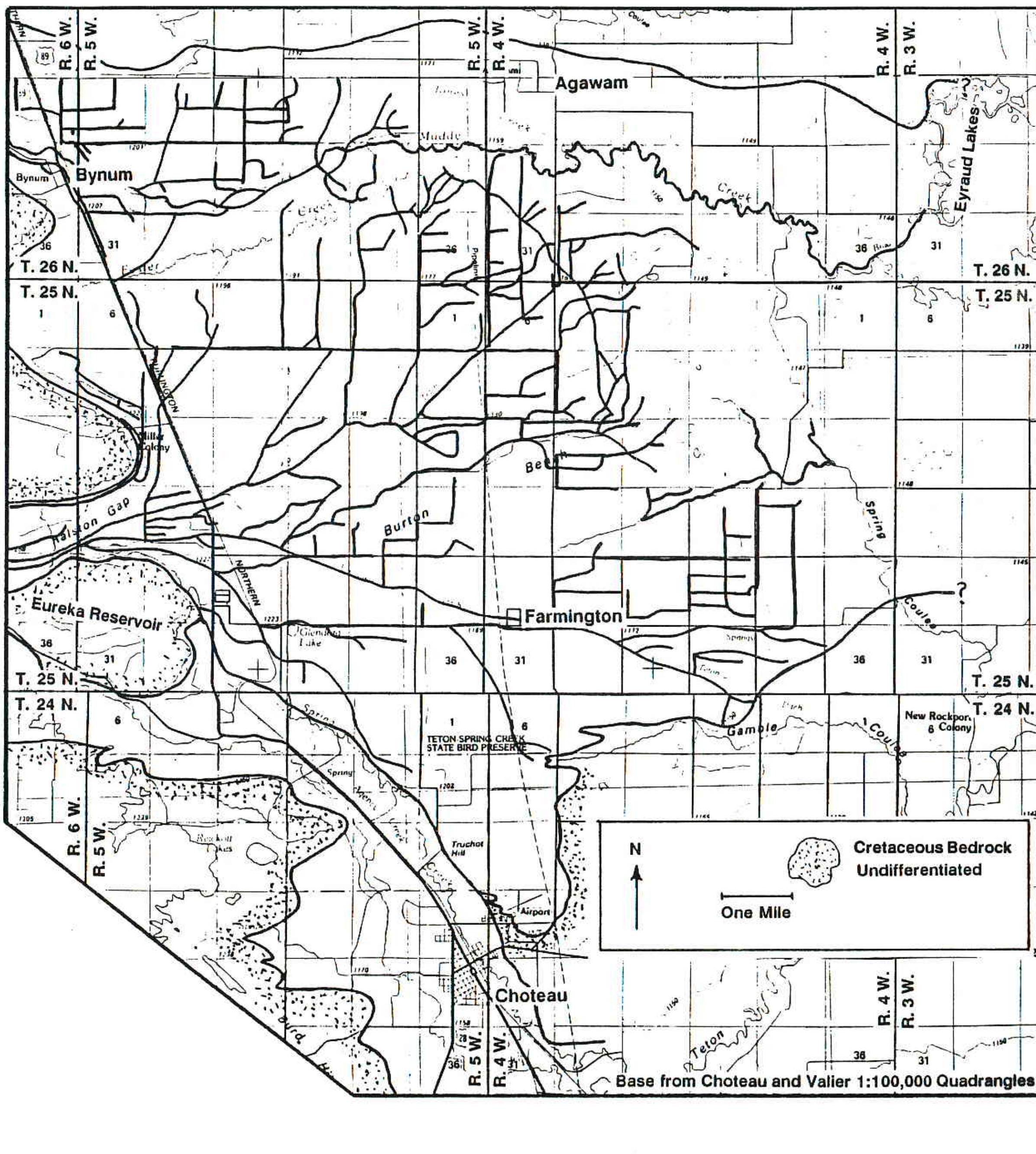

Figure 22: Irrigation ditches on the Burton Bench aquifer.

roll in the hydrology of the aquifer. High altitude bedrock along its southern margin produces a dry southern margin to the aquifer and affectively separates the Burton Bench Aquifer from the topographically lower Teton River Valley Aquifer. The relationship of the bedrock to the gravel deposits along the southern margin of the Burton Bench Aquifer is best shown in cross section B - B′ on Plate 4.

The geometry of the Burton Bench aquifer is important in estimating the amount of water stored in the aquifer. Bedrock altitudes and water table altitudes can be subtracted to obtain an estimate of the amount of water stored in the Burton Bench aquifer after consideration is made for the void space in the aquifer. Subtraction of the bedrock altitudes from the water table altitudes determines saturated thicknesses at different points in the aquifer, the saturated thicknesses are posted on a base map, and then contours on lines of equal thicknesses can be drawn. The aerial coverage of different saturated thickness categories can be determined and then evaluated to estimate the amount of water in storage. The amount of water in storage will be the saturated volume of the aquifer multiplied by estimated void space in the aquifer.

Davis and DeWeist 1966 (page 375) show that porosities for non-indurated relatively coarse sediments (sands, gravels, etc.) similar to those on the Burton Bench range from about 25 to a much as 52 percent of the total volume of the material. Freeze and Cherry 1979 (page 37) also suggest that sands and gravels have porosities ranging from 25 to 50 percent. The Cole aquifer test located in Section 18 CBBB Township 25 North, Range 4 West produced a storativity of 29 percent for the Burton Bench sediments which should be under water table conditions. The storativity at this site should be slightly less than the actual porosity of the sediments within the influence of this well during the pumping test. For the purposes of calculating a volume in storage for the Burton Bench aquifer, an average porosity of 20 percent will be used which should provide a conservative estimate of the amount of water in storage. This calculation is at best a scientific estimate and is based on water level measurements made in January 1987 (Plate 5) and bedrock altitudes (Plate 2). Saturated thicknesses for the artesian portion of the aquifer were derived from gravel thickness data on Plate 3. A total saturated volume of 6.6×10^{10} cubic feet for the Burton Bench aquifer determined based on data collected during the study period. Using a porosity of 20 percent to determine the portion of the total saturated volume that is water yields a total of approximately 1.3×10^{10} cubic feet of water or approximately 302,000 acre feet in storage at the time of the water table measurement.

The amount of water in storage is dynamic and will vary from time to time. For example, water levels in the TCCD/MBMG/LEYS observation well fluctuate up to 10 feet annually and this amount of fluctuation will cause the amount of water stored in the aquifer to vary considerably over the course of the year. Longer term trends in the water table can not be determined from the brief water level record available from the aquifer study, but the data do suggest that conditions are stable and that storage in the Burton Bench aquifer is not substantially increasing or decreasing.

Discharge from the Burton Bench aquifer:

Water is removed from the Burton Bench aquifer via several different natural and man-caused mechanisms. Natural discharge occurs in a band 2 to 3 miles in width extending northward from about Sections 5, 6, and 7 of Township 24 North, Range 4 West to about Sections 25, and 26 of Township 26 North, Range

5 West. The discharge zone extends westward from Sections 25 and 26 along Foster Creek to its headwaters in Section 1 of Township 25 North, Range 6 West. The band is marked on the land surface by land used mostly for grazing and for raising natural for hay. Topographically higher portions of the natural discharge zone tend to be dry and need irrigation from surface water sources while topographically low zones are saturated, and if tributary to surface streams, drain water into those streams.

Water level records indicate that an area southeast of Farmington in Sections 31 - 34 of Township 25 North, Range 4 West and in Sections 4 - 6 of Township 24 North, Range 4 West exhibit characteristics of both the recharge and the discharge zones. Several large ditches (Teton Ditch, Farmers Ditch) extend across this area and water levels in wells fluctuate more closely with wells west of Farmington. However, topographically low tracts discharge water to springs and small surface streams, some fields have sub-surface drains to help control the water table, and the area is geographically adjacent to the discharge zone.

The placement of the natural discharge zone within the Burton Bench aquifer is determined by the thickness of the aquifer relative to its saturated thickness. For example, in the TCCD/MBMG/LEYS observation well in Section 14 BCCC, Township 25 North, Range 4 West, sand and gravel deposits are 58 feet thick and water levels are 45 to 50 feet below land surface. Two miles east at the TCCD/MBMG/COLE observation well in Section 18 CBBB Township 25 North, Range 4 West, the sand and gravel deposits are 64 Feet in thickness and water levels are about 12 feet below land surface. In Section 17 AADB Township 25 North, Range 4 West in the TCCD/MBMG/MALONE W. observation well the sand and gravel deposits are 25 feet thick and water levels are 3 to 4 feet below land surface. A groundwater drain is located less than 100 feet north of this well. The relationship of the thickness of the sand and gravel deposits to the saturated thickness of the aquifer is apparent on cross section A-A' on Plate 4. Figure 23 is a schematic drawing of the topographic-saturated thickness-discharge relationship of the Burton Bench aquifer. Topographic differences are exaggerated in Figure 24 to illustrate the relationships more clearly.

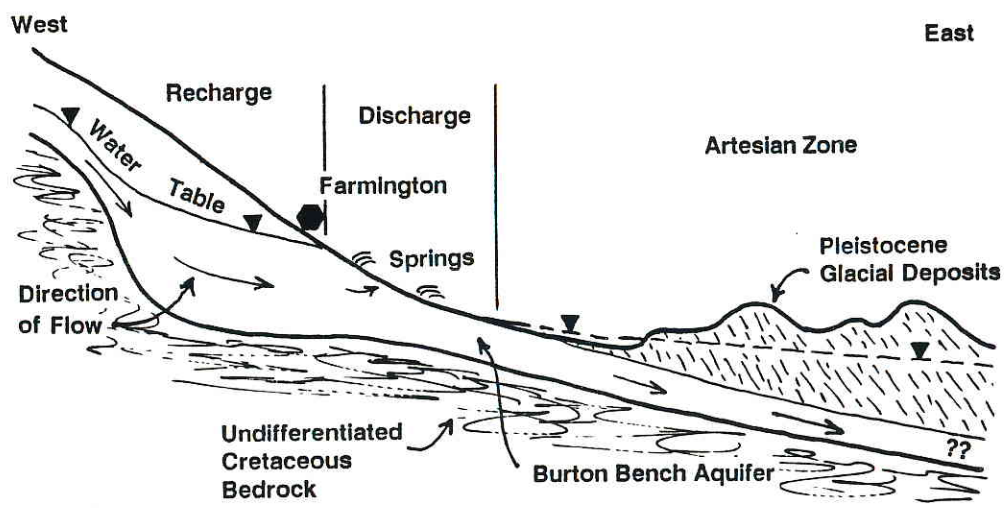

Figure 23: Schematic profile of the topographic relationship between water levels and the thickness of the Burton Bench aquifer in an east-west direction.

The discharge zone contains numerous groundwater drains such as those located in Section 32 of Township 25 North, Range 4 West and in Section 17 of Township 25 North, Range 4 West. Water also is removed from the aquifer in a drain which parallels Montana Highway 220 from the southeast corner of Section 30 of Township 25 North, Range 4 West to where it discharges into a tributary of Spring Coulee in the southeast corner of Section 18 Township 25 North, Range

4 West. Water from all three of the drains described is either appropriated and put to use downstream or applications to put the water to use have been filed with the Montana Department of Natural Resources and Conservation.

Other man caused discharge from the Burton Bench aquifer is through wells where water is pumped for domestic, stock and irrigation uses. Water pumped for domestic and stock uses represents a minor amount of water discharged from the aquifer in comparison to the amount of water in storage and to the amount of recharge available. Groundwater pumpage for irrigation purposes is the largest use with about 2,200 acres of land being irrigated from this source.

Groundwater also flows eastward in the Burton Bench aquifer into the artesian zone. Water is discharged from the aquifer by transmittal through the aquifer to areas east of the study area, by flowing wells, and probably by upward leakage through thin confining beds in Sections 34 and 35 of Township 26 North, Range 4 West. Water discharged naturally in the artesian zone flows into the Spring Creek drainage. Some water is discharged in the artesian zone by artesian flowing wells which are uncontrolled. Norbeck (1978) suggested that upward leakage in the vicinity of Muddy Creek in Section 36 of Township 26 North, Range 4 West and Section 31 of Township 26 North, Range 3 West may also be discharge from the Burton Bench aquifer.

Water Quality

Water quality data for 31 locations on the Burton Bench are shown on Figure 5 (page 13) and represent both historic and new data collected during the aquifer study. Copies of water quality analyses for the Burton Bench are presented in Appendix D. Twenty-seven of the analyses are from sample sites which produce water from the Burton Bench aquifer, 1 analysis is from a gravel unrelated to the Burton Bench aquifer, 2 analyses are from bedrock aquifers, and 1 analysis is for nitrate only.

Generally, water quality in an aquifer is best near sources of recharge because water at or near recharge zones has been in the aquifer a relatively short time and has had less time to dissolve mineral matter contained in the aquifer media. As water flows downgradient, changes in its occurs. Among many others, dissolved solids generally increase because more time has passed to dissolve soluble minerals from the aquifer material; cation exchange processes, or precipitation of minerals from dissolved constituents cause changes such as the water becoming more sodium or magnesium rich as it flows dowgradient. Water in discharge zones or in a part of an aquifer which has limited groundwater flow, will often contain highest concentrations of dissolved solids in the aquifer or will be of a different type from that near the recharge zone. Groundwater quality in an individual well or spring can also reflect mixtures of water from different sources providing water of differing quality than that of other discharge points in the aquifer.

Groundwater on the Burton Bench is generally of quality suitable for domestic, livestock, and irrigation uses. Some water northeast of Muddy Creek in the northeastern part of the study area is far from the main flow path in the Burton Bench Aquifer and is suitable only for stock-watering purposes because of undesirable high dissolved solids (see Muddy Creek Ranch analysis Section 24 DACA, Township 26 North, Range 4 West - Appendix D).

Dissolved solids concentrations for the Burton Bench aquifer average 401 milligrams per liter with a standard deviation of 131 milligrams per liter. Based on this sample set, 95 percent of the water in the Burton Bench aquifer should range between 139 and 663 milligrams per liter dissolved solids. Ground water containing less than 200 milligrams per liter dissolved solids is considered very high in quality for most uses. Measured dissolved solids concentrations for the Burton Bench Aquifer range from 242 milligrams per liter in water from a well located in Section 21 CCC, Township 25 North, Range 5 West to 672 milligrams per liter in a well in Section 28 BBCB, Township 25 North, Range 5 West. The distance between the wells producing the highest and lowest dissolved solids water for the Burton Bench aquifer is approximately 0.5 mile and is an exception to the general rules describing water quality changes discussed above.

Other parameters also show that water in the Burton Bench aquifer is suitable for most uses. Average values for different parameters in the Burton Bench aquifer, with one exception, meet or exceed public drinking water supply standards shown on Table 2. The average hardness of Burton Bench water is 300 milligrams per liter which is at the recommended limit and is considered to be very hard water.

Trace element concentrations for the Burton Bench aquifer are compared to water-use standards in Table 3. Results for most analyses for the elements listed on Table 4 were below instrumental detection limits. The apparent most abundant trace metal is bromide followed in average concentration by strontium and Boron. The detection limit for Bromide for analytical laboratory instruments used during the Upper Teton Aquifer Study was 0.1 milligrams per liter (1,000 micrograms per liter). The 5 bromide results reflected in the average on Table 4 were all at the detection limit of 0.1 milligrams per liter and are suspect. When analytical measurements are at or very near the detection limit, statistical error in the measurement means that "measured" concentrations slightly above the detection limit may actually reflect concentrations which are below the detection

Table 2
Common constituent concentrations and water quality standards
for the Burton Bench Aquifer

Parameter	Number of Analyses	Values > Detection	Average Value	1-Sigma Range	Standards		
					Drinking[1]	Stock	Irrigation
Calcium	27	27	52	72 - 32	--	--	--
Magnesium	27	27	42	54 - 30	--	2000[c]	--
Sodium	27	27	38	74 - 2	--	2000[c]	Variable
Potassium	27	25	3	8 - 0	--	--	--
Iron	27	9	0.10	0.30 - 0.0	0.3	Variable	5[b]
Manganese	27	14	0.04	0.11 - 0.0	0.05	Variable	0.2[b]
Silica	27	25	9	11 - 7	--	--	--
Bicarbonate	27	27	335	402 - 268	--	--	--
Chloride	27	27	6	17 - 0	250	1500[c]	--
Sulfate	27	27	87	153 - 21	250	1500[c]	--
Nitrate(as N)	27	25	3	9 - 0	10	100[b]	--
Fluoride	27	27	0.6	0.8 - 0.4	2	2.0[b]	15[b]
pH	27	27	7.97	8.26 - 7.68	6.0 - 8.5	--	4.5 - 9.0[c]
Dissolved Solids	27	27	401	532 - 270	500	3000[b]	~2000[c]
Specific Cond.	27	27	690	870 - 510	750 - 1000	--	~2000[c]
Total Hardness	27	27	300	365 - 235	<300	--	--
Total Alkalinity	27	27	275	330 - 220	30 - 500	--	--
Sodium Adsorption ratio	27	27	0.96	1.94 - 0.0	--	--	8 - 18[c]

[1]Items with an "A" are maximum contaminant levels for public water systems (Federal Register, December 24, 1975, p.59566-59588); all other values are recommended limits; (--) indicates the absence of a recommended limit.

[b]Bouwer, H., 1978, Ground Water Hydrology, McGraw Hill books-Table 10.6 page 365, Table 10.9 page 370.

[c]MBMG internal form 196.

limit for that parameter. Of the 23 analyses for bromide conducted during the Upper Teton Aquifer Study, 5 were at the detection level confirming that bromide is not a parameter of consequence in the Burton Bench aquifer.

Boron and strontium concentrations in water from the Burton Bench aquifer are substantially above the instrumental detection limit and represent valid measurements. However, concentrations for these two elements are also far below recommended limits for drinking, stock-watering, and irrigation purposes (Table 3).

Ten analyses for dissolved selenium were obtained for water from the Burton Bench aquifer. Six of the samples contained measurable concentrations of dissolved selenium ranging from 0.5 to 24.5 micrograms per liter but 5 of the 6 analyses contained 2 micrograms per liter or less dissolved selenium. The highest selenium concentration is from a well producing non-typical water from the Burton Bench aquifer in Section 24 CDDD, Township 25 North, Range 5 West.

Water chemistry in the Burton Bench aquifer, although relatively consistent, does vary in different parts of the aquifer. Dissolved solids

Table 3
Trace constituent concentrations and water quality standards for the Burton Bench Aquifer

Parameter	Number of Analyses	Values > Detection	Average Value	1-Sigma Range	Standards Drinking[1]	Stock[2]	Irrigation[2]
Aluminum	26	1	*	*	--	5000	5000
Arsenic	8	6	0.38	19.3 - 0.0	50[A]	200	100
Boron	26	16	99	136 - 62	1000	5000	750
Bromide	23	5	1000	*	--	--	--
Cadmium	23	3	3	*	10[A]	50	10
Chromium	25	2	2.5	*	50[A]	1000	100
Copper	25	6	9.2	15.5 - 2.90	1000	500	200
Lithium	26	25	15	25.2 - 5.2	--	--	2500
Molybdenum	23	0	*	*	--	--	10
Nickel	25	3	13.3	*	--	--	200
Selenium	10	5	4.7	*	10[A]	50	20
Silver	23	0	*	*	50[A]	--	--
Strontium	25	25	617	934 - 300	--	--	--
Titanium	22	17	6.7	10.3 - 3.10	--	--	--
Vanadium	23	5	2.2	*	--	100	100
Zinc	25	13	50.5	121 - 0	5000	25000	2000
Zirconium	23	0	*	*	--	--	--

[1]Items with "A" are maximum contaminate levels for public water systems (Federal Register, December 24, 1975, p.59566-59588); all other values are recommended limits; (--) indicates the absence of a recommended limit.

[2]Bouwer, H., 1978, Ground water Hydrology, McGraw Hill Books - Table 10.6 p.365, Table 10.9 p.370.

*Too few values to determine.

concentrations are less than 300 milligrams per liter in the Ralston Gap and in an area north of Farmington (Figure 24). Concentrations above 400 milligrams per liter are found across a wide area the eastern part of the Burton Bench aquifer generally east of Spring Coulee. Dissolved solids between 400 and 600 milligrams per liter occur in wells in the artesian flowing part of the aquifer. Highest dissolved solids concentrations (> 600 milligrams per liter) are represented by three analyses for water from wells in Sections 22 and 28 of Township 25 North, Range 5 West.

Figures 25 and 26 are designed to be examined together. Figure 25 is a Piper Plot of water quality data for the Burton Bench aquifer on which the dot position represents the type of water determined by the analyses. Figure 26 is a map of the Burton Bench Aquifer showing the geographic locations of the analyses shown on Figure 25.

All but 3 of the sampled waters fall in the Calcium-Magnesium Bicarbonate-Carbonate (Calcium-Bicarbonate) field on the Piper Plot. Analyses for those waters outside of this field (Numbers 2, 9, and 28 on Figure 25) still plot relatively close to the Calcium-Bicarbonate field. In the diamond shaped portion of the Piper Plot and within the Calcium-Bicarbonate field, analyses for the Burton Bench aquifer plot in 3 groups. The bulk of the analyses (18 of 27) plot in a group near the left corner of the central diamond (group 1). A group of 4 analyses (Numbers 2, 7, 9, and 32) plots near the lower-right edge of the Calcium-Bicarbonate field (group 2). A third group (Numbers 24, 27, 28, and 31) plots near the upper-right edge of the Calcium-Bicarbonate field (group 3). A single analysis (Number 34) does not plot with any group but is most closely related to group 3.

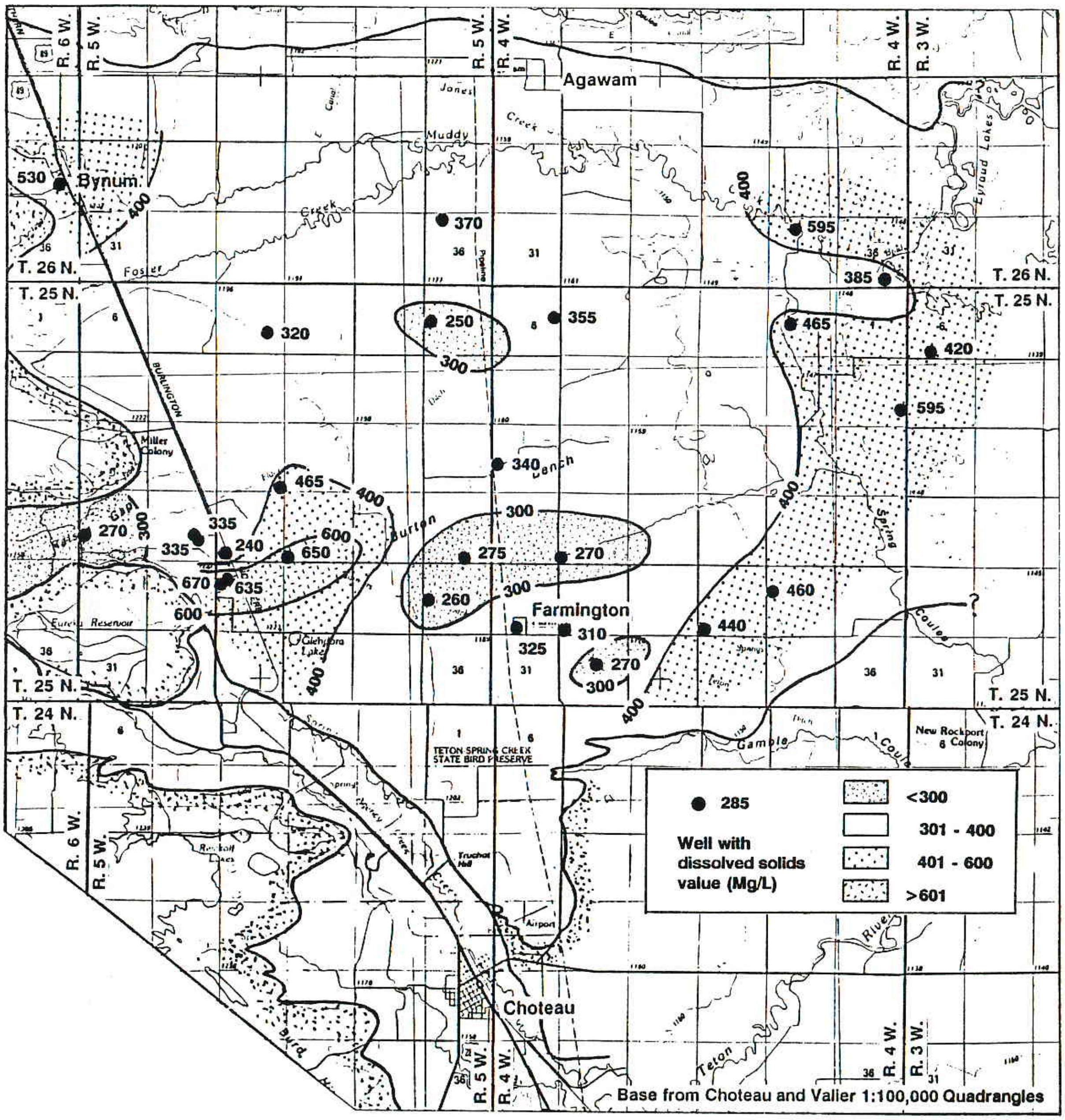

Figure 24: Dissolved solids concentrations for water samples from the Burton Bench aquifer.

The three groups of analyses are also shown on Figure 26. Group 1 analyses cover most of the Burton Bench and groups 2 and 3 two small areas in the eastern and western parts of the aquifer. Group 2 analyses all represent water from wells discharging from the artesian part of the Burton Bench Aquifer. The artesian part of the aquifer is downgradient in the flow system and the water is relatively rich in sodium compared to other waters in the Burton Bench aquifer. Group 3 waters are split geographically in the Burton Bench aquifer. Three of the analyses are from wells at the southwestern edge of the aquifer in the vicinity of Sections 22 and 28 of Township 25 North, Range 5 West. One well (Number 31) is in the artesian flowing zone of the aquifer.

In the lower left triangle of the Piper Plot (cation field) the plotted analyses show considerable variation. The cation field is subdivided into 4 sub-fields 3 of which represent the three major cations - Calcium, Magnesium, and Sodium. A central sub-field designates an area where no cation is dominant. The same groups of analyses outlined on the central part of the Piper Plot are also outlined on the cation field. Group 1 analyses all contain more than 78 percent Calcium and Magnesium and less than 18 percent sodium. However, the group contains analyses in which no cation is dominant (Numbers 10, 13, 18, 20, 22, and 33); analyses in which calcium is slightly dominant (Numbers 21, and 23); and analyses in which magnesium is dominant. Examination of Figures 25 and 26 shows that easterly downgradient analyses in group 1 are more magnesium rich than analyses in western up-gradient areas of the aquifer such as the Ralston Gap. Group 2 analyses are centrally located in the central sub-field of the cation field and do not have any dominant cation. Group 3 analyses are more sodium rich than the other groups ranging from having no dominant cation to having sodium as a dominant cation. Locations for the analyses in groups 2 and 3 are shown

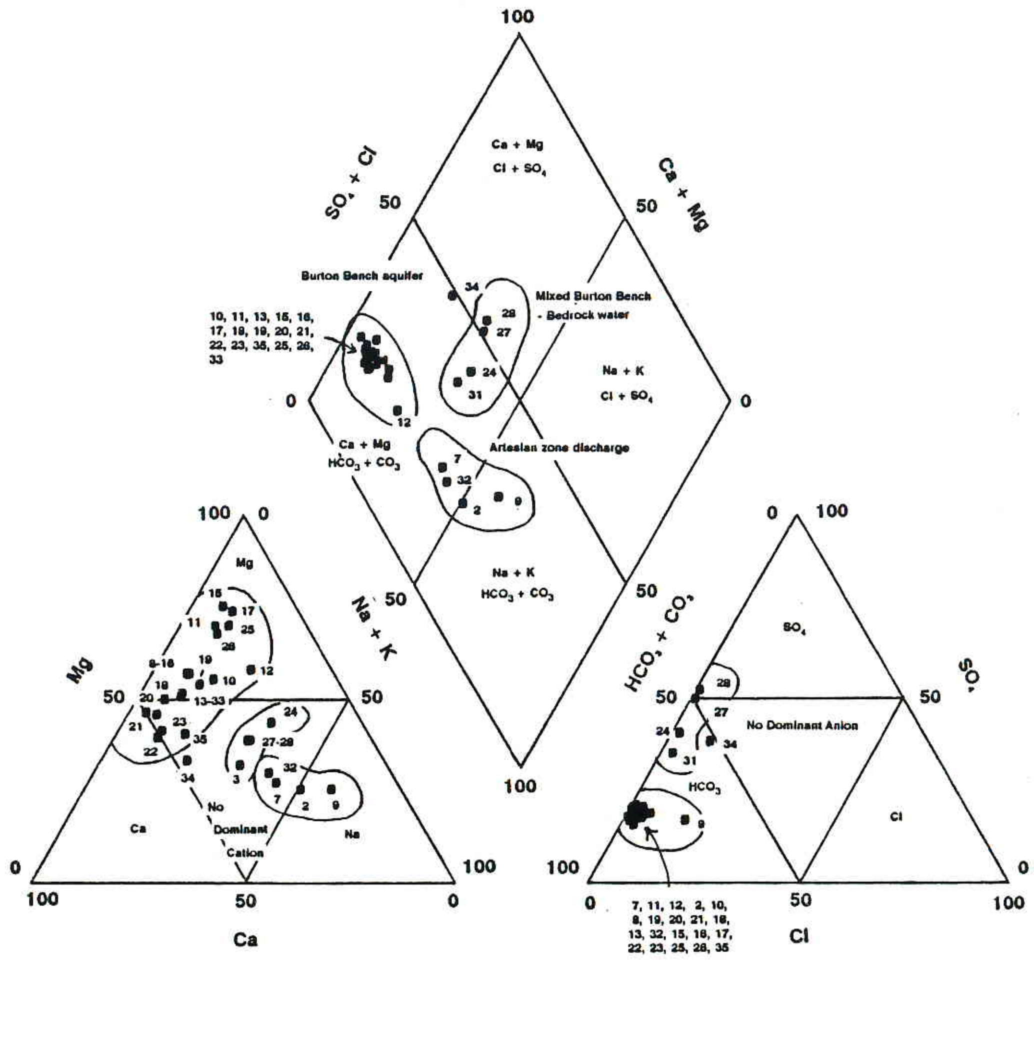

Figure 25: Piper Plot for water quality analyses for water from the Burton Bench aquifer.

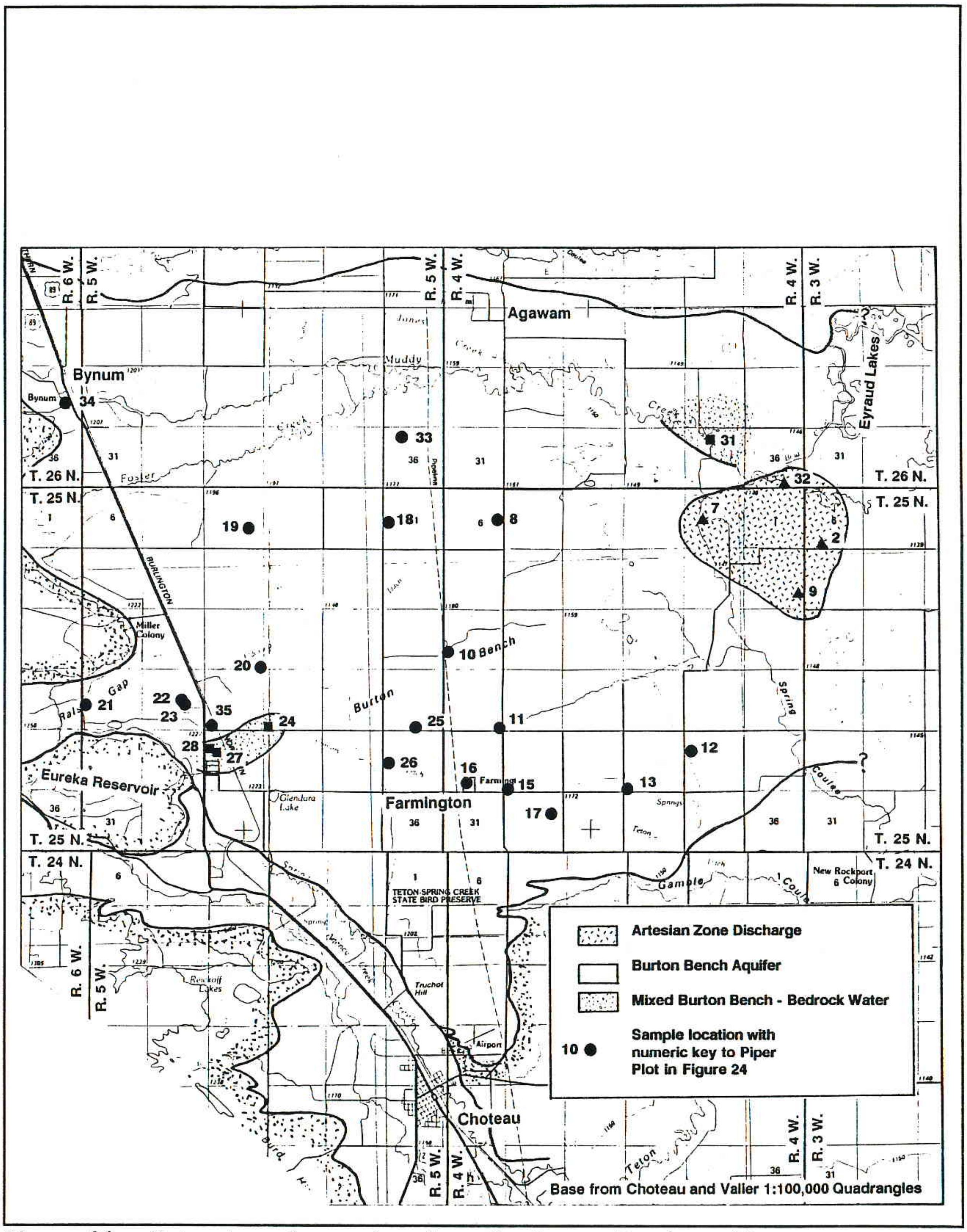

Figure 26: Water type in samples from the Burton Bench aquifer.

on Figure 26.

In the lower right triangle on the Piper Plot (anion field) the analyses are tightly grouped. The anion field is subdivided into 4 sub-fields 3 of which represent the major anions - bicarbonate, sulfate, and chloride. The central field represents waters in which no anion is dominant. Groups 1 and 2 can not be differentiated on the anion field. Group 3 analyses plot along the upper left side of the anion field and contain more sulfate than other analyses for the Burton Bench aquifer. Analyses numbers 27 and 28 contain approximately 50 percent sulfate and 50 percent bicarbonate.

Group 1 water shows very little modification in the flow system across the Burton Bench aquifer. Anions are virtually unchanged as the water flows downgradient but the water does become progressively more magnesium rich in the flow system (compare analysis locations on Figure 26 with water level flow on Plate 5). The change from approximately equal shares of calcium and magnesium in the up-gradient part of the aquifer to approximately 80 percent magnesium and 20 percent calcium probably is a result of calcium precipitation in the flow system as the water moves downgradient. The calcium is being precipitated as calcite in the discharge and middle parts of the flow system decreasing the amount of calcium in the water. Calcite cemented gravel (caliche), observable in ditches and fields of the area east of Farmington in Sections 26 and 27 of Township 25 North, Range 4 West, is probably the result of precipitation of calcite from the groundwater system.

Group 2 water is similar to group 1 water in anion content. Sodium is the most common cation in group 2 water, magnesium the second most common, and calcium the third. Magnesium content in group 2 water is similar to that in downgradient group 1 water. Sodium is probably being leached from aquifer materials as the water flows downgradient replacing the calcium which is being precipitated in the discharge and downgradient zones of the Burton Bench aquifer.

Water from analyses 24, 27, and 28, on Figures 25 and 26 (group 3) are more difficult to explain because of their geographic location in the Burton Bench aquifer 0.5 to 0.75 mile from the site of the lowest dissolved solids concentration noted on the Burton Bench during the sampling program. No information beyond being cased with a 48 inch diameter culvert is available for the well providing sample 24 but conditions similar to those noted below for samples 27 and 28 are likely. The wells from which samples 27 and 28 were obtained are 50 feet apart in an east-west direction. The western well is cased with a 30 inch culvert 20 feet in length. A 48 inch diameter perforated lateral extends approximately 24 feet from the casing. The eastern well is 32 feet deep, 7 inches in diameter, and perforated between 13 and 33 feet below land surface. Both wells encounter bedrock at total depth. The wells are located in an area of rapidly thinning gravel and rapidly rising bedrock in a westerly direction on the edge of the Burton Bench aquifer (see Plates 2 and 3). Description of bedrock encountered by the two wells is poor but bedrock in a well drilled approximately 1.5 miles to the southeast in Section 34 BACB Township 25 North, Range 5 West was dark blue Colorado Shale (cuttings examined in the field during drilling). Bedrock in outcrop 0.75 mile to the south is Virgelle Sandstone. Considering these factors, it is reasonable that sandstones in the basal Virgelle Sandstone or sandstones in transitory rocks between the Colorado Shale and the Virgelle Formation (Telegraph Creek equivalent rocks) could be discharging water into Burton Bench gravels at these locations. No information is available on the quality of any water discharged by these rocks but it is possible that it could be high in sulfate and relatively lower in bicarbonate. The water would be at the end of a long subsurface flow path in the bedrock system and would likely be reduced in bicarbonate and enriched in sulfate caused by precipitation of carbonate minerals and solution of sulfates along its path.

Sample 31 comes from a well 95 feet deep drilled on the south side of Muddy Creek in the artesian flowing part of the Burton Bench aquifer. Water quality degrades rapidly north of Muddy creek with many wells producing water high enough in n dissolved solids to prevent domestic use. A sample of water from Section 24 DACA Township 26 North, Range 4 West approximately 2 miles northeast of sample 31 contains 2,850 milligrams per liter dissolved solids and 1,781 milligrams per liter of sulfate (82.9% of the dissolved anion content in the analysis). One possibility is that sample 31 water is being influenced by mixing with water of other type north of Muddy Creek causing its sulfate content to be elevated over that in other parts of the artesian zone.

Aquifer Test Data

Locations for aquifer tests conducted during the aquifer study on the Burton Bench are shown in Figure 4 (page 11). Testing at a number of locations in the aquifer provided hydraulic characteristic information for a wide area of the aquifer. Tests were conducted in the Ralston Gap which provided information necessary to calculate subsurface flow through the Gap; in the central portion of the aquifer; and in the artesian portion of the aquifer. Results of the testing are summarized in Table 4. Tabulations of aquifer test data and plots of the data are contained in Appendix C as are definitions of terms. Aquifer tests for the Burton Bench aquifer will be discussed in a generally downgradient order starting in the Ralston Gap and ending at the Old School site in the artesian zone. The quality of the test results are mixed. Technical difficulties with some of the tests restrained the amount and quality of data developed by the testing program.

Guthrie Gap: The aquifer testing site in the Ralston Gap consisted of a 4 inch diameter polyvinyl chloride (PVC) cased and screened well with a 2 inch diameter PVC cased observation well located 20 feet away. The TCCD/MBMG/GUTHRIE 1 observation well in Section 19 CBBC of Township 25 North, Range 5 West was pumped for 720 minutes (12.0 hours) on August 26, 1986. Water level data were obtained from the pumping well and from the TCCD/MBMG/GUTHRIE 10 observation well on which a Stevens F type water level recorder was installed. Discharge from the well averaged 26.4 and ranged from 26 to 28 gallons per minute. The standard deviation of the discharge measurements was 0.66 gallons per minute. Initial water levels in the pumping well were 6.6 feet below top of casing and the maximum drawdown was 3.36 feet. Initial water levels in the observation well were 8.41 feet below the top of the casing and the maximum drawdown was 0.55 feet. Recovery in the pumping well was measured for 35 minutes (0.6 hours) and in the observation well for 750 minutes (12.5 hours) after pumping ceased.

Water level data for the pumping well were evaluated using both the Newman unconfined delayed yield method (Newman) and for comparison a Theis non-leaky confined analysis (Theis). Fits for both sets of type curves were made using a computer analysis package (Ground Water Analysis Package) published by Groundwater Graphics in 1987. Analysis of the data provided transmissivity values of 5,000 and 12,600 gallons per day per foot for the Newman and Theis methods respectively. The difference in the values is related to non-consideration of delayed yield by the Theis method.

Data for the observation well provided better information. Theis analysis for time greater than 90 minutes provided a transmissivity of 26,400 gallons per

Table 4: Aquifer Test Results Burton Bench Aquifer

TEST NAME	WELL NAME	EVALUATION METHOD	TRANSMISSIVITY (GPD/FT)	STORATIVITY (SPECIFIC YIELD)	REMARKS
Old School	TCCD/Otness	Theis/Leaky	200	--	Pumping well t < 123 minutes
	Old School	Theis/Leaky	620	0.0028	Observation well 65.3 ft north of pumping well - t < 123 min.
	Old School	Birsoy-Summers	940	--	Observation well - drawdown and recovery data
	Old School	Jacob-Cooper	960	--	Recovery - t/t' > 50 and t/t' < 120
	TCCD/Otness	Birsoy-Summers	230	--	Step drawdown test: 4-30 minute steps - early data each step - pumping well
Cole	Cole-North	-	-	--	Pumping data too flat to use
	Cole-North	Jacob-Cooper	283,000	--	t/t' < 1,000 - 90% of recovery t' < 1.0 minute - late data
	Cole-South	Newman delayed	22,3000	0.29	Very flat data - 90% of drawdown in t < 1.0 minute
	Cole South	Jacob-Cooper	290,000	--	Observation well 21 feet from pumping well - t/t' < 100 - 90% of recovery in t' < 1.0 minute
Guthrie	TCCD/Guthrie 16E	Theis-nonleaky	17,600	--	Pumped well t > 10 minutes
	TCCD/Guthrie 16W	Theis-nonleaky	44,300	0.016	Observation well 15.5 feet from pumping well - t < 10 minutes
	TCCD/Guthrie 16W	Newman-delayed	42,300	0.02	Observation well - pumping
	TCCD/Guthrie 16W	Jacob Cooper	42,000	--	Recovery data - t/t' < 100 min.
Ralston Gap	Guthrie 1	Newman-delayed	5,000	--	Pumping well
	Guthrie 1	Confined-nonleaky	12,700	--	Pumping well
	Guthrie 10	Theis-nonleaky	26,400	0.071	Observation well 20 feet from pumping well t > 90 minutes
	Guthrie 10	Newman-delayed	31,800	0.049	Observation well
	Guthrie 10	Jacob-Cooper	23,400	--	Recovery data T/T' < 4
Joramo	Joramo	Birsoy-Summers	22,000	--	Step 1 - t < 150 minutes
	Joramo	Birsoy-Summers	44,000	--	Step 2 - adjusted time 60-110 min.
Malone	Malone	Birsoy-Summers	66,000	--	Steps 2, 3, and 4. Step 1 not usable because of delayed yield

day per foot and a specific yield of 0.071. Newman delayed yield analysis provided a transmissivity of 31,800 gallons per day per foot and a specific yield of 0.049. The Newman analysis provided a better curve match, drawdown was corrected for changing aquifer thickness during the test and probably provided the better transmissivity and storage values. Values provided by both methods are of the same order of magnitude and are reasonably consistent. Jacob-Cooper evaluation of recovery data for the observation well provided a transmissivity of 23,400 gallons per day per foot for t/t' less than 4.

Aquifer test data for the Ralston Gap showed that transmissivities were not large. The relatively low transmissivities and correspondingly lower hydraulic conductivities ranging between 3,310 and 3,970 gallons per day per square foot provide data which show that subsurface flow through the Ralston Gap is relatively small. Specific yields are lower than anticipated but are probably related to the large amount of secondary calcium carbonate present in the sand and gravel deposits in the Ralston Gap. Cuttings examined during drilling of the Ralston Gap wells contained large amounts of calcite cement and in places very well indurated.

Guthrie east: The Guthrie east aquifer testing site is located approximately 1 mile east of the Ralston Gap. A 4 inch diameter polyvinyl chloride (PVC) cased pumping well and a 4 inch diameter PVC cased observation well located 15.5 feet away were constructed at the site. The TCCD/MBMG/GUTHRIE 16E observation well in Section 16 DDDD of Township 25 North, Range 5 West was pumped for 1,440 minutes (24.0 hours) on August 27, 1986. Water level data were obtained from the pumping well and from the TCCD/MBMG/GUTHRIE 16W observation well on which a Stevens F type water level recorder was installed. Discharge from the well averaged 53 and ranged from 49 to 58.5 gallons per minute. The standard deviation of the discharge measurements was 3.1 gallons per minute. During the test the yield varied more than would be desired ranging from 7.5 percent below the average discharge to 10.4 percent above. Initial water levels in the pumping well were 7.43 feet below top of casing and the maximum drawdown was 4.78 feet. Initial water levels in the observation well were 7.61 feet below the top of the casing and the maximum drawdown was 1.19 feet. Recovery in the pumping well was measured for 30 minutes (0.5 hours) and in the observation well for 1,275 minutes (21.25 hours) after pumping ceased.

Data from the pumping well during the pumping period best fit the Theis nonleaky type curve for times greater than 10 minutes of pumping. This match provided a transmissivity of 17,600 gallons per day per foot for the aquifer. Observation well data were evaluated using both the Theis and Newman methods. The Theis method suggested a transmissivity of 44,300 gallons per day per foot and a specific yield of 0.016 for pumping times greater than 10 minutes. The Newman method produced a transmissivity of 42,300 gallons per day per foot and a specific yield of 0.022. Recovery data evaluated by the Jacob-Cooper method produced a transmissivity of 42,000 gallons per day per foot for t/t' less than 100. Data produced by the aquifer test are reasonably consistent but the storage factors are much lower than expected. Reasons for the low specific yields have not been determined but reevaluation of the data confirms the initial calculations. It is not thought that the variation in yield during the testing period caused storage calculations to produce low results.

Joramo: The Joramo aquifer testing site is located in the north-central portion of the Burton Bench aquifer. A 4 inch diameter polyvinyl chloride (PVC) cased pumping well was constructed at the site. There was no observation well. The TCCD/MBMG/JORAMO observation well in Section 4 DBDD of Township 25 North, Range 5 West was pumped in three steps for 450 minutes (7.5 hours) on October 16, 1986. Water level data were obtained from the pumping well. Discharge from the well was 27.3 gallons per minute for step 1; 35.3 gallons per minute for step 2; and 22.2 gallons per minute for step 3. The initial water level in the pumping well was 35.34 feet below top of casing. Drawdown occurring during step 1 was 5.65 feet but increased to 13.02 feet at the end of step 2. No recovery data were collected during the test because of the variable pumping rate. The data were analyzed using a method developed for variable rate pumping tests by Birsoy and Summers (1980).

The Joramo aquifer test provided difficult data to evaluate. A step drawdown test was initially envisioned because of the lack of an observation well at the site and because of the availability of the Birsoy and Summers method to evaluate the data. The Birsoy and Summers method adjusts time and drawdown data to allow all steps in a step drawdown test to be used in evaluation of aquifer characteristics and is a modification of the Jacob-Cooper method.

Step 1 of the test proceeded more or less normally. Approximately 4.8 feet of drawdown occurred in the well during the first 45 seconds of the test. During the next 9 minutes an additional 0.4 feet of drawdown occurred and an additional 0.4 feet in the remaining 140 minutes of the step. After about 10 minutes of pumping, the rate of drawdown increased even though a constant yield was maintained which resulted in variations in the drawdown/time plot of the data from a straight line. The increase in drawdown could be related to plugging of the well screen during this portion of the pumping period or by a decrease in vertical leakage (delayed yield) in the aquifer near the well bore. By the end of the step, conditions appeared to be under control and the data plot reapproached a straight line. At the end of the pumping step 19 feet of water remained in the well above the pump.

During step 2 conditions in the well changed greatly. The rate of drawdown increased from about 0.001 foot per minute at the end of step 1 to about 0.05 foot per minute. At the end of step 2 the water level in the well was 48.36 feet below the measuring point and only 11.6 feet above the pump. At the end of step 2 it was clear that increasing the yield for step 3 would likely result in noncompletion of that step because the water level in the well would reach the well intake. Step 3 was conducted at a lower rate than steps 1 or 2. The data from step 3 proved to be unreliable and no conclusions regarding transmissivity have been drawn from the data.

Birsoy and Summers evaluation of step 1 data (Jacob Cooper method) produces a transmissivity of 22,000 gallons per day per foot for the Burton Bench aquifer at the Joramo Site. Evaluation of step 2 data for adjusted time between 60 and 110 minutes produces a transmissivity of 44,000 gallons per day per foot. Later data points in step 2 deviate from the initial line for the step and probably represents a decrease in delayed yield in the aquifer during the step. Therefor the reported step 2 transmissivity is probably high.

Cole: The Cole aquifer testing site is located approximately in the center of the Burton Bench aquifer. A 4 inch diameter polyvinyl chloride (PVC) cased pumping well and a 4 inch diameter PVC cased observation well located 21 feet away were constructed at the site. The TCCD/MBMG/COLE-NORTH observation well in Section 18 CBBB of Township 25 North, Range 4 West was pumped for 1,680 minutes (28.0 hours) on October 12, 1986. Water level data were obtained from the pumping well and from the TCCD/MBMG/COLE-SOUTH observation well on which a Stevens F type water level recorder was installed. Discharge from the well averaged 83.8 and ranged from 81.3 to 86.4 gallons per minute. The standard deviation of the discharge measurements was 1.6 gallons per minute. During the test the yield varied ranging from 3.0 percent below the average discharge to 3.1 percent above. Initial water levels in the pumping well were 12.18 feet below top of casing and the maximum drawdown was 9.08 feet. Initial water levels in the Cole-south observation well were 12.88 feet below the top of the casing and the maximum drawdown was 2.095 feet. Recovery in the pumping well was measured for 1,442 minutes (24 hours) and in the observation well for 2,439 minutes (40.7 hours) after pumping ceased.

The Cole north observation well was pumped three times. Tests 1 and 2 were unsatisfactory because pumping rates were too low or discharge from the well was not controlled sufficiently to obtain valid data. Data from the third testing period are presented in Appendix C. Drawdown in the pumping well occurred very quickly and was 8.07 feet at 15 seconds into the test. Over the remainder of the pumping period (1,679 minutes) an additional 1.01 feet of drawdown occurred. Small increases in drawdown in the later portion of the pumping period were obscured by very small changes in discharge from the well that were uncontrollable. Voltage fluctuations between 207 and 214 volts at the generator created small changes in discharge which resulted in up to 0.08 foot of change in drawdown. In a well where drawdown is occurring at a larger rate these small differences would not be a problem but in the Cole-North well these small changes created scatter in the data during this portion of the pumping period. The resulting data set is too flat to evaluate and has not been evaluated for this document. Information relative to generating transmissivity data for this well apparently is contained in the first 15 seconds of pumping and different equipment such as computer assisted data loggers using pressure transducers would be necessary to obtain meaningful information from the pumping well.

Recovery in the pumping well produced a transmissivity of 283,000 gallons per day per foot based on t/t' less than 1,000. Ninety percent of the recovery in the pumping well took place when t' was less than 1 minute. For example, at the end of the pumping period drawdown in the well was 9.00 feet. After the pump had been shut off for 0.5 minute, residual drawdown in the well was 0.36 feet. The Burton Bench aquifer reacted more quickly than anticipated to the stress of pumping and data produced during the pumping period and during recovery may not be valid.

Data from the Cole-South observation well also poses difficulty in interpretation. Drawdown during the pumping period mostly occurred during the initial minute of the test and only an additional 0.42 foot of drawdown occurred during the remaining 1,679 minutes. Water level data for the observation well were not as flat as those for the pumping well and were interpreted with the Newman method. A transmissivity of 22,300 gallons per day per foot and a specific yield of 0.29 were produced by the best match of a Newman type B curve with a beta of 0.004. Other type curves did not match the data as closely although the overall flatness of the drawdown data leaves much room for error in the matching procedure. A calculated transmissivity of 290,000 gallons per day per foot from recovery data in the observation well closely matched that of the pumping well. Again, it is unclear whether or not this is a valid value because most of the water level recovery occurred in the first minute after pumping ceased. For example, at the end of the pumping period, drawdown in the observation well was 2.095 feet. Pen traces on the water level recorder during the first minute of recovery overlap indicating that over 1.5 feet of recovery happened in the first few minutes of the recovery period. Residual drawdown in the observation well was 0.26 feet 8 minutes after pumping ceased.

The best information available for aquifer characteristics at the Cole test site is that for the observation well during the pumping period. Because so much of the recovery occurred very quickly after pumping stopped, recovery measurements for both the pumping and observation wells occurs more or less after recovery is complete. Conditions in the aquifer probably do not match requirements for application of the Jacob-Cooper method to recovery data and the values provided by the recovery data may not be valid.

Malone J: The Malone aquifer testing site is located in the north-central portion of the Burton Bench aquifer. A 4 inch diameter polyvinyl chloride (PVC) cased pumping well was constructed at the site. There was no observation well. The TCCD/MBMG/MALONE J. observation well in Section 36 BACA of Township 26 North, Range 5 West was pumped in four steps for 760 minutes (12.7 hours) on October 15, 1986. Water level data were obtained from the pumping well. Discharge from the well was 40.9 gallons per minute for step 1; 51.5 gallons per minute for step 2; 66.9 gallons per minute for step 3; and 88.5 gallons per minute for step 4. The initial water level in the pumping well was 3.95 feet below top of casing. Maximum drawdown occurred during step 4 and was 2.08 feet. No recovery data were collected during the test because of the variable pumping rate. The data were analyzed using a method developed for variable rate pumping tests by Birsoy and Summers (1980).

Data generated by the Malone J. aquifer test are reasonable. The Birsoy and Summers method when applied to steps 2 - 4 produces a transmissivity of 66,000 gallons per day per foot. Data for each step of the pumping test should overlap using the Birsoy and Summers method given an ideally efficient well.

Pumping data for the Malone J. well show that it is not efficient but do share a common slope in steps 2 - 4. The slope of this line is evaluated to produce the transmissivity for the aquifer at this location. Step 1 data do not plot along the common slope probably because of effects of delayed yield and are not used in the transmissivity calculation. Early portions of Steps 2 and 4 are also affected by delayed yield and are not used in the fitting of the lines of common slope to the data.

Malone W: An aquifer test was attempted at the TCCD/MBMG/MALONE W. observation well located in Section 17 AADB of Township 25 North, Range 4 West but was not successful due to low discharge from the well. During construction of the well the upper section of well screen collapsed. The collapse of the screen prevented adequate development of the well and prevented setting the pump deep enough in the well to allow a test.

Old School: The old school aquifer testing site is located on the eastern edge of the Burton Bench aquifer. A 7 inch diameter steel cased pumping well with a 5 inch diameter PVC liner and 4 inch PVC well screen was constructed at the site. An existing well at the site located 65.3 feet from the pumping well was used as an observation well for the aquifer test. A Stevens F type water level recorder was installed on the observation well. The TCCD/MBMG/OTNESS observation well in Section 6 CCDD of Township 25 North, Range 3 West was pumped twice. The initial test began on June 17, 1987, lasted for 737 minutes (12.3 hours), but was cut short by generator failure. Recovery data for the pumping well were not obtained because of the generator failure but were digitized from the recorder chart for the observation well. An accidental change in the pumping rate at 124 minutes into the test allowed evaluation of only the early data in the test. A recharge boundary (or substantial leakage within the aquifer) prevented use of the Birsoy and Summers method for evaluating pumping well data as a two step test because all measured values in the second step of the test ($t > 124$ minutes) fell beyond the influence of the boundary condition in the data set and could not be used. Pumping period data for the pumping well were evaluated using Theis leaky type curves. Observation well data were evaluated using Theis leaky artesian type curves for the pumping period and the Jacob-Cooper method for the recovery period. Data from the observation well were also evaluated using the Birsoy and Summers method for comparison. Discharge from the well averaged 15.7 gallons per minute. Initial water levels in the pumping well were 1.66 feet below the measuring point for the test. Initial water levels in the old school observation well were 1.135 feet below the measuring point. Maximum drawdown in the pumping well was 23.79 feet and 6.295 feet in the observation well. Recovery in the observation well was measured for 799 minutes (13.3 hours).

Data from the pumping well at the old school aquifer test site during the pumping period were matched with a Theis $r/B = 0.30$ leaky artesian type curve using the Groundwater analysis package. Only the initial 123 minutes of pumping data were used and evaluation of the match produced a transmissivity of about 200 gallons per day per foot. Evaluation of water level data for the observation well for the initial 123 minutes of the test using a Theis $r/B = 0.50$ leaky type curve produced a transmissivity of about 620 gallons per day per foot and a storativity of 0.0028. Recovery data from the observation well suggested a transmissivity of 960 gallons per day per foot. For comparison purposes drawdown and recovery data for the observation well were evaluated using the Birsoy and Summers method. A calculated transmissivity of 940 gallons per day per foot and a storativity of between 0.003 and 0.004 were derived from the data. Step 1 and recovery data were used in the Birsoy and Summers evaluation. Step 2 data were not used in the analysis because they did not match the slope of a line common between step 1 and the recovery data.

Because of the problems with the initial aquifer test at this site a second test was conducted on June 18, 1987. The second test consisted of 4 steps of 30 minute duration evaluated using the Birsoy and Summers method. The well was pumped at 3.8 gallons per minute during step 1; 9.9 gallons per minute for step 2; 14.2 gallons per minute for step 3; and 19.1 gallons per minute for step 4. No recovery data and no data from the observation well were obtained. Maximum drawdown during the test was 33.51 feet at the end of step 4. The second test produced a transmissivity for the aquifer of 230 gallons per day per foot. Data from the test plotted nicely and are relatively tightly grouped indicating that the well is reasonably efficient. Early data for each step contained the common slope used for the transmissivity calculation and consistent changes in slope in the later portions of each step clearly illustrate the affect of the recharge (leakage) boundary near the pumping well.

Transmissivities at the old school site range from 200 to 960 gallons per day per foot depending on the method used for evaluation of the data. Data from the observation well produce slightly higher transmissivities but in general all of the values are reasonably consistent. The Birsoy and Summers method appears to correspond very well with the more traditional Theis leaky artesian treatment of the data if the recharge (leaky) boundary condition is recognized and care taken in the evaluation of the data to account for the boundary.

Summary and Conclusions

The importance of the aquifer study ultimately is "what does it mean" for water users in the Burton Bench aquifer. All of the data generated by the study has certain academic interest, however, the initial premise of conducting the aquifer study was to provide general knowledge useful in solving specific problems related to groundwater use in the Burton Bench area. Many of the specific water use problems are related through the common thread of groundwater movement and occuuence in the Burton Bench aquifer. Concentration in the aquifer study has been on beginning to understand the movement and occurrence of groundwater in the Burton Bench aquifer and the information developed during the project may generally be related to specific water use issues.

Review of the data developed during the aquifer study produces the following conclusions.

1. Fisher (1909) observed that water levels on the Burton Bench had risen considerably since the time irrigation began.

2. Water level data determined during the aquifer study shows that most recharge to the Burton Bench aquifer occurs as a result of irrigation practices.

3. Calculations show that approximately 300,000 acre feet of water are in storage in the Burton Bench aquifer.

4. A discharge zone consisting of sub-irrigated ground and tracts of land with high water table conditions has developed in an area north and east of Farmington.

The following discussion covers the "big picture" regarding water use and hydrogeology in the Burton Bench aquifer. The "big picture" is the result of many individual activities which take place in the aquifer, any one of which may or may not disrupt recharge to or discharge from the aquifer and influence water uses relying on discharge. For example, installation of a well to water livestock in the upgradient portion of the aquifer will not cause a flowing artesian well in the eastern portion of the aquifer to fail. An irrigation well installed in the central portion of the aquifer will not dewater a domestic well 5 miles away with no other impacts between the irrigation and domestic wells.

Most failures of wells and springs are related to water level or other changes near the failed diversion. For example, failure of a pumping well is most often related to failure of the pumping equipment installed in the well. If not the pumping equipment, then failure of the well construction itself is most likely. Casings collapse, well screens plug, and iron bacteria can invade and plug the pump and other portions of the well. If all local causes are ruled out, then other nearby potential causes must be evaluated. If a nearby irrigation well has been put into service, a field converted from flood to sprinkler, or a irrigation ditch abandoned, any of these could be having an adverse effect on the failed well. The evaluation process continues at larger distances from the well until a cause for the failure becomes apparent.

Figure 27 is a schematic diagram of the Burton Bench aquifer. On Figure 27, a central 'U' shaped element or bucket, analogous to the sand and gravel deposits of the aquifer, represents the Burton Bench aquifer. The bucket is partially filled with water and the level below which the sand and gravel of the bucket is saturated is the water table which is shown by a horizontal line and marked by an inverted triangle. Below the water table on Figure 27 is a dashed line which represents a potential fluctuation in the water table. At any given altitude of the water table, the volume of water stored in the aquifer is the saturated volume of the aquifer below the water table. On Figure 27 this volume is shown by a 'S'. The altitude of the water table at any time is dependent on the amount of water available to put in the bucket relative to the amount of

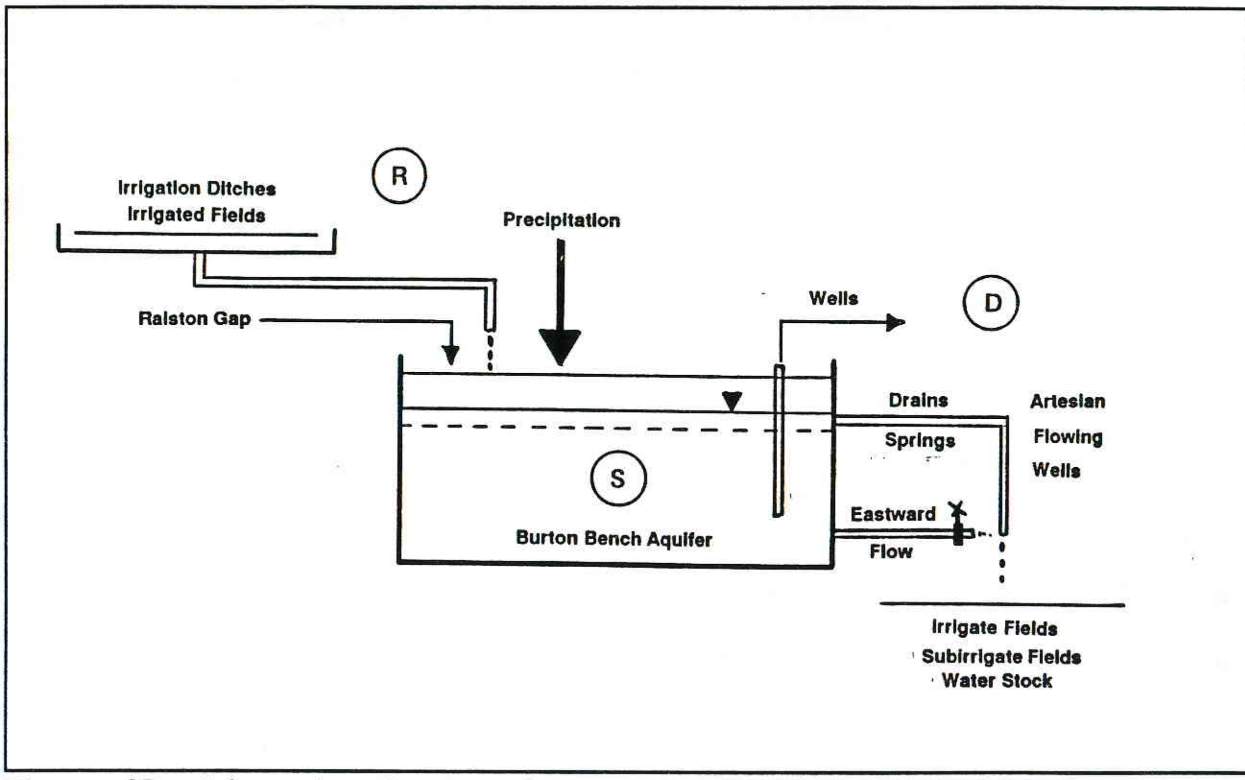

Figure 27: Schematic diagram of Burton Bench aquifer showing relationship between recharge, storage, and discharge.

water being taken out of the bucket. Friction related to flow through the aquifer causes water levels or changes in storage to lag in time relative to changes in recharge.

Recharge to the Burton Bench aquifer ('R' on Figure 27) occurs in the form of precipitation, underflow through Ralston Gap, and leakage from irrigation ditches. Precipitation not used by run-off, evaporation, or by plant transpiration enters the aquifer directly through the land surface. Entry of precipitation to the aquifer on Figure 27 is shown by a vertical black arrow. Underflow from Ralston Gap enters the aquifer through the subsurface and is shown by a horizontal arrow labeled Ralston Gap. Leakage from irrigation ditches is shown schematically by a pan shaped structure under the irrigation ditches and irrigated fields leading to a pipe which discharges water through the land surface into the Burton Bench aquifer.

Discharge ('D' on Figure 27) occurs through eastward lateral groundwater flow through the aquifer, leakage from the aquifer in the form of springs, leakage of water to groundwater drains, and by withdrawals of water from wells -- primarily for domestic and stockwatering purposes -- although some is removed for irrigation purposes. Lateral groundwater flow from the aquifer on Figure 27 is represented by a pipeline leaving the aquifer near its base. Because lateral discharge does not completely drain the aquifer at the present rate of recharge, the rate of flow through the pipeline is restricted which is illustrated by a valve. Discharge from the aquifer through springs, drains, and flowing artesian wells is shown by a pipeline leaving the aquifer at the approximate level of the water table. Flowing artesian wells are included because they rely on specific water level altitudes to produce water. In the case of the Burton Bench aquifer, some of the water discharging through springs and drains is used downstream for other purposes such as irrigation and watering stock. Man caused discharge through wells is shown on the figure by a production well drawn to intercept the water table.

Because the aquifer does not transmit water instantaneously, changes in recharge and discharge have effects on the amount of water stored in the aquifer at any one time. For example; if recharge to the aquifer increases, storage in the aquifer will also increase, and water levels will rise. The increase in storage ultimately causes increased discharge to springs, groundwater drains, and sub-irrigated fields until volumes discharged again match the amount of recharge. Man-caused discharge not related to water levels would remain relatively constant because increases in recharge do not directly cause increases in man-caused discharge. If the reverse is true and recharge to the aquifer is declining, water levels (and storage) in the aquifer would drop because for a period of time discharge from the aquifer would be greater than the amount of recharge. The decline in water levels would cause some springs, groundwater drains, and flowing artesian wells, which rely on specific water level altitudes, to cease flowing, decreasing discharge from the aquifer. Water levels will not stabilize until the amount of discharge again matches the new lower amount of recharge.

In the Burton Bench aquifer the above recharge/storage/discharge relationship has created a situation in which water rights conflicts can easily occur and helps create a difficult problem about how, and if, additional development of the aquifer can take place. Water levels in the Burton Bench aquifer are unnaturally elevated because of leaky ditches and fields providing recharge to the aquifer over a period of decades increasing the volume of discharge over time. Because increased discharge has been available for more than one generation; general lack of knowledge has existed on internal operations of the aquifer; the amount of and location of discharge from the Burton Bench aquifer has become accepted as "the way it is" and in many cases has been appropriated; and because changes in amount of recharge over the long term have been relatively small; a mix of junior and senior appropriators in the discharge zone has developed. Appropriation of discharge from the Burton Bench aquifer by many individuals over a long period of time has created a situation where many water rights are relying on the "status quo" in recharge to the aquifer and "status quo" in discharge from the aquifer.

If the relationship as described above is to be preserved, then the "status quo" in the recharge portion of the aquifer must be preserved. This means that the aquifer is presently effectively fully appropriated and that further development of large scale (greater than domestic or stockwater developments) should not be permitted. For example; new irrigation supported by groundwater wells may not be permitted because developments of this magnitude may lower water level altitudes in the discharge zone, adversely effecting some senior water rights. However, discharge zone water rights can also be influenced by actions not related to water rights permits. Groundwater drains, conversion of flood to sprinkler irrigation, and ditch lining are all activities which can influence recharge and therefore discharge in the Burton Bench aquifer. Among others, no new groundwater drains should be allowed for water logged land; no conversion of flood to sprinkler irrigation to more efficiently use water should be allowed; no ditches should be lined to more efficiently use water; and irrigation ditch companies should not be allowed to combine facilities because fewer miles of unlined ditch may result in less leakage to the aquifer. All conditions presently creating the present water level regime in the Burton Bench aquifer would have to be preserved so that all present users of the aquifer may receive the same amount of water in the same manner.

There is a second way to view the Burton Bench aquifer. According to calculations presented in this study, approximately 300,000 acre feet of water presently exist in storage in the Burton Bench aquifer. Not all of this water is economically and physically available, but a large percentage would be potentially able to be appropriated. In comparison, Eureka Reservoir has a capacity of approximately 5,500 acre feet according to the Water Resources Survey for Teton County (Montana State Engineers Office, 1962). It is difficult to know of a resource of this size and not use it to solve the needs of the residents of the region. If alternative means of providing water to water users which do not rely directly upon specific water level altitudes were developed, then much greater use of water stored in the Burton Bench aquifer by additional and existing users would be possible.

How much or little additional water should be appropriated from the Burton Bench aquifer will not be defined here. Both sides of the situation are outlined and it should ultimately be the responsibility of local water users, in conjunction with the Department of Natural Resources and Conservation Water Rights Bureau, in making the decision about further development of the Burton Bench aquifer. If present methods of appropriating water are preserved for downgradient and discharge zone water rights, then little additional development will be possible. If longterm effort is made to convert the means of diversion for downstream and discharge zone rights from types that require specific water levels to types that are more tolerant of variable water levels, then considerable additional water could be appropriated from the aquifer.

The major water problem in the Burton Bench aquifer is not one of water supply but is one of diversion method. Totally eliminating changes in water use is probably an impossible task in the long term and conditions in the aquifer will change. Individuals have the right and obligation to use water resources as efficiently as possible, ditches may eventually be lined, additional groundwater drains will be constructed, flood irrigated land will be converted to sprinkler irrigation, and ditch companies may eventually combine facilities. All of these will probably lower water levels, decrease storage in the aquifer, and effect downgradient water uses which rely on certain water levels. Because many of these types of changes are not governed by water rights law and rules, individuals who have water uses with diversions requiring specific or narrow ranges of water levels for successful operation, should begin to convert those uses to means of diversion which are much less sensitive to water level change. If a groundwater drain is used to water stock, drill a well to provide the water and convert the stockwater right from the drain to the well to preserve the priority date. If actions such as these have been completed by appropriate water users over a long term basis, eventual impact on these rights by any water conservation measures will be lessened and the potential for using much more of the water in the Burton Bench aquifer will be increased.

Teton Valley Aquifer

Static Water Levels

Static water level measurements were obtained from 7 wells located in the Teton Valley aquifer between the City of Choteau in Sections 24 and 25 of Township 24 North, Range 5 West and the Newman Ranch (Old Knaff Ranch) in Section 32 of Township 25 North, Range 5 West. Locations of wells for which hydrographs are available are shown on Figure 3 (Page 9). Hydrographs for all wells measured during the aquifer study are also contained in Appendix B.

Three hydrographs have been selected which generally illustrate static water level conditions in different parts of the Teton Valley Aquifer. Farthest up-gradient is the UTSWL 42 observation well located in Section 32 DDDA, Township 25 North, Range 5 West (see Figure 3). The UTSWL 42 hydrograph provides water level change information in the up-gradient portion of the Teton Valley Aquifer near Eureka Reservoir. A second hydrograph is from a well located in Section 24 CDD, Township 24 North, Range 5 West, on the west edge of the City of Choteau. The UTSWL 01 hydrograph provides information about the water table in the Teton Valley aquifer on the up-gradient side of the city. Additionally, use of a recording device to measure water levels in this well allowed more detailed information about the water table to be gathered. The UTSWL 16 observation well located in Section 25 ADCD, Township 24 North, Range 5 West, provides information about the water table downgradient from well and spring developments supplying water to Choteau.

Water level traces shown on Figures 28 - 30 represent relative differences from a datum for each well, and can not be correlated to distance from land surface. Hydrographs in Appendix B show water level altitudes above sea level and can be used to calculate distances to water below land surface.

The UTSWL 42 (Figure 28) hydrograph shows that water levels in this well fluctuate approximately 14 feet during the period of record. Highest water levels approach approximately 19 feet and deepest water levels approximately 33

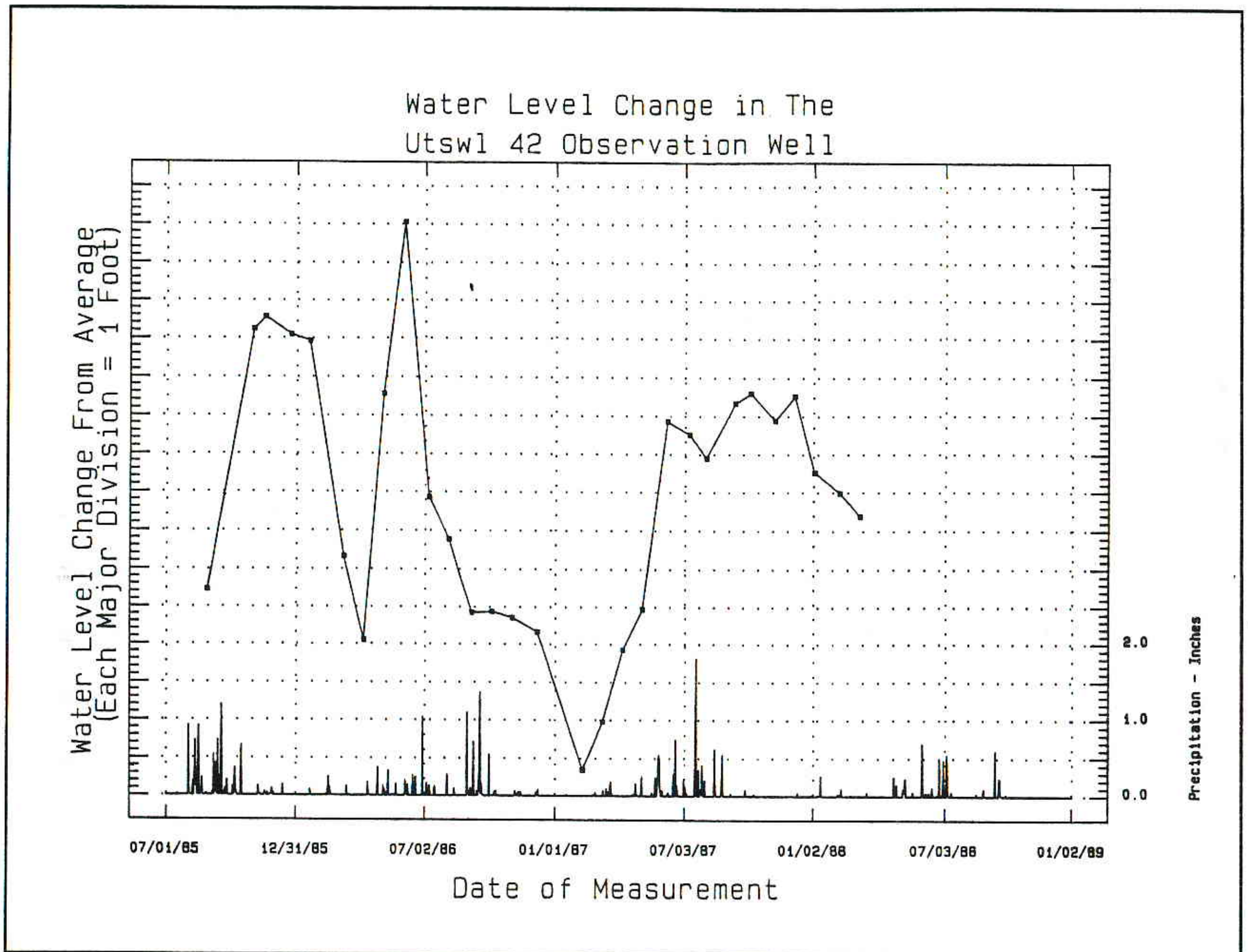

Figure 28: Water-level change in the UTSWL 42 observation well in Section 32 DDDA, Township 25 North, Range 5 West.

feet below land surface (see UTSWL 42 hydrograph - Appendix B for distance to water figures). After the lowest point on the record occurred in about February 1987, water levels began rising and reached a peak in about October 1987. A decline in the summer months similar to that of 1986 did not occur in 1987 but water levels were falling in the first few months of 1988.

Despite the amount of fluctuation in the UTSWL 42 well, the period of record is too short to determine if any longer term upward or downward trends in water levels are occurring or if the water level fluctuation seen in 1986-1987 occurs periodically. Another observation well (UTSWL 41) is located in Section 4 DBBA, Township 24 North, Range 5 West, approximately 1 mile downgradient (see Figure 3 for location and Appendix B for the hydrograph). Water levels in the UTSWL 41 observation well underwent similar but lesser magnitude fluctuations over the same periods as those in the UTSWL 42 observation well. The parallelism between the two hydrographs indicates that water level changes in this part of the aquifer are most likely related to climatic conditions, streamflow in the Teton River, or irrigation water use in the vicinity of these wells rather than pumping in the two observation wells. If the water level changes were caused by local pumping, it is unlikely that the UTSWL 41 and 42 hydrographs would reflect water level movement as closely because pumping periods for the two wells approximately 1 mile distant from each other would not coincide.

Daily values for precipitation events occurring during the Upper Teton Aquifer Study are also plotted on Figure 28. The hydrograph does not contain enough detail to accurately correlate water level changes with precipitation events although water levels in July and August 1987 rose during those relatively wet months and the rate of decline in water levels occurring in the late summer of 1986 decreased for a few months after several 1 to 2 inch precipitation events. Most water level responses to these precipitation events were probably too short in duration to be observed with a monthly measurement frequency.

The UTSWL 01 observation well (Figure 29) is located in Section 24 CDD, Township 25 North, Range 5 West on the west edge of the City of Choteau. A continuous recorder was placed on the well and it operated periodically between August of 1985 and August of 1987. The recorder showed that water levels over

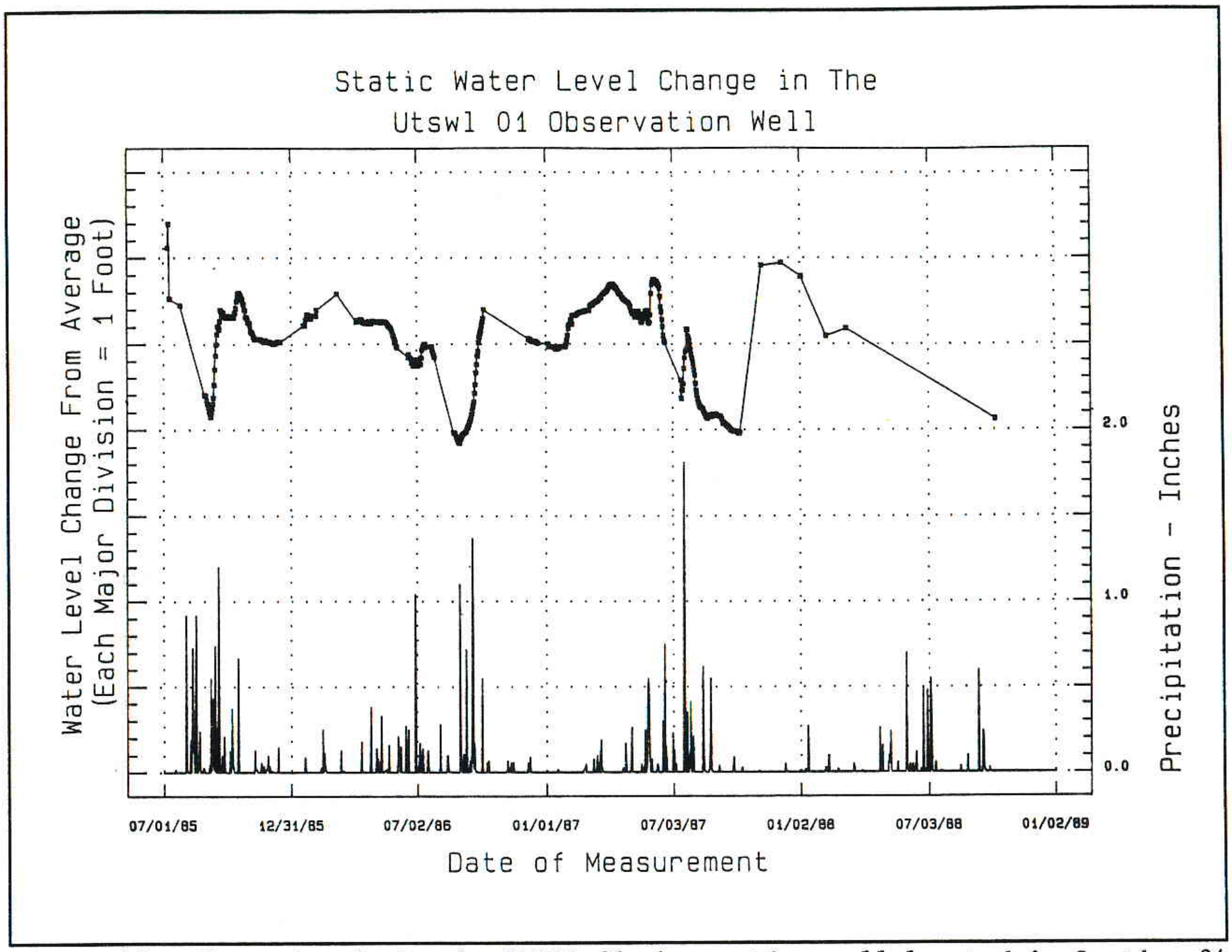

Figure 29: Water levels in the UTSWL 01 observation well located in Section 24 CDD, Township 24 North, Range 5 West.

the term of the record did not trend upward or downward but that numerous short term water level changes occurred. The largest magnitude and longest duration of the water level changes are declines of approximately 1 foot occurring during the months of July and August in 1985, 1986, and 1987. Water levels in the UTSWL 01 observation well recovered to late spring altitudes in September or October of each year. Reason for these declines are unknown but several possibilities exist. Declines in the water table similar to those shown on Figure 29 could be related to nearby irrigation wells or other pumping from the aquifer. However, the UTSWL 01 observation well is centrally located in a non-irrigated 40 acre field relatively distant from other wells. Additionally, the water level declines occur over a period of months and generally show no upward breaks which would be related to times when nearby pumping ceased. Other reasons for the water level declines could be related to pumping by the City of Choteau during the summer months for city water supply, pumping by private wells for lawn and garden irrigation, or to phreatic water use by cottonwood trees and other plants. The UTSWL 16 "Mini-Park" observation well (See Figure 30) undergoes similar water level changes in the summer months.

Daily precipitation at Choteau is also plotted on Figure 29 and some correlations between precipitation events and water level rises on the hydrograph are apparent. The most obvious is a water level rise of about 0.8 foot which occurred in July 1987 following a precipitation event which produced about 3.6 inches of water. The main precipitation event was followed by several days of lesser magnitude events ranging in size from 0.5 to 0.8 inches. Following the large precipitation event, the water level in the observation well rose for approximately 7 days. After the recharge event caused by this precipitation was over, the water level in the well declined and eventually moved along a path similar to that anticipated from water level declines in 1985 and 1986. The recharge event related to these precipitation events took place during and interrupted the annual summer month fall in the water table. Several other short term upward movements of the water table which occur in 1985, 1986, and 1987 appear related to recharge from precipitation.

The UTSWL 16 "Mini-Park" observation well located in Section 25 ADCD, Township 24 North, Range 5 West has been operated by the City of Choteau since the late 1970's and because of its length of record is the most important water level data collection point in the Teton Valley Aquifer. The record is approximately 11 years in length covering a period from January 1977 to January 1988. The complete record is shown on the UTSWL 16 hydrograph in Appendix B. Water levels range from a low of just over 7 feet below land surface in the summer of 1977 to a high of just over 4 feet below land surface in December of 1978. Most water levels on the hydrograph fall between 5 and 6 feet below land surface. No long-term upward or downward trend in the water levels is apparent.

Figure 30 shows both water level changes in the UTSWL 16 observation well collected during the Upper Teton Aquifer Study and daily precipitation for the project period. Because measurements were more infrequent than those in the UTSWL 01 observation well (monthly) the record is less detailed than in that well. No direct responses to precipitation events are observable on Figure 30. These responses may have occurred but were of too short duration to be observed. However, water level declines during the summer months similar to those observed in UTSWL 01 are apparent on the UTSWL 16 hydrograph. The water level changes confirm that water levels in the Teton Valley Aquifer decline at the City of Choteau over the summer months of each year and that recovery to pre-summer levels occurs over the intervening fall-winter-spring months.

Groundwater Flow

Water level measurements in the Teton Valley Aquifer can be used to determine the general direction of groundwater flow in the aquifer. The water level contours on Figure 31 are not meant to show the precise altitude of the

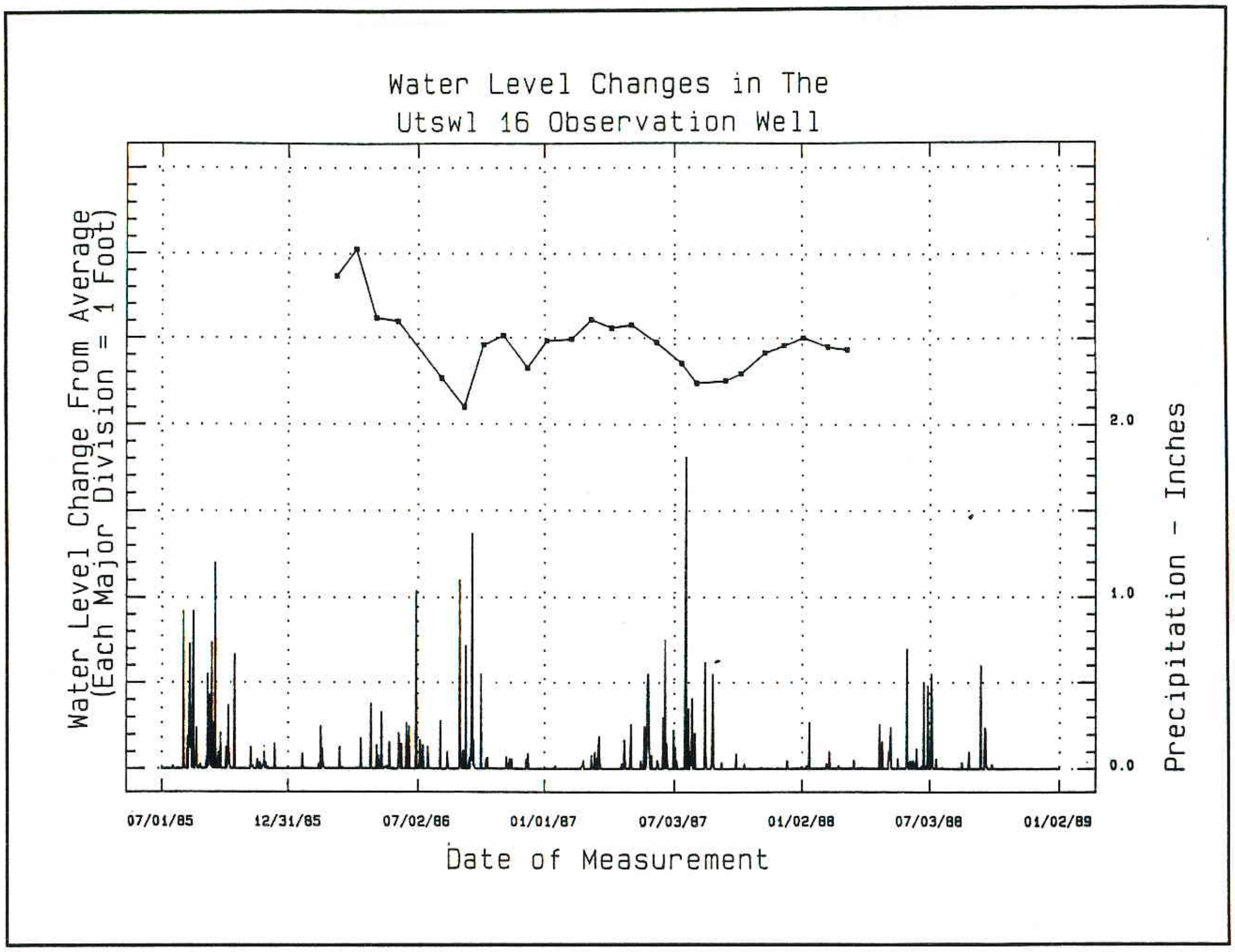

Figure 30: Water levels in the UTSWL 16 observation well in Section 25 ADCD, Township 24 North, Range 5 West.

water table because not enough data exists to accurately delineate the contours but do show that groundwater flows down the Teton River Valley more or less parallel to the length of the valley. In the up-gradient part of the valley near the Newman Ranches in Section 32 of Township 25 North, Range 5 West and in Sections 4 and 5 of Township 24 North, Range 5 West, inferred water level contours show that the Teton River is probably an influent stream (a stream that leaks water to groundwater systems) during periods of flow in the stream channel. Leakage through the bed of the stream may be one reason that it takes considerable time for the Teton River to begin to flow through and downstream of Section 5 of Township 24 North, Range 5 West, after the river has been dry for a period of time. If flow rates in the river are not high (ie below flood stage) at the time flow in the river restarts, leakage through the bed causes the downstream edge of the new surface flow to migrate slowly down the channel because much of the flow is lost re-saturating the bed of the river channel. The influent stream-aquifer relationship is derived from examination of the Teton River bed at several points at several times as well as distances to water in the UTSWL 41 and UTSWL 42 observation wells.

Farther down in the flow system in Sections 10 and 14 of Township 24 North, Range 5 West, the water level contours are drawn directly across the valley showing that groundwater generally continues to flow down-valley. Observation well measurements show that the water table is from 7 to 9 feet below the land surface in this part of the aquifer. The contours curve up-valley in the vicinity of Spring Creek on the north side of the valley where the land surface is topographically lower indicating that Spring Creek up valley from the City of Choteau is probably effluent (a stream that gains water from a groundwater system). The effluent relationship between the aquifer and Spring Creek is inferred based on topographic relationships between the water table, Spring Creek, and several springs observed in the area and shown on topographic maps.

Farther downstream in the vicinity of Choteau, groundwater contours continue to show that groundwater flow is down-valley to the southeast. Water levels are between 4 and 7 feet below land surface in the City of Choteau. The contours have small up-valley re-entrants where the contours cross springs or small feeder streams gaining water from the aquifer.

A different view of the Teton Valley Aquifer is shown in Figure 32 which is a vertical cross section extending from the Newman Ranch well in Section 32

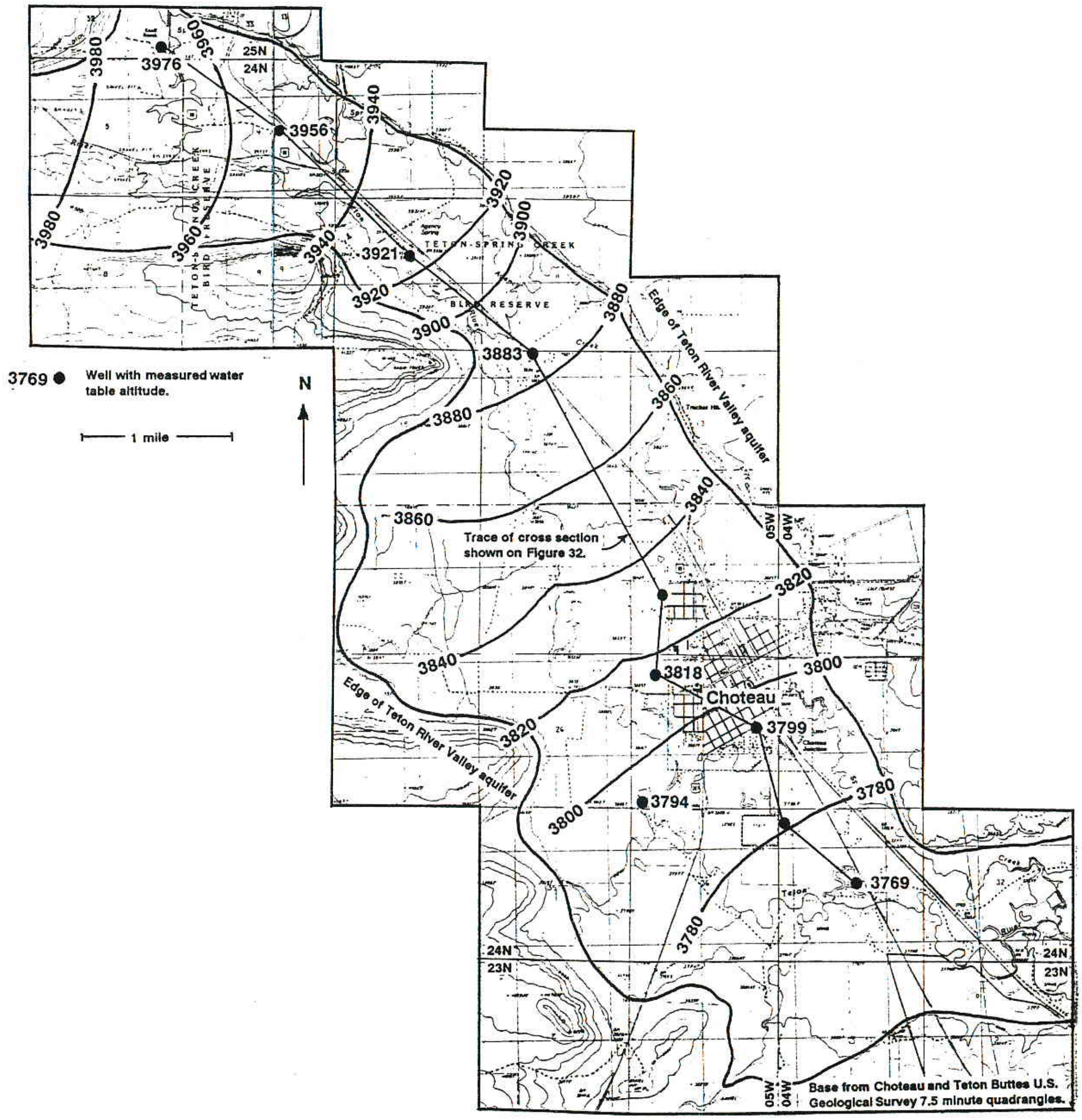

Figure 31: Generalized water-level contours in the Teton Valley Aquifer, Teton County, Montana, based on December 6, 1986 measurements.

of Township 25 North, Range 5 West, to the Anseth well in Section 31 of Township 24 North, Range 4 West. The cross section illustrates the apparent increase in gravel thickness in the upper end of the aquifer. The water table as measured on December 6, 1986 is plotted on the cross section and clearly shows the increase in the distance to water from the land surface in the vicinity of the Newman and Knaff ranches. In areas where the water table is farther below the land surface, streams and other surface water bodies are leaking water into the subsurface. In areas where the water table is closer to the land surface, topographically low areas such as abandoned stream channels of the Teton River collect water from the water table and distribute it into the surface water system.

Recharge

Recharge to the Teton Valley Aquifer comes from at least 5 sources. The first is subsurface flow from parts of the valley aquifer upstream from Eureka Reservoir. Second, the aquifer receives leakage from the Teton River when surface flow is sustained in the river bed past Spring Hill. Third, losses from irrigation ditches and fields in the Teton River Valley between Spring Hill and the City of Choteau would recharge the aquifer. Fourth, the aquifer would receive recharge from direct infiltration of water derived from precipitation and snowmelt events. Finally, some recharge to the Teton Valley Aquifer may also come from buried sandstones in the vicinity of Spring Hill where the Teton River has cut across the outcrop of the Eagle Formation. The first three sources of recharge to the aquifer are the most important.

No information quantifying the amount of recharge available to the Teton Valley Aquifer was obtained during the aquifer study. Gaging discharge in the

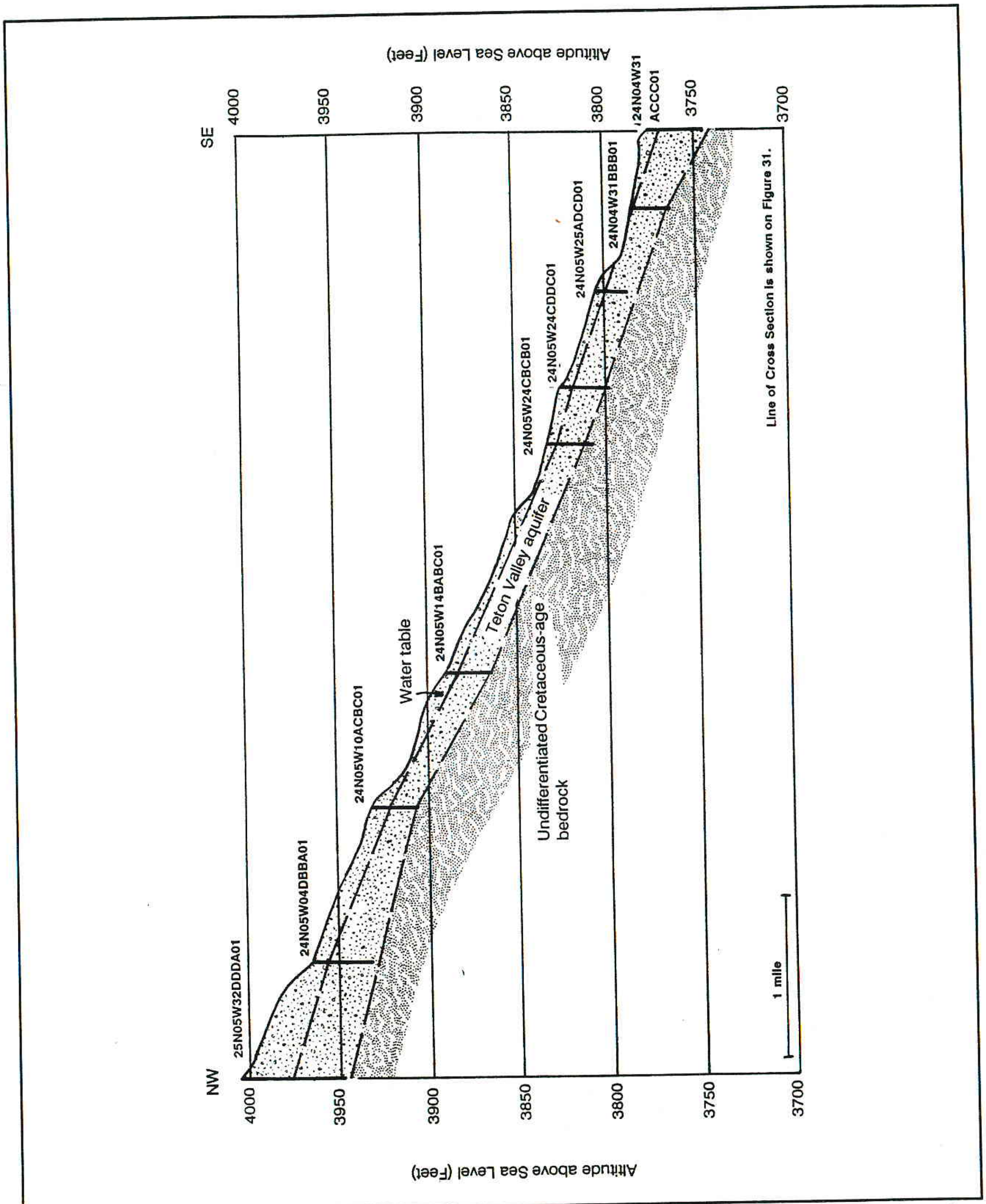

Figure 32: Generalized cross section down the Teton River Valley from Section 32, Township 25 North, Range 5 West, to Section 31, Township 24 North, Range 4 West.

Teton River, measuring the amount of water in ditches, correlating streamflow measurements to water level changes, and drilling in the vicinity of the Knaff Ranch in Section 32, Township 25 North, Range 5 West, were beyond the resources of the study effort. Consequently, only general statements about the amount of recharge are possible and are based primarily on water level changes in observation wells.

Proof that groundwater is present in the Teton River Valley aquifer near Spring Hill is provided by water level measurements in the UTSWL 42 observation well (Figure 28) in Section 32 of Township 25 North, Range 5 West (old Knaff Ranch just below Spring Hill) and the UTSWL 41 observation well in Section 4, Township 24 North, Range 5 West (See Figure 3). The measurements show that water is contained in the aquifer even when the Teton River is not flowing past Spring Hill and when irrigation ditches are not flowing. Because no long-term changes in water level, and therefore storage, are apparent on the UTSWL 42 and UTSWL 41 hydrographs, the Teton River Valley Aquifer over the period of the study is receiving enough recharge to balance discharge. Because water does not flow in the Teton River below Spring Hill during parts of most years, subsurface flow in the aquifer must provide a certain amount of recharge to the aquifer in the vicinity of the Knaff Ranch.

It is difficult to recognize that recharge can occur through subsurface flow because the source is not visible and because of numerous local reports that gravel pits developed in alluvial deposits of the Teton River in Section 5 DC, Township 24 North, Range 5 West, are dry. The operator has apparently not been able to obtain water from pits excavated on the site to run a washing plant (Hamilton J., oral communication 1989) and examination of the pits in the spring of 1989 showed that they were dry. Several explanations are possible for the lack of water in the alluvium at the site of the gravel pits. The UTSWL 42 observation well is completed in gravel at a depth of 57 feet below land surface and shows that gravel fill in the valley is thicker below Spring hill than it is only a few miles downstream. Also, water levels in the UTSWL 42 well were, at their shallowest, at least 19 feet below land surface during the period of record for the hydrograph and that most measurements were greater than 22 feet below land surface. Because the gravel pits are approximately the same altitude as the UTSWL 42 observation well, and if the gravel pits were not constructed to depths of about 22 to 25 feet below land surface it is unlikely they would encounter water. The gravel pits could also be dry if thinner valley fill exists at the site of the pits and the altitude of the alluvial-bedrock contact is above the water table. If this is the case, groundwater flow in the Teton River Valley aquifer through the vicinity of Spring Hill could be concentrated in the northern part of the valley. Groundwater flow would not appear in the gravel pits as a water table and the lack of water in the pits would not preclude the existence of the recharge. A situation similar tho this was observed in the Miller Colony pit located in Section 17 BAAA, Township 25 North, Range 5 West, on the Burton Bench where the pit itself was dry but a shallow water table exists in the Ralston Gap gravel deposits approximately 1 mile to the south.

If the alluvial aquifer were not receiving any recharge through subsurface flow, hydrographs for the wells for both the Knaff and Baker places would exhibit a steady decline reflecting loss of water stored in the aquifer during periods of no precipitation or lack of surface flow in the Teton River Valley. If water levels declined continually for a number of years there would be eventual impacts on the amount of water stored in the aquifer at the City of Choteau. However, there is no evidence in the hydrographs for UTSWL 42 and UTSWL 41 wells or the

7 other monitored wells in the Teton Valley Aquifer to indicate that such a situation is currently taking place.

Additional work would be needed in the vicinity of the Knaff Ranch to define the shape of the subsurface part of the Teton River Valley and to quantify the amount of recharge available from this source.

Water in Storage

The subsurface shape of the Teton River Valley at Choteau is shown on Figure 12 (Page 46) and discussed on pages 44 to 47. Not enough data exists up-valley from the City of Choteau to estimate the amount of water in storage in the Teton Valley aquifer in a manner similar to that previously provided for the Burton Bench aquifer. However, based on an average saturated thickness of approximately 20 feet (from well logs), a porosity of about 0.09 (from aquifer testing), and an areal extent of about 5.25 square miles for the Teton Valley Aquifer shown on Figure 12, approximately 6,000 acre feet of water are in storage. Using these assumptions, approximately 2,300 acre feet of water are in storage under Sections 24 and 25 of Township 24 North, Range 5 West on which most of the City of Choteau is located.

Discharge from the Teton Valley Aquifer

Groundwater discharge from the Teton Valley Aquifer occurs as a result of natural discharge (springs, swampy areas, etc.) and from wells, developed springs, or other man-made development. Except for withdrawals by the City of Choteau, groundwater discharge in the Teton River Valley Aquifer has not been quantified.

Several springs in Section 4, Township 24 North, Range 5 West and between that point and the City of Choteau provide flow to Spring Creek. Flow in Spring Creek derived from springs between its head and the City of Choteau represents discharge from the groundwater system. Within Choteau, however, Spring Creek loses water to the groundwater system at one or possibly more points. At the Munson observation well (City of Choteau operated) located about 30 feet north of Spring Creek in Section 24 DB, Township 24 North, Range 5 West, measurements in May of 1989 showed that the water level in the well was between 3 and 4 feet lower in altitude than that of the water flowing in the creek.

In Sections 23, 24, 25, and 26, of Township 24 North, Range 5 West, the Teton Valley Aquifer is discharging water from storage to springs, wet areas, small feeder streams to the Teton River, and to other forms of natural groundwater discharge. All of these features are readily apparent on the Choteau 7.5 minute U.S. Geological Survey topographic map and from examination of the Teton River Valley. Water levels in the UTSWL 01 observation well in Section 24 of Township 24 North, Range 5 West (just west of the hospital) are 6 to 8 feet below land surface. Water levels in the City of Choteau observation well (UTSWL 16) in Section 25 of Township 24 North, Range 5 West (at the Minipark) range from 4 to 6 feet below land surface. These water levels are close enough to the land surface to allow relatively shallow depressions in the land surface to intersect the water table creating wet spots and swampy areas.

Subsurface discharge from the Teton River Aquifer may appear as surface flow in the Teton River Valley where it crosses the Dutton Road in Section 26, Township 24 North, Range 4 West. At this locality the Teton River is cutting a channel in dark gray shale of the Colorado Group and the Teton River Aquifer is not present. However, water flow was observed at the Dutton Road crossing at many occasions during the aquifer study even when upstream reaches of the Teton River were dry. Local reports also state that the river is never dry at the Dutton Road.

The city of Choteau is the largest water user in the Teton River Aquifer pumping an average of 652 acre feet annually between 1984 and 1989 (Stan Brown, written communication, 1990). In 1989 the City withdrew approximately 3.0 acre feet per day during the April - September period and 1.6 acre feet per day during the remainder of the year. The City water system obtains its water from 2 developed springs, a large diameter well with laterals, and a large capacity well approximately 20 feet on a side and 20 feet deep. Numerous other privately owned wells and sandpoints have been constructed in Sections 24 and 25, Township 24 North, Range 5 West, and discharge water from the aquifer.

Water Quality

Five water quality samples were collected in the Teton River Valley aquifer during the aquifer study. Dissolved solids in the aquifer range from about 290 milligrams per liter in up-gradient parts of the aquifer to about 400 below the City of Choteau. All of the waters sampled were Calcium-Magnesium Bicarbonate-Sulfate type. The highest concentration trace element in the water was strontium ranging between 310 and 400 micrograms per liter followed by boron which ranged between 60 and 390 micrograms per liter. Four of the five boron values were less than 100 micrograms per liter but the highest concentration was in the City of Choteau test well. Concentrations of none of the parameters for which analyses were made were above recommended limits for drinking water in any of the Teton River Valley aquifer samples.

No evaluation of water quality in terms of nutrients or in potential organic contaminants (herbicides/pesticides or volatile organic compounds) was made during the aquifer study although such work is probably warranted in the vicinity of Choteau where many people use the water for domestic purposes. The potential susceptibility of the aquifer to contamination by man-made compounds such as herbicides/pesticides or volatile organics suggest that this type of work should be attempted.

Aquifer Test Data

Two aquifer tests were conducted in the Teton Valley aquifer during the aquifer study. The UTSWL 01 observation well was pumped for 320 minutes (0.22 days) at approximately 150 gallons per minute but the test was cut short by failure of the well to provide enough water. The failure is attributed to lack of open area in the well bore to allow efficient access of water to the well from the aquifer and not a lack of water in the aquifer. A second test was conducted at the City of Choteau test well constructed during the aquifer study in Section 24 CBD, Township 24 North, Range 5 West. The City well was pumped at approximately 210 gallons per minute for 3,000 minutes (2.1 days). Water levels were measured in the pumping well as well as 3 observation wells between 63 and 208 feet from the pumping well. A summary of the aquifer test results for the Teton Valley aquifer is contained in Table 5. Complete tabulated aquifer test data and data plots for both the UTSWL 01 and City of Choteau aquifer tests are included in Appendix C.

UTSWL 01: The aquifer test was conducted on a 12 inch diameter steel culvert cased well which is 28 feet deep located in Section 24 CDD, Township 24 North, Range 5 West. The well casing is perforated between 8 and 28 feet below

Table 5: Aquifer test results for the Teton Valley Aquifer

TEST NAME	WELL NAME	EVALUATION METHOD	TRANSMISSIVITY (GPD/FT)	STORATIVITY (SPECIFIC YIELD)	REMARKS
Choteau	Choteau	Newman delayed	15,700	--	Pumping well - reliability poor
	Choteau	Jacob-Cooper	35,400	--	Recovery data - t/t' < 140
	Chotobs 1	Newman delayed	72,000	0.11	Well 63 feet NE of pumping well
	Chotobs 1	Jacob-Cooper	82,950	--	Recovery data - t/t' < 40
	Chotobs 2	Newman delayed	86,500	0.09	Well 208 feet NE of pumping well
	Chotobs 3	Newman delayed	60,000	0.09	Well 99 feet N of pumping well
	Combined Obs	Newman delayed	72,000	0.09	---
	Combined Obs	Theis	72,000	0.09	---
Anderson	Anderson Obs	Newman delayed	68,400	0.02	Well 24.5 feet from pumping well

land surface. Water level measurements during the test were not collected from the pumping well but were obtained from a 2 inch diameter observation well constructed 24.5 feet from the pumping well. The observation well casing was pulled and the well bore back-filled after the aquifer test. Discharge from the pumping well ranged from 143 to 153 gallons per minute and averaged 150 gallons per minute. The standard deviation of the discharge measurements was 6.1 gallons per minute. The initial water level in the observation well was 8.07 feet below the measuring point and maximum drawdown during the test occurred at 320 minutes and was 1.47 feet. No water level recovery data were obtained after pumping ceased.

Drawdown data for the pumping period were evaluated using Newman unconfined delayed yield method (Newman). A type B match curve with a beta of 0.60 provided the best match with the field data observed during the aquifer test resulting in a transmissivity of 68,400 gallons per day per foot and a storativity of 0.022. Based on an aquifer thickness of 24 feet at the UTSWL 01 observation well, the hydraulic conductivity is approximately 2,850 gallons per day per square foot.

City of Choteau Test: An aquifer testing site for the Teton Valley aquifer was constructed in an unused field owned by the City of Choteau in Section 24 CBD, Township 24 North, Range 5 West. A pumping well was constructed by the Montana Bureau of Mines and Geology for the purposes of the test and its log is contained in Appendix E. The well has 5 inch diameter polyvinyl chloride (PVC) casing and factory slotted (0.040 inch slots) pipe placed between 12 and 22 feet below land surface. The casing bottom was capped so that all water entered the well through the slotted pipe.

Three observation wells were used during the aquifer test (Figure 33). Choteau observation well 1 (Chotobs1) was constructed by the Montana Bureau of Mines and Geology specifically for the aquifer test 63 feet northeast of the pumping well. Chotobs1 is cased with 4 inch diameter PVC water well casing, is perforated between 19 and 23.5 feet below land surface, and is 28 feet deep. The initial water level in the well was 4.4 feet below the measuring point. A Stevens "F" type water level recorder was installed on this well during the aquifer test. Choteau observation well 2 (Chotobs2) is an existing 2 inch diameter steel cased observation well located 207.5 feet northeast of the pumping well. The measuring point on this well is 2.2 feet above land surface and the total depth is 4 feet below land surface. The initial water level in the well was 5.27 feet below the measuring point. Choteau observation well 3 (Chotobs3) is an existing 2 inch diameter steel cased well located 99 feet north of the pumping well. The Chotobs3 well is 14.8 feet deep and had an initial water level

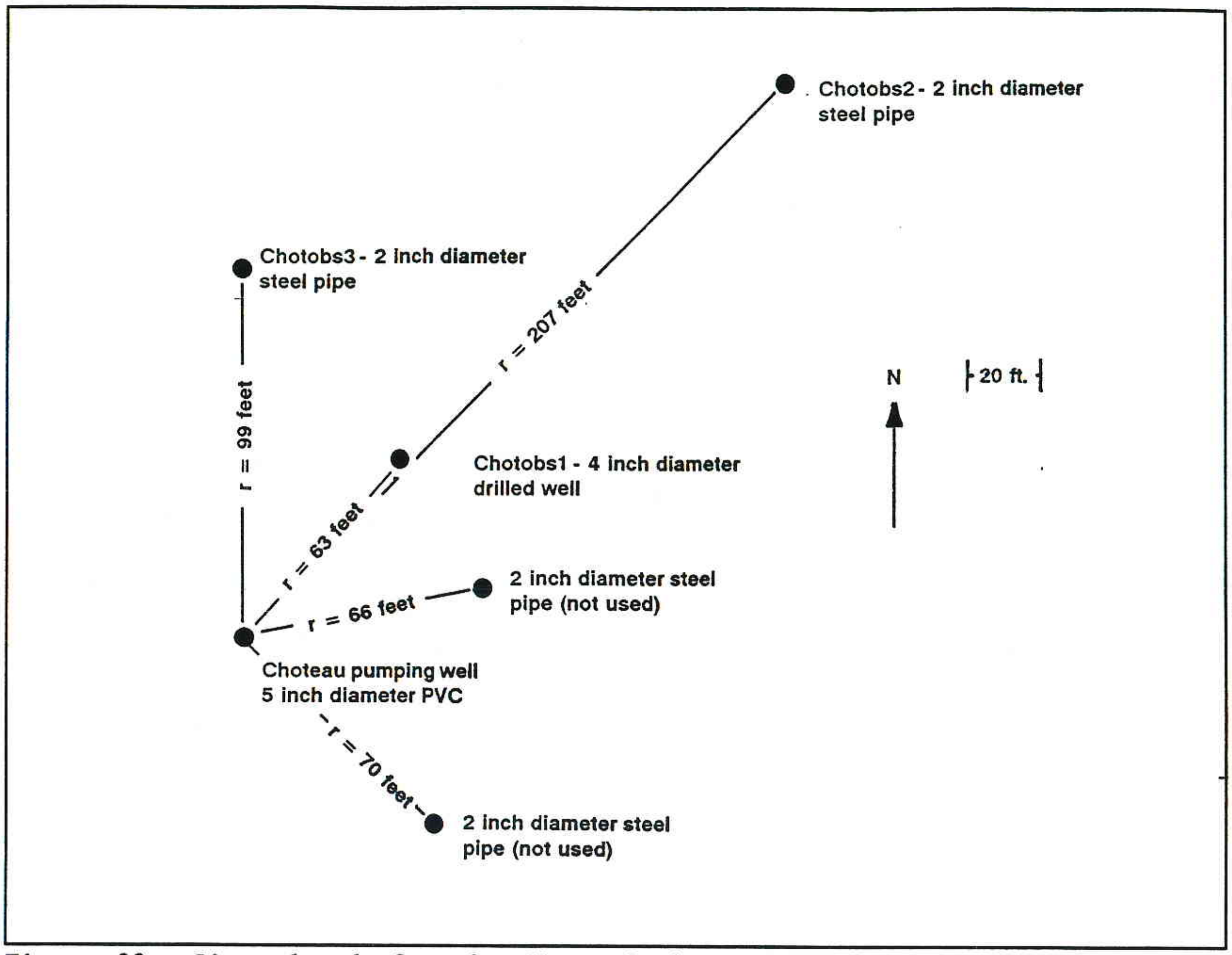

Figure 33: Site sketch for the City of Choteau aquifer test in Section 24, Township 24 North, Range 5 West.

of 7.54 feet below the measuring point. The measuring point is 4 feet above land surface. Both the Chotobs2 and Chotobs3 wells were measured periodically during the aquifer test. Water level recovery in the Chotobs1 observation well was monitored for 3,150 minutes after pumping stopped.

The production well was pumped at an average rate of 208 gallons per minute and the discharge ranged from 198 to 220 gallons per minute. The first standard deviation on the discharge measurements was 6.6 gallons per minute. The initial water level in the pumping well was 6.78 feet below the measuring point and the maximum drawdown observed during the test was 8.6 feet. Water level recovery was measured in the pumping well for 168 minutes after pumping stopped.

Aquifer test data for the pumping well were evaluated using Newman delayed yield type curves and is tabulated in Table 5 above. Based on time-drawdown data, transmissivity in the aquifer during the pumping period was 15,700 gallons per day per foot. Based on the data collected during the test, the transmissivity of the aquifer at the pumping well is considerably lower than those calculated for the observation wells (72,000 gallons per day per foot for Chotobs1 - 60,000 gallons per day per foot for Chotobs3, and 86,500 gallons per day per foot for Chotobs2). The lower transmissivity in the pumping well is attributed to non-ideal conditions near the well bore due to high entrance velocities and turbulent flow caused by the high pumping rate relative to the amount of open area in the screened section of the well bore. The factory slotted casing in the pumping well contains only approximately 11.8 square inches of open area per foot of pipe (based on 6 inch diameter pipe) and under ideal entrance velocities of 0.1 foot per second would be expected to produce approximately 3.7 gallons per minute. There are 10 feet of slotted pipe in the well and the ideal yield for the well would be about 37 gallons per minute. As noted above, the well was pumped at 208 gallons per minute, approximately 6 times the ideal yield creating a zone of turbulent flow in the vicinity of the well bore during the pumping period. Equations developed to model aquifer response to pumping specify that flow in the aquifer is laminar and not turbulent. Because of the non-ideal conditions near the pumping well, the transmissivity calculated from the pumping well data is not considered reliable and is not representative of the aquifer.

Recovery data for the pumping well are also suspect. Analysis of recovery information requires that conditions in the well bore and the aquifer be reasonably close to those contained in the underlying assumptions for aquifer test analysis during the pumping period. As noted before, conditions near the well bore deviated substantially from ideality. Evaluation of the recovery period data produced a transmissivity value of approximately 35,400 gallons per day per foot.

Observation wells Chotobs1 and Chotobs3 are 63 and 99 feet distant from the pumping well (see Figure 33). Conditions in the aquifer at these locations were not affected by the non-ideality near the pumping well bore because flow in the aquifer at these locations was laminar during the test. Time-drawdown data from the observation wells can be used to calculate transmissivity and specific yield (storativity) values for the Teton Valley Aquifer at the locations of the observation wells.

Transmissivity and specific yield for the Teton Valley Aquifer at the location of Chotobs1 were calculated to be 72,000 gallons per day per foot and 0.11 respectively. A Newman analysis using a type B curve with a Beta of 0.40 was used in the analysis. Analysis of drawdown using a Theis non-leaky type curve for times greater than about 700 minutes after pumping began produced similar results. Recovery data in the Chotobs1 well produced a higher calculated transmissivity of about 83,000 gallons per day per foot, about 15 percent greater than that from the pumping data.

Chotobs3 is located 99 feet north of the pumping well. A Newman analysis of the pumping period drawdown data produced a calculated transmissivity of 60,000 gallons per day per foot with a specific yield of 0.09. A Newman type B curve with Beta equal to 0.60 was used in the analysis. Time-drawdown data evaluated using a Theis non-leaky curve for times greater than about 500 minutes since pumping began produced similar results. No water level recovery data were collected for this well.

Chotobs2 is located 207 feet northeast of the pumping well and also was not affected by the non-ideality in the aquifer near the pumping well. A Newman analysis of pumping period time-drawdown data produced a calculated transmissivity of 86,500 gallons per day per foot and a specific yield of 0.091. A Newman type B curve with Beta equal to 2.00 was used in the analysis. Different evaluations of Chotobs2 time-drawdown data using slightly different matching positions of the type curves produce possible transmissivities of up to approximately 95,000 gallons per day per foot and the 86,500 gallons per day per foot transmissivity represents a conservative value in the lower-middle part of the range of possible solutions. The transmissivity value for the Teton Valley aquifer at the Chotobs2 observation well is approximately 20 and could be as much as 30 percent greater than transmissivities in the Chotobs1 and Chotobs3 wells.

A combined analyses of the observation well data illustrates the apparent differences in transmissivity and storativity of the aquifer at the three points in the aquifer. Figure 34 is a plot of time-drawdown data for all three observation wells for the City of Choteau test. If the Teton Valley aquifer was isotropic and homogeneous all three data plots would be superimposed on the graph. Chotobs1 and Chotobs3 plot in similar positions on Figure 34 illustrating their similar transmissivities and storativities. Chotobs2 plots below the traces of Chotobs1 and Chotobs3 for times early in the aquifer test and overlies a part of the plot of Chotobs1 data late in the test. Satisfactory matches with type curves are difficult for the plots on Figure 34 because of the spread in

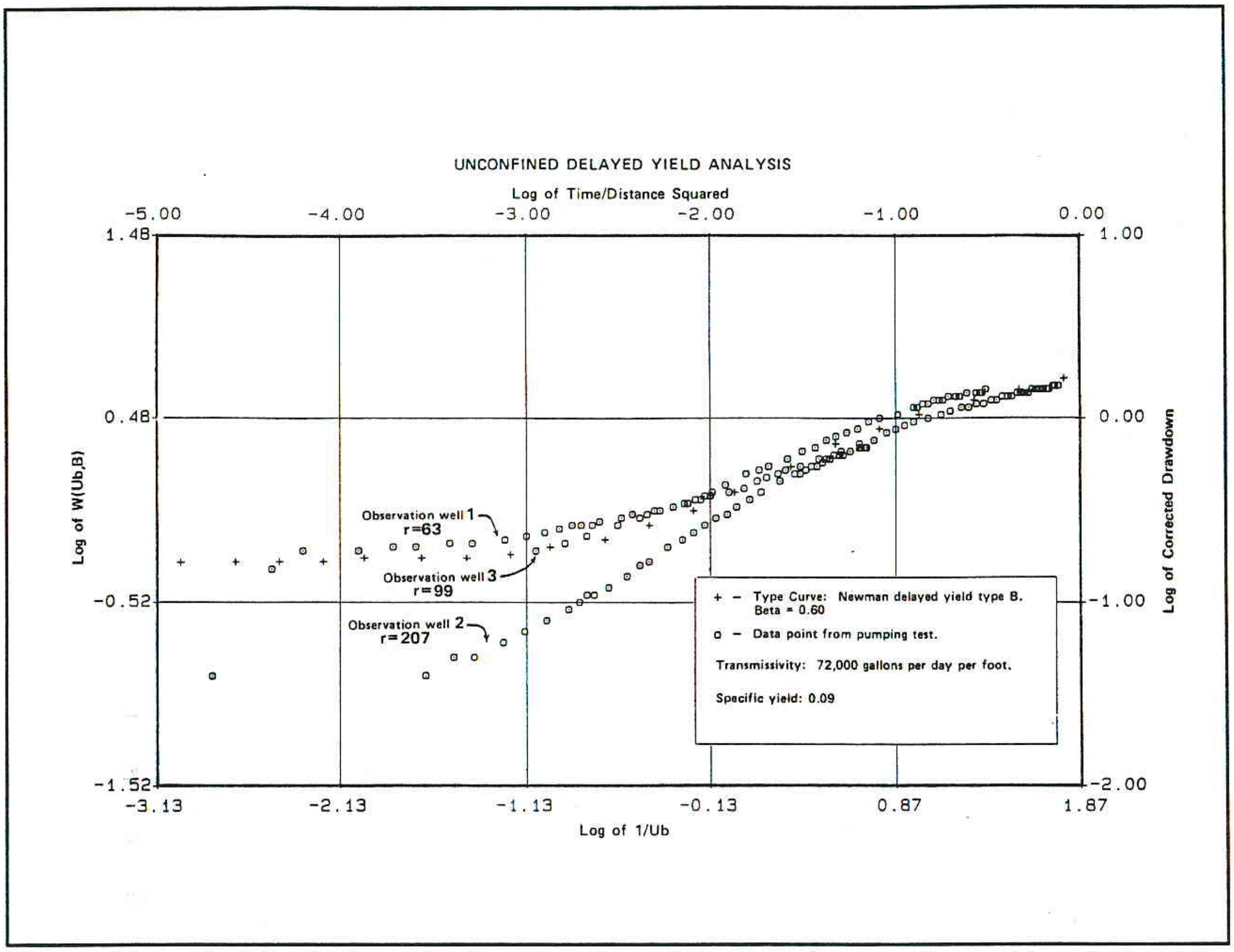

Figure 34: Combined plot of time-drawdown data for observation wells of the City of Choteau aquifer test.

the data. The most satisfactory matches are provided by Newman or Theis curves matched for later times in the test to the Chotobs1 and Chotobs3 data sets. Both evaluations resulted in values of transmissivity and storativity (specific yield) of 72,000 gallons per day per foot and 0.09 respectively for the Teton Valley aquifer.

A specific use of the aquifer test data for the Teton Valley aquifer is evaluating the potential for a production well at the site of the aquifer test. For example, would it be feasible to develop a well capable of producing 200 gallons per minute on a sustained basis at this site? In order to determine this

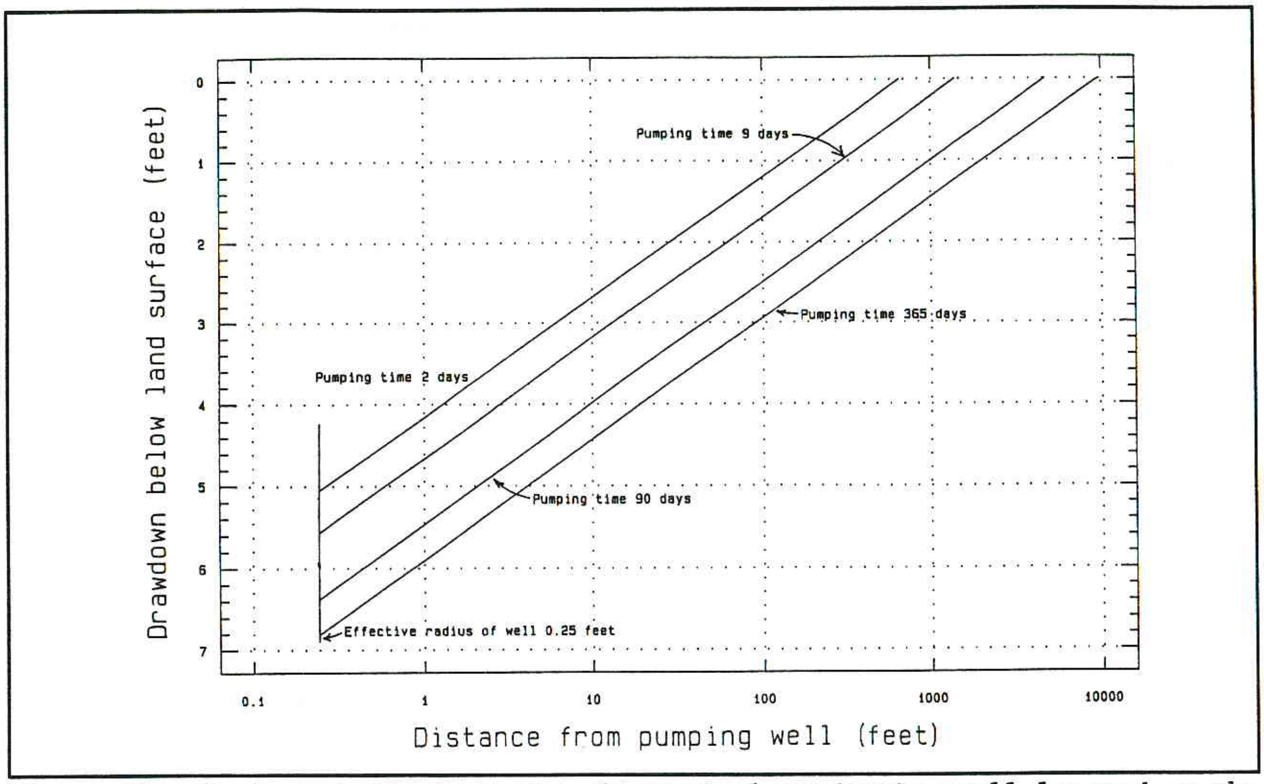

Figure 35: Projected drawdown at a theoretical production well located at the City of Choteau aquifer test site for different pumping lengths.

feasibility, distance-drawdown plots can be generated from the aquifer test data and can be used to project impacts of the pumping well into the future. Assuming that the transmissivity is 72,000 gallons per day per foot and the storativity is 0.09, drawdown at 2, 9, 90, and 365 days of continuous pumping shown on Figure 35 will result in the aquifer near the theoretical production well. Most of the drawdown occurs during pumping periods of less than 9 days of duration. As pumping time lengthens, the rate of increasing drawdown slows.

At 360 days of pumping, the theoretical drawdown in the aquifer at the pumping well would be approximately 6.8 feet. The water level in the aquifer would be approximately 11 feet below land surface at this time based on an initial static water level of 4 feet below land surface. The lack of thickness in the aquifer becomes a problem in designing a production well if drawdown is of this magnitude. For example, the City of Choteau test well was perforated between 9 and 19 feet below land surface. If a production well was constructed with a similar perforated interval to that of the test well, the water level in the aquifer would be approximately 2 feet below the top of the well screen. Because of well losses, the water level in the well bore would be even lower causing adverse conditions in the operation of the well. Cascading water, turbulent flow in the dewatered parts of the well screen, and potential for air entrapment in the aquifer would all limit the feasibility of the production well to be operated on a long term basis.

Examination of Figure 35 shows that all theoretical drawdowns at times greater than 2 days of pumping are at least 5 feet. Coupled with initial water levels of approximately 4 feet below land surface, pumping water levels in the aquifer at pumping lengths of greater than 2 days will present design problems for the construction of the well. Alternatives in construction include shortening the screen length at a cost of lessening the open area in the well, drilling and casing the well into the underlying bedrock to provide a place to set the pump, lessening the yield of the well, or going to a collector well with perforated laterals design.

The performance examples included in Figure 35 are worst case situations. It is not likely that the well would be turned on and left running indefinitely in most operating scenarios. Any amount of time the well did not operate would allow water level recovery lengthening the amount of elapsed time necessary for water levels to reach critical levels in the well bore. Data from the City of Choteau aquifer test site shows that the aquifer is capable of yielding up to 200 gallons per minute for a lengthy period of time but that lack of thickness in the aquifer at the testing site will probably present special design problems to production wells. A solution may be to install additional water production capability for the City of Choteau using designs similar to that utilized by its existing caisson and horizontal collector well installed in 1969.

Summary and Conclusions

The Teton Valley aquifer is shown by existing evidence to contain adequate water to provide a source of municipal water supply for the City of Choteau. Water level data for the aquifer show that to date little if any affect on water levels in the vicinity of Choteau is observable and that seasonal water level declines are offset by water level rises leading to very small net changes in water stored in the aquifer. Aquifer test data shows that the aquifer in the vicinity of the City of Choteau is relatively transmissive and will provide several hundred gallons per minute of water to individual water wells or developments. The quality of the water is good with dissolved solids ranging from 290 to 410 milligrams per liter.

The greatest danger to the Teton River aquifer lies in its small thickness and shallow water levels. Water levels are generally less than 10 feet and often less than 5 feet below land surface in much of the populated area of the valley. The aquifer is comprised of permeable sand and gravel which often extends to the land surface providing quick and direct paths for potential pollutants to enter the aquifer. The water supply is virtually unprotected naturally and culturally from contamination from man caused sources.

Although quality problems have yet to occur on a serious basis with the water supply for the City of Choteau, the municipality is in a tenuous position regarding the security of its supply relative to quality. Present withdrawal points for the city supply are within the populated part of the valley comprising

Choteau. The old City Well on Highway 287 is only a few hundred feet from the highway near a relatively busy intersection. The collector well installed in 1969 is also in a built up area of town. A third source of water is from a developed spring in a built up portion of the townsite.

Difficulties with the present supply are most likely to arise from man caused pollution of the aquifer. For example, if a gasoline spill occurred from a tanker truck in the vicinity of the Highway 287 well the shallow depth to water in the aquifer and the permeable sand and gravel near the land surface would almost guarantee that the well would be contaminated with the spilled material. Response to the spill by city and other officials would not be quick enough under almost any imaginable circumstances to prevent contamination of the aquifer. Land use near other water developments for the city system could also present danger. Closely quartered livestock, private fuel tanks, gasoline stations, agricultural chemical suppliers, county shops. county weed departments, or many other potential consequences of both public and private land use could at any time present a contamination problem in the Teton Valley aquifer at a point where the present city development of the aquifer would be in danger.

The people of the city of Choteau have two choices regarding the security of the city water supply. A reactive position is to wait until the system is contaminated, isolate the problem, and determine an alternative point of supply to replace the lost source. A proactive position would be to plan now to gradually obtain a secondary source or location in the aquifer to supply the city. The secondary source would need to be hydrologically capable of providing the needed quantity and quality for the city supply and would also need to be culturally and politically protected to preserve the quality of the supply. An intermediate step is to begin to culturally and politically protect the existing sources of supply from contamination as much as possible.

Based on the information derived during the Upper Teton Aquifer Study, the general concepts regarding aquifer protection outlined above, and the fragility of the aquifer regarding its potential contamination from man-caused sources the following recommendations should be considered by the City of Choteau and other groundwater users in the Teton River Valley aquifer.

** The City of Choteau should begin to plan for alternative points of diversion for wells and other developments which will supply water to the town. To accomplish this goal a site should be selected by the City up-gradient from the town itself as the location for a new well field. The site should be as remote as possible from highway 287 and from any presently built up area of the valley. Hydro-geologic work should be completed on the site prior to its selection by the city to determine that it is capable of providing the necessary amount of water for the municipality.

** The City of Choteau should continue to actively monitor up-gradient potential sources of contamination of the Teton Valley aquifer. If necessary, the City should seek professional assistance in designing a monitoring program for any potential sources of contamination so that the program will be successful in detecting contamination in the aquifer if problems should occur.

** The City of Choteau should investigate zoning or land use management programs to protect the aquifer from land uses which provide danger of contamination to the Teton Valley aquifer or to their water developments in that aquifer. For example, new gasoline station development on the northwest edge of town up-gradient from the city wells if requested should be prohibited. Businesses which sell herbicides or pesticides should be carefully controlled particularly if they mix or formulate chemicals at the business site and none should be allowed up-gradient from the city water developments.

** Because zoning regulations enforced by the City can not be enforced outside of the City limits, cooperation between the City and Teton County might be necessary to provide protection for the aquifer. The City and County together might investigate the Environmental Protection Agency's well head protection program (Administered through the State Department of Health) as a cultural and political way to protect the water in the Teton Valley aquifer. The well head protection program allows local government to legislate and control land use within certain distances of groundwater development to protect the quality of water available to that development.

If care is taken by local citizens and governmental bodies in protection of the Teton Valley aquifer, available data indicate that a sufficient supply of water is present in the aquifer to continue to supply existing levels of use indefinitely. Moderate increases in use of the aquifer could also be supported. If a major contamination incident should occur in the aquifer, however, the suitability of the aquifer for a municipal water supply could be seriously degraded. The City of Choteau and other local governmental bodies should actively investigate ways to protect the aquifer using some of the suggestions listed above and should determine if other avenues to protect the aquifer are available. If the source of water for the City of Choteau should become contaminated the only alternative would be to develop an expensive alternative source of water up-gradient of the contaminated zone. If the aquifer is protected, the likelihood of contamination is greatly lessened and more local less expensive sources of water can be used to supply the City.

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