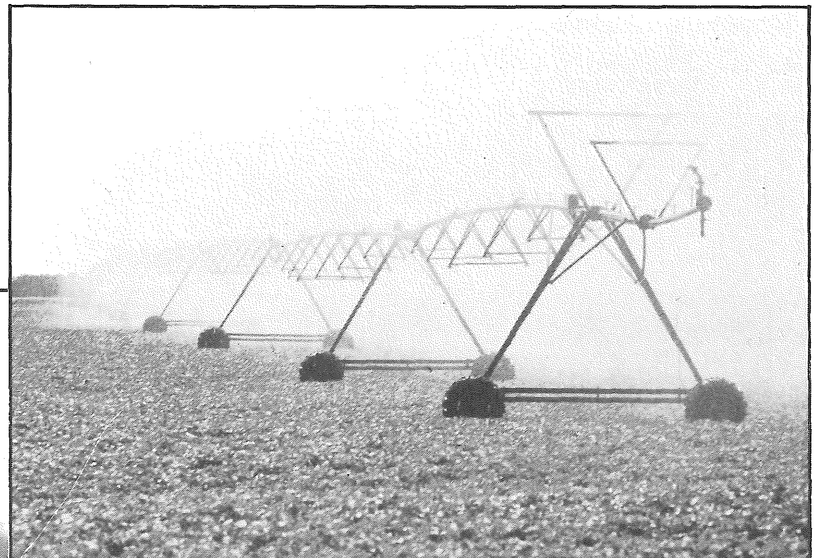
Understanding Ground Water Level Trends: A Key to Managing Water Use



A HISTORICAL SUMMARY ON GROUND WATER LEVELS AND TRENDS

DIVISION OF WATERS

MINNESOTA DEPARTMENT OF NATURAL RESOURCES

APRIL 1987

UNDERSTANDING GROUND WATER LEVEL TRENDS: A KEY TO MANAGING WATER USE

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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) is entrusted with the responsibility of monitoring the use of the State's water and allocating that resource to assure that there is water of sufficient quality and quantity to supply the needs of future generations. With regard to ground water, 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 being routinely observed in over 500 wells statewide. While the primary objective in gathering the ground water levels is to provide estimates of changes in water supply, these data also help the Department resolve well interference complaints, other allocation issues, and are useful to ground water researchers. These data are also used by the U.S. Geological Survey (USGS), local units of government and others involved in the management of this important resource.

From the observation well network, measurements of ground water levels are systematically recorded. 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 recorded 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 groundwater 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.

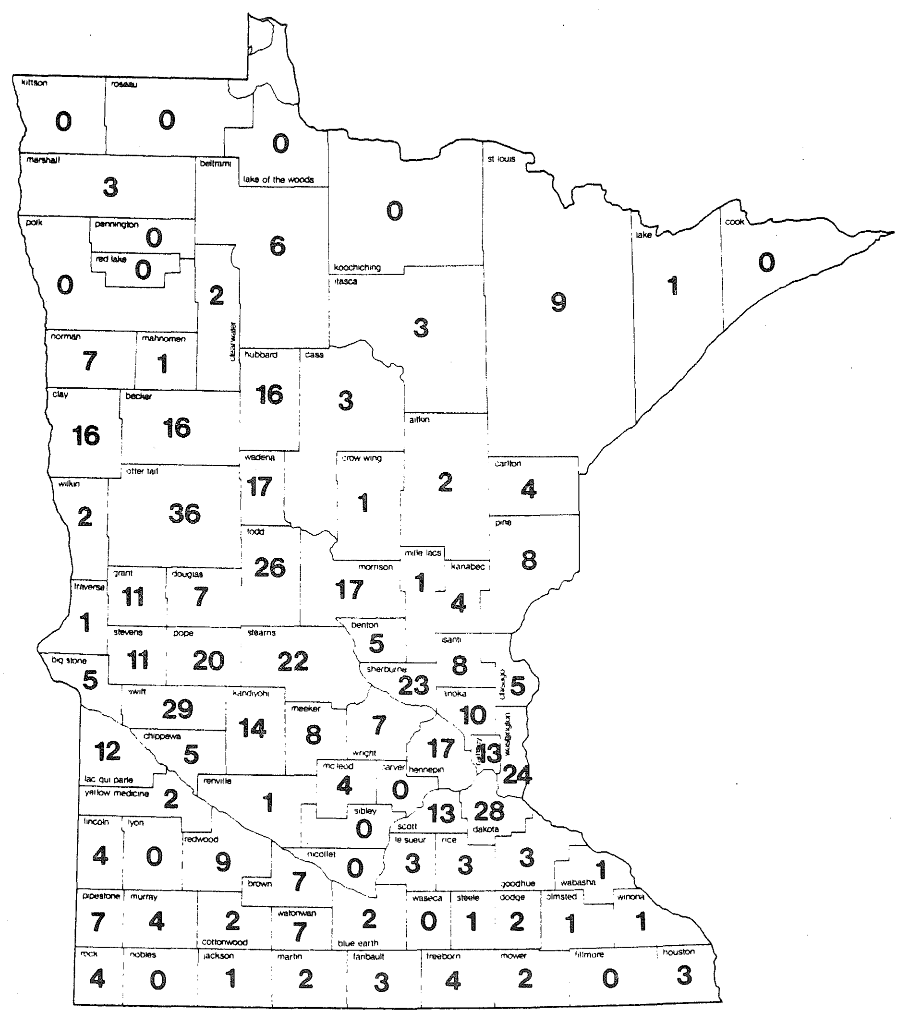
HISTORY OF THE OBSERVATION WELL NETWORK

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 582 wells at the end of 1986 (See Figure 1).

The DNR Division of Waters has the responsibility to manage the observation well network. The existing program is composed of two subnetworks, 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.

Figure 1: NUMBER OF ACTIVE OBSERVATION WELLS IN 1986, PER COUNTY



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, 34 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.

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 taking in consideration 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 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.

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

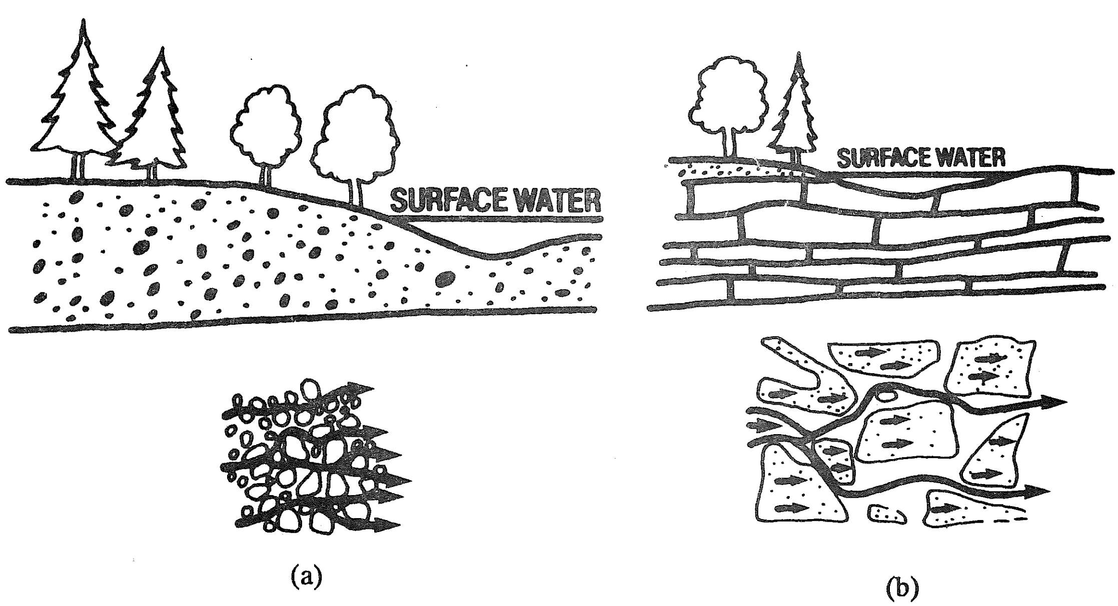


Figure 2: Storage and movement of ground water
a) porous media like sand or gravel
b) fractured porous media like limestone

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 the 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).

PUMPAGE CONSIDERATIONS

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.

STORAGE CONSIDERATIONS

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 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 fluctuations are 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.

HYDROLOGICAL DIFFERENCES IN AQUIFER

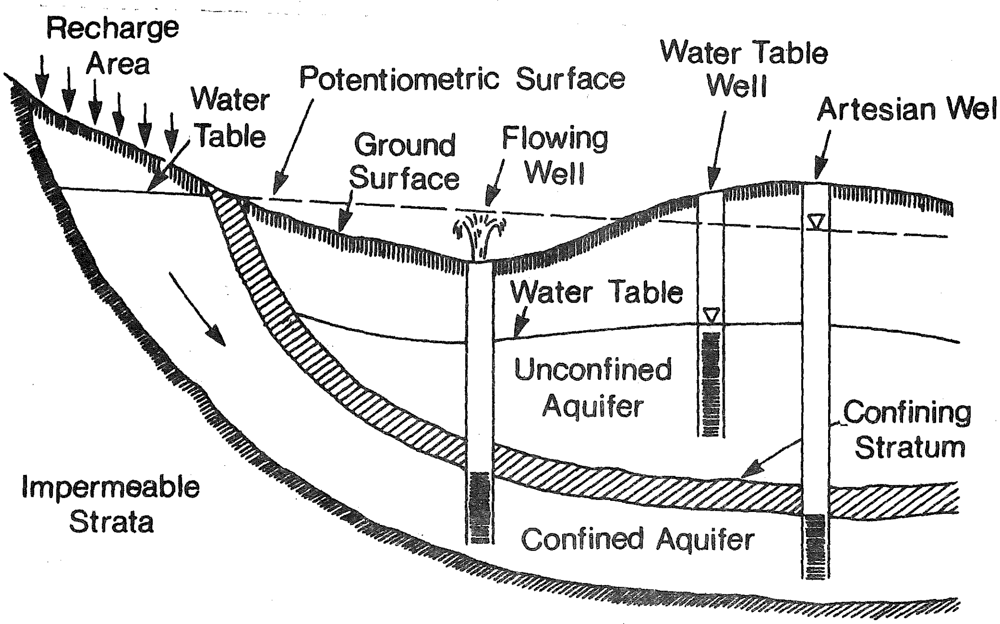


Figure 3: Schematic cross section illustrating unconfined and confined aquifers (from Todd).

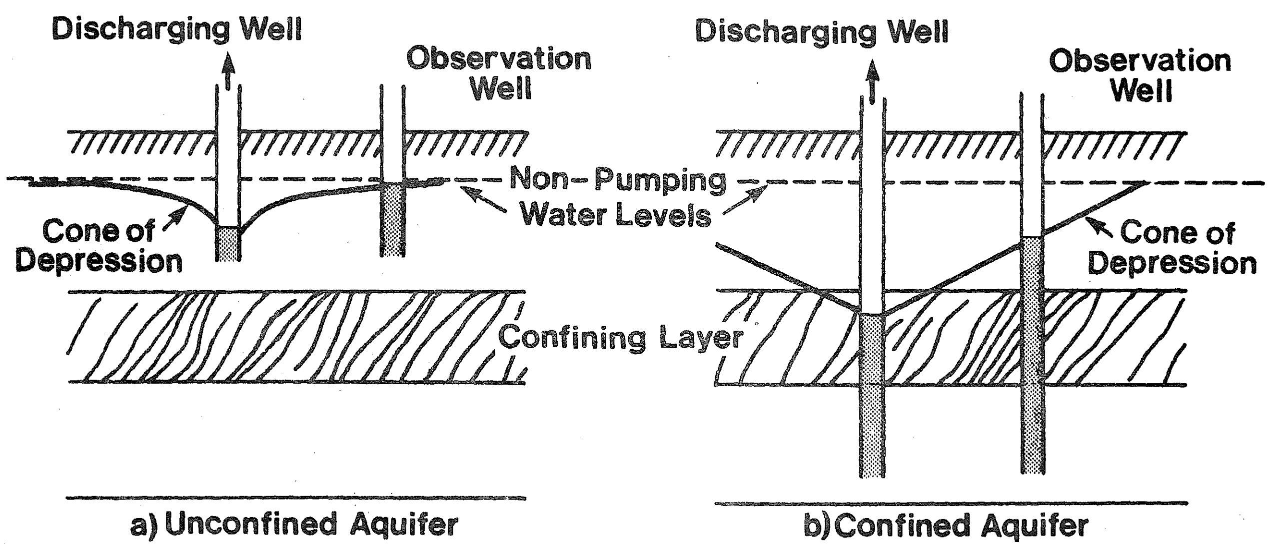


Figure 4: Comparison of drawdown cones for unconfined and confined aquifers. As water is withdrawn from the unconfined aquifer the aquifer becomes unsaturated above the cone of depression. In a confined aquifer as water is withdrawn, pressure is reduced. The aquifer itself remains saturated. The hydrogeologic difference between these aquifers necessitates separate monitoring and management practices.

RECHARGE AND DISCHARGE CONSIDERATIONS

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.

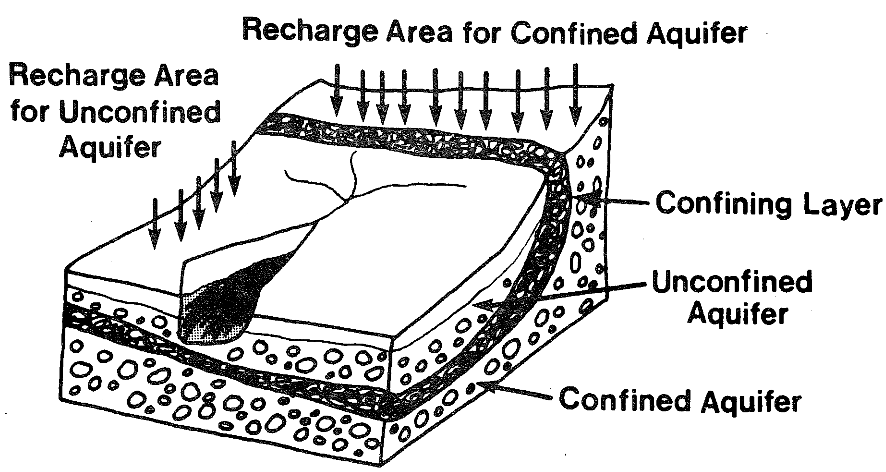


Figure 5. Schematic diagram of aquifer conditions showing recharge and discharge areas.

AQUIFER MINING

Aquifer mining occurs when the long term pumpage from an aquifer exceeds the long term recharge. 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

Please mark the answer that is most correct.
(confined or unconfined)

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. Pumpage effects are 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?

confined	unconfined

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

While aquifers can take many forms within Minnesota's diverse geology the major aquifers are: 1) unconsolidated deposits of sand and gravel left by glaciers or post-glacial sand and gravel deposits and 2) consolidated (bedrock) sedimentary formations of sandstone, limestone and dolomite. To a lesser extent ground water is also obtained from fractures in consolidated igneous and metamorphic bedrock formations such as granite, basalt, slate and quartzite. A well driller's search for water is really a search for one of these geologic materials. (At least in Minnesota there's a good chance 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 in a confined or unconfined condition. Glacial aquifers that lie below layers of silt and clay are confined and are termed "buried drift aquifers". Glacial aquifers that have a continuous layer of unsaturated porous material above a saturated sand or gravel deposit are unconfined and are termed "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.

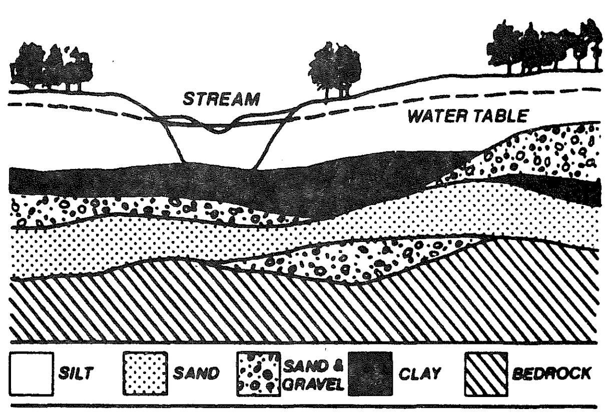


Figure 6. Aquifers in glacial deposits.
(Redrawn from DiNovo and Delin)

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 and pollutants introduced at the ground surface can quickly enter shallow aquifers. This condition has caused aquifer contamination in shallow limestone formations in southeast Minnesota.

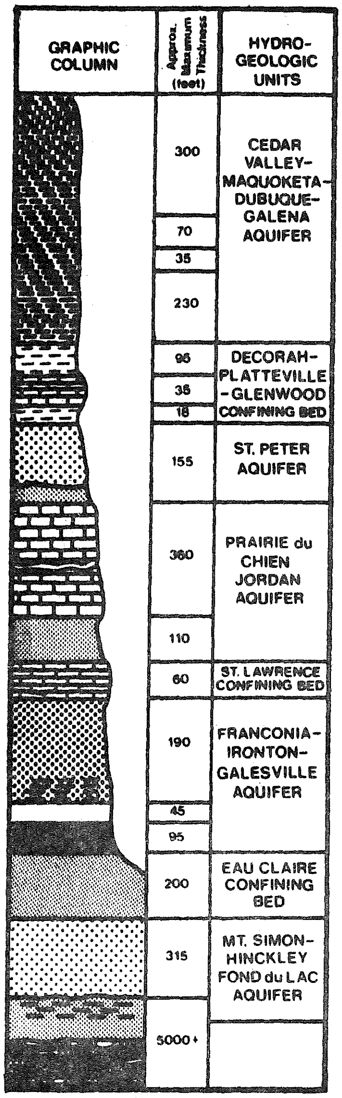


Figure 7: Hollandale Embayment: Sequence of bedrock aquifer systems and confining beds for southeastern Minnesota (revised from Delin and Woodward).

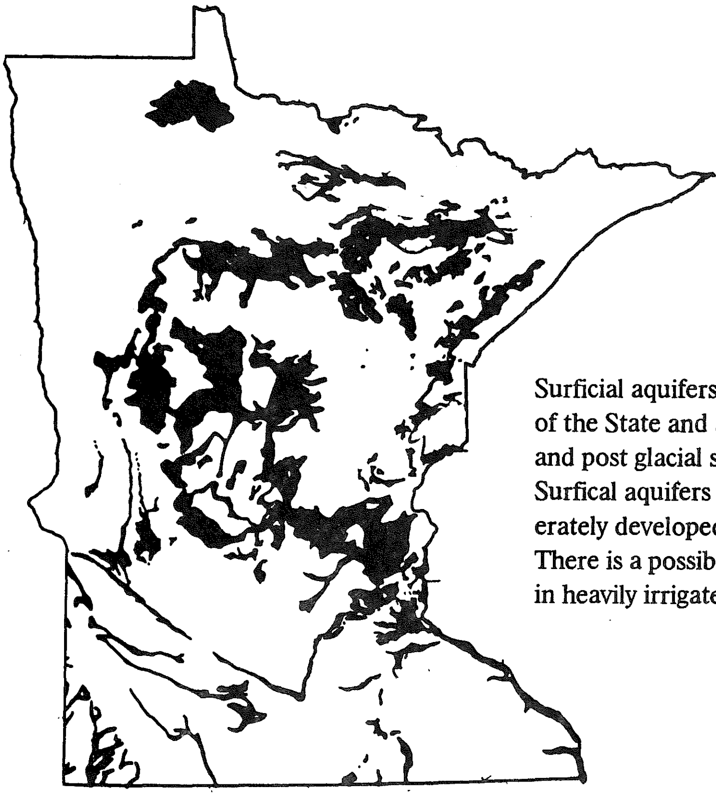
Minnesota's largest ground water reserves are contained in a multiple aquifer system of layers of Paleozoic age sandstone, limestone and dolomite in southeastern Minnesota (Figure 7) known as the Hollandale Embayment. These aquifers are separated by confining layers of shale and siltstone formations. 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 8:

UNCONSOLIDATED AQUIFERS



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

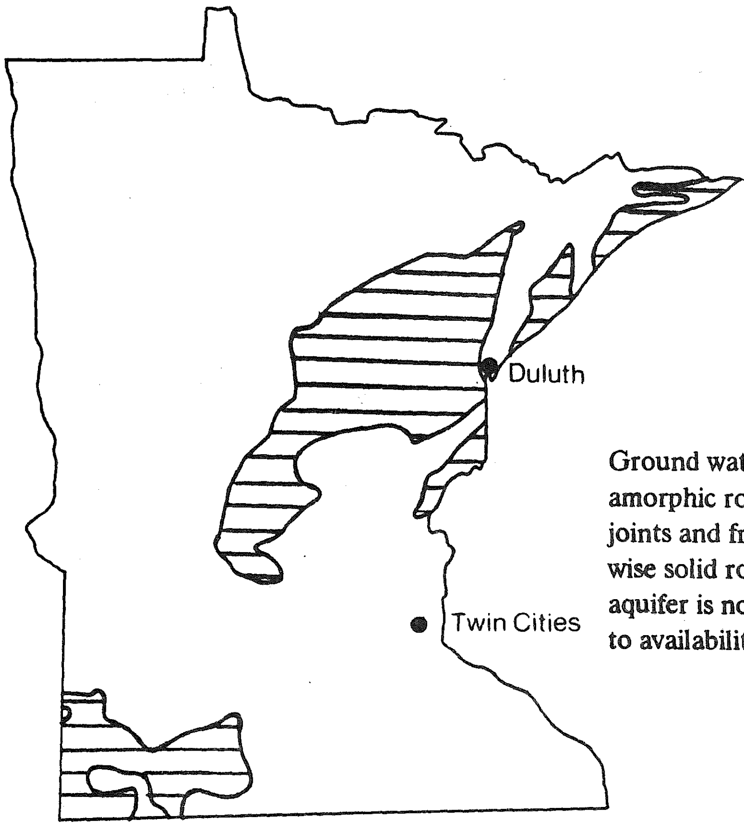
SURFICIAL AQUIFERS

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.

MAJOR BURIED DRIFT AQUIFERS
KNOWN OR SURMISED FROM EXISTING DATA

Sources: Adophson, Ruhl and Wolf; Kanivetsky.

FIGURE 9: BEDROCK AQUIFERS

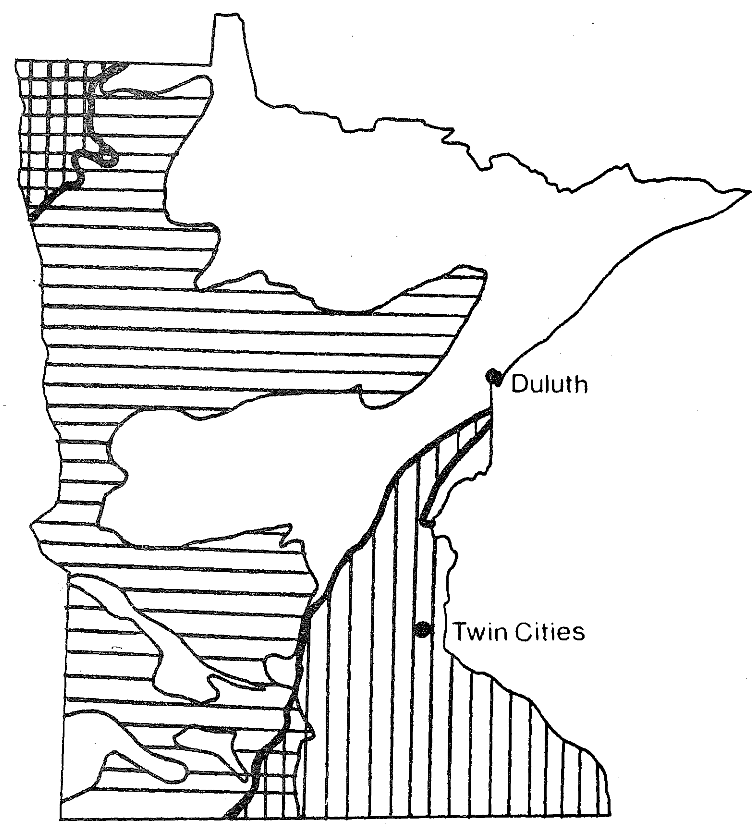


Ground water in igneous and metamorphic rocks is found in cracks, joints and fractures within otherwise solid rock formations. This aquifer is not extensively used due to availability of other aquifers.

IGNEOUS & METAMORPHIC BEDROCK AQUIFERS

Paleozoic sedimentary bedrock aquifers in southeastern Minnesota contain large ground waters reserves that supply water to the Twin Cities and southeastern Minnesota. The Paleozoic sedimentary bedrock aquifer in northwestern Minnesota has great potential for large supplies but is generally not suitable for drinking due to high salt concentrations.
Cretaceous sedimentary bedrock aquifers are found primarily in western Minnesota. Yields to wells from this aquifer are generally low and consequently generally do not supply water for large municipal and industrial use.

Cretaceous Aquifers | Paleozoic Aquifers | Cretaceous overlying Paleozoic Aquifers



SEDIMENTARY BEDROCK AQUIFERS

Source: Adolphson, Ruhl and Wolf

GROUND WATER 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 pumpage and determine the best management strategy for maintaining ground water supplies for both present and future users.

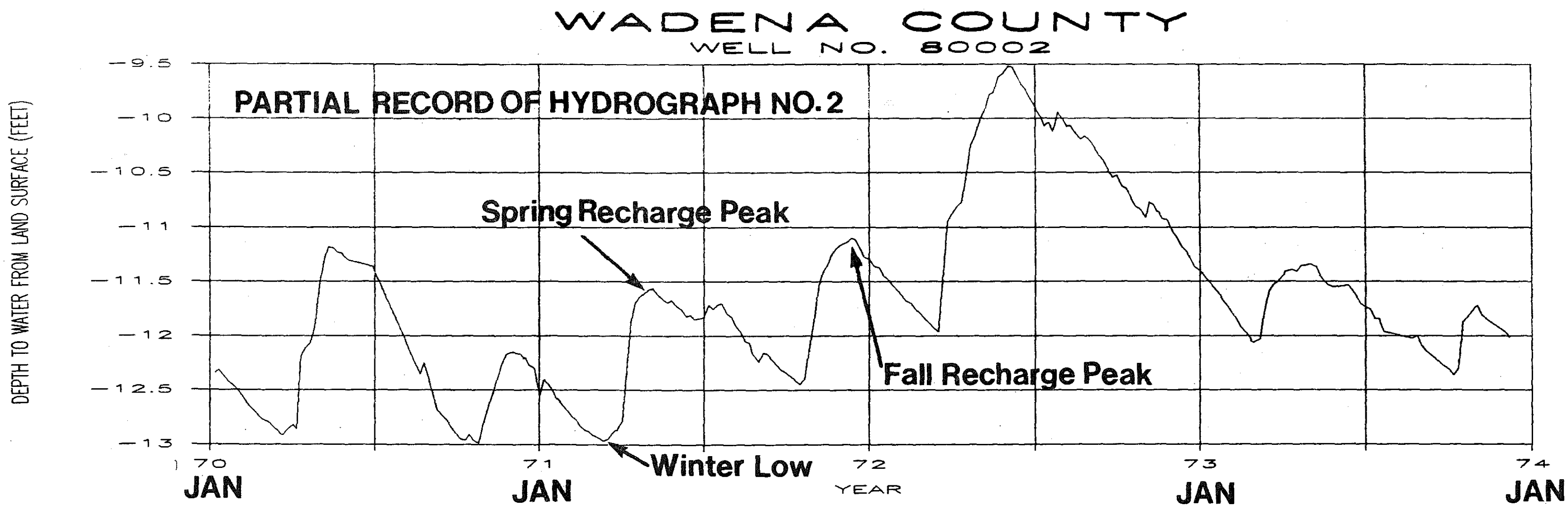
This section presents several hydrographs that illustrate:

* seasonal trends affected by climate
* seasonal trends affected by pumpage
* multiple layer aquifer water level comparison
* long term trends affected by climate
* long term trends affected by pumpage

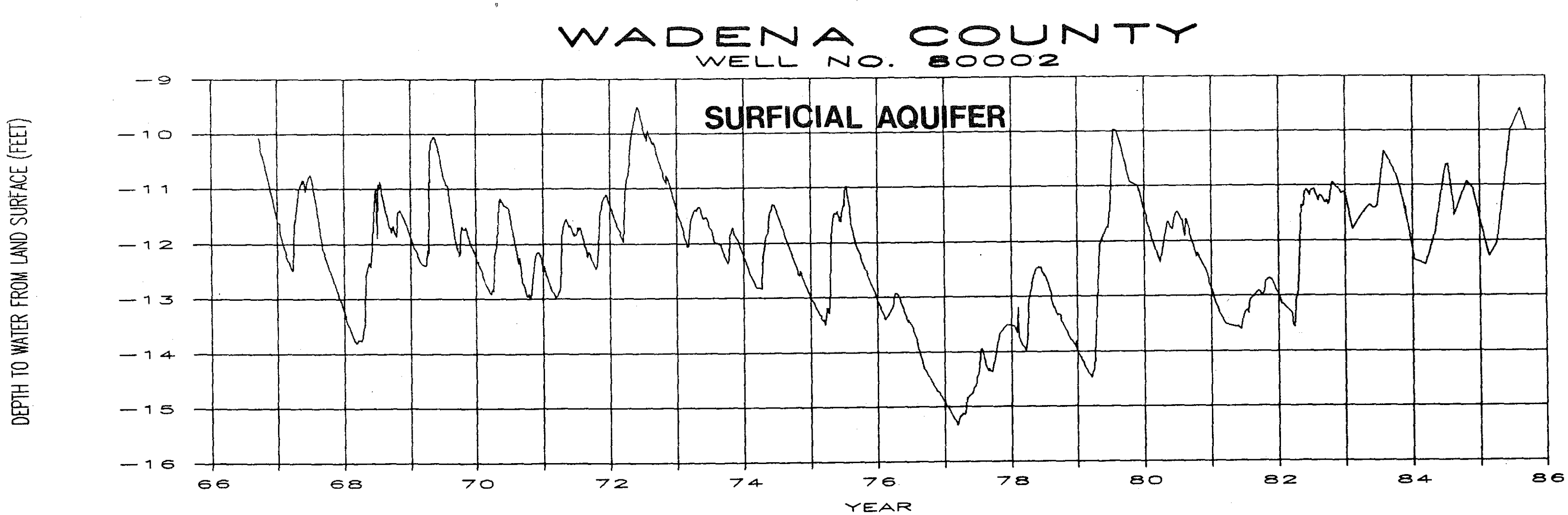
Trends are viewed for both unconfined and confined aquifers. Observation wells were selected from various parts of the state and ground water level comparisons are made for each aquifer type; surficial, buried drift, and bedrock.

SEASONAL TRENDS - EFFECTS OF FOUR SEASONS

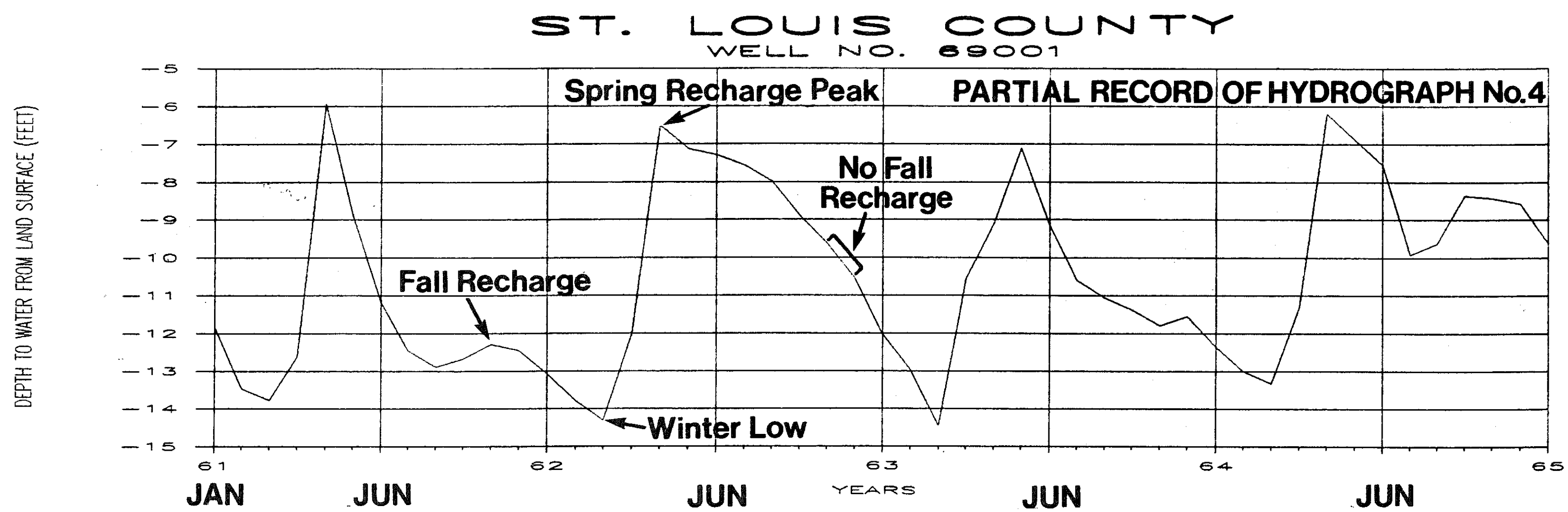
Seasonal water level trends are illustrated on Hydrograph #1 for a surficial drift aquifer in Wadena County. This 3-year period is a portion of the hydrograph shown below it. The seasonal trends expanded for illustration purposes on Hydrograph #1 can be observed over the entire record period in Hydrograph #2. Ground water levels are generally at their highest level in early spring. This is when little evaporation from the soil and little or no transpiration from plants occur. 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 this season.



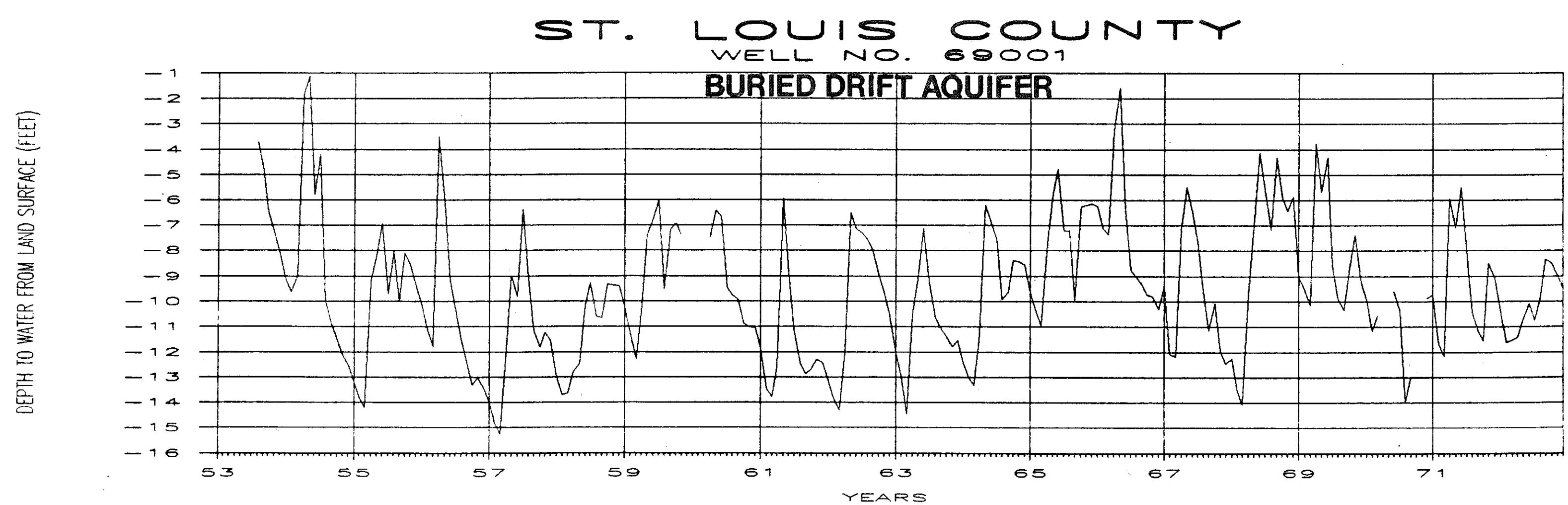
HYDROGRAPH NO. 1



HYDROGRAPH NO. 2



HYDROGRAPH NO. 3



HYDROGRAPH NO. 4

In summer, when evapotranspiration is at its peak, most rainstorms do not contribute at all to the ground water supply. Levels decline as ground water is lost to streams, springs, plants and other discharge areas. The effects of unusually heavy and prolonged summer rainstorms can be observed on the hydrographs as sporadic rises or the rate of decline may be lessened. It is important to note is that even in a year of average precipitation, the ground water level declines during this period (Baker, Nelson and Kuehnast, 1979).

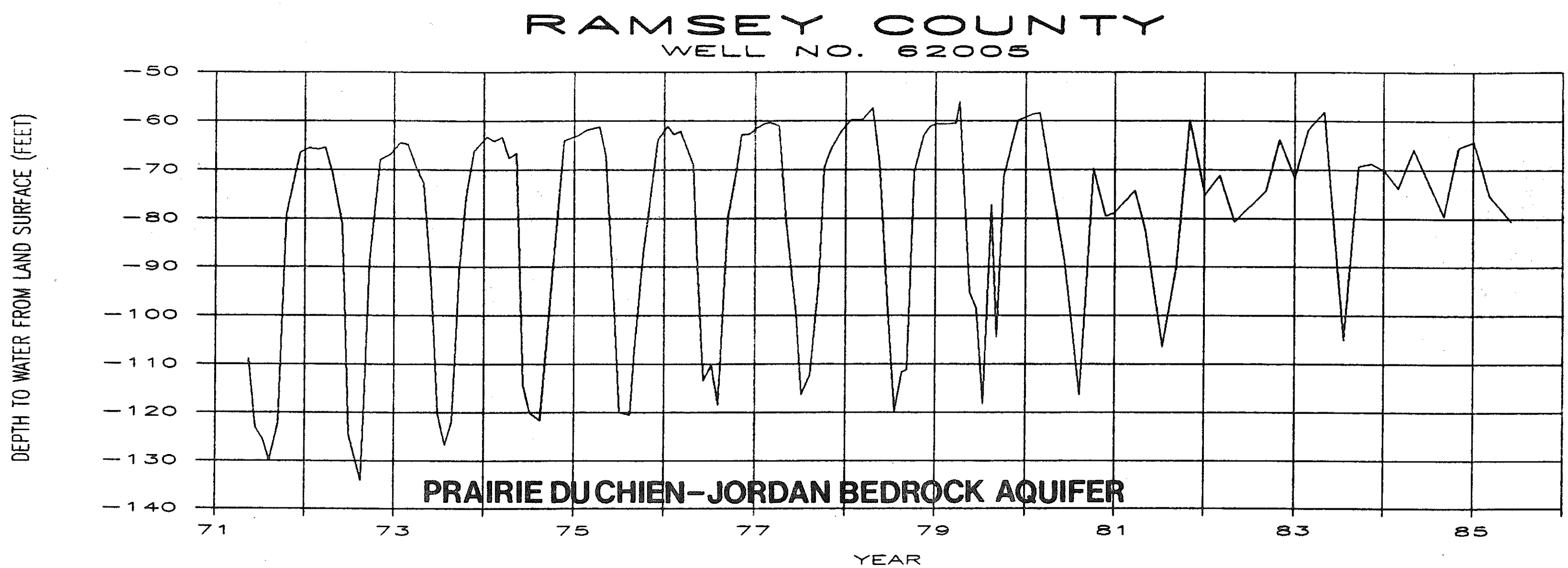
In fall, with the return of cool weather and the dormant period for vegetation, rainfall is no longer lost to evapotranspiration and is available for soil replenishment. Rainfall entering the soil must first replenish the unsaturated soil matrix which had been depleted during the summer. It can then move downward and become part of the ground water supply. Ordinarily, little water is left to percolate into the ground water system. Consequently, the fall stage will have either declining water levels or a small recharge period. The Wadena Hydrograph appears about equally divided between years with small fall recharge and those with no fall recharge. Nevertheless, this recharge period is much smaller than the spring recharge event.

In winter, frozen ground curtails recharge and water levels decline because ground water is discharged into streams and lakes. The lowest water levels commonly occur in early spring just before the ground thaws.

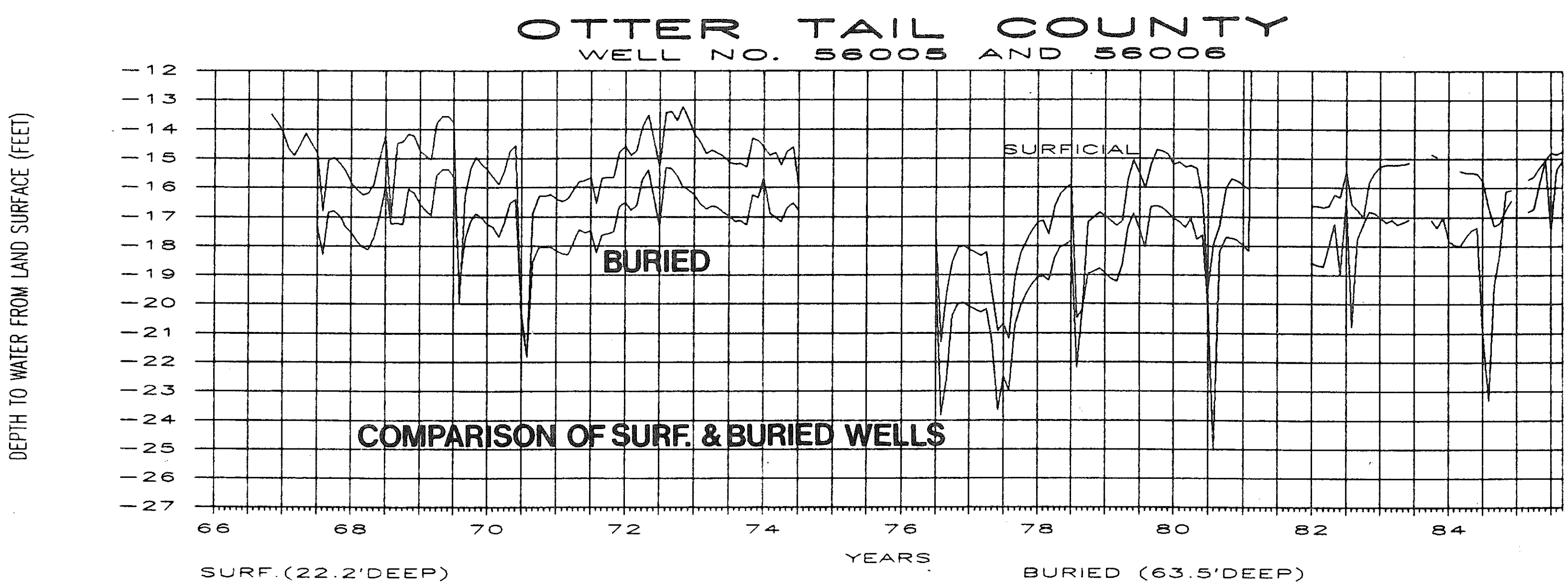
Hydrographs #3 and #4 illustrate seasonal water level patterns for a confined buried drift aquifer in St. Louis County. The seasonal pattern illustrated on these hydrographs is similar to Hydrographs #1 and #2. The St. Louis County well is screened in sand at a depth of 40 feet below the land surface and 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.

SEASONAL TRENDS - EFFECT OF LARGE PUMPAGE

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.



HYDROGRAPH NO.5

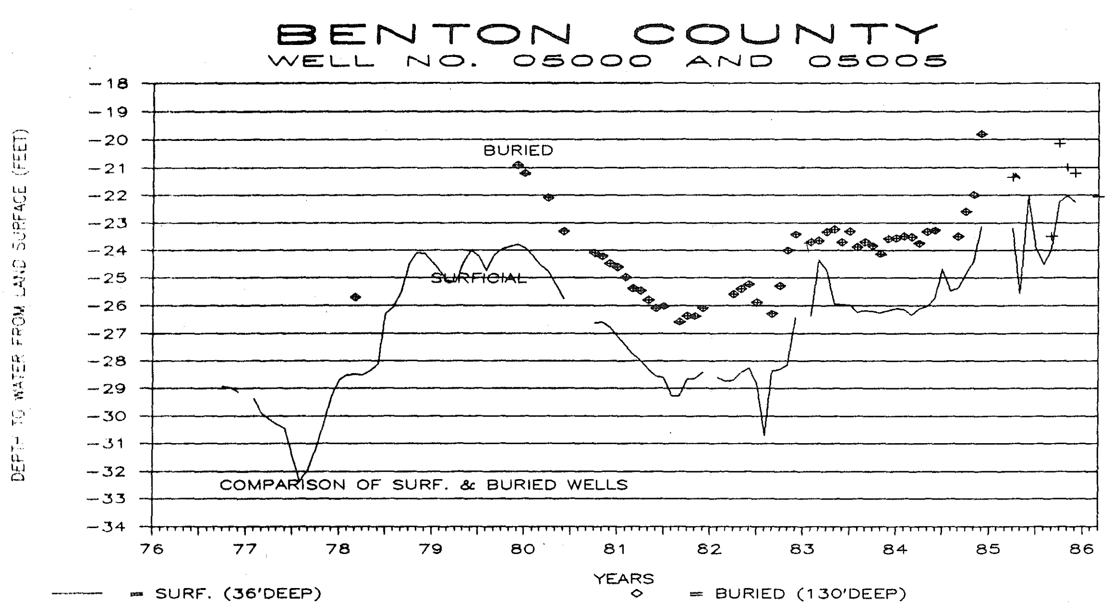


HYDROGRAPH NO.6

COMPARING WATER LEVELS WITHIN LAYERS OF AQUIFERS

The similar water level fluctuations of the two aquifers shown on Hydrograph #6 is 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 aquifer. For example, water withdrawn for irrigation from the buried 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.

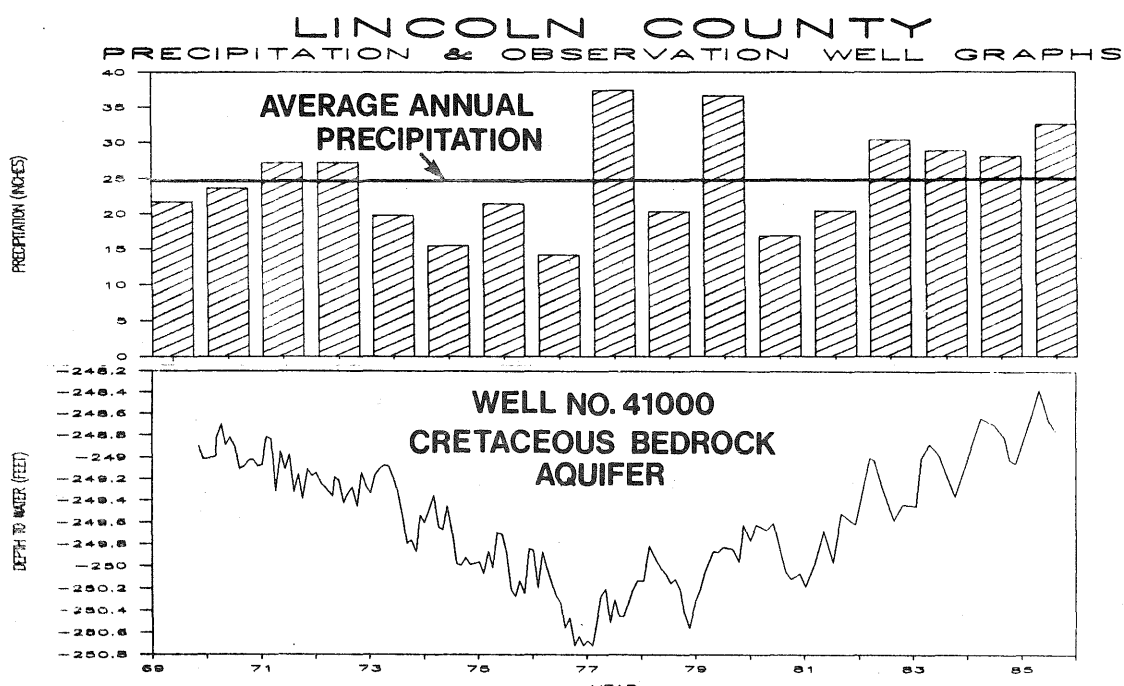


HYDROGRAPH NO. 7

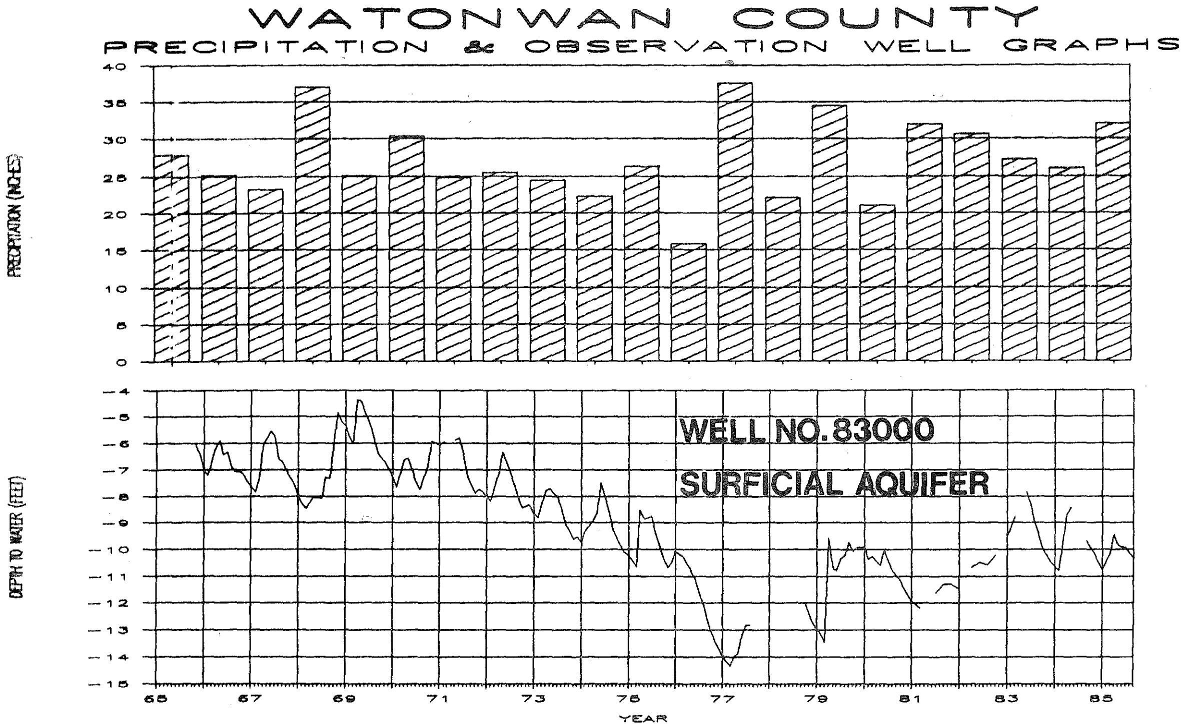
LONG TERM TRENDS - EFFECT OF PROLONGED CLIMATE CHANGES

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

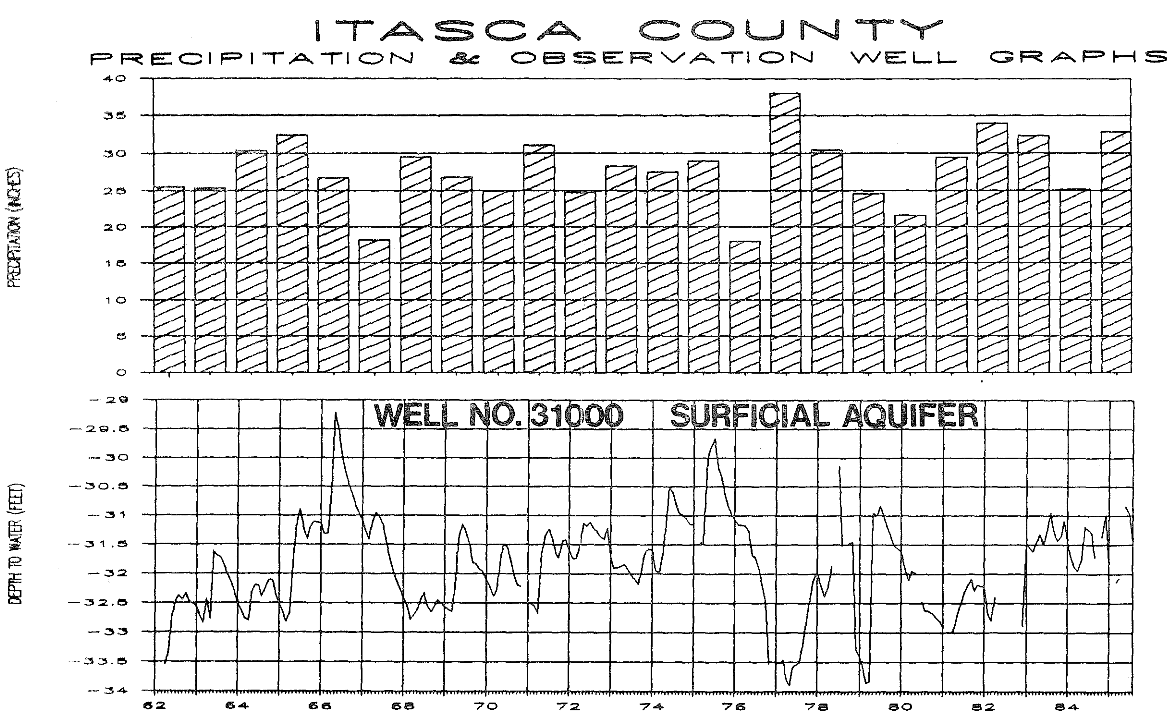
Hydrograph #8, a confined bedrock aquifer in Lincoln County, shows two very distinguishable trends. The decline in water levels between 1969 and 1977 is marked by 8 consecutive years when annual precipitation was generally below the normal 25 inches and averaged only 21 inches. The nine following years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



HYDROGRAPH NO. 8



HYDROGRAPH NO. 9



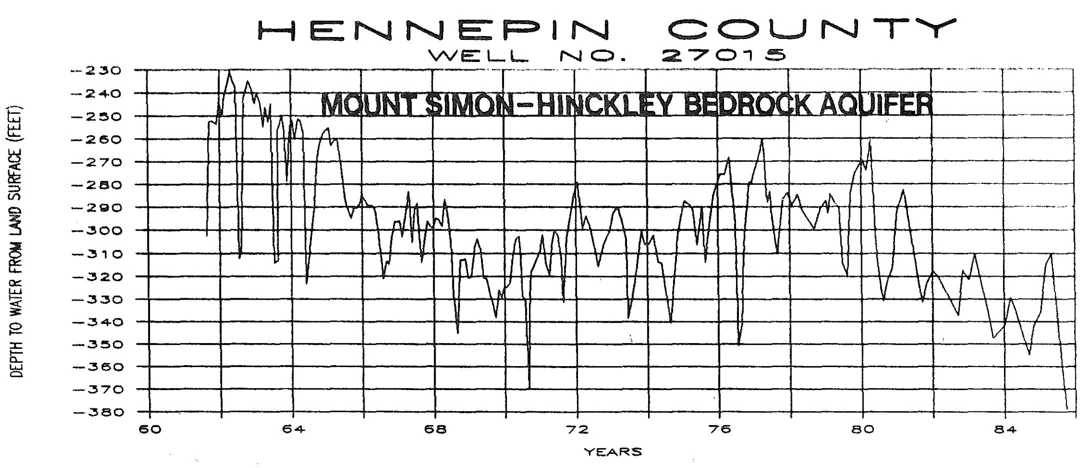
HYDROGRAPH NO. 10

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 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.

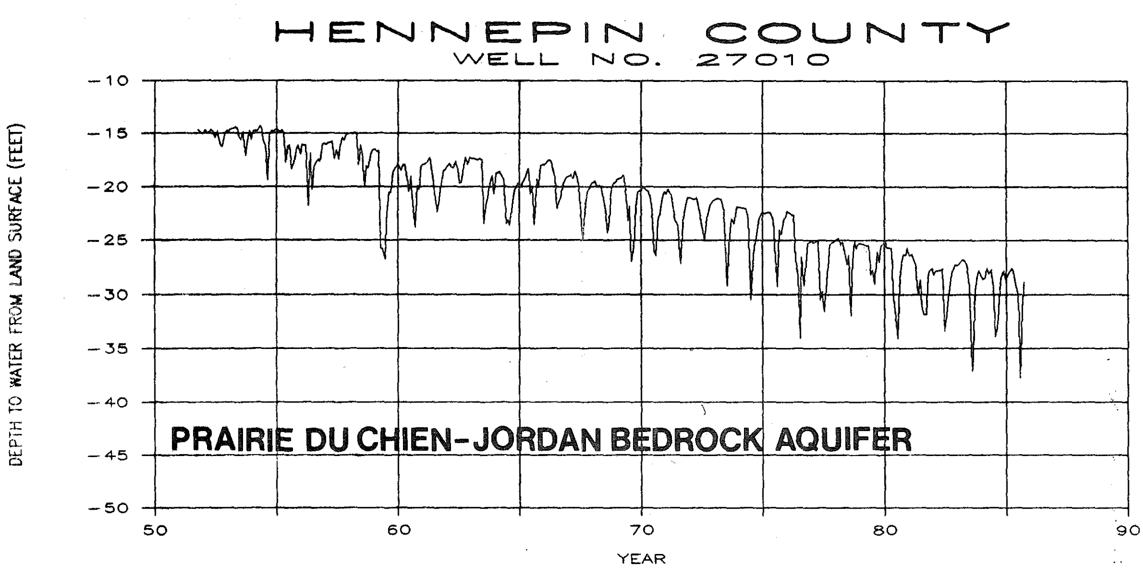
LONG TERM TRENDS - EFFECT OF PUMPING

Hydrograph #11 for an observation well in Hennepin County has interesting long-term trends which are largely associated with ground water appropriation. This hydrograph shows ground water levels for a 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 (Schoenberg, 1984).



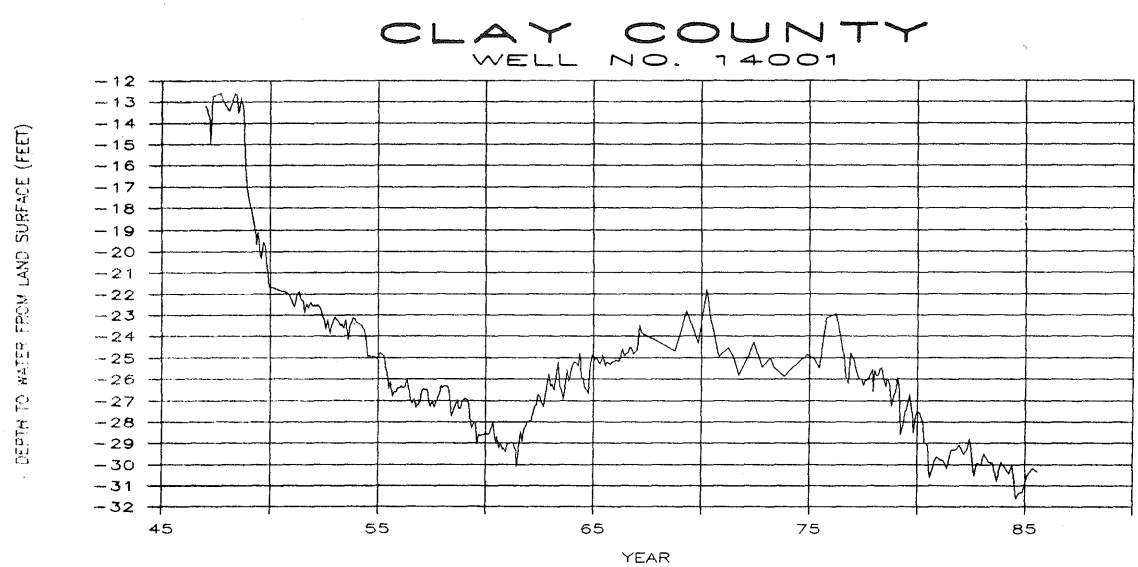
HYDROGRAPH NO. 11

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 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 local ground water decline 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 Twin Cities ground water needs. Future ground water allocation problems, related to lower water levels, will only be avoided by careful management of the use of this resource.



HYDROGRAPH NO. 12

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 are observed to drop steadily from the first record in 1947 to 1962. Starting in 1962, levels have started to increase and remained relatively stable from 1963 to 1978. Since 1978, levels are beginning to drop 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.



HYDROGRAPH NO. 13

AIDS TO INTERPRETING HYDROGRAPHS

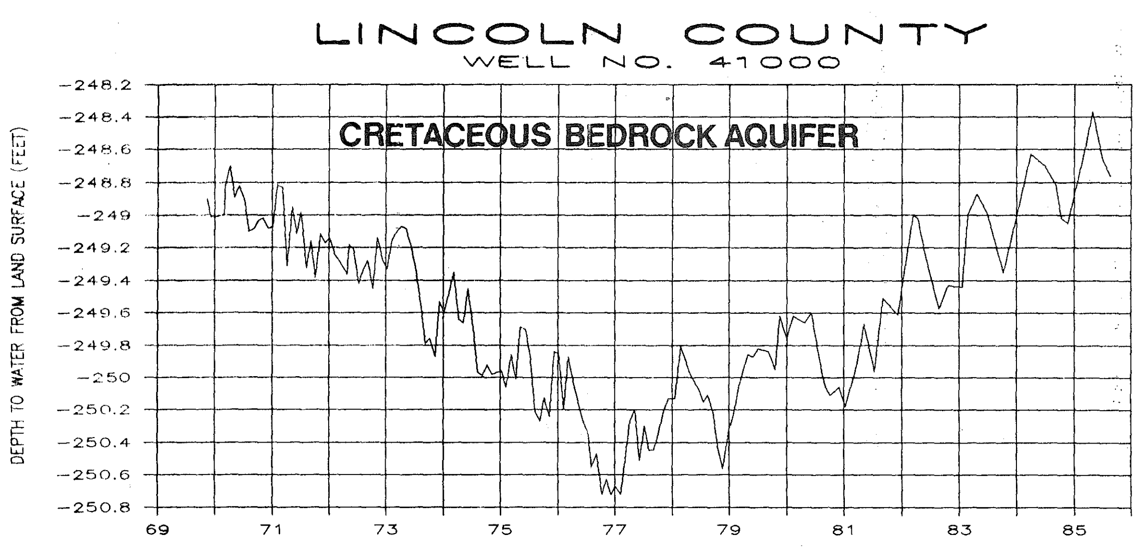
Hydrographs 14-17 demonstrate some practical aspects of ground water hydrograph interpretation. These are two steps: 1) observing a trend, abnormality or point of interest and 2) answering why this trend occurred. Erroneous conclusions can result from misinterpretation of ground water hydrographs. Five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

SCALE

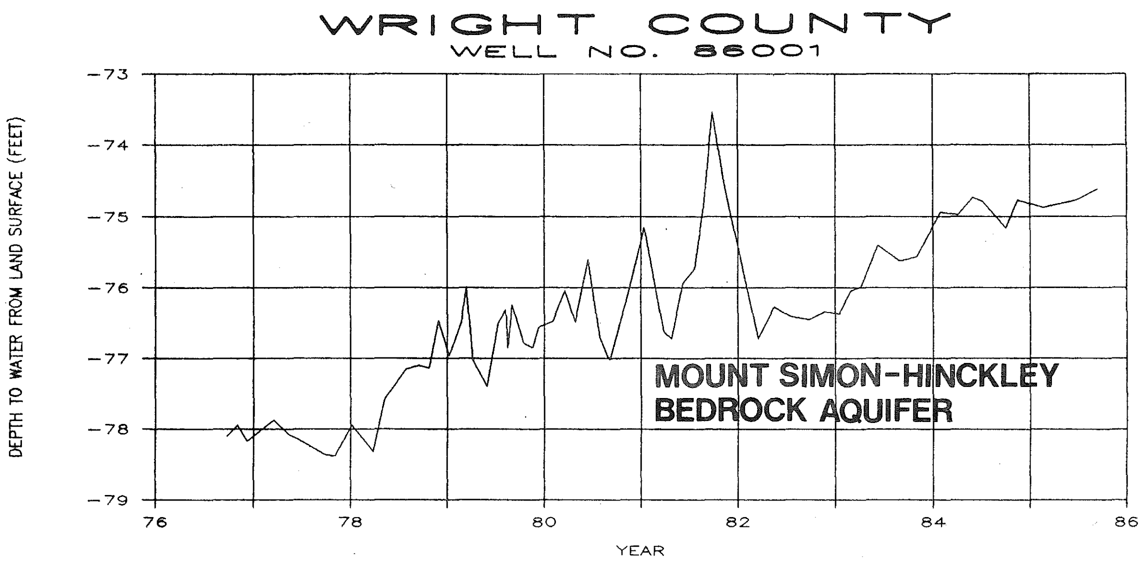
Hydrograph 14 shows how scale can be very misleading. The long drawdown for the first half of this record is quite alarming. But if you'll look again you'll note the maximum difference is 2.5 feet. Not so bad after after all! Despite its small amplitude, this trend has resulted from prolonged variation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

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 this rise is probably recovery from the very low levels that occurred in 1976 and that current levels are probably near normal.



HYDROGRAPH NO. 14



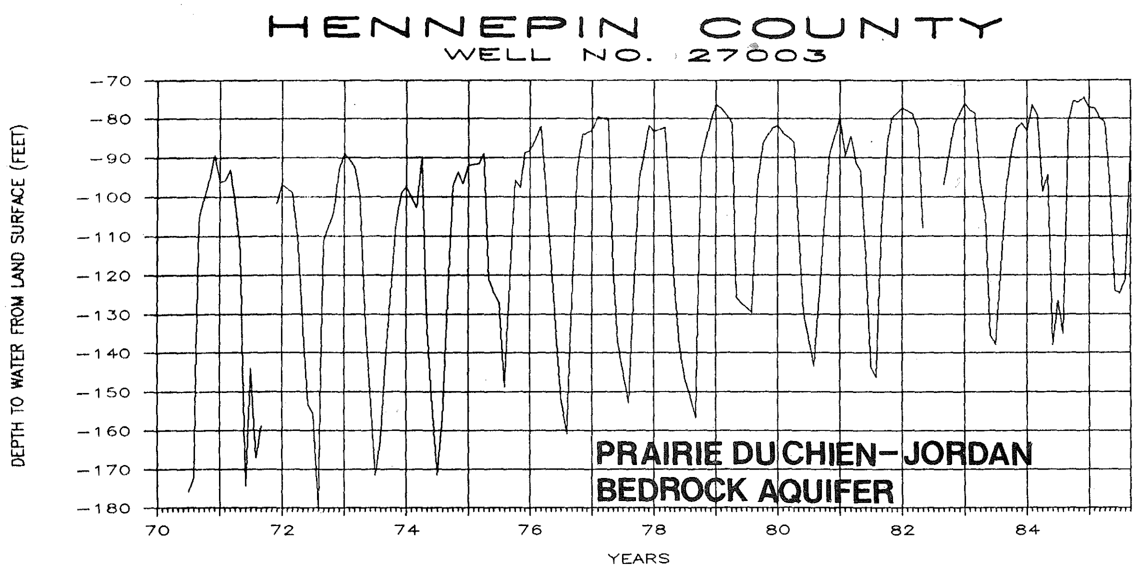
HYDROGRAPH NO. 15

HYDRO-GEOLOGICAL CONSIDERATIONS

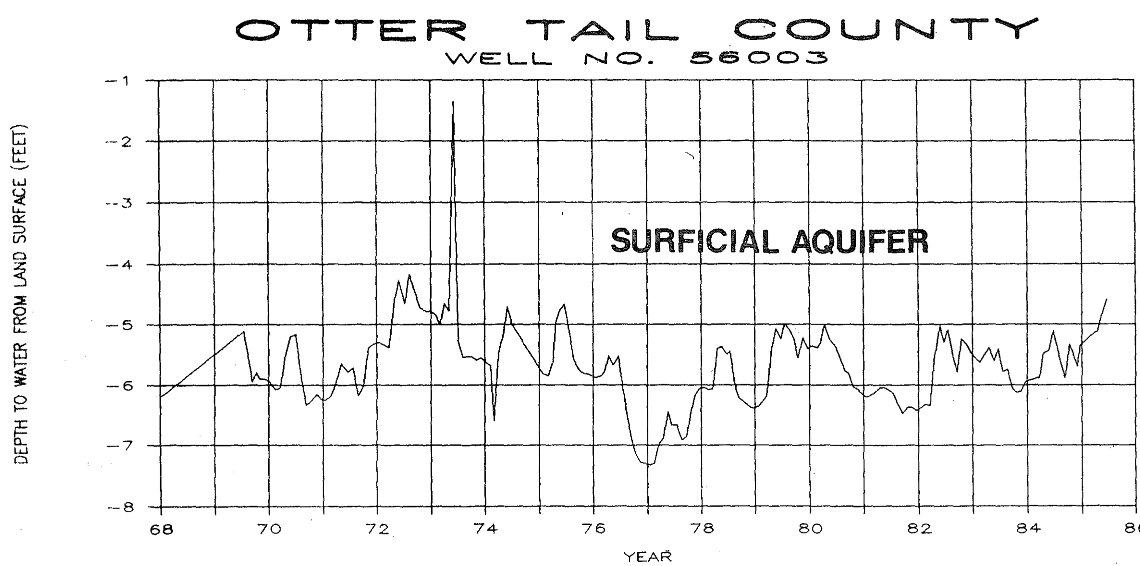
Interpretation of ground water data must be appropriate for the given aquifer. Consideration must be given to the aquifer condition (confined or unconfined), recharge rate, size, storage and permeability. The 80 foot seasonal drawdown for the confined bedrock aquifer shown on hydrograph #16 is replenished 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 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 42). 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. 16



HYDROGRAPH NO. 17

ERRORS OR QUESTIONABLE DATA

Errors in observation well data that go unnoticed while data is being gathered and inputted into the observation well network glaringly come to surface when plotted on a hydrograph. Such is the case for the spike in water levels for 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 its origin. If a source of error in not located, the data in question remains in the network. The user must determine if this data is valid.

State Ground Water Overview

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 pumpage and do 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 although present levels are above the long term norm.

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:

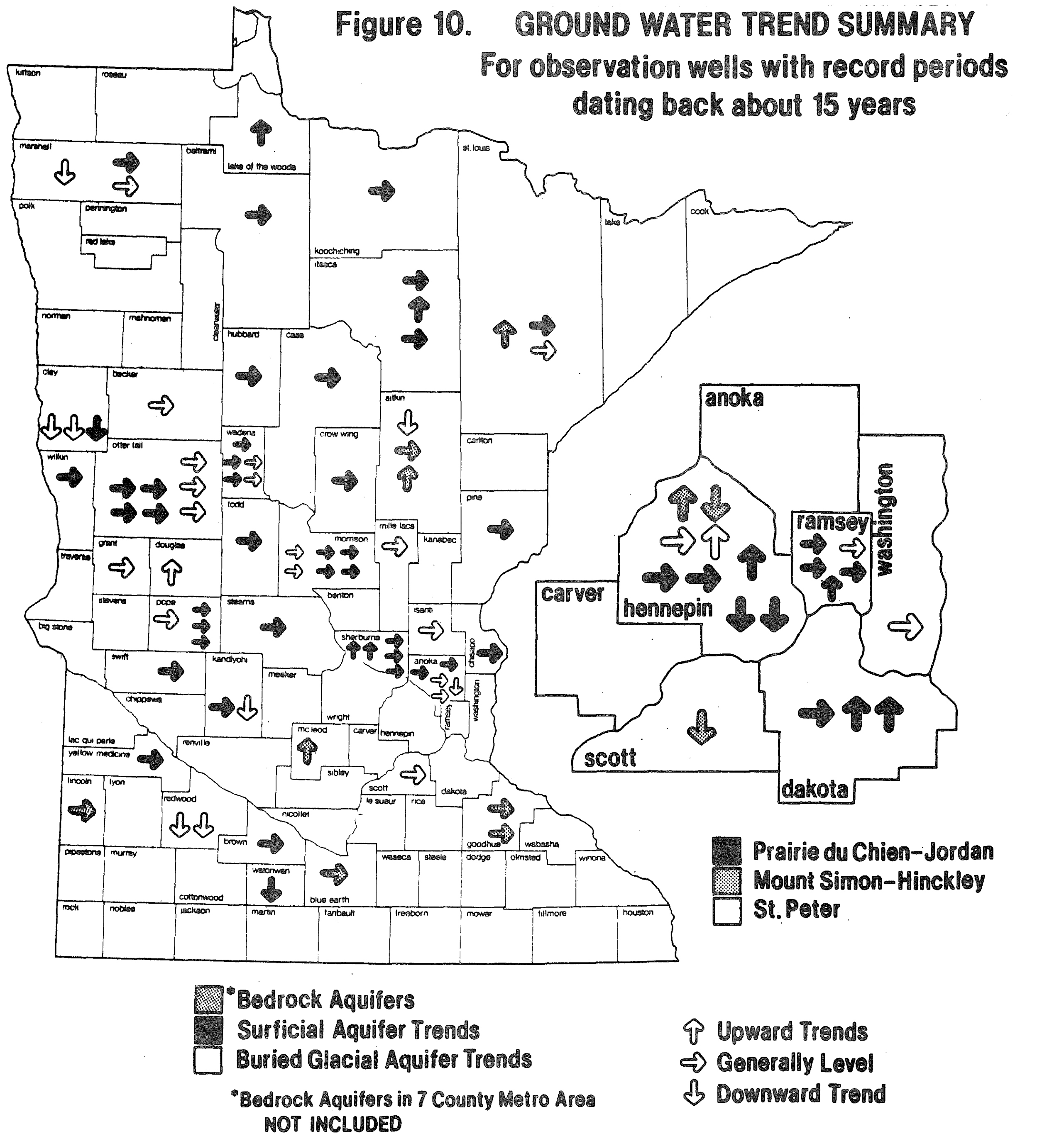
* present levels are above the long term average and are at or nearly at record highs.
* record lows commonly occurred in the spring of 1977 resulting from a statewide drought in 1976-1977.
* ground water levels from 1977 to present have slowly recovered to predrought levels and, in many cases, have reached new highs.
* a smaller drought in 1980 caused ground water levels to decline in many parts of Minnesota.
* highest ground water levels typically occurred in 1972, 1975, 1979 or at present. These peak levels follow large rainfall events or unseasonable wet springs and/or summers.
* ground water levels that are affected by pumpage do not generally reveal climatic trends.

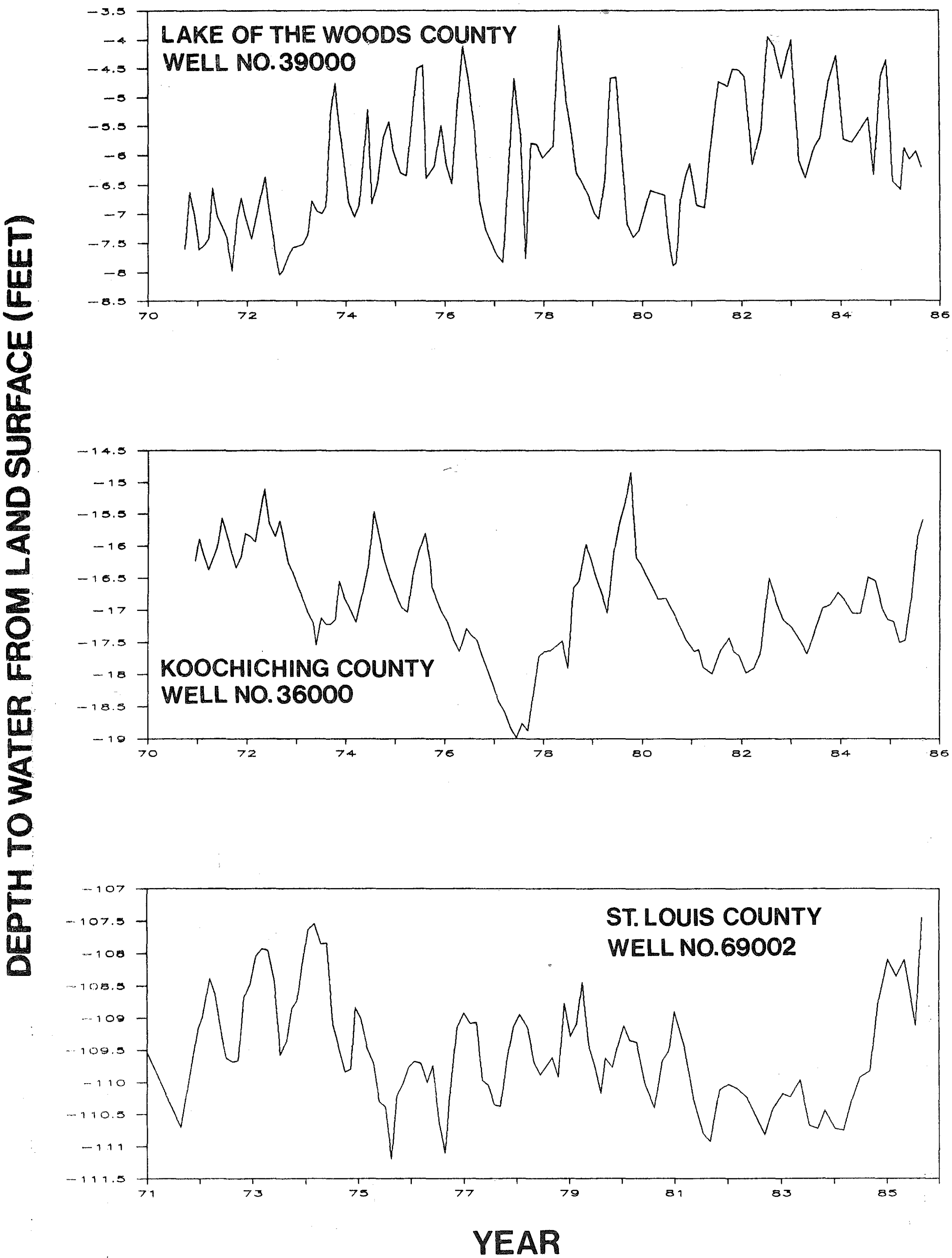
Many of the ground water hydrographs used to summarize the long term ground water trends on this map are included in this section. These are presented to show a regional review of ground water levels for each aquifer type surficial, buried drift and bedrock aquifers. Hydrographs for other observation wells may be obtained by writing to the address printed on the inside cover. The breakdown of hydrographs shown is as follows:

* 10 hydrographs that typify ground water levels in surficial aquifers

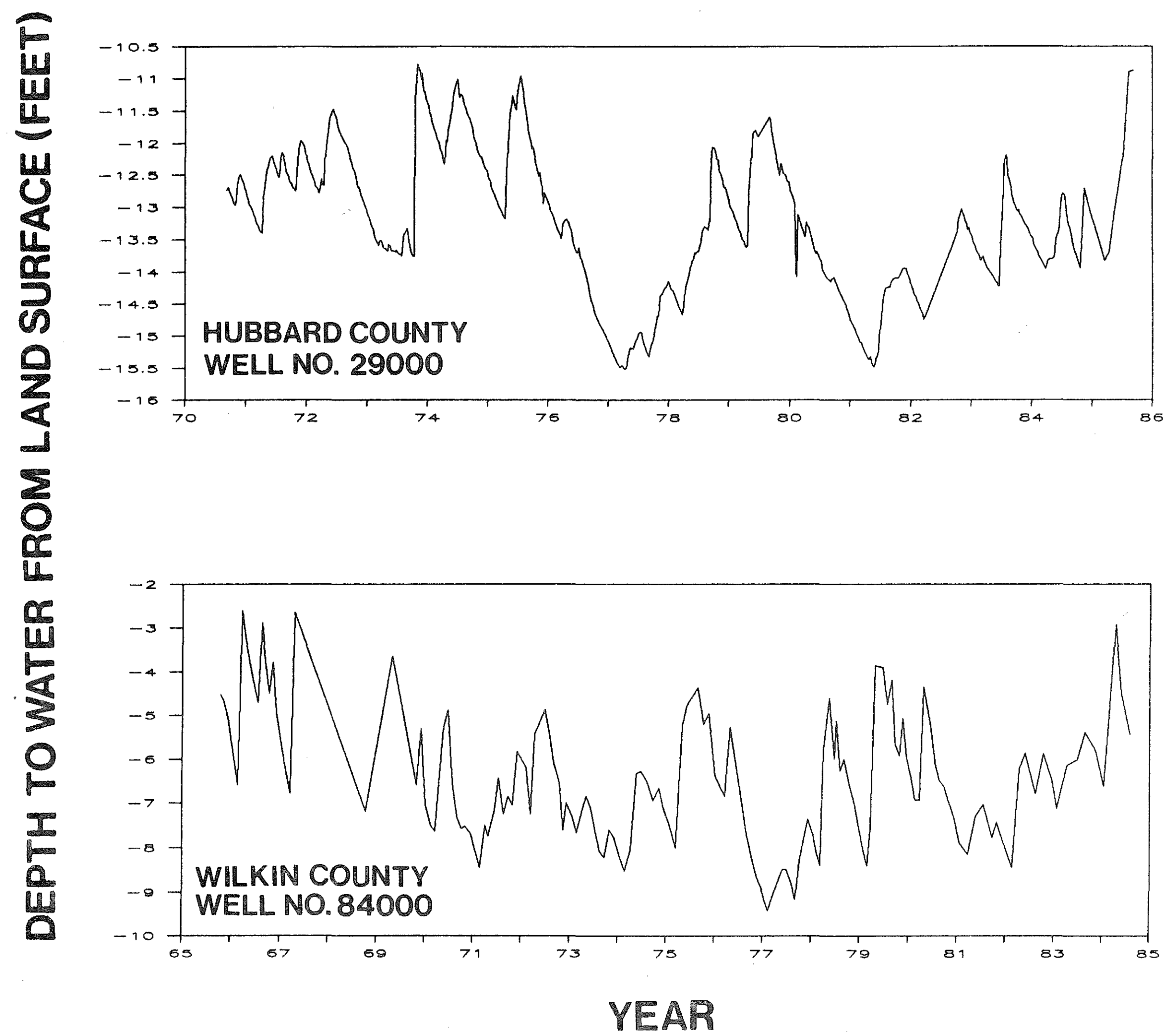
* 10 hydrographs that typify ground water levels in surficial aquifers
* 4 hydrographs that show abnormal ground water trends (trends that differed significantly from regional trends) in surficial aquifers
* 10 hydrographs that typify ground water levels in buried drift aquifer
* 5 hydrographs that show 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

Figure 10. GROUND WATER TREND SUMMARY
For observation wells with record periods dating back about 15 years





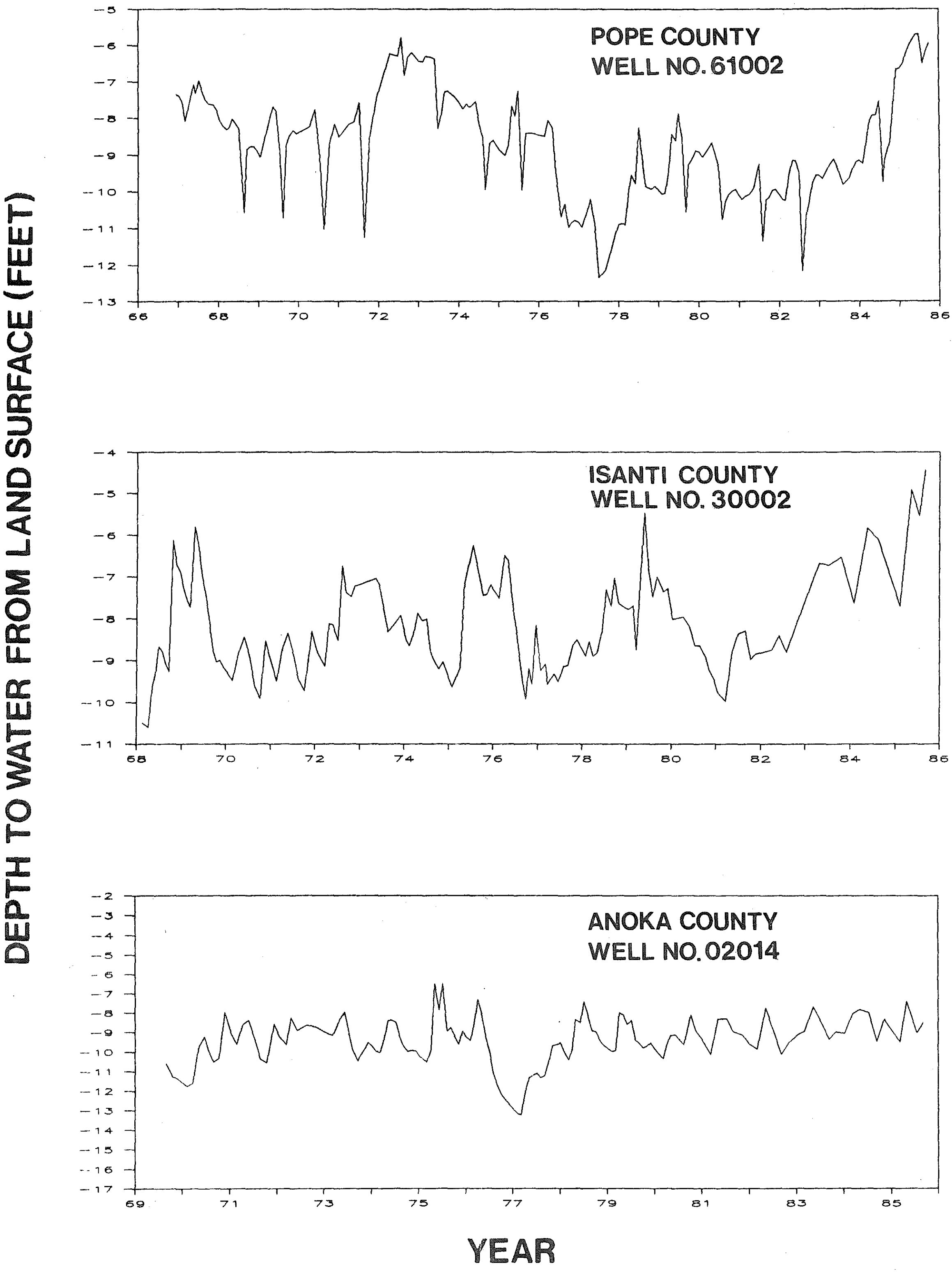
Regional Ground Water Levels in Surficial Aquifers



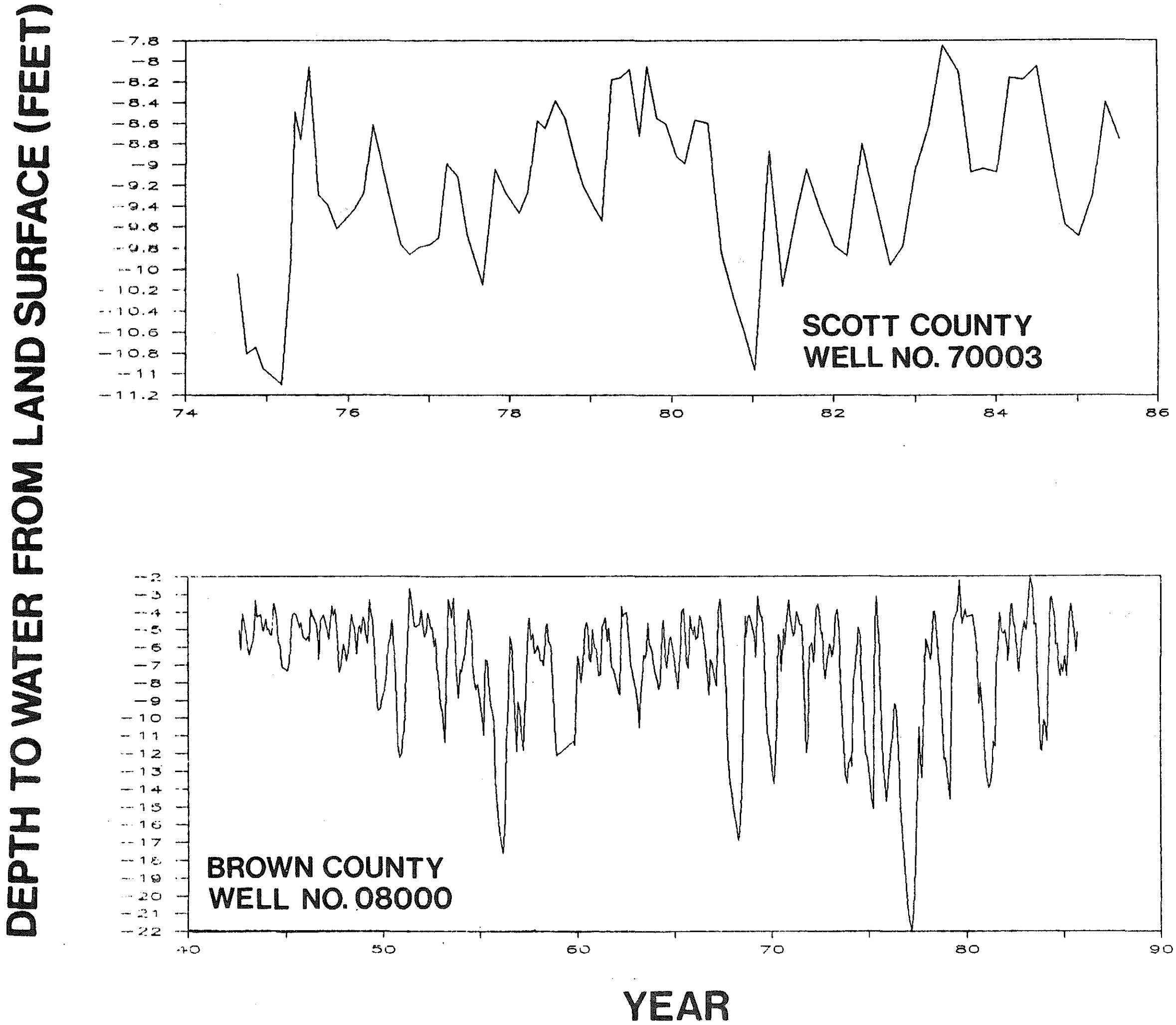
These 5 hydrographs show ground water trends in surficial aquifers in the northern half of Minnesota.

* Present levels are among the highest recorded and are similiar to levels recorded in early 1970's.
* 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.
* Levels have generally risen since the 1980 drought. This is largely due to above normal precipitation which is occurring in most of Minnesota.

Regional Ground Water Levels in Surficial Aquifers



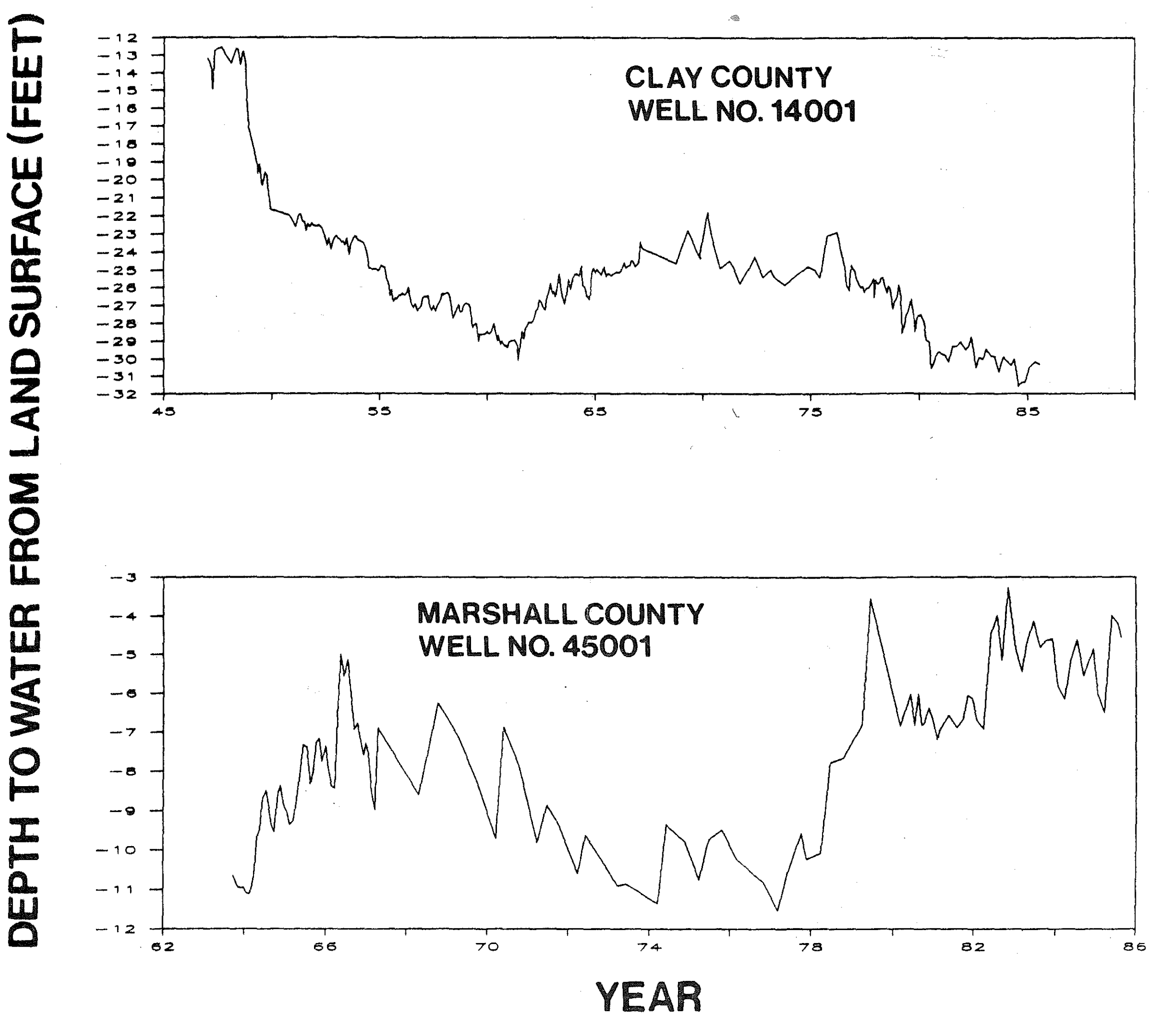
Regional Ground Water Levels in Surficial Aquifers



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

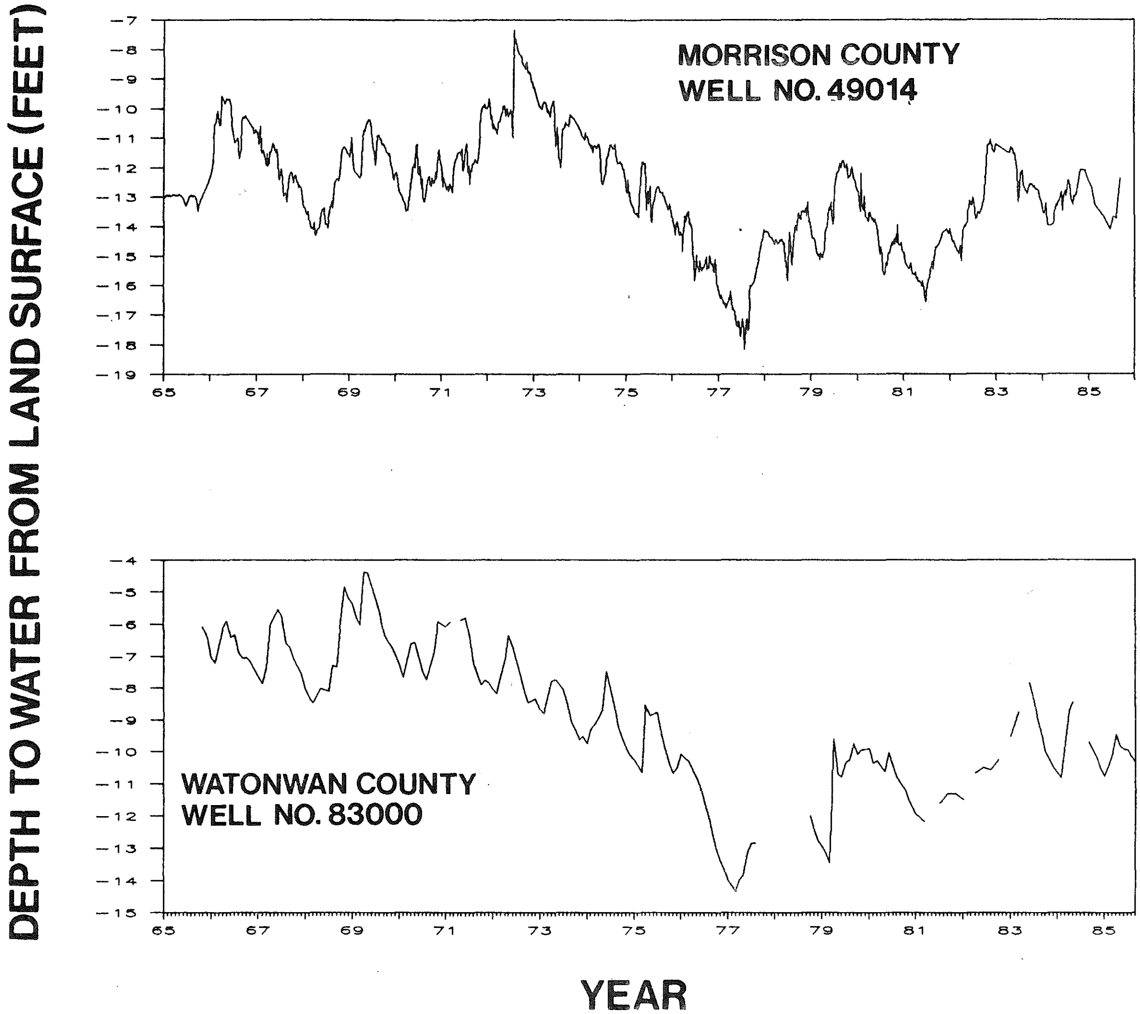
- Present levels are among the highest recorded.
- Lowest levels commonly occurred in the spring of 1977 resulting from the 1976-77 drought.
- Ground water levels from the above drought appear to have recovered quite quickly, generally by 1979.
- The small drought of 1980 is evident on most hydrographs.
- Levels have generally risen since the 1980 drought.
- The Brown County hydrograph dates back to 1942, the start of the network. Its ground water levels have remained stable over the 45 year period.

Regional Ground Water Levels in Surficial Aquifers



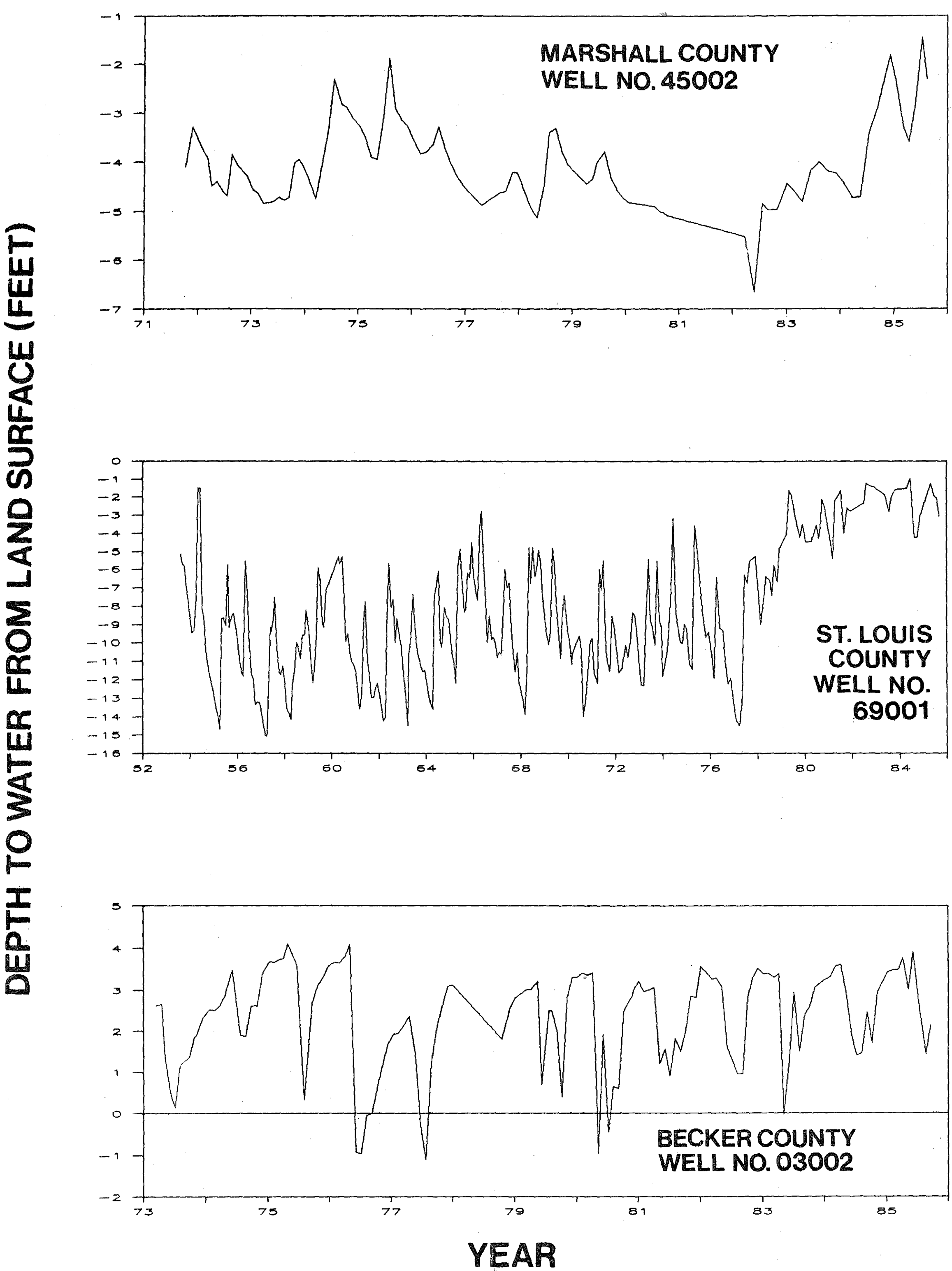
- Water level decline in the Clay County observation well is due to pumping from the Buffalo Aquifer near Moorhead.
- The water level decline for the period between 1966 and 1976 in the Marshall County observation well is unusual.

Abnormal Ground Water Levels in Surficial Aquifers

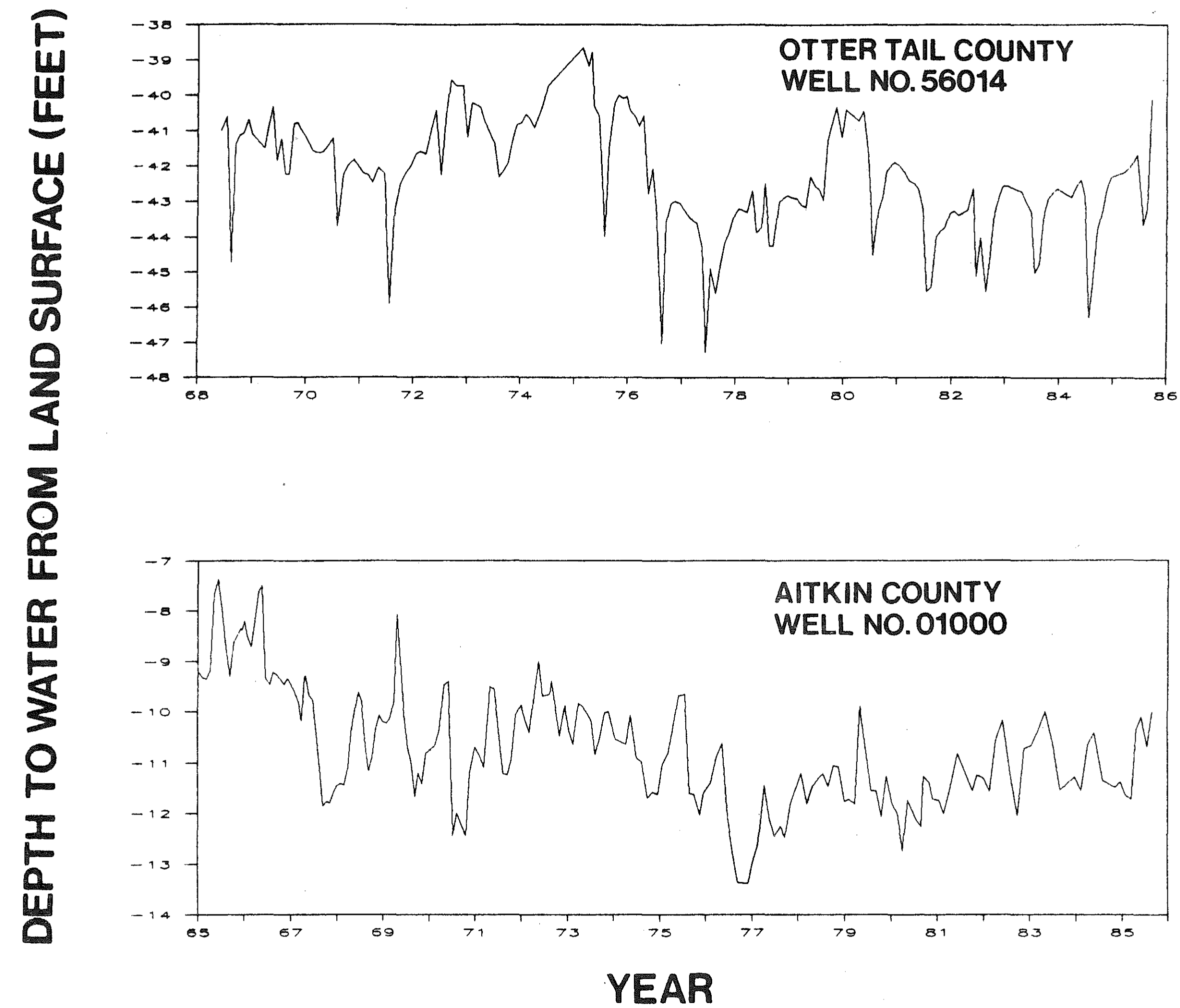


* The water level decline from 1972 to 1977 in the Morrison County observation well does not show up in any other observation well in central Minnesota. Generally, wells in central Minnesota show a decline for this period that is interrupted by recharge. Since 1977 the water level trends for this well are 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.

Abnormal Ground Water Levels in Surficial Aquifers



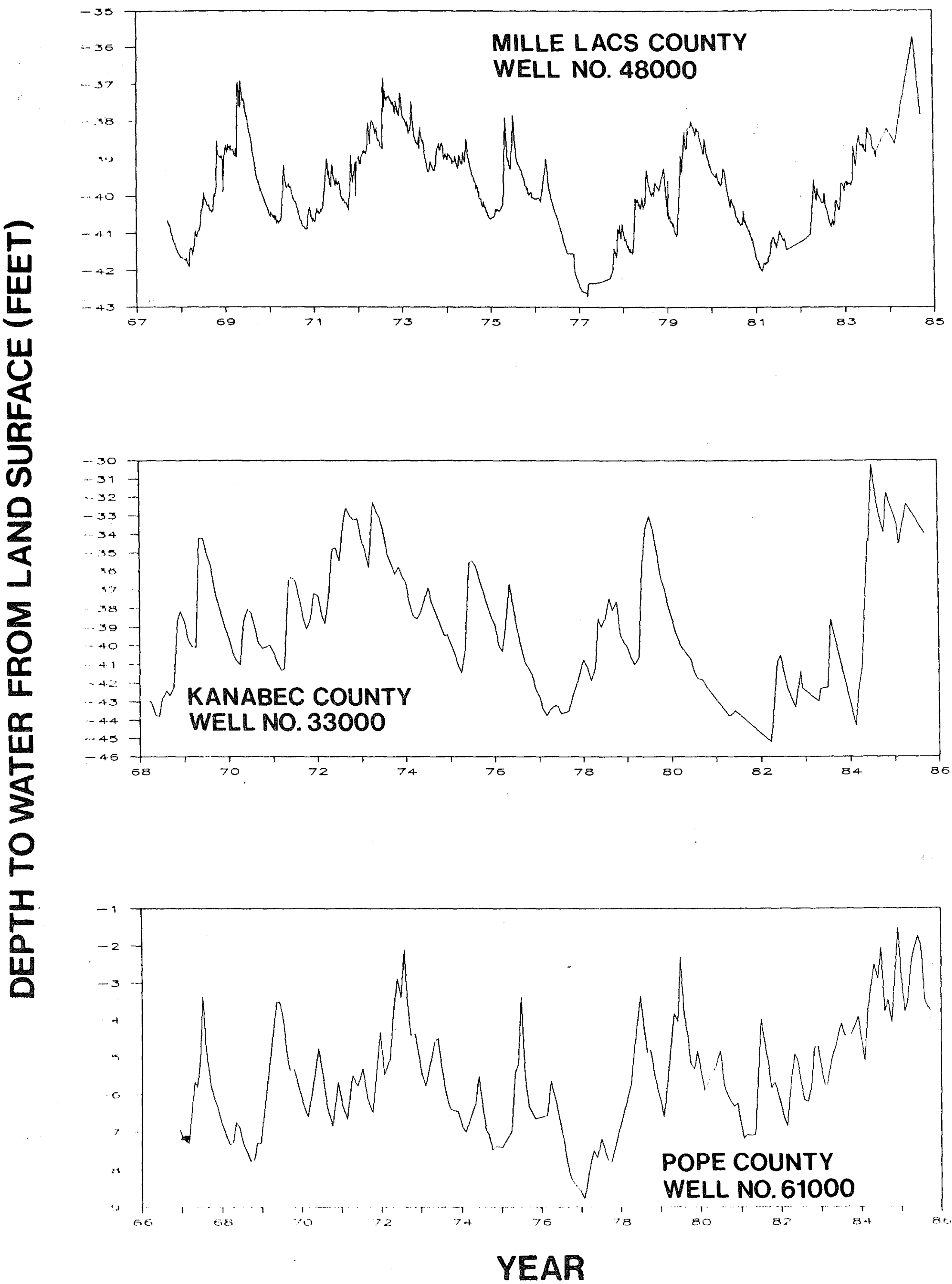
Regional Ground Water Levels in Buried Drift Aquifers



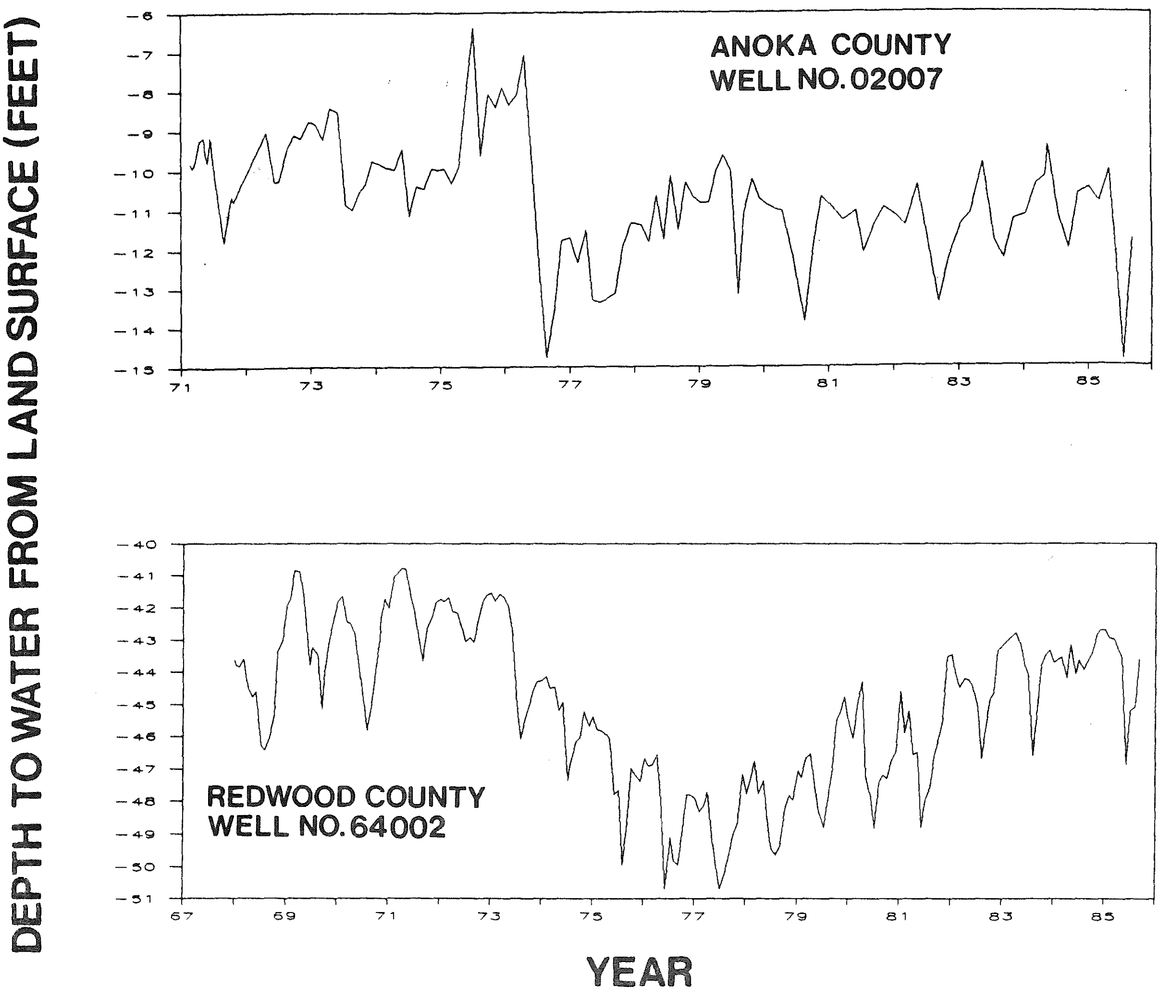
These 5 hydrographs show ground water trends in buried drift aquifers in the northern half of Minnesota.

- Present levels are among the highest recorded and are similiar to levels recorded in early 1970's.
- The 1976-77 drought is not as distinguishable on some wells in this region as compared to many of the surficial wells. One reason for this is that readings are to 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.
- Levels have generally risen since the 1980 drought. This is largely due to above normal precipitation which is occurring in most of Minnesota.

Regional Ground Water Levels in Buried Drift Aquifers



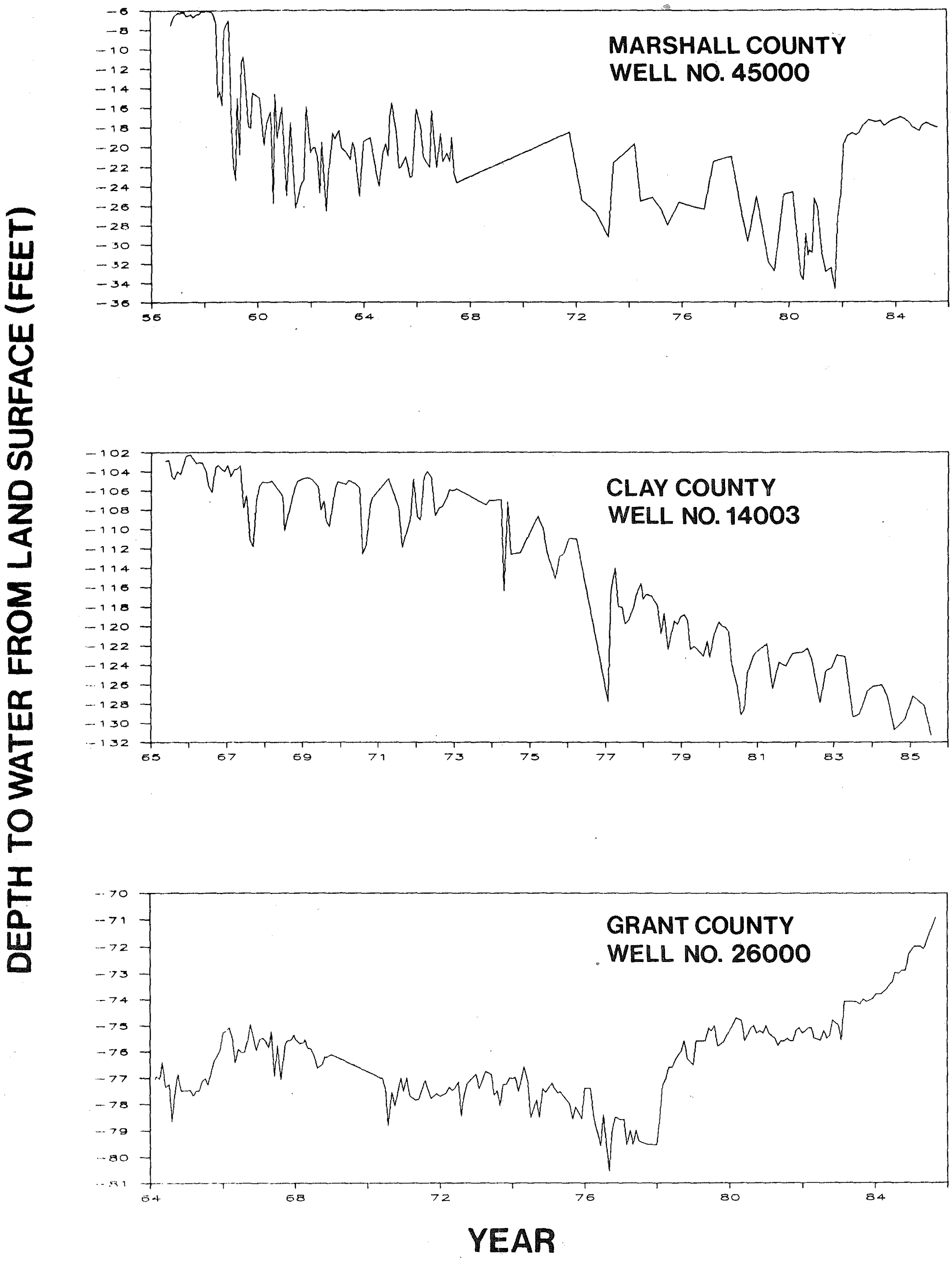
Regional Ground Water Levels in Buried Drift Aquifers



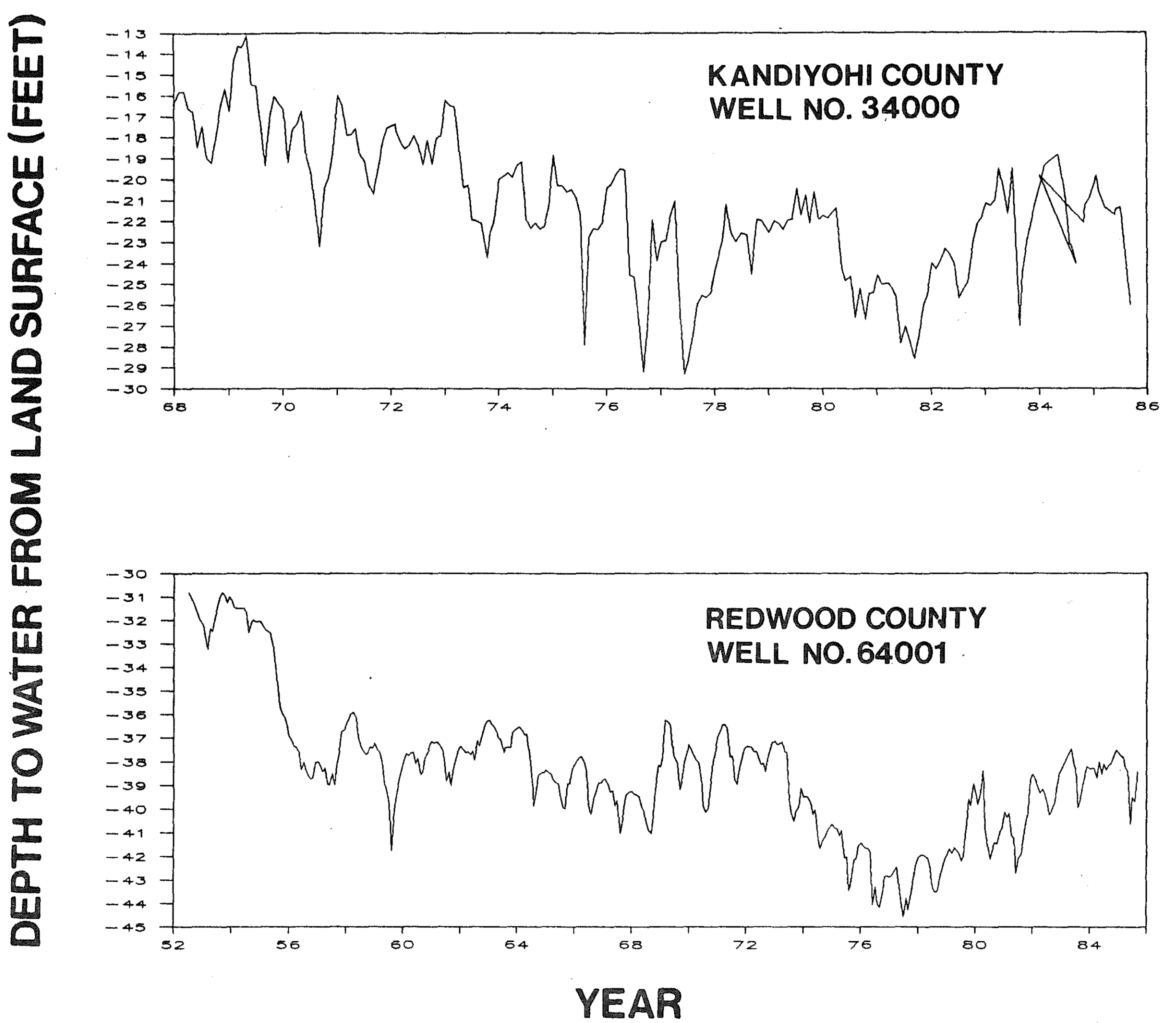
These 5 hydrographs show ground water trends in buried drift aquifers in the southern half of Minnesota.

* Present levels are among the highest recorded.
* Lowest 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 Anoka and Redwood County wells have not fully recovered. There are not enough buried drift observation wells in the southern part of the state to make a statement about this trend.
* The small drought which occurred in 1980 is very evident on most hydrographs.
* Levels have generally risen since the 1980 drought.

Regional Ground Water Levels in Buried Drift Aquifers



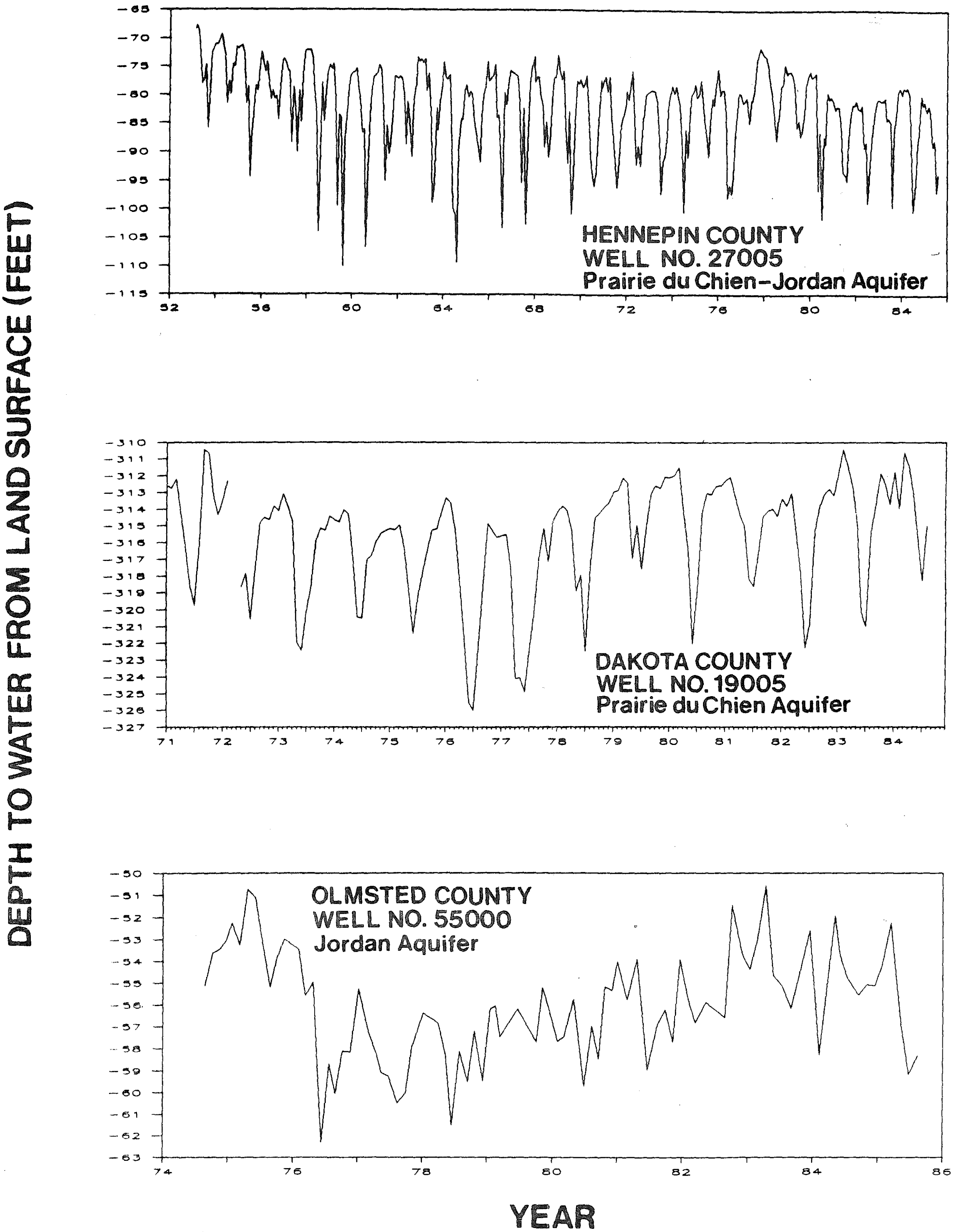
Abnormal Ground Water Levels in Buried Drift Aquifers



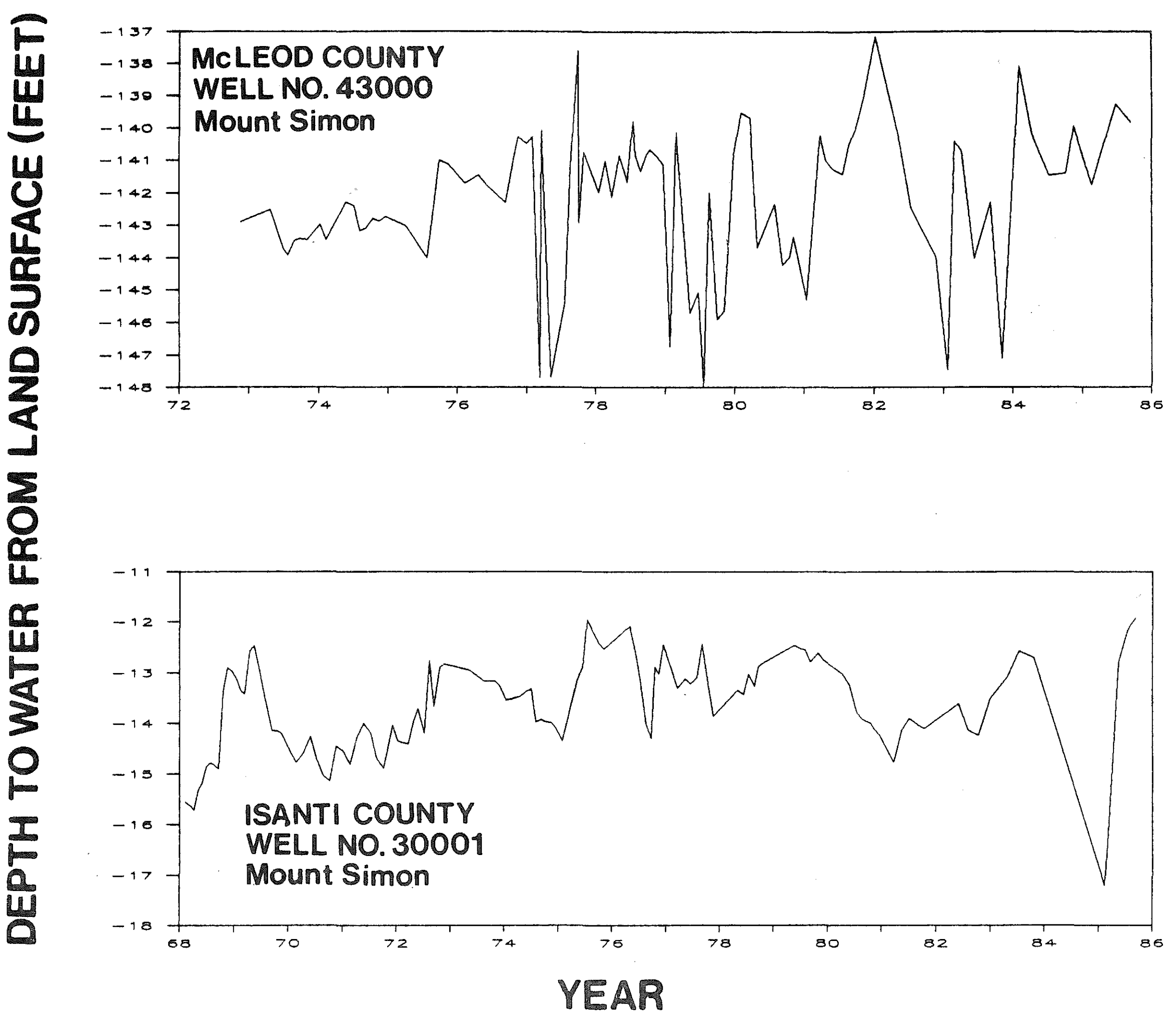
These five hydrographs show abnormal groundwater trends in buried drift aquifers.

- The Clay County observation well is located just outside the Buffalo aquifer near Moorhead. This decline is probably due to pumpage
- The Grant County well's current water levels are several feet above earlier recorded levels for this well.
- The decline in water levels for the first period on graphs in the remaining three counties is generally not observed but does show up on various wells in western Minnesota.

Abnormal Ground Water Levels in Buried Drift Aquifers



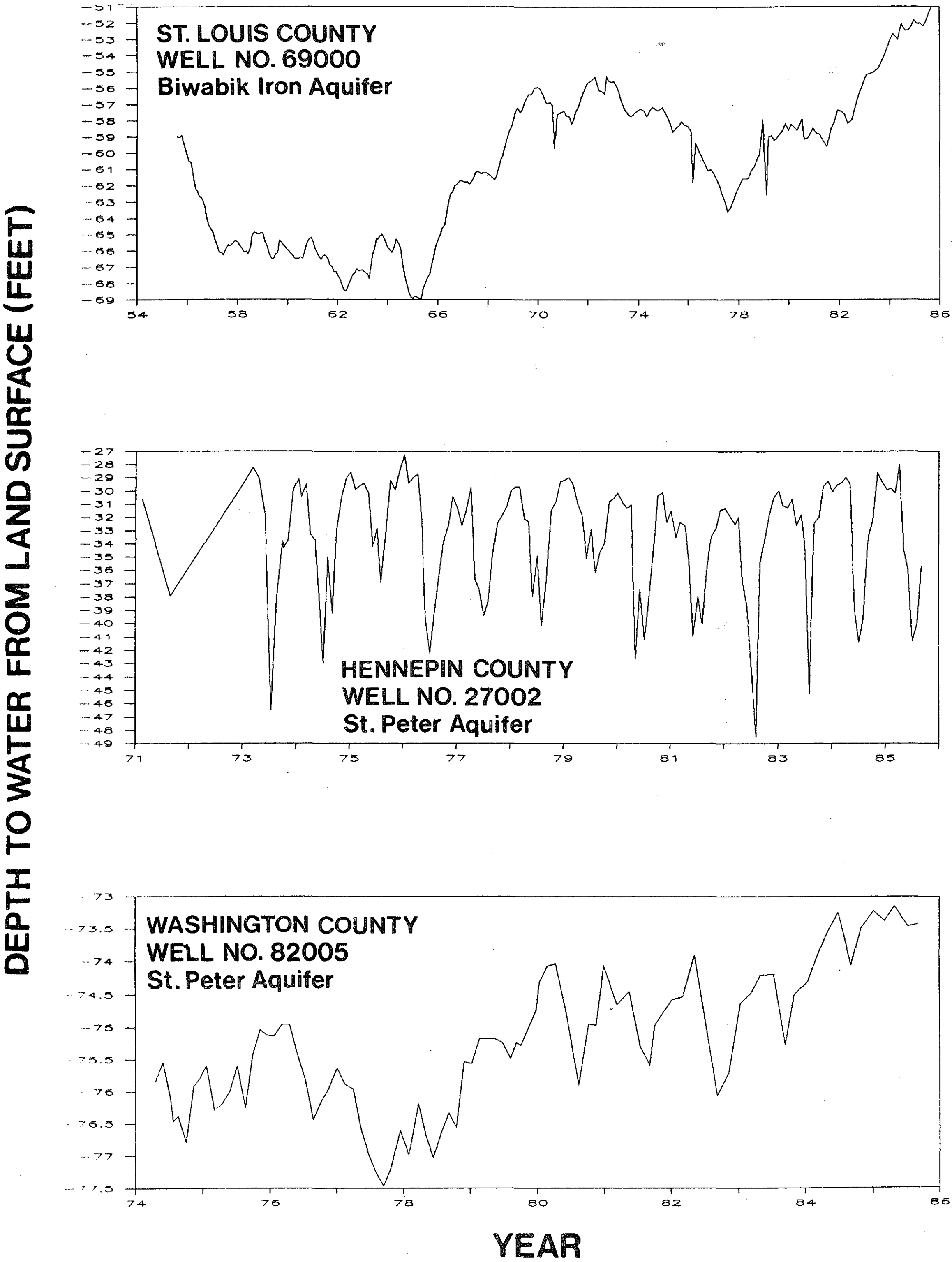
Ground Water Levels in Bedrock Aquifers



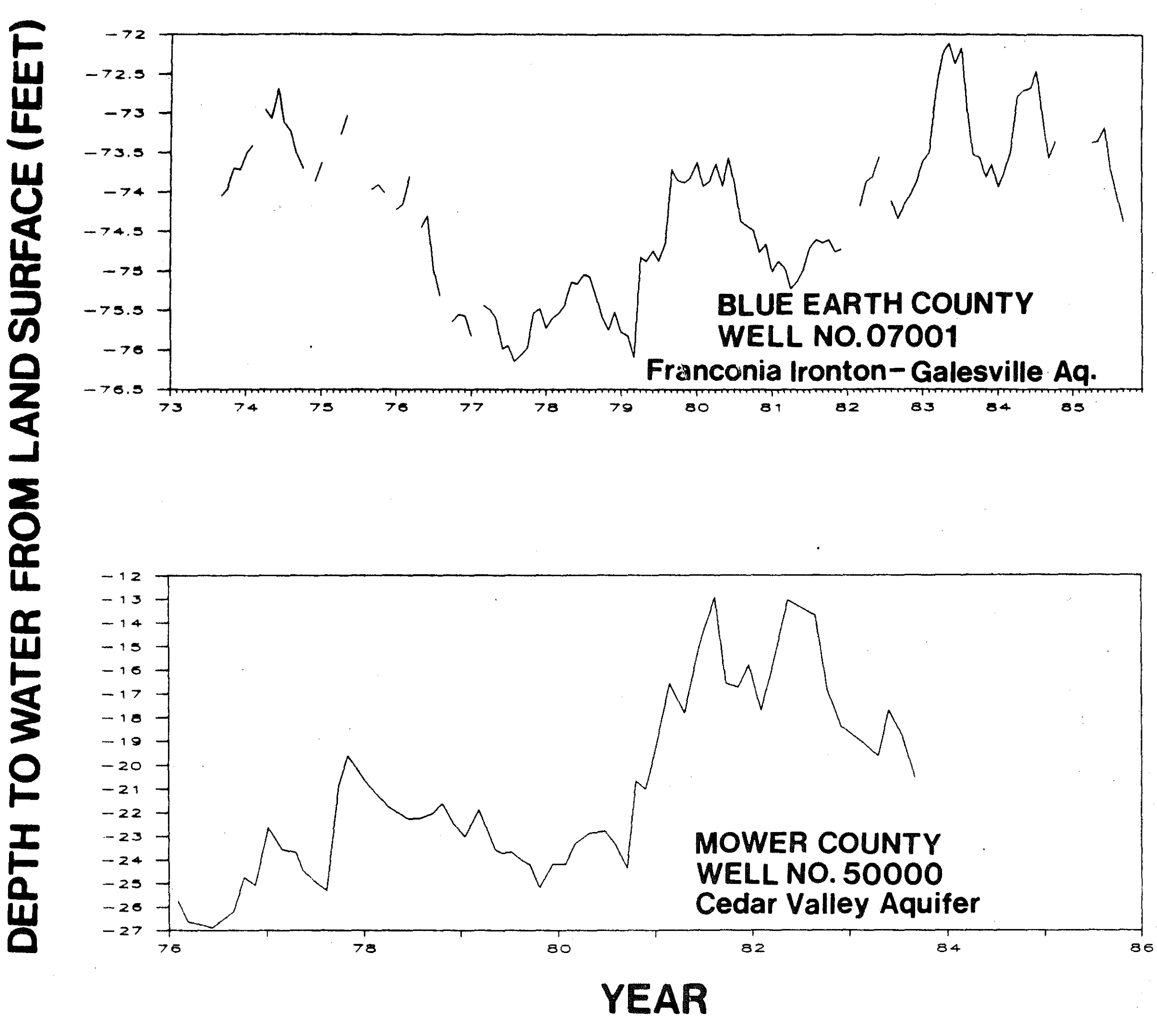
These 5 hydrographs show ground water trends in the Twin Cities two principal aquifers.

* Observation wells that are affected by pumpage do not reveal climatic trends. This is evident on the Hennepin County well. Note that neither drought nor the rise in water levels in the 1980's occurs on this hydrograph.
* The 1976-77 drought is not as evident on these graphs as compared to the surficial and buried drift hydrographs; Olmsted County hydrograph does show this drought.
* The ground water rise (if any) since 1980 in these bedrock aquifers is more subdued as compared to the surficial and buried drift hydrographs.

Ground Water Levels in Bedrock Aquifers



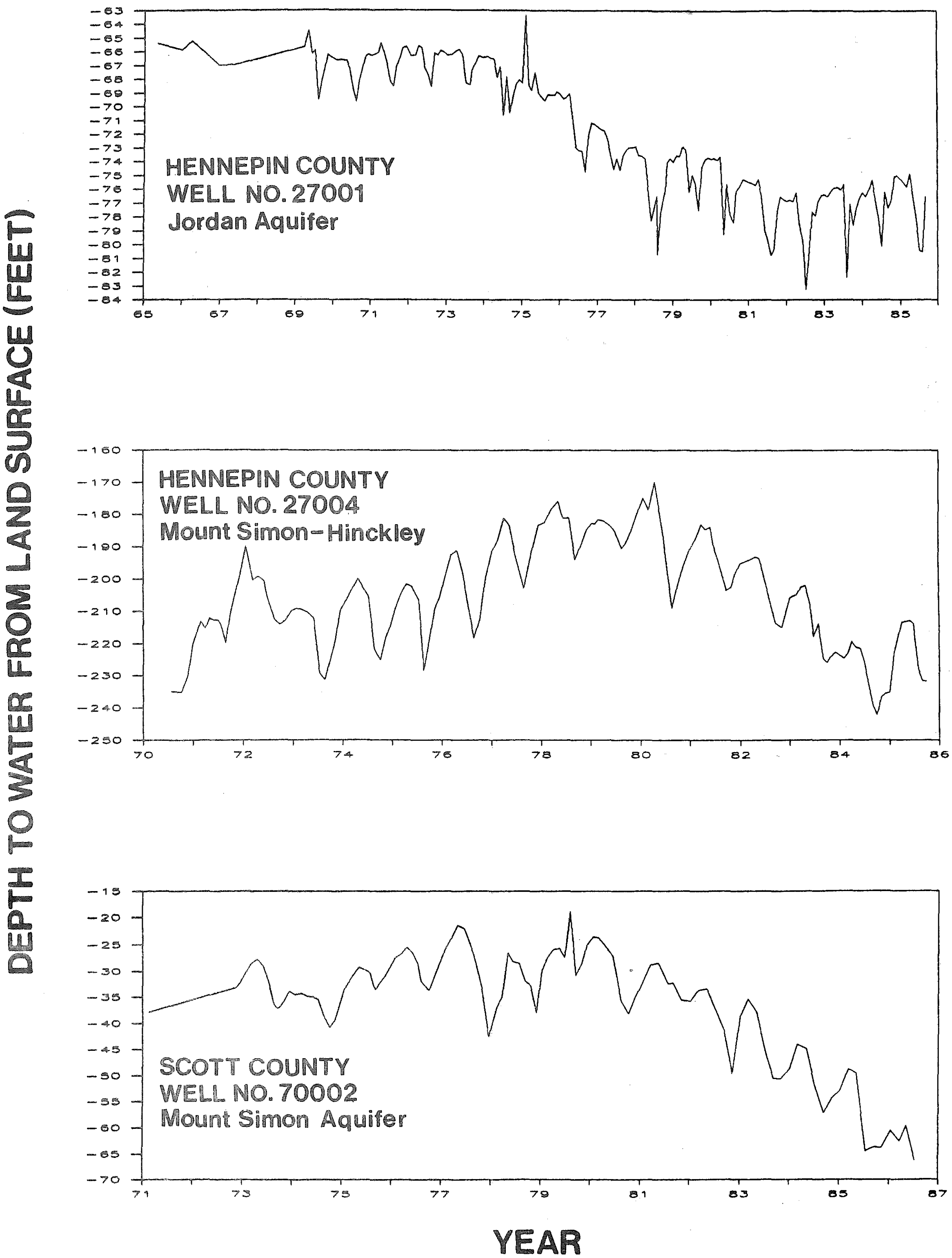
Ground Water Levels in Bedrock Aquifers



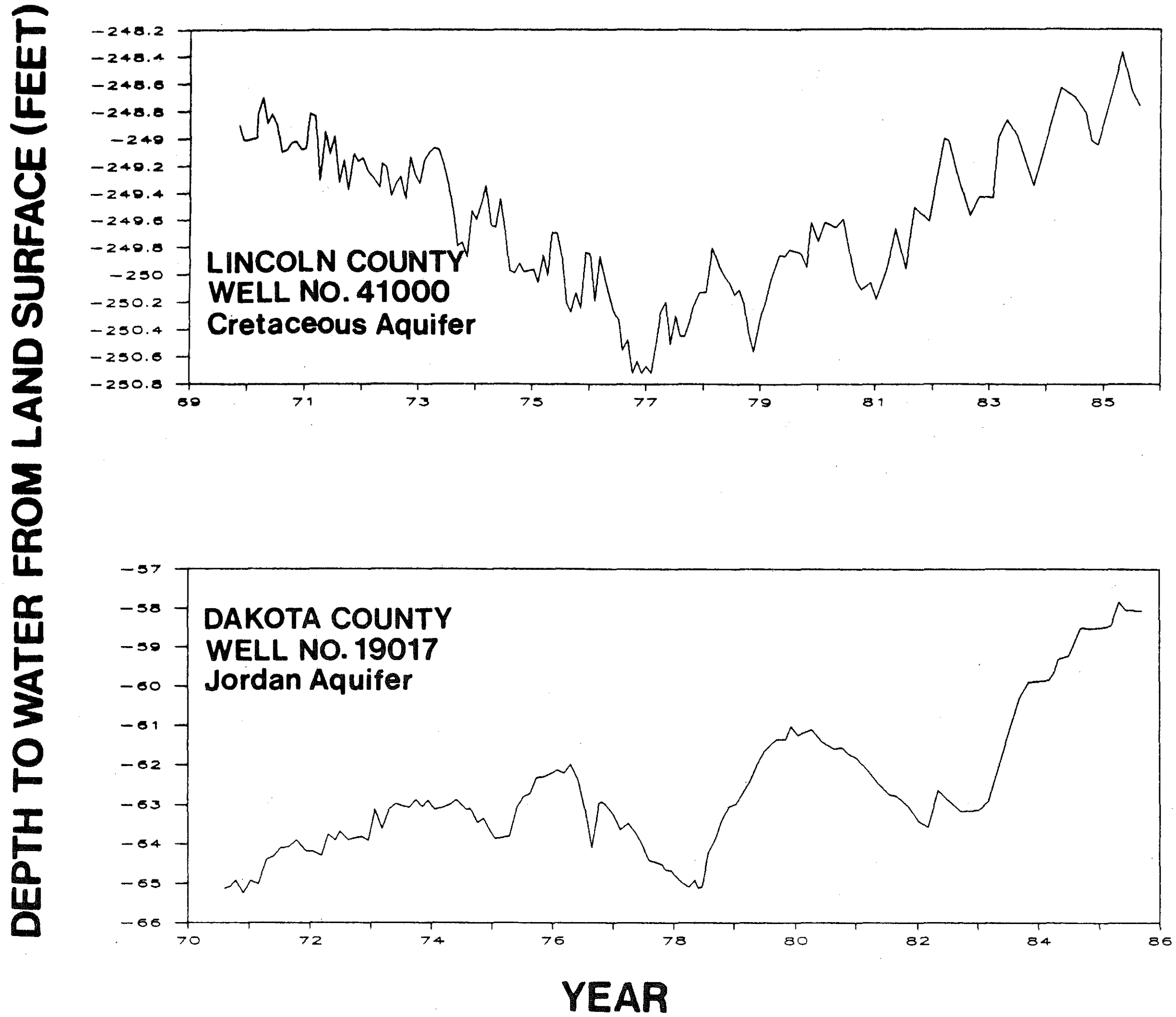
These 5 hydrographs show ground water trends in various bedrock aquifers.

- Present levels are among the highest recorded and are similiar to levels recorded in early 1970's.
- The 1976-77 drought is very evident on hydrographs not affected by pumpage. 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.
- Levels have generally risen since the 1980 drought. This is largely due to above normal precipitation which is occurring in most of Minnesota.

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 pumpage. Ground water levels in the Prairie du Chien-Jordan are declining in local areas of concentrated pumpage.
* The two hydrographs on this page are probably affected by climatic trends.

Abnormal Ground Water Levels in Bedrock Aquifers

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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