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5-7-84

Ground Water in Minnesota

A User's Guide to Understanding Minnesota's Ground Water Resource

Minnesota Pollution Control Agency

May 3, 1984

Dear Interested Minnesotan:

Enclosed is a copy of a report entitled, "Ground Water in Minnesota: A User's Guide to Understanding Minnesota's Ground Water Resource," which was prepared jointly by staff of the State Planning Agency (SPA) and the Minnesota Pollution Control Agency (MPCA), with input from other state and federal agencies responsible for ground water management issues.

The report includes a basic introduction to factors which determine quantity and quality of ground water, the Minnesota ground water picture including policy and strategy concerns, and emerging issues in ground water management such as heat pumps, aquifer thermal energy storage, irrigation, and peat development.

The report is part of the MPCA's overall effort to increase public awareness of the importance of our valuable ground water resources. Any questions concerning this report should be directed to John Holck of my staff at 612/296-7787.

Sincerely,

Dale Wikre

Dale L. Wikre
Division Director
Solid and Hazardous Waste Division

DLW:bh

Enclosure

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GROUND WATER IN MINNESOTA

A User's Guide to Understanding Minnesota's Ground Water Resource

January, 1984

A Report to the Citizens of Minnesota
Prepared Jointly by Staff of the

Minnesota Pollution Control Agency
and the
Minnesota State Planning Agency

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ACKNOWLEDGMENTS

This report is the product of a cooperative effort, reaching far beyond a single state agency. Lovell Richie and Mike Robertson of the Minnesota Pollution Control Agency identified the need for a general publication which could serve as a user's guide to understanding Minnesota's ground water resource and the administrative framework for its management. Tom Kalitowski and Jack Ditmore of the Minnesota Water Planning Board agreed that there was a need for this report and arranged a staff loan to provide major support in preparing it.

Many people were involved in a range of activities from the preliminary discussions of the scope of the report through the review of the final draft. The authors would like to express appreciation for valuable assistance to:

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The report would not have been possible without the patience and swift-fingered ability of Patty Stadstad, Roberta Wells, and Marcia Neilson. The cover was done by Bill Hodgins. Len Nelson drafted many of the graphics for the report.

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LIST OF ACRONYMS

LCMR — Legislative Commission on Minnesota Resources
MDA — Minnesota Department of Agriculture
MDH — Minnesota Department of Health
MDNR — Minnesota Department of Natural Resources
MDOT — Minnesota Department of Transportation
MEEB — Minnesota Environmental Education Board
MEQB — Minnesota Environmental Quality Board
MGS — Minnesota Geological Survey
MPCA — Minnesota Pollution Control Agency
MWMB — Minnesota Waste Management Board
MWPB — Minnesota Water Planning Board*
SWCB — Soil and Water Conservation Board
USEPA — United States Environmental Protection Agency
USGS — United States Geological Survey

*Now, Environmental Division, State Planning Agency.

SUMMARY

"Ground Water in Minnesota" is an introduction to ground water as a natural resource and its importance to the people of Minnesota. The need for a general report of this nature was recognized because of the increasing frequency of inquiries about ground water in the state. This report is divided into two parts. First, it focuses on the ground water phase of the hydrologic cycle, explaining basic elements of ground water flow and geology. The second part deals with specifics on Minnesota.

In order to understand the contamination problems which have recently been discovered, we must have a grasp of the natural quality and quantity of ground water, along with an understanding of its movement. Ground water has the advantage of being a "protected" source of water as compared to surface water. For contamination to occur, pollutants must work their way through the soil or streambeds, down wells, or through cracks in the bedrock. Also, some chemicals which may make water undrinkable occur naturally in ground water because of the type of rock through which the ground water moves. We must appreciate these different aspects of ground water before we can determine the status of our own supply.

In Minnesota, the bedrock and glacial geology determine most of the variations in natural ground water quantity and quality throughout the state. How the resource is managed is determined by a set of federal and state laws and programs. The state's programs provide the tools with which ground water is developed and protected.

In June, 1983, the Minnesota Pollution Control Agency (MPCA) released the "Ground Water Protection Strategy Framework for Minnesota" which, in addition to explaining the policy of protecting ground water from degradation, outlines a strategy to deal with increasing demands for ground water and discovery of contamination. As a corollary to the strategy, we look at four emerging issues of ground water use — ground water heat pumps, aquifer thermal energy storage, irrigation, and peat extraction.

INTRODUCTION

The amount of cropland irrigated by ground water supplies has increased dramatically in Minnesota in the last ten years.

The growing demand for the development of ground water for irrigation, industrial, commercial, and drinking water supplies along with the increased detection of ground water contamination currently focus attention on this resource throughout the world. Management of any ground water supply must be supported by a basic understanding of the occurrence, movement, and composition of the ground water resource.

The purpose of this report is to answer some basic questions about ground water, to provide specific information about its use and quality in Minnesota, and to outline the state's statutory, regulatory, and operational policies which affect its use and abuse. By summarizing the existing programs, available information, and emerging issues which have an impact upon ground water, this report can not only serve as an information document but also can provide guidance for future policy development.

The subject matter is covered as simply as possible, while, at the same time, using geologic and hydrologic terminology to acquaint the reader with the general vocabulary of ground water science. Much of the information in this report has been compiled from federal and state documents and standard textbooks. References are included for readers who choose to pursue some aspect of ground water in greater detail.

1. THE HYDROLOGIC CYCLE

The World Supply of Water

In order to provide a perspective of the importance of ground water as a source of fresh water, an overview of the world supply and distribution of water is a good point of departure. Approximately 97 percent of the earth's water is salt water in the seas and oceans. The remainder is water on or below the land surface and amounts to only 2.8 percent of the total supply. The land surface supply of water is distributed as follows:

- 2.14 percent, ice caps and glaciers;
- 0.61 percent, ground water to 13,000 feet;
- 0.009 percent, fresh water lakes;
- 0.008 percent, saline lakes;
- 0.005 percent, soil moisture;
- 0.001 percent, rivers.

In addition, 0.001 percent of the total supply is found in the atmosphere at any given time (Fetter, 1980).

It is apparent from these figures that available fresh water is quite limited and that the main source of supply which is available for human consumption and use is the fresh water from surface and underground sources. Surface sources include lakes, streams, wetlands, and reservoirs; underground sources include surficial and bedrock aquifers from which water is obtained by wells and springs or as the baseflow component to streams and lakes. At present, ice caps and glaciers are not considered as readily available sources of water.

The worldwide importance of ground water is evident in that over 97 percent of the available fresh water supply is ground water. The total amount of ground water in the world has been estimated at 2,607,200 trillion gallons (UOP-Johnson, 1974). Not all of this water can be extracted from the geologic formations in which it is contained. Some of the water is too deep to recover economically and some is held too tightly in the rock. But even considering only the obtainable amount, ground water exceeds all the available supplies of fresh surface water found in lakes and streams. It is apparent that ground water is an immeasurably valuable resource for present use and future generations.

The worldwide distribution of fresh water is, of course, not uniform. On the global level, the majority of the fresh water available is ground water; only a small percentage is surface water. In contrast, estimates of water availability for Minnesota show different proportions. The majority of the water occurs on the surface rather than within the ground. Minnesota is clearly not typical of worldwide water distribution. At the headwaters of three major river basins, Minnesotans are not often subjected to anyone else's pollution. The surface and ground water are generally clean when upstream or upgradient Minnesotans use them. Our responsibility is to act as good stewards as the waters pass through Minnesota and on to downstream or downgradient users.

The Hydrologic Cycle

The hydrologic cycle describes the endless circulation of the earth's water driven primarily by the forces of solar radiation, gravity, molecular attraction, and capillary attraction. Figure 1 is a simple diagram of the hydrologic cycle showing how water moves in its liquid, vapor, or solid state from oceans to the air, air to land, over the land surface or into the ground, and back to the oceans. Unlike other natural resources, water is renewable because of its movement through these pathways. The total amount of water in the world remains constant, although the amounts of liquid, vapor, and solid have changed significantly through time.

The mechanics of the hydrologic cycle are generally as follows. Evaporation, taking place at the water surface of oceans and other open bodies of water, results in the movement of water vapor to the atmosphere. Under certain conditions, water vapor condenses to form clouds which subsequently release moisture as precipitation in the form of rain, snow, hail, or sleet. Precipitation may occur over the oceans, returning water directly, or over land, having been transported by wind. The water may evaporate immediately, returning moisture to the atmosphere. Of the remainder that reaches the ground surface, some runs off into streams or oceans, while the remainder filters into the ground, contributing to ground water flow. Vegetation extracts soil moisture through root systems and releases moisture from its leaves, a process called evapotranspiration.

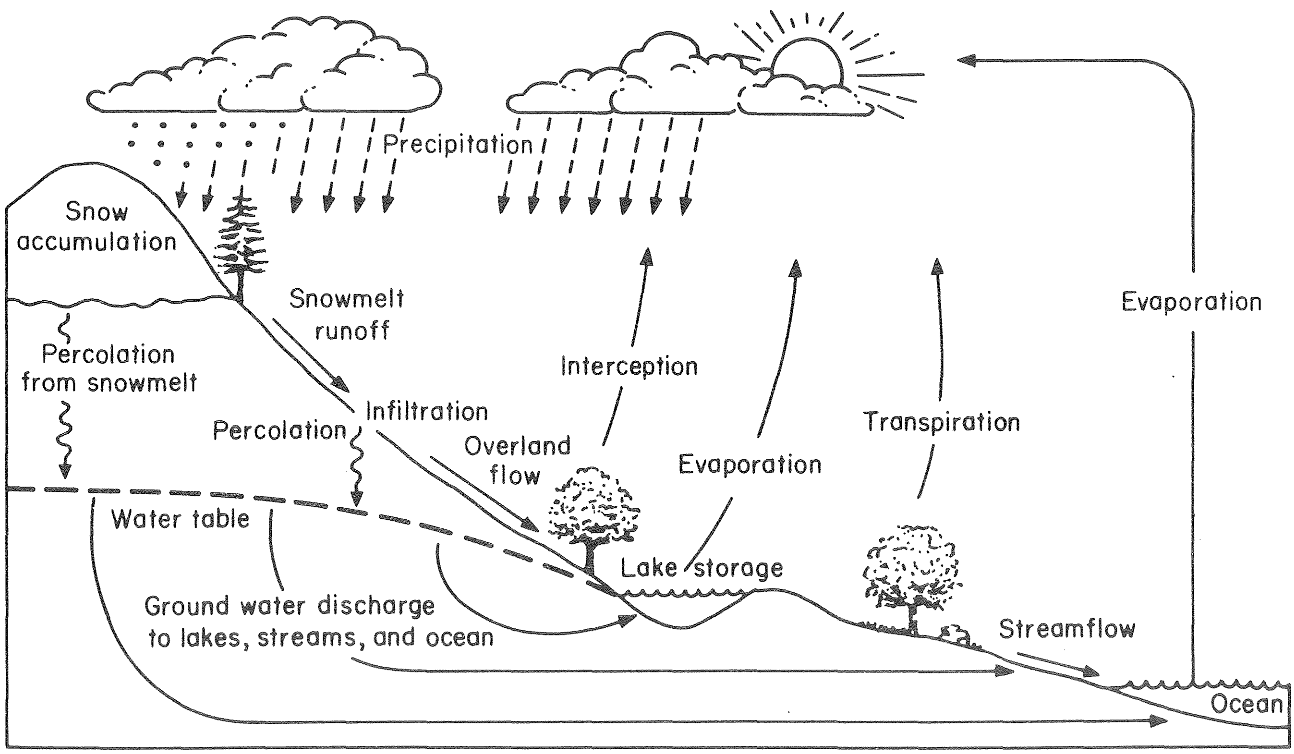


FIGURE 1. SCHEMATIC DIAGRAM OF THE HYDROLOGIC CYCLE (DUNNE AND LEOPOLD, 1978).

The Subsurface Phase

Water percolating into the ground enters two zones: the zone of aeration (or unsaturated zone) and the zone of saturation, separated by the water table. Figure 2 is a diagram of subsurface water. In the unsaturated zone, water is under pressure less than that of the atmosphere. Some of that water is held tightly to soil particles by capillary attraction, while other water moves downward to recharge the zone of saturation. The presence of air or gases in the unsaturated zone can cause physical or chemical changes to occur as the water moves vertically through it.

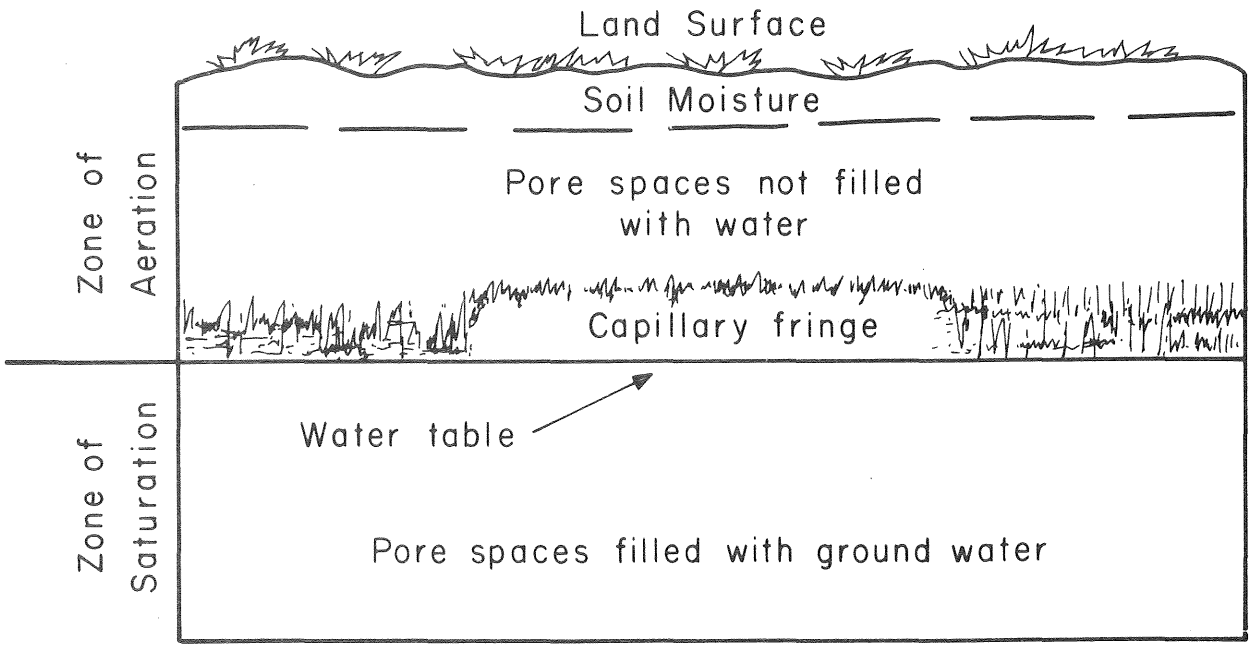


FIGURE 2. SUBSURFACE DIVISION OF GROUND WATER.

The zone of saturation is the subsurface area where the spaces between soil or rock particles are completely filled with water under pressure greater than atmospheric and where air is not present. The water table is the upper surface of the zone of saturation and, in some cases, is determined by the elevation of the water level in a shallow well. The depth of the water table depends on the complexity of the geology, how the geologic units are arranged and interconnected, and the kind of rocks present.

An aquifer is a water-saturated geologic unit that will yield water to wells or springs at a sufficient rate so that the wells or springs can serve as practical sources of water for supply purposes (UOP-Johnson, 1974). Whether a water-bearing geologic unit is called an aquifer depends on the economics of drilling and of obtaining water from it by use of wells. Not all saturated rock units give up water easily. In addition, at some point, water is simply too deep to allow cost-effective withdrawal from the ground. The relative abundance of surface and ground water sources in a region can determine whether a specific zone of saturation is considered an aquifer.

Ground water may occur either in bedrock or in unconsolidated deposits. Granite, sandstone, and limestone are examples of bedrock. Granite is an especially dense rock with water occurring only in fractures. Sandstone is usually porous and contains water throughout. Limestones can be quite dense but are often permeated with solution channels and layers of highly variable porosity. Unconsolidated deposits are loose materials such as sand, gravel, and clay and can be very important sources of water. To be an aquifer, a geologic unit must be sufficiently porous and permeable to store, transmit, and release useful quantities of water. The openings or pores in an aquifer store water and serve as a network for movement of water through the unit. The ratio of the total volume of openings to the total volume of rock is the porosity (usually stated as a percentage). Figure 3 shows the textures of various geologic materials and demonstrates the types of openings found in them. Cracks, fractures, and fissures are all types of openings which allow water to move through rock.

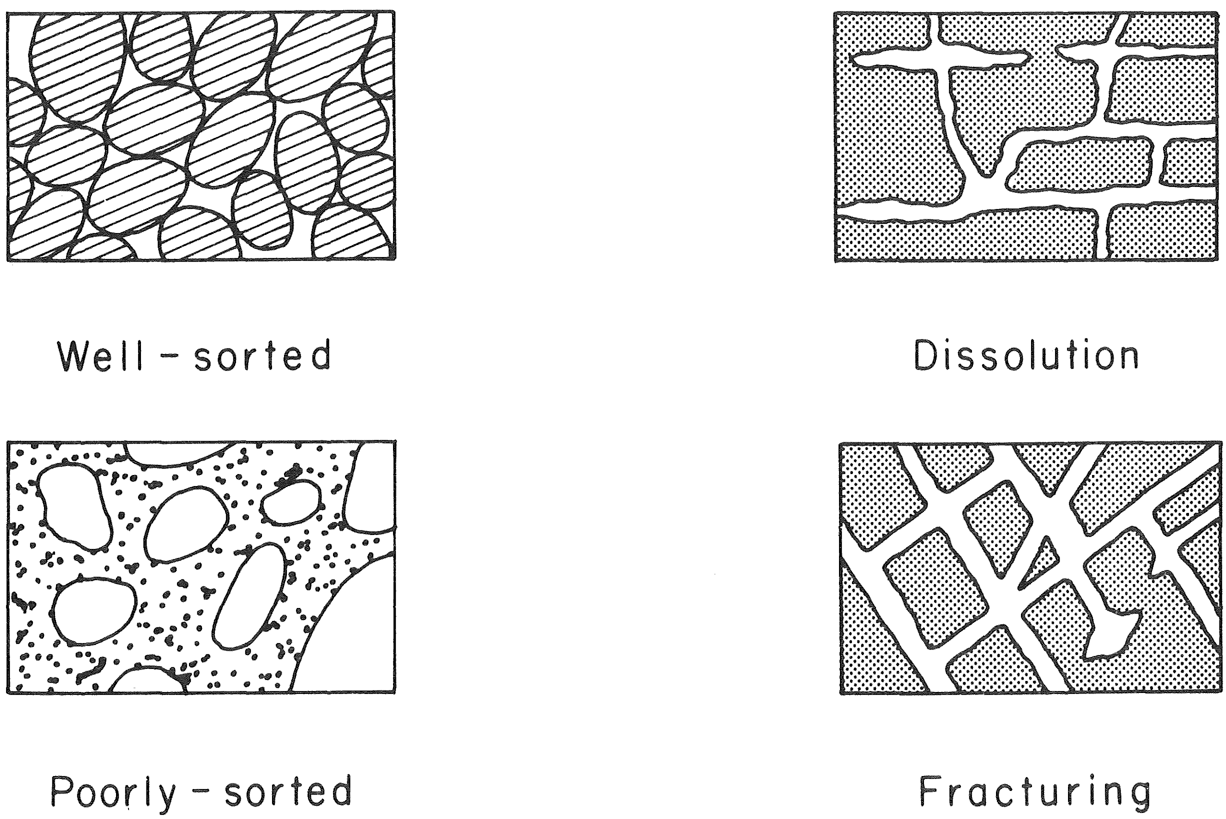


FIGURE 3. TEXTURES OF GEOLOGIC MATERIAL.

The network of openings in the rock or soil determines the permeability of the geologic unit. The permeability is the ability of the geologic material to transmit water and is dependent upon the interconnected openings. If the size of openings is too small, the water may be held in place by capillary attraction and although the rock contains water, it would not be a usable source of water. Just as fractures in granite and solution channels in limestone must be interconnected to allow effective ground water movement, pore spaces must be interconnected in sandstone aquifers. As shown in Figure 3, the sorting of sand grains in a sandstone can affect its porosity and its ability to transmit water.

To illustrate this principle, imagine a room completely filled with basketballs. There is a considerable amount of space left between the basketballs — the porosity. Now assume that golf balls and basketballs are mixed in the same room. Much less porosity exists because much of the space has been filled with golf balls. If peas were added to the mixture of basketballs and golf balls, even more of the remaining space would be filled. This "formation" is poorly-sorted because of the mixture of "grain" sizes. Thus, it does not have a very high porosity. Sorting is an important factor in the porosity of an aquifer and the analogy helps illustrate how certain glacial drift deposits which have been water-transported and naturally well-sorted are important shallow aquifers.

The flow of water in an aquifer, although it cannot be physically observed, can be predicted by the use of known physical principles relating to the porosity, permeability, and hydraulic head of the aquifer. The basic force which moves both ground and surface water is gravity. In a hypothetical example, compare water flowing in a stream to ground water which is found in generalized conditions such as those shown in Figure 2. The surface water encounters only marginal resistance from the river channel and moves at relatively high speeds, measured in feet per second. The ground water generally encounters constant resistance from the surrounding aquifer material. Just as the resistance varies according to the nature of the material (i.e., bedrock or unconsolidated deposits), the rate of movement varies from feet per day to inches per year (Wilson, 1982).

Subsurface geology is often more complex than has been portrayed in the first few figures. Geologic units undergo any number of physical alterations, such as folding and fracturing, weathering, erosion and redeposition, or chemical changes induced by heat and pressure. Evidence of these changes can be examined with the use of well logs, well records, or borings, and by studying exposed rock surfaces, called outcrops. The complexity of the ground water system depends on a number of factors such as the size of the system influenced by or influencing ground water movement, the number of different zones or layers of rock materials containing ground water, and the variations in depth, mineralogy, thickness, storage characteristics, and permeability of these layers.

Figure 4 represents a slightly more complicated scheme than displayed in Figure 2. A variety of geologic units exists and the units are no longer portrayed as being horizontal. Confining beds which restrict the vertical flow of the ground water have been added. They are geologic units capable of storing and transmitting less water than the beds above and below them because they have a lower permeability than the beds they confine. A water table aquifer, also called an unconfined aquifer, contains ground water in contact with the atmosphere directly or through the unsaturated zone below the land surface. Such an aquifer is vulnerable to contamination from the land surface because contaminants have rather direct access simply by seeping into the ground and being carried directly downward by gravity to the water table. From here, the contaminants are free to move laterally along the natural direction of ground water flow.

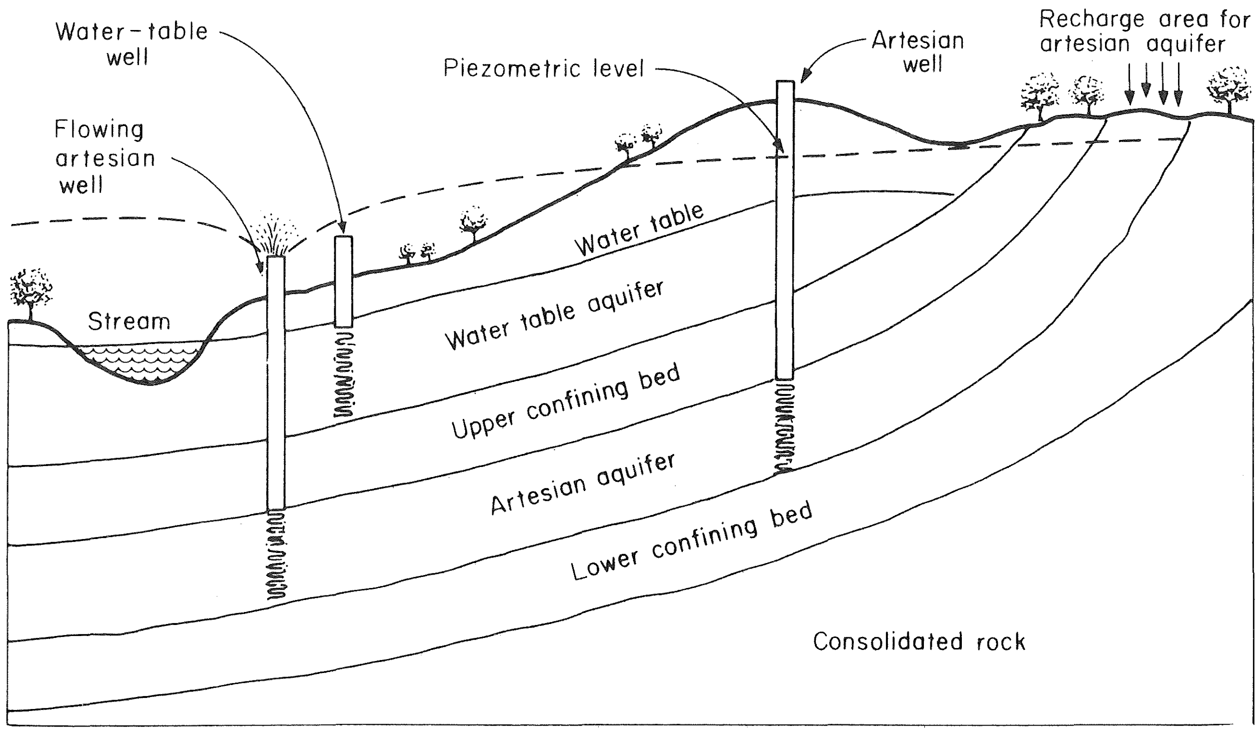


FIGURE 4. SUBSURFACE AND GROUND WATER PHASE OF THE HYDROLOGIC CYCLE (UOP-JOHNSON, 1974).

An artesian aquifer, also known as a confined aquifer, has a much higher degree of natural protection in the immediate withdrawal area. The aquifer is sandwiched between two confining beds. Water is under sufficient pressure to rise above the base of the confining bed when a well or hole pierces the upper confining bed. A common misconception is the assumption that an artesian well will always flow without pumping. Figure 4 shows two artesian wells, only one of which flows naturally, where the artesian pressure forces the water above the ground surface (UOP-Johnson, 1974).

Other terms which are included in Figure 4 and should be explained are "piezometric level" and "recharge area." The piezometric (or potentiometric) level represents the level to which water will rise in a well. The water table is a potentiometric surface. Figure 4 exhibits two different piezometric levels, one for each aquifer shown. The piezometric level of the flowing well is above the top of the pipe and therefore, water flows out without pumping. Recharge is the process of adding water to the zone of saturation (U.S. Water Resources Council, 1980). The recharge area is the area of land surface where water can percolate downward to eventually reach the zone of saturation. In unconfined aquifers, recharge areas are usually topographically high places. The recharge area for a confined aquifer is usually some distance, perhaps miles, from the withdrawal area. Conversely, a discharge area is an area in which ground water is discharged to the land surface or to surface waters, usually a low area where seepage flows into the channels of streams and lake beds. A particular area such as a pond or marsh may be alternately a discharge area or a recharge area, depending on local rainfall conditions at a given time. Ground water usually provides the base flow in rivers and streams during winter months and also can be a major factor controlling lake levels. During high rainfall months, the process may be reversed with the lakes and rivers recharging the ground water system.

2. DETERMINANTS OF NATURAL QUANTITY AND QUALITY

Ground Water Quantity

Under natural conditions, the long-term quantity of water in aquifers is in a state of approximate equilibrium. Natural release occurs by gravity as baseflow to surface waters, seepage from springs, and as artesian flow where the land surface is lower than the aquifer's piezometric surface. Pumpage from wells represents one type of demand which is imposed upon a previously stable system. This new demand must be balanced by an increase in recharge of the aquifer, by a decrease in the old natural discharge, by a loss of storage in the aquifer, or by a combination of these adjustments (U.S. Water Resources Council, 1980). Figure 5 is a graph of possible normal ground water level fluctuations in a well which occur in response to both natural and man-made influences.

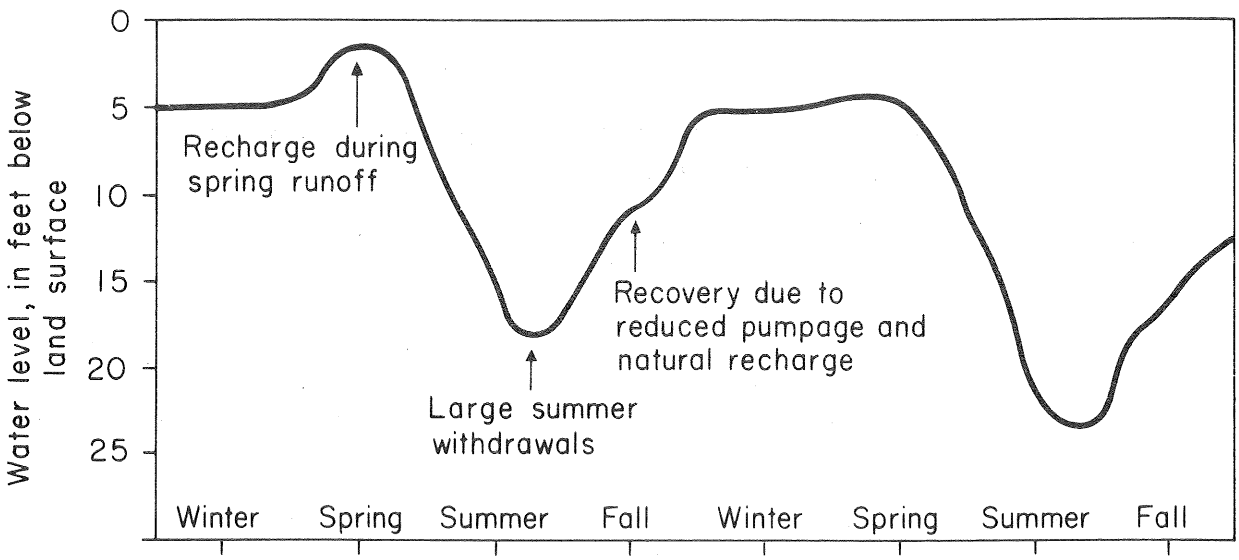
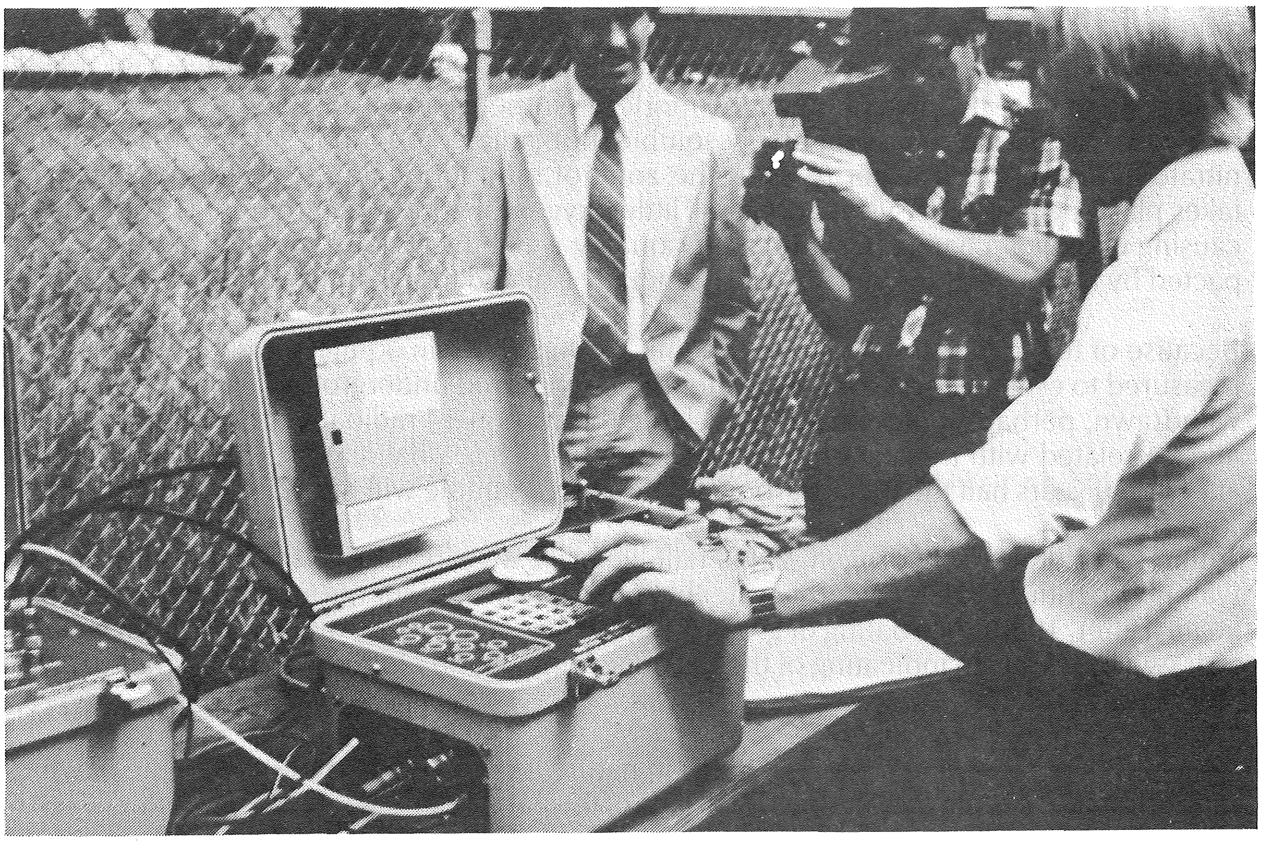


FIGURE 5. GROUND WATER LEVEL FLUCTUATIONS IN RESPONSE TO NATURAL AND MAN-MADE INFLUENCE.

Aquifer tests are conducted to measure the water-bearing properties of rocks. Typically, the experiment is a pumping test in which the effect of pumping a well at a known rate is measured in the pumped well, a control well, and in observation wells in the same aquifer. Pumping tests are run for as long as is necessary to reveal significant recharge or barrier conditions. In a confined or artesian aquifer, the radius of influence of the pumping well expands quickly and a period of 24 hours is usually adequate. Since the radius of influence of an unconfined aquifer expands less quickly, a pumping period of 72 hours might be necessary to intersect any significant aquifer boundaries (MDNR, 1978). Such tests provide analytical data but the reliability of the data and the resulting management program depend on regular monitoring and refinement of the information base as pumpage occurs.

The term "safe yield" is used to describe the amount of water which can be withdrawn within a set time period without producing an undesirable effect such as reducing the total amount of water available (mining) or allowing entry of low quality water from adjacent geologic units. Because this concept involves legal and economic as well as hydrologic questions, there is no general agreement on what constitutes safe yield (Dunne and Leopold, 1978).

Another common misconception in ground water hydrology is that a water budget, the water input and output of an area, determines the maximum potential ground water withdrawal. It is not so simple an equation, since the response of a ground water system to withdrawal depends on the aquifer's porosity and permeability, the boundaries of the aquifer, and the location and pumping schedule of withdrawal from wells within the aquifer system (Bredehoeft and others, 1982).



Measurement of changes in elevation of the water table during a pumping test can involve the use of sophisticated equipment.

Ground Water Quality

The relatively slow movement of water percolating through the ground allows extended contact of the water with minerals in rocks and soil. Depending on the solubility of the minerals, ground water will tend to reach chemical equilibrium with the dissolved substances and those in the rock (UOP-Johnson, 1974; Burmaster, 1982). Most ground water contains no suspended matter and practically no bacteria. It is usually clear and colorless, normally of excellent sanitary quality, potable directly as withdrawn, and maintains a relatively constant temperature.

Although many of the constituents of ground water are natural materials from the rocks, the soil, and the air, some are waste products of men or animals. In addition to naturally occurring waste products are artificial or synthetic materials, made and used for man's convenience, that inadvertently find their way into water. Ground water is vulnerable to contamination from these materials in a more subtle way than surface water. Although some pollutants are removed from percolating water by filtration and adsorption, soil and rock do not remove many dissolved materials or toxic chemicals. Plants and microorganisms, for example, do not break down many of the modern synthetic chemicals, nor is the natural system very effective in removing highly soluble inorganic compounds such as road salt and nitrate fertilizer. Once water reaches the zone of saturation, almost no further cleansing takes place because the system contains little oxygen, the most common reactive element causing chemical change. Ground water quality is relatively constant with time if not impacted by human actions, because it is generally isolated from surface influences.

Because of the long residence time of some ground water in aquifers, radioactivity can be measured to estimate how long the water has been stored underground. When the water is withdrawn, perhaps thousands of years later, the carbon-14 radioactivity can be measured and correlated with the age of the water. Carbon-14 has a half-life of 5,570 years. That is, after 5,570 years half the initial carbon-14 atoms in a sample will have disintegrated.

Tritium, an isotope of hydrogen with a half-life of 12.4 years, is used to date young ground water. If no tritium is detected, the water has probably been underground for at least 50 to 90 years (Fetter, 1980). Age dating of ground water helps characterize the aquifer from which it is drawn by giving an indicating of the residence time of the ground water and the recharge rate of the aquifer.

Water is never present as pure H_2O. Even in nature it occurs with impurities, some of which are desirable to sustain life. Figure 6 lists many of the parameters for which water is analyzed to assess its quality. They are divided into categories of bacteriological, chemical, physical, and radiochemical components. One selection of water quality parameters may be used to characterize the ambient quality; a different selection, perhaps overlapping the first, might be used to determine whether the water is safe for human consumption; a third selection might be necessary to see if land disposal of waste has contaminated the ground water. The assortment of parameters for which water is tested must be selected according to the ultimate use of the water or, if possible, to determine what specific contaminants have entered the water supply. A more detailed discussion of water quality parameters follows in Chapter 3.

I. BACTERIOLOGICAL

Total coliform
Fecal coliform
Fecal streptococci
Viruses

II. CHEMICAL

Inorganic

- Metals

Arsenic
Barium
Boron
Cadmium
Chromium
Copper
Iron
Lead
Manganese
Mercury
Nickel
Silver
Sodium
Zinc

- Nonmetals

Chloride
Fluoride
Nitrogen
Phosphate
Selenium
Sulfate, sulfide
Hardness

Organic

- Acid fraction phenolics
- Base-neutral fraction polyaromatic hydrocarbons (PAH's); phthalates; nitrosamines
- Volatile fraction halogenated (solvents, trihalomethanes); non-halogenated (alcohols, ketones, aromatics)
- Pesticides
- Polychlorinated biphenyls (PCBs)

III. PHYSICAL

Specific conductance
Turbidity
pH
Taste, odor, temperature

IV. RADIOCHEMICAL

Radon

FIGURE 6., SELECTED LISTING OF SOME COMMON WATER QUALITY PARAMETERS

Water quality is often labelled as "good" or "safe." The term "good quality water" includes the bias of the individual consumer and the intended use of the water. A "safe" or "healthful" water supply is water free from pathogenic or disease-causing organisms and from minerals and organic substances that can have adverse physiological effects; the water should also be aesthetically acceptable to the consumer (Lehr and others, 1982). It is evident that we cannot protect every drop of ground water in a pristine condition. However, ground water quality standards should protect the ground water to the highest degree possible. The intent of judging water quality by standards is to provide a mechanism to identify and limit degradation of ground water quality in all usable aquifers. In Minnesota, virtually all aquifers are usable as fresh water supplies.

3. THE MINNESOTA PICTURE

Introduction

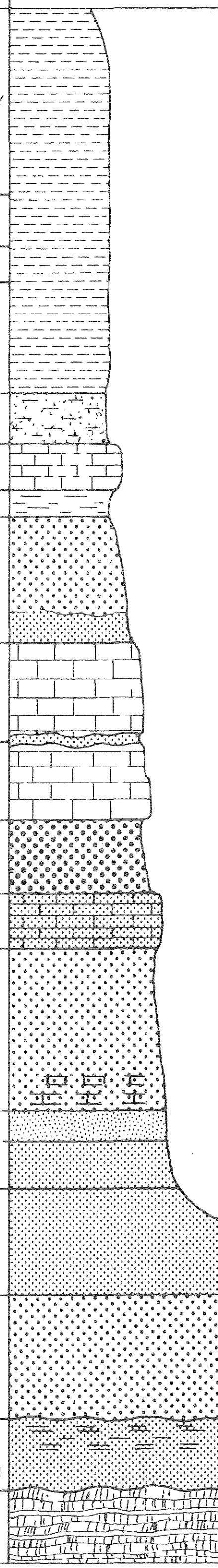
Minnesota's water resources consist of both surface and ground water. Although best known for its "10,000 lakes," Minnesota is highly dependent on ground water. About two of every three Minnesotans use ground water as a high quality source of drinking water. The natural availability and quality of ground water in Minnesota are determined by its geologic history. Ground water generally occurs in uneven, layered sequences of rock materials at varying depths below the land surface. The two types of geologic units which commonly contain ground water are the bedrock and the unconsolidated deposits which overlie the bedrock. Geologic and hydrogeologic maps are available from the Minnesota Geological Survey (MGS) and the U.S. Geological Survey (USGS), St. Paul Office, as is the more site-specific geological information from which the maps are derived.

Ground Water Availability

The basement rocks, usually igneous or metamorphic rocks, are the oldest and hardest layer of rocks and underlie more porous and permeable bedrock formations. Above the bedrock, unconsolidated sand, gravel, and clay occur in varying thicknesses and form the visible land surface in much of Minnesota. The basement rocks are generally not important as prominent aquifers because they generally do not contain ground water. They are dense and hard, and seldom have open spaces capable of holding water, except perhaps in cracks and crevices created by differential earth movements. In areas of the state where the basement rocks occur at or very near the land surface, for example, in Lake, Cook, and parts of St. Louis, Carlton, and Pine counties, there is a good possibility that even small supplies of ground water may not be available. In these drift-thin areas, fractured basement rocks are the only aquifers available and are locally important. Fractures and cracks in the basement rocks may be interconnected to provide some open storage space for ground water but it is rare to have significant yields of water over large areas. Exceptions are a few known sites where there are extensive interconnected fracture systems and thick porous zones between basement rocks.

In southwestern Minnesota, the basement rock is composed of a very old layer of hard, cemented sandstone called quartzite. This area includes most of Rock and Pipestone counties, and parts of Nobles, Lincoln, Murray, and Jackson counties. Although these rocks are generally so hard and dense that they would not be considered major aquifers, they are locally important because they may be the only source of water supply in this part of the state.

Bedrock formations are found on top of the basement rock in most parts of the state. The most important source of ground water in Minnesota is the porous and permeable sedimentary bedrock of the southeastern two-thirds of the state, consisting of one to five major water-yielding sandstone and limestone aquifers. The Twin Cities are located within this geologic setting. These layers of sandstone and limestone are separated by relatively impermeable layers of shale and siltstone which confine the ground water under artesian conditions over most of the areal extent of the aquifers. In areas adjacent to river valleys, however, they are unconfined.



ERA	SYSTEM	GROUP	FORMATION	GRAPHIC COLUMN	APPROX. MAXIMUM THICKNESS (FEET)	HYDROGEOLOGIC UNITS
PALEOZOIC	DEVONIAN		CEDAR VALLEY		300	CEDAR VALLEY-MAQUOKETA-DUBUQUE-GALENA AQUIFER
	ORDOVICIAN		MAQUOKETA		70	
			DUBUQUE		35	
			GALENA		230	
			DECORAH		95	DECORAH – PLATTEVILLE – GLENWOOD CONFINING BED
			PLATTEVILLE		35	
			GLENWOOD		18	
			ST. PETER		155	ST. PETER AQUIFER
		PRAIRIE du CHIEN	SHAKOPEE		360	PRAIRIE du CHIEN JORDAN AQUIFER
			ONEOTA			
	CAMBRIAN		JORDAN		110	
			ST. LAWRENCE		60	ST. LAWRENCE CONFINING BED
			FRANCONIA		190	FRANCONIA – IRONTON – GALESVILLE AQUIFER
			IRONTON		45	
			GALESVILLE		95	
			EAU CLAIRE		200	EAU CLAIRE CONFINING BED
			MT. SIMON		315	MT. SIMON – HINCKLEY FOND du LAC AQUIFER
PRE-CAMBRIAN			HINCKLEY FOND DU LAC SOLOR CHURCH		5000+	
			IGNEOUS & METAMORPHIC ROCK			NOT AN AQUIFER

FIGURE 7. SEQUENCE OF BEDROCK AQUIFER SYSTEMS AND CONFINING BEDS FOR SOUTHEASTERN MINNESOTA.

Figure 7 is a geologic column of the major bedrock aquifer systems in southeastern Minnesota. The column shows the order in which these units may be found underground. Not all units are present at all locations due to uneven deposition and pre-glacial and post-glacial weathering and erosion. The more familiar names are the Prairie du Chien, Jordan, St. Peter, and Mt. Simon-Hinckley aquifers, each of which provides a moderate to high yield of relatively good quality water. These rock units are generally named for the location in the state where they have been identified as surface outcrops. The individual bedrock aquifers in the system are up to 600 feet thick and yield more than 2,500 gpm to wells where they are deepest and thickest in the Twin Cities area and in southeastern Minnesota.

The southeastern corner of Minnesota is underlain by gently dipping sedimentary rocks which feature prominent beds of limestone and dolomite. The bedrock is normally fractured and contains numerous cracks, crevices, channels, and caves and is commonly eroded by surface streams. "Karst" is the geologic term for this land area characterized by streams which disappear into the ground or which lose most of their flow underground; valleys which have no surface outlet; caves; springs; and circular depressions called sinkholes. The ground water system is particularly vulnerable to natural and man-induced contamination in this part of Minnesota because the near surface bedrock deposits have little or no natural protection since there is very little glacial drift cover. Both biological and chemical surface contaminants can enter the ground water through sinkholes and travel swiftly into open channels for considerable distances with little or no filtration, adsorption, and/or chemical reaction. The quality of the shallow ground water is often the same as the surface water in the area. Reliable protection of these karst aquifers is virtually impossible.

Much of the southwestern quarter and extreme western edge of the state contain scattered remnants of sedimentary bedrock of Cretaceous age. These rocks generally consist of mixtures of loose sand, sandstone, siltstone, and shale, usually varying in thickness from 400 to 500 feet. They commonly have short-term yields of less than 50 gpm. Along the western border, yields are generally less than 10 gpm, but do reach as much as 100 to 200 gpm in a few areas.

Unconsolidated layers and lenses of sand, gravel, silt, clay, and boulders cover the bedrock or basement rock over practically all of the state except where the basement rocks or porous bedrock are found at the land surface. They commonly provide a major portion of the ground water for individual households in the state. In addition, they supply the majority of irrigation wells and most municipal wells in western Minnesota. These sand and gravel aquifers can be divided into two major types: surficial sand and gravel which are located at the land surface, and buried sand and gravel which generally occur as lenses at varying depths. These commonly were deposited by glacial meltwater along ice-contact areas, or as beach ridges along the edges of ancient glacial lakes. The surficial sands and gravels usually can be easily located because they are visible at the land surface. They are relatively easy to develop because of their shallow depths.

Buried sand and gravel lenses located at various depths below the land surface are much more difficult to locate than surficial deposits. They are highly variable in thickness and yield because they generally occur as lenses of sand and gravel of different size and shape within great masses of clayey and silty glacial deposits. To demonstrate this variability, some lenses are less than 50 feet thick with yields less than 100 gpm, while many irrigation and municipal wells tap buried sand aquifers with yields over 600 gpm.

Yields from unconsolidated and bedrock aquifers vary considerably throughout the state. However, in most areas, ample ground water for household use is readily available. Except for the hard rock areas of the northeast, the dense clay areas of the Red River Valley, and scattered areas where bedrock occurs at the surface, ground water sources are generally adequate for municipal, irrigation, and industrial uses as well.

Sampling a spring for water quality, southeastern Minnesota.

Ground Water Quality

As water availability varies both geographically and with depth, the water quality also changes across the state. The dissolved material in water consists mainly of carbonates, bicarbonates, chlorides, sulfates, phosphates, nitrates, calcium, magnesium, sodium, and potassium, with traces of iron and manganese. A dissolved solids concentration of less than 500 mg/l is generally satisfactory for domestic and many industrial uses (UOP-Johnson, 1974; USEPA, 1977). Water with dissolved solids over 1000 mg/l usually contains sufficient minerals to cause taste and corrosion problems.* The usefulness of a water supply must be based on the concentration of the individual ions rather than the total concentration of all sub-

*Milligrams per liter (mg/l) and parts per million (ppm) are equivalent terms for our purposes. When dealing with a contaminant in water, 1 ppm or 1 mg/l is one part of a contaminant in one million parts of water, by weight. Although one ppm is a very small concentration, we are often concerned with even smaller amounts — parts per billion (ppb) and parts per trillion (ppt) — when looking at concentrations of synthetic organic compounds in water.

stances which total dissolved solids shows. Figure 8 shows the distribution of the average dissolved solids in Minnesota ground water which can be used as an indicator of its chemical quality. The map does not reflect the generally much lower levels of dissolved solids found in the surficial deposits.

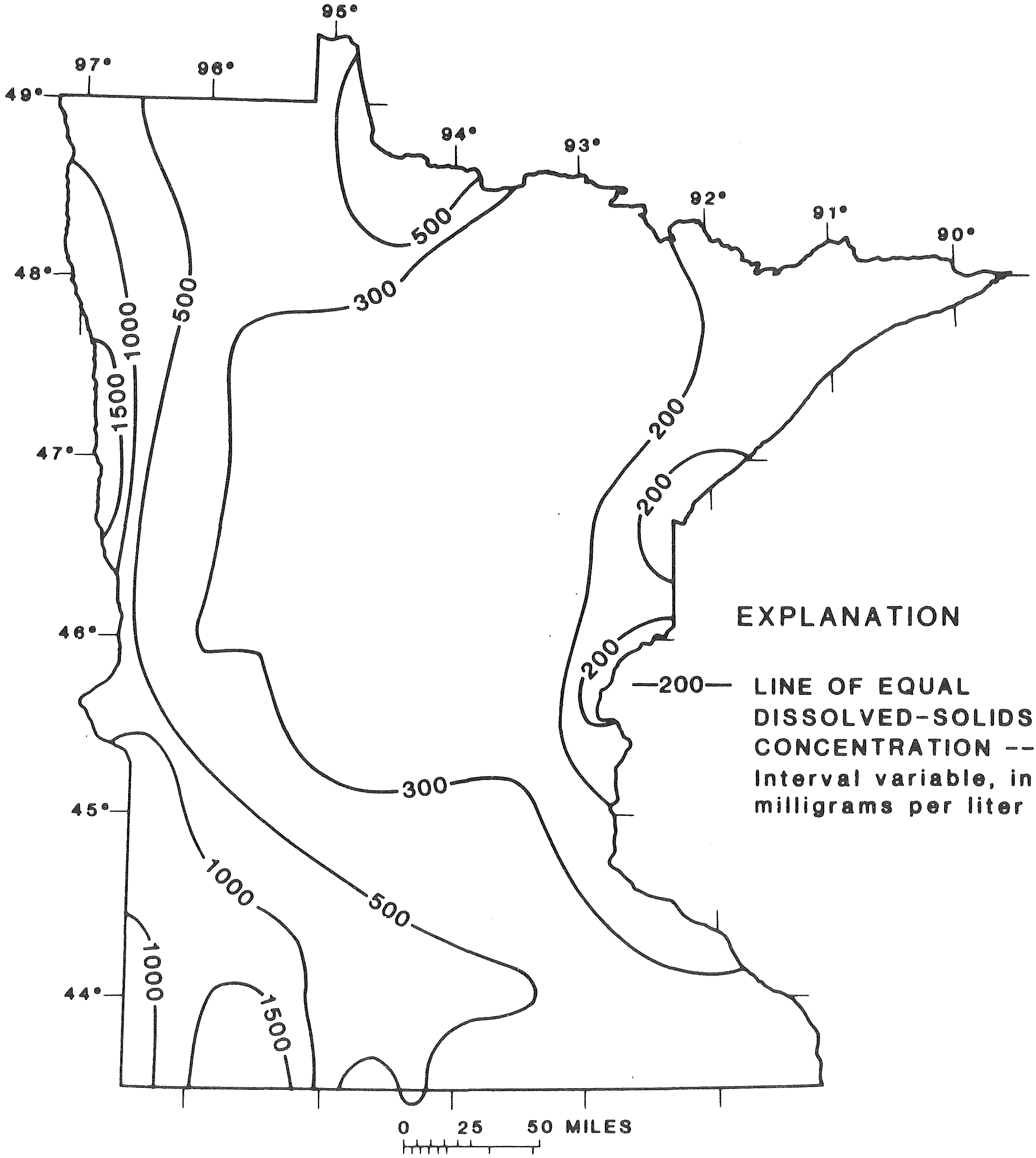


FIGURE 8. GENERALIZED DISTRIBUTION OF MEAN DISSOLVED-SOLIDS CONCENTRATION OF GROUND WATER USED IN MINNESOTA (USGS, 1981).

Hardness depends primarily on the concentration of calcium and magnesium in the water. It does not present a health hazard but can cause economic problems. Hard water tends to deposit a scale on pipes, water heaters, and boilers reducing flow and heating efficiencies. Soap does not clean as effectively in hard water. Ground water is usually hard water because the rocks and soils which contain the water also contain relatively large amounts of calcium and magnesium, so it is a naturally-caused source of pollution. Bicarbonate and carbonate content contribute to alkalinity — the capacity to neutralize acid. Alkalinity is used to help characterize water quality although there is no drinking water standard for alkalinity because it has no recognized health effects.

Sulfate-rich rocks in the western edge of the state leach sulfate into the ground water. This ground water can have a laxative effect on people unaccustomed to consuming high-sulfate water. Sodium bicarbonate also occurs in this water and although it contributes to total dissolved solids, it does not contribute to hardness. Sodium is very soluble so it does not form scale like calcium or magnesium. In fact, most ion exchange water softeners use salt to convert calcium and magnesium carbonate to a sodium form. Water treated by this process is called soft water. Waters with high sodium chloride (salt water) also occur and are undesirable for most uses. (Sea water contains about 35,000 ppm; 35,000 ppm = 3.5 percent.)

The temperature of ground water is fairly constant, ranging from 47°F to 56°F across the state, approximating the annual mean air temperature of Minnesota. The consistent temperature of ground water can simplify treatment and generally reduce chemical costs compared to treating surface water. This range of temperatures also makes ground water desirable for use in air conditioning and heat pump systems.

Monitoring and an informed knowledge of the natural quality of the ground water will help identify any changes in the quality due to the contamination by land-surface activities. Unnatural chemicals, when found, can then hopefully be traced to their origin, once it has been determined that they are not normally present.

Ground Water Estimates and Use

Methods of estimating the total amount of ground water in Minnesota provide results which vary widely. Assumptions for any estimates must be made and can change the estimates dramatically. Primary assumptions involve the amount of ground water discharging naturally to surface waters, the average annual recharge rates, and the location of aquifer boundaries both vertically and horizontally. Two estimates which have been made, 1.1 to 2.0 trillion gallons (Kanivetsky, 1979) and 330 trillion gallons (Ross, 1976), illustrate the point. These estimates of total ground water do not necessarily represent the amount of water which can be withdrawn practically. The estimates do however provide an idea of how much of the state's water supply is ground water. Estimated ground water resources of Minnesota are shown by drainage basin in Figure 9.

Accurate information on the extent of ground water supplies in high-use areas is necessary for effective ground water management. In general, there is adequate knowledge of surficial glacial drift aquifers and of consolidated bedrock aquifers in most high-use areas. There is less information available on the size, shape, and yield characteristics of unconsolidated

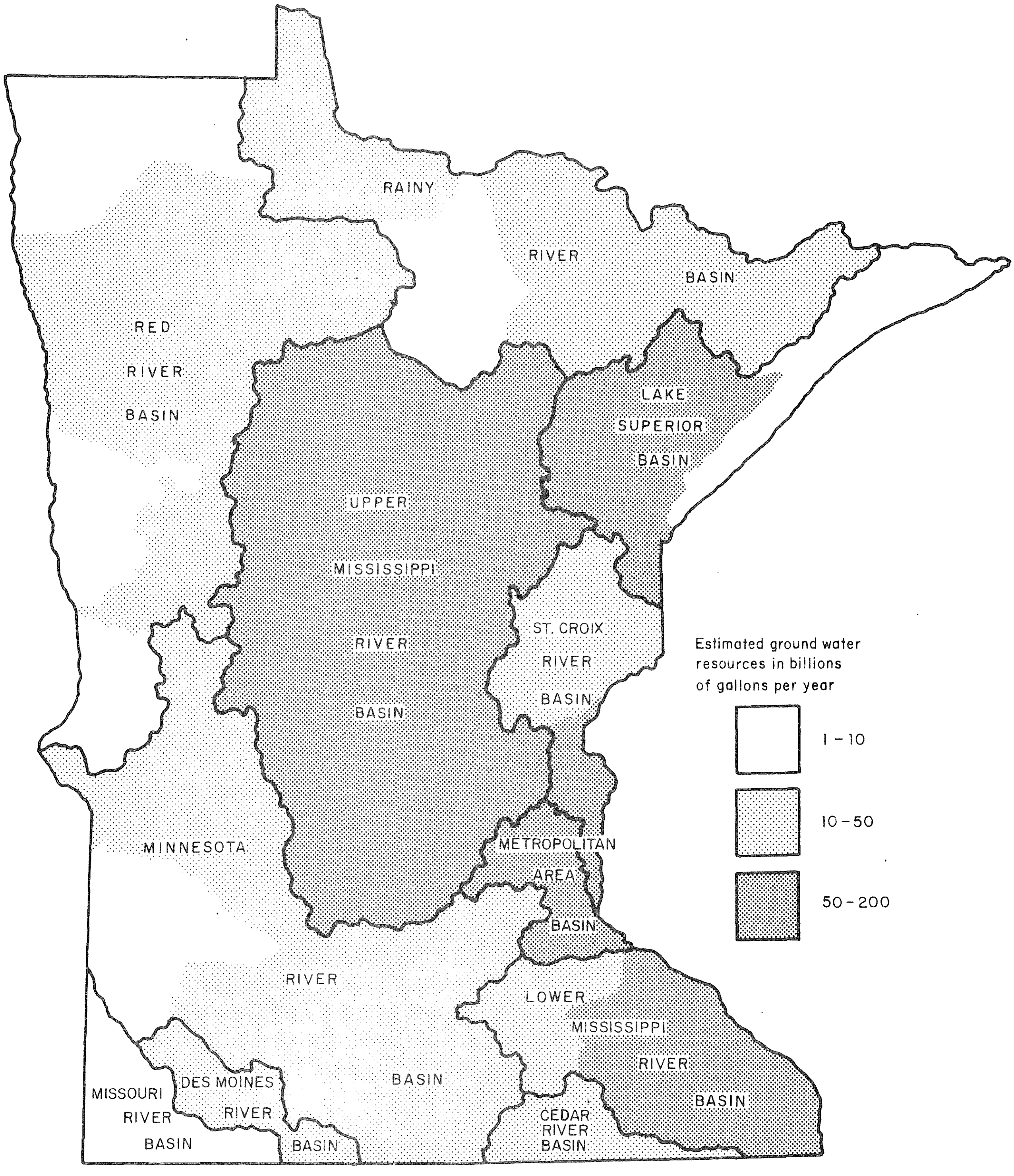


FIGURE 9. ESTIMATED GROUND WATER RESOURCES OF MINNESOTA.

buried drift aquifers in high-use and in growing-demand areas. In some areas of Minnesota (for example, the western part of the Minnesota River basin and in the Red River basin), unconsolidated buried drift aquifers are the only good source of ground water supply.

The importance of ground water in Minnesota is reflected in the state's reliance on it for drinking water, industrial production, food processing, and irrigation. In 1976, ground water was 14 percent of the total water withdrawn. By 1980, ground water accounted for 21 percent of the state's total water withdrawal (228.4 billion gallons of ground water out of a total of 1,109.6 billion gallons water withdrawn). Most of this water (ground water) is for high priority use, that is, municipal water supplies and irrigation.

Water use in Minnesota for 1980 is shown in Figure 10 and was estimated from pumpage reported to the MDNR Division of Waters, agricultural statistics, and population data. Water use within the state was divided into five major categories: 1) public water supply; 2) rural domestic and livestock; 3) irrigation; 4) thermoelectric power generation; and 5) self-supplied industrial use.

Water usage was tabulated separately for ground water and surface water sources for these five categories. Public water supplies account for 36.6 percent of the total amount of ground water withdrawn. Rural water use is the second largest category of ground water withdrawal at 28.5 percent of the total ground water use. Rural water usage can be further subdivided into domestic and livestock uses. Domestic water use accounts for 19.3 percent of the ground water withdrawn; livestock watering accounts for 9.2 percent. Surface water is rarely used for rural domestic purposes. Irrigation water use also comprises a large portion (22.3 percent) of ground water withdrawals and is growing rapidly.

To reiterate the point that ground water plays a central role in Minnesota's water supply picture as compared to the entire United States, Figure 11 presents summary comparisons of United States ground water use and Minnesota ground water use by percentages. The water use statistics are taken from a variety of sources (U.S. Water Resource Council, USGS, and MDNR); the main purpose in presenting them is to show the high reliance on ground water for public and rural water supply in Minnesota compared to a much lower reliance nationwide.

When the number of individual permits rather than the sheer volume of water use is examined, ground water appropriations emerge as being even more significant in the Minnesota water use picture. For example, 63 percent of the water withdrawn by municipal water treatment plants in 1976 came from wells. However, 93 percent of all the municipal systems use ground water. The figures may seem a bit incongruous, but that is because major cities such as Minneapolis, St. Paul, and Duluth use surface waters.

Despite the generally positive picture of demand and supply, there are significant cautions. Localized shortages can occur either due to well interference or to water quality problems. The potential for this to occur is greatly amplified where users are concentrated. Shortages can also occur when the capacity of the water supply system cannot keep up with the demand, generally falling short during peak use periods. Adequate capacity can be defined by

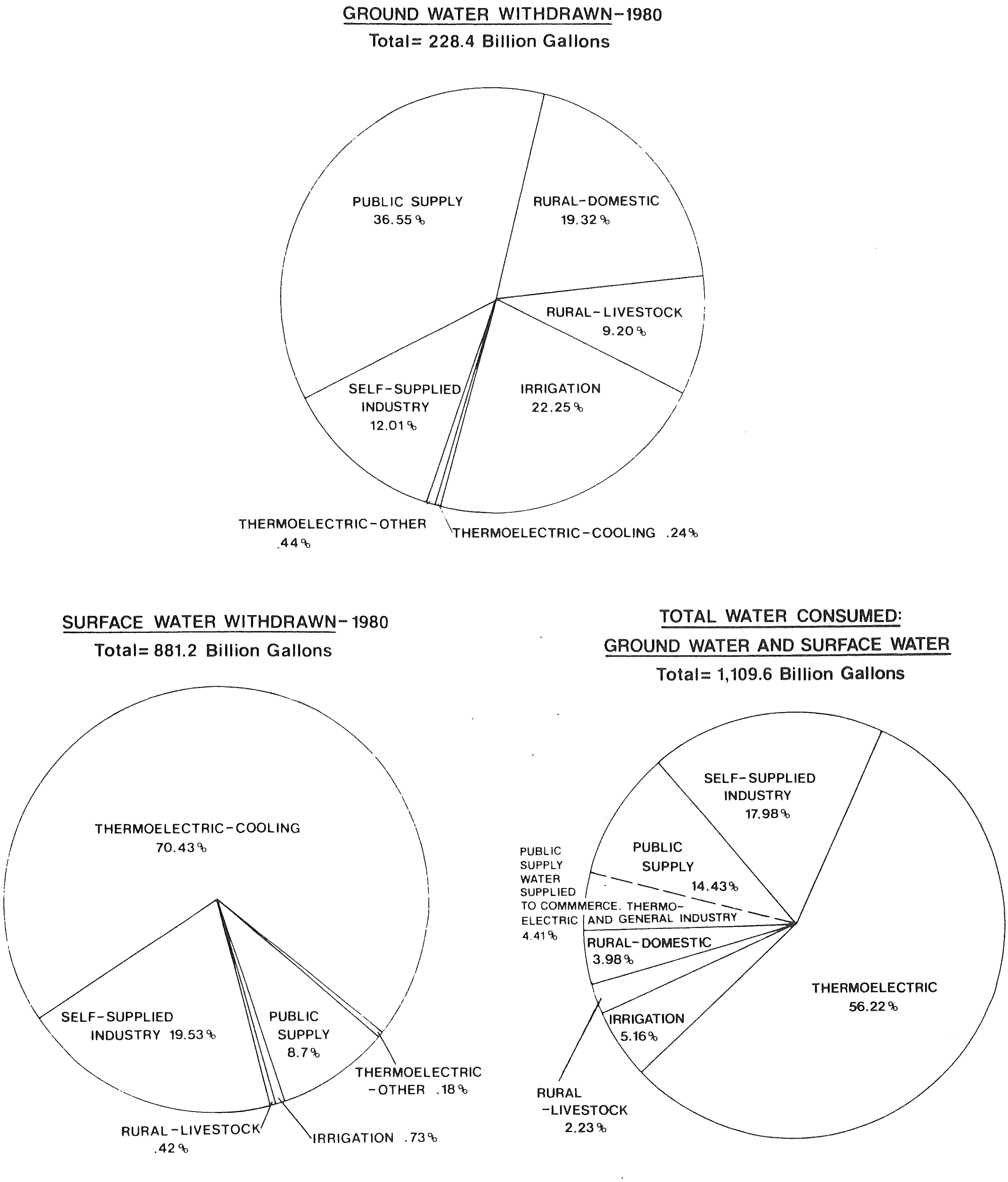


FIGURE 10. MINNESOTA WATER USE — 1980 (MDNR, 1982).

GROUND WATER — UNITED STATES USE
1950 — 1975

USE	Percent of Total 1950	1960	1970	1975
Irrigation	62	68	66	69
Industry	18	13	15	14
Public Supplies	12	13	14	13
Rural Supplies	8	6	5	5
TOTAL (trillion gallons per year)	**12.4**	**18.3**	**24.8**	**19.9**

GROUND WATER — MINNESOTA USE
1970 and 1980

USE	Percent of Total 1970	1980
Irrigation	2	22
Industry	46	12
Public Supplies	26	37
Rural Supplies	25	29
TOTAL (trillion gallons per year)	**0.21**	**0.23**

FIGURE 11. SUMMARY COMPARISON OF GROUND WATER USE — UNITED STATES AND MINNESOTA.

the economics of meeting the marginal demand and by acceptable uses within a community. In some cases, however, the system may simply be unable to sustain pumping at desired rates. Major natural occurrences, such as the drought of 1976 and 1977, cannot be accurately predicted and can also cause unanticipated shortages.

To demonstrate how the information on geology, water quality, water quantity, and supply and demand are used to define and manage ground water resources, we can look at the aquifer system which underlies the Twin Cities Metropolitan Area.

The Twin Cities are located in a roughly oval, northeast-trending basin filled with sedimentary bedrock strata. A number of faults in the underlying rock originally formed the basin which then acted as a sediment trap during the Paleozoic era. As much as 1000 feet of Paleozoic sedimentary rock are present in the Twin Cities basin. Bordered by the St. Croix River on the east, the spoon-shaped basin stretches from Taylors Falls to Elk River, around the Twin Cities Metropolitan Area down to Belle Plaine, and across to Hastings (Sims and Morey, 1972).

Based on the present level of understanding of the water-bearing characteristics of the geologic units that underlie the seven-county metropolitan area, nine hydrogeologic units are now recognized. Figure 12 illustrates the vertical distribution of these units as a simplified hydrogeologic section. These nine hydrogeologic units are not uniformly present across the entire Twin Cities region. Bedrock valleys dissect the area, filled partly or totally with drift or recent river deposits. These valleys complicate the ground water flow by providing hydraulic connections between deeper bedrock formations and surficial deposits and the major rivers. They also can cause localized recharge or discharge to occur which differs from the general regional flow.

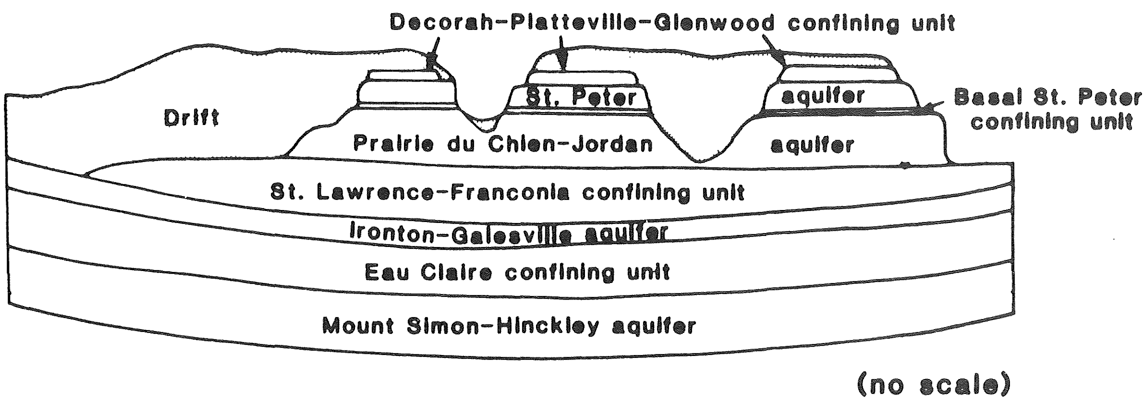


FIGURE 12. THE VERTICAL DISTRIBUTION OF THE NINE HYDROGEOLOGIC UNITS OF THE TWIN CITIES AREA IN SIMPLIFIED CROSS-SECTION (USGS, 1982).

Fortunately, the ground water resources of the Twin Cities Metropolitan Area are abundant. Average ground water withdrawal in the area was estimated to be about 168 million gallons per day (mgd) for 1971 through 1977 (USGS, 1978). The majority of the water is withdrawn from the Prairie du Chien-Jordan aquifer. In 1980, 867 out of 991 water appropriation permits in the seven-county metropolitan area were for ground water withdrawal, a total withdrawal of 242 mgd with approximately 45 mgd actually consumed.

Since 1890, ground water withdrawals have caused water levels to decline in the Prairie du Chien-Jordan and Mount Simon-Hinckley aquifers, approximately 90 and 200 feet, respectively. Water levels in the Prairie du Chien-Jordan are lowered up to an additional 65 feet in some areas during summer when pumping is greatest, but that 65-foot seasonal decline recovers during the winter. In the summer, extensive pumping in the downtown areas for air conditioning is a major factor in the lowering of ground water levels. Withdrawals from the Mt. Simon-Hinckley have declined in the past decade, while withdrawals from the Prairie du Chien-Jordan increased slightly (USGS, 1983).

Although the long-term water level declines appear to have stabilized by 1978, the demand on the ground water resource is increasing. For example, additional demand for ground water is seen in Dakota County where acreage irrigated from wells increased from 3,000 acres in 1970 to 42,000 acres in 1977. The city of St. Paul is developing ground water for supplemental municipal supply. At present, approximately 25 percent of the supply is ground water, with a goal of reaching 50 percent ground water (Englund, 1983). Minneapolis has also examined the possibility of augmenting its Mississippi River supply with well water.

Sound management to lessen the impact of uncontrolled development, no matter where it may be, depends on thorough knowledge of the hydrogeologic system. Pumping which depletes the ground water close to lakes can cause water to seep through lake bottoms to recharge an aquifer. Declining water levels have, in fact, been a problem with lakes in the metropolitan area and some lake levels are maintained by pumping ground water into them. Rising lake levels are also a problem. The ground water-surface water interactions of some of these lakes are currently being investigated cooperatively by the USGS and MDNR. Clearly, new demands need to be properly managed. Overall, the quality of ground water in Minnesota is good but problems of contamination are being identified due to surface activities. These incidents of contamination are discussed in Chapter 4.

In summary, the ground water in Minnesota is a unique and immeasurably valuable resource because of its consistent high quality and quantity. Figure 13 provides a summary of the predominant ground water characteristics in the state. The state has a large natural reservoir in its system of aquifers, providing ground water which is widely available. However, we must constantly remind ourselves that it is not limitless, nor is it something we can afford to have degraded to gain short-term benefits. Normally, ground water is naturally protected from direct "insults," although land surface activities can have a great influence on the water resource. We must guard against selfish use and misuse or we will lose for all time one of Minnesota's most valuable natural resources.

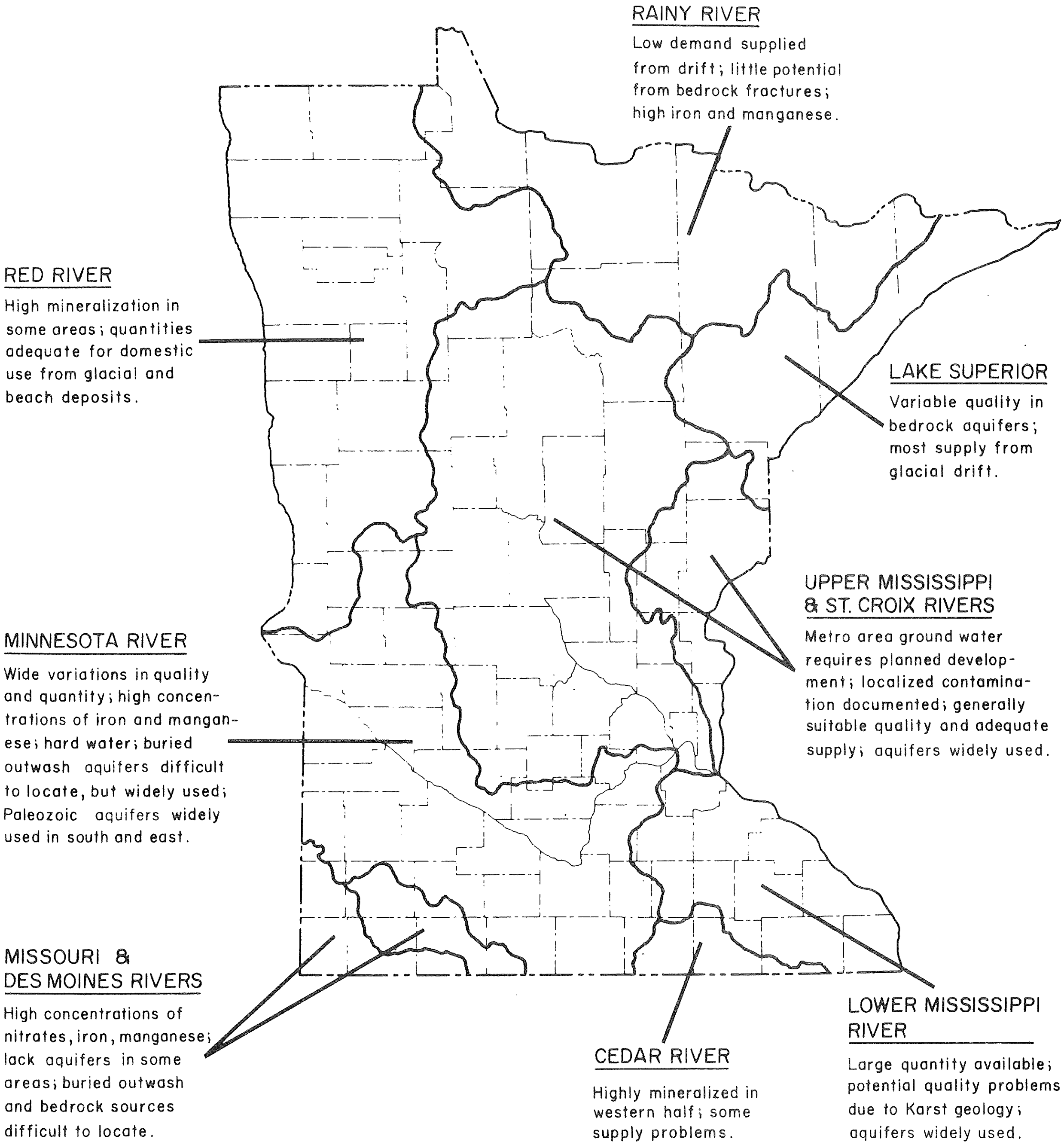


FIGURE 13. GROUND WATER SUMMARY BY RIVER BASIN.

4. LEGAL AND ADMINISTRATIVE ASPECTS OF MANAGEMENT

Ground Water Law

The legal framework within which Minnesota manages its ground water resources comprises common law, federal and state laws, and resultant regulatory programs. Common law, evolving from court decisions and opinions, separates ground water into two distinct divisions: underground streams and percolating water. No connection to surface flow is recognized. Although these assumptions are hydrologically incorrect, the distinction is maintained in the courts.

Five levels of government are potentially involved in the decision making which affects water and related land resources. Federal, interstate, state, regional, and local government entities oversee ground water management through an assortment of laws, regulations, compacts, plans, strategies, and ordinances. International water resource issues do arise and are generally handled through federal channels or interstate commissions and associations which include, in the case of Minnesota, Canadian representation. The federal laws generally deal with surface waters and define national water quality standards but have also attempted to protect ground water from land surface activities which may lead to its contamination. Most laws and amendments that provide the federal government with the tools to deal with ground water pollution problems were passed in the 1970's. Minnesota has adopted water quality standards and established state programs to carry out the mandates of these federal environmental laws. In some cases, the effect of these laws on ground water is implied and untested. A summary of some of the more important federal laws follows:

- The Clean Water Act of 1972 (PL 92-500) gives USEPA jurisdiction over ground water quality but the authority is somewhat ambiguous. Numerous states have outlined ground water elements in their Water Quality Management Plans under Section 208 of this act. Land application of effluents from wastewater treatment plants is also regulated under this law.
- The 1974 Safe Drinking Water Act (SDWA-PL 93-523) gives USEPA the authority to set water quality standards for drinking water, to establish standards for the control of underground injection of wastes, and to designate aquifers as sole sources of drinking water in specific areas. Sole source designation requires special review of projects with federal funding in that area to ensure that the ground water quality will not be degraded.
- The 1976 Resource Conservation and Recovery Act (RCRA-PL 94-580) was designed to improve solid waste disposal practices, to regulate hazardous wastes from their generation to disposal, and to establish resource conservation as the preferred solid waste management approach.

- The Toxic Substances Control Act of 1976 (TOSCA-PL 94-469) and the 1972 amendments to the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA-PL 92-516) require inventories to be kept of assorted chemicals and control their use. These laws indirectly protect ground water by controlling potential contaminants.
- The Comprehensive Environmental Response, Compensation, and Liability Act (Superfund-PL 96-510) was passed in 1980, creating the authority and resources to act immediately to prevent the spread of ground water contamination as a result of waste disposal activities.

The federal presence in the area of ground water protection enhances existing state enforcement authority and attempts to achieve consistent performance among the states. In some cases, the federal law allows direct transfer of authority to the states for enforcement of programs.

Interstate water management has generally focused on surface water use and quality until recently. In 1982, two court cases were heard which dealt with interstate appropriation of ground water. In July 1982, the U.S. Supreme Court overturned a Nebraska law which was being used to deny an appropriation permit along the Colorado-Nebraska border **(Sporhase v. Nebraska).** The court opinion stated that the Nebraska law which required a reciprocal appropriation, placed a greater burden on interstate transfers of water than intrastate transfers and was, therefore, hindering interstate commerce. In a similar decision, the U.S. District Court, citing Sporhase, overturned a New Mexico ruling forbidding El Paso, Texas, from obtaining appropriation permits (January 17, 1983 — **El Paso v. New Mexico**). Until these decisions, ground water appropriations had been left to state jurisdiction, but with increased competition for water, the federal commerce law has been used as the basis for sending these cases to the federal courts. The main thrust of these decisions is that states may not be able to prohibit interstate transfers of ground water.

Ground water law has not yet developed satisfactory answers to a number of recurring problems in the management and administration of aquifers. One difficulty is determining the extent to which the owner of a ground water right has or should have a responsibility to maintain underground water levels. Another is the extent to which aquifers can be depleted, mined, or even exhausted and the extent to which this use interferes with the rights of others. Both of these issues fall in the general category of well interference. A third problem is the extent to which ground and surface water supplies can be integrated for management purposes so that interconnecting sources of supply can be used with fair administration of existing rights and so that the total water supply can be better put to optimal use (Seinwell, 1977).

The legal principle on which Minnesota water law is based is called the American Reasonable Use Doctrine of Riparian Rights. Under this doctrine, each landowner has the right to make reasonable, beneficial use of water available adjacent to or underneath his property. Reasonable, beneficial use provides for, but does not necessarily deal with water quality concerns.

State Ground Water Law and Programs

In the evaluation of state laws, rules, and procedures for public water resource management and regulation, the Minnesota Water Planning Board (MWPB) identified 16 state agencies and boards which administer over 80 water-related programs in Minnesota (1979). Seventy-five percent of the primary statutory responsibilities and regulatory programs for ground water fall within three agencies: the Minnesota Department of Natural Resources (MDNR), the Minnesota Department of Health (MDH), and the Minnesota Pollution Control Agency (MPCA). The division of authorities among these agencies places control and conservation of water use, that is water quantity management, in the MDNR; health-related and domestic supply matters in the MDH; and surface and ground water quality issues and pollution control requirements within the MPCA. While this division of authority seems clear conceptually, it requires great interdependence among the agencies.

Figure 14 summarizes the legislative authorities relating to ground water management in Minnesota. In one form or another, state management of water resources has been around for a long time. Because of the health aspects of polluted water, which were clearly recognized around the turn of the century, water supplies and discharges were the first areas to be regulated or managed. The earliest provisions of the state's statutes dealing with water are found in Minnesota Statutes, Chapter 105. Since the enactment of this statute in 1947, the legislature continued to seek development of a water policy for the state (Seinwell, 1977).

General charge and control over the waters of the state and of their use, sale, leasing, and other disposition is given to the Commissioner of the MDNR. The regulation of water quantity is carried out through the MDNR's appropriation permit program (6 MCAR §§1.5050-1.5058). Appropriation permits are required of all users (except for domestic use for 25 persons or less) and annual pumpage must be reported. At present the MDNR has approximately 5,300 active permits in the state. The MDNR maintains a data base of water use based on over 10,000 appropriation permits recorded since the historical record of the program began in 1947.

The statutes set priorities for water appropriation in the state. They are as follows:

1. Domestic supply, excluding industrial and commercial uses of municipal water supply;
2. Any use of water that involves consumption of less than 10,000 gallons per day. For the purposes of this section, "consumption" means water withdrawn from a supply which is lost for immediate further use in the area;
3. Agricultural irrigation, involving consumption in excess of 10,000 gallons per day, and processing of agricultural products;
4. Power production, involving consumption in excess of 10,000 gallons per day;
5. Other uses involving consumption of 10,000 gallons per day (Minnesota Statutes, Chapter 105.41).

FIGURE 14. LEGISLATIVE AUTHORITIES RELATING TO GROUND WATER MANAGEMENT

Area of Authority	MDNR	MDH	MPCA	Other
1. General	*M.S. 105.38(2)* Policy to control use in order to conserve and utilize the waters of the state.	*M.S. 144.05* State's official health agency including environmental health matters.	*M.S. 115.03(1)* To administer and enforce all laws relating to the pollution of any waters of the state.	MGS — *General Laws of Minnesota* 1872, Ch. XXX, *Sec. 2* To provide a complete account of the mineral kingdom. EQB. *M.S. 116C.04* WPB. *M.S. 105.401* SWCB. *M.S. 40.02(4)* DPS. *M.S. 12.02* MDA. *M.S. 1703* WMB. *M.S. 115A.06*
2. Conservation **a. General**	*M.S. 105.39(1)* Water conservation program for guiding issuance of permits for use. *M.S. 105.405* Water supply management for long-range . . . seasonal requirements including quality and quantity needs *M.S. 105.51* DNR authorized to prevent waste by well owners.	*M.S. 144.35* to preserve domestic water supplies from pollution. *M.S. 144.383* To ensure safe drinking water. *M.S. 156A.01* To reduce and minimize waste.	*M.S. 115.03(1)* To establish reasonable pollution standards for any waters of the state.	*M.S. 116D.02* State Environmental Policy.
b. Critical or Emergency Periods	*M.S. 105.41(2a)* Modificaiton of permits endangering domestic supply. *M.S. 105.418* Conservation of public water supplies during periods of critical water deficiency.	*M.S. 144.34* Protect sources of domestic supply from pollution which could endanger public health. *M.S. 144.383* Emergency plans and orders to protect public when a decline in quality or quantity creates a serious health risk.	*M.S. 116.101* Hazardous waste control and spill contingency plan. *M.S. 116.11* Emergency powers to direct discontinuance or abatement of pollution endangering health and welfare.	*DPS M.S. 12.03(4)* Emergency services to prevent, minimize, and repair injury and damages resulting from disasters. MDA. *M.S. 18A.37* Procedures to contain and control pesticides in an emergency.

FIGURE 14. LEGISLATIVE AUTHORITIES RELATING TO GROUND WATER MANAGEMENT (Continued)

Area of Authority	MDNR	MDH	MPCA	Other
3. Regulation	*M.S. 84.57* Permits for underground storage of gases or liquids. *M.S. 105.41* Appropriation and use of waters permits. *M.S. 105.418* Public water supply restrictions based on DNR rules for critical periods. *M.S. 105.41(3)* Abandonment of wells of specified size to comply with DNR recommendations.	*M.S. 114.12* Regulations relating to disposal of sewage, pollution of waters, sanitation of resorts. *M.S. 144.35* Charge to preserve water supply sources from pollution as may endanger public health. *M.S. 144.383* Safe Drinking Water regulations for supply development and management. *M.S. 156A.03* Regulation and licensing of drillings construction and abandonment of water wells to release and minimize waste.	*M.S. 115.03* Regulation to control or abate water pollution. *M.S. 116.101* Hazardous waste management regulation.	EQB. *M.S. 116C.23* Environmental permits coordination. *M.S. 116D.04* Environmental impact statements. MDA. *M.S. 18A.25* Pesticides regulation. *M.S. 31.54* Water supplies of packing plants. *M.S. 32.392* Approval of dairy plants including water supplies and disposal of wastes.
4. Planning	*M.S. 105.39(1)* Development of a water conservation program to guide the issuance of use permits. *M.S. 105.403* Statewide framework and assessment water and related land resources plan, including water supply and quality needs. *M.S. 105.41(1a)* Requirement of permit consistency with state, regional, and local water and related land resources plans.	*M.S. 144.383* To develop an emergency plan to protect the public when a decline in quality or quantity creates a serious health risk. *M.S. 145.918* To establish a planning process for development of community health services plans.	*M.S. 116.10* Long range annual plan and program for implementation of pollution control policies. *M.S. 116.101* Statewide hazardous waste management plan, and including a spill contingency plan.	EQB. *M.S. 116C.07* Annual preparation of a long range plan and program for the effectuation of state environmental policy. WPB. *M.S. 105.401* Preparation of a framework for water and related land resources plan. WMB. *M.S. 115A.11* Preparation of a hazardous waste management plan.

FIGURE 14. LEGISLATIVE AUTHORITIES RELATING TO GROUND WATER MANAGEMENT (Continued)

Area of Authority	MDNR	MDH	MPCA	Other
5. Data Collection & Management				
a. Information Systems Development	*M.S. 105.39(6)* DNR in cooperation with other state agencies shall establish and maintain a statewide system to gather, process and disseminate information on availability, distribution, quality, and use of waters of the state.	*M.S. 156A.07* May establish procedures for coordinating water well data collection for geologic and water resource mapping to assist in development of a state water information system.		*Laws of Minnesota, 1977, Ch. 446, Sec. 20(4)* To complete a statewide data bank of waterwell logs and compilation of data obtained from current drilling activities.
b. Collection Reporting & Monitoring	*M.S. 105.40(10)* Written approval of Waters Director required for state and local water data collection contracts with federal government. *M.S. 105.41(2)* Owner or manager of every installation for water appropriation to file requested information with DNR. *M.S. 105.41(4)* Requirement for measuring and recording quantity used. *M.S. 105.41(5)* Annual pumpage reports required. *M.S. 105.416(2)* Information requirements for class B irrigation appropriation permit applications. *M.S. 105.51* Reports of well logs and pumping tests required of drillers.	*M.S. 144.383* Board to conduct, or contract with local boards for sanitary surveys and investigations of operation and service. *M.S. 156A.05(2)* Establishment of a system for reporting on wells drilled by licensed contractors. *M.S. 156A.05(3)* Inspection of wells drilled, or being drilled. *M.S. 156A.07* Submission of verified reports by licensed contractors with copies to DNR, MGS, and SWCD's. Establishment of procedures and criteria for submission of data.	*M.S. 115.03* To gather the data and information necessary in administration and enforcement of pollution laws. *M.S. 116.101* Hazardous waste plan to include information reporting system.	MDA. *M.S. 31.54* Supply source and quality data collection relating to packing plant approval. MDA. *M.S. 32.392* Supply source and quality data collection relating to dairy plant approval. DOT. *M.S. 161* Collection of undisturbed boring data for highway construction and development.

FIGURE 14. LEGISLATIVE AUTHORITIES RELATING TO GROUND WATER MANAGEMENT (Continued)

Area of Authority	MDNR	MDH	MPCA	Other
6. Coordination and Assistance	*M.S. 105.49* Personnel from PCA, MDH and local governments to cooperate in monitoring and enforcement.	*M.S. 156A.03* Consultation with DNR and PCA in development of standards for design, location, and construction of water wells. *M.S. 156A.07* May establish procedures for coordinating well data collection with other state and local agencies.	*M.S. 115.06(3)* Cities, towns, counties, sanitary districts, public corporations, and other governmental subdivisions to cooperate in obtaining compliance and to enforce requirements within their jurisdictions. *M.S. 116.05* State departments to cooperate and to assist Agency in performance of its duties.	
7. Regional and Local Roles	*M.S. 105.41* Permit consistency with local and regional plans is required provided these are consistent with state plans. *M.S. 105.41(1b)* Local or regional processing of permits authorized with conditions. *M.S. 105.416(1)* SWCD's as a source of ground water data. *M.S. 105.416(3)* SWCD recommendations on adequacy of soil and water conservation measures of proposed water uses for irrigation. *M.S. 105.418* Public water supply authorities to adopt and enforce restrictions during critical periods. Consistent with DNR rules.	*M.S. 144.12* County and local health officers may be required to make investigation and enforce regulations under supervision of Board. *M.S. 144.383* Local boards of health may contract with state Board for water supply testing. *M.S. 145.031* One or more counties, and cities may enter into formal agreements to perform functions of state Board. *M.S. 145.911* Local administration of community health services under State guidelines and standards. *M.S. 145.92* Plan review by regional development commissions or Metropolitan Council.		

FIGURE 14. LEGISLATIVE AUTHORITIES RELATING TO GROUND WATER MANAGEMENT (Continued)

Area of Authority	MDNR	MDH	MPCA	Other
	M.S. 105.44(8) SWCD's may make recommendations on compatibility of permit applications with comprehensive SWCD plans. *M.S. 105.49* County and municipal cooperation in monitoring and enforcement.			

Prepared by: Minnesota Water Planning Board, Water Management Work Group, 1979b, in Management Problems and Alternate Solutions, MWPB Draft Technical Paper 14.

The system of water use priorities came under scrutiny in the case of the **Crookston Cattle Company v. MDNR** (December 1980). The city of Crookston was changing its source of water supply from the Red Lake River to wells. The change was recommended by the MDH because the city's water treatment plant needed extensive renovation and the city felt that switching to ground water would lower maintenance costs.

The Crookston Cattle Company applied for water appropriation permits for 12 irrigation wells in the vicinity of the four municipal wells. The MDNR refused the permit until the company could prove that its withdrawal would not affect the municipal supply. The Minnesota Supreme Court supported the MDNR's position based on the facts that: (1) municipal use is first priority and agricultural irrigation is third priority; and (2) riparian rights are subordinate to the rights of the public and are subject to state regulation. The MDNR's refusal to give a permit to the Crookston Cattle Company was not an absolute refusal, rather a conditional one requiring proof that the third priority use would not have a deleterious effect on the municipal supply.

Two other subdivisions in Chapter 105 specifically mention ground water. Minnesota Statutes, Chapter 105.416 defines special requirements for water appropriation permits for irrigation from ground water. If the application is submitted for wells in an area of the state where the MDNR does not have adequate information, MDNR has the authority to require data regarding the well, aquifer, pumping rate, and water quality with the application. Minnesota Statutes, Chapter 105.51 defines general operational constraints which MDNR may set. "For the conservation of underground water supplies of the state, the commissioner is authorized to require the owner of wells, especially flowing artesian wells, to prevent waste" (Subdivision 1). The quantity of ground water pumped by permittees is submitted to MDNR annually. In addition to the pumpage report, water levels are measured in an observation well network. Data from selected wells are plotted on monthly high, low, and mean levels for the period of record to aid in the description of seasonal fluctuations (USGS, 1982).

The MDH Water Well Construction Code developed under Minnesota Statutes, Chapter 156A, provides a preventive approach to water quality; if a well is properly drilled and maintained, it is less likely to act as a conduit for contamination. This code (7 MCAR § 1.210-1.224), effective in 1974, has provisions for: (1) licensing water and exploratory well drillers and registering monitoring well engineers; (2) delineating location and construction requirements of wells depending on the geology of the site and existing structures; (3) requiring the submittal of a well log and a water sample for each new or reconditioned well; (4) requiring proper sealing and abandonment of wells if the well is no longer in use, contaminated, or the source of contamination; and (5) prohibiting the use of a well for disposal of surface water, near-surface water, or ground water or any other liquid, gas, or chemical. In Minnesota, we normally construct about 10,000 water wells each year.

In 1981, the Legislature added a limited program which allows a specific number of permits to be granted for the reinjection of ground water and ground water thermal exchange devices, commonly called ground water heat pumps (Minnesota Statutes, Chapter 156A.10). Public water supply regulations are administered by the MDH to carry out the Safe Drinking Water Act in Minnesota (Minnesota Statutes, Chapter 114.381 and 7 MCAR § 1.145-1.150).

Public water supplies currently serve about 3,042,000 Minnesotans. The objectives of the program are:

1. To achieve all monitoring requirements as defined by the Minnesota Safe Drinking Water Regulations;
2. To identify all community and non-community supplies in the state;
3. To enforce drinking water quality standards (maximum contaminant levels);
4. To see that records are maintained and public notice takes place when standards are violated; and
5. To inspect each community supply once every 15 months.

The third agency that has authority to regulate ground water is the MPCA. MPCA's statutory charges pertaining to ground water are very broad and, consequently, have the potential to allow comprehensive programs. Quite simply, Minnesota Statutes, Chapter 115 directs the MPCA "to administer and enforce laws relating to pollution of any waters of the state" and Minnesota Statutes, Chapter 116 requires the MPCA to promote solid waste disposal control, hazardous waste control, and have a spill contingency plan.

The MPCA administers its programs through a system of rules aimed at controlling pollution. Minnesota Rule 6 MCAR § 4.8022 (WPC-22) was developed by MPCA to preserve and to protect the underground waters of the state by preventing any new pollution and by abating existing pollution. Numerous other MPCA rules provide for ground water protection and include sewage sludge landspreading (6 MCAR § 4.6101-4.6136), hazardous waste facilities (6 MCAR § 4.9001-4.9010), sanitary landfills (Minnesota Rule SW-6 and SW-12), septic tanks and drainfields (6 MCAR § 4.8040), storage of liquid products (WPC-4), and intrastate (6 MCAR § 4.8014) and interstate (6 MCAR § 4.8015) standards of water quality and purity. Permits are required for the operation of disposal practices and facilities which could impact either surface or ground water quality.

Figure 15 is a table of the state's ground water and related land resources programs. The ground water management programs generally fall into the categories of planning, research, regulation, and monitoring. The top portion of the figure represents boards with statutory charges to carry out long range planning. The Water Planning Board's framework water plan, "Toward Efficient Allocation and Management," MPCA's "208 Water Quality Management Plan," and the Southern Minnesota Rivers Basin Board's "Southeast Minnesota Tributaries Basin Report" all contain recommendations which address the need for continued close attention to the problem of ground water quality. The Environmental Quality Board (EQB) and the Soil and Water Conservation Board are in the initial stages of defining broader long range planning activities. With the consolidation of the EQB, the WPB, and the SMRBB in July 1983, long-range planning will play a stronger role in state government by combining efforts to assess changes in the quality of the environment and effectiveness of agency programs.

UNIVERSITY OF MINNESOTA

— Minnesota Geological Survey —

Hydrogeologic Mapping (Statewide)   Water Well Drillers Logs Database

Hydrogeochemistry Mapping   High Capacity Well Database (HICAPS)

— Department of Geology and Geophysics —

Research and Mapping of Karst in Southeastern Minnesota

WATER PLANNING BOARD*

Statewide Framework Water and Related Land Resources Plan   Coordination of State Water Resources Management

SOIL AND WATER CONSERVATION BOARD

Oversight of Soil and Water Conservation Districts

WATER RESOURCES BOARD

Water Policy Conflict Resolution   Watershed District Formation and Plan Review

SOUTHERN MINNESOTA RIVERS BASIN COUNCIL**

Regional Water and Related Land Resources Planning   Coordination of Natural Resources Management

WASTE MANAGEMENT BOARD

Hazardous Waste Management Plan   Solid Waste Management

Siting of Hazardous Waste Facility

PUBLIC SAFETY

— Division of Emergency Services —

Emergency Water Supply Services

ENVIRONMENTAL QUALITY BOARD

Environmental Impact Assessment   Critical Areas

Program Review and Policy Conflict Resolution   Pipeline Routing and Power Plant Siting

Economic Development   Environmental Policy Planning

*Effective July 1, 1983, the Water Planning Board is merged with the Environmental Quality Board.
**Formerly, Southern Minnesota Rivers Basin Board.

FIGURE 15. MINNESOTA GROUND WATER AND RELATED MANAGEMENT PROGRAMS

ENERGY, PLANNING, AND DEVELOPMENT

Land Management Information Center

Systems for Water Information Management

POLLUTION CONTROL AGENCY
— Division of Water Quality —

Water Quality Management Planning   NPDES Permits Program

Standards Development   State Disposal System Permits

Municipal Sludge Disposal   Agricultural Waste Unit

Emergency Response Unit (Spills)

— Division of Solid and Hazardous Waste —

Site Response Section   Solid and Hazardous Waste Facility Review

Hazardous Waste Generator Program   Ground Water Surveys Ambient Monitoring

Solid and Hazardous Waste Facility and Transportation Permits   Solid and Hazardous Waste Program Development

Underground Injection Control

NATURAL RESOURCES
— Division of Waters —

Water Appropriation Permits   Underground Gas and Liquid Storage Permits

Ground Water Hydrology   Information Systems Development

FIGURE 15. MINNESOTA GROUND WATER AND RELATED MANAGEMENT PROGRAMS (Continued)

Several ground water research projects have been funded by the LCMR, particularly in the southeastern region of Minnesota. Historically, ground water research has been directed at this region because of concern for ground water quality where the ground and surface water link is obvious (for example, through sinkholes, disappearing streams, and springs) and because approximately two-thirds of Minnesota's ground water is contained in aquifers underlying this region. In addition to the research carried out under the LCMR, the Water Resources Research Center at the University of Minnesota has funded eight projects on ground water since 1976. The University departments which have participated in these studies include the School of Public Health, Agricultural Engineering, Geology and Geophysics, the Minnesota Geological Survey, and Agriculture and Applied Economics.

Within the state ground water programs, agencies collect information on which they must base permit decisions and also maintain inventories of data submitted on permits and licenses. Planning activities rely on regulatory and research programs for data on which to base long range plans. Routine monitoring is generally required as part of the regulatory programs. In order to carry out their responsibilities to protect ground water quality, regulatory agencies generally share monitoring results. The background or natural quality of ground water is being documented so that changes, such as contamination, can be detected.

The MPCA conducts a ground water quality monitoring program to assess ambient conditions for overall trends and changes. The statewide program ran an array of analyses on 124 wells and 13 springs in 1978, 79 wells and 20 springs in 1979, and 61 wells and no springs in 1980. The program currently consists of 360 wells or springs located throughout Minnesota. The network of wells and springs is sampled in five year intervals. The data are published by the MPCA in annual reports, and are widely distributed.

Water Quality Standards and Monitoring

The standards by which water quality is judged depend on the use for which the water is intended. If the water is to be consumed by people, the MDH monitors and enforces the allowable limits for specific parameters with known health effects. These standards are set by the USEPA and are called the National Interim Primary Drinking Water Standards. Under the Minnesota Safe Drinking Water Act, equal or more restrictive standards may be set by the state. These standards are not cast in stone; they change as research on health effects provides new information on short and long term exposure, particularly to chemicals (see Figure 16).

The MPCA uses the National Interim Drinking Water Regulations as a gauge against which ground water quality is assessed. In many cases, the natural level of a water quality parameter is less than the "maximum contaminant level" allowable by standards. For example, since nitrate is highly water soluble, its presence in ground water is linked directly to activities on the land surface. It is generally agreed that there is a very small amount of naturally occurring nitrate in Minnesota ground water. A margin of 10 mg/l exists between the negligible natural levels and the maximum level of nitrate-nitrogen recommended for human consumption.

Conversely, in some locations ground water may have naturally occurring characteristics which exceed recommended standards for potable water. MPCA regulations allow the higher natural level to be used as the ground water standard when the background level has been determined and the size and the hydrology of the aquifer are known. Natural background levels of iron, manganese, and total dissolved solids exceed the drinking water standards in some aquifers in Minnesota.

The analyses which are performed on water samples can be expensive and, therefore, are selected according to the intended use of the water of the suspected problem. A basic test which is run is the analysis of nitrate and coliform bacteria, commonly called "indicators." Because of the common occurrence of nitrate on the land surface and coliform bacteria in the feces of warm-blooded animals, these two parameters are frequently tested and will probably be present in well water if there is contamination present in the well.

FIGURE 16. GROUND WATER STANDARDS (JANUARY 1981)

Substance	Minnesota 1A Drinking Water Standard	USEPA Interim Primary Drinking Water Standard	USEPA Proposed Secondary Drinking Water Standard
Arsenic (As)	10 ug/l	50 ug/l	
Barium (Ba)	1 mg/l	1 mg/l	
Cadmium (Cd)	10 ug/l	10 ug/l	
Carbon Chloroform Extract	0.2 mg/l		
Chloride (Cl)	250 mg/l		250 mg/l
Chromium (Cr)	50 ug/l (+6)	50 ug/l (total)	
Coliform Organisms, Total	1 MPN/100 ml		
Color	15 units		15 units
Copper (Cu)	1 mg/l		1 mg/l
Cyanides (CN)	10 ug/l		
Dissolved Solids, Total	500 mg/l		500 mg/l
Endrin		0.2 ug/l	
Fluorides (F)	1.5 mg/l	*	
Foaming Agents			0.5 mg/l
Iron (Fe)	0.3 mg/l		0.3 mg/l
Lead	50 ug/l	50 ug/l	
Lindane		4 ug/l	
Manganese (Mn)	50 ug/l		50 ug/l
Mercury (Hg)		2 ug/l	
Methoxychlor		0.1 mg/l	
Methylene Blue Active Substance (MBAS)	0.5 mg/l		
Nitrate	45 mg/l (as NO_3)	10 mg/l (as N)	
Odor Number, Threshold	3		3
pH Range			6.5 to 8.5
Phenol	1 ug/l		
Radioactive Materials	***	**	
Selenium (Se)	10 ug/l	10 ug/l	
Silver (Ag)	50 ug/l	50 ug/l	
Silvex (2,4,5-TP)		10 ug/l	
Sulfate (SO_4)	250 mg/l		250 mg/l
Toxaphene		5 ug/l	
Turbidity Value	5 units		
Zinc (Zn)	5 mg/l		5 mg/l
2,4-D		0.1 mg/l	

*Refer to the "National Interim Primary Drinking Water Regulations," (EPA-570/9-76-003). There is a fluoride standard which applies only to community water supplies and is dependent upon the annual average of maximum daily air temperatures for the supply in question; see page 5, Section 141.11(c) for the appropriate standard.

**Refer to the "National Interim Primary Drinking Water Regulations," (EPA-570/9-76-003) for the limits on specific particle and/or photon emitters, see pages 7-8 and 16.

***Not to exceed the lowest concentrations permitted to be discharged to an uncontrolled environment as prescribed by the appropriate authority having control over their use.

The nitrate portion usually reflects infiltration from the land surface which may or may not be a cause for concern, depending on what other contaminants might accompany the nitrate. Coliform bacteria indicate bacterial contamination of the well; the coliform bacteria are normally not disease-causing but do indicate a rather direct access of surface contamination, suggesting the water might be polluted by human or animal waste.

MPCA and MDH have routine monitoring programs that assess ground water quality. The MPCA's ambient ground water program, mentioned previously, samples many of the parameters shown in Figure 16 from selected water wells and springs on a five-year, rotating basis. The raw water quality data is entered and stored on the USEPA computer database called STORET.

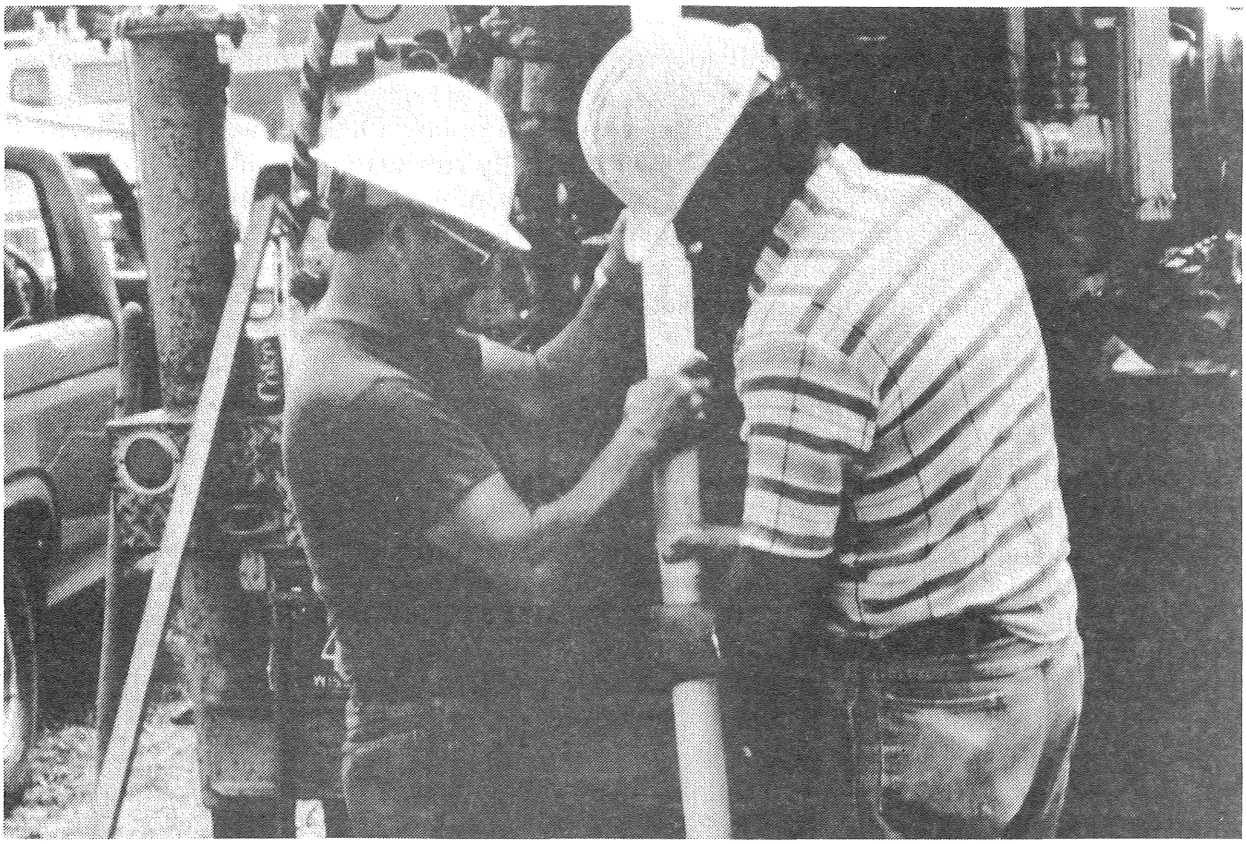
MDH has responsibility for routinely monitoring the treated water quality of municipal water supply systems. Once every 15 months, each water supply is inspected and the water is sampled to determine if it meets Safe Drinking Water Standards. The frequency of sampling beyond this basic program depends on a number of factors such as the population served by the system, treatment processes used, and the source of water. These data are kept in manual files.

In addition to routine monitoring, site-specific studies and single-time sampling are carried out regularly because of suspected contamination or concern for health effects from consuming ground water which may have been affected by a source of contamination. Whenever a new well is constructed, the licensed well driller is required to submit a water sample for nitrate and coliform bacteria analysis. The well must meet minimal standards for drinking water if it is for domestic use.

Occasionally, a special concern about ground water contamination because of a spill, ongoing industrial activity, or discovery that hazardous waste has been buried in a sanitary landfill requires site-specific samples to be taken. Recently, organic chemicals have received increasing attention in such sampling because of their pervasive use and persistence in the environment. Analysis can be very expensive, in part because minute quantities must be detected. In 1979, the USEPA published a list of 129 priority pollutants, organic compounds, and metals for which industrial effluents are screened.

In addition to sampling initiated by state agencies, individuals might want to have water samples taken. To get a water sample taken for a private well, the owner should contact his local county community health service office. Each county has its own system for collection and payment for well water samples, but they all recommend a periodic check of nitrate and coliform bacteria in the well at a minimum.

If a specific source of contamination is suspected, additional parameters may be analyzed. If health problems seem to be the result of ingesting the water, the MDH regional or central office should be contacted. If pollution is taking place from a spill or improper waste disposal, MPCA may run samples for suspected toxic contaminants. If a person's home is served by a municipal water supply, the municipal water treatment plant can be contacted for water quality information or possible sampling at the home tap. Either the MPCA or the MDH may be contacted initially and the other agency will be consulted as necessary.



Wells in Minnesota must meet specifications of the Water Well Construction Code, administered by the Minnesota Department of Health (MDH); here, drillers install a plastic-cased well for monitoring shallow ground water near a waste disposal facility.

Aside from the MPCA ambient water quality monitoring program, there is no central collection of water quality data in Minnesota. An attempt has been made to coordinate and improve this data collection problem through the Minnesota Land Management Information Center (LMIC) and a project entitled Systems for Water Information Management (SWIM). Through this project, summary ground water data bases have been built from: (1) correlation of water appropriation permits issued by the MDNR, the municipal identification numbers used by the MDH, and National Pollutant Discharge Elimination System (NPDES) permit numbers used by the MPCA; (2) correlation of agency reference numbers for individual wells in the Twin Cities area; and (3) coordination of reference information on high capacity wells throughout the state.

There has been little work done on coordination of county well sampling aside from specific site studies or special regional studies such as the USGS Multi-State Regional Aquifer System Analysis. The quality of water in private wells is not routinely sampled through state or county programs to monitor whether or not it is safe to drink. Private well sampling is the responsibility of the owner but sometimes county health officials do tabulate well water sampling data in order to be generally aware of ground water quality in their area.

Due to a general awareness by local governments and rural populations of the sensitivity of the ground water in southeastern Minnesota, county and regional officials have been working since January 1982 to coordinate domestic well sampling. Of the nine southeastern Minnesota counties, only Olmsted and Mower currently run water quality laboratories; the other counties previously used labs in the Twin Cities. Since July 1983, the Olmsted County lab has been accepting samples from other counties for nitrate-nitrogen and coliform bacteria analyses. The results are being compiled and computerized for the region on a trial basis through the Agricultural Extension Service in Rochester.

Ground Water Contamination

If contamination is discovered in a water sample, steps should be taken to identify the source and entry point of the contaminant. Whether ground water contamination occurs depends largely on the nature of land surface activities, the waste products, the amount of runoff, and the capacity of the contaminant to reach the aquifer directly by injection or indirectly through soils and bedrock. Ground water problems that originate on the land surface may simply be caused by infiltration of polluted surface water as recharge to an aquifer. Land disposal of either solid or liquid waste materials in stockpiles, landfills, or dumps may also result in contaminated ground water. Deliberate actions such as salt spreading on roads and application of fertilizers and pesticides on agricultural lands also influence ground water quality. Animal wastes, if concentrated to the point of overloading the land's ability to filter out contaminants, can also affect ground water. Accidental spills of hazardous materials are of particular concern because they occur at random locations as opposed to areas of planned disposal.

In any situation where infiltration introduces contaminants into the ground, several mechanisms can naturally hold the contamination in the soil. Among the most important factors are the texture and composition of the earth materials. Fine-grained deposits filter out bacteria and reduce concentrations of some chemical constituents by ion exchange. Clay minerals have a high capacity for exchanging ions, immobilizing certain contaminant ions and reducing their concentrations in solution. In general, positively charged ions such as cadmium, lead, zinc, copper, mercury, and chromium (+3) tend to be adsorbed by clay minerals. Arsenic, selenium, chromium (+6), chloride, and nitrate, on the other hand, are only weakly adsorbed. The amount of ion exchange that takes place is a function of the clay minerals involved, the amount of ion exchange which has already taken place, other positive ions in solution, and accompanying negatively-charged ions.

Some ground water problems originate in the ground above the water table, bypassing the surface removal mechanisms to some extent. Holding ponds, lagoons, and sanitary landfills are expected to generate some amount of leachate below the land surface. Leachate is the fluid produced when surface infiltration contacts waste and moves through geologic material. Some systems such as septic tank cesspools and drainfields are built as soil absorption systems where the waste is supposed to seep into the water table. While septic tank systems may be acceptable for many applications, ground water problems can occur when infiltration systems become clogged, overloading the natural removal mechanisms and contaminating the aquifer.

The most common ground water problem resulting from septic tanks and cesspools is elevated nitrate levels. In addition, septic tank cleaning fluids which break up sludge in the drainage field contain trichloroethylene (TCE), benzene, or methylene chloride which are organic compounds being found in well water with increasing frequency. Home water softeners, when part of the water supply system, contribute salt residues to the ground water. High levels of sodium (salt) can cause soil plugging and system failures for certain clay soils.

Land application of wastes will generally remove nutrients, metals, and organisms from the water that reaches the aquifer. However, sand and gravel and fractured bedrock aquifers generally do not attenuate either chemical or bacteriological contaminants. Uncontrolled burial of waste and leakage from underground pipes are direct threats to the ground water. Waste disposal at or below the water table (directly into the aquifer) can lead to even more serious problems. Waste disposal in wet excavations, drainage wells, well disposal of wastes (underground injection), underground storage, and exploratory and abandoned water supply wells can all potentially provide a direct conduit for contaminants to reach an aquifer.

The position of the source of contamination within the ground water flow system is an important factor in determining the extent of contamination which may occur. In most circumstances, the zone affected is the shallow, unconfined aquifer near the surface. If contamination originates in an upland recharge area, a large portion of an aquifer may be contaminated. Dilution and dispersion are slow to attenuate subsurface contamination. Consequently, proper planning of land use and control of activities affecting the subsurface are the best means of avoiding many cases of ground water pollution. Proper loading of infiltration systems, correct sizing of facilities, and environmentally-sound location are essential design characteristics. Once facilities have been built or activities have been authorized, care must be taken to continue good management practices, including ground water monitoring.

In spite of Minnesota's nondegradation policy toward ground water quality, contamination has obviously taken place. Inventories have been made by the MPCA of facilities which may be the source of ground water contamination (MPCA, 1983). Slightly more than 1,400 active and closed landfills and dumps were counted in Minnesota in the 1980 MPCA Open Dump Inventory. Although 237 of these facilities do have solid waste disposal permits, over 50 of the 237 are estimated to have inadequate ground water monitoring systems. Inconsistent enforcement of monitoring regulations has occurred because requirements have changed rapidly over a short period of time and have not been uniformly applied to all facilities. The contamination potential of the remaining unpermitted sites is generally unknown.

There are an estimated 4000 underground bulk storage sites in Minnesota. Leakage from the underground storage of liquids, mostly petroleum products, is estimated to be occurring in 25-50 percent of all underground tanks. The volume of liquid which can be lost from an underground storage tank is not limited to the volume of the tank. Small leaks may go unnoticed, contaminating a large area in the vicinity of the tank before being detected (MPCA, 1983).

Collection of ground water samples from monitoring wells requires special equipment, in this case, a portable submersible pump which will fit inside narrow-diameter well casings.

Surface waste impoundments are natural depressions, artificial excavations, or diked areas which are used to store or dispose of a liquid or semi-liquid waste. The inventory of municipal, industrial, agricultural, and mining impoundments reported 2,733 active and abandoned impoundments. Animal feedlot waste storage areas comprise the largest fraction (1,500) of the total. When one examines the number of manufacturers, agricultural chemical applicators and dealers, and underground storage tanks, it is easy to understand why contamination is being dealt with on a "site-response" basis. The inventories for the state of the different types of facilities which could cause ground water contamination are shown in Figure 17.

Unregulated waste disposal generally occurs: (1) on the site where the waste is generated; (2) in landfills and dumps from which the waste supposedly has been excluded because of its hazardous nature; or (3) randomly at sites which are not normally disposal areas. The undesignated sites generate the most concern for ground water contamination because problems may go undetected for long periods of time.

In March 1983, 61 sites were identified on the MPCA's Hazardous Waste Site Response list — 36 in the seven-county metropolitan area and 25 in the remainder of the state. The sites included 64 percent where disposal occurred on the site where the waste was generated, 17 percent where waste was deposited in known landfills and dumps, and 17 percent where

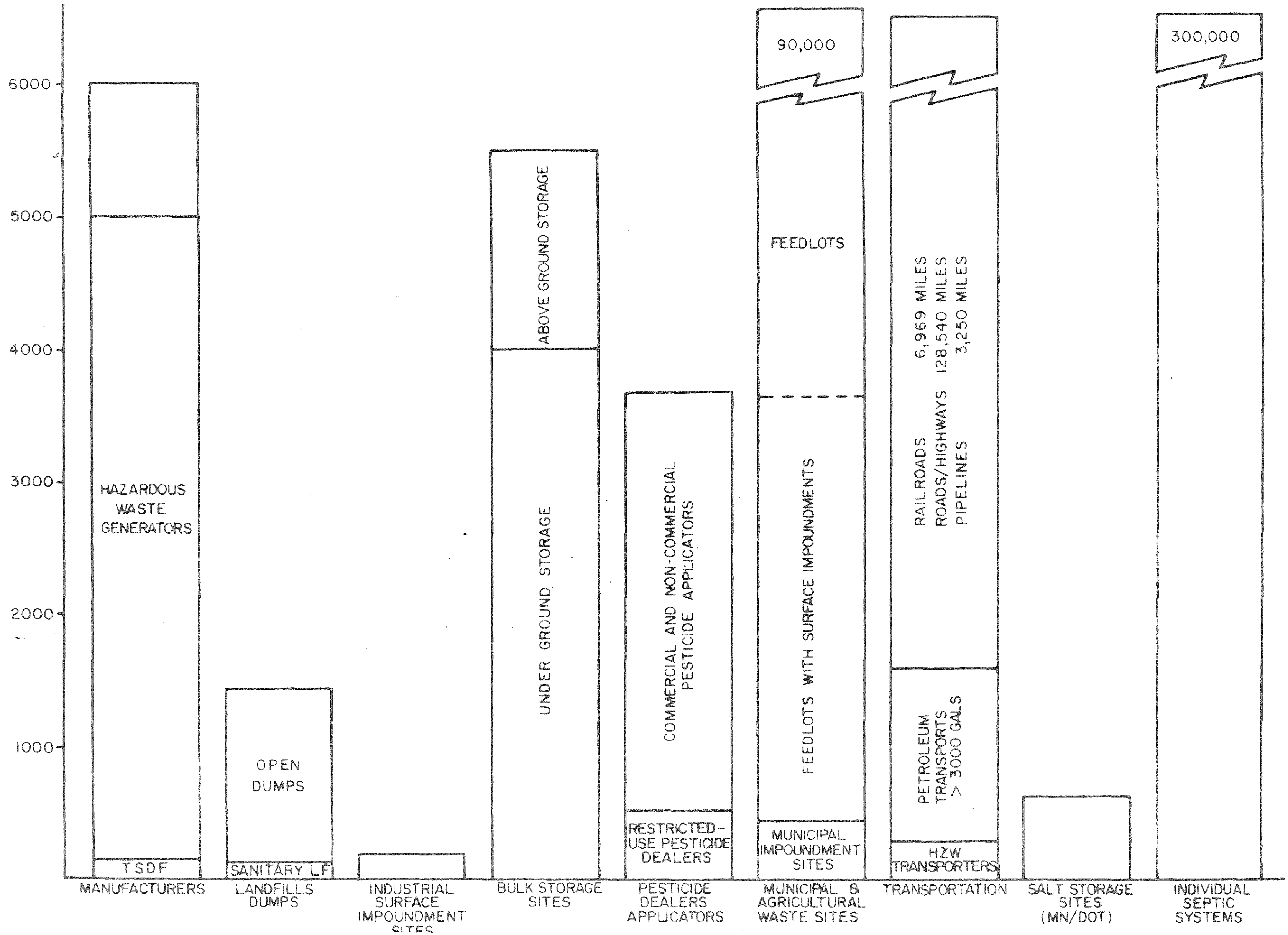


FIGURE 17. POTENTIAL SOURCES OF GROUND WATER CONTAMINATION IN MINNESOTA

disposal occurred in random dump sites. The majority of these sites involve ground water contamination by organic solvents. When a new site is investigated, contaminants must be identified and the ground water flow and the extent of the affected area must be delineated. Remedial action for ground water cleanup may include any of the following:

1. **Surface cleanup** — Proper disposal of wastes, soil excavation and disposal;
2. **Physical containment measures** — Barriers to ground water flow such as grout curtains, slurry trench cutoff walls, controlled long-term pumping of on-site wells;
3. **Aquifer rehabilitation** — Pumping of contaminated wells and treatment of water, biodegradation of petroleum and chemical spills, chemical and biological neutralization of wastes.

Average cleanup costs of ground water contamination in the United States were estimated for testimony to the U.S. Senate Environment and Public Works Committee. The hydrogeologic investigation to define the extent of a problem may cost in the range of $25,000 to $250,000. The actual cleanup may run from $5 to $10 million per year with completion possibly taking decades (Miller, 1982).

Cleanup at one hazardous waste site has recently been completed, although samples are still being collected from monitoring wells. At the Isanti (County) solvent sites, solvents and other waste materials had been stored and buried since 1970. Ground water and soil contamination were confirmed in February 1982 when three of nine residential wells were reported to have 1,1,1 trichloroethane, a solvent. Investigation of a hazardous waste hotline tip led to a Notice of Violation being sent to four property owners in February 1981 after 843 drums were found on the site. The cleanup activities on the 120-foot by 100-foot site included several steps.

The underground storage tank containing chlorinated and nonchlorinated solvents and waste oil located at the Isanti Creamery has been pumped and removed; contents were transported to Illinois for disposal (July 1981). The owner paid for this portion of the cleanup. Hydrogeologic study of the area was begun by the USEPA Field Investigation Team in August 1981. The waste was pumped from above-ground barrels for recycling and approved incineration (January 1982). Cost for above-ground cleanup was $40,000. A total of 843 barrels were excavated from the site to a depth of 68 feet; 931 barrels were temporarily stored on the site for transportation and disposal in another state (March 1983). Approximate cost for this step and transportation of wastes was $600,000.

The wastes were repackaged and transported to approved disposal sites by the end of May 1982. The overall project, including filling in of the excavation and landspreading, grading and seeding of the site, was completed by May 28, 1982. In this limited example of excavation of a ground water contamination site, costs may run up to $900,000 for study and cleanup of less than 1/3 acre site outside the Twin Cities metropolitan area.

Within the seven-county metropolitan area, an inventory of close to 400 sites where hazardous waste disposal may have taken place has been made by the MPCA staff. Information regarding many of these sites still needs to be field-verified. They include abandoned dumps, hazardous waste sites, spills, permitted sanitary landfills, industrial waste dumps, fly ash sites, surface impoundments, feedlots, foundry sand and slag sites, sludge sites, tree disposal sites, and demolition sites.

Finally, in certain areas of the state, an abundance of ground water and geologic conditions sensitive to contamination combine to call for general caution in all land use activities. These critical areas are the karst region of the state, where fractured limestone and dolomite are covered only by a thin layer of soil, and the sandplain and outwash areas, where sand and gravel with some silt and clay are found in alluvial plains or wide channels. Once contamination occurs in these areas it may spread rapidly and may affect the drinking water of many people. This is because wells may be, for all practical purposes, pumping surface water from aquifers where little natural protection is available.

Physical containment measures for disposal sites may include use of liners to protect ground water supplies.

5. MINNESOTA GROUND WATER POLICY AND STRATEGY

The development of a ground water management strategy is, in a sense, like putting together a jig-saw puzzle. The state of Minnesota has the border pieces in place, forming the framework for effective ground water protection, and is now in the process of filling in the other pieces. The goal of the ground water strategy for Minnesota is to assure the maintenance of an adequate supply of ground water of sufficient quality to meet reasonable demands for its use through:

1. Improved water and related land resources management;
2. Identification of areas of the state where ground water development may be beneficially pursued and where additional development may not be feasible;
3. Protection of the ground water of the state against contamination to assure a safe source of water for human and animal consumption.

This goal can be achieved through enhancement of existing programs. It does not require enactment of major new programs, although it does require new initiatives within existing programs. Part of Minnesota's ground water strategy is the identification of areas of the state where ground water development (especially for irrigation) may be beneficially pursued and where additional development may not be feasible. Accurate information on the extent of ground water supplies in high water use areas is necessary for effective ground water management. In general, there is adequate knowledge of surficial glacial drift aquifers and of consolidated bedrock aquifers in most high use areas. However, there is little information available on the size, shape, and yield characteristics of buried aquifers in the high use and growing demand areas.

Ambient ground water quality in Minnesota generally meets primary and secondary drinking water standards established by the USEPA. For most parameters, the existing natural quality is better than the standards, emphasizing the high quality of the ground water resource in Minnesota. Because of the cost of restoring contaminated water supplies to potable quality, a primary objective of any ground water protection program should be prevention of contamination rather than restoration.

In order to protect ground water, the main thrust of state programs must be to enable state government to be responsive to ground water quality problems and to have sufficient resources to develop case-by-case information to provide solutions to these problems. Programs must emphasize information collection as the reason for inspection of facilities and for monitoring of ground water. A cooperative approach among agencies is necessary because of the complex nature of ground water problems. Most ground water threats will not be controlled quickly because ground water is generally not amenable to "quick-fix" solutions.

Public policy on ground water protection may fall somewhere on the spectrum between non-degradation and laissez-faire. A non-degradation policy recognizes ground water as an essential resource which should be protected in its natural state. Limited degradation allows decisions to be made to write off a portion of the ground water or an aquifer as a sink for disposal. A laissez-faire policy puts no controls on activities such as underground injection of wastes.

The current state rule on ground water protection (Minnesota Rule 6 MCAR §4.8022) is essentially a preventive, non-degradation standard. Usually such a standard would be too rigorous to be meaningful or readily enforced, but it is essential to provide a framework upon which to base management decisions. In order to protect and assess ground water quality, standards must be recognized. However, development of standards is inevitably hampered by the lack of perfect scientific data. Since ground water is a major source of drinking water, the standards are based on the health implications of a variety of pollutants. The number of potential pollutants is in the thousands yet drinking water standards have been developed for only a handful of substances. Hard data on the impacts of many substances are limited. Where data exist, there is still a question of the appropriate level of control. A standard might have to take into account both acute and chronic toxicity levels.

A second complication is the fact that there are limited data on the interaction of wastes with the soil/bedrock/ground water system. Interaction takes place over extended periods of time and at locations which make monitoring extremely difficult. Fairly sophisticated models exist to predict the interaction of waste discharge and the receiving stream. Models to predict impacts on ground water are still in the formative stages.

The implementation of any standards has financial impacts on industry, local governments, and the general public. Relatively loose standards may mean lower, short-term costs for business in Minnesota and less expensive waste disposal for the public. They could also lead to magnified costs in the future in providing drinking water, increased health care costs, and a general shift of environmental consequences to future generations. Relatively stringent standards, while they may add to the immediate cost of industrial and municipal treatment and waste disposal, also have the potential to ensure long-term improvement of Minnesota's economic picture by providing an abundant supply of clean water. The appropriate level of control is always a major issue in any regulatory program and the state ground water protection strategy is no exception.

In June 1980, a problem definition workshop was held by the USEPA as the first step toward defining a ground water strategy for the nation, an activity which grew out of the increased identification of hazardous waste contamination of ground water, and the development of rules and regulations for the RCRA and the Underground Injection Control program. The 1980 draft stated: "It should be the national goal to assess, protect, and enhance the quality of ground waters to the levels necessary for current and projected uses and for the protection of the public health and significant ecological systems." Also included was a proposal to set up a three tier classification system for ground water. Class A ground water would require no treatment to meet drinking water standards; Class B would require some treatment; Class C would be designated for waste disposal. In order to implement this system, aquifers would have to be mapped and the irreversible decision to allow contamination of an aquifer would have to be made.

In commenting on the USEPA draft strategy, the MPCA, MDH, and the Water Planning Board all expressed concern over the direction in which the federal government was heading. It is extremely difficult to accurately estimate future activities, particularly regarding water. Water use and land use are determined by a wide variety of economic, social, and political factors. Similarly, it is difficult to predict future water quality standards and criteria.

If some system of controlled degradation were allowed as a national or state policy, it would clearly establish a precedent which could adversely and irreversibly affect ground water quality for generations. The Minnesota position is that policy makers should not, at any time, establish a principle or policy that sanctions intentional ground water degradation. The fact that information is inadequate with regard to projections of future activities and needs, health risk information, and ground water quality and quantity indicated to the state agencies that adoption of the proposed federal strategy as a general policy would not be appropriate for Minnesota. Instead, efforts should be directed at managing information needs for evaluating environmental and health risks; assessing ground water resources in terms of quality and quantity; developing effective monitoring and remedial strategies; investigating contaminant movement and behavior in soil and ground water systems (transport and fate); expanding the presently limited and hard-pressed analytical capabilities and capacities; providing technical assistance and training to state and local authorities; and disseminating information efficiently and effectively to those directly involved with water resource management and to the general public.

In reference to the suggestion of aquifer classification, the MDH pointed out that to be in any way effective, a classification program would need to include some extensive controls of land use activities. This raises a major obstacle in that, through zoning, land use management is largely the power and responsibility of local government. Implementing an effective ground water classification program would, at the very minimum, require strong cooperation of local authorities. Any classification of ground water should concentrate on identifying and assessing the vulnerability of areas rather than appropriate uses. A long term goal and policy should be elimination of contamination rather than identification of appropriate areas for degradation. A more desirable approach to ground water management and development of a protection strategy would be to establish high standards of siting, operation, and type of use. Primary reliance should be placed on stringent design and siting criteria, operation and performance guidelines, and thorough plan and permit review. A secondary reliance should be placed on operation and performance evaluation and on development and implementation of contingency plans.

The USEPA received numerous comments stating that any ground water protection strategy should be directed by the state under federal guidelines and funding. Currently, the redrafted federal policy on ground water proposes to: (1) recognize the primary role of the states in ground water protection; (2) coordinate federal authority and resources; and (3) encourage voluntary state strategies to protect ground water resources according to their current and projected future uses. Drafts of the new USEPA Ground Water Policy were released in December 1982, however no significant changes have been made except for a change in focus from a "strategy" to a "policy" statement.

In Minnesota, work has been continued on the State Ground Water Protection Strategy. The MPCA was assigned to begin the task under the MPCA/USEPA Agreement for federal fiscal year 1981. The goal of the MPCA Ground Water Protection Strategy is to establish the framework for the development of comprehensive ground water protection policies and procedures which are consistent with existing state and federal requirements, yet specific to the needs of Minnesota and formulated with a firm technical basis. Although the framework has been developed with the USEPA, state initiative will play the primary role in its implementation.

The development of the Ground Water Protection Strategy is being achieved through the review and analysis of new or previously collected site-specific ground water data, ambient ground water quality information and summary of existing ground water programs, regulations and data availability. In addition, a task force comprising individuals from outside the MPCA and familiar with the technical aspects of the ground water resource has worked on all stages of the strategy. Their charge has not been to set policy but to assist in developing technically sound recommendations for establishing policies in the area of ground water quality protection (MPCA, 1982). A final report defining a Ground Water Protection Strategy Framework for Minnesota has recently been completed by MPCA (June 1983).

Figure 18 is a listing of activities which are or should be regulated in order to protect ground water. The unit of government that has primary or secondary authority through regulations and ordinances is indicated for each activity. Minnesota's overall program appears to be comprehensive in this assessment of authorities. The key to protection of ground water is, however, how well these responsibilities are understood, are carried out through specific programs, and can adapt to new areas of ground water use.

	MPCA	MDH	MDNR	LOCAL
A. Disposal of solid wastes.	X			(X)
B. Installation, operation, and maintenance of individual sewage systems.	X			(X)
C. Operation of animal feedlots.	X			(X)
D. Disposal of wastes or surplus waters in wells or sumps.	X	X		
E. Construction and abandonment of water wells.		X		(X)
F. Construction, operation, and abandonment of oil and gas wells.			X	
G. Drilling and abandonment of exploratory holes.		X		
H. Spreading, disposal, and storage on land of substances that may cause ground water pollution, including placement in holding structures.	X			
I. Discharge of polluting substances into water and air.	X			
J. Mining, quarrying, and other excavating activities.			X	
K. Handling and storage of liquids including installation and operation of tanks, pipelines, and sewers.	Authority but no rule			
L. Irrigation.	X		X	
M. Artificial recharge.	X			
N. Management of ground water levels and pumping rates.	X		X	
O. Storage of solids, liquids, and gases underground.	X		X	
P. Adoption of zoning and building ordinances and regulations.				X
Q. Reporting and cleanup of accidental spills.	X			

( ) — possible local authority

FIGURE 18. REGULATION OF ACTIVITIES FOR GROUND WATER PROTECTION

6. EMERGING ISSUES IN GROUND WATER MANAGEMENT

Introduction

In addition to increased public interest in ground water, specific areas of concern have emerged due to increasing demand and development of ground water. Foremost in the public eye is degradation of ground water quality due to toxic and hazardous wastes. This issue is discussed in Chapter 4, because it is a current problem, not one which has only recently come to light.

Another water quality concern is the impact that the application of pesticides and fertilizers have on the shallow, surficial aquifers when paired with irrigation. Pesticides, which are organic chemicals, are costly to analyze and the analysis must be specific for the pesticide which has been applied. Fertilizers may increase the nitrate-nitrogen content in shallow domestic wells which are generally only sampled when the owner takes the initiative.

Emerging issues in ground water quantity focus in the Twin Cities which have historically relied largely on surface water for their supply. Because of increased competition for municipal water supplies, St. Paul and Minneapolis have begun investigating means of augmenting their surface water supplies with ground water. Due to increased pumping rates from individual high capacity wells, well drillers are seeing changes in some of the aquifers which comprise the Twin Cities basin. For example, the Mt. Simon-Hinckley sandstone aquifer may collapse when drilled where it used to stand up to penetration. Perhaps some time in the future, pumping rates will have to be restricted within parts of the Twin Cities basin.

Quantity issues also point to the need to employ conjunctive management of ground and surface water. Conjunctive management means that all water appropriations are permitted within the context of both surface and ground water withdrawals in an area. Conjunctive management can be carried out within the scope of current Minnesota water law, but has not yet been addressed specifically.

In addition to broad policy concerns in the management of the quantity and quality of Minnesota's ground water, four areas of ground water development which impact both quantity and quality have become major issues within the last ten years. These include the use of ground water for energy purposes, either as a heat source or as a storage medium for heated water; the withdrawal of ground water for irrigation, currently the fastest growing use of water in the state; and, the harvesting of peat as an alternative source of energy which may impact the hydrology of peat bogs and fens. The following sections are selected excerpts from working drafts of papers written because of an immediate need to address these emerging issues (Water Planning Board, 1980; Minnesota Department of Agriculture, 1981).

Ground Water Heat Pumps

The heat pump essentially "extracts" heat from one area and discharges it to another, thereby cooling the first area and heating the second. The refrigerator and the air conditioner are examples of air-to-air heat pump technologies used for cooling. The heat pump can be used either to heat or to cool a home, depending upon the direction of the cycle (NCSL, 1980).

Because the heat pump uses electricity only to "move" ambient heat from one area to another, it is more efficient and cheaper than electric resistance space heating. Central to the heat pump system is a refrigerant (often Freon), a circulating liquid with an extremely low boiling point. Electric energy is used to circulate and to compress the refrigerant. As the liquid expands and evaporates to a gas, it absorbs heat from the surrounding area; this heat then can be extracted using another heat exchanger. The source of the initial heat used for evaporation can be outside air (for heating), inside air (for cooling), or ground water (for heating) (Connelly, 1979). This system is what is commonly used in air conditioning and refrigeration units.

Ground water is a promising source for heat pump heating and cooling because of its high, relatively constant temperature. Ground water temperatures in Minnesota range from 47°F to 56°F, a range suitable for heat extraction. The ground water heat pump system can be used with or without reinjection of ground water to the well. A reinjection system requires a dual-well system. In the heating mode, water is pumped and run through the heat exchanger to extract heat; then the cooler water is discharged, either to a second well or to surface areas (a stream, land, or sewer system).

Use of ground water heat pumps has several potential impacts on ground water resources. These possible impacts are site-specific. Extensive experimentation and testing need to be done in order to evaluate the extent of changes to the ground water system by heat pump use. Impacts vary greatly between "once through" and "reinjection" systems.

Where the water is used only once (whether for heating or cooling) and discharged to a receiving body (whether a lake, river, land, or sewer), quantities of water withdrawn from the aquifer are substantial. A typical household heat pump may withdraw anywhere from 1.5 to 5 million gallons of water per year (Meyer, 1980). Well-interference may occur if wells are located close together. Impacts of discharge depend upon how the water is discharged.

Discharge into a septic system designed to handle a much smaller domestic flow may cause the system to overload, resulting in in-house backups or surface seepage. Similarly, although sewer systems are much larger, they are designed to meet a certain projected domestic need. Installation of large numbers of domestic heat pumps could overload these systems and cause additional capacity to be required sooner than anticipated.

Reinjection of the water eliminates some of these objections but has other potential consequences. Use of a reinjection well gives the heat pump system owner direct access to ground water and therefore the opportunity to contaminate it either by accident or on purpose. The physical impacts from the operation of the system will only be evident after testing and monitoring of operational systems. Contamination due to human activity is always difficult to predict.

In 1981, a law was passed, Minnesota Statutes, Section 156A.10, to authorize the MDH to issue a limited number of permits for reinjection through the use of ground water thermal exchange devices, otherwise known as ground water heat pumps. The following requirements are delineated in the law:

- the wells must withdraw from and reinject into the same aquifer;
- the wells must be constructed to allow inspection of water quality and temperature;
- the system must be constructed as a completely closed system which is sealed against the introduction of foreign substances; and
- the owner must agree to allow inspections by the MDH during normal working hours.

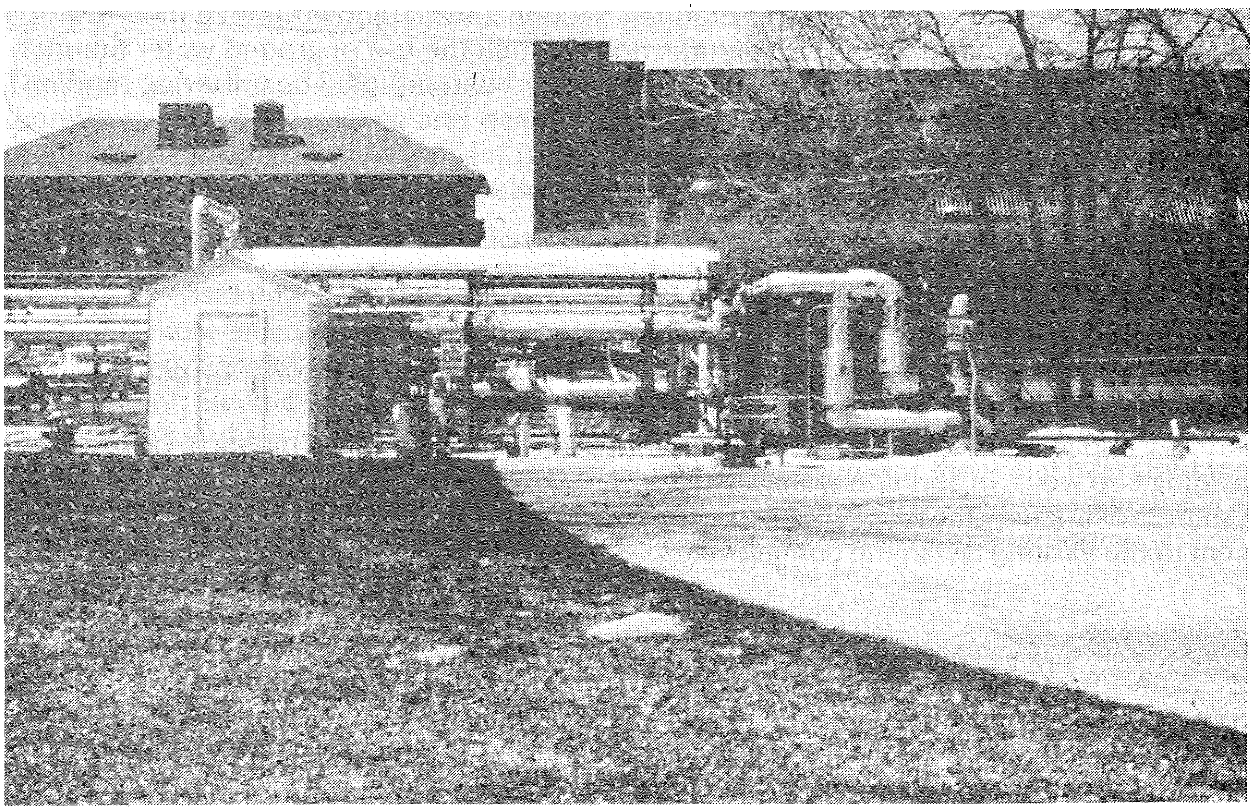
Very few applications have been submitted for permits because of the practical problem of needing two wells, in addition to a water supply well, to operate a ground water heat pump system as defined by the law. This is a problem which may be addressed through an amendment to the existing law in the coming years.

Aquifer Thermal Energy Storage (ATES)

A pilot project at the University of Minnesota has brought attention to the potential for seasonal storage of heat in aquifers for later extraction. Such storage would enable efficiency increases in heating and cooling systems, possibly delaying the need for additional capacity, thus resulting in reduction in air pollution. However, the use of aquifers to store thermal energy is a relatively new technology, and its impact on aquifer systems must be thoroughly evaluated before consideration of a commitment to widescale use.

The University of Minnesota has received a grant from the U.S. Department of Energy to conduct a research and demonstration project for aquifer thermal energy storage involving reinjection of ground water. The full-scale ATES system will involve heat production using space capacity at the southeast (Minneapolis) cogeneration power plant which is currently being retrofitted; thermal transport to the St. Paul Campus; storage in the Franconia-Ironton-Galesville aquifer beneath the campus; and withdrawal for use in the St. Paul Campus buildings. Heat recovery efficiency from the aquifer is expected to be approximately 80 percent. The presence of the system is expected to replace a new heat producing facility which would be required on the St. Paul Campus. Since any additional capacity would require coal as a fuel, this system is expected to reduce air pollution impacts (University of Minnesota, 1979).

The Phase I program involved developing a conceptual design for the system; characterizing the Franconia-Ironton-Galesville aquifer under the St. Paul Campus; establishing the economic, commercial, and financial viability of the ATES system concept; identifying the institutional and environmental concerns associated with future development; and developing plans for Phase II. Phase II calls for detailed design, construction, start-up, and operation of the demonstration system.



Aquifer Thermal Energy Storage (ATES) project on the University of Minnesota's St. Paul campus; photograph courtesy of the Minnesota Geological Survey (MGS).

Testing in Phase I consists of initial injections of water below 100°C and subsequent withdrawal, for periods of 8-10 days. Monitoring procedures record changes in heat, temperature, and water composition. Subsequent runs inject water at higher temperatures — up to 300°C, the expected discharge temperature of the operating system — to test the aquifer's response. Monitoring wells are used to record responses.

According to system proponents and the Department of Energy, the Franconia-Ironton-Galesville aquifer is "ideally suited" for thermal energy storage: the bedrock geology keeps several aquifers confined; unlike other aquifers in the aquifer system, the Franconia-Ironton-Galesville is little used for water supply; and, hydraulic conductivity appears to be fairly low, enabling high recovery efficiency. Preliminary findings include problems with the formation becoming clogged and pumps not operating well when injecting high-temperature water.

In view of the lack of experimental data necessary to evaluate environmental impacts of future systems and since the impact of the system is not expected to go beyond the University's surrounding land holdings, MPCA and MDH have granted variances from the pertinent regulations for reinjection for the testing stages of the program. The variances are conditional upon strict monitoring and evaluation to provide data for making future decisions, and are subject to termination if harmful effects occur. According to these variances, Phase I is scheduled to end in June 1984.

Irrigation

The majority of the irrigation taking place in Minnesota uses ground water. In 1980, according to MDNR water use figures, 89 percent of all irrigation water was ground water; surface water is generally only used for flood irrigation of wild rice paddies. Irrigated cropland increased from approximately 17,500 acres in 1964 to 272,000 acres in 1978 (1.2 percent of Minnesota's cropland) according to the U.S. Census of Agriculture (see Figure 19). Agricultural Extension Service estimates for 1978 were much higher (433,000 acres). More than half the total acreage was established during the dry years of the mid-1970's. Irrigation is expected to continue expanding through the year 2000, but at a slower rate. In 1981, from one-third to one-half the land most favorable for irrigation — with sandy soils and abundant ground water — had been developed.

Most irrigation in Minnesota occurs where ground water is of good quality and on porous, sandy soils where natural leaching minimizes the accumulation of salts and sodium within the root zone. In drier western states, the build up of minerals in the soil can be a serious problem. Some ground water of quality unsuitable for irrigation occurs in the western quarter of Minnesota. There are no documented cases of soil contamination from the use of highly-mineralized ground water in Minnesota but irrigation with this ground water, in combination with heavy clay soils such as those of the Red River Valley, could potentially result in soil and crop damage.

The volume of water required depends upon the acreage to be irrigated, the specific water requirement of the crop, the moisture retention characteristics of the soil, and precipitation. A typical quarter-section, center pivot system needs a water yield rate of 400 to 1,200 gallons per minute. This requirement effectively limits the use of quarter-section pivot systems to the surficial sand aquifers of central Minnesota and the bedrock formations of east-central and southeastern Minnesota that yield sufficient quantities of water. In areas of the state that yield less ground water, smaller center pivots and other types of sprinklers and water distribution systems that require lower pressure and lower volumes of water may be used.

The rate of irrigation expansion over the coming decades will most certainly slow from that experienced in the 1970's when acreage increased eight to ten times. The availability of water and the economic feasibility of irrigation are likely to limit expansion of irrigation and discourage new systems. There are abundant ground water supplies in surficial sand aquifers from east-central to west-central Minnesota where much of Minnesota's irrigation now exists and will likely intensify. There are also abundant ground water supplies from bedrock sources in southeastern Minnesota but the land is hillier and there is less need for supplemental water because of higher precipitation and heavier soils.

Peat

Utilization of Minnesota peatlands for energy production is still in the research and testing stage, and it is not yet known which methods will prove feasible. However, there are potential and, to a large extent, speculative impacts associated with all proposed uses. Peat may be used for energy production by either extractive or non-extractive methods, or by a combination of the two. Extractive methods involve actual removal of the peat for gasification or

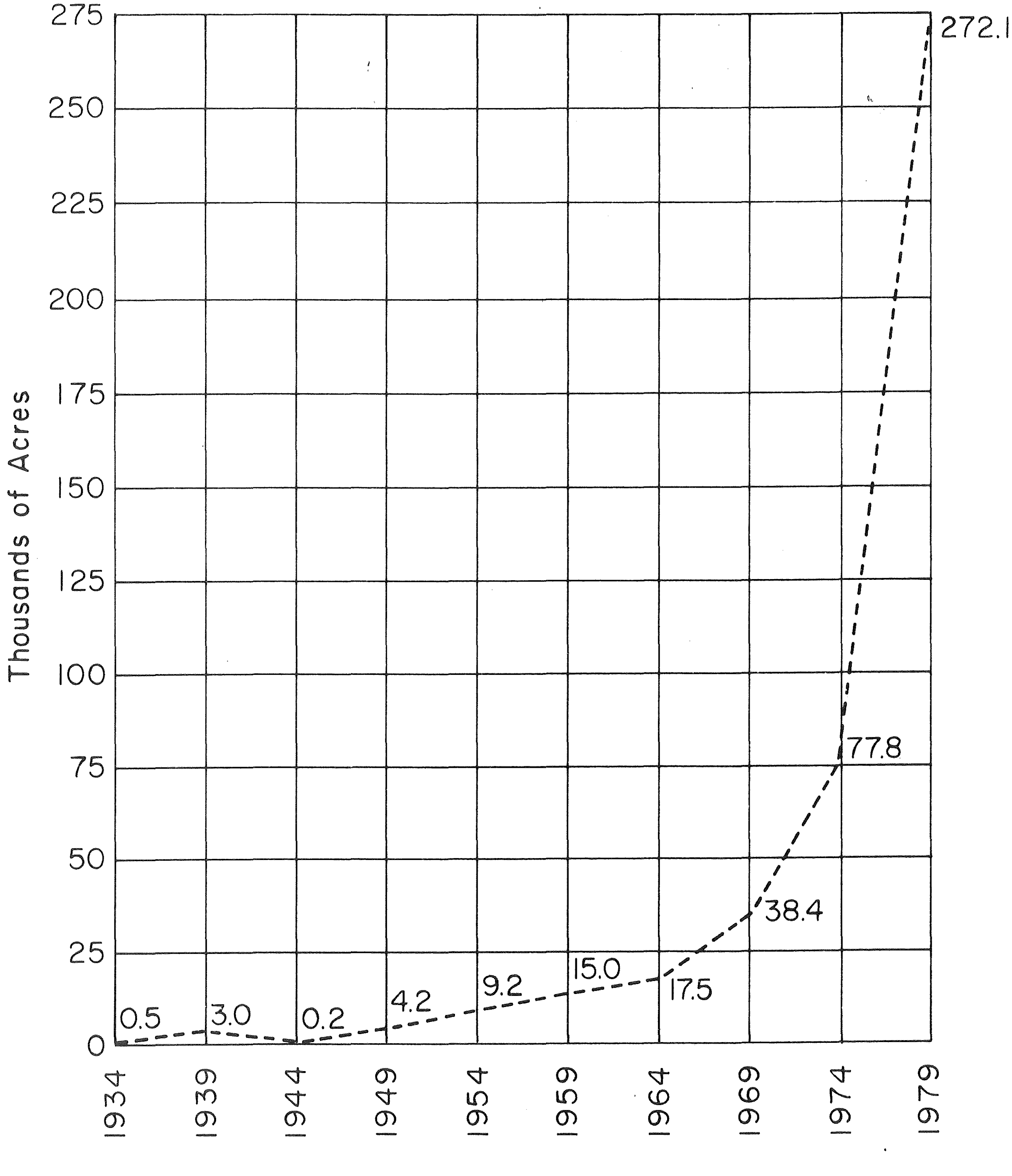


FIGURE 19. IRRIGATED LAND IN MINNESOTA (U.S. CENSUS OF AGRICULTURE, 1978)

direct burning. Non-extractive methods involve the use of the peat base as a growing medium for special energy crops, such as cattails.

Extraction of peat would have different impacts, depending upon the harvesting method used. Some harvesting techniques involve prior drainage of the peat bog, which may increase water yield and peak discharge from the area. The quality of receiving waters may be affected by increased concentrations of nutrients, humic acids, and particulate organic matter in discharge water. Harvesting methods which do not require drainage may still alter the hydrologic characteristics of the region while water quality impacts affect only the immediate area being mined.

Water quality research under the Minnesota Peat Program has examined the movement of ground water through peat lands. The regional ground water systems of the peat complexes in north-central Minnesota have been the subject of research cooperatively funded by the MDNR Peat Program and the USGS. Ground water modeling indicates that ground water movement in the peatland system is more complicated than previously thought; vertical movement associated with large raised bogs may be occurring and resulting in ground water discharge into fens. The complexity of the ground water movement makes it difficult to predict the hydrologic impacts of large scale development or to adequately assess the potential for reclaiming these areas.

7. THE FUTURE FOR GROUND WATER IN MINNESOTA

The management of Minnesota's ground water resource must continue to be a dynamic, ongoing effort. Threats to the quality and quantity of our aquifers will not be controlled quickly because ground water, by its nature, is generally not amenable to "quick-fix" solutions. The effort to develop a comprehensive ground water management program can never be permanently bought or achieved but only transiently obtained, and with continued persistence, perpetuated.

Five general goals to guide future ground water programs identified in the MPCA's Ground Water Protection Strategy Framework report are:

1. To maintain the quality of ground water to levels consistent with intended best use and to prevent degradation consistent with public health, economic, and social goals.
2. To assure that land use activities which have or may have the potential to impact ground water do not endanger the value of aquifers and associated surface water resources.
3. To monitor ground water to determine ambient conditions, water levels, trends, and compliance with regulatory requirements.
4. To manage all discharges, withdrawals, and recharges of ground water to ensure that the above goals are realized.
5. To ensure the availability, transfer, and appropriate use of pertinent information, data, strategies, and studies to involved institutions and the public.

In addition, there are four underlying principles which should guide implementation of future ground water programs to achieve the above goals.

1. **Build on the existing institutional system for ground water management:** As discussed earlier in this report, there are at least 16 institutions currently administering a wide variety of programs pertaining to ground water management in Minnesota. Historically, the fact that there are so many involved parties has had the advantage of forcing institutions to coordinate their efforts in order to provide for effective ground water management. Although ground water has not been the major emphasis of each program, their objectives are generally compatible with ground water goals. Although some totally new ground water initiatives ultimately might be necessary, the existing structure of the operating programs already contains much of the essential management framework. Thus, the focus should be to evaluate existing programs carefully and to adjust them to ensure that ground water will receive equal emphasis with surface water in all water management areas.

2. **Acknowledge regional differences:** Another strategy emphasis is the need to encourage regional ground water management sensitive to local differences in physical resources, uses, and problems. Since available ground water is not distributed equally,

since uses vary from one locality to another, and since ground water is more naturally-protected in some areas than others, problems and appropriate responses will differ throughout the state. Local government also has an important role in protection of both the quantity and quality of ground water through its land use control responsibilities.

3. **Encourage federal participation:** Successful implementation of a ground water strategy will also require continuing participation by the federal government. Financial assistance for program development efforts, cooperation in developing information and knowledge about the state's ground water resources, dissemination of information on means of solving ground water problems, and the setting of standards for drinking water are all activities which federal agencies should continue.

4. **Target a long-term preventive strategy:** Responding to immediate ground water problems and learning from the success and failures of these efforts to begin to anticipate future problems are but the beginning of development of a long-term strategy to protect the quantity and quality of our ground water resources. Several specific, long-term program development efforts should be undertaken if the eventual goal of a sound ground water management program for Minnesota is to be realized. These may be categorized as follows:

    a. Develop a ground water classification system which recognizes the high ambient quality of Minnesota's ground water, the sensitivity of certain aquifers in the state to degradation or depletion, and the necessity of protecting critical recharge areas.

    b. Develop an automated ground water data management system to provide information necessary for evaluating immediate impacts and making decisions, to assemble and use pertinent ambient and site-specific data on ground water quantity and quality, and to prevent potential problems from occurring by guiding regulatory program operations.

    c. Refine current programs dealing with assessment and cleanup of unregulated or illegal land uses which may impact ground water.

    d. Conduct a review of rules for permitting, operating, and monitoring those facilities having the greatest potential to impact the quality and quantity of ground water resources.

    e. Continue to inventory and prioritize activities for which the potential to degrade ground water is either known or suspected.

    f. Develop a strategy to address emerging issues in ground water protection in Minnesota such as ground water source heat pumps, underground injection control, aquifer thermal energy storage, peat development, and irrigation systems.

Although many ground water problems relating to quantity and quality have been effectively addressed in recent years, those that remain are increasingly complex and less amenable to simple, proven approaches. Although the focus of the challenges has changed, hopefully the commitment has not. By anticipation and prevention of future problems related to quantity and quality, a clean, adequate supply of ground water can be our achievement for many years to come.

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