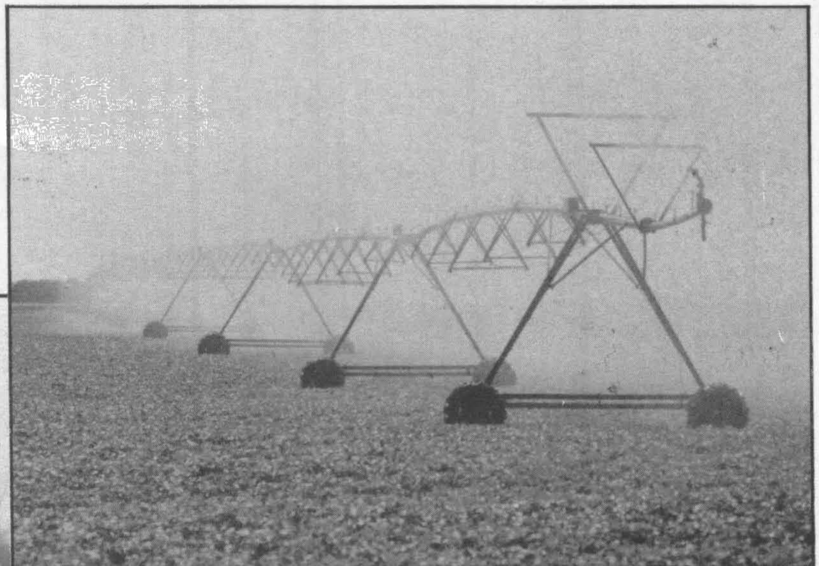
# Understanding Ground Water Level Trends:
# A Key to Managing Water Use



**A HISTORICAL SUMMARY ON GROUND WATER LEVELS AND TRENDS**

**DIVISION OF WATERS**

**MINNESOTA DEPARTMENT OF NATURAL RESOURCES**

**JUNE 1989**

# Understanding Ground Water Level Trends:

## A Key to Managing Water Use

A Historical Summary of Ground Water Levels and Trends

Division of Waters

Minnesota Department of Natural Resources

Second Edition

JUNE 1989

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Cover photos: Department of Natural Resources

An annual report on ground water levels can be obtained by writing: Observation Well Manager, DNR Division of Waters, 500 Lafayette Road, St. Paul, MN 55155-4032.

# Introduction

## Background

The Department of Natural Resources (DNR) monitors the use of the State's water and allocates that resource to assure that there is water of sufficient quality and quantity to supply the needs of future generations. The primary tool used by the Department for assessing future ground water availability is the observation well network. Under the observation well network program, ground water levels are routinely measured in 600 wells statewide. The primary objective is to provide estimates of changes in water supply. In addition, these data help the Department resolve well interference complaints, other allocation issues, and are useful to ground water researchers. The U.S. Geological Survey (USGS), local units of government, and others involved in ground water use data from the observation well network.

Systematic records of ground water levels measured in each of the wells in the network form the database. Water levels in aquifers fluctuate in both a long and short term sense, primarily in response to changes in precipitation and/or pumping. A plot of these fluctuations through time is called a hydrograph. The changes tell something about an aquifer's recharge and discharge rates, the geological properties of the aquifer and overlying materials. The purpose of this report is to provide a historical overview of ground-water trends and levels throughout Minnesota. To accomplish this, we present a historical background of the observation well program, a hydrogeological primer on aquifers, a description of seasonal and long term trends in ground water levels, and finally, a statewide overview of ground water levels.

## History of the Observation Well Network

Monitoring of ground water levels has been a cooperative effort by the USGS and DNR since 1947. The network at that time contained 4 wells. By 1956, when the first hydrographs were published by the DNR in its Bulletin 9 there were 32 wells in the network. In 1974 there were 152 active observation wells, in time to record the effects of the ensuing drought on ground water levels. Beginning in 1983 the DNR began contracting with Soil and Water Conservation Districts to measure additional wells. The current network consists of 589 wells at the end of 1988 (See Figure 1).

The DNR Division of Waters manages the observation well network. The existing program is composed of two networks, one managed by the USGS, the other by the DNR. The DNR's portion of the network is sometimes referred to as the "SWCD network" because most of the field measurements are made by the local Soil and Water Conservation Districts.

A two phase program was started in July 1983 to upgrade the DNR/SWCD network by improving the quality and quantity of ground water level measurements collected. The first phase began with the establishment of a set of strict criteria for each observation well in the network. A well is required to have a geologic record and well construction data to identify which aquifer is being monitored. To be certain that the static water level of a single aquifer is being observed, an observation well cannot be screened in multiple aquifers. Also, no active domestic wells are used to ensure that the level recorded is not the result of normal use. Existing wells which conformed to the criteria were located and included in the DNR/SWCD network.

Phase two of the observation well program consists of drilling new wells which meet observation well criteria and began with three wells in Sherburne County in the fall of 1983. To date, 49 observation wells have been installed. All new observation wells are being drilled in areas of future or present high ground water use where existing wells do not meet observation well criteria.

## Objectives of the Observation Well Network

The goal of the observation well program is to produce the basic data which enables the DNR to manage and protect the State's ground water resource more effectively. The program provides an assessment of existing ground water level conditions and documents significant changes in these conditions over time. The program provides data to predict the effect of future land use practices, climatic changes, and ground water pumpage and will detect areas of existing and developing ground water problems.

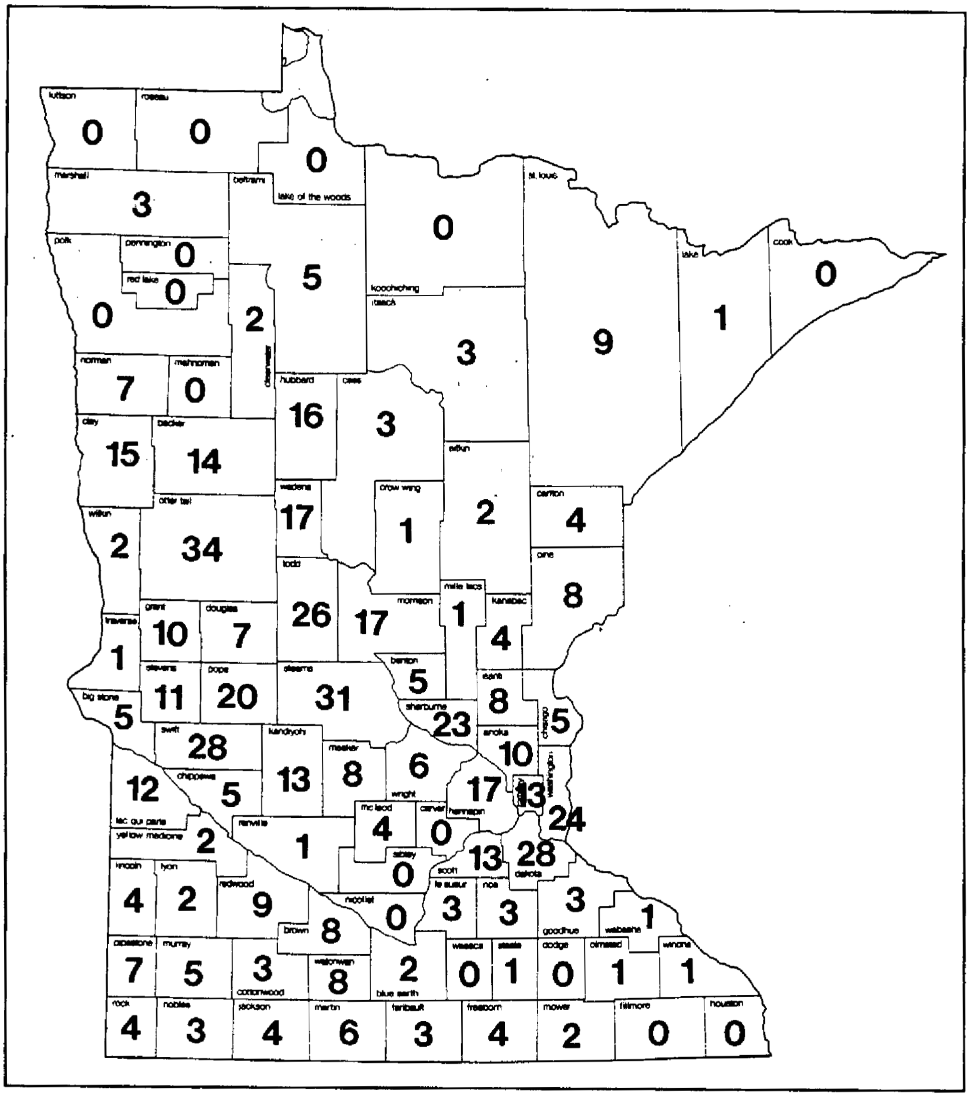


Figure 1: Number of Active Observation Wells in 1989.

Site specific information obtained from observation wells is usable only in the immediate vicinity of the observation well site. Values extrapolated on the basis of similar geologic and hydrologic conditions may be useful in terms of regional or area wide planning, but are not likely to be appropriate for solving a local ground water problem. This is why observation wells must be placed to provide both comprehensive statewide coverage of principal aquifers and more intensive well placement where ground water quantity or quality problems are developing or are anticipated.

**The specific objectives of the observation well network are to:**

- place wells in areas of future or present high ground water use while considering variations in geologic and other environmental conditions.
- identify long term trends in ground water levels.
- detect significant changes in ground water levels.
- provide data for evaluation of local ground water complaints.
- provide data to resolve allocation problems.
- target areas which need further hydrogeologic investigation, water conservation measures, or other remedial action.

# What is an Aquifer?

## Aquifer Definition:

An aquifer is a geologic formation that is capable of yielding sufficient quantities of water to wells. It must readily store and transmit water. Ground water occupies the openings in earth materials such as intergranular pores in sands and gravels or cracks or cavities in otherwise solid rock (Figure 2). Two primary factors determine whether a given rock or sediment will be a good source of water for a well. The first factor is porosity and is the percentage of pores and cracks in a rock or sediment formation. The second factor is called permeability. Permeability defines how readily water can move from pores or cracks to a well. For a soil or rock to be a good source of water it must contain a high percentage of interconnected openings through which water can flow. Most aquifers with relatively high yields to wells consist of clean coarse sands, mixtures of sand and gravel and some fine-grained sedimentary rocks such as sandstone. Highly fractured rocks such as limestones, can also be good aquifers.

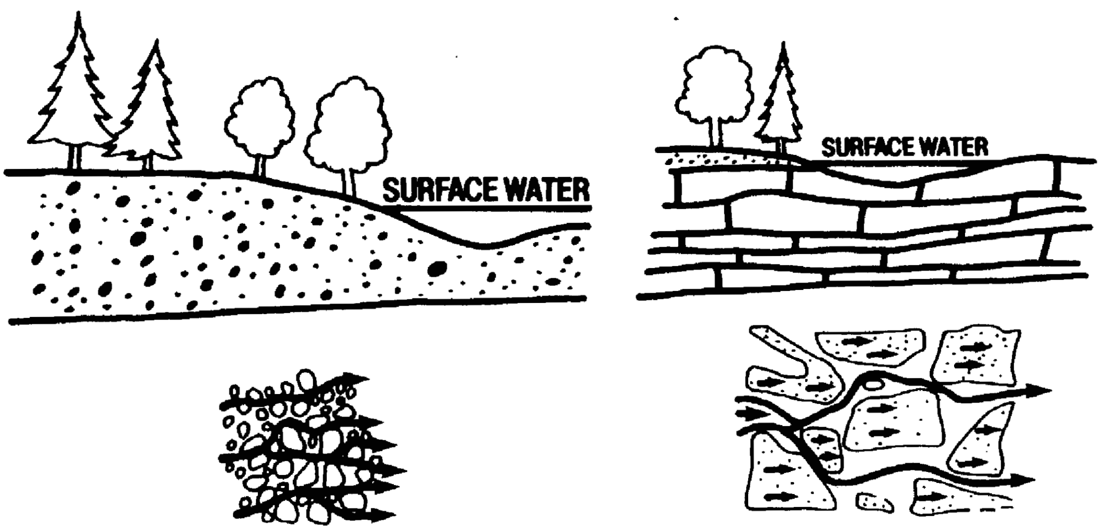



Figure 2: Storage and movement of ground water.
a) porous media, e.g. sand or gravel.
b) fractured porous media, e.g. limestone.

## Unconfined and Confined Aquifers

Ground water in aquifers occurs either under water table (unconfined) or artesian (confined) conditions. Unconfined aquifers generally are close to the land surface and are exposed to the atmosphere through pores in the overlying formation. The upper surface of the saturated zone in this aquifer is called the water table. The water level in a water table well will be the same as the level of the water table. Artesian aquifers are bounded at the top by relatively impermeable formations called confining layers. The water level in a well cased in an artesian aquifer will be higher than that of the aquifer itself. The level to which water will rise in a well in a confined aquifer is termed the potentiometric surface. If the potentiometric surface of a confined aquifer is above the land surface, a flowing artesian well will occur (Figure 3).

## Effect of Pumping

The hydraulic differences between these two types of aquifers can be visualized by observing what happens in the vicinity of a well when water is pumped. Suppose we pump at the same rate from two wells, one located in a confined aquifer and the other in an unconfined aquifer. As water is pumped from the well, the water table or potentiometric surface near the well is lowered (See Figure 4). The lowered surface near the well causes water in pores farther from the well to flow toward the well. The resulting decline in water levels, called a cone of depression, can be measured by a series of observation wells penetrating the aquifers. As shown, the cone of depression from the unconfined aquifer develops more quickly and is steeper near the well than the cone of depression from the confined aquifer. The effect of pumpage from the confined aquifer is noticeable at a greater distance from the well. As a result, wells can be drilled closer together in unconfined aquifers without interference than in confined aquifers given that all other conditions are identical.

## Release of Water from Storage

The way water is released from these two types of aquifers can also be shown using this same example. An equal volume of water was discharged from each aquifer, yet the water table declined differently than the potentiometric surface from the confined aquifer. This difference is due to the way the water was

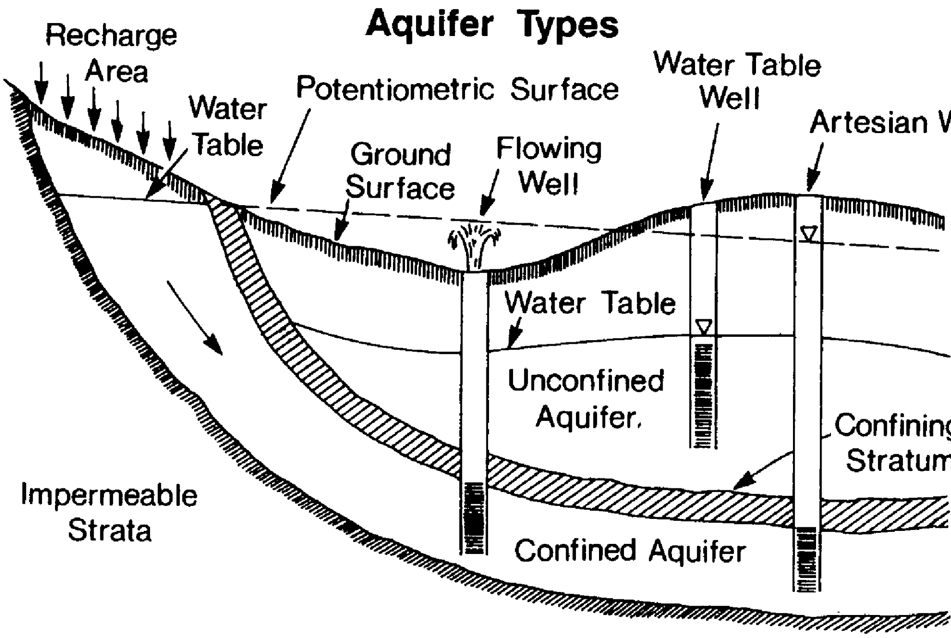



Figure 3: Schematic cross section illustrating unconfined and confined aquifers (after Todd, 1980).

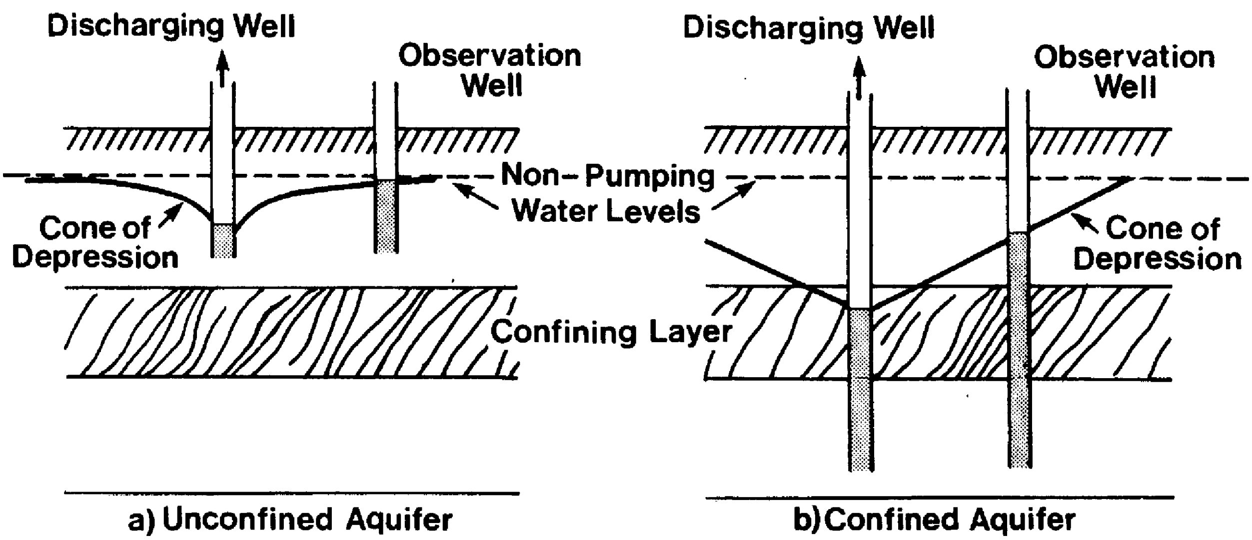



Figure 4: Comparison of cones of depression for unconfined and confined aquifers. As water is withdrawn from the unconfined aquifer, water drains from the material above the cone of depression. In a confined aquifer, withdrawals result in pressure reduction. The aquifer remains saturated. This basic difference in the response of the two aquifer types means that separate monitoring and management practices are needed.

released from the aquifers. In the unconfined aquifer the changes in storage took place at the water table. As water was released from the unconfined aquifer, the water table fell, and a portion of the unconfined aquifer was dewatered. In the confined aquifer the effect of removing water was to lower the pressure throughout the aquifer. The potentiometric surface declined, but the aquifer itself remained saturated. The effects of pumping are spread through pressure changes, not by dewatering, and are thus larger. This result is important for interpretation of observation well data. Water level fluctuations in confined observation wells tend to occur more rapidly and are changes much larger. A 50 foot decline in water level can be observed in many observation wells located in confined aquifers that are being seasonally pumped for irrigation or cooling purposes. Seasonal declines in unconfined aquifers seldom exceed 3 to 7 feet.

## Recharge and Discharge

Recharge is the process by which ground water is replenished. Aquifers are primarily recharged as water from melting snow or rain seeps into the ground. Discharge is the process by which ground water leaves the aquifer. Discharge occurs mainly by ground water seepage into discharge areas such as swamps, rivers and lakes and through pumping. Recharge areas are generally located in areas of topographic highs and discharge areas are located in areas of topographic lows. Ground water generally moves within an aquifer from recharge areas to discharge areas.

Figure 5 illustrates recharge and discharge areas for confined and unconfined aquifers. The unconfined aquifer, having only permeable unsaturated material above it, is recharged relatively quickly as water infiltrates into the ground. Recharge to the confined aquifer occurs primarily in the upland area where the confining layer is not present and to a lesser extent through slow downward leakage through the confining layer.

The discharge area for the unconfined aquifer is the river. The ground water discharge area for the deeper confined aquifer is not shown and may be miles away. Ground water in confined aquifers may travel hundreds of miles at a very slow rate before surfacing again in a stream. For this reason it is not uncommon for water within confined aquifers to be thousands or even millions of years old.

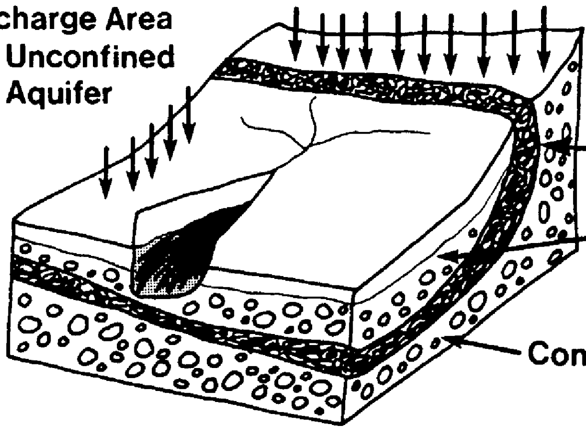



Figure 5: Schematic diagram of aquifer conditions showing recharge and discharge areas.

## Aquifer Mining

Aquifer mining occurs when more water is pumped from an aquifer than is recharged over a period of time. The resulting water level declines may create major environmental and economic consequences long before an aquifer is depleted. As the water level drops, shallower wells dry up and must be replaced with deeper, more costly wells. In extreme cases, land subsidence or collapse of the material overlying the aquifer can occur due to loss of buoyant support. Ground water flow patterns can be altered which might affect the amount of water flowing into a lake or river. This in turn might displace wildlife and hamper water recreation. Lower ground water levels also lead to reduced soil moisture within the rooting zone of many crops and reduce crop production.

# Get to Know your Aquifer

Decide whether unconfined aquifer or confined aquifer is the best answer to each question.

1. Water table aquifer is another name for?
2. Artesian aquifer is another name for?
3. Aquifer with fastest recharge rate?
4. Aquifer with largest seasonal variation in ground water levels?
5. Aquifer with oldest water?
6. Effect of pumping is larger in (assuming all else the same)?
7. Aquifer bounded at the top by a confining layer?
8. Aquifer exposed to the atmosphere through unsaturated pores in the overlying formation?

ANSWERS

1. unconfined 2. confined 3. unconfined 4. confined 5. confined 6. confined 7. confined 8. unconfined

# Principal Types of Aquifers

## Unconsolidated and Consolidated Aquifers

Aquifers can take many forms within Minnesota's diverse geology. The major aquifers are in:

- unconsolidated deposits of sand and gravel left by glaciers or post-glacial sand and gravel deposits.
- consolidated (bedrock) sedimentary formations of sandstone, limestone and dolomite.
- fractures in igneous and metamorphic bedrock formations (e.g. granite, basalt, slate and quartzite).

A well driller's search for water is really a search for one of these geologic settings. (At least in Minnesota there's a good chance that if it is present, it'll have water).

## Glacial Aquifers

Glacial aquifers consist of discontinuous lenses of fine to coarse sand and gravel that are isolated from one another by till. These sand lenses can be extensive (for example the sand plain aquifers in Anoka County) or extremely complex isolated thin layers of sands, gravels, clays and silts buried in the glacial debris (Figure 6). Yields to wells in these deposits can vary greatly over short distances.

Glacial aquifers can be confined or unconfined. Confined glacial aquifers lie below layers of silt and clay. They are "buried drift aquifers". Unconfined glacial aquifers that have a continuous layer of unsaturated porous material above a saturated sand or gravel deposit are "surficial drift aquifers". The principal difference between these aquifers is the confining layer, which results in quite different hydraulic behavior as previously discussed. Surficial drift aquifers cover about one-third of the state. Buried drift aquifers occur in nearly all areas of Minnesota except where the drift is thin or absent as in the northeast and southeast portions of Minnesota.

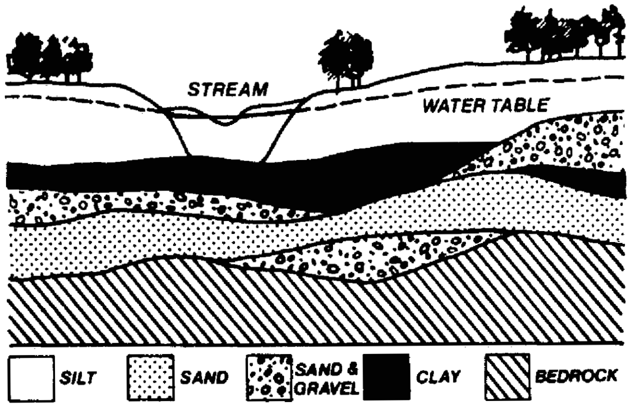



Figure 6: Aquifers in glacial deposits (after DiNovo and Jaffe, 1984).

## Bedrock Aquifers

Bedrock aquifers are categorized based on the rock material they are composed of: igneous, metamorphic, or sedimentary. Water in bedrock aquifers is typically under confined conditions but unconfined conditions exist where the bedrock intersects the ground surface or where the aquifer is directly overlain by an unconfined drift aquifer. Ground water in sedimentary rock formations can be found in pores between grains as well as in fractures and joints. Ground water movement through sedimentary rock pores does not differ significantly from flow through sands and gravels. Carbonate sedimentary rocks (limestone and dolomite) have an appreciable number of fractures and can yield large volumes of water to wells through honeycombed caves and cavities of all shapes and sizes. These fractures, which give these aquifers very high permeability, can also make the aquifer susceptible to contamination; virtually no filtering takes place within these cavities. Pollutants introduced at the ground surface can quickly enter shallow aquifers. This condition has caused aquifer contamination in shallow limestone formations in southeast Minnesota.

Minnesota's largest ground water reserves are contained in a multiple aquifer system of layers of Paleozoic age sandstone, limestone and dolomite in southeastern Minnesota (Figure 7) known as the Hollandale Embayment. These aquifers are separated by confining layers of shale and siltstone formations.

This aquifer system is of vast importance for the Twin City metropolitan area and southeastern Minnesota. The Paleozoic age aquifer in northwestern Minnesota is composed mainly of sandstone, limestone, and shale. This aquifer is generally not extensively developed due to availability of glacial drift aquifers and, in some cases, poor water quality. Another sedimentary bedrock aquifer composed of Cretaceous age sandstone, limestone and shale is found in the western half of Minnesota. This aquifer is a major source of ground water southwest of the Minnesota River.

Bedrock aquifers of igneous and metamorphic origin yield water to wells through cracks, joints, and fractures within otherwise solid rock formations. Water well construction in these aquifers is difficult and, although high yielding wells are sometimes encountered, several test holes are often necessary before getting one with even a low yield. These aquifers are found everywhere in Minnesota but are not widely used because drift or sedimentary aquifers are available and because it is difficult to find fracture zones. An exception to this is northeast Minnesota where the igneous bedrock formation is widely used since alternative aquifers are unavailable.

Major unconsolidated and bedrock aquifers are shown in Figures 8 and 9.

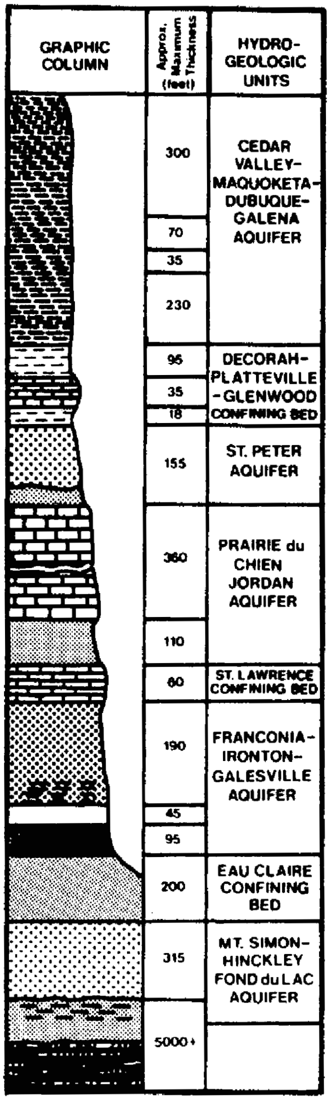
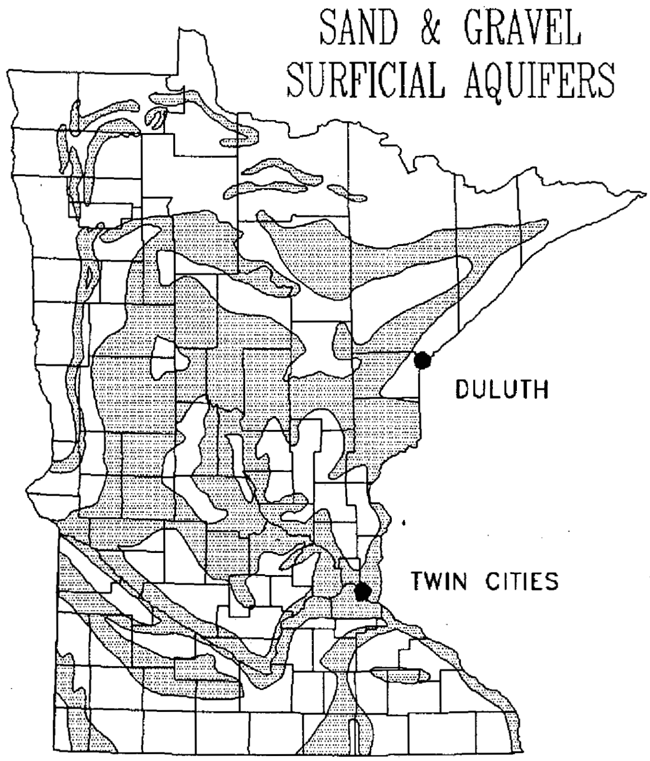
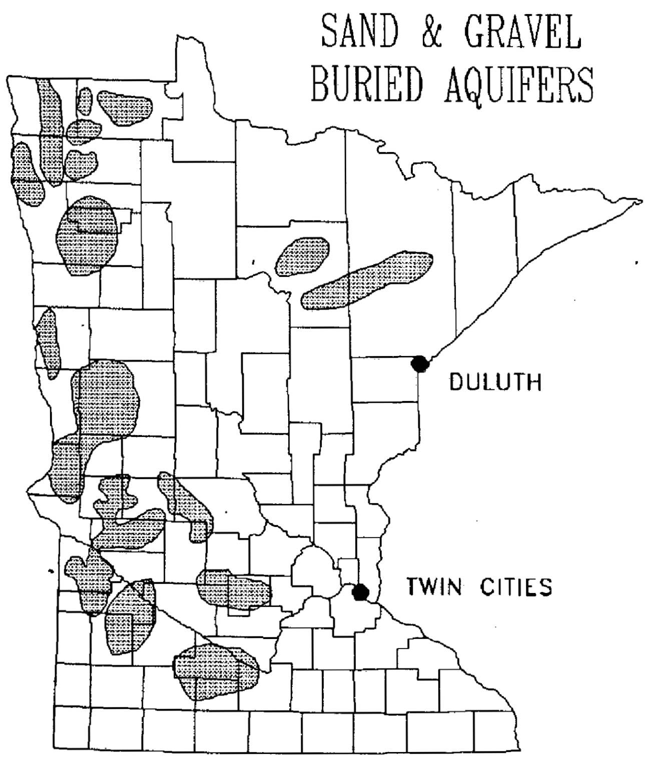



Figure 7: Hollandale Embayment: Sequence of bedrock aquifer systems and confining beds for southeastern Minnesota (revised from Delin and Woodward, 1984).

Figure 8: Unconsolidated Aquifers.



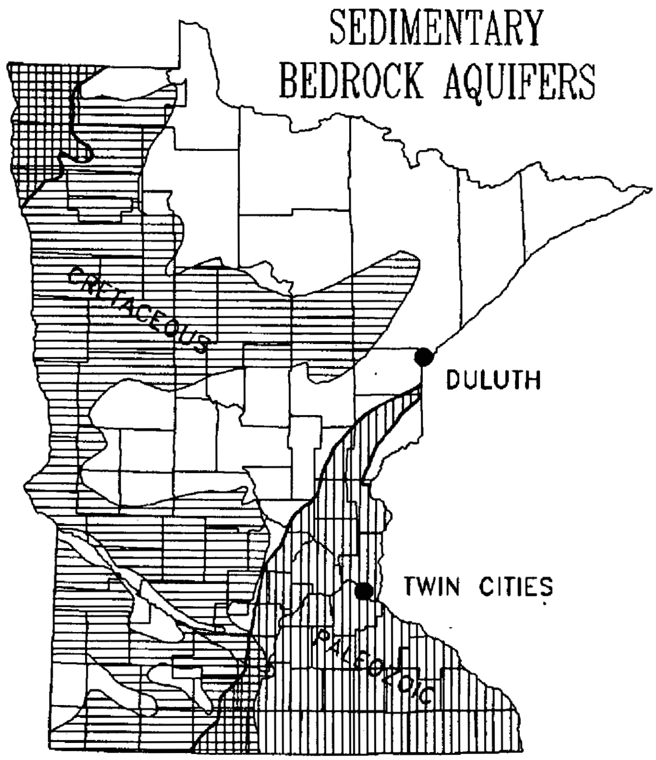

Surficial aquifers cover about one-third of the State and are comprised of glacial and post glacial sand and gravel deposits. Surficial aquifers are only slightly to moderately developed in most of the State. There is a possibility of overdevelopment in heavily irrigated areas.



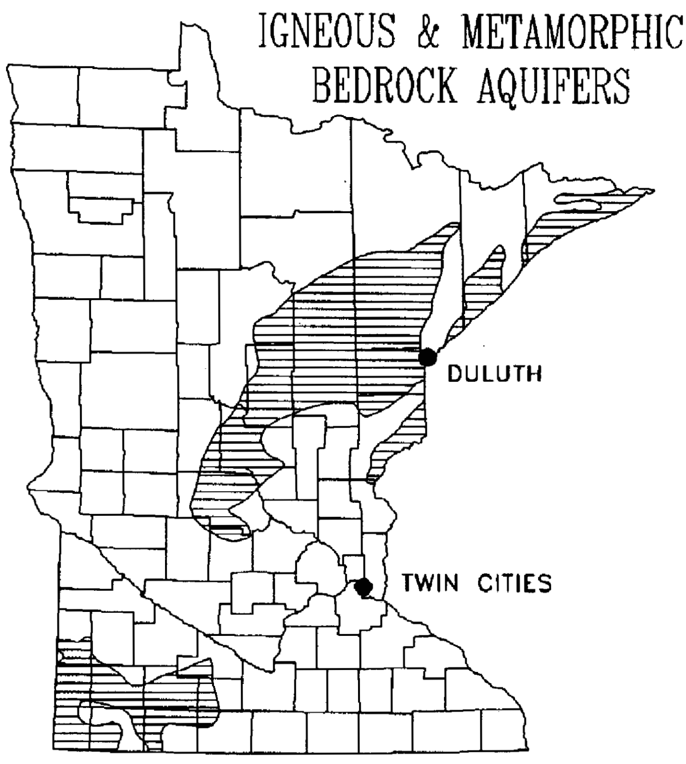

Buried sand and gravel aquifers occur in nearly all areas of the State except where glacial drift is thin or absent such as in the northeast and southeast. Buried aquifers are the major source of water in the western third of the state and are only slightly developed in other areas.

Sources: Adolphson, Ruhl, and Wolf, 1981; Kanivetisky, 1979.

Figure 9: Bedrock Aquifers.




Paleozoic sedimentary bedrock aquifers in southeastern Minnesota supply water to the Twin Cities and southeastern Minnesota. The Paleozoic sedimentary bedrock aquifer in northwestern Minnesota has great potential, but the water is generally too salty for drinking. Well yields from Cretaceous sedimentary bedrock aquifers are low.




Ground water in igneous and metamorphic rocks is found in cracks, joints and fractures within otherwise solid rock formations. This aquifer is not extensively used due to availability of other aquifers.

Sources: Adolphson, Ruhl, and Wolf, 1981; Kanivetsky, 1979.

# Ground Water Level Trends

Water level fluctuations can result from a wide variety of hydrologic phenomena, some natural and some induced by man. Good management practices demand adequate information on how much water is in storage and how this volume varies with time. The amount of ground water in storage is obtained by periodic measurements of the depth to water from some reference point and keeping track of these measurements over time. Rising water levels in the well means that more water is in storage and vice versa.

As stated earlier, a plot of ground water levels through time is called a hydrograph. Two types of trends are seen in hydrographs: seasonal trends and long term trends. Seasonal trends produce a cyclic pattern in a hydrograph. Long term trends occur when the yearly average recharge or discharge deviates from the norm for a prolonged period of time. By studying a hydrograph, water resource managers can monitor the impact of droughts or ground water pumping and determine the best management strategy for maintaining ground water supplies for both present and future users.

This section presents several hydrographs that illustrate:

- seasonal trends affected by climate.
- seasonal trends affected by pumping.
- multiple layer aquifer water level comparison.
- long term trends affected by climate.
- long term trends affected by pumping.

Trends are viewed for both unconfined and confined aquifers. Observation wells were selected from various parts of the state and ground water level comparisons are made for each aquifer type; surficial, buried drift, and bedrock.

## Seasonal Effects on Water Levels

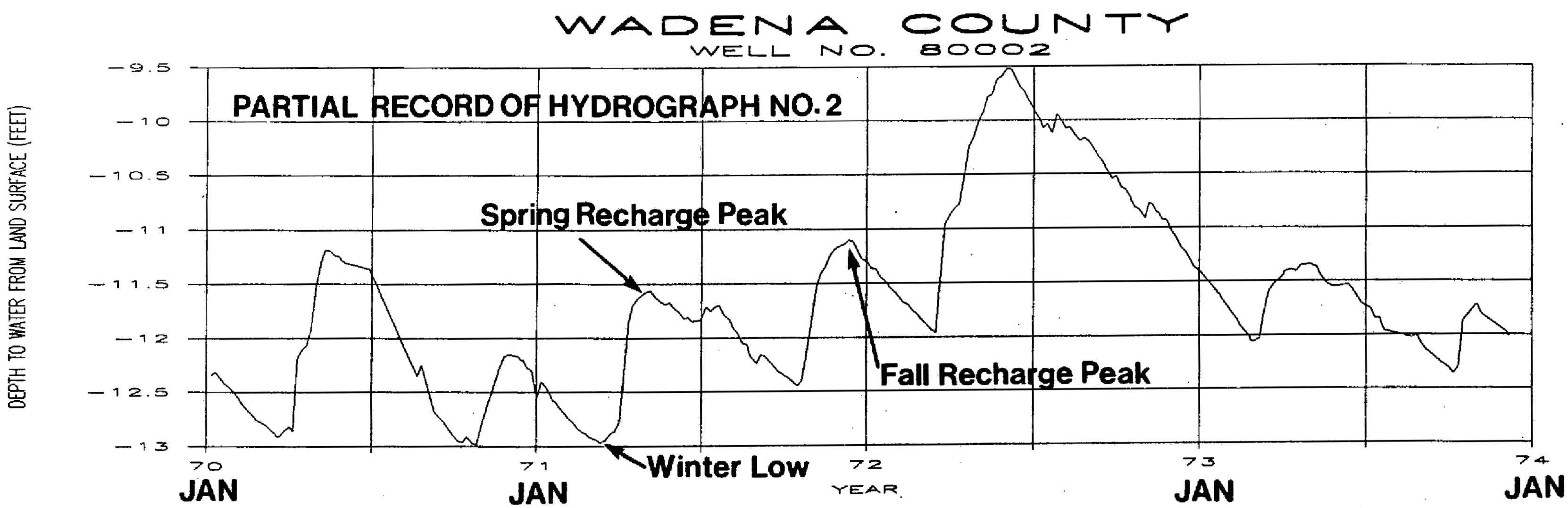
Seasonal water level trends over a three year period are illustrated on Hydrograph #1 for a surficial drift aquifer in Wadena County. The seasonal trends expanded for illustration purposes on Hydrograph #1 can be observed over the entire period of record in Hydrograph #2. Ground water levels are generally at their highest in early spring when little evaporation from the soil and little or no transpiration from plants occurs. The generally ample amounts of rainfall and surface water are, thus, available for ground water replenishment. Note that nearly all ground water recharge takes place during spring.

In summer, when evapotranspiration is at its peak, most rainstorms do not contribute at all to ground water. Levels decline as ground water is lost to plants and to streams, springs, and other discharge areas. The effects of heavy and prolonged summer rainstorms can be observed on the hydrographs as sporadic rises or as a reduction in the rate of water level decline. Ground water levels decline during summer even in years of average precipitation (Baker, Nelson, and Kuehnast, 1979).

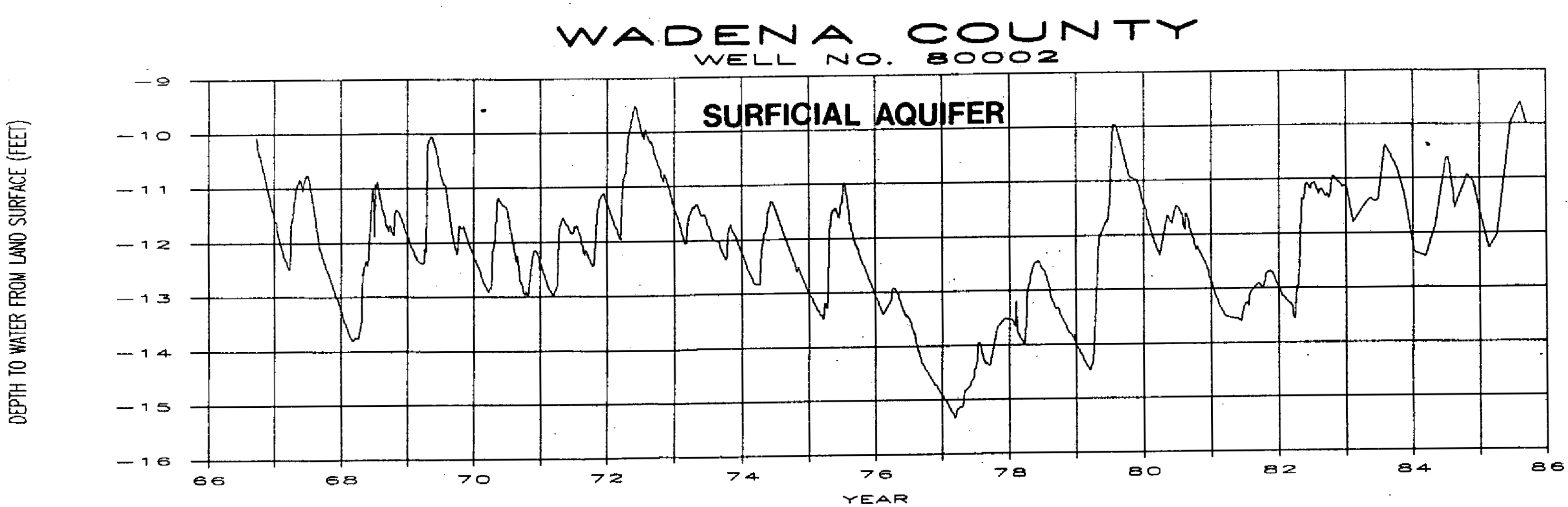
In fall, with the return of cool weather and the dormant period for vegetation, rainfall is no longer lost to evapotranspiration and is available for soil moisture replenishment. Rainfall entering the soil must first recharge unsaturated soil which was depleted during the summer. Ordinarily, little water is left to percolate into ground water and the fall hydrograph will show either declining water levels or a small recharge period. At Wadena there are about as many years with small fall recharge as with no fall recharge. As a rule, fall recharge is less than spring recharge.

During winter, water levels decline as ground water is discharged into streams and lakes but is not recharged due to frozen ground. Lowest water levels commonly occur just before spring thaw.

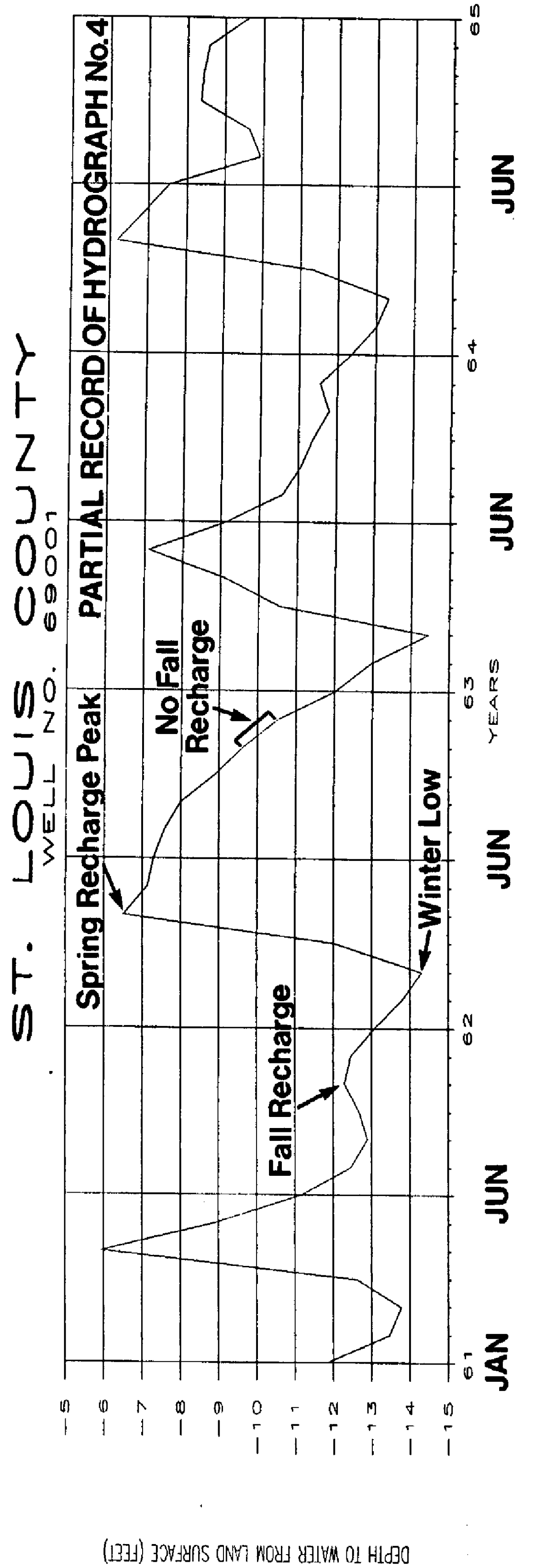
Hydrographs #3 and #4 illustrate seasonal water level patterns for a confined buried drift aquifer in St. Louis County. The seasonal pattern illustrated on these hydrographs is similar to Hydrographs #1 and #2. The St. Louis County well is screened in sand at a depth of 40 feet below the land surface and the aquifer is overlain by a 20 foot clay layer. Apparently, the confining clay layer is quite "leaky" and, thus, recharge is quite rapid. Buried wells at greater depth with a tight clay layer do not show a distinct seasonal climatic pattern.



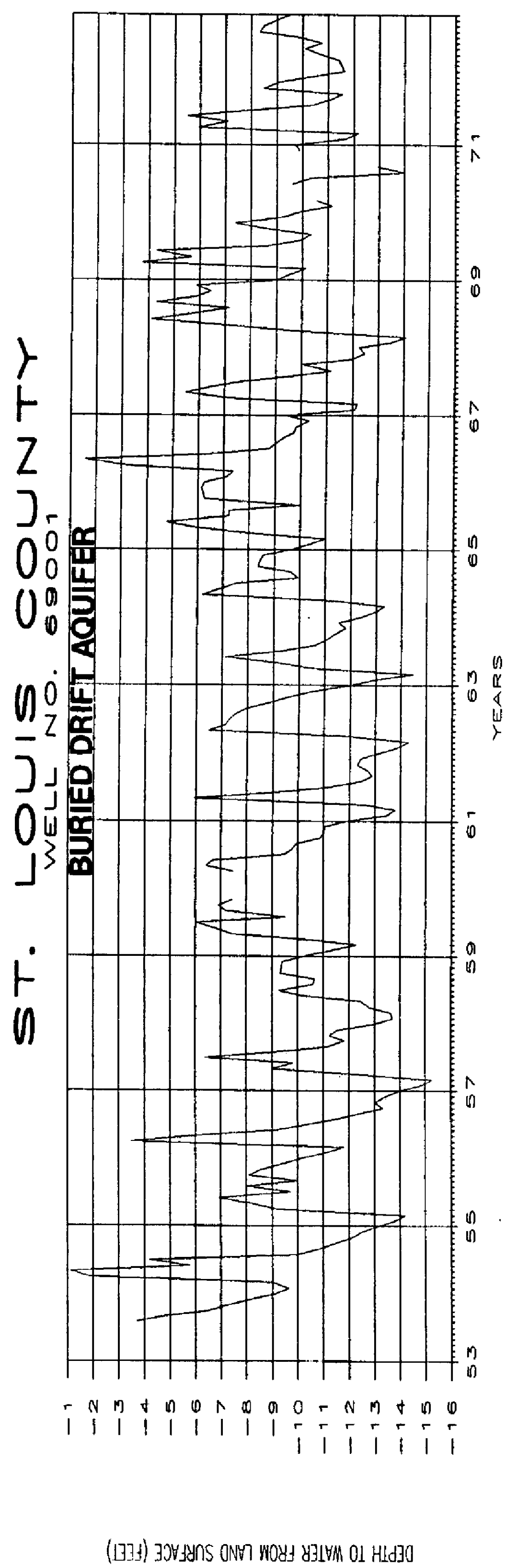

Hydrograph No. 1



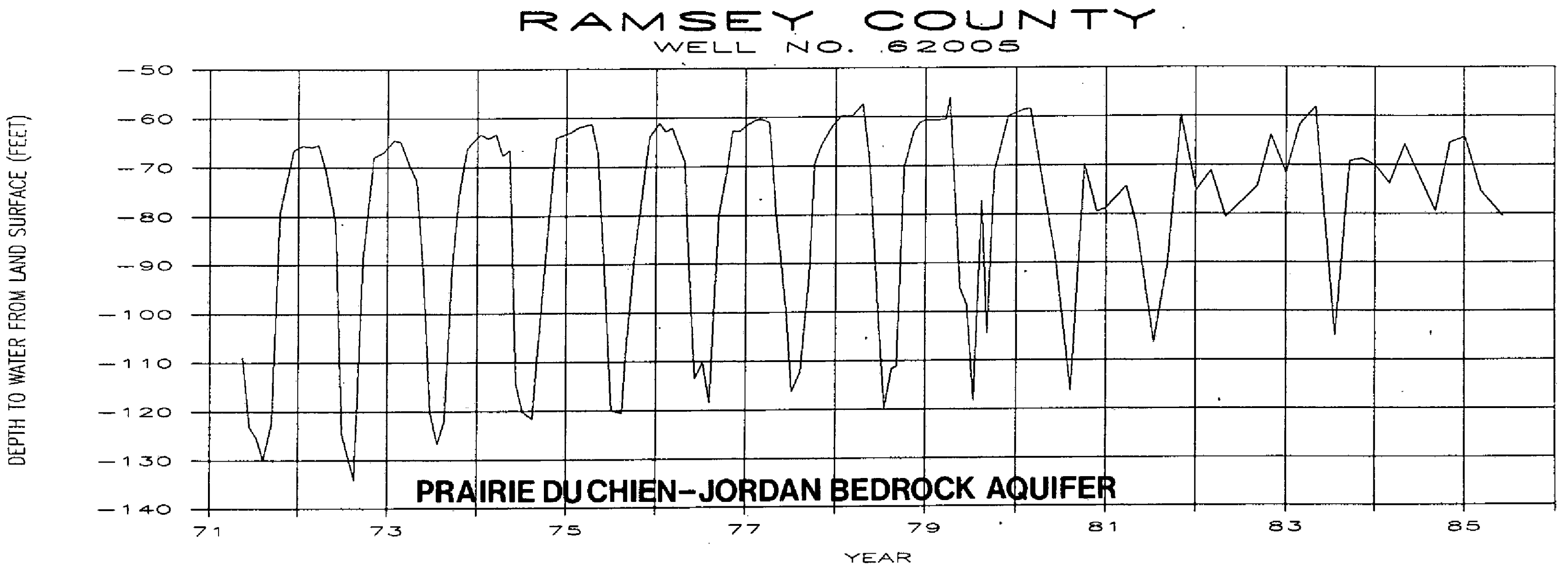

Hydrograph No. 2



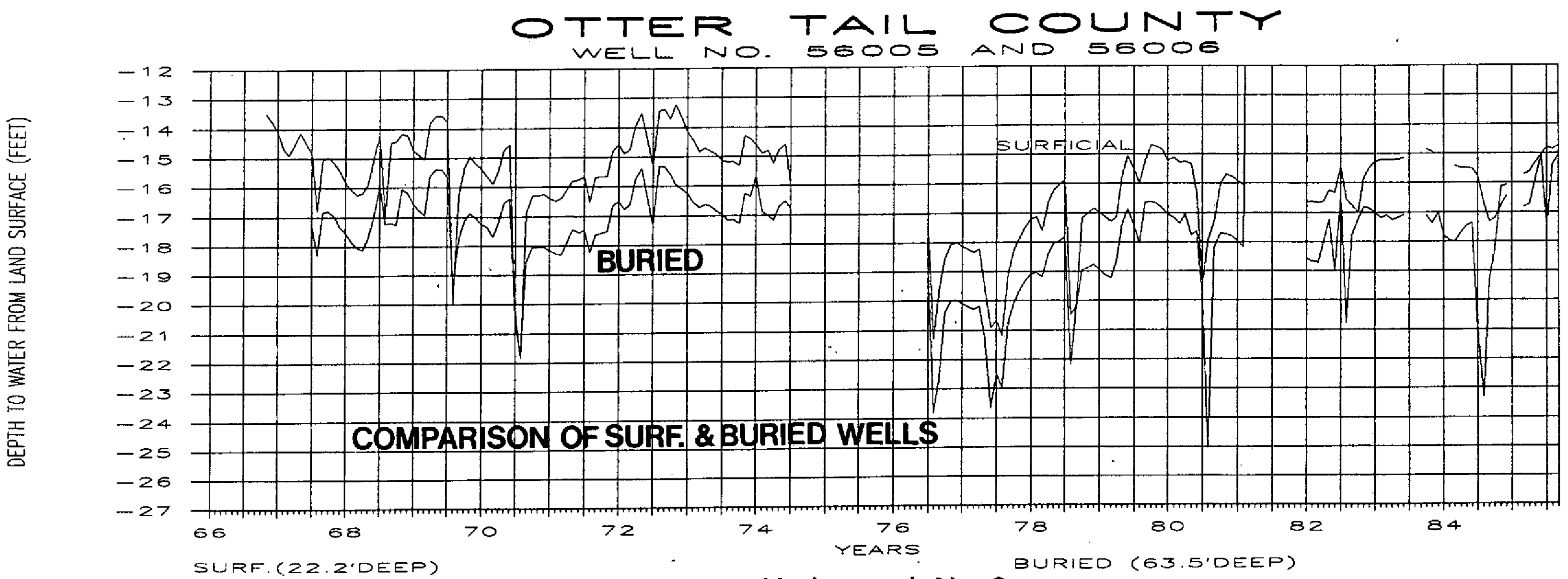

Hydrograph No. 3




Hydrograph No. 4




Hydrograph No. 5



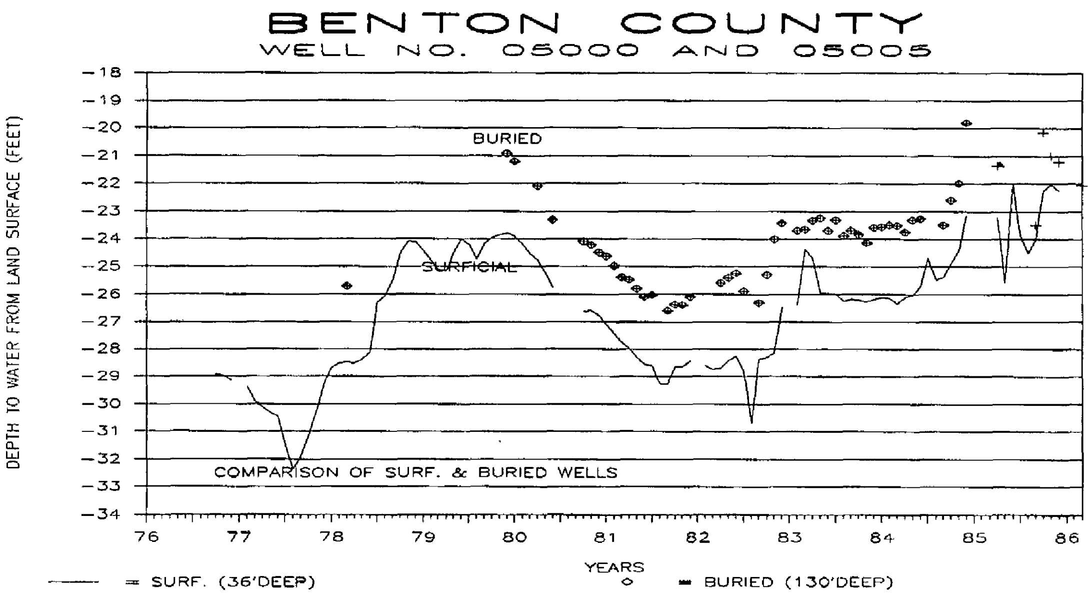

Hydrograph No. 6

## Effect of Seasonal Pumping

The effects of pumping on ground water levels are illustrated in Hydrograph #5 and #6. Hydrograph #5 shows the water level for a bedrock observation well in Ramsey County. Hydrograph #6 compares water levels for a surficial and a buried observation well located in the same quarter section in Otter Tail County. Water levels in each of these wells are lowered by large summer water appropriations for either irrigation or cooling purposes. Lowest levels are reached in late summer. This is in contrast to nonpumping wells where lowest levels occur in late winter. Water levels begin to recover after the irrigation and air conditioning season and generally return to seasonal levels by midfall.

## Comparing Water Levels in Upper and Lower Aquifers

The similar water level fluctuations of the two aquifers shown on Hydrograph #6 are interesting. The buried drift well, screened 40 feet below the surficial drift well, is separated from the surficial drift well by thin (possibly discontinuous) clay layers. The parallel fluctuations of these aquifer water levels indicate that these aquifers are in hydraulic communication, that is, the water level in one aquifer can affect the level of the other aquifer. For example, water withdrawn for irrigation from the buried



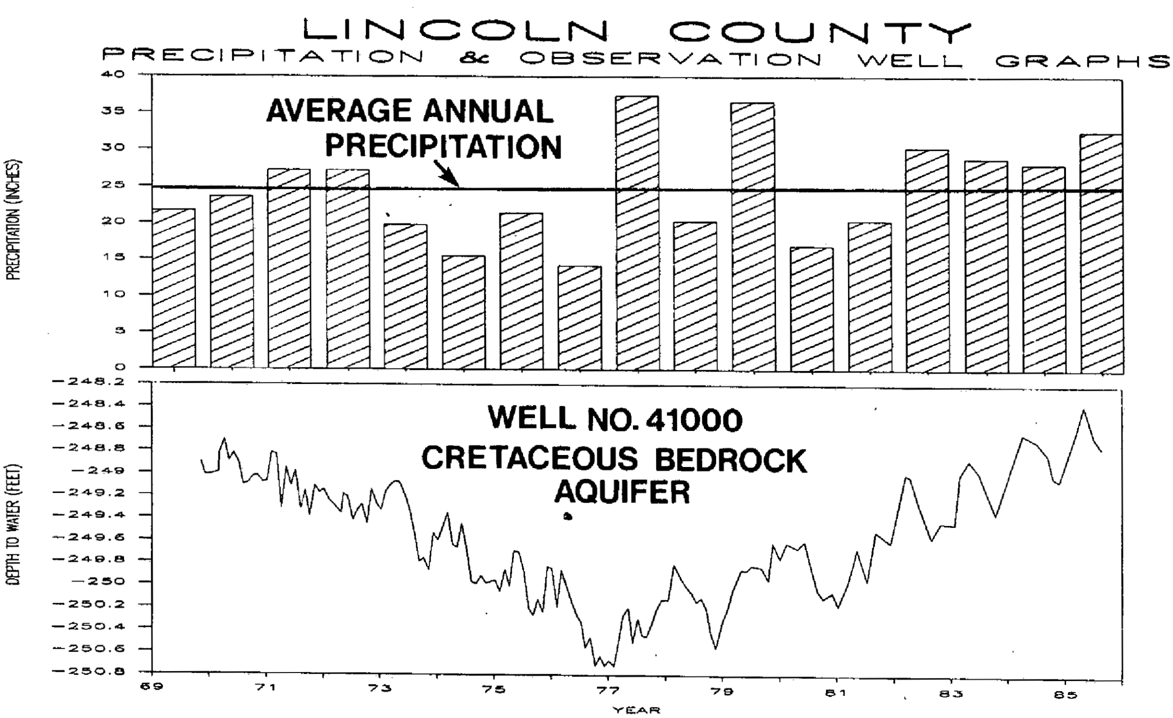

Hydrograph No. 7

aquifer may draw upon the water supply of a shallow aquifer and affect the ability of the shallow well to supply water, perhaps to domestic wells.

Observation wells installed in groups can also be used to show the direction of ground water flow. The flow in Hydrograph #6 is from the higher surficial aquifer to the lower buried aquifer. In contrast, Hydrograph #7 shows that the vertical ground water movement is upward; that is, from the deeper buried aquifer to the shallower surficial aquifer. This is not illogical if one recalls that water always flows downhill, which in this case means from higher water levels to lower water levels.

## Long Term Trends - Effect of Prolonged Climatic Changes

Prolonged climatic changes mean sustained periods of departure from "normal" precipitation amounts, for example droughts or successive wet years. These precipitation trends, when severe and lengthy, leave noticeable effects on ground water levels. Well Hydrographs #8-10 illustrate long term trends due to prolonged periods of drought or excessive precipitation.



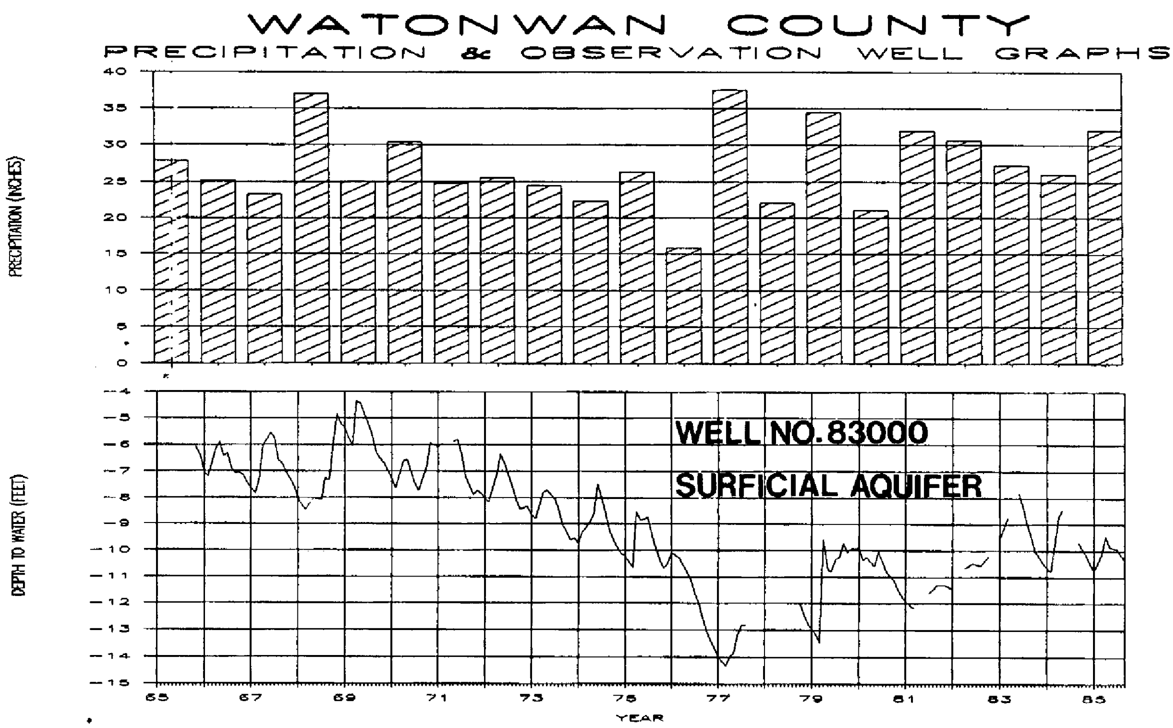

Hydrograph No. 8

A plot of annual precipitation from a gage located near the well can be viewed directly above each hydrograph.

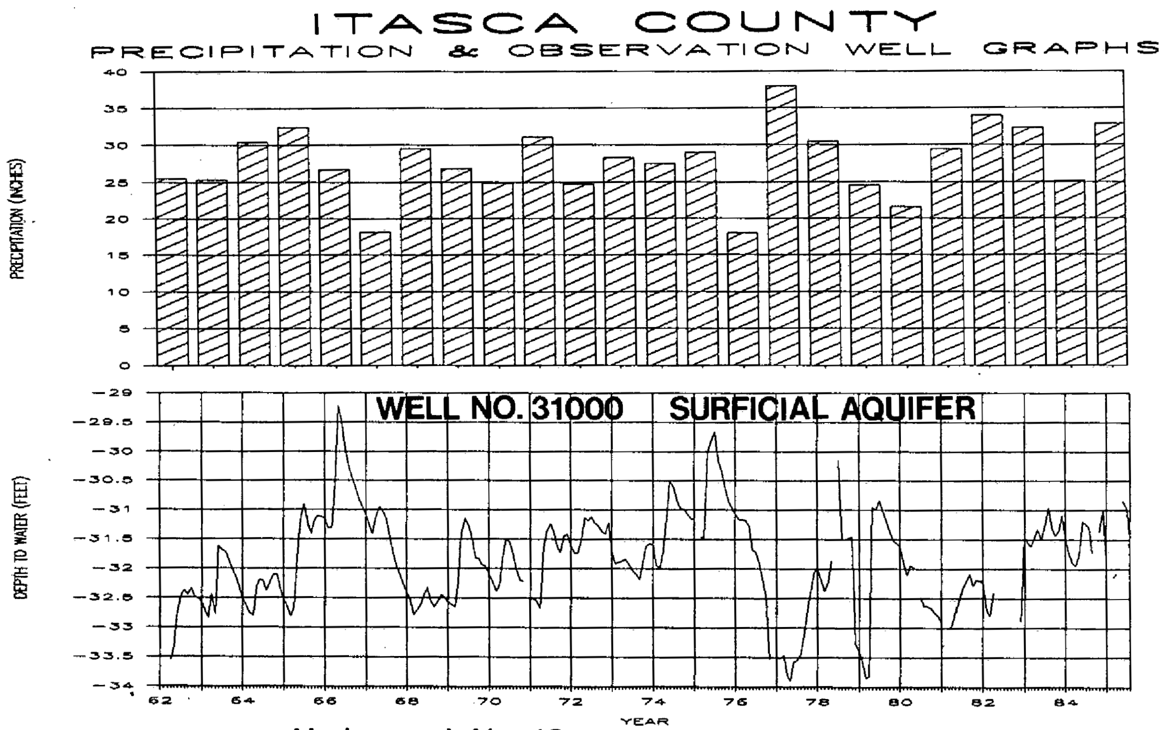
Hydrograph #8, a confined bedrock aquifer in Lincoln County, shows two very distinguishable trends. The decline in water levels between 1969 and 1977 is marked by 8 consecutive years when annual precipitation was generally below the normal 25 inches and averaged only 21 inches. The nine following years averaged 28 inches and water levels, at present, are highest on record for this well.

Hydrograph #9 is a surficial aquifer well also located in Watonwan County and shows similar trends. This trend is noted for several other wells in southwestern Minnesota. Another prevalent trend is that lowest water levels in these wells occurred around March of 1977 prior to the spring thaw. This of course is correlated with the severe drought which occurred in 1976-77. A second, less severe drought shows up in 1980.

Representative ground water levels in north central Minnesota can be viewed on Hydrograph #10 from a well in Itasca County. This graph shows a rise in water levels during the early 1970's in contrast to the decline in parts of southwestern Minnesota. Water levels in other parts of the state are level or rise slightly during




Hydrograph No. 9



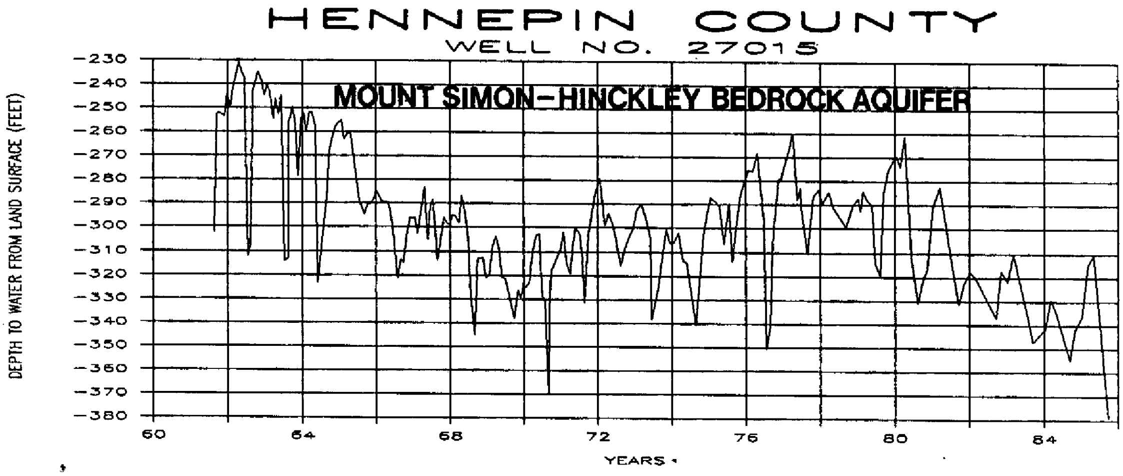

Hydrograph No. 10

this period. The 1976 drought and the smaller drought of 1980 make their mark on this graph as well. A final similarity are generally increased water levels since the 1976 drought. These last three trends are visible in nearly in every well in the state that is not near a pumping well. Present ground water levels statewide are among the highest recorded.

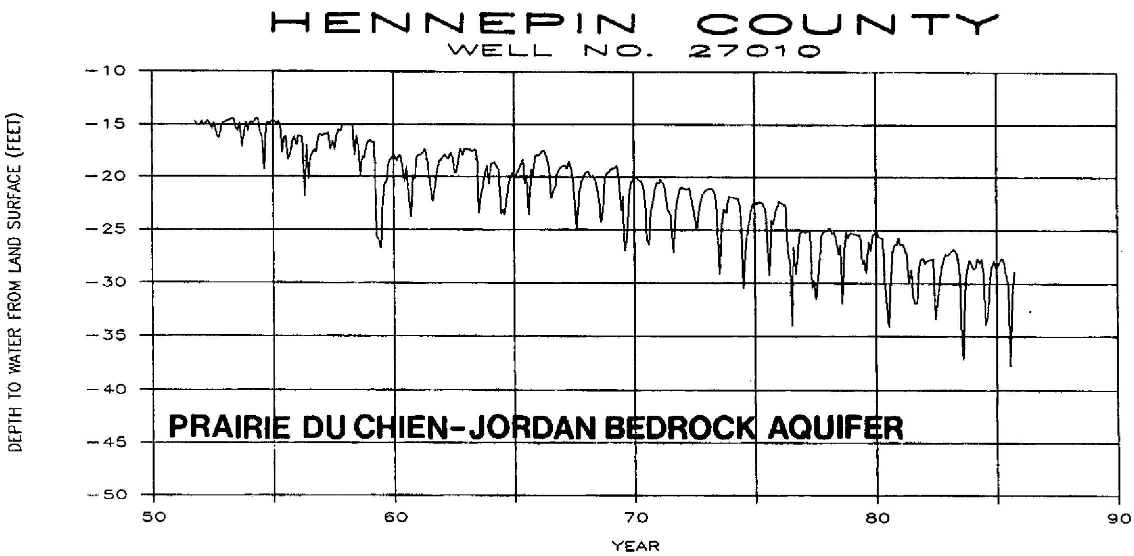
## Long Term Trends - Effect of Pumping

Hydrograph #11 for a Hennepin County well has interesting long-term trends which are largely associated with pumping. This hydrograph shows ground water levels for a well in the Mount Simon-Hinckley Aquifer near Minneapolis. The water level declined slowly until 1970. From 1970 to 1980 a general water level rise is observed. This trend has been attributed to a decrease in pumping from the Mount Simon-Hinckley aquifer in the metropolitan area during that period (Schoenberg, 1984).

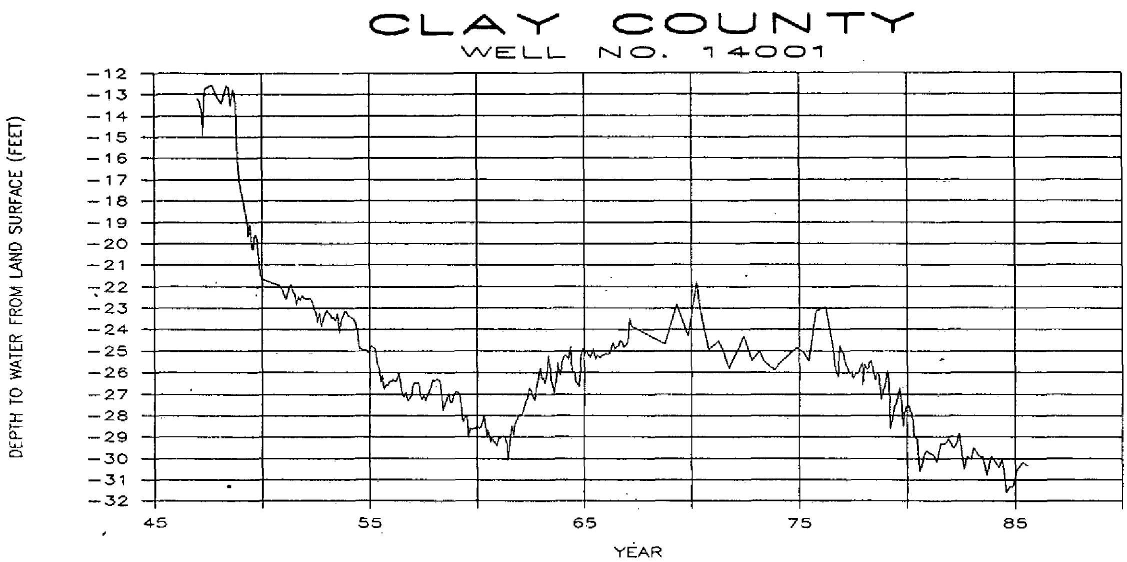
Water levels in Minnesota's most heavily used aquifer, the Prairie du Chien-Jordan, were reported by Schoenberg to be fairly stable for a period between 1971 and 1980 due to relatively constant pumpage withdrawals. However, local ground water declines have occurred in areas where pumping is concentrated. Hydrograph #12 shows a decline in water levels since 1950 for a




Hydrograph No. 11




Hydrograph No. 12




Hydrograph No. 13

Prairie du Chien well located in central Hennepin County. This decline is probably due to increased pumpage from this aquifer in the vicinity of the well (Schoenberg, 1984). Overall, since 1880, withdrawals have caused declines in ground water levels in the Mount Simon-Hinckley and Prairie du Chien-Jordan aquifers of 200 and 90 feet, respectively, in the Twin Cities area. These two aquifers supply about 80% of the ground water in the Twin Cities. Future ground water allocation problems, related to lower water levels, will only be avoided by careful resource management.

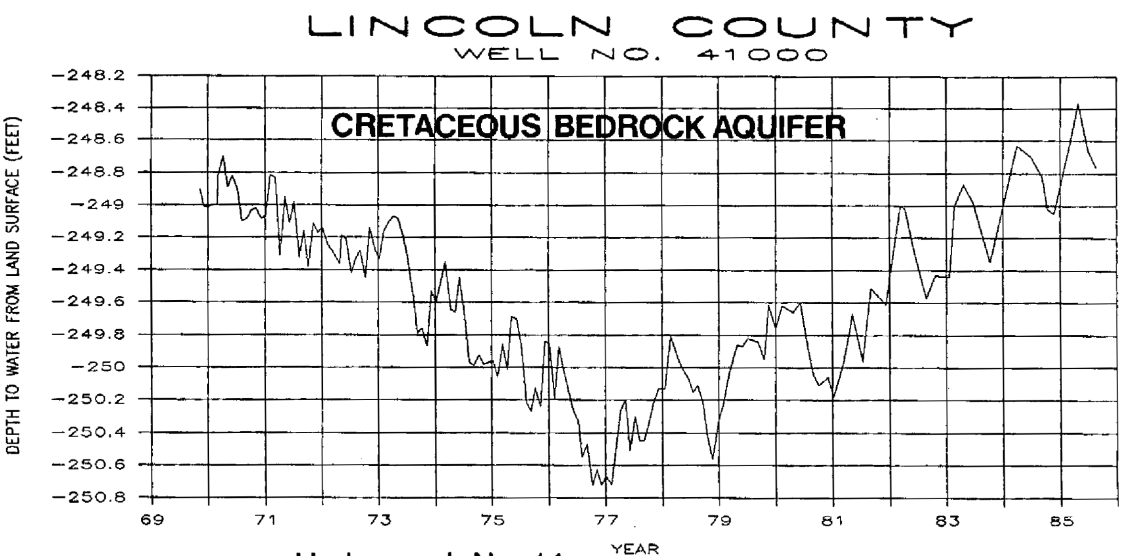
Declining water levels due to pumping are not limited to the Twin Cities area. Hydrograph #13 shows ground water levels for a well in the Buffalo aquifer near Moorhead. Water levels dropped steadily from the first record in 1947 to 1962. Starting in 1962, levels increased and remained relatively stable from 1963 to 1978. Since 1978, levels have been dropping once again. These historic water level trends follow the ground water use patterns of the City of Moorhead. In the late 1940's, the City began pumping water from the Buffalo aquifer to meet their growing water supply needs. In the early 1960's, concern over declining levels and future needs prompted the City to draw water from a nearby surface water supply, the Red River of the North, as their primary source of water. In 1978, the City began a new management scheme that combined surface and ground water appropriation and ground water levels began to drop once again. These declining levels are not limited to this well but can be observed in several wells in this thin aquifer along the Buffalo River.

# AIDS TO INTERPRETING HYDROGRAPHS

Hydrographs 14-17 demonstrate some practical aspects of ground water hydrograph interpretation. There are two steps: 1) observing a trend, abnormality or point of interest and 2) answering why this trend occurred. Erroneous conclusions can result from misinterpretation of ground water hydrographs. Five features of hydrographs will be briefly described here. Proper understanding of these features will decrease the chance of misinterpretation.

## Scale

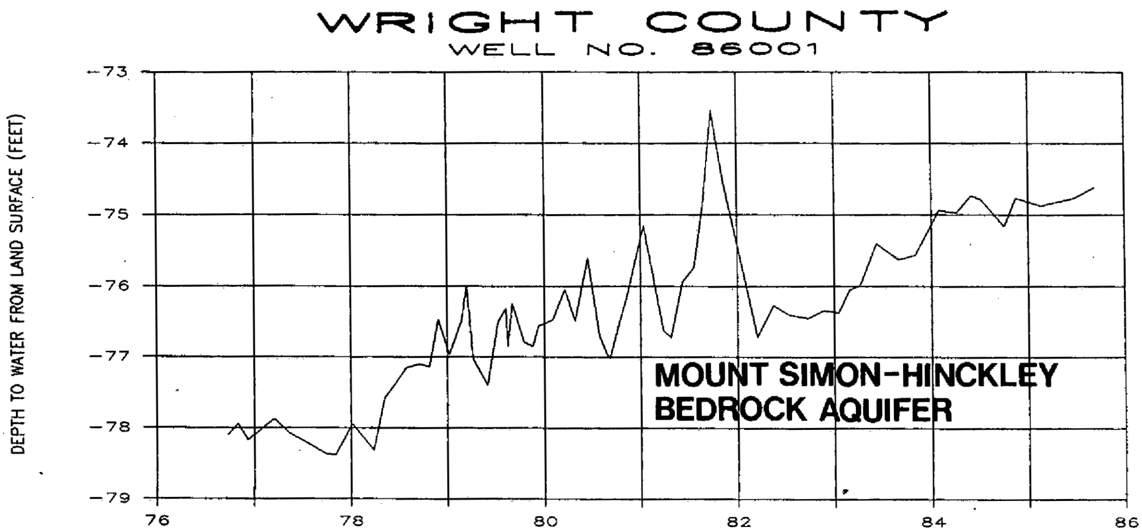
Hydrograph 14 shows how scale can be very misleading. The long drawdown for the first half of this record is quite alarming. But if you'll look again you'll note the maximum difference is 2.5 feet. Not so bad after all! Despite its small amplitude, this trend has resulted from prolonged variation in climate as noted earlier.



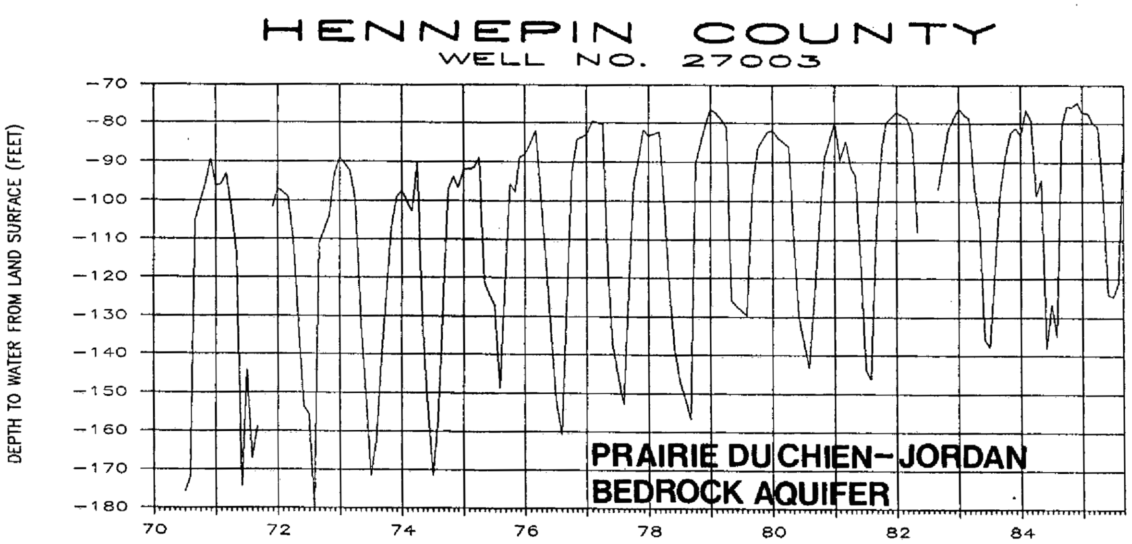

Hydrograph No. 14

# Period of Record

When you are asked to consider the period of record, what we are really concerned with is having the whole picture. Drawing a conclusion from too short a period may lead to an erroneous conclusion. From the rise in water levels for hydrograph #15 it may appear that water levels in Wright County are high and climbing. However, other graphs have shown that this rise is probably recovery from the very low levels that occurred in 1976 and that current levels are probably near normal.




Hydrograph No. 15



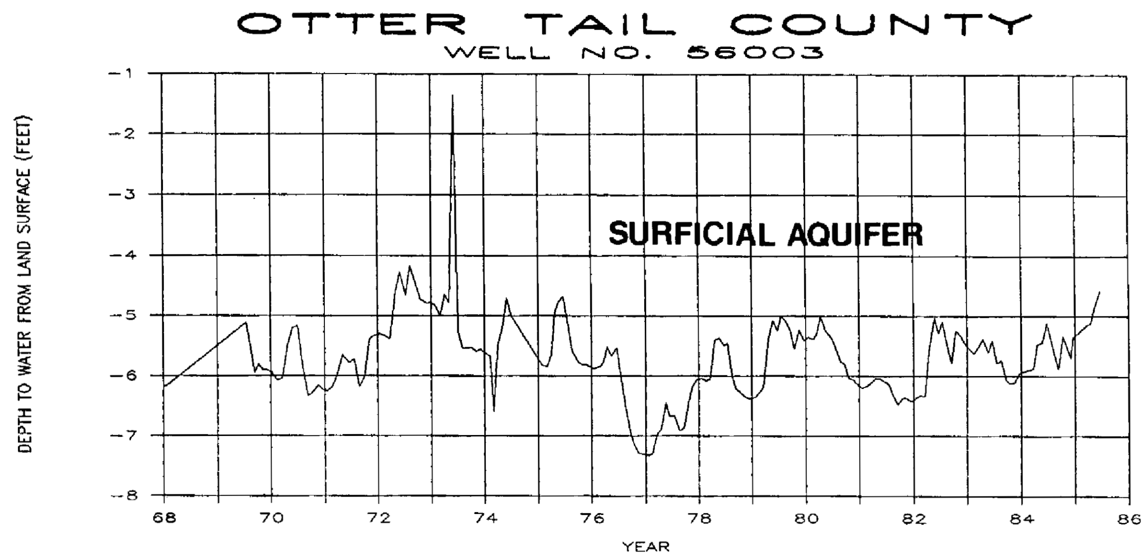

Hydrograph No. 16

# Hydrogeologic Considerations

Interpretation of ground water data must be appropriate for the given aquifer. Consideration must be given to the aquifer condition (confined or unconfined), recharge rate, size, storage, and permeability. The 80 foot seasonal drawdown for the confined bedrock aquifer shown in hydrograph #16 is replenished annually. The aquifer in the vicinity of the observation well is not being mined. An 80 foot drawdown in an unconfined aquifer (if the unconfined aquifer had the thickness to sustain such a large drawdown) would certainly mean that the aquifer is being mined.

# Regional Ground Water Review

Hydrograph #16 also shows the importance of comparing observation well data with other observation well data. This well shows a general rise in water levels. Other Hennepin County observation wells in this same Prairie du Chien aquifer have shown declining or stable water levels (see hydrograph #12 and the top hydrograph on page 46). This variation in ground water levels within an aquifer not only demonstrates the need for regional observation well analysis but also that several observation wells may be necessary to depict water levels within an aquifer.




Hydrograph No. 17

## Errors or Questionable Data

Errors in observation well data that go unnoticed while data are being gathered and entered into the observation well network glaringly come to surface when plotted on a hydrograph. Such is the case for the water level spike in hydrograph #17. Such data spikes are considered "questionable data". When we see questionable data, we check available water level records and precipitation files to determine the origin of the abnormal or questionable water level. If a source of error is not located, the data in question remain in the network. The user must determine if these data are valid.

# State Ground Water Overview

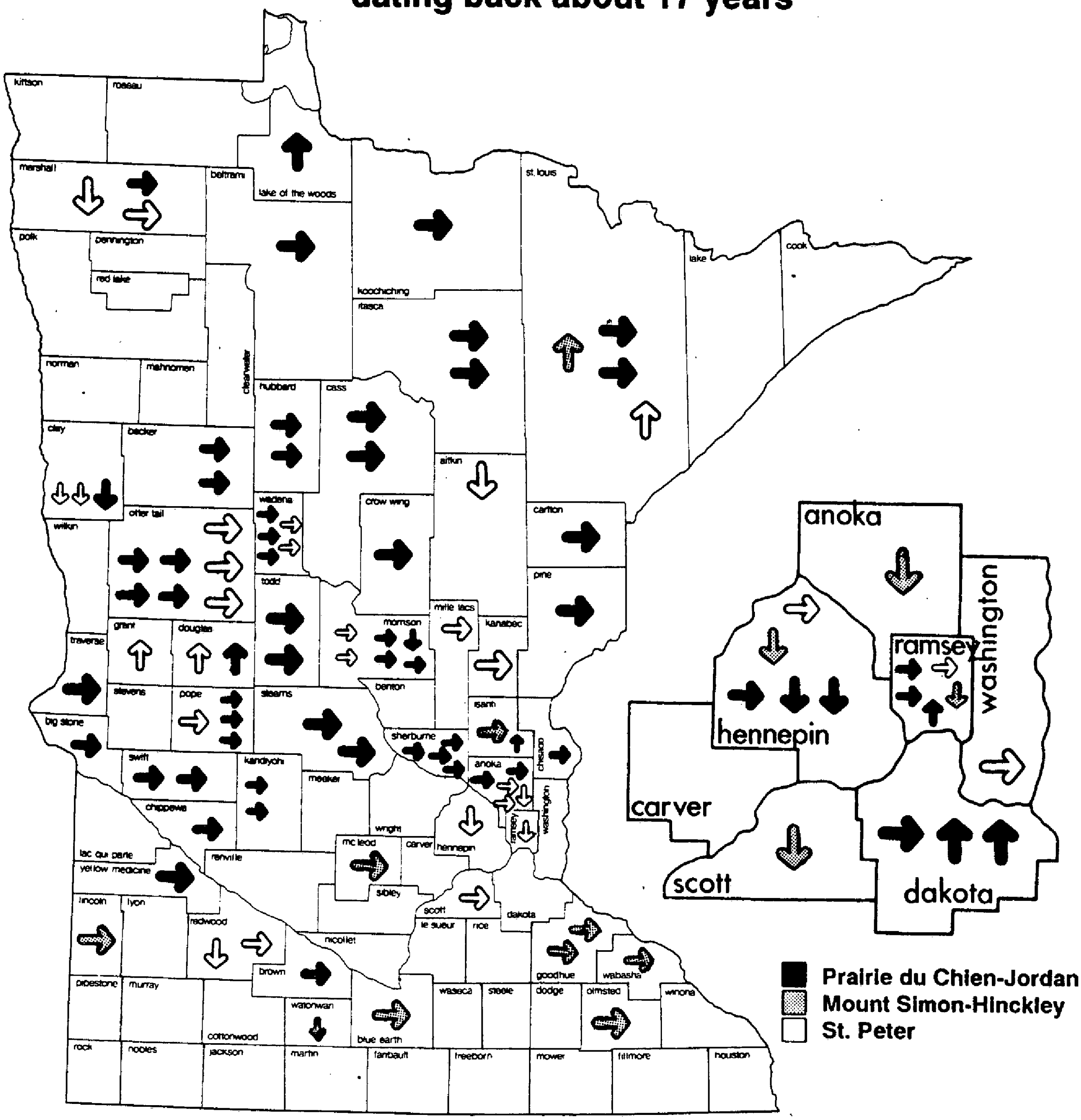
The previous section emphasized that hydrographs do not stand alone. When interpreting trends in ground water hydrographs, these levels must be compared with other hydrogeological data and regional ground water levels. Figure 10 summarizes the long term average ground water level trends for observation wells having a record period dating back to the early 1970's. The early 1970's were chosen as a base period for evaluation since very few wells have water level records predating the 1970's. For the most part, these graphs show that ground water levels have remained relatively stable across the state. Many of the downward trending levels were affected by pumping and may not reflect regional ground water trends of the aquifer. Downward trending wells typically are found in buried drift aquifers in western Minnesota and in bedrock aquifers in the Twin City area. Upward trends do not occur frequently. Water levels in September 1988 in many places were among the lowest recorded.

Ground water levels were considered "level" if levels in the early 1970's were similar to present levels. Common trends noted on almost all graphs are:

- Highest ground water levels typically occurred in 1985 - 86. These record water levels resulted from nearly a decade of above normal precipitation. In the fall of 1986, the heavy rains stopped and the water table levels began to decline. Extreme high ground water levels also occurred in 1972, 1975, and 1979. These peak levels typically followed large rainfall events or unseasonably wet springs and/or summers.
- As of September 1988 record low water levels were being recorded in the southern 2/3 of the State. Ground water levels in the southern 2/3 of the State were typically 2 - 5 feet below seasonal average. The central portion of the State was most severely affected by the drought. Water table levels commonly were 5 feet below seasonal average. These levels are typically 8 feet below

# FIGURE 10. GROUND WATER TREND SUMMARY

## For observation wells with record periods dating back about 17 years




*Bedrock Aquifers
Surficial Aquifer Trends
Buried Glacial Aquifer Trends

*Bedrock Aquifers in 7 County Metro Area NOT INCLUDED

Upward Trends
Generally Level
Downward Trend

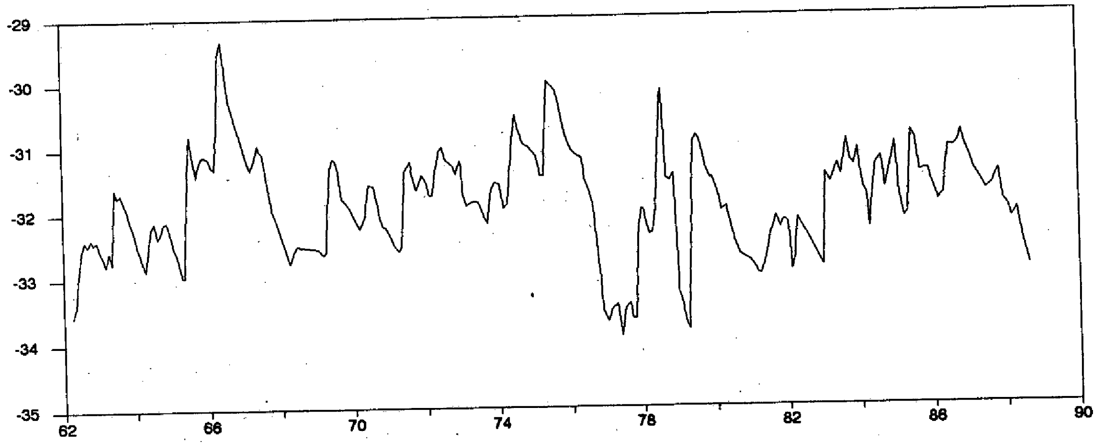
the recorded high levels in 1986 and 1 - 2 feet below previous record lows. These record low ground water levels result from a two year drought which began in the fall of 1986. Only the northeastern and north central regions of Minnesota were not severely affected by this drought. Levels in these regions remained near seasonal average due to more normal precipitation. Extremely low ground water levels also occurred in 1977 resulting from a statewide drought in 1976 - 1977. A drought of lesser severity occurred in 1980.

- Aquifers that are heavily pumped, such as the Prairie du Chien and Mount Simon - Hinckley bedrock aquifers in the Twin Cities area do not generally reflect climatic trends. These aquifers typically dropped to record seasonal lows in 1988 due to large ground water use for irrigation and air conditioning purposes.

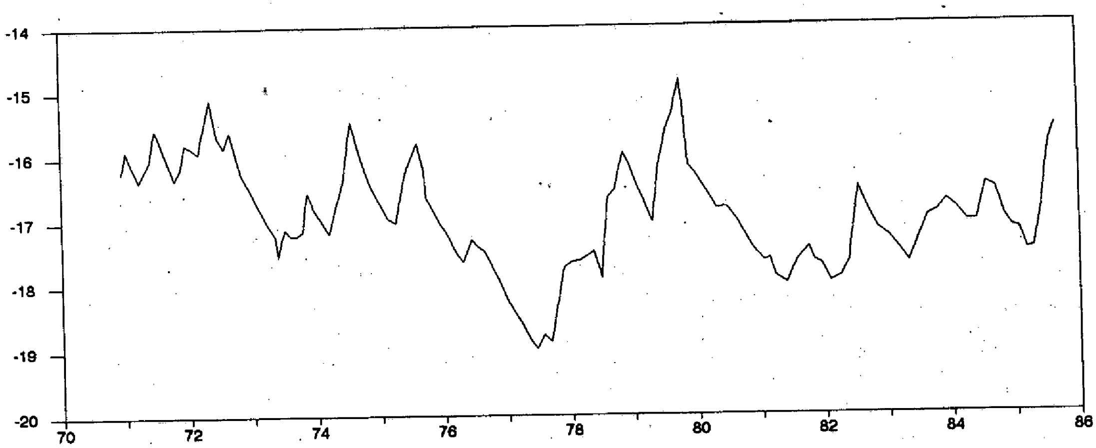
Many of the ground water hydrographs used to summarize the long term ground water trends on this map are included in this section. They are presented to show a regional review of ground water levels for each aquifer type: surficial, buried drift, and bedrock aquifers. Hydrographs for observation wells not shown here may be obtained by writing to the address printed on the title page. The breakdown of hydrographs shown is as follows:

- 10 hydrographs that typify ground water levels in surficial aquifers.
- 4 hydrographs that show abnormal ground water trends (trends that differed significantly from regional trends) in surficial aquifers.
- 10 hydrographs that typify ground water levels in buried drift aquifers.
- 5 hydrographs that show abnormal ground water trends in buried drift aquifers.
- 5 hydrographs showing ground water levels in the Prairie du Chien - Jordan and the Mount Simon - Hinckley aquifers.
- 5 hydrographs showing ground water levels in other bedrock aquifers.
- 5 hydrographs that show abnormal ground water levels in bedrock aquifers.

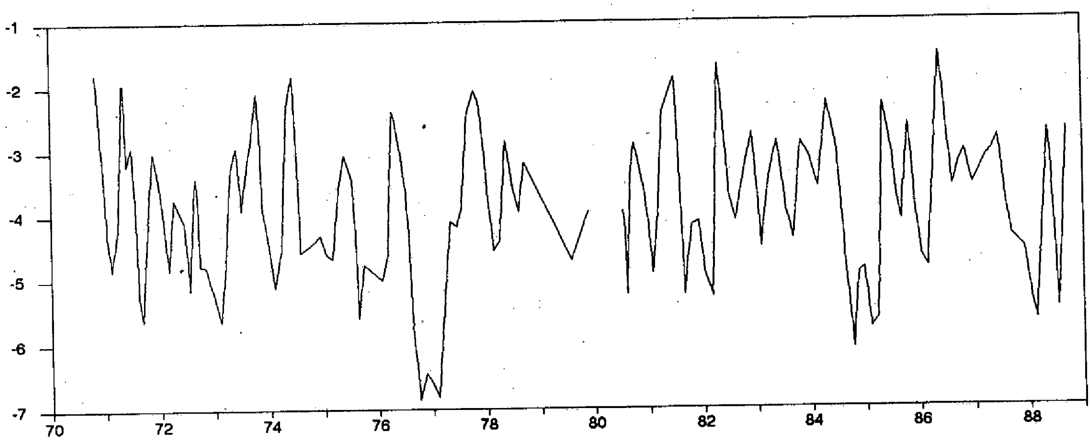
ITASCA COUNTY WELL# 31000




KOOCHICHING COUNTY WELL# 36000

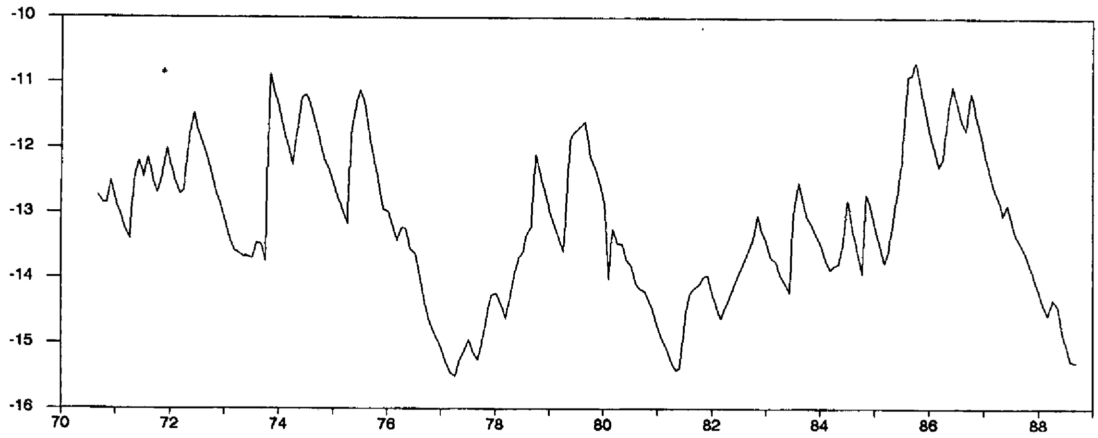



ST. LOUIS COUNTY WELL# 69002

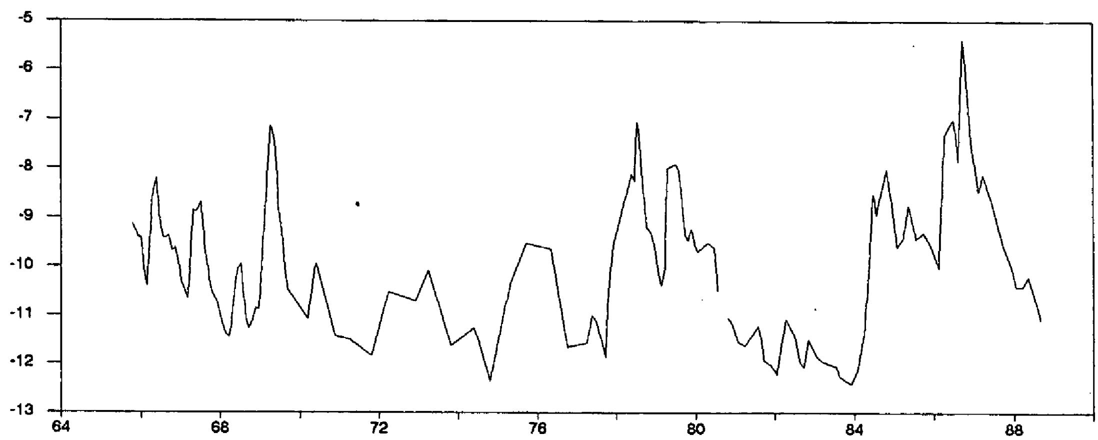



# Regional Ground Water Levels in Surficial Aquifers

HUBBARD COUNTY WELL# 29000




TRAVERSE COUNTY WELL# 78000

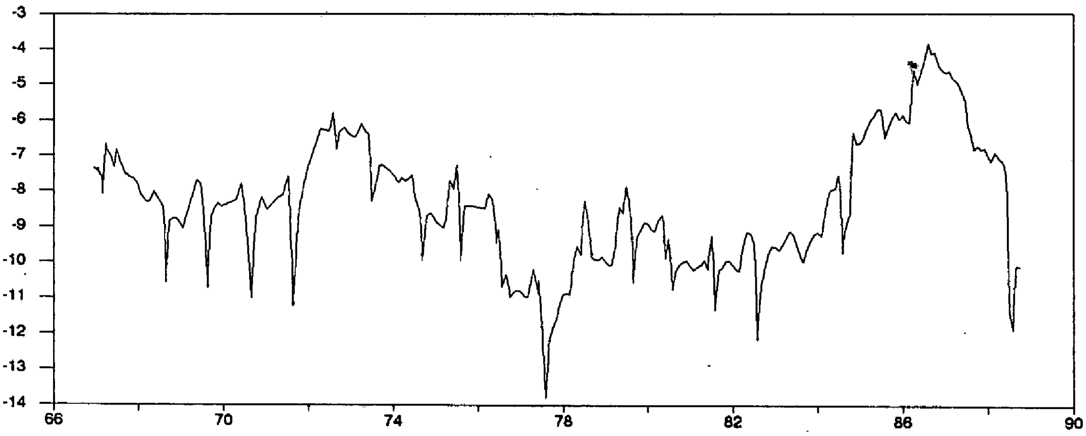



# Regional Ground Water Levels in Surficial Aquifers

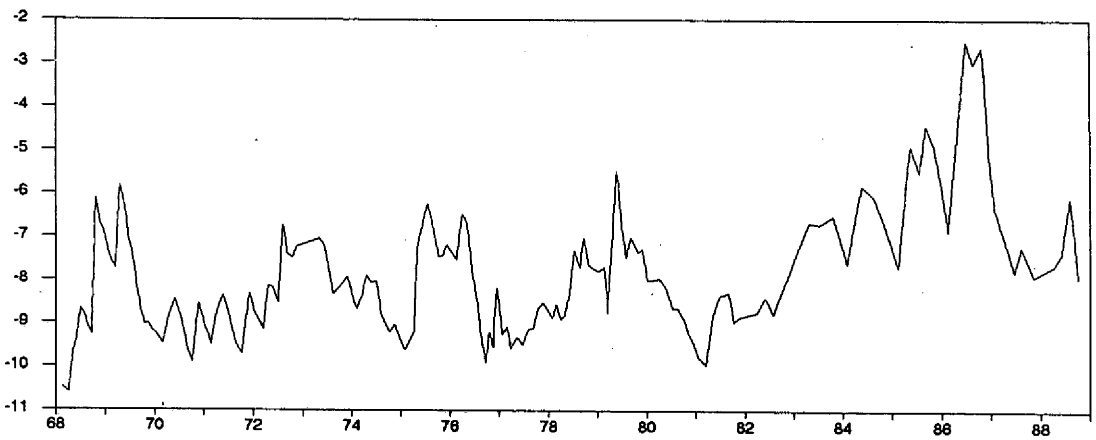
These 5 hydrographs show ground water trends in surficial aquifers in the northern half of Minnesota.

- Lowest levels commonly occurred in the spring of 1977 resulting from the 1976-77 drought. The ground water decline from this drought is very distinguishable.
- Ground water levels from the above drought appear to have recovered quite quickly, generally by 1979.
- Highest ground water levels typically occured in 1986. This is largely due to above normal precipitation for nearly a decade.
- Ground water levels declined sharply between the fall of 1986 and September of 1988 in the northwest (Hubbard and Traverse Counties). Levels in northeastern Minnesota as of September are near average.

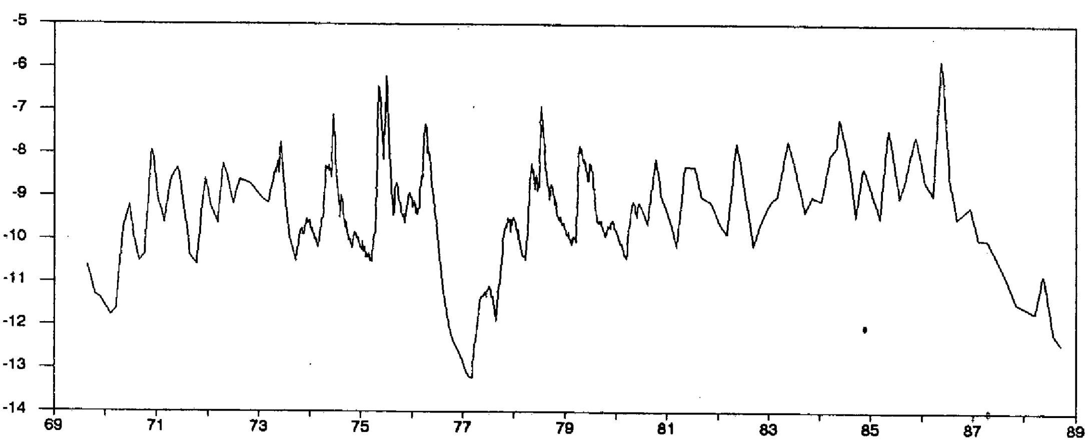
POPE COUNTY WELL# 61002



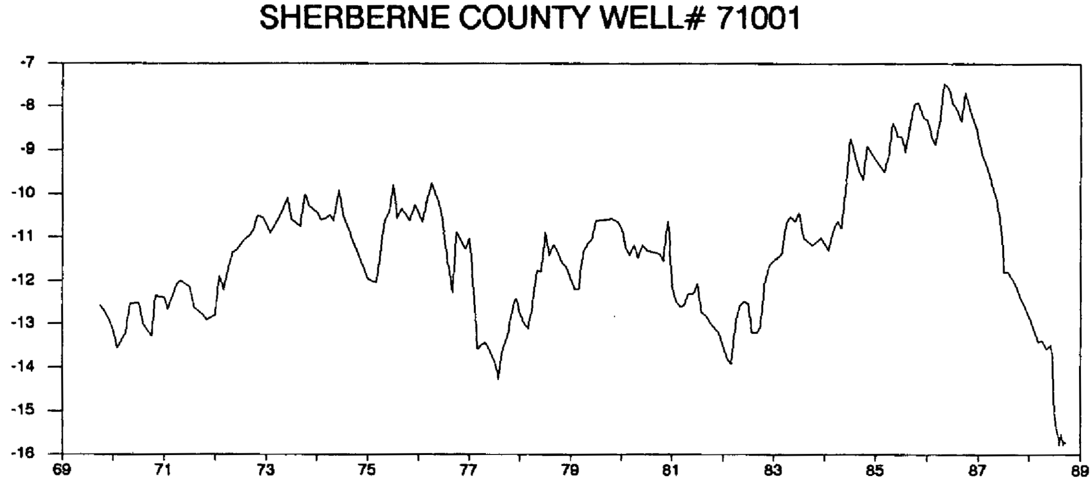

ISANTI COUNTY WELL# 30002

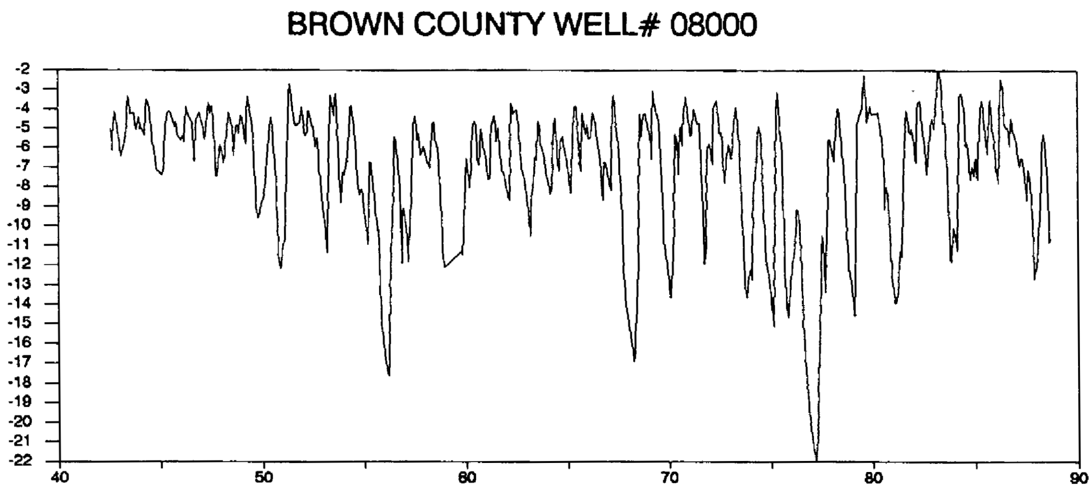



ANOKA COUNTY WELL# 02014




# Regional Ground Water Levels in Surficial Aquifers



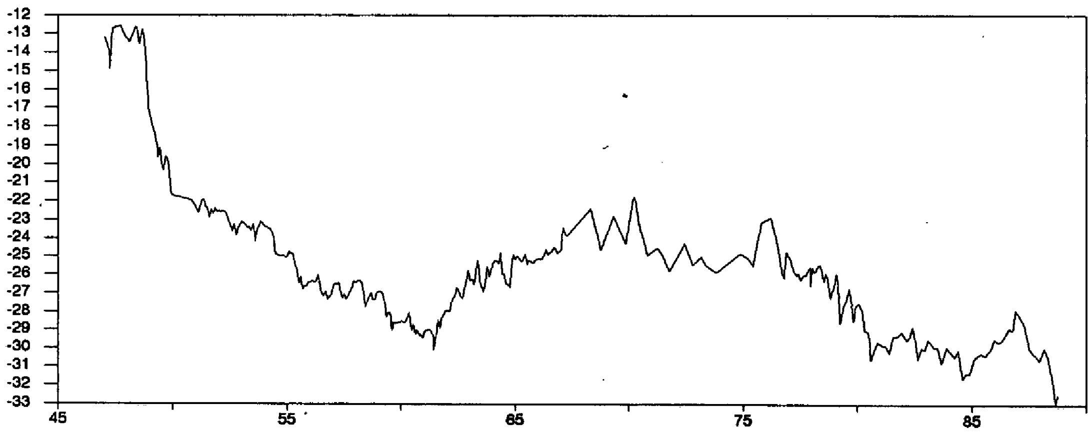




# Regional Ground Water Levels in Surficial Aquifers

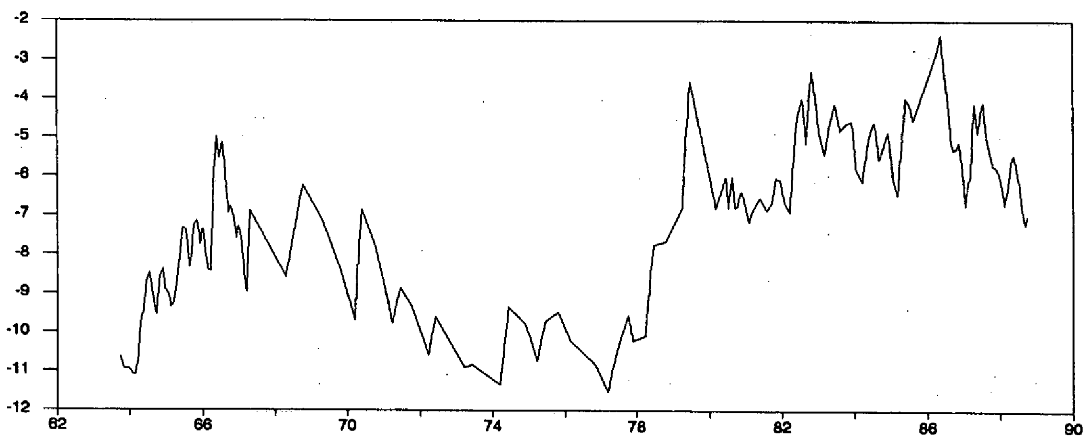
These 5 hydrographs show ground water trends in surficial aquifers in the southern half of Minnesota.

- Low ground water levels commonly occurred in the spring of 1977 resulting from the 1976 - 77 drought. Another drought occurred in 1980.
- Ground water levels from the above drought appear to have recovered quite quickly, generally by 1979.
- Highest ground water levels typically occured in 1985 - 86. This is largely due to nearly a decade of above normal precipitation.
- Ground water levels declined sharply since the fall of 1986 and reached record low levels in the summer of 1988. These levels were typically 3-5 feet below average, 1-2 feet below previous lows and 8 feet below the highest levels recorded in 1985 - 86.
- The Brown County hydrograph starts in 1942. Its ground water levels have remained stable over the 45 year period.

CLAY COUNTY WELL# 14001



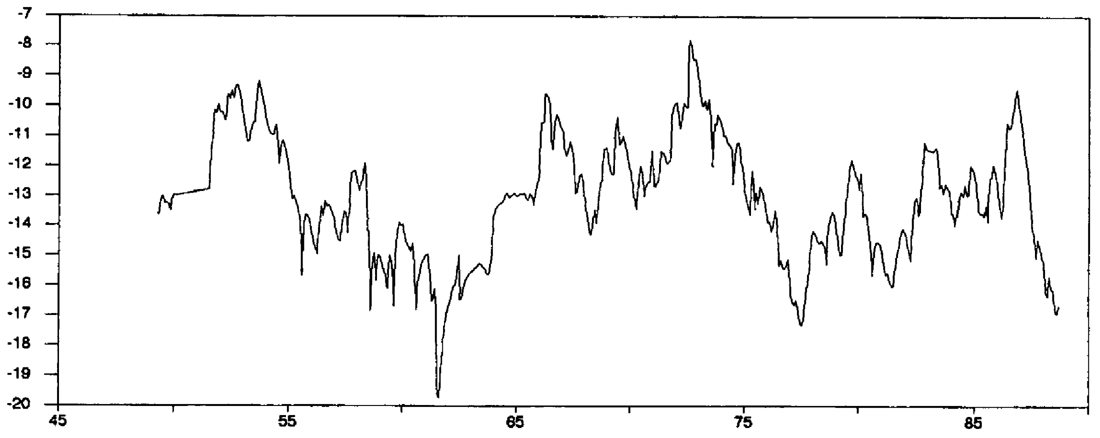

MARSHALL COUNTY WELL# 45001



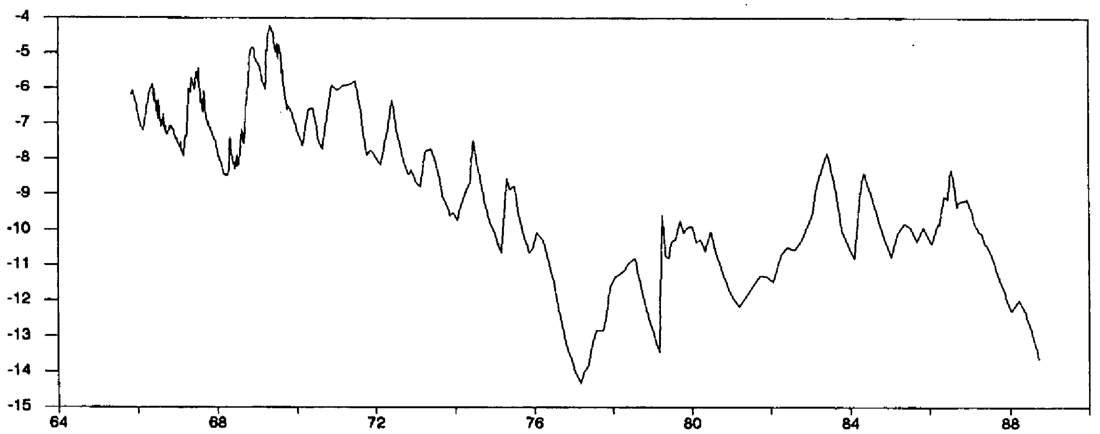

# Abnormal Ground Water Levels in Surficial Aquifers

- Water level decline in the Clay County observation well is due to pumping from the Buffalo Aquifer near Moorhead.
- The water level decline for the period between 1966 and 1976 in the Marshall County observation well is unusual.

MORRISON COUNTY WELL# 49014



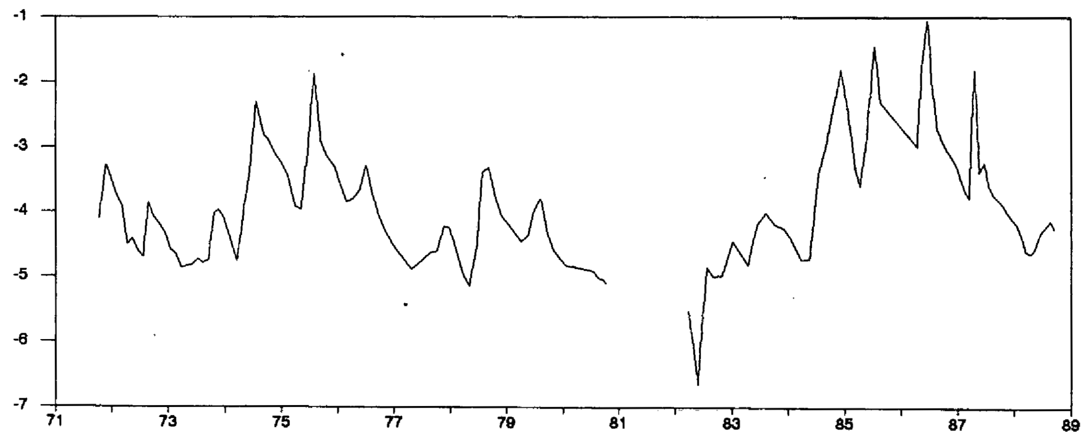

WATONWAN COUNTY WELL# 83000



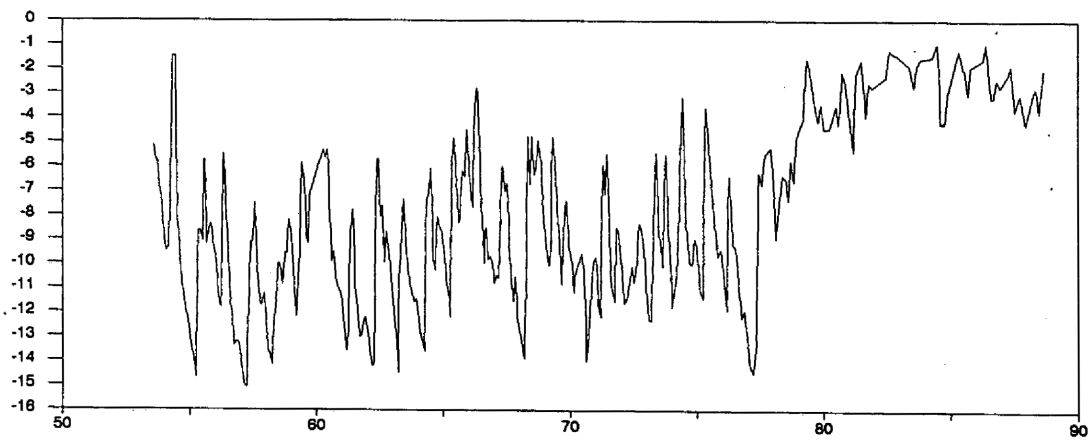

# Abnormal Ground Water Levels in Surficial Aquifers

- The water level decline from 1972 to 1977 in the Morrison County observation well does not show up in any other observation well in central Minnesota. Generally wells in central Minnesota show a decline for this period that is interrupted by recharge. Since 1977 the water level trend for this well is typical of surficial wells.
- The water level decline from 1969 to 1977 in Watonwan County is unusual but noted on a few other observation wells in southwestern Minnesota.

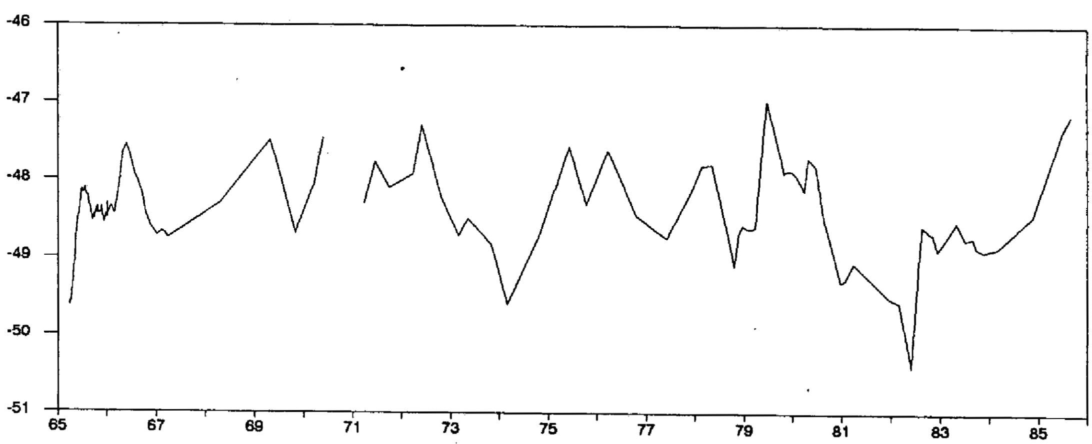
MARSHALL COUNTY WELL# 45002




ST. LOUIS COUNTY WELL# 69001

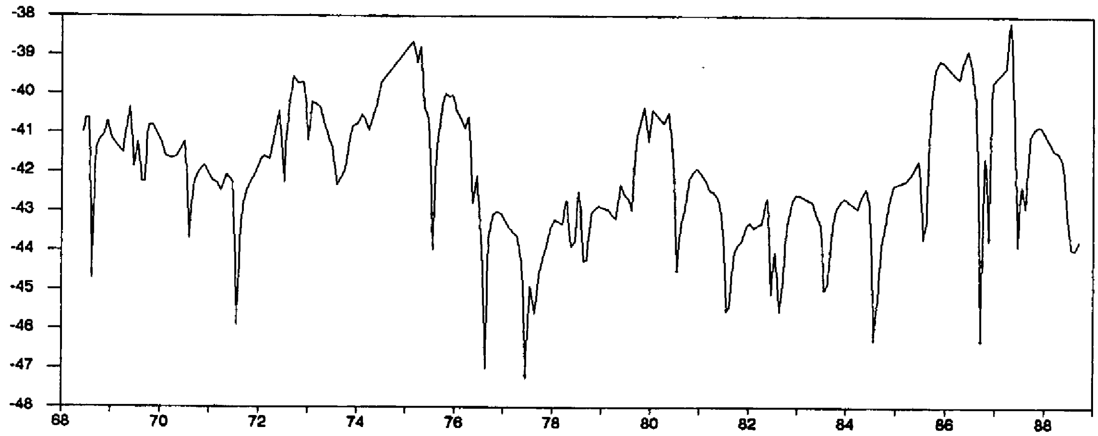



OTTER TAIL COUNTY WELL# 56016

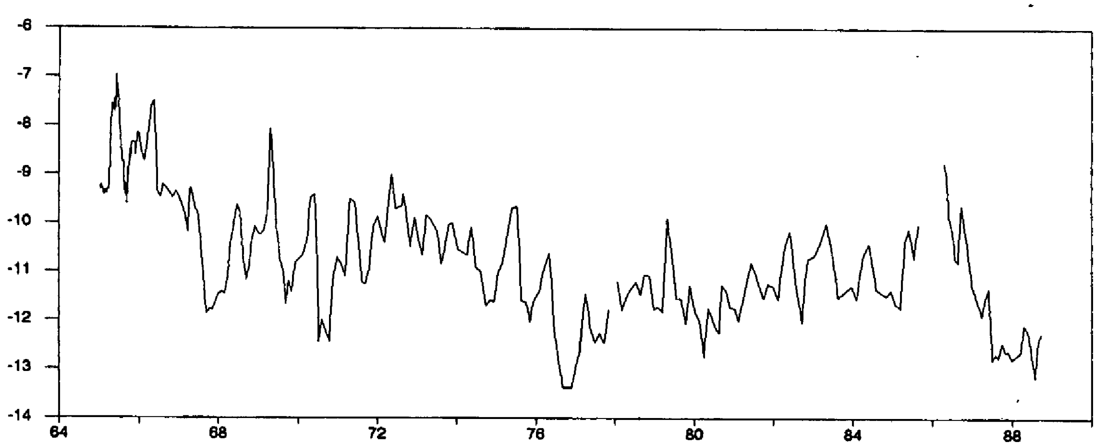



# Regional Ground Water Levels in Buried Drift

OTTER TAIL COUNTY WELL# 56014




AITKIN COUNTY WELL# 01000

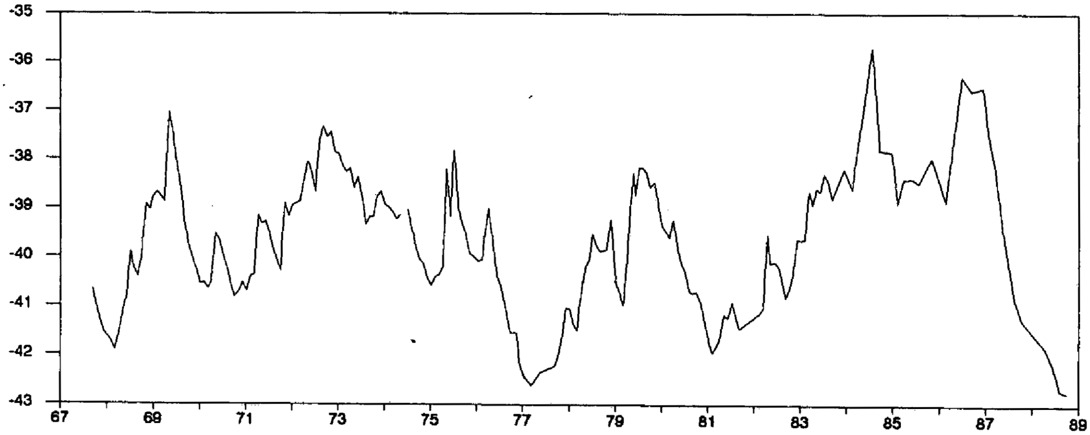



# Regional Ground Water Levels in Buried Drift

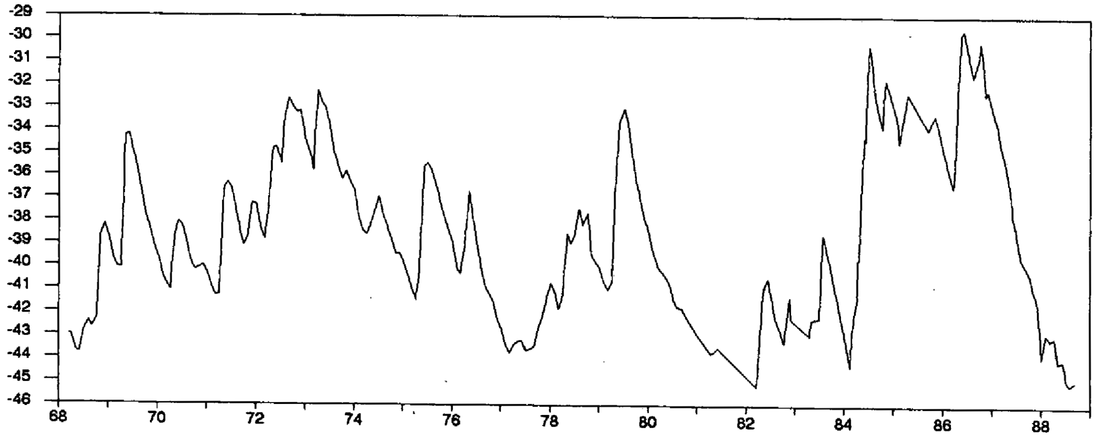
These 5 hydrographs show ground water trends in buried drift aquifers in the northern half of Minnesota.

- The 1976 - 77 drought is not as distinguishable in the records of some wells in this region as it is in many of the surficial well records. One reason for this is that readings are too infrequent and portions of the low water period were missed.
- Ground water levels have recovered from this drought, generally by 1979.
- The smaller drought of 1980 is evident on most graphs.
- Highest ground water levels typically occurred in 1985 - 86. This is largely due to nearly a decade of above normal precipitation.
- Ground water levels declined sharply since the fall of 1986 and reached record low levels in portions of northern Minnesota. Long term records on buried drift wells in northeastern Minnesota are not available.

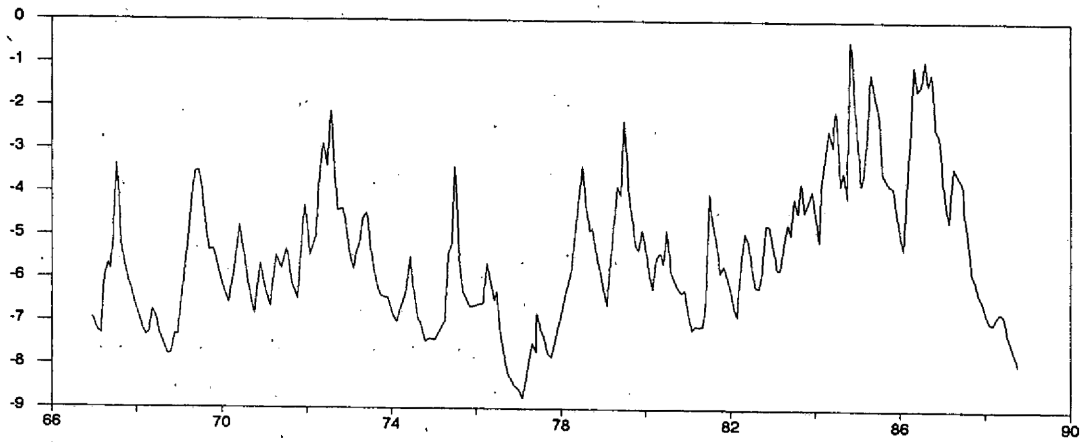
MILLE LACS COUNTY WELL# 48000



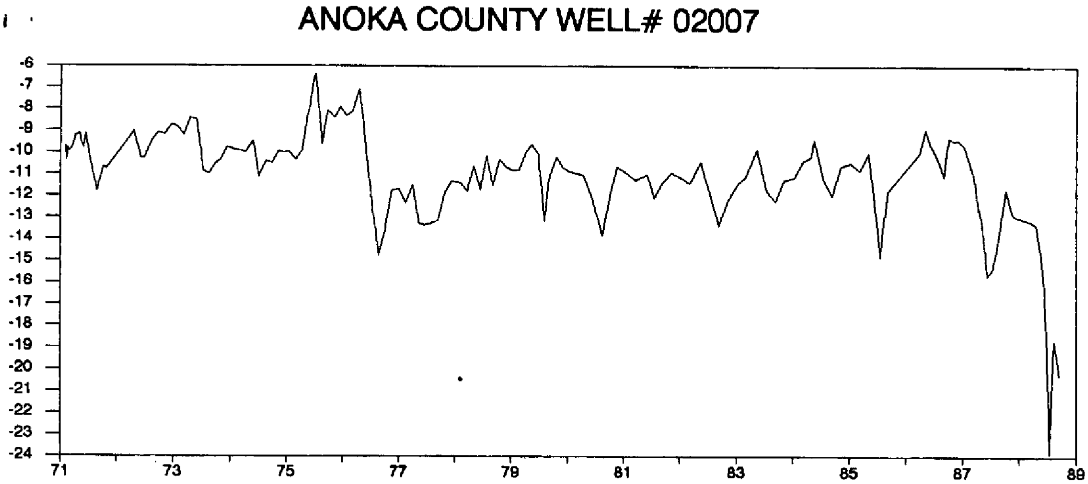

KANABEC COUNTY WELL# 33000

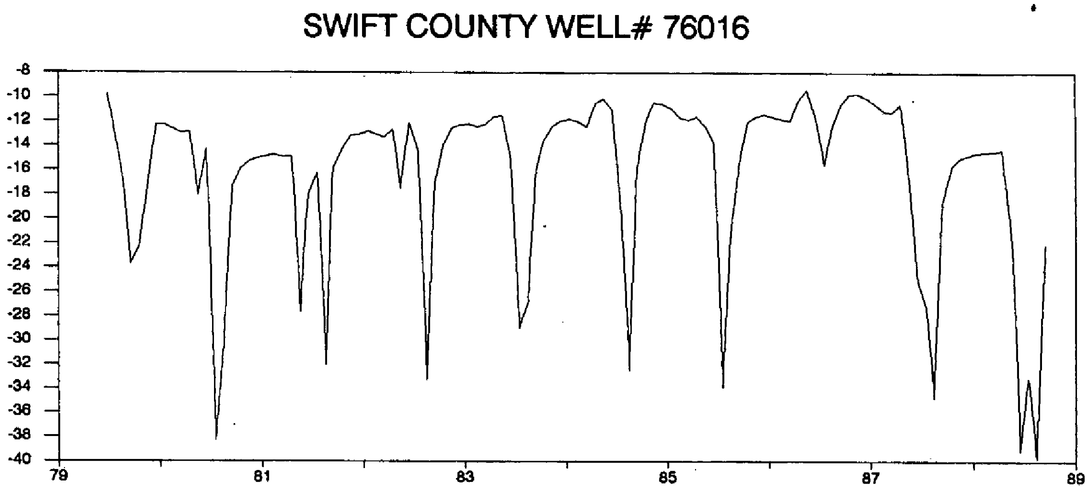



POPE COUNTY WELL# 61000




# Regional Ground Water Levels in Buried Drift



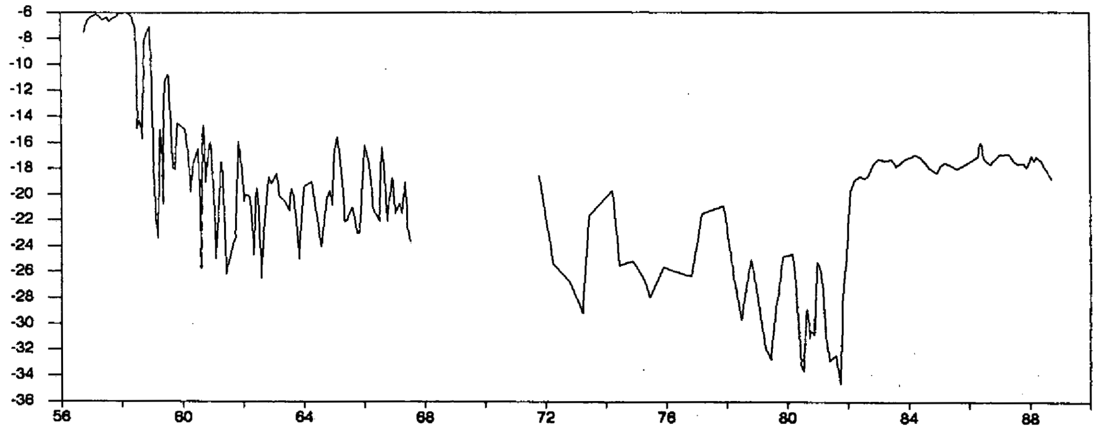




## Regional Ground Water Levels in Buried Drift

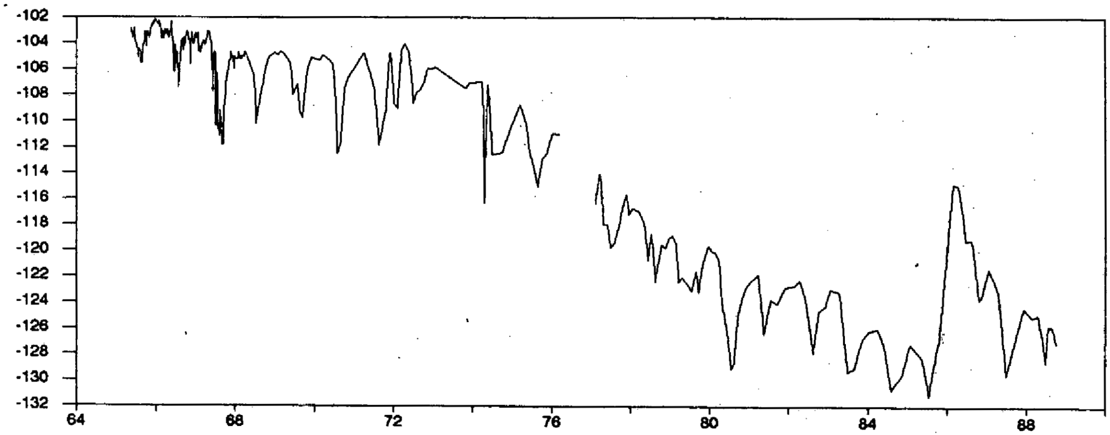
These 5 hydrographs show ground water trends in buried drift aquifers in the southern half of Minnesota.

- Low levels commonly occurred in the spring of 1977 resulting from the 1976 - 77 drought.
- Ground water levels from this drought have generally recovered by 1979.
- The small drought which occurred in 1980 is very evident on most graphs.
- High ground water levels typically occured in 1985 - 86. This is largely due to nearly a decade of above normal precipitation.
- Ground water levels declined sharply since the fall of 1986 and reached record low levels in the summer of 1988. The Swift county well is strongly effected by seasonal pumping in summer for irrigation, but recovers quickly after cessation of pumping if an adequate volume of water is available for recharge. Note that the recovery for the last two years is about 4 feet short.

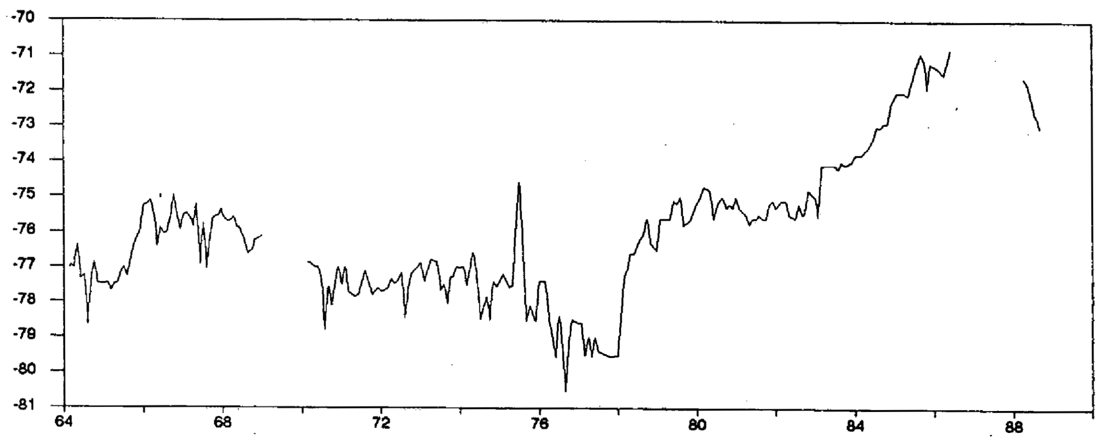
MARSHALL COUNTY WELL# 45000



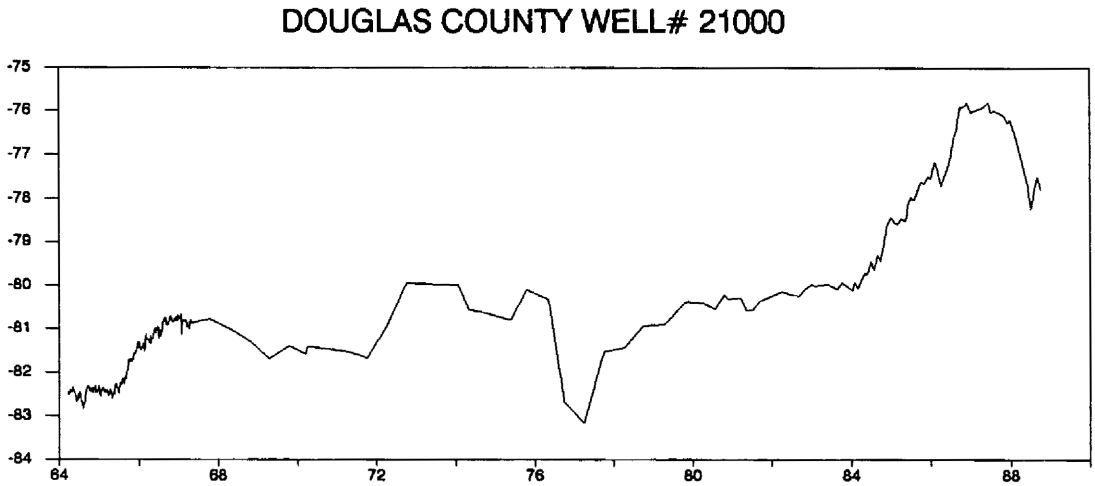

CLAY COUNTY WELL# 14003

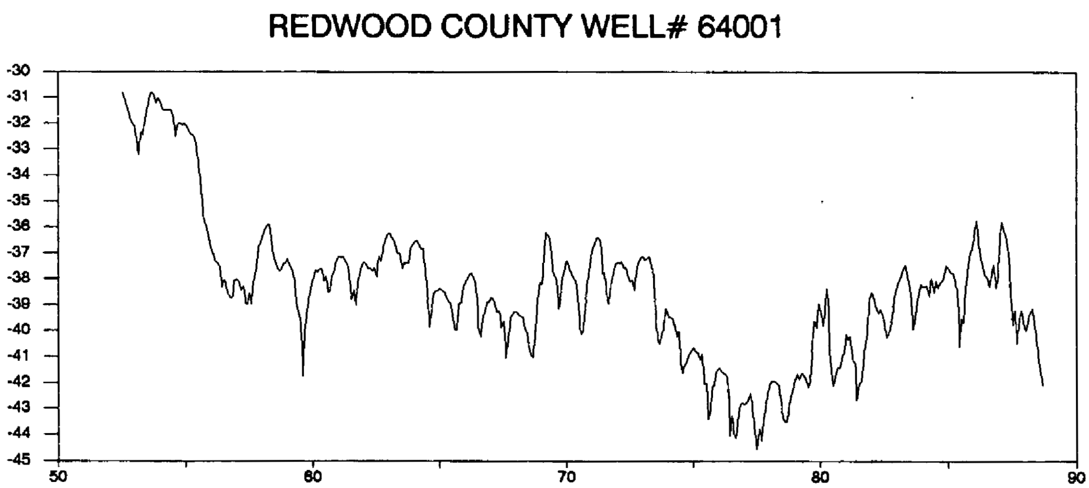



GRANT COUNTY WELL# 26000




# Abnormal Ground Water Levels in Buried Drift



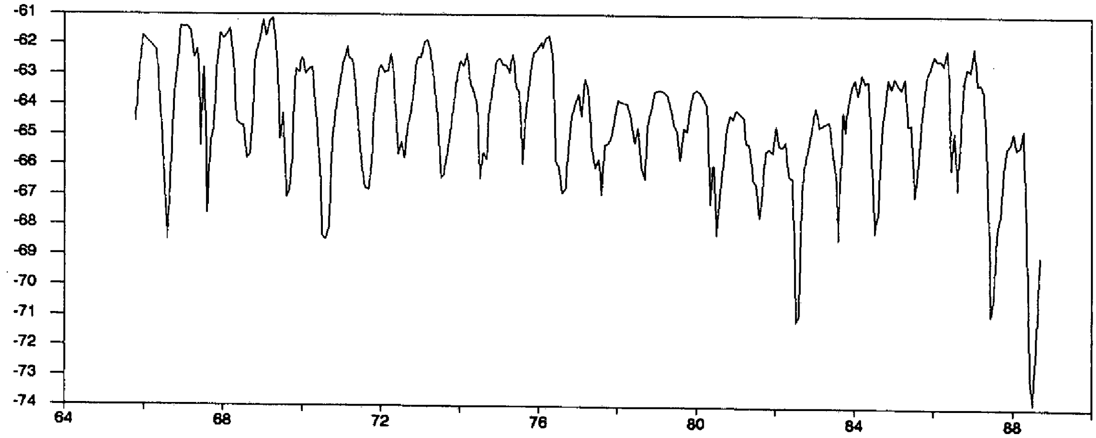




# Abnormal Ground Water Levels in Buried Drift

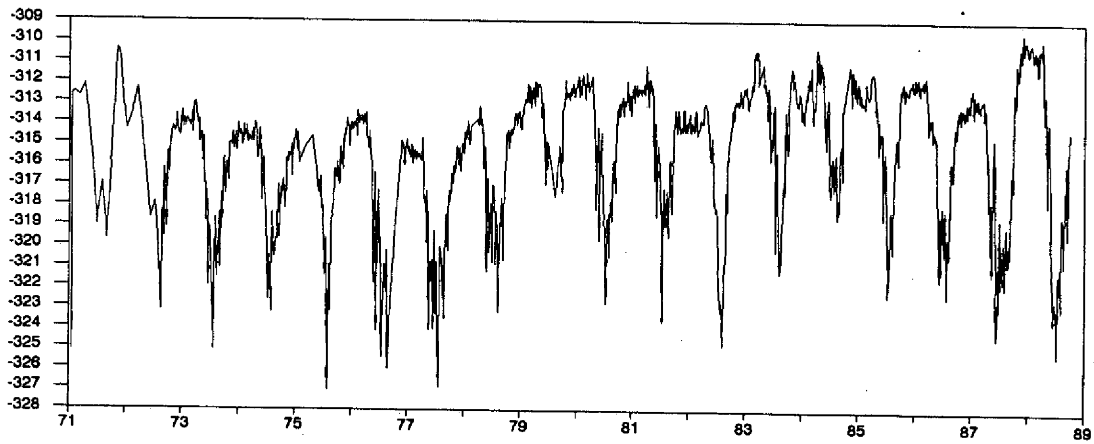
These five hydrographs show abnormal groundwater trends in buried drift aquifers.

- The Clay County observation well is located just outside the Buffalo aquifer near Moorhead. This decline is probably due to pumping.
- The Grant County well's current water levels are several feet above earlier recorded levels for this well.
- The steady decline in water levels for the first period on graphs in Redwood and Marshall counties is generally not observed but does show up on various wells in western Minnesota.
- Rising water levels between 1964 and 1986 on the Douglas County graph are unusual.

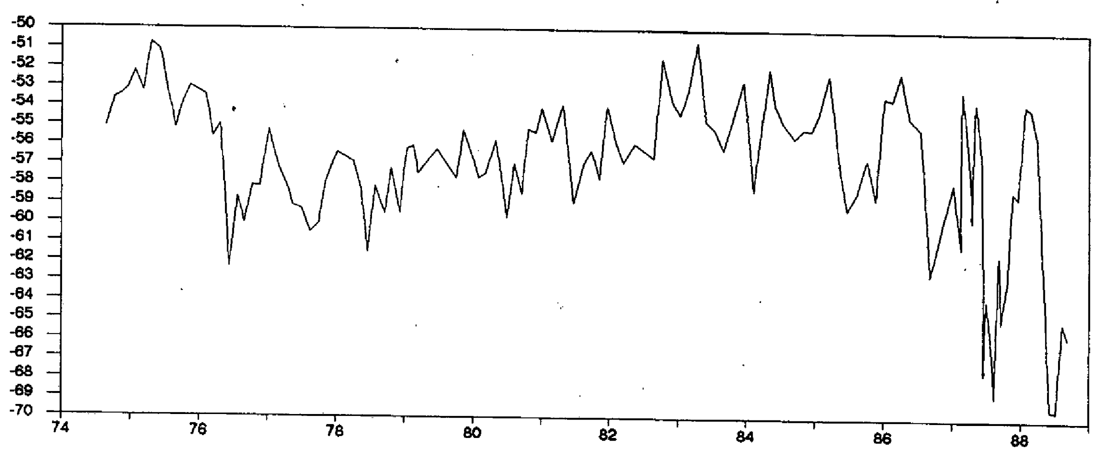
HENNEPIN COUNTY WELL# 27011



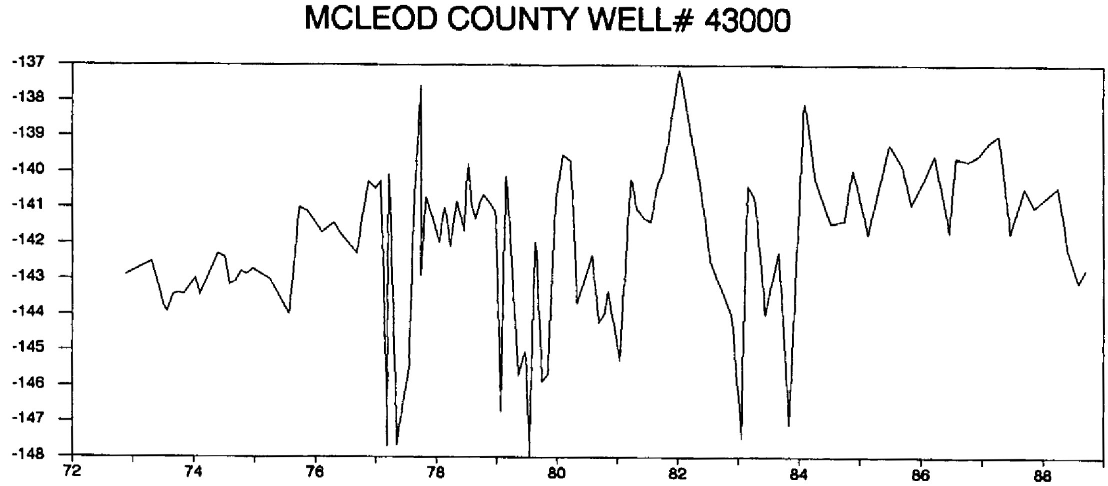

DAKOTA COUNTY WELL# 19005

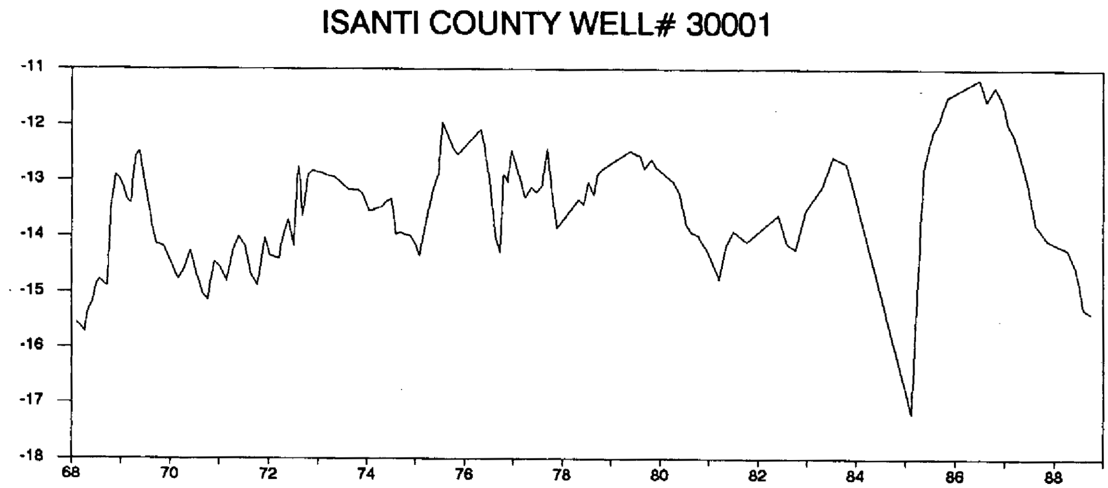



OLMSTED COUNTY WELL# 55000




# Ground Water Levels in Bedrock Aquifers



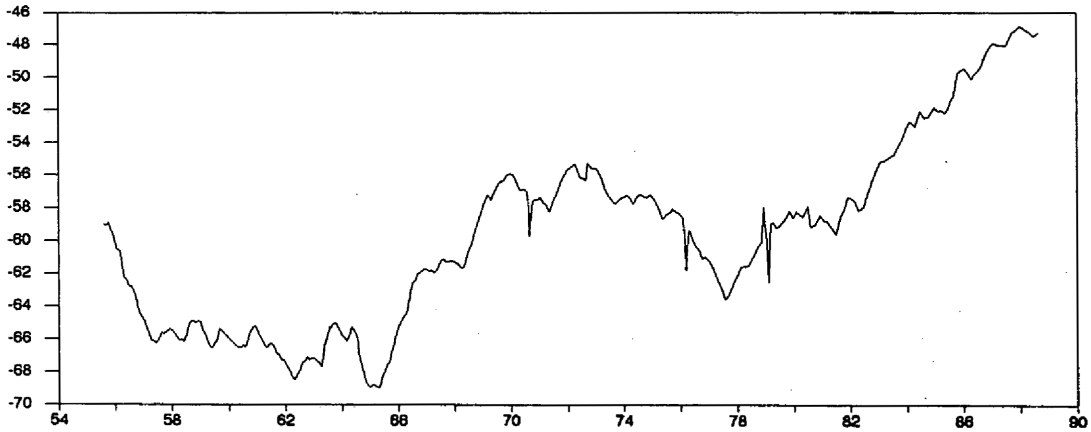




## Ground Water Levels in Bedrock Aquifers

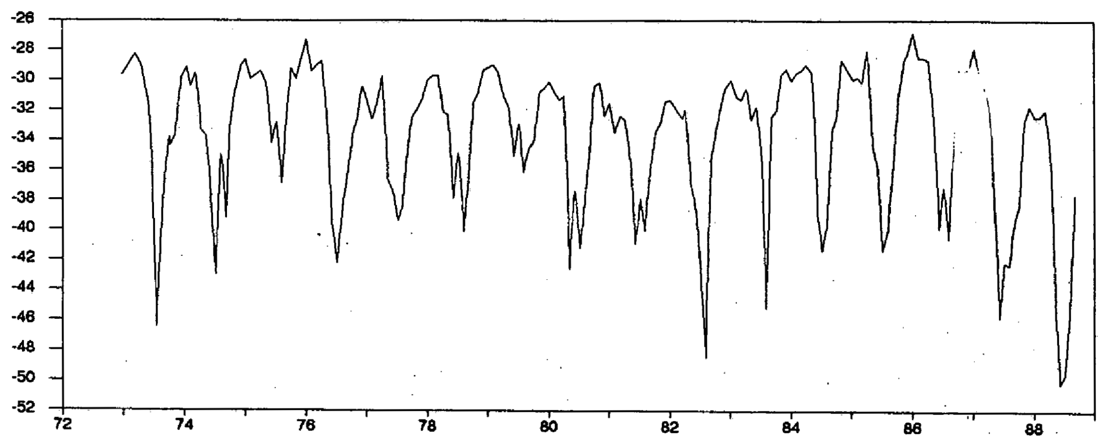
These 5 hydrographs show ground water trends in the Twin Cities' two principal aquifers.

- Observation wells that are affected by pumping do not reveal climatic trends. This is evident on the Hennepin County well. The rise in water levels on this graph in the 1970's is due to a local decline in pumping.
- The 1976 - 77 drought is not as evident on these graphs as compared to the surficial and buried drift hydrographs; the Olmsted County hydrograph does show this drought.
- The ground water rise (if any) since 1980 in these bedrock aquifers is more subdued than the rise in surficial and buried drift aquifers.
- Record low water levels occurred in several bedrock observation wells during the summer of 1988 due to large ground water withdrawals for air conditioning and irrigation.

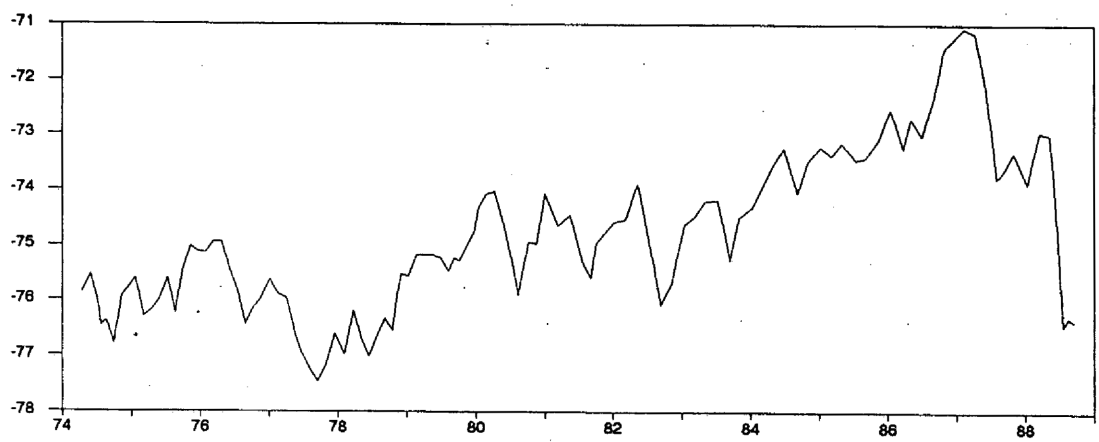
ST. LOUIS COUNTY WELL# 69000




HENNEPIN COUNTY WELL# 27002

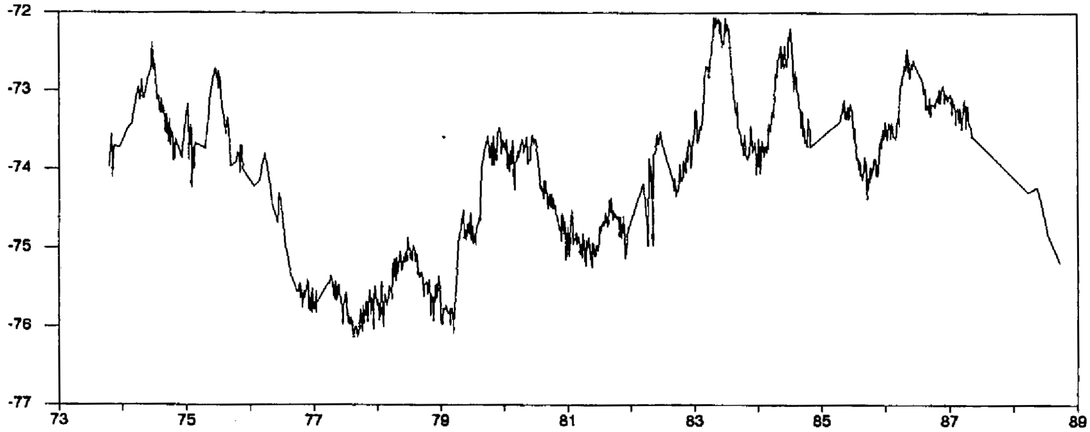



WASHINGTON COUNTY WELL# 82005

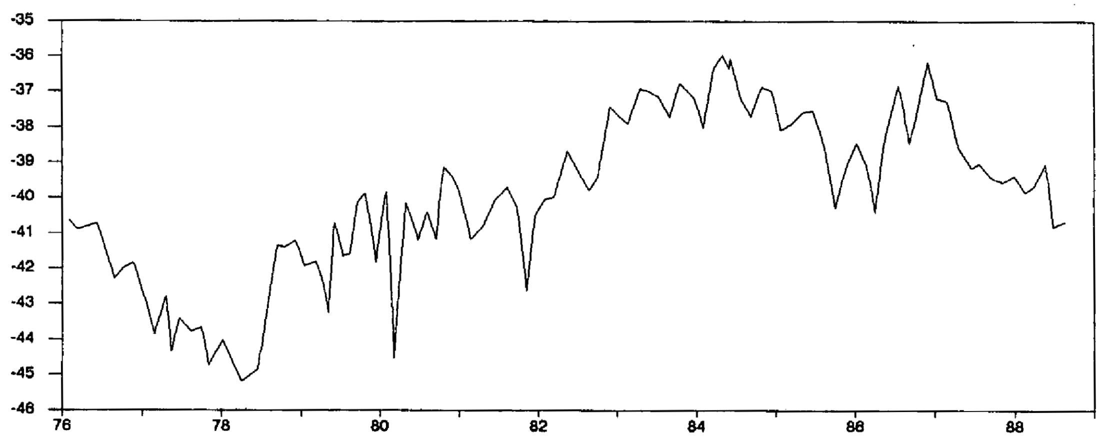



# Ground Water Levels in Bedrock Aquifers

BLUE EARTH COUNTY WELL# 07001




MOWER COUNTY WELL# 50000

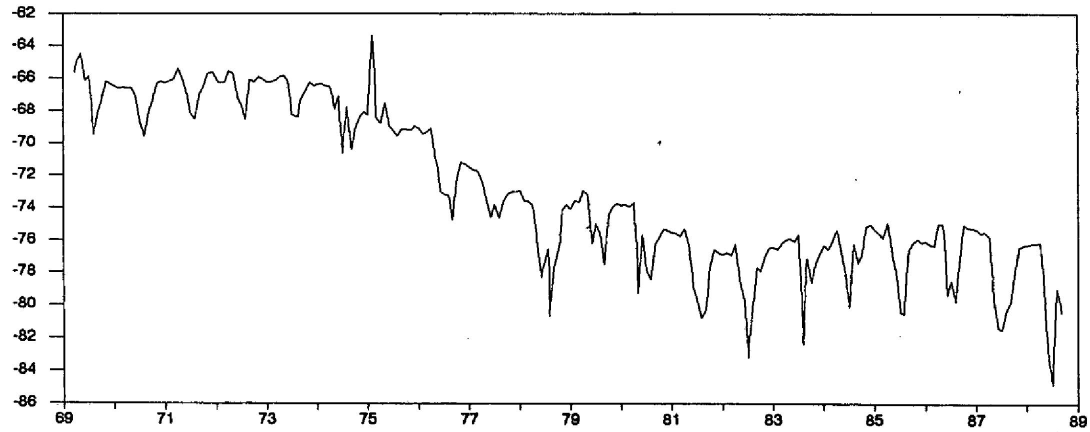



# Ground Water Levels in Bedrock Aquifers

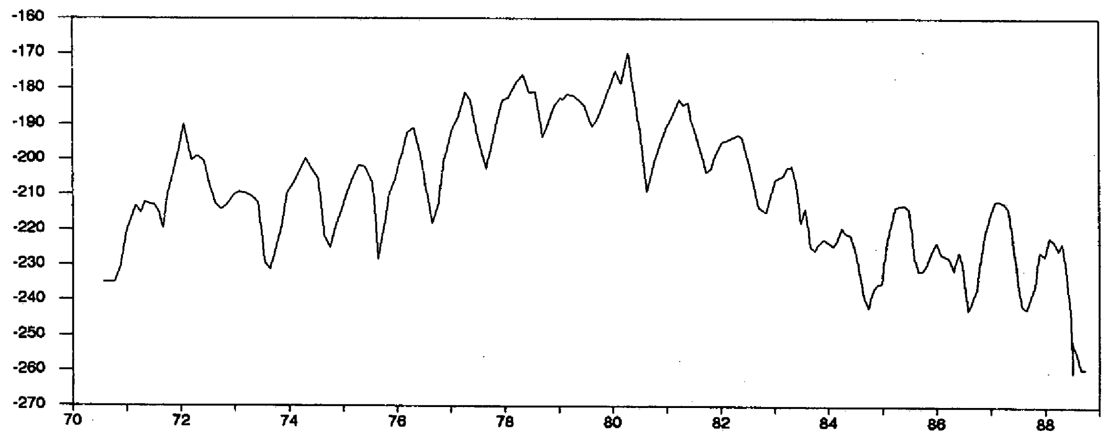
These 5 hydrographs show ground water trends in various bedrock aquifers.

- There appears to be a lag between a climatic event and ground water response in bedrock observation wells.
- The 1976 - 77 drought is very evident on hydrographs not affected by pumping. Lowest ground water levels commonly occur in this period.
- Ground water levels have recovered from this drought, generally by 1979.
- The smaller drought of 1980 is evident on most graphs.
- Highest ground water levels typically followed the successive years of above normal precipitation which occurred before 1986.
- The droughts of 1987 and 1988 have caused ground water levels to decline considerably in bedrock aquifers.

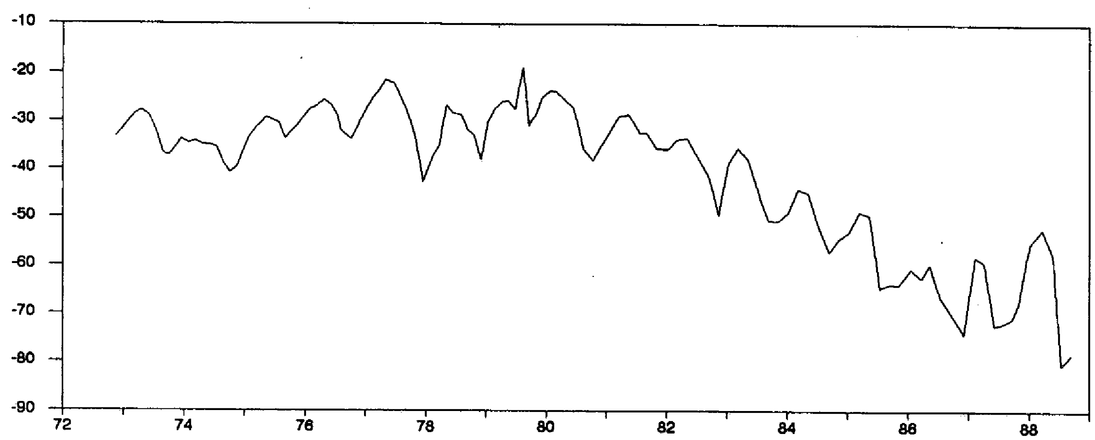
HENNEPIN COUNTY WELL# 27001



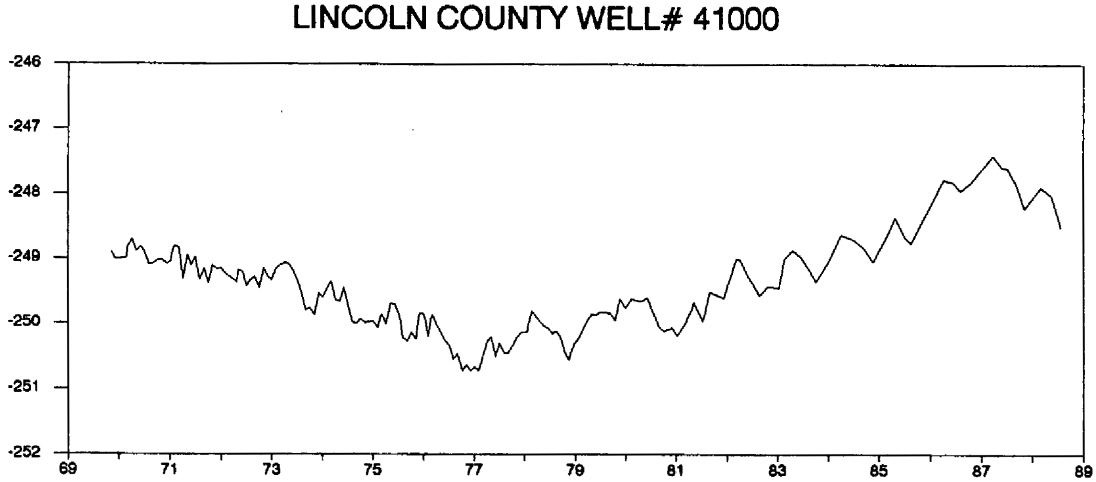

HENNEPIN COUNTY WELL# 27004

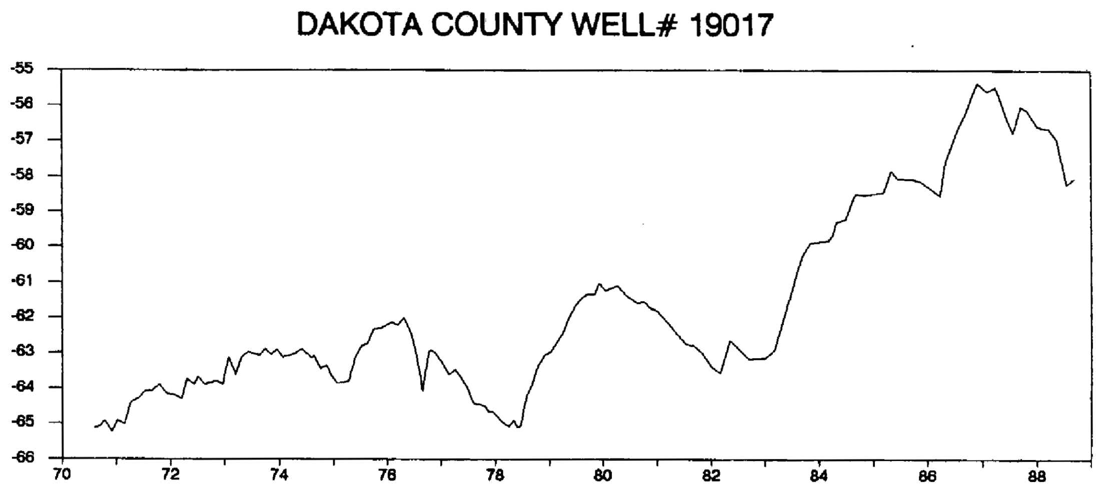



SCOTT COUNTY WELL# 70002




# Abnormal Ground Water Levels in Bedrock Aquifers




# Abnormal Ground Water Levels in Bedrock Aquifers

These 5 hydrographs show abnormal ground water trends in bedrock aquifers.

- The first three hydrographs shown on the opposite page are probably affected by pumping. Ground water levels in the Prairie du Chien - Jordan and Mount Simon - Hinckley aquifers are declining in local areas of increased pumping.
- The two hydrographs on this page are probably affected by climatic trends.

# Glossary

**Aquifer** - Rock or sediment in a formation, group of formations, or part of a formation that will yield sufficient water to be considered a source or supply.

**Aquifer, confined** - An aquifer that is overlain by a confining bed. The confining bed has a significantly lower hydraulic conductivity than the aquifer. Synonym: artesian aquifer.

**Aquifer, unconfined** - An aquifer connected with the atmosphere either directly or through the unsaturated zone above the water table. Synonym: water-table aquifer.

**Bedrock** - Consolidated or semiconsolidated rock formations or parts of formations that crop out at the land surface or underlie the glacial drift.

**Cone of depression** - A depression in the pressure surface of a body of ground water that has the shape of an inverted cone and develops around a well from which water is being withdrawn. It defines the area of influence of a pumped well.

**Confining layer** - A body of impermeable or distinctly less permeable material stratigraphically adjacent to one or more aquifers. It may lie above or below the aquifer.

**Cretaceous** - The geologic period marked by the dying out of toothed birds, ammonites, and dinosaurs, the development of early mammals and flowering plants, and the deposit of chalk beds.

**Drawdown** - A lowering of the water table of an unconfined aquifer or the pressure surface of a confined aquifer caused by pumping of ground water from wells.

**Drift** - A catchall term that includes all rock materials that were deposited by glaciers. Drift is composed of stratified and unstratified materials ranging in size from clay to boulders.

**Formation** - Any igneous, sedimentary, or metamorphic body of rock sufficiently homogeneous or distinctive to be represented as a unit.

**Ground water** - The water located below the water table in an unconfined aquifer or located in a confined aquifer.

**Hydraulic Communication** - Interconnection between distinctively different aquifers. Water levels within different aquifers change in direct response to water level changes of another aquifer.

**Observation Well** - Ideally a nonpumping well used to observe the ground water level in a single aquifer.

**Outwash** - Stratified drift deposited by melt water flowing from a glacier. It is mostly sand and gravel, but clay to boulder sizes may be included.

**Paleozoic** - The geologic era between 600,000,000 and 230,000,000 years ago and was characterized by the development of the first fished, amphibians, reptiles, and land plants.

**Permeability** - The capacity of a porous rock, sediment, or soil for transmitting a fluid, it is a measure of the relative ease of fluid flow in response to pressure.

**Porosity** - The ratio of the volume of void spaces in a rock or sediment to the total volume of the rock or sediment.

**Recharge** - Water added to the saturated zone; the main source of recharge is precipitation.

**Saturated Zone** - The zone in which all the voids in the rock or soil are filled with water at a pressure greater than atmospheric. The water table is the top of the saturated zone in an unconfined aquifer.

**Static Water Level** - The water level in a well that is not being affected by withdrawal of ground water.

**Till** - A heterogeneous mixture composed of sand to boulder size material imbedded in a silty clay matrix and deposited directly from glacial ice.

**Unsaturated Zone** - The zone between the land surface and the water table. The pore spaces contain water at less than atmospheric pressure, as well as air and other gases. Saturated bodies, such as perched ground water, may exist in the unsaturated zone.

**Water Table** - The surface in an unconfined aquifer at which the pore water pressure is at atmospheric pressure. It is defined by the levels at which water stands in tightly cased wells that penetrate the water body just far enough to hold standing water.

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