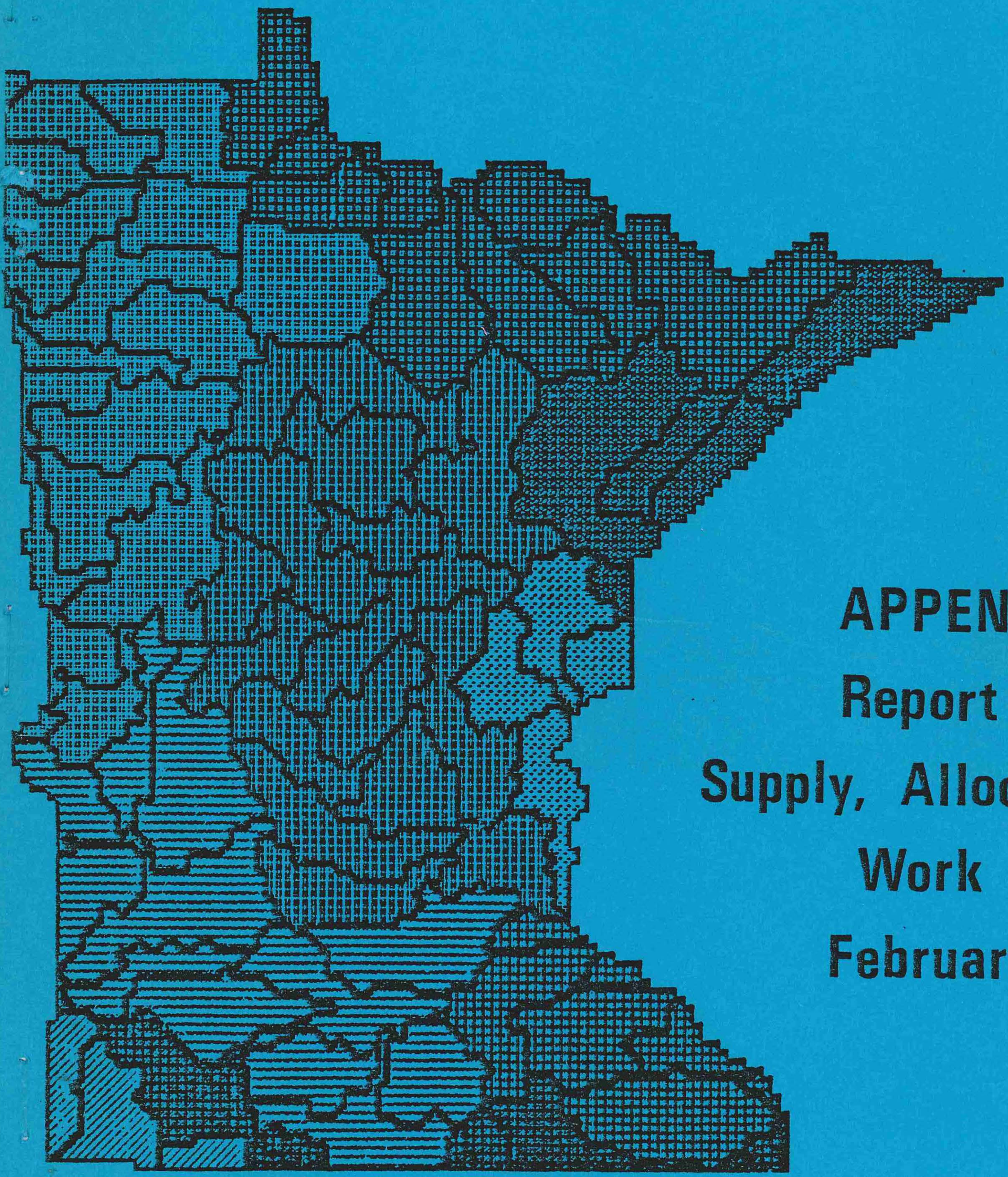
Toward Efficient Allocation and Management:



APPENDIX B:
Report of the Supply, Allocation & Use Work Group
February 1979

A REPORT OF THE MINNESOTA
WATER PLANNING BOARD
TO
THE LEGISLATIVE COMMISSION
ON MINNESOTA RESOURCES
AND
GOVERNOR ALBERT H. QUIE

ACKNOWLEDGMENTS

This "Report of the Supply, Allocation, and Use Work Group" represents principally the efforts of individuals who were members of the Work Group. The development and extensive review of this report was also facilitated by the cooperation of representatives from many other agencies, including the Departments of Agriculture, Health, and Natural Resources; the Energy, Pollution Control, and State Planning Agencies; the Soil and Water Conservation Board, Water Resources Board, Metropolitan Council, and the Regional Development Commissions. The entire report has been reviewed and approved by the Technical Committee of the Water Planning Board.

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The recommendations presented are those of the Work Group, and are not necessarily identical to those adopted by the Water Planning Board. This report provides documentation of the rationale and development of major elements of the framework plan. Additional supportive documents written by the Work Group include the following:

"Water: Whence It Comes and Where It Goes (A Benchmark Report on Water Resources in Minnesota)," Technical Paper No. 2, July, 1978.

"Water Forecasting System for the State of Minnesota (Final Report)," Technical Paper No. 3, June, 1979.

"Rural Water Supply Systems," Technical Paper No. 4, June, 1978.

"Flooding and Flood Damage Reduction," Technical Paper No. 7, November, 1978.

"The Economic Impacts of Water Shortages and Water Allocation Policies," Technical Paper No. 8, October, 1978.

"Water Availability, Water Use, and Potential Conflicts," Technical Paper No. 10, January, 1979.

"Minnesota Water Quality: Management and Issues," Technical Paper 11, December, 1978.

"Water Conservation Methods for Irrigation, Agricultural Processing Industries and Domestic Consumption," Technical Paper No. 12, December, 1978.

"Toward Efficient and Equitable Water Allocation in Minnesota: A Report on Water Allocation Options and Approaches," Technical Paper No. 13, January, 1979.

"Water Appropriations in Minnesota - 1976," Working Paper No. 1, March, 1978.

"An Analysis of Instream Flow Needs in Minnesota," Working Paper No. 2, October, 1978.

"An Evaluation of the Natural Ordinary High Water Elevation in Minnesota Lakes," Working Paper No. 3, November, 1978.

Primary funding for this project was provided by the Legislative Commission on Minnesota Resources, with additional assistance provided by U.S. Water Resources Council Title III Water Resources Planning Grants.

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INTRODUCTION

Minnesota's 2.6 million acres of lake surface, twenty-five thousand miles of streams, and substantial supplies of ground water attest to the relative abundance of the state's water resources. However, there is an underlying apprehension detectable among the public, legislators, and those who manage the state's resources. Put as simply as possible, the anxiety is that present water management policies, institutional arrangements, and strategies may not be sufficient to cope with an unforeseen future.

At the heart of the concern are questions related to supply, allocation, and use of the state's water resources. A brief review of 1977 Minnesota newspapers reveals the following headlines:

** "Energy shortage, drought still threatening the state" (March 12, 1977);

** "Drought hurting rural areas, bank survey finds" (June 2, 1977);

** "Mississippi down to third of normal" (April 19, 1977);

** "Missing water glasses signs of short supply" (date uncertain);

** "Lawn watering ban likely this summer" (June 1, 1977); and,

** "14 to 20 inches of rain needed to fill deficit" (February 7, 1977).

In 1976, state crop losses due to drought conditions were estimated at $1.5 billion and northern Minnesota was made off-limits for many activities because of forest fire dangers.

How serious a problem we face is at best an educated guess. Studies which predict future water use must contend with a large number of variables, some quite remote from those generally associated with water management policy. Estimates of supply require time and costly study. Thus, no exhaustive answer to the question of future problems can be provided. However, planning, institutional analysis allocation policies, and efficient usage have been suggested as important areas to pursue in relieving anxieties about the future.

To this end, the Legislative Commission on Minnesota Resources initiated the Framework Water and Related Land Resources Planning project in the latter part of 1976. The first phase of the planning effort, carried out through the Minnesota Water Resources Council, provided information on Minnesota's ground- and surface-water resources and on the major uses of the state's waters. It provided the necessary background for the second phase of the planning effort.

In June, 1977, the Governor signed into law an Act creating the Minnesota Water Planning Board. Concurrently, the Legislative Commission on Minnesota Resources approved funding requests of six agencies for work on the second phase of the Framework Plan effort. This work was to be directed by the newly created Water Planning Board.

In September, 1977, the Board adopted a "technical committee-work group" structure for its direction of planning effort. The duty of the Technical Committee, composed of representatives of 10 agencies directly involved in the planning effort, is to advise the Board on Framework Plan elements. The duties of the Work Group are to develop issues, conduct research and analysis relative to the issues identified, prepare background materials, and synthesize information for presentation to the Technical Committee and the Board. Three Work groups were formed: the Supply, Allocation, and Use Work Group; the Management Work Group; and the Data Work Group.

The Supply, Allocation, and Use Work Group has determined that four major questions must be addressed in relation to the supply, allocation, and use of the state's waters. These questions are:

1. How much water is available, from what sources, and of what quality?

2. How much water is being used now and is expected to be demanded in the future?

3. How should the available supply be distributed among users?

4. How can more efficient use be made of water resources in the future?

In addition, specific attention must be focused on the occurrence of flooding in the state, the alteration of wetlands, and lake management.

The following chapters of this report address the major questions and the three related special concerns.

WATER AVAILABILITY IN MINNESOTA

The context in which Minnesota's water resources must be viewed has changed dramatically over the past 100 years. At one time, water appeared to be limitless. The quantity used was very small and there were few conflicts between users.

As the population of the state grew, technology changed, and economic development continued, the quantity of water used has increased and the potential for conflicts between users has risen. The drought of 1976-77 illustrated that even in a relatively "water-rich" state, water is not limitless and -- at certain times and places -- can be a very scarce resource.

Despite changes over time and periodic crises, water is so important to so many activities that people are reluctant to conceive of a world in which it might not be cheap and plentiful. Further, water has long been associated with economic development. Governmental investment in water -- especially at the federal level -- has been an accepted strategy to generate growth. Water as a factor limiting growth has been an uncommon perception.

A conception of water without limit has led users of water to view their interests as discrete and separable. Water as a resource has been considered infinitely divisible into particular and specific uses. The game of water politics is seen as a variable sum: everyone expects to reap some reward and no one is conscious of incurring only costs.

Neither government nor the public has shown evidence of change in basic conceptions about water resources. There is little recognition of the finite nature of the resource and little change in the perception of water as an unlimited birthright. Structural solutions rather than behavior modification have been pursued. Water has been viewed as a "good" falling outside the usual operation of the market system. Priorities among basic uses of water have been shifted, but the basic habit of distribution has remained the same.

The greatest possibilities for changing the traditional perception of water as a limitless birthright lie in promoting an understanding of the physical characteristics of the resource. The base of the present problems in dealing with the state's water resources is the body of perceptions which are held about these sources.

This chapter of the report attempts to explain water as a resource -- where it comes from, where it goes, how it impacts man, and how man impacts it. It is within such a framework of understanding that future water policy for Minnesota must be developed.

The Hydrologic Cycle

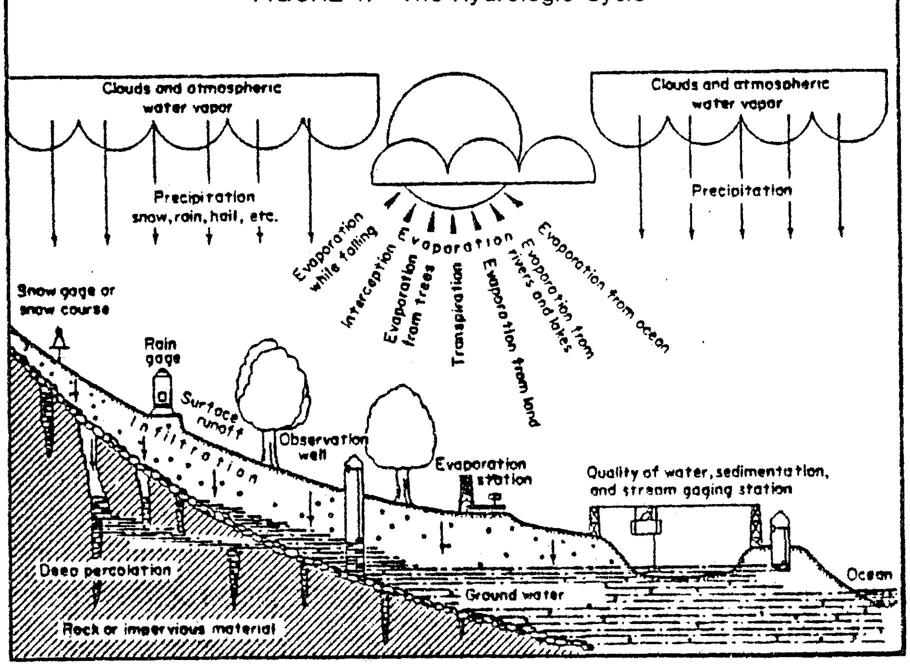
The water supplies of the state are not static. Water is constantly on the move. It falls to earth as precipitation. It is carried back into the atmosphere through the process of evapotranspiration. Some rainfall and snow-melt infiltrates the soil and percolates downward into temporary storage. Stored water may be drawn on by plants or man, or it may move under the surface to streams. Surface runoff and underground movement of water supplies streams. Streams carry water toward oceans, constantly subject to evaporation which feeds moisture to the atmosphere to produce precipitation. This process is described as the "hydrologic cycle." Understanding this cycle is central to understanding the total quantity of water which might be available for use and the policies which might be adopted to manage our water resources.

The hydrologic cycle describes the processes of motion, loss, and recharge of the earth's waters. It is subject to the processes of (1) precipitation, (2) evaporation, (3) transpiration, (4) interception, (5) infiltration, (6) percolation, (7) storage, and (8) runoff. The four major phases of the cycle can be simply described in the terms of an equation:

Precipitation = Evapotranspiration + Recharge + Runoff

The hydrologic cycle has neither a beginning nor an end. Water evaporates from the land, oceans, and other surfaces to become part of the atmosphere. The moisture evaporated is lifted, carried, and temporarily stored in the atmosphere until it finally precipitates and returns to earth. The precipitated water may be intercepted or transpired by plants, may run off over the land surface to streams, or it may infiltrate the ground. Much of the intercepted water and surface runoff is returned to the atmosphere by evaporation. The infiltrated water may be temporarily stored as soil moisture and subsequently evapotranspired, used by man or plants, flow out as springs, or seep into streams. Finally, even this water evaporates into the atmosphere to complete the cycle. Figure 1 provides a graphic description of the cycle, including the ways in which man intervenes in it.

FIGURE 1. The Hydrologic Cycle



1. Precipitation

The source of nearly all water in Minnesota is precipitation. Precipitation includes all forms of moisture falling from the atmosphere, but its principal forms are rain and snow. Because the state is at the head of three of the North American continent's major watersheds, essentially all of the state's waters originate as rain or snow and flow from the state. The average annual precipitation in Minnesota ranges from a minimum of 19 inches in the northwest to a maximum of 32 inches in the extreme southeast (Figure 2). The amount of snow which can be expected in the state during a normal winter season varies from 30 inches along the western border to over 70 inches in a small section of northeastern Minnesota. Most areas of the state receive 40 inches or more of snow annually.

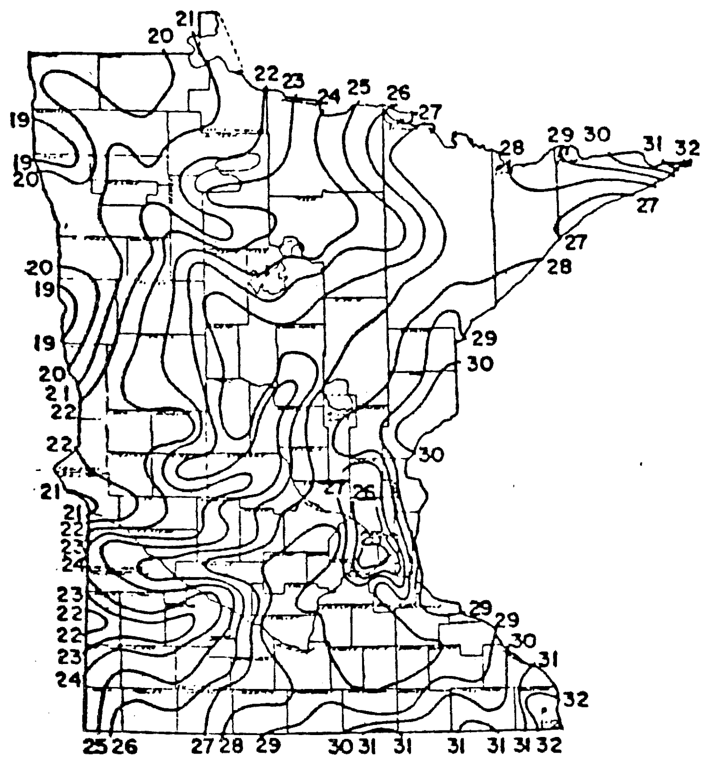


FIGURE 2. Annual normal precipitation in inches.

Small amounts of precipitation (in terms of water yield) fall during the winter season. Precipitation increases during the spring months of March, April, and May. The summer period of June, July, and August accounts for 40 to 50 percent of the state's annual precipitation. Precipitation amounts decrease during the fall months of September, October, and November. As with water resources in general, the spatial (location) and temporal (time) distribution of precipitation is highly variable. Figure 3 exhibits the minimum annual precipitation expected in two percent of years.

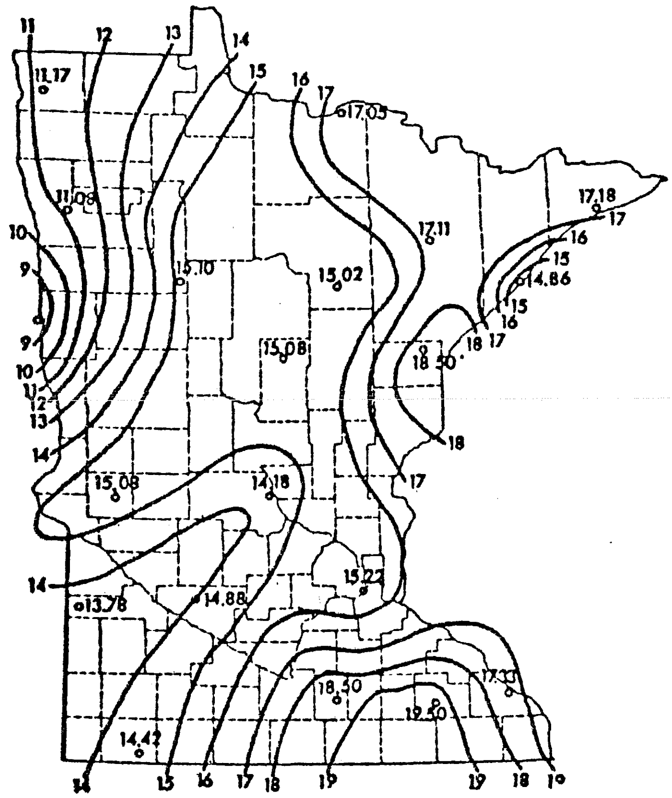


FIGURE 3. **Minimum annual precipitation expected in 2 percent of years, in inches.**

2. Evaporation and Transpiration

Evaporation is the change of state of water from liquid to gas. Transpiration is the process in which water is used by vegetation and released as water vapor to the atmosphere. The combination of evaporation and transpiration is called evapotranspiration.

Water is evaporated from both open water and land surfaces. Evaporation from land surfaces will vary greatly depending on land use, the type of vegetation, soil moisture, wind, temperature, and solar radiation. In southwestern Minnesota, average annual evaporation from open water exceeds average precipitation reaching the open water surface by as much as 11 inches. The amount of transpiration which is released to the atmosphere will depend upon the type and density of vegetation cover. Normal seasonal transpiration varies from eight to twelve inches.

From about 65 percent to nearly 100 percent of annual precipitation in Minnesota is released to the atmosphere by evapotranspiration. Northeastern Minnesota receives considerably more precipitation than it can evaporate in a normal year (about 1.3 times more), so runoff to lakes and streams tends to be high. The ratio of annual values of precipitation to potential evaporation in southwestern Minnesota is 0.8, so runoff is quite low. (See Figure 4.)

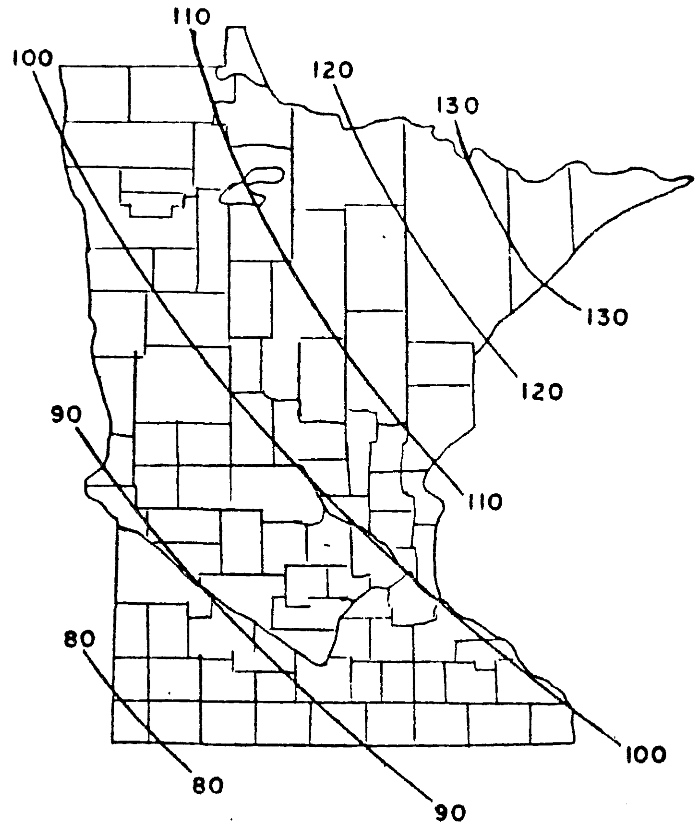


FIGURE 4. Ratio of annual values of precipitation and potential evaporation in percent.

3. Interception

A portion of precipitation falling to the earth's surface may be stored or collected by vegetal cover and subsequently evaporated. That volume of water caught by vegetation is referred to as interception, and the portion retained and evaporated is called interception loss. The total interception loss for a canopy of vegetation is a function of (1) the storage capacity of the vegetation; (2) the ratio of the vegetation's surface area to its projected area; (3) the evaporation rate from the vegetation surface; and (4) the duration of precipitation.

4. Infiltration and Percolation

Infiltration and percolation are the downward movement of precipitation and surface water into the surface layer of soil and the subsurface. Water enters the soil surface due to gravity and capillary forces. Both forces act to cause percolation downward. As the process continues, the capillary pore spaces in soil and rock become filled.

The rate of infiltration depends on many factors, including (1) precipitation density and type; (2) the condition of the soil surface; (3) the density, type, and stand of vegetation; (4) the chemical composition of the water; and (5) the physical properties of the soil, such as grain and pore size, porosity, and moisture content.

Infiltration and percolation also recharge ground-water supplies. The amount of infiltration and percolation to glacial drift and bedrock aquifers in Minnesota varies, but generally ranges from three to five inches of precipitation annually. Estimates as high as seven inches have been made for areas of sandy soil.

5. Storage

Precipitation which is in storage is either surface water or ground water. Surface water and ground water are addressed in some detail below. It is important to point out at this time that even storage is a temporary state because water is always moving. For example, rivers are constantly flowing toward a sea -- but rivers may contribute to or take water from lakes. Similarly, ground water usually moves from high areas to lower areas. Along the way, it can be taken out of storage by being discharged into streams or pumped through a well.

6. Runoff

Runoff is that water which leaves a region as streamflow. Streamflow consists of surface runoff, ground-water discharge, and channel precipitation. Channel precipitation is precipitation that falls directly on the water surface of lakes and streams. Surface runoff occurs when the intensity of precipitation is greater than the rate of infiltration of the soil. It reaches streams rapidly and is generally discharged from basins within a few days. Ground water percolates toward streams gradually.

The amount of runoff depends on five factors: (1) the amount and intensity of precipitation; (2) the slope of the land; (3) the vegetation, (4) the type and moisture content of soil; and (5) temperature. In Minnesota, there is a general trend toward increasing runoff as one proceeds from west to east. Variations in this pattern stem from changes in precipitation patterns, as well as differing slopes and soil conditions. The average annual runoff in Minnesota varies from less than one inch at the western border; to about eight inches in the southeastern corner; and to more than 10 inches in the northeastern part of the state (Figure 5).

Surface Water

Surface water is one form of water in temporary storage in the hydrologic cycle. Three primary forms of surface water are found in Minnesota: lakes, wetlands, and rivers and streams. The distribution of these features throughout the state is largely a function of the most recent period of glaciation, but man has also had a significant impact on these features.

Surface waters in Minnesota drain toward three major receiving waters. About one-third of the state's area drains into the Red and Rainy Rivers (Figure 6) and eventually into Hudson Bay. Eight percent of the land drains to Lake Superior, and the remainder of the state (58%) is in the Mississippi River basin (Walton, 1975). Figure 6 depicts the ten major river basins in Minnesota.

FIGURE 5.
Average Annual Runoff
(Inches)

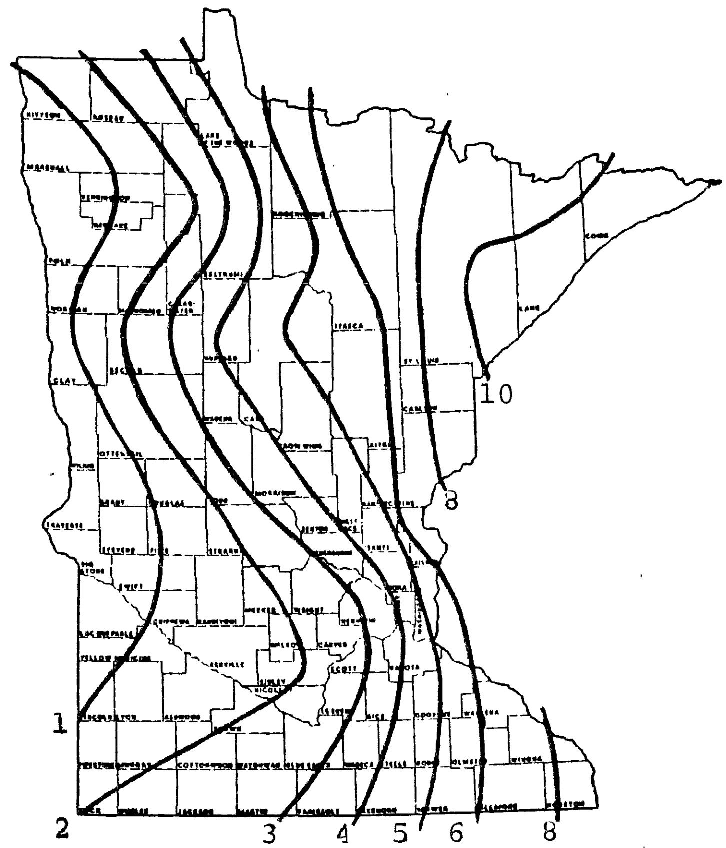
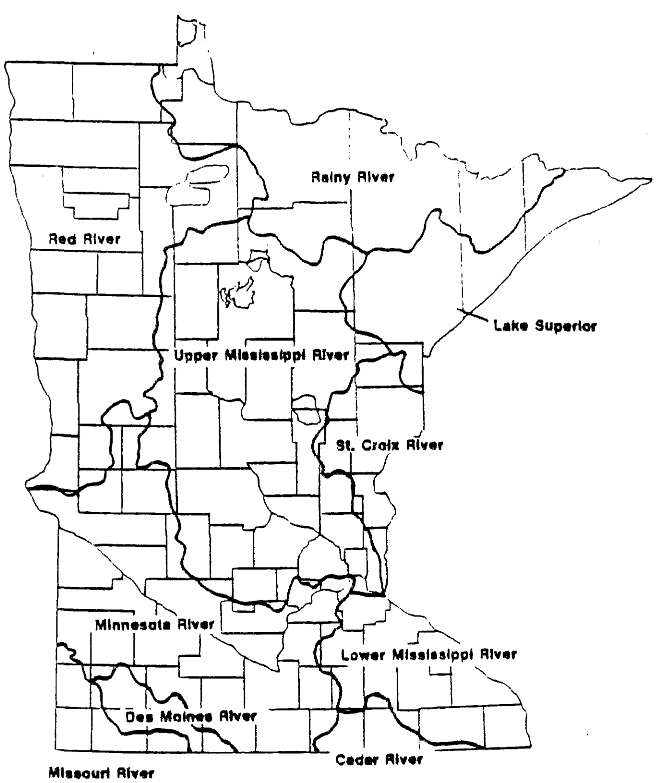


FIGURE 6.
Major River Basins



In Minnesota, there are 15,291 lake basins larger than 10 acres. Excluding the state's portion of Lake Superior, lakes cover an area of 4,059 square miles, or about 4.8 percent of the state's total area. Of the 15,291 lake basins, 3,257 are classified as partly or completely dry. About 90 percent of the lake basins which are dry are affected by the construction of artificial drainage ditches or by the deepening of natural channels.

Lakes are not evenly distributed throughout the state. They are more numerous in the northeast and the central part of Minnesota. The northwestern, extreme western, and southern parts of the state have only a sparse distribution of lakes.

Lakes located entirely within the state range in size from Red Lake near Bemidji, which is 25 miles across and 288,800 acres, to lakes only a few acres in size located in the pine forests along the northern shore of Lake Superior. (Although not located entirely within Minnesota, Lake of the Woods is even larger than Red Lake, covering 308,000 acres.) There are 62 lakes in the state which are 5,000 acres or larger.

The majority of Minnesota's lakes are less than 100 feet deep. Excluding Lake Superior, the deepest lake known in Minnesota is Saganaga on the Canadian border (240 feet deep). At least four other lakes are known to be over 200 feet deep. In southern Minnesota, many lakes are very shallow. Such lakes are highly productive, but may freeze out during the winter causing fish to suffocate. These lakes provide indirect benefits to the area by retarding runoff, replenishing ground water supplies, trapping nutrients and sediments, and supporting wildlife.

Surface waters are subject to comparatively rapid changes in quality because they are easily affected by various natural and artificial contaminants. Due to man's influence and natural causes, many of Minnesota's lakes are subject to the effects of eutrophication. Many streams have suffered the impacts of municipal and industrial discharges, as well as the effects of agricultural runoff.

Wetlands are another form of surface water important to Minnesota. At one time wetlands were prominent landscape features throughout southern, western and central Minnesota. However, agricultural drainage, urban development and highway construction have affected or eliminated wetlands in many areas. Remaining concentrations are found primarily in the central and west-central parts of the state. Efforts are currently underway to identify the nutrient and sediment entrapment, fish and wildlife, flood stage reduction, ground-water recharge, recreation and other benefits of the remaining wetlands.

Like its lakes, Minnesota's 25,000 miles of rivers and streams exhibit considerable diversity. North Shore streams plunge rapidly toward Lake Superior, forming many rapids and falls (e.g., Gooseberry, Baptism, and Caribou). To the west and south of the Arrowhead Region, streams become unpredictable, changing quickly from placid flows to heavy rapids (e.g., the St. Louis, Cloquet, Big and Little Fork, and Crow Wing Rivers). In the northwestern and southwestern parts of the state where few lakes exist, streams provide a primary recreation resource. In the southeast, spring-fed streams (e.g., the Root, Cannon, and Zumbro Rivers) tumble through steeply wooded bluffs, providing another major recreation resource.

Total average annual streamflow varies across the state, generally increasing from west to east. A high degree of variance from average levels also exists, with streams in the southern and western parts of the state showing the greatest variance (primarily due to snowmelt). About two-thirds of the state's watersheds have recorded low flows of zero. Low-flow problems are particularly severe in western and south-central Minnesota. Since appropriations from rivers and streams are expanding, it is increasingly important that some portion of the flow be protected for instream uses such as fish and wildlife, recreation, navigation and hydropower. In most of western Minnesota, this will be difficult because low flows occur frequently even in natural conditions. However, in the central and eastern portions of the state, restrictions on appropriations may effectively preserve some flow for instream uses.

1. Surface-Water Availability

By far the largest part of the state's streamflow occurs in the Mississippi River Basin and leaves the state via the Mississippi River. In terms of average flow, the Rainy River at the northern boundary of the state is second only to the Mississippi River below Hastings. Estimates of surface-water availability based on annual streamflow for the period of record and for the 1976 drought are shown in Table 1. These annual flow figures may be misleading because flow is highly variable throughout the year. One-third to one-half of the average annual flow usually occurs during spring flooding in April through June. Extreme low flow conditions usually exist during the fall and winter months.

The quantity of water potentially available from lakes and reservoirs in Minnesota is estimated at 300-400 billion gallons annually. This estimate is based on the current withdrawal limitation of six acre-inches of water for each acre of lake basin, for lakes larger than 500 acres. The wide range in this estimate is caused by a lack of up-to-date information on the number of drained lake basins and the unknown impact of current legislation on the management of water levels in reservoirs.

There are several factors that limit the actual use of this amount of water. Many of the large lakes and reservoirs in the state are located in areas where water withdrawals are quite low and are expected to remain low, so a relatively large fraction of this available water is inaccessible for potential users.

A second factor is that protected elevations are required for lakes. If water levels fall below the protected elevation, withdrawals will not be allowed until water levels rise again. This factor might be particularly significant during a drought period.

Because of the tremendous recreational value of lakes, future withdrawals should be carefully monitored and regulated to avoid conflicts.

TABLE 1

Estimates of Surface-Water Runoff by Basin

Billions of Gallons

	Average for Period of Record	1976 Drought
Lake Superior Basin[1]	698	474
St. Louis River	539	339
Lake Superior[1]	159	135
Rainy River Basin[2]	3137	2153
Rainy Lake[2]	2630	1900
Little Fork River	247	130
Big Fork River	166	85
Lake of the Woods	94	38
Red River Basin[3]	768	673
Mustinka-Bois de Sioux[3]	19	8
Otter Tail River	72	43
Buffalo River	31	14
Wild Rice River	62	35
Red Lake River	265	261
Middle River	10	5
Two Rivers	26	6
Roseau River	72	30
Upper Mississippi River Basin	2035	1285
Mississippi Headwaters	747	355
Crow Wing River	350	133
Crow River	148	83
Rum River	141	113
Mississippi-Sauk[4]	390	420
Metropolitan[4]	259	181
Minnesota River Basin	627	269
Big Stone Lake	123	33
Pomme de Terre River	25	13
Lac Qui Parle River	28	7
Chippewa River	62	29
Yellow Medicine River	24	6
Redwood River	23	17
Cottonwood River	63	21
Blue Earth River	297	46
MN River Hawk Creek[4]	461	25
Lower Minnesota River[4]	165	94
St. Croix River Basin[5]	1330	1146
Kettle River	180	99
Snake River	142	90
Lower St. Croix River[5]	486	267
Lower Miss. River Basins 4,5	2607	2392
Cannon River	114	80
Zumbro River	122	82
Root River	231	185
Cedar River Basin	44	25
Des Moines River Basin	64	20
Rock River[6]	27	9

[1]Estimates are low because many tributaries to Lake Superior are ungaged. Lake Superior provides a very large source of water for users located on the lake but this amount is not quantified.

[2]Streamflow includes runoff from the Canadian portion of the basin.

[3]Includes runoff from the North Dakota portion of the basin.

[4]Water availability does not include substantial amounts of inflow from upstream basins.

[5]Includes runoff from the Wisconsin portions of the basin.

[6]Both amounts are estimates. No gages are currently in operation in this basin in Minnesota.

2. Surface-Water Quality

Studies by the Minnesota Pollution Control Agency in 1976 have indicated that the quality of water in many of the state's rivers is currently in conformity with the national goal of "fishable" and "swimmable" waters. However, 23 percent of the 75 water quality monitoring stations used in state studies were considered to be in noncompliance with either the "fishable" and/or "swimmable" goal in 1976. Reaches of rivers in this category were: the Mississippi River below Minneapolis-St. Paul; the Zumbro River below Rochester; the Cedar River below Austin; Buffalo Creek below Glencoe; Center Creek below Fairmont; and the headwater tributaries of the Missouri and Des Moines Rivers.

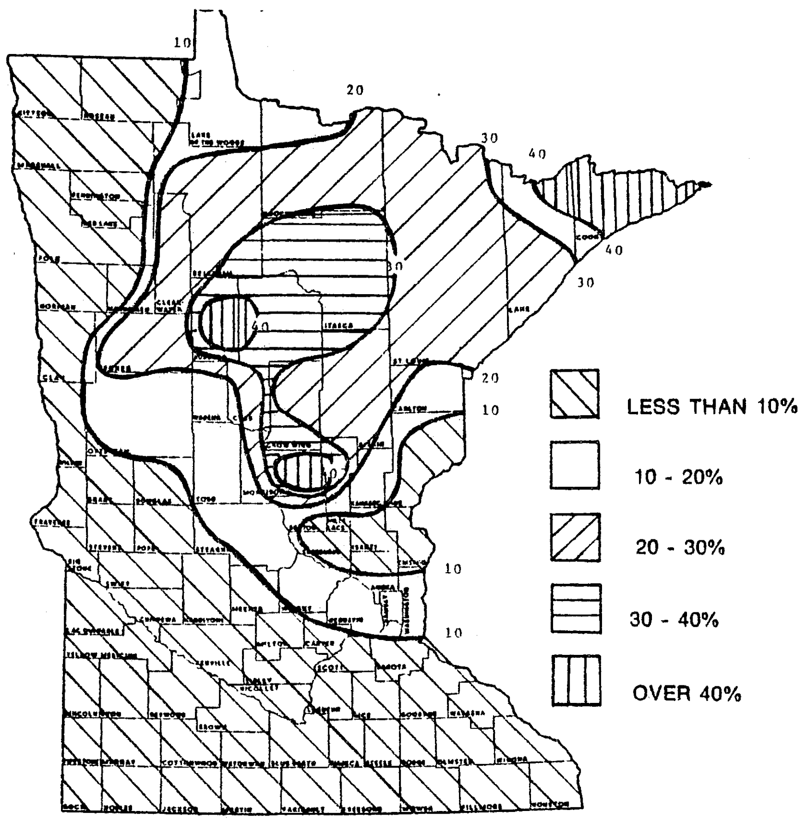
For the purposes of determining the "fishable" aspect of the national goal, six parameters were grouped together: temperature, dissolved oxygen, turbidity, ammonia, pH, and copper (heavy metal). When the average frequency of violations for the six parameters exceeded 10 percent at a monitoring station, the "fishable" goal was considered not met. Of the 75 water quality monitoring stations, 12 percent were not in general compliance with the "fishable" goal in 1976: Buffalo Creek below Glencoe; the Mississippi River below Minneapolis-St. Paul; the Zumbro River below Rochester; Center Creek below Fairmont; the Cedar River below Austin; the East Fork of the Des Moines River; Okabena Creek; Pipestone Creek; and the Rock River.

Fecal coliform levels were used by the Pollution Control Agency as the indicator of whether a surface water is suitable for swimming. While the use of this index as the only criterion for classifying water as "swimmable" is not recommended, it was the most appropriate parameter readily available. Other aesthetic factors such as appearance or smell may be better determinants of "swimmable" but are more difficult to measure in a consistent manner. Fecal coliform levels in excess of the generally-used standard are both common and widespread in Minnesota. At 20 percent of the 75 monitoring stations, the fecal coliform standard was exceeded 50 percent of the time. Five rivers--the Twin Cities segment of the Mississippi; the Crow River; the Cottonwood River; the Des Moines River headwater tributaries and the Missouri headwater tributaries are classified as being in non-compliance with the "swimmable" aspect of the national goal.

As noted above, many of Minnesota's lakes suffer the effects of eutrophication. "Eutrophy" is defined as a state of overnourishment. During eutrophication, lakes experience a series of ecologic successions characterized by increased productivity and sedimentation, often detrimental to the lake and its users. Albert Lea Lake in southern Minnesota is an example of a lake affected by man's activities. Examples of naturally eutrophic lakes are found within the prairie-grassland regions of southwestern, western, and northwestern Minnesota.

The Secchi disk is a device for measuring the clarity of waters. In many cases, the Secchi reading reflects the degree of phosphorus pollution of lakes, with higher readings indicating higher quality waters. There is a natural trend of decreasing lake clarity from northeastern Minnesota to the southwestern part of the state, which has been accelerated by man's activities. Over 40 percent of the fish lakes in the extreme northeast and in areas of central and north central Minnesota have water clarity of more than 12 feet. In contrast, southern Minnesota and the northwestern part of the state have less than 10 percent of fish lakes with clarity in excess of 12 feet (Figure 7).

FIGURE 7.



PERCENTAGE OF FISH LAKES WITH WATER CLARITY (SECCHI' DISC) MORE THAN 12 FEET

Lake Superior is a major water resource for Minnesota. While the overall water quality of Lake Superior is considered to be excellent and in compliance with the national "fishable" and "swimmable" goals, a major concern has resulted from the discharge of taconite tailings to the lake. As a result of asbestos-like fibers from discharges, municipalities located on the north shore of Lake Superior have been forced to construct facilities to provide further treatment of Lake Superior water. The movement of tailings disposal to land is designed to prevent further water quality deterioration.

In recent years, the Mississippi River in the vicinity of Lake Pepin has been the site of study concerning possible health problems posed by polychlorinated biphenyls (PCB's) found in the indigenous fish. In May, 1975, the United States Food and Drug Administration halted the interstate shipment of fish taken from Lake Pepin because the fish flesh exceeded FDA limits for PCB's. In addition, mercury problems have been identified in some northern lakes. While PCB's are known to be of human origin, the source of the mercury in northern lakes is unknown.

Ground Water

Ground water exists in openings of subsurface geologic formations. These openings are of three general classes: (1) openings between individual rock particles, as in sand and gravel; (2) crevices, joints, or fractures in bedrock which have resulted from the breaking of the rock; and (3) solution cavities and caverns in limestone. A ground-water aquifer exists where the geologic formations containing openings which receive the water will yield sufficient quantitites of water to be considered an adequate source of supply.

The ability of a rock to store water is dependent on its porosity. The ability of a rock to transmit water is dependent on the rock's permeability, or the interconnections between openings by passages of greater than capillary size. The ground water becomes a usable resource when the rocks in the zone of saturation (that part of the subsurface in which all available openings are filled with water) are permeable enough to yield useful supplies of water to wells, springs, or streams; when the zone of saturation is perennial (or at least lasts long enough each season to allow practical use); and when mineral substances dissolved by the water as it percolates through the soil and rocks do not reach such levels as to make the water unfit for desired use.

The major ground-water aquifers in Minnesota occur in two broad geologic categories: (1) unconsolidated glacial deposits and (2) bedrock (consolidated rocks). The bedrock category may be further divided into stratified sandstones, limestone and dolomites, and crystalline rocks which underlie these sedimentary deposits.

Except in the Arrowhead Region, in the "Driftless Area" of the southeast, in a strip along the Minnesota River, and in a portion of east central Minnesota, the state is covered by a layer of glacial drift more than 100 feet thick. In the western part of the state, glacial drift up to 600 feet thick has been found. Some glacial drift deposits have a high clay content and poor permeability and porosity, making them less useful as ground-water sources. Large usable ground-water resources in glacial areas occur mainly in aquifers of outwash sand and gravel. In the Red River Valley, once the location of post-glacial Lake Agassiz, the subsurface is typically rather silty and impervious, but there are numerous beach sands and gravels in old channels and bars of the lake that yield significant quantitites of water. Large quantities of water are available from sand and gravel deposits in the central part of the state.

The major bedrock aquifers in Minnesota are sandstone and limestone sedimentary rock formations in the southeastern quarter of the state. The remainder of the state is underlain by a crystalline rock complex which is thoroughly cemented (or crystallized). As a result, these rocks lack porosity. Available ground water is mainly limited to fracture zones and joints.

As an integral part of the hydrologic cycle, ground water is subject to continuous movement. There are regions of recharge where percolating water from rainfall, snowmelt, or surface bodies of water moves into the ground-water system; regions of discharge where water is lost from the ground-water system to surface streamflow, evapotranspiration, or directly to oceans; and areas of ground-water transmission.

In a typical water-table aquifer, recharge occurs through percolation of surface precipitation over a major portion of the aquifer (Figure 8). At places, deeply buried aquifers are recharged in part by the vertical leakage of water through thick, unconsolidated deposits. Artesian aquifers (those aquifers in which ground water is confined under pressure by overlying and underlying confining beds and in which water levels in wells rise above the top of the aquifer) are recharged over only a small portion of the aquifer by surface precipitation, and to some degree by vertical leakage.

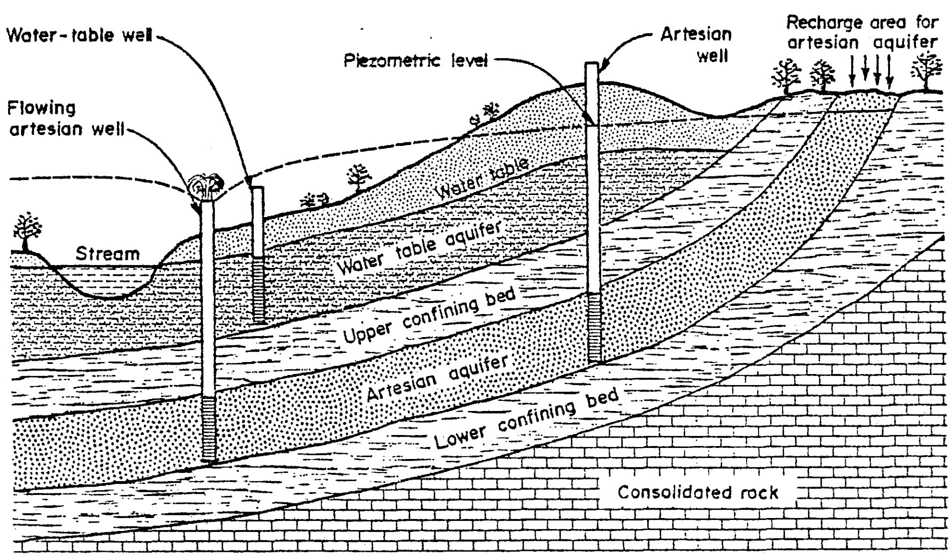


FIGURE 8. Classic confined and water-table aquifers.

Most recharge of aquifers from precipitation commonly occurs during the spring months when evapotranspiration is small and soil moisture is at or above field capacity. During the summer and early fall months, evapotranspiration and soil moisture requirements are so great that little precipitation percolates to the water table, except during periods of excessive rainfall. Recharge during winter months, when the ground is frozen, is negligible. As a result of the interplay between discharge and recharge of ground water, water levels in wells are almost constantly fluctuating.

1. Ground-Water Availability

Widely varying yields may be obtained from the glacial drift and bedrock aquifers in Minnesota. Some surficial and buried deposits of sand and gravel in the state are capable of providing yields of up to 1,000 gallons per minute. Areas in north central Minnesota; the Bonanza Valley; large parts of Sherburne, Anoka, Isanti, and Chisago Counties; and areas along the Minnesota and Mississippi Rivers have been found to yield from 100 to 500 gallons per minute or more. In some cases along the stretch of the Minnesota River from Mankato to the Twin Cities and along the Mississippi around and below the Minneapolis-St. Paul area, yields of over 500 gallons per minute occur.

More than two-thirds of Minnesota has bedrock water yields which are inadequate for most uses. Only in the southeastern part of the state are bedrock aquifers capable of consistently providing water yields in excess of 500 gallons per minute. The iron mining region (Animikie Iron Formation) and the Sioux Quartizite bedrock aquifers are capable of providing for the needs of local areas. Very localized fault zones exist in bedrock in certain areas and are capable of providing water.

The generalized nature of statements about aquifer yields must be emphasized. Aquifer yields can vary within a local area, and even within a given aquifer. For example, a study of the geology and water supply potential of the Anoka Sand Plain Aquifer revealed that about 20 percent of the Anoka-Sand-Plain is underlain by surficial outwash capable of yielding more than 500 gallons per minute. In about 45 percent of the area, however, expected well yields are less than 100 gallons per minute. Even these estimates may vary from actual well yields because of the effect of hydrologic boundaries, lithological heterogeneity (varying origin of the structure of rock formations) in the aquifer, and well efficiencies of less than 100 percent.

One major concern about the ground-water resources of the state has been about the amount of ground water potentially available for use. Conservative estimates have been made for the 39 watersheds units in the state, based on three sources of data: (1) estimates of ground-water contribution to streamflow; (2) 30-day duration low-flow characteristics; and (3) ground-water hydrographs.

These estimates of ground-water availability include only aquifers that discharge water to streams. They include surficial sand and gravel aquifers and the upper layers of the bedrock aquifers in southeastern Minnesota. Deeply buried drift and bedrock aquifers are not included in these estimates.

Table 2 provides estimates of ground-water availability by basin and by watershed. According to these estimates, ground-water availability decreases to the north and to the east from the eastern and southeastern portion of the state (Figure 9).

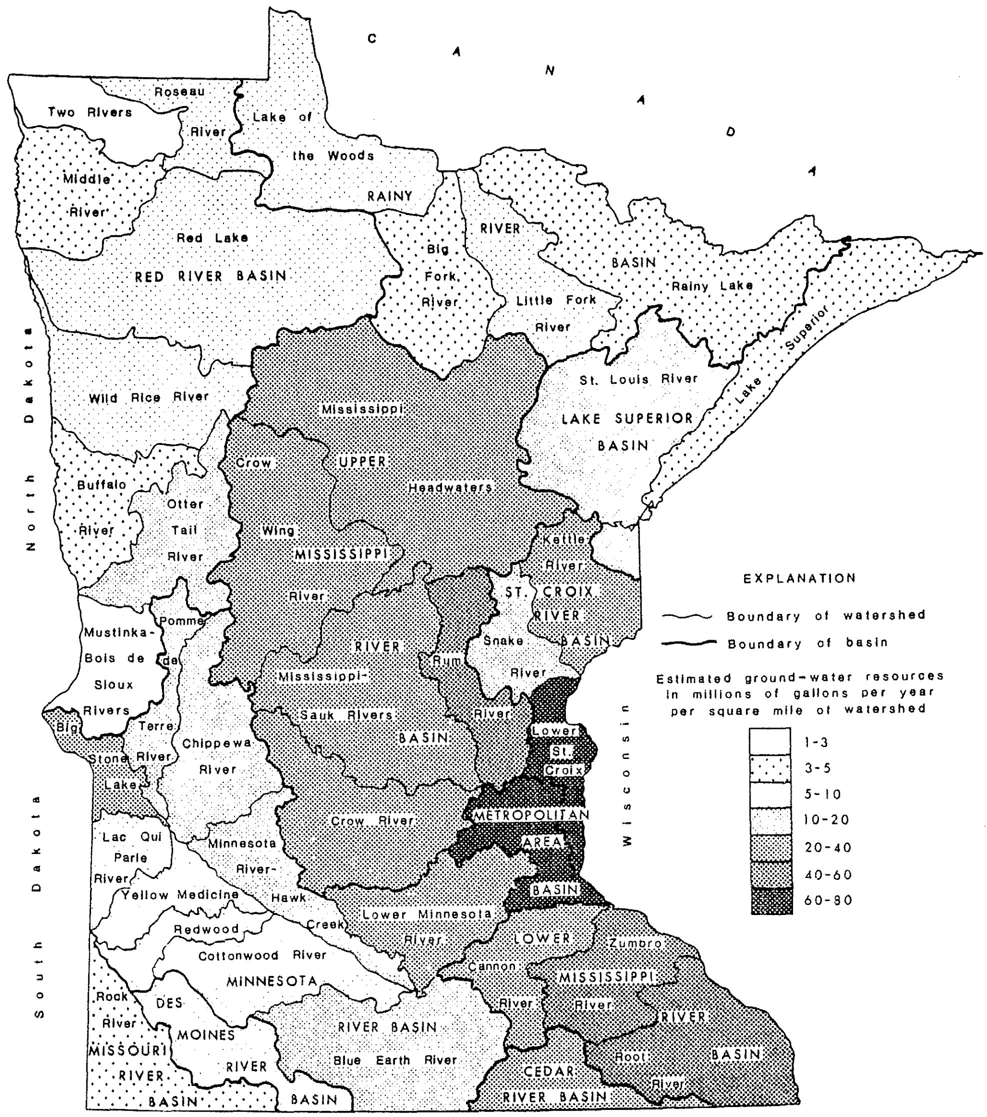


FIGURE 9. Estimated ground-water resources of Minnesota (Kanivetsky, 1979).

TABLE 2

Estimates of Ground-Water Availability[1]

Billions of Gallons Per Year

Basin	BGY
Lake Superior Basin	55-110
St. Louis River	50-100
Lake Superior	5-10
Rainy River Basin	35-85
Rainy Lake	10-25
Little Fork River	10-25
Big Fork River	5-10
Lake of the Woods	10-25
Red River Basin	77-165
Mustinka-Bois de Sioux	1-5
Otter Tail River	25-50
Buffalo River	5-10
Wild Rice River	10-25
Red Lake River	25-50
Middle River	5-10
Two Rivers	1-5
Roseau River	5-10
Upper Mississippi River Basin	500-800
Mississippi Headwaters	150-200
Crow Wing River	100-150
Crow River	50-100
Rum River	50-100
Mississippi-Sauk	100-150
Metropolitan	50-100
Minnesota River Basin	130-280
Big Stone Lake	10-25
Pomme de Terre River	10-25
Lac Qui Parle River	5-10
Chippewa River	25-50
Yellow Medicine River	5-10
Redwood River	5-10
Cottonwood River	10-25
Blue Earth River	25-50
Minnesota River-Hawk Creek	10-25
Lower Minnesota River	25-50
St. Croix River Basin	85-175
Kettle River	25-50
Snake River	10-25
Lower St. Croix River	50-100
Lower Mississippi River Basin	175-300
Cannon River	25-50
Zumbro River	50-100
Root River	100-150
Cedar River Basin	25-50
Des Moines River Basin	10-25
Rock River Basin	5-10

[1]Estimates are based on aquifers discharging water to streams. Deeply buried aquifers are not included.

Based on preliminary analysis, it appears that ground-water supplies are adequate -- and in some areas abundant -- on a regional basis. Problems still exist due to concentrations of pumpage and a lack of water at specific sites.

There is a vital need to understand the cause-and-effect relationship of ground-water withdrawals sufficiently to be able to describe a series of possible alternative development and management choices and the consequences of each. Although the state of Minnesota attempts to make such evaluations, critical information is not necessarily available. For full development and protection of ground-water resources, ground water's place in the hydrologic cycle must be better understood, and the quantification of ground-water resources must be improved.

2. Ground-Water Quality

Although information on surface-water quality is limited, far less information is available on ground water. This results because the quantity of ground water available to the state has not been determined; its flow is very slow; and the direction of flow is difficult to determine. If a stream is sampled, it is often possible to make a reasonable estimate of the quality of the stream a mile away. However, if a well is sampled, the geologic formations the well penetrates and the direction of ground water flow within the formations must be reasonably known if an estimate is to be made of the quality of the water in an adjacent well.

Ground water is generally suitable for most uses over much of the state. Ground-water quality is generally better in the eastern part of the state than in western Minnesota, where water from deep drift or bedrock aquifers may be highly mineralized. While ground water in the state is typically hard and high in iron, this does not pose a health problem.

Surficial outwash deposits tend to have the best quality ground water, but because of their location near the surface may be subject to pollution. In some areas, nitrate problems have been reported in these aquifers.

There are several specific sources of information on the quality of Minnesota ground-water supplies. The most important source is the Minnesota Department of Health, which analyzes samples of water from public water supply systems and samples submitted by individuals. In addition, the United States Geological Survey has analyzed the quality of ground water in connection with its detailed studies of aquifers in areas where heavy use (often for irrigation) is occurring or anticipated; the United States Department of Energy is sampling ground-water quality as an element of the National Uranium Resources Evaluation Program; the Minnesota Pollution Control Agency requires certain categories of waste dischargers to submit regular analyses of ground-water quality near their disposal sites; and other state agencies (such as the Minnesota Department of Agriculture) perform specific water quality analyses.

In reporting on municipal supply systems in Minnesota (over 90 percent of which rely on ground-water sources), the Department of Health has noted:

** A clustering of high sulfate sources in southwestern Minnesota;

** High nitrate levels in southwestern Minnesota, although only 19 supplies were actually found to have levels in excess of the standard;

** Relatively lower values for iron, manganese, and suspended solids in the Arrowhead Region, with increasing values toward the southwest corner of the state. While these factors are classified as aesthetic factors and have no proven health effects, if they make the water supply unpalatable to the consumer, they may drive the consumer to use a more palatable, but less safe, supply.

Rural domestic supplies are monitored through evaluation of well water samples for coliform counts, nitrates, and, in the past, surfactants. Lab records tallied for about 4,000 wells for July through September of 1975 and 1976 produced:

** Coliform counts indicating bacterial contamination in 20 to 25 percent of the wells; and

** Nitrates in excess of 10 milligrams per liter in about 10 percent of the well samples.

The majority of the samples found to be in excess of accepted standards came from the southwestern part of the state. (However, the results of this tally may be skewed by the nonrandom sample selection.)

Because contamination problems relating to nitrates and bacteria have been encountered by farms and municipalities in the southeastern corner of Minnesota, where unique geologic conditions are known to exist, the Legislative Commission on Minnesota Resources has funded a special cooperative project in this area. The Minnesota Department of Health and the United States Geological Survey are cooperating to evaluate interflow in uncased multi-aquifer wells in relation to ground-water contamination in the Karst region of southeast Minnesota. To date, underground tracing of water flow has revealed that there is significant potential for pollutants to spread underground. Dye added to a single water sinkhole has been detected in as many as three separate springs. The potential of such situations to spread pollutants underground is obvious.

Another major problem which has been recently detected is creosote seepage into the water supply of St. Louis Park. Several municipal wells have been closed since the discovery of this problem. Solutions are under investigation, principally through the Health Department and the Pollution Control Agency.

As part of its Water Quality Management Planning, the Minnesota Pollution Control Agency has contracted with the United States Geological Survey for the design of a ground-water quality monitoring network. When complete, a network of more than 200 wells across the state will be sampled on a regular basis. Although the network is incomplete, sampling of recommended wells has begun and, combined with other sampling evidence, indicates:

** Iron and manganese content of ground water exceeds limits in many areas of the state;

** Phenols exceed limits in various locations around the Twin Cities, most notably in St. Louis Park;

** Chlorides exceed limits in the Rochester-Winona-Red Wing area; and

** Cases of nitrates exceeding established limits are found in shallow wells located near feedlots and fertilizer storage areas.

The latter finding supports a widely held conviction that the leaching of nitrogen fertilizers into ground-water supplies due to increased irrigation and the disposal of toxic and hazardous wastes will focus additional attention on ground-water quality in coming years.

The University of Minnesota Agricultural Extension Service has pointed out problems in water quality for irrigation along the western border of Minnesota and in the southwestern portion of the state.

More information is needed on the natural quality of ground-water throughout the state. Greater knowledge is also needed on the effects of certain land use practices, such as agriculture, solid waste disposal, and toxic chemical disposal and storage, on long term ground-water quality. Maintenance of good quality ground water will require more intensive monitoring and careful planning and management of potential sources of contamination.

Conclusions and Recommendations

The analysis that has been conducted on surface- and ground-water availability in the state has shown that under normal conditions few severe regional water availability problems exist. However, severe localized problems are known to exist. The primary surface-water availability problem is the extreme variability of flow in many rivers in the state. In addition, analysis of seasonal variations in flow and water use may suggest additional concerns.

Although many basins in the state have flooding problems in the spring, in the western portion of the state this situation changes to one of extremely low or no flow by the fall and winter. During a major regional drought, such as the one in 1976-77, low-flow situations can be common over most of the state and impacts can be severe on streams with concentrations of large surface-water appropriations.

There do not appear to be many major regional ground-water availability problems, although there are currently problems due to a lack of ground-water at specific sites or to large concentrations of users at one site. These can be expected to continue. Some communities are out-growing their water supplies as water use increases and water availability is unchanged. Efforts are needed in these communities to either reduce water use or to locate additional sources of water.

Surface- and ground-water quality is generally adequate, although there are areas where quality is unacceptable either due to natural conditions or to the effects of man. Efforts to control both point and non-point sources of pollution need to be continued and in some cases accelerated to maintain or improve water quality.

The following specific recommendations are from the analysis of surface- and ground-water availability:

1. Adoption of watershed units. The 30 watershed units described in Bulletin 10, Hydrologic Atlas of Minnesota and in the Hydrologic Investigations Atlas Series need to be modified for use in future studies. In many cases the watershed units are too large or are otherwise unsuitable for reasonable analysis of water availability - water use conflicts. Once the watershed mapping effort being conducted by the Department of Natural Resources - Water Policy Planning Project for the Water Planning Board is completed, a new set of smaller watershed units will be proposed for adoption by the state agencies. These new watershed units or aggregations of them should be used in any future analysis of water availability and water use.

2. Modification of streamflow gaging station network. A comprehensive statewide program of streamflow measurement should be established. The current network of streamflow gaging stations is inadequate for analyzing streamflows for many hydrologic units in the state. The existing network should be examined and modified where feasible. Where possible, the Pollution Control Agency and the Department of Natural Resources should attempt to combine water quantity and water quality monitoring at the same site. This review and modification does not necessarily have to result in an expanded network of gaging stations. Many stations can be moved to locations where the information will be more useful, such as areas with large surface-water withdrawals or frequent low streamflow problems. Additional monitoring of high and low flows is also needed on many streams where permanent gages are not feasible.

3. Improved ground-water monitoring. The ground-water observation and monitoring programs conducted by the U.S. Geological Survey, Department of Natural Resources, and others should be expanded. There is currently an insufficient density of observation wells throughout the state, including many areas with large withdrawals from ground water.

The Department of Natural Resources and the Pollution Control Agency should coordinate their efforts to expand the network of wells for water quality and quantity monitoring. There should be many opportunities for a single observation well to be used for both quality and quantity purposes. Priorities for expansion of the observation well network should be based on areas with currently large ground-water use and areas where surface-water supplies may be insufficient to meet current or future demand for water.

4. Emphasis of USGS Cooperative Ground-Water Studies on buried aquifers. In recent years, much of the emphasis of the U.S. Geological Survey Cooperative Ground-Water Study Program has been on the examination of surficial sand-plain aquifers. These studies have been valuable because they have provided hydrologic information for many areas where ground-water use has been increasing rapidly, largely due to irrigation. It is known, however, that water is abundant in these aquifers and that they do recharge rapidly.

   Increasingly important sources of ground water in some parts of the state are buried aquifers, and very little is known about many of them. The U.S. Geological Survey Cooperative Ground-Water Study Program should be modified to place more emphasis on the examination of buried aquifers, although substantially increased expenses will be involved. Information is needed on the capacity and the recharge rates of these aquifers in order to determine permissible amounts of appropriation from them.

   Priorities for buried aquifer studies should be areas with relatively limited surficial ground-water aquifers and areas of increasing water use. The irrigation data base being developed by the Department of Natural Resources - Division of Waters, ground-water appropriation permits, and well logs are important sources of information for the determination of priorities for these studies.

5. Continuation of research functions of the Minnesota Geological Survey. The hydrologic research functions and the well-log data acquisition and interpretation programs of the Minnesota Geological Survey should be continued until an adequate hydrogeologic data base is established. These data are needed both for detailed ground-water studies and for ground-water management through the Appropriation Permitting Program.

6. Maintenance and improvement of the water use data base established by the Water Planning Board. The water use data base that has been developed by the Department of Natural Resources - Water Policy Planning Project for the Water Planning Board should be maintained and expanded by the DNR - Division of Waters, in conjunction with the state coordinating body.

   Estimates of withdrawals by unpermitted and non-reporting users, and projections of statewide and regional water use should be updated by the DNR in conjunction with the Water Planning Board, or its successor. Information contained in the data base should be a valuable source of information for evaluating appropriation permit applications and for long-term planning.

7. Hydrogeologic data-gathering by the Department of Natural Resources. Even though this analysis shows that ground water is abundant throughout much of the state, it is essential that the Department of Natural Resources continue to utilize well logs, require information on source aquifers, and conduct pumping tests with permit applications, when this data is not available from other sources. The basic data used to generate the information in this report are not adequate for evaluating permit applications.

   Detailed information from the prospective appropriator or from detailed hydrologic studies is necessary to fully evaluate permit applications. These data from ground-water appropriation permit applications will help to eliminate local ground-water conflicts and will also improve the knowledge of ground-water availability.

8. Accurate measurement of water use. All permitted appropriators shall be required to accurately measure their water use. Flow meters shall be used, except in cases where users can demonstrate that employing meters is technically infeasible or too costly. It shall be the responsibility of the appropriator to demonstrate that a flow meter cannot be used. Where successfully demonstrated, an alternative means of accurate withdrawal measurement shall be required.

9. Improved enforcement of appropriation permit requirements. Additional efforts are needed to identify unpermitted appropriators that are required to have permits and to bring all appropriators to report their annual pumpage (as required by law). Many unpermitted appropriators were identified during the development of the water use data base. There are still, however, billions of gallons of unpermitted and unreported water withdrawals in the state.

   Information on the amount and location of water appropriations is essential for resolving local conflicts (such as well interference or streamflow allocation problems). In areas where localized conflicts do occur, it is difficult to resolve the problem equitably because appropriators and/or the amounts they are pumping are sometimes unknown. Additionally, this information can be used to develop strategies for regions with potential water availability - water use conflicts.

10. Analysis of impact of low streamflows. Low streamflows are a serious problem in much of the western part of the state. Additional study is needed to determine the impacts of low flows on water use. Once these impacts are quantified, it is necessary to establish management plans for the watersheds to insure sufficient water for withdrawal uses and for the protection of instream uses.

11. Local water management planning. Many localized areas of the state have current or projected water availability - water use conflicts.

A program should be established to assist local units of government in these areas in developing water management plans, so that existing conflicts can be alleviated and potential conflicts can be avoided.

Local, regional, state and federal input may be required to address these problems and to develop acceptable solutions. Priorities for the development of management plans should be based first on areas with existing problems and second on areas with projected problems. The management plans could also address other water and related land resources problems in these areas.

12. Protection of instream uses. Watersheds with severe low-flow problems require both a long-term and a short-term management approach to protect instream uses.

    A potential long-term approach would be to restrict the total amount of consumptive appropriations to a level (yet to be defined) that is beneficial to fisheries. One authority (Tennant, 1975) identified 40 percent of the average annual flow during the summer months as a "good" flow for fisheries.

    A potential short-term approach would be to restrict consumptive surface-water appropriations during a drought period when streamflow approaches a minimum level (yet to be defined). Specific minimum flow levels should be determined for each major stream, but until that can be accomplished interim minimum flow levels are needed. These could be based on the (10 percent of the average annual flow) "short-term survival" level identified by Tennant or on two studies funded by the Corps of Engineers on the Mississippi and Minnesota Rivers. These studies will identify available fish habitat at various flow levels and should be completed in 1979.

13. Monitoring of precipitation and soil moisture. The development of an adequate precipitation monitoring network should be continued and expanded where necessary. Special emphasis should be given to research studies that determine ground-water recharge from precipitation in areas of increasing ground-water use. A soil moisture monitoring program should be supported as an integral part of the overall effort.

WATER USE IN MINNESOTA

In order to assess the water supply and demand outlook for Minnesota, it was necessary that the Water Planning Board establish a detailed picture of current water use and develop a regional water demand forecasting capability. While statewide estimates of water use and future demand have been made in the past, such efforts were inadequate for the Framework Water and Related Land Resources Plan effort because the area covered -- the state as a whole -- was too large for any meaningful comparison of estimated demand and supply.

This chapter addresses the approaches employed in estimating present use and future demand, and reviews the results of these approaches. In addition, two special uses of increasing significance to Minnesota are discussed -- irrigation and rural water supply systems.

During the last decade, irrigation in Minnesota has grown from an insignificant activity to a water use of major proportions. Irrigated acreage has increased from an estimated 44,000 acres in 1970 to almost 277,000 acres in 1977. Recent growth has been spurred by drought conditions of the mid-seventies, and can be expected to level off. However, the issues of the impacts of irrigation on competing water supply systems and on overall water quality and quantity need to be addressed.

Rural water supply systems provide central water treatment and delivery of potable water through hundreds of miles of plastic pipeline in order to supply widely dispersed users. A rural area would consider the installation of a water supply system when individual supplies, largely private wells, cannot provide water of sufficient quantity or adequate quality. The planners of the system must also consider the potential for significant land use impacts, population growth, and increased water demand.

Irrigation plays a substantial role in current, seasonal water demand whereas rural water supply systems may have a more significant impact on water demand in the future.

Current Water Use and Future Water Demand

Scope of Work

1. Geographic Boundaries

   The localized nature of water resources and water problems in Minnesota necessitates water use analysis and forecasting below the state level. Since water demand is driven by economic activity, forecasts of future demand require data aggregated by free-standing economic areas. Minnesota's thirteen Regional Development Commission areas were employed to meet this condition in the Framework Plan effort.

Available supply is best estimated in terms of hydrologic regions. Regional Development Commissions are not established along hydrologic boundaries. Minnesota's ten major river basins were employed in estimating supply.

In order to bring these estimates together, base year (1976) water use and demand forecasts were first derived for each Regional Development Commission area and then mapped into the ten major river basin units. Due to the difficulty in obtaining economic data below the county level, major watersheds were defined to the nearest county boundary. For most basins, this procedure was expected to provide a reasonable approximation of overall water use.

Figures 10 and 11 illustrate the Regional Development Commission and Major River Basin (county-line approximation boundaries). (Actual hydrologic boundaries are illustrated in Figure 6.)

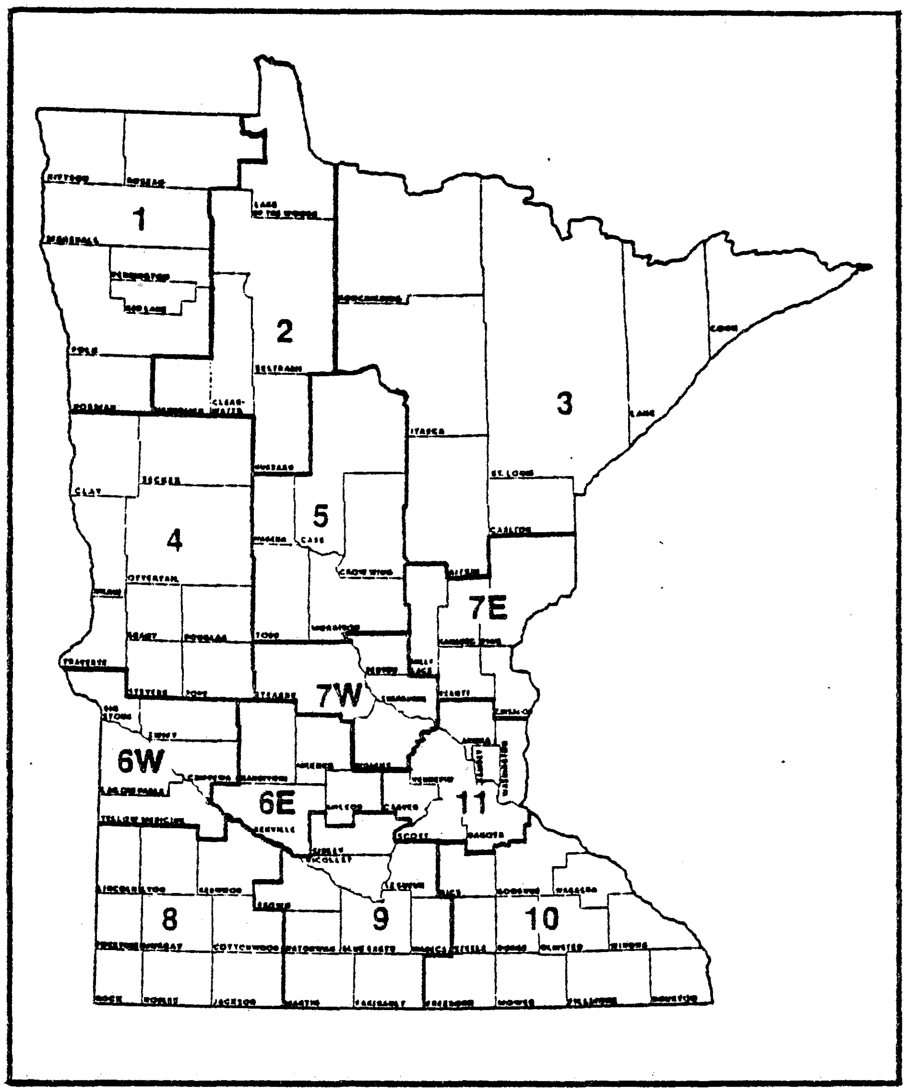


FIGURE 10. Regional Development Commission Areas

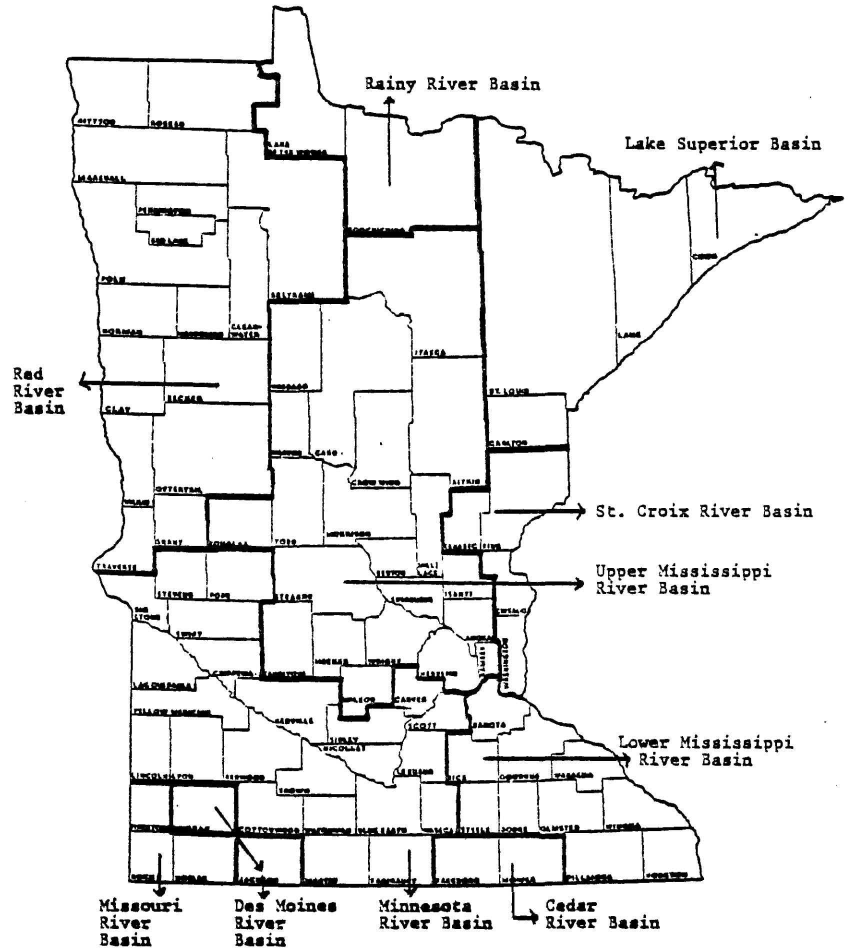


Figure 11. Major River Basins
(County-line Approximation)

2. Withdrawal and Consumptive Use

Two types of use must be determined for planning purposes: withdrawal use and consumptive use. The most commonly used definitions of water withdrawal and consumption are those used by the United States Geological Survey (Murray and Reeves, 1977):

** The principal requisite for withdrawal use is that water must be taken from a ground-water or surface-water source and conveyed to the place of use.

** Consumptive use is that part of the water withdrawn that is no longer available because it has either been evaporated, transpired, incorporated into products and crops, consumed by man or livestock, or otherwise removed from the water environment.

Because almost all available primary data recount water withdrawals, withdrawal uses provided the basis for control totals and forecasts. Most studies have also focused on withdrawal uses. Although withdrawal data are useful in presenting total requirements for all activities, they are somewhat misleading because they double-count the actual amount of water taken.

Consumptive use data provide better information for planning, since they denote water made unavailable to competing users. However, little primary data exists for consumptive use. Except for a few activities for which primary data exists (e.g., for electric power plants and some manufacturing activity), consumptive estimates are theoretical. Consumptive use estimates in this report are largely based on fractions derived from a literature survey of water use.

3. Level of Detail

For the 1976 base year estimates, water withdrawal data were aggregated into six major categories: (1) residential; (2) commercial; (3) manufacturing; (4) mining; (5) electric power; and (6) agriculture. While data sources do not report water withdrawal in this manner, this type of breakdown was required for the forecasting effort. A number of miscellaneous activities (e.g., temporary withdrawals, level control, dewatering, wild rice irrigation, uses in ski areas for snow-making, and golf course irrigation) were aggregated into a "miscellaneous" grouping for 1976. However, future "miscellaneous" uses were not forecast.

Major activities were further subdivided to provide more detailed water use estimates. Livestock and crop irrigation were treated separately within the agricultural category. Mining and manufacturing activities were disaggregated into specific sectors, roughly conforming to two-digit Department of Commerce Standard Industrial Classification (SIC) categories for most activities and to three-digit SIC codes for the food and kindred products sector. Commercial and institutional uses were not differentiated or disaggregated into SIC categories because specific use information was not available and because water use within these categories was not expected to vary as significantly as that within manufacturing sectors.

1976 Water Use Estimates

In order to estimate future water use, it was first necessary to develop a credible set of water use estimates, at county and regional levels, for a base year. Minnesota did not have a credible set of base year figures.

Water use estimates, aggregated in the form required for the water use forecasting process, were developed for the year 1976. Because available water withdrawal records and estimates were found to be incomplete and sometimes in conflict, it was necessary to compare data from different sources, verify and reconcile the data to the degree possible, and reclassify and improve it where necessary to meet forecasting needs. Estimates were made for classes of users for which no records were available. The 1976 water use estimates were used as "control totals" for the forecasting effort.

Concurrently, the APPROP data base was developed by the Water Planning Board, in cooperation with the Department of Natural Resources Division of Waters, as a computer-retrievable water use record, based upon DNR appropriations permits and supplemental estimates of non-reported uses.

The following data records and estimates provided the main sources for the 1976 water withdrawal control totals.

** Public supplies. Minnesota Department of Health records of total annual water withdrawal by municipal suppliers were used as the base data for a publicly-supplied water use. These data were further divided into "residential", "commercial-institutional", and "industrial" end uses based on: (1) records of the Metropolitan Waste Control Commission, for municipal suppliers in the Twin Cities metropolitan area; (2) a 1976 survey of municipal water use made by the University of Minnesota Water Resources Research Center (Gardner and Waelti, 1977); and (3) a telephone survey of municipal suppliers by project staff.

** Self-supplied uses. Four separate sources of data on self-supplied water withdrawals were employed: DNR water pumpage reports; Minnesota Energy Agency staff research; Minnesota Department of Agriculture estimates; and supplemented estimates based on population, per capita use, and employment.

The Department of Natural Resources requires annual pumpage reports from active, permitted appropriators. Reports for 1976 were used for base year controls. Although small appropriators are exempted and the level of compliance with reporting requirements is questionable, the DNR pumpage reports remain the most complete source of water withdrawal data in Minnesota. DNR data, aggregated by SIC code, formed the basis for mining, manufacturing, and miscellaneous use estimates.

Minnesota Energy Agency (MEA) Forecasting staff compiled water withdrawal and consumption information for public electric generating facilities based upon figures filed by those utilities with the Federal Energy Regulatory Commission (FERC), on all steam-electric generating plants. Steam-electric plants in 1976 accounted for 96 percent of all electricity generated, and for almost all power plant water use (water use by other types of generating plants is negligible). FERC-reported figures were used because, for a number of power plants, no pumpage records were available. Where DNR data were available and reported figures varied significantly from the FERC data, actual pumpage figures were obtained from the utility.

The Minnesota Department of Agriculture (MDA) estimated water withdrawn for irrigation and livestock production in 1975 (Levy, Skelton, Ditmore, 1977). The 1975 irrigation figures were based upon University of Minnesota Agricultural Extension Service estimates of irrigated acreage, a MDA survey of crop types irrigated, and Soil Conservation Service and DNR estimates of amounts of water required by various crops. The reported method was used to estimate 1976 water use. On the advice of the Department of Agriculture, the 1975 livestock water use estimate was used directly for 1976. To make these estimates, MDA used Minnesota Crop and Livestock Reporting Service data to compile livestock numbers by animal class by county. Coefficients were derived for each animal class and used to determine livestock water use by county.

Rural domestic water use and non-permitted self-supplied manufacturing water use were also estimated. Rural domestic water withdrawal was calculated based upon an assumed per capita use figure (50 gallons per capita per day) for all population not served by municipal supplies (Minnesota Department of Health). Non-permitted self-supplied manufacturing water use was calculated using estimates based upon employment data and nationally-reported coefficients.

APPROP Data Base

The estimation of 1976 water withdrawal "control totals" for forecasting purposes paralleled the verification of Department of Natural Resources water appropriation permit data and its computer-retrievable storage in the APPROP data base. In order that the APPROP data base represent all uses and not just those under DNR permit, three sets of supplemental data from the 1976 forecasting water use estimates were added:

1) estimates of use for use classes not covered generally by the permit system: rural domestic, livestock.

2) supplemental data on non-permitted uses in user classes which were partially represented: electric power plants; municipal water supplies; estimates of non-permitted irrigation; and self-supplied manufacturing.

3) consumptive use estimates for all classes of uses.

With these additions, use on the APPROP data base and the 1976 withdrawal control totals for forecasting are in relative agreement. The APPROP data base represents the first computer-retrievable volumetric data base to be developed in Minnesota. The types of detail stored on APPROP include: permitted amount of use, as well as 1976 reported withdrawal and estimated consumption; water source (actual name and type); specific location; seasonal as well as annual withdrawals.

The extent of the information stored on APPROP allows data retrieval by source, by use, and by location at the 39-watershed level, a level of detail which is not available from the forecasting water controls. An example of the type of information available is shown in Figure 12: withdrawal and consumption data are compiled by source type for the 39 watersheds.

Consumptive Use Estimates

While it was possible to derive base year withdrawal estimates from actual water withdrawal records, water consumption estimates for most types of activity were generated by applying theoretical consumption coefficients to the baseline withdrawal use. Consumptive use is generally expressed as a percentage of water withdrawn for a given type of activity.

Consumptive fractions and the sources from which these factors were drawn are listed in Table 3.

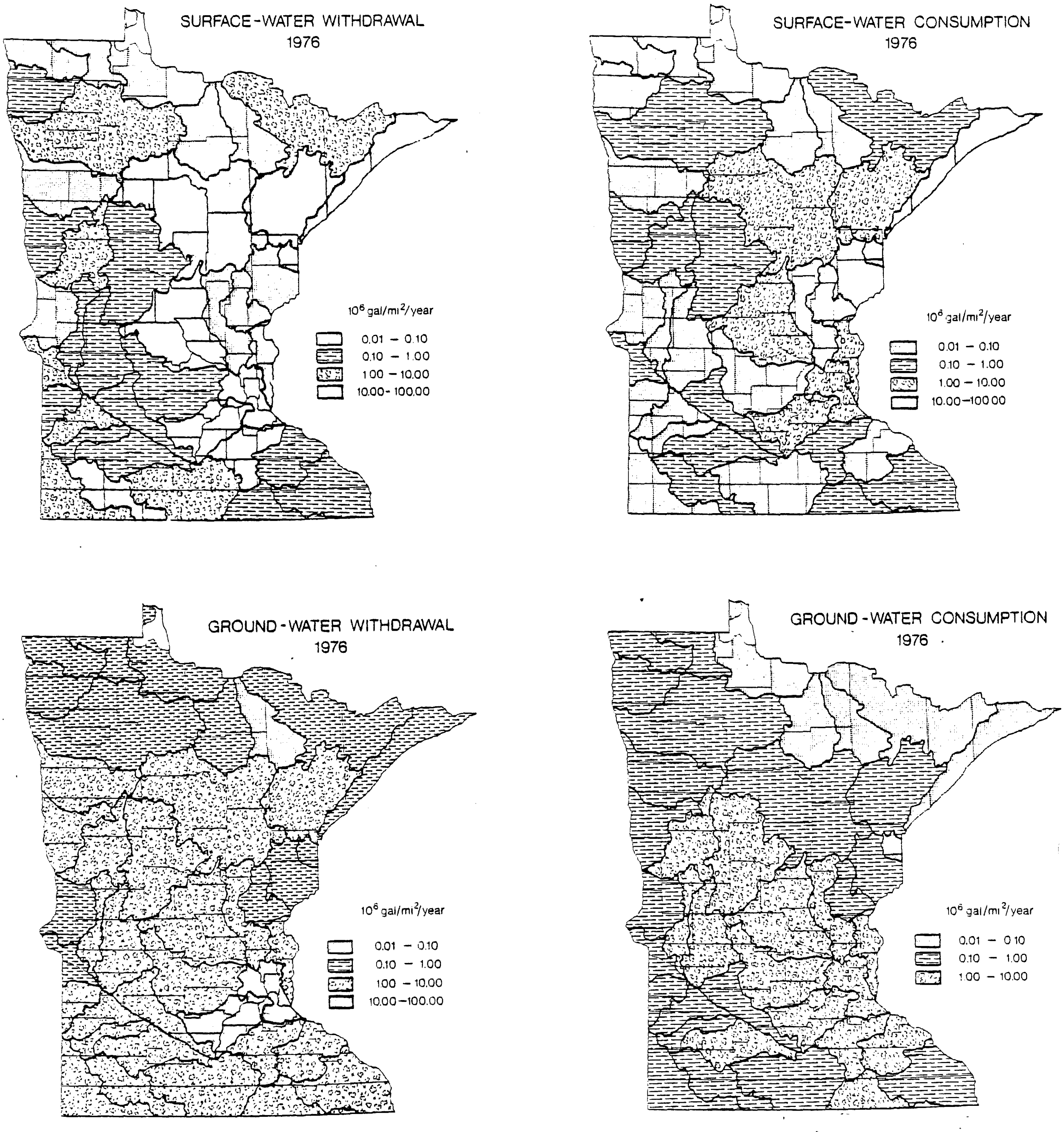


FIGURE 12. 1976 Water use by source: APPROP Data Base

TABLE 3

Consumptive Use Coefficients

Sector	Consumptive Fraction (% of withdrawal)	Source of Factor
Livestock	100	Bodette and Reeves, U.S.G.S.; U.S. Water Resources Council; Upper Mississippi River Basin Commission
Irrigation	80	U.S. Water Resources Council; University of Minnesota Agricultural Extension Service (Range 70 to 90%) *
Iron Mining	36	U.S. Water Resources Council
Quarrying	12	U.S. Water Resources Council
Manufacturing	SIC-Specific (range, 4-23%)	U.S. Census Bureau, Water Use in Manufacturing, 1972
	SIC Unknown, 11	Bodette and Reeves, U.S.G.S.; U.S. Water Resources Council
Commercial, Residential, and Municipal Water Works	10	United States Geological Survey; Upper Mississippi River Basin Commission
Electric Utility	Power Plant Specific 1% to 90%	Federal Energy Regulatory Commission
Wild Rice Irrigation Temporary, and Level Control	20	This factor is high. Will be revised to 5%

*Personal Communication, F. Bergsrud, 1978.

Estimating Future Water Demand

Most articles addressing water resource planning and management imply or openly portray the future as one marked by an ever growing demand for water. Therefore, it is necessary that the planning effort for Minnesota quantify -- at least within a general range -- the concerns which the state must address.

Studies which forecast future water use must contend with a large number of variables. Their results are, at best, an educated guess. With this clearly understood, the Water Planning Board set out to obtain a general idea of what water demand the state may face over the next 15 to 25 years. The discussion of future demand centers on the year 1990, although growth rates and forecasts are presented through the year 2000 for most sectors (electric power and other energy are examined only to 1995). The focus on 1990 occurs because (1) projections based on historic trends are likely to be more accurate in the near-term, and (2) the timing, siting, and sizing of electric power plants becomes more problematic after 1990.

Water withdrawals were divided into major use categories: residential, commercial, mining, electric utility and other energy, and agriculture. Where necessary, uses were subdivided further (e.g., manufacturing uses were disaggregated by major Standard Industrial Classification (SIC) categories). Each major use category was forecast differently.

For the residential, commercial, manufacturing, and mining sectors, "determinant variables" were identified which were expected to "drive" water use (for example, economic variables such as employment, output, and income; demographic variables such as population and number of households). Forecasts of these "driving" variables were linked with water use relationships to produce water forecasts.

1. Residential Estimates

Using demographic data and water withdrawal records of municipal water utilities, a residential model was constructed. Water use per household was regressed against several variables: persons per household, water price, income, and proportion of single-family homes. The resulting equation indicated the relative importance of those variables in determining water use. Projections of future values of those variables, (population and housing projections from the State Demographer, income projections from the economic model) were used to estimate related water use.

2. Commercial, Manufacturing, and Mining Estimates

An economic model was constructed for the commercial, manufacturing, and mining sectors. To forecast water use in manufacturing, all types of manufacturing activity were first categorized as either "export" (or "basic") or "residentiary" type industries. "Export" industries are those industries, often based upon a local natural resource, which are oriented toward national markets and conditions. (Mining, food processing, and pulp and paper manufacturing are examples of "export" industries in Minnesota). They vary from region to region. "Residentiary" industries and commercial activity exist to serve the needs of the export industries and local and residential demands for goods and services.

Forecasts of the "export" industry employment were based upon national forecasts of future economic activity, modified by their historic regional growth. Residentiary employment, regional earnings, and income were related to export industry employment through a set of six simultaneous equations. Regressions on time series data were performed in order to derive parameters of the six equations for each region, relating employment and earnings (export, residentiary, and commercial), population, personal income, and time. The system of six interacting equations stands as a compromise between a single-equation model and a full-scale input-output model, which was judged to be tedious at the regional level of detail. Water use relationships tied employment forecasts to estimates of water use.

3. Electric Utility Estimates

Fifteen-year forecasts of generation and capacity needs filed by utilities with the Minnesota Energy Agency (MEA), modified by the outcomes of Certificate of Need hearings and MEA statewide electric demand projections, were used to time and site (where possible) future power plant capacity additions and retirements. Forecasts reflect utility planning revisions as of April 1, 1979. Environmental Impact Statements of proposed power plants provided information on new plants' expected water use. Where these were unavailable, water withdrawals and consumption expected for the Northern States Power "Sherco" No. 3 and No. 4 plants were used as "state of the art" for future power plants of the same expected size and cooling method. Plants for which no site has been determined were left "unsited" in the forecasts.

4. Other Energy Estimates

Numbers, sizes, and possible regional distribution of coal and peat gasification plants to 1995 were estimated. The basis for this estimation was a study of industries whose natural gas supplies are being terminated and whose needs for a clean gaseous fuel for processing make them likely candidates for on-site, low-Btu gasification processes, should such processes prove commercially feasible. Water use for such plants was calculated, based upon literature available on these technologies, their needs, and their impacts.

5. Agriculture Estimates

No projections have been made by a state agency of future livestock production or water use. Therefore, livestock production growth rates for the region prepared by the U.S. Department of Agriculture for the United States Water Resources Council's Second National Water Assessment (USDA 1975 Nationwide Analysis: Livestock Water Use) were applied to base year Minnesota Department of Agriculture estimates. No change in the nature of livestock-related water use was assumed in the Second National Water Assessment.

For irrigation water use, an estimate of "potentially irrigable acreage" was derived on a county-by-county basis. The number of acres of "potentially irrigable" land estimated to be under irrigation by 1990 was based on Soil Conservation Service reports from Soil and Water Conservation Districts (in conjunction with the Resource Conservation Act process) where such reports were available, and from the Water Planning Board where unavailable. Irrigation was estimated to continue to develop consistent with historic trends. In all cases except those in which irrigated acreage already exceeds estimates of "potentially irrigable" land, estimates of future irrigation based on historic trends were constrained by the estimated number of irrigable acres.

6. Linking of Estimates

The commercial, mining, and manufacturing forecasts are interrelated by means of the economic model. Residential projections are related to the economic projections insofar as income projections from the economic model are used in forecasting residential water use. The energy and agricultural sectors are forecast individually and independently of the other sectors.

7. Water Coefficients

Water withdrawal coefficients are a "tie" between measures of a specific type of activity and its related water use (e.g., "gallons withdrawn per year per employee" for a given type of manufacturing activity; "gallons withdrawn per acre irrigated" in crop production; "gallons withdrawn per capita per day" for rural domestic use). Water withdrawal coefficients were used in the manufacturing, mining and commercial sectors; they were calculated by dividing the 1976 water use estimate by the relevant statistic to be forecast (employment). These water withdrawal coefficients, with some modifications (as described under "Alternative Futures"), were used to assign water use to levels of employment forecast to the year 2000. Withdrawal coefficients were also used to calculate water use for rural domestic agricultural water use; no coefficients as such were required in forecasting the residential or electric power sectors.

Consumptive use coefficients are expressed as a percentage of water withdrawn (see previous discussion and Table 3). They are based on literature sources rather than Minnesota data records.

8. Alternative Futures

Water use relationships as established for 1976 cannot be assumed to remain static. Water price, price of other inputs in manufacturing processes, water availability, changing technologies, or regulation may change the way in which water is used. To account for changes over time, the forecasting effort derived two possible futures, or sets of assumptions about changes over time. These scenarios are:

** "baseline" scenario (i.e., an extrapolation of current trends)

--no increases in the price of water in the residential model.

--no increases in water use efficiency in the commercial, mining, manufacturing, or irrigation sectors.

** "conservation" scenario

--a doubling of water price in the residential sector by 1985.

--efficiency increases in the commercial and manufacturing sectors as assumed in the Second National Water Assessment by the U.S. Water Resources Council.

--a 10-percent increase in the efficiency of water use in irrigation.

In the residential sector, price is seen as the major incentive for water conservation. For the commercial, and industrial sectors, government regulation, rather than price, is expected to have the major influence on water conservation. The conservation forecast uses the water recycling rates developed for the U.S. Water Resources Council's Second National Water Assessment, where it is assumed that the objectives of the 1972 Water Pollution Contol Act Amendments (which set the goal of "zero discharge" by 2000) will be met. "Zero discharge" requires increased recycling of water, resulting in a decrease of water withdrawn, but an increase in related consumptive use. While many believe that the goal of "zero discharge" is unrealistic, this assumption serves to set a lower limit to the range of possible commercial and manufacturing water withdrawal. Because the imposition of such regulations implies such a marked change in water practices, no additional conservation is assumed to take place due to price effects.

In the electric utility sector, some water conservation measures have already taken place. For example, due to federal regulations concerning thermal pollution, closed-cycle cooling is required on all new power plants. Thus water withdrawal will decrease markedly compared with existing plants, although consumption will increase. It is not thought likely that older plants, many near retirement, would construct closed-cycle cooling systems under any price assumptions. Therefore, no separate "conservation" scenario was developed for the electric power industry.

9. Assumptions

A number of assumptions underlie both scenarios:

** United States industry growth consistent with Data Resources, Inc., Winter, 1978 forecasts;

** Industry-specific labor productivity growth rates consistent with Bureau of Labor Statistics data;

** Historic employment growth trends and regional competitive positions consistent with data from County Business Patterns (Bureau of the Census) 1965-76;

** Population growth consistent with Minnesota State Planning Agency projections;

** Rates of removal, conversions, and number of households consistent with State Planning Agency studies.

For the mapping procedure from economic development region to river basin, an additional assumption is made. It is assumed that projected growth occurs evenly over the entire region (i.e., that a county's share of regional activity for each sector remains the same over the period of projection). For electric power, where projections were made on a plant-by-plant basis, and for irrigation, where county-level projections were made originally, this assumption is not necessary.

Findings

1. 1976 Withdrawal and Consumption

Figure 13 represents 1976 withdrawals by major use and by Economic Development Region, and illustrates 1976 consumption by the same categories.

In 1976, nearly 1.4 trillion gallons of water were withdrawn from Minnesota's streams, lakes, and ground-water supplies. This is approximately enough water to supply 4.2 million five-person families for one year. (Even by 1985, Minnesota is expected to have only 1.5 million households). By volume, this is approximately enough water to cover the seven-county metropolitan area to a depth of 2.5 feet. While these comparisons are somewhat unfair because withdrawal data involves "double-counting," it does indicate that Minnesotans use a lot of water.

Of the nearly 1.4 trillion gallons withdrawn in 1976, the largest amount was withdrawn by the electric utility industry (about 740.6 billion gallons, or over 54 percent). This water was used largely for power plant cooling. The mining industry withdrew over 20 percent of the total, or about 278.0 billion gallons. All other withdrawals accounted for less than ten percent of the total each. In descending order, they include: manufacturing, eight percent (110.0 billion gallons); residential, seven percent (95.8 billion gallons); agriculture, six percent (79.8 billion gallons); commercial, three percent (41.4 billion gallons); and other miscellaneous uses, one percent (15.2 billion gallons).

Approximately 178.7 billion gallons of water, or 13 percent of all water withdrawn in 1976, are estimated to be consumed. The distribution of water consumption among major using sectors is considerably different from the withdrawal distribution. Agriculture and mining are the most substantial consumers of water, accounting for 38 percent (67.9 billion gallons) and 34 percent (60.6 billion gallons), respectively. Agriculture, a relatively minor withdrawal of water, is a major consumer, largely because all of the water withdrawn for livestock use and 80 percent of the water withdrawn for irrigation are estimated to be consumed. The electric utility industry is the third largest consumer of water, about 12 percent of the total (22.1 billion gallons). Other consumptive uses are manufacturing (10.1 billion gallons or six percent);

residential (9.6 billion gallons or 5 percent); commercial and institutional (4.1 billion gallons or 2 percent); and miscellaneous uses (4.3 billion gallons or 2 percent).

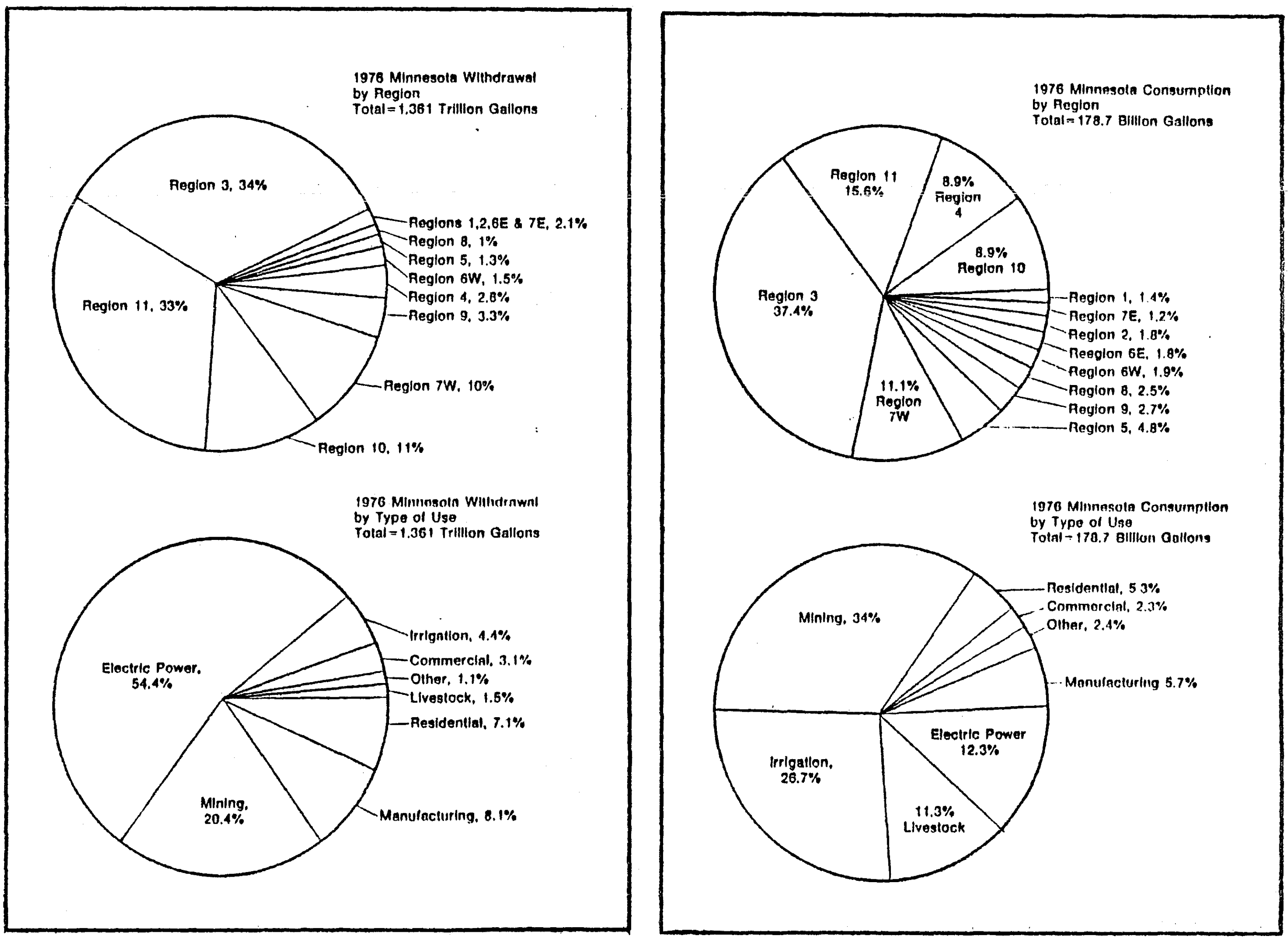


FIGURE 13. 1976 Water withdrawal and consumption.

In 1976, surface waters (i.e., lakes and streams) were the largest sources of withdrawals. Nearly 78 percent of total withdrawals come from surface waters, with withdrawals about equally divided between lakes (41 percent) and streams (36 percent). Surface waters appear as the largest source of withdrawals because they are the primary sources for electric power generation and for mining activities. Ground water provides the source for about 22 percent of withdrawals.

When individual sources are examined, however, ground-water appropriations appear as more significant. For example, 63 percent of the water appropriated by waterworks in 1976 came from wells, with the reamining 37 percent evenly distributed between lakes and streams. Nearly 91 percent of the water appropriated for agricultural irrigation came from ground-water sources.

In 1976, Region 3 (the Arrowhead region) made the greatest withdrawals of water, 465.1 billion gallons (34 percent of the state total). Region 11 (the Metropolitan region) followed closely, with nearly 33 percent of total state withdrawals (or 444.2 billion gallons). Region 10 (southeastern Minnesota) and Region 7W (central Minnesota) accounted for 11 and 10 percent of withdrawals, respectively. The other nine regions withdrew the remaining 12 percent. A concentration of iron mining activity combined with electric power generation result in the high water withdrawal in Region 3. Electric power, combined with a high concentration of residential, commercial, and manufacturing activity cause water withdrawals to be high in Region 11. Water withdrawals in regions 7W and 10 are also dominated by electric power generation.

The same four regions, along with Region 4 (the Lower Red River Valley), dominate consumptive use. Region 3, largely because of its concentration of mining which is water-consumptive, accounts for over thirty-seven percent of water consumed in the state. Region 11 accounts for over 15 percent, while Regions 4, 7W, and 10 consume on the order of 10 percent each. The remaining eight regions account for 18 percent of the total. The share of consumptive use in these regions is larger because of the dominance of the highly-consumptive agricultural sectors.

It is important to note that, because of the uneven distribution of water resources across the state, a high consumptive use in a water-rich area such as Region 3 may be less of a concern than a relatively low consumptive use in the drier western areas of the state.

As might be expected, the Upper Mississippi (36 percent), Lake Superior (27 percent) and Lower Mississippi (18 percent) basins have the highest water withdrawals. They are followed by the St. Croix (eight percent), the Minnesota (six percent) and the Red (three percent). Four river basins (the Rainy, Cedar, Des Moines, and Missouri) account for the remaining two percent of withdrawal use. Water distribution among the Lower Mississippi, St. Croix and Minnesota basins is somewhat distorted due to the county-line watershed approximation. Specifically: (1) the NSP "Black Dog" electric generating plant on the Minnesota River at Burnsville is assigned to the Lower Mississippi basin because of its Dakota County location and (2) all of Washington County is assigned to the St. Croix River basin, while a portion of its residential, commercial and manufacturing activity is actually part of the Upper Mississippi Basin.

In consumptive use, the Upper Mississippi and Lake Superior basins predominate, with 34 percent and 30 percent of total use, respectively. These are followed by the Lower Mississippi (14 percent), Minnesota (10 percent), and Red River (7 percent) basins. The other five basins account for the remaining five percent of consumptive use. The prevalence of agricultural activity is responsible for the increased share of consumptive use by the Des Moines, Missouri, Cedar, Rainy, and St. Croix basins.

2. Estimated Future Demand

Figure 14 illustrates 1990 shares of water withdrawal and consumption, by major user and by Economic Development Region.

As described above, estimates of future demand were developed under a "baseline" and a "conservation" scenario. The "baseline" estimates are discussed first.

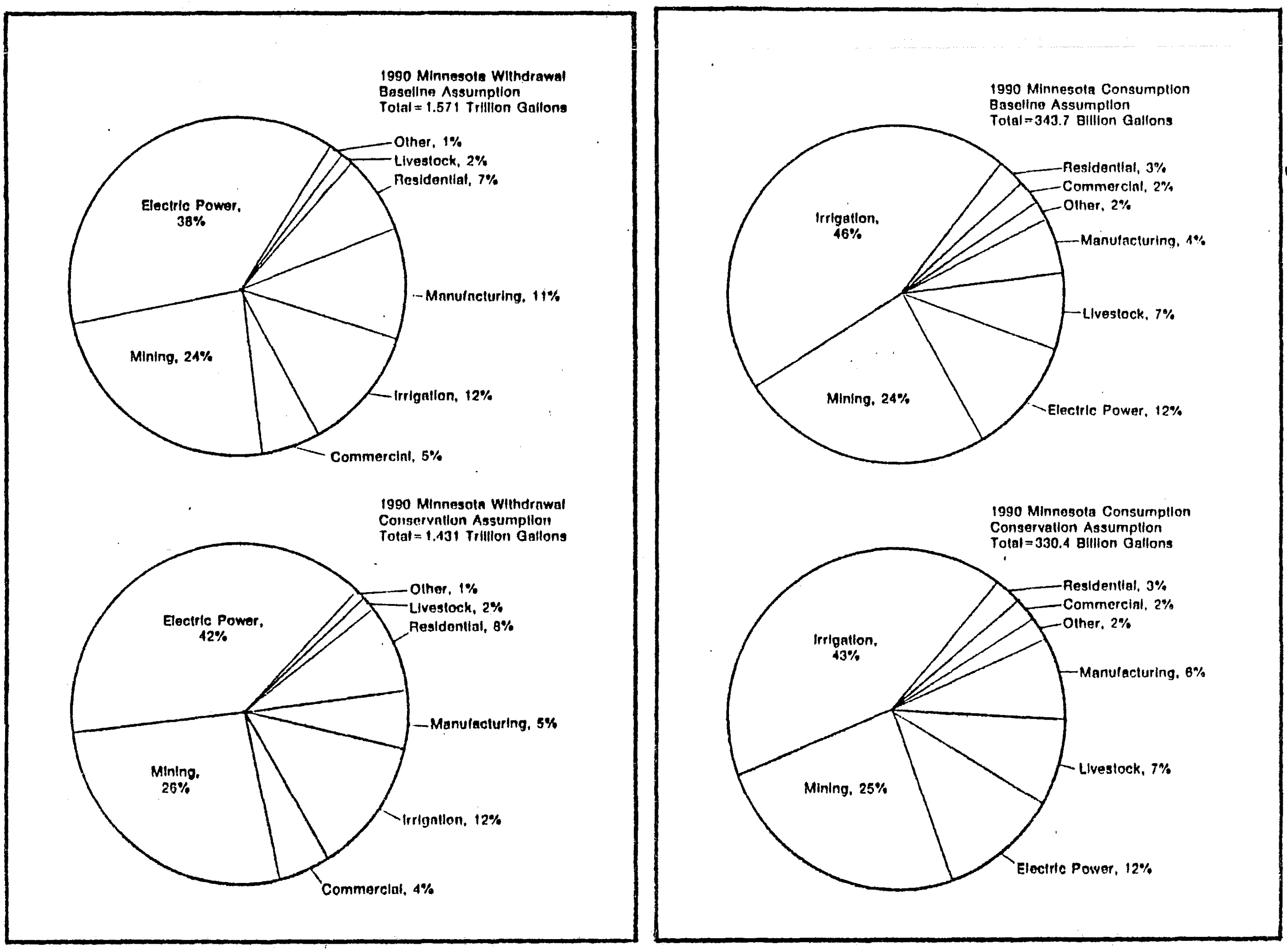


FIGURE 14. 1990 Water withdrawal andconsumption.

According to State Planning Agency projections, population over the period 1975-2000 is expected to grow at 0.68 percent annually, while the household formation growth rate is expected to be 1.32 percent per year (Office of the State Demographer, 1975). Since the baseline scenario assumes constant water coefficients for the mining, manufacturing, and commercial sectors, the increases in water use by those sectors reflect increases in employment, modified only by increases in labor productivity growth. With the exception of electric power, consumptive use growth rates under the baseline assumption are the same as those for withdrawal.

On a statewide basis, under the "baseline" assumption, irrigation withdrawals reflect the highest average annual growth rate of any sector -- over eight percent annually to 1990 (the annual growth rate from 1976 to 2000 will be over five percent, implying that irrigation growth will taper off). The commercial-institutional sector, at almost 5 percent annually, is also growing rapidly.

Over the period 1976-2000, mining is expected to experience an annual growth rate of about two percent, while manufacturing as a whole will grow at about three percent. The pulp and paper, machinery, chemicals, and residentiary industries will grow more rapidly then the overall manufacturing rate (an average of three to four percent), while the lumber and food sectors will grow more slowly (about two percent per year). Livestock water requirements will grow at about 1 1/2 percent annually. Since no water efficiencies are assumed, this reflects expected production increases within the industry. Statewide residential water use in increasing at about 1.4 percent, roughly in line with the household formation rate projected by the State Demographer.

Water withdrawal for electric power generation exhibits a decrease comparable to a 1.6 percent decline annually. This is due to the installation of wet cooling towers on all new facilities, which increases water recycling and reduces withdrawals. Overall, state water withdrawals are expected to increase at slightly more than one percent per year.

By 1990, water withdrawals under the "baseline" scenario are expected to increase from 1.36 trillion gallons to 1.57 trillion gallons, or approximately 15 percent. Consumption under the same scenario is expected to increase by nearly 92 percent, from 179 billion gallons to 344 billion gallons.

The large increase in consumption relative to withdrawals results principally from changes in two sectors. First, irrigation -- which is highly consumptive -- is expected to be the most rapidly increasing water-withdrawing sector. Second, electric power production withdrawals are expected to decline, while related consumptive use will increase markedly, due to changes in cooling technology. Because of their magnitude, the decline in electric power withdrawals masks increases in withdrawals occurring in other sectors.

In relative terms, it is estimated that electric power's share of total state withdrawals will decrease, from 54 percent in 1976 (740.6 billion gallons) to 38 percent in 1990 (593.1 billion gallons). Irrigation is expected to account for a significantly larger share of withdrawals, from over 4 percent in 1976 (59.7 billion gallons) to 12 percent in 1990 (196.7 billion gallons). Mining withdrawals are expected to increase from 278 billion gallons in 1976 to 376 billion gallons in 1990, but its overall share of the state total will not increase markedly (from 20.4 percent in 1976 to 24 percent in 1990).

Manufacturing water withdrawals will increase, from 8 percent of state totals in 1976 (110 billion gallons) to 11 percent in 1990 (168 billion gallons). Other uses of the state's water supply are estimated to retain about their same share of total withdrawals.

While mining accounted for 34 percent of statewide water consumption in 1976 (60.6 billion gallons), its share drops to about 25 percent in 1990 (82.1 billion gallons). Irrigation in 1990 accounts for a much larger share of total consumption (157.3 billion gallons or 43 percent, compared with 47.7 billion gallons or 27 percent, in 1976). Although electric power consumptive use increases from 22.1 billion gallons to 40 billion gallons, its share of statewide consumption remains at about 12 percent. Other sectors retain approximately the same share of statewide consumptive use.

Under the conservation assumptions, manufacturing and commercial withdrawals decrease as pollution control regulations mandate increased recycling of water. Irrigation withdrawals decrease, relative to the baseline estimate for 1990, as improved management techniques increase the efficiency of irrigation practices. Price effects cause residential water withdrawal to decrease slightly.

More specifically:

- ** Irrigation withdrawals are held to about 177.0 billion gallons in 1990, rather than 196.7 billion gallons under the baseline scenario.
- ** Manufacturing withdrawals are estimated at 75.4 billion gallons, compared to 168.5 billion gallons without conservation measures.
- ** Estimated commercial-institutional withdrawals decrease from 80.4 billion gallons in the baseline scenario to 58.7 billion gallons in the conservation estimate.

Mining and electric power generation do not vary between the scenarios. Consequently, they claim a higher percentage of total withdrawals under the conservation scenario.

The "conservation scenario" developed for the state does suggest that the implementation of conservation options would dampen the growth in water withdrawals and consumption in the state. The "conservation scenario" suggests the withdrawal of 140 billion (9 percent) fewer gallons of water in 1990 than under the "baseline scenario" and the consumption of 13 billion (4 percent) fewer gallons. Under the "conservation" scenario for 1990, withdrawals might be held to about a 5 percent increase over 1976 levels. Consumption under the same scenario would increase by 85 percent.

Electric power production and mining accounted for 75 percent of all water withdrawn in Minnesota in 1976, and for an estimated 46 percent of consumption. Because of the magnitude of these uses, further study and analysis is required before the impact of their potential future use can be understood.

Current mining consumptive use estimates are still subject to further verification. Production in this sector is subject to national and world markets; historically, production has fluctuated markedly from year to year; this makes projection very difficult. In addition, the water use impacts of future copper-nickel need to be studied and incorproated into these projections.

Electric power water use estimates are based upon utility siting and sizing projections as of April 1, 1979, subject to state projections of future energy demand. Utility construction plans over the last several years have been characterized by delays, postponements, site changes, and withdrawal from the state permitting processes. Given the magnitude of power plant water use, any change in the projected size, location, or in-service date of plants (or, for instance, a trend toward more smaller plants, located near load centers and possibly tied in with district heating systems) would drastically alter the distribution of power plant water use. Therefore, estimates of water use for electric power production, especially on a regional basis, are subject to considerable fluctuation over time. Regional water use projections would change accordingly.

Special Water Uses

Irrigation

Irrigation has emerged as a special water use concern in Minnesota. The general data cited above suggest why this is true. Because it is a special concern, it is addressed in greater depth in this section of the report.

1. History

When and where sprinkler irrigation first occurred in Minnesota is unknown. Historical records show that in 1905 Minnesota was a participant in the Twelfth National Irrigation Conference. However, conference proceedings neither describe irrigation in Minnesota nor estimate affected acreage.

It is known that by the early 1920's sprinkler irrigation had taken hold in the Twin Cities area for fruit and vegetable growing and in the Red River Valley for sugar beet production. By the late 1930's, a survey indicated approximately 1,000 acres irrigated in the state. Interest in the 1930's may have been spurred by the historic drought of the period. Through the 1940's, only about 1,500 acres were estimated to be irrigated in Minnesota, with any thoughts of expanding irrigation limited by the lack of materials for distribution systems during the war years. After the war years, expansion began to occur. By the early 1960's, some 20,000 acres were reported irrigated. As shown in Table 4, expansion accelerated through the 1970's to a point where irrigated acreage is estimated to be doubling almost every two years. (Recent experiences have been spurred by the drought conditions of the mid-1970's and likely will not hold at such a rapid pace.)

TABLE 4

Sprinkler irrigated acreage in Minnesota 1970-1977

YEAR	ACREAGE	% INCREASE FROM PREVIOUS YEAR
1970[1]	44,379	--
1971	55,466	25
1972	64,338	16
1973	86,156	34
1974	111,233	29
1975	174,094	57
1976[2]	221,521	27
1977[3]	276,900	25

[1]Surveys conducted by field staff for the University of Minnesota Agricultural Extension Service.

[2]Estimate taken from Department of Natural Resources water appropriation files by the University of Minnesota Agricultural Extension Service.

[3]Estimate taken from a field survey conducted by the Minnesota Department of Agriculture. Estimates taken from DNR permit files approach 387,000 irrigated acres.

It is also important to note that the practical history of irrigation in Minnesota differs from that of many other states. Sprinkler irrigation dominates the type of water application in Minnesota. Many other areas of the country have large amounts of surface irrigation, in which loss of water due to seepage is a major problem. This form of irrigation is generally used for wild rice in Minnesota.

In addition, sprinkler irrigation has developed in Minnesota predominantly in those areas with sandy, well-drained soils and gently rolling topography. Surficial aquifers predominate in these areas. As a result, most irrigation in Minnesota is not accomplished from buried bedrock aquifers, as in many other states (e.g., Nebraska or Texas). Surficial aquifers are more readily recharged and less subject to being "mined".

2. Development and Management

Irrigation has developed in Minnesota to meet three important needs: (1) supplementation of occasionally sporadic precipitation, (2) protection of crops from unexpected, long-term drought, and (3) increased production on less fertile lands.

To regulate development the Legislature has adopted a water appropriation permit program in Minnesota Statutes, Chapter 105. Power for permit issuance is delegated to the Commissioner of Natural Resources (Minn. Stat. 105.39, Subd. 1). The program originated in the 1930's. Until 1976, agricultural irrigation received first priority in case of rationing in the state. The 1976 state legislature altered priority ratings giving irrigation 3rd priority. The permitting authority also discourages use of surface water suppliers for irrigation so that the vast majority of irrigators obtain ground water from either shallow sand and gravel aquifers or deep, bedrock wells. The allowable volume to be withdrawn is determined by the numbers of acres to be irrigated, soil type, climatic area and crop grown.

3. Water Use for Irrigation

Current irrigation water use has been approximated for the entire state through the 1977 growing season. Substantial public and legislative interest in agricultural irrigation led the Water Planning Board, through the Department of Agriculture, to examine and assess irrigation development. This assessment made limitations of the existing data base apparent. Department of Natural Resources water appropriation files as one source of data have been determined as indicative of public interest in irrigation and the state's commitment to it. The files are not indicative of actual, on-going irrigation. Reliable, annual, field-checked surveys with readily accessible results simply do not exist in the state. Most statewide surveys have been obtained through cooperation with county personnel, which provides widely variable responses. Results heretofore have not been verified in the field.

Based on the State Department of Agriculture data for 1977 (including information on the type of crop irrigated), supplemented by University of Minnesota estimates of acres irrigated in 11 counties for which the Department of Agriculture did not receive survey reports, it is estimated that about 77.1 billion gallons of water were used in Minnesota for agricultural irrigation. The Upper Mississippi basin is estimated to be the largest appropriator of water for agricultural irrigation based on the 1977 survey, using nearly 36.6 billion gallons (or 42 percent of the state total). This represents a 56 percent increase in water used for irrigation in this basin between 1975 and 1977, based on Department of Agriculture estimates. Similarly, pumpage estimates for the:

** Minnesota River basin increased from 9.5 billion gallons in 1975 to over 17.3 billion gallons in 1977, an 82-percent increase.

- ** Red River basin increased to nearly 13.3 billion gallons in 1977 from 8.2 billion gallons in 1975, a 61-percent increase.

- ** Lower Mississippi basin increased to 4.7 billion gallons in 1977 from 4.0 billion gallons in 1975, a 15-percent increase.

- ** The Metropolitan area as a whole increased only slightly, from 5.9 billion gallons in 1975 to 6.0 billion gallons in 1977.

The numerous problems associated with existing irrigation data and the tenuous nature of the resultant estimates have led to the examination of alternatives for obtaining the necessary information. The central problems being addressed include (1) a method of accurately determining the number of acres irrigated in a given season and (2) an approach to an annual updating of the irrigation data base. Options include remote sensing, local reconnaissance, annual records review, and special surveys (or a combination of the above).

4. Future Irrigated Acreage and Water Use

Potential future water use for irrigation was presented in the preceding sections. While all such forecasts are, at best, educated guesses, they do tend to show potential future directions.

To arrive at these estimates, estimates were made of potential future irrigated acreage. These estimates have attempted to consider economic, climatic, water quality, and water supply factors, as well as historic trends and locally-estimated future trends. While all estimates of future irrigated acreage are particularly sensitive to economic and climatic factors, the estimates of future irrigated acreage suggest that total acreage could exceed 850,000 acres by 1990.

5. Environmental Considerations

While the above discussion was focused on the concern for the effects of irrigation growth on water supplies, the potential impacts of continued irrigation growth on water quality must also be considered.

Sprinkler irrigation can have a substantial impact on the immediately affected environment and a lesser but important impact on the environment down-hill or downstream from the irrigated field. Prevention of negative impacts can be achieved by careful scheduling and monitoring of irrigation in the field.

Water quality is altered by irrigation as a result of run-off, infiltration and deep percolation. Run-off occurs because the irrigation application rate exceeds the soil intake rate. Water applied on sandy soil quickly infiltrates through top soil, percolating downward to fill the soil profile. Greatest irrigation efficiency is achieved when the rate of infiltration keeps the root zone adequately moist for crop needs. When the soil profile is saturated, additional moisture which cannot infiltrate runs off the surface.

Run-off carries sediment which has been described as the most serious surface water pollutant. Pesticides, herbicides and fertilizers are especially necessary to irrigation farming and are often applied concurrently with irrigation. These compounds accompany sediment as it leaves the irrigated fields as run-off.

Ground water quality is affected by deep percolation of irrigation water leaching nutrients through the soil profile, into shallow sand and gravel aquifers. Preliminary aquifer monitoring has shown that, under certain environmental conditions, nitrogen and sulphur compounds can be traced from field application to the aquifer within a matter of days. The aquifer polluted may well be the water source supplying irrigation and/or domestic uses.

Sedimentation, as discussed earlier, implies soil erosion. If the irrigation application rate exceeds the soil intake rate, stagnant water gathers in flat areas and erosion occurs in grades. Water erosion in particular can damage standing vegetation, create tilling problems and in the long run, diminish soil fertility by reducing topsoil depth. Both erosion and soil compaction are problems associated with the alley ways created by center pivot flotation tires and travelling guns.

Soil quality is susceptible to change due to irrigation as a result of run-off, deep percolation and evaporation. Run-off depletes fertility by horizontal removal of nutrients. Deep percolation of water leaches soil nutrients, both existing and applied, downward through the soil profile and potentially into local, underground water sources. Evaporation of water can lead to salinization of soil if the water applied is saline and evaporation is more prevalent than run-off or infiltration. Such fertility losses can lead to higher operating costs as nutrients are replaced by fertilizer applications. Additional nutrients may in turn be leached or otherwise lost, feeding the cycle of pollution.

Wind erosion is increasingly becoming a problem as more center-pivots are employed. Wind breaks and shelter belts historically have been planted for square fields. Center pivots traverse fields in a circular pattern, requiring removal of all vegetation taller than the pivot towers. Research has identified vegetation and planting patterns amenable to center-pivot operations. Loss of protection from wind can lead to vegetation damage and loss which increases soil exposure to wind and susceptibility to water erosion.

6. Irrigation Conclusions and Considerations

Projections suggest continued development of irrigation over the next decade, although the actual rate of growth is dependent on a number of factors. While such growth will place an additional stress on the state's water resources (especially on surrounding wells in localized areas), it would also be expected to benefit the economies of regions of the state. For example, for a 14-county area in western Minnesota, Maki et al., have suggested that the total increase (1970-1985) due to irrigation development could be in the area of $235 million for industry gross output, $106 million for gross regional product, and $5,000 for total employment. Growth of irrigation, however, might also impose environmental damages (e.g., nitrate contamination of ground waters or increased soil erosion).

The State of Minnesota requires that water resources be managed to "serve a material beneficial public purpose" and has adopted a priorities system for allocation of water resources. In practice, this has resulted in case by case decision-making. It has been argued that an explicit irrigation policy for Minnesota is essential.

Several options are available:

** Continuation of the present case-by-case decision-making system. The 1977 Legislature took a number of steps to strengthen this system, including pumping test requirements in most areas of the state and increased involvement of local bodies in the decision process. However, decisions continue to focus primarily on the resource capability at a given point in time.

** Continuation of case-by-case decisions, but within a framework of mandated considerations. The 1977 Legislature adopted the concept of placing conditions on permit issuance which go beyond resource capability. Specifically, the Department of Natural Resources cannot (unless the requirement is waived for just cause) issue a permit for irrigation appropriation from ground water where adequate soil and water conservation measures are not in place. Such conditions might be expanded to consider soil types, withdrawal impacts on future economic development of a region, and potential for ground water contamination.

** Limitation of future irrigation development to areas determined to be suitable for such development. Under this option, the state would be required to define areas in the state where irrigation development may be encouraged and areas in which irrigation permits will not be granted. Irrigation permits would be issued only in the former areas, based on resource capability within those areas. Information to make such determinations is severely limited at the present time.

Further, the State of Minnesota must consider the level of support it should provide to developing information for further irrigation policy-making. The Water Planning Board has found available information on present irrigation location, ground-water supplies, reported pumpage, soil type-ground water relationships, and environmental impacts of irrigation to be severely limited. The Board has, however, identified several future approaches (e.g., use of remote sensing data and detailed area studies) which may benefit the state.

In the immediate future, availability of information is a principal criterion in selecting among these options. In the long-run, this may become a lesser consideration. In addition (1) administrative complexity, (2) economic development impacts, and (3) individual equity should be considered in selecting among the available options.

Rural Water Supply Systems

Rural water supply systems are generating increased interest in the State of Minnesota. Such systems have many and varying costs and benefits associated with their development. The main purposes of Technical Paper #4, "Rural Water Supply Systems," are: To serve as an informational document on the planning and design, enabling legislation, and financing of rural water systems in Minnesota; to examine the existing forms of legislation, administration, and financing and to analyze their strengths and weaknesses; and to make recommendations on the establishment of rural water systems to insure their appropriateness to specific areas of the state.

A rural water supply system is a type of public water supply system which provides central water treatment and delivery of potable water through water mains. The primary difference between the traditional municipal supply system and a rural water supply system is that the latter will run hundreds of miles of plastic pipeline in order to supply widely dispersed users. A rural area would consider the installation of a water supply system when individual supplies, largely private wells, cannot provide water of sufficient quantity or adequate quality.

Rural water systems are appropriate only in limited areas of the state, but when they are developed, they have the potential for significant land use impacts. System development can lead to rapid and irregular population growth. It can contribute to urban sprawl, and a condition where a town or other municipality grows outward to meet a rural water system. System development can lead to land inflation and speculation. Importantly, rural water supply system development does not necessarily lead to these results and can be a highly positive rejuvenation of an area.

Within the wide range of potential impacts of rural water system development are such social and economic concerns as human health, livestock production, population growth, water consumption, and waste water management. Therefore, particularly in terms of land use considerations, a rural water system is a potentially powerful mechanism for a region and can serve as the catalyst for a wide range of development.

The stimulus provided by a system may be seen in terms of benefits and adverse effects. Positive economic indicators include improvements in livestock and milk production, increases in property value and tax revenue, and expenditures on appliances, home improvements, and home construction. Many rural water districts in other states have experienced population growth and expansion of the area of service districts. However, system development has also coincided with the loss of prime agricultural land, urban sprawl, duplication of urban and rural water service, and inflated land prices.

In June 1978, there were two operating rural water supply systems in Minnesota, the Marshall-Polk and Kittson-Marshall systems; two were scheduled to begin construction, the North Kittson and Rock County systems; and one in the initial organization phase, the Lincoln-Pipestone system. In addition, ground-water studies in southeastern Minnesota have discussed the potential of rural water systems to alleviate problems in achieving a good water quality supply where individual domestic wells encounter quality problems.

To deal with the issue of what actions are necessary to balance the beneficial and adverse effects of rural water system development in Minnesota, three factors must be considered: (1) legislation, (2) administration, and (3) financing.

** Legislation. Rural water systems may now be formed under provisions of M.S. 116A or M.S. 110A. Options in the legislative arena are: (1) maintenance of the two statute system, (2) selection of one statute over the other, or (3) adoption of a new statute combining the best aspects of both laws, along with new considerations. Central concerns in legislation should include clarification of the organization of systems, obligations and responsibilities of district courts or county boards, boundaries, powers and obligations, and methods of financing.

** Administration and Financing. The overall role of the state in rural water system development has not been defined. Although there are two pieces of legislation concerning the organization, rights, and obligations of rural water systems, the legislation is passive in its position on the state's role in rural water delivery systems. While the Department of Health must authorize all system design and structure and the Department of Natural Resources is responsible for water appropriation permits, there has been little recognition by state government of the potential significance of these systems on the development of water-poor areas of the state.

The range of options for a state role in rural water system development includes (1) maintenance of the current posture of the state, (2) assumption by the state of planning responsibilities for rural water systems, (3) the state as "coordinator" in system development, and (4) the state as organizer and developer of rural water supply systems.

If the state maintains its current posture, the state role will only continue to involve appropriation permits and approval of facility designs. Assumption of planning responsibilities could encompass loans to proposed systems for their planning requirements or in-kind assistance in planning (e.g., aid in drafting preliminary and for final system plans, feasibility studies, needs assessments, engineering plans, ground-water surveys, or land use surveys). Adoption of a "coordinative" approach might include coordination of financial sources, informing projects of government requirements, and assisting projects in dealing with the judicial and regulatory structure. Finally, as an organizer and developer the state could become fully involved in the financial, engineering, and legal aspects of system implementation.

Conclusions and Recommendations

Several conclusions and recommendations may be drawn from this chapter. They are briefly outlined in the following paragraphs.

1. Water Use and Demand Forecasting. The State of Minnesota should continue to develop annual water use estimates and improve and update water demand forecasts. Use estimates and forecasts are potentially powerful planning and management tools. More specifically:

    ** The water-use data base developed by the DNR Water Policy Planning Project should be maintained and improved by the DNR Division of Waters. In conjunction with the state coordinating body, the DNR Division of Waters shall update estimates of withdrawals by unpermitted and non-reporting users and statewide and regional water use projections.

    ** Efforts should be undertaken (through the Water Planning Board or its successor) to improve water consumption coefficients, making them closely applicable to Minnesota industrial, commercial, and residential uses.

2. Irrigation. While the Board recognizes the need for an explicit state strategy for future irrigation development in the State of Minnesota, it acknowledges the limitations of available data to make such decisions. Therefore, the Board recommends that Minnesota continue case-by-case decision-making but within a framework of mandated considerations (e.g., soil types topography, economic impacts, and potential for ground-water contamination). For the longer term, the Board recommends an interagency study group (including the Department of Agriculture and Natural Resources and the Pollution Control and State Planning Agencies) be charged with the responsibility to develop data and analyses sufficient to detail areas where irrigation development should be encouraged and where such development should be discouraged.

3. Rural Water Supply System Development. It is recommended that (1) M.S. 116A and M.S. 110A be replaced by a single new piece of legislation which draws on the important parts of existing law and specifically resolves concerns relating to petitions for organization, obligation, and responsibilities of district courts or county boards, boundaries, boards of directors, powers and obligations, and assessments versus user charges and (2) the Minnesota Department of Health take on an expanded role as "Coordinator" of system development.

ALLOCATION OF AVAILABLE RESOURCES

The planning goal adopted by the Water Planning Board is "to outline alternatives to maximize the benefits of available water supplies at the present and in the future." Two of the steps to be taken in meeting this goal are (1) development of an assessment of the present and future water supplies and needs of the state and (2) preparation of a system for equitably allocating resources in situations where supplies appear in danger of becoming inadequate to meet demands. These two steps are closely related.

The purpose of this chapter is to compare estimates of available supplies with present and future water resource withdrawal and consumption demand; to assess the economic implications of water shortages; and to discuss means of distributing finite water resources in an efficient and equitable manner during shortage situations.

Supply, Demand, and Potential Conflicts

The goal recommended for the State of Minnesota by the Water Planning Board with regard to the state's water resources is:

> To efficiently employ the water resources of the state to assure maintenance of a supply and quality, from surface and/or ground-water sources, which is adequate to meet seasonal long-range requirements for domestic, municipal, industrial, agricultural, power, recreation, navigation, wildlife, and aquatic ecosystem needs.

As a first step in developing the evaluation required for decisions on the efficient use of the state's water resources, the Board instituted projects to estimate water supply and use in Minnesota. The results of these projects are described in the previous chapters. While the results do not approach the level of detail the State of Minnesota should require in the long run, they may be used for a general (i.e., regional level) assessment of supply, demand and potential conflicts.

In brief review, supply information came from two sources: (1) estimates of ground-water availability made by the Minnesota Geological Survey for the Water Planning Board and (2) estimates of surface-water availability adapted for this project from United States Geological Survey average monthly and average annual flow data (compiled by DNR-Water Policy Planning staff for the Board).

Annual ground-water recharge rates were used as an indicator of ground-water resources. Ground-water reserves (i.e., the total amount of water in the ground-water reservoir) were not estimated. Thus the estimates of potential groundwater supply reflect quantities which can be extracted without "mining" the resource. Surface-water availability was determined for two conditions: (1) the normal, or average condition, based upon the streamflow for the period of record (10 years to 75 years, depending on the gaging station) and (2) the low-flow, or drought condition, represented by 1976 streamflow records. Estimates of ground- and surface-water availability were developed for each of the 39 watershed units in the state.

Water use for 1976 for each of the 39 watershed units in the state was extracted from the APPROP data base. Because of the unavailability of economic data below this level, water use projections were made only at the 10-major-river-basin level. Projected water use was not broken down by source. The APPROP data base, 1976 water controls and 1990 forecasts are discussed in a previous chapter. Both withdrawal and consumption use estimates were used in the comparison.

A ten-watershed level analysis, as used in the forecasts, can provide only a gross comparison of supply and demand, since water supply problems may be quite localized. This level was used only because sufficiently detailed economic information was not available. It was anticipated that the 39-watershed level watershed comparison for 1976, along with the 1990 10-watershed comparison, supplemented by the sector growth rate information provided in the forecasts, would be sufficient to identify some problem areas.

The preliminary analysis indicated that for the base year 1976 at the 39-watershed level, there were no widespread, severe ground-water shortages. Most ground-water problems which were reported were of localized and are due to too much concentrated use or a lack of ground water at a specific demand site. Assuming that the 1990 breakdown is the same as that for 1976 (although no source breakdown is made in the forecasts) the same seems to be the case for 1990 water use.

Surface-water availability and use conflicts do appear to be problems in several parts of the state. The predominant problem is that during periods of low streamflow there may not be enough water to meet demands. This situation is prevalent in many of the sub-basins of the western part of the state. Other problems are that users may be too concentrated or too near the headwaters of a sub-basin to allow sufficient flows to meet the demands of users downstream, particularly if substantial increases in water use occur in the basins. Assumptions of "protected flow" for streams were made at two levels -- 10 percent and 30 percent. Under drought conditions such as those of 1976, some western river basins could not maintain at either protected flow level in many streams.

There are two problems with this preliminary supply/demand comparison. First, the forecast is too "global" in nature: the demand region is still too large to pinpoint problem areas, and no distinction is made between ground-water and surface-water sources. While 1976 data was available at the 39-watershed level by type of water source, it was not possible to produce forecasts at this level of detail. Second, supply and use data compiled was annual. Since one-third to one-half of streamflow can occur in the spring, and since water demand is not necessarily evenly distributed throughout the year, a monthly supply/demand analysis could identify many more shortage areas.

A follow-up effort was undertaken to further specify the data for a "Target Area" -- comprising 5 of the 39-watershed level units in the Minnesota River basin. For this region, detailed economic data were developed in order to estimate future water use at this level. Although the monthly demand analysis is not yet complete, that process has already indicated more potential water shortage areas in the year 1990.

The supply/use analysis has indicated that, at the 10-major basin level, overall water supplies seem to be available to meet expected demands. The absence of major regionwide conflicts does not lead to the conclusion that Minnesota need not be concerned with water resource allocation questions. Localized problems are occurring and will continue to arise. Both seasonal and annual variations in precipitation may lead to supply shortfalls relative to demand in regions of the state. Finally, the possibility of long-term water shortages in areas of the state cannot be ruled out.

Allocation of Water Resources

The term "allocation" with regard to any resource refers to the way in which that resource is "distributed" among uses. Depending on the focus of the discussion, "allocation" may refer to distribution in a single time period or over several time periods. With specific reference to water, concern over allocation arises in the context of water shortages, well-interference problems, and the distribution of water by utilities.

The concept of a "water shortage" is both an economic one and a political one. By definition, a water shortage exists in an area when the consumptive and non-withdrawal demands for water relative to available supplies are such that the real costs of obtaining and/or using water become unacceptable to the public. Further, a distinction should be drawn between a "water shortage" and "drought." In this report, a "drought" is defined as a prolonged absence of precipitation which results in a "water shortage" for an area.

The basic problem of water shortages is that as consumption and non-withdrawal demands upon a water source increase, the real costs of using water in (and/or from) that source begins to rise. These costs may take the form of increased pumping costs for obtaining ground water, increased costs for the treatment of intake water as the concentration of pollutants and of dissolved and suspended substances from natural sources and water rises, inconvenience to swimmers as water becomes murkier and more polluted, higher electricity rates if power production must be curtailed and electricity imported because of insufficient flows in a river, and so on. Alternatively, a drought may cause a reduction in the supply of water which can also cause the real costs of using water to rise. A special case is that in which the cost of obtaining or using water for an activity is so prohibitive that for all practical purposes, the water is unavailable. This would be the circumstance for a farm whose well has run dry during a drought. Theoretically, the farmer could pay to have water hauled in, but the cost of doing so may rule out this alternative.

In fact, there is always some cost for using water. This cost will rise as the demand for water from a given source increases or as the available supply of water decreases. How then do we decide when there is a water shortage? The answer to this question depends on what the public perceives and is willing to accept. If only a few individuals in an area are inconvenienced, no widespread problem of water shortages will be seen to exist. On the other hand, if many individuals have noticed unacceptable costs of obtaining or using water, a general water shortage will be seen to exist by the public at large.

The use of the word "real" in the phrase "real costs" in the definition of water shortages, is intended to distinguish a general rise in the types of costs discussed in the previous paragraphs from situations in which the cost of using water shifts among groups of users. An example of the latter situation is one in which users of heretofore underpriced municipal water receive an increase in their water rates. The water may have previously been underpriced because the water works were subsidized with local tax revenues or because of hidden costs of municipal water use, such as reduced or terminated yields in other (non-municipal) wells, which have been imposed on non-municipal users. There may be no change in the availability of water or in the overall use of water from the ground-water source which precipitates the rate increase, and, in general, there may be ample availability of water in the area. What happens is that there is a redistribution in the costs of using water, but not an overall rise in the real costs as required by the definition.

Water shortages are characterized by time and space dimensions. They may be restricted to a particular region of the state, or they may occur in several regions simultaneously as during the drought of 1976. They may be brought about by seasonal dry weather conditions or by occasional (or periodic) droughts. They may be of limited duration or they may last for several seasons. Or, they may become a chronic condition brought about by increasing demands upon the water resources of an area due to population growth and industrial (including agricultural) development. One effect of increasing demands over time is to make the consequences of droughts and seasonal dry periods more severe.

The real costs of water shortages are to a great extent determined by the degree to which water demands are over-extended in relation to the timing and spacing of precipitation. Critical water shortages represent a complex interaction between the natural variations in moisture availability and the particular resource utilization demands of human systems on variable supplies of water. The severity of a water shortage depends upon the degree to which human water demands exceed the long-run availability of moisture and man's ability to adapt institutions and technologies to these conditions.

Specific Water Shortage Problems and Economic Impacts

The public's perceptions of water shortages are based on specific problems which exist or can potentially exist in the State of Minnesota. Among these are the following:

** Low flow in rivers and streams resulting in: (a) higher concentrations of pollutants and of suspended and dissolved substances of natural origin in the water, thereby increasing the costs of treating water for withdrawal purposes, interfering with recreational use of the water, and spoiling wildlife habitat; (b) increased competition for available water among withdrawal and non-withdrawal uses; (c) threats to wildlife and wildlife habitat due to insufficient river or stream flows; (d) possible limitations on the navigational use of rivers; (e) conflicts between users of river and stream water and recreational and other uses on reservoir lakes; (f) increased costs of waste treatment facilities in order to meet more stringent effluent standards; and (g) reduced recharge to ground-water supplies, thereby affecting ground-water users.

** Lower lake levels resulting in the depreciated value of lakes for recreational and other purposes because of: (a) deteriorating water quality; (b) more restricted access for boating as the water recedes from the shore; (c) deterioration of the market value of lakeshore properties, especially if there is a trend for the average annual lake level to fall over time; (d) decreased aesthetic value of the lake environment; (e) reduced recharge to groundwater supplies; (f) water temperature changes which could have adverse effects on aquatic life and habitat; and (g) increased turbidity on lakes used to aquatic recreation which could adversely affect recreation and aquatic life and habitat.

** Ground-water problems such as: (a) wells going dry necessitating the expense of deepening existing wells, installing new pumps, adding more sections of drop pipe, digging new wells, or using alternative water sources; (b) increased energy costs of pumping water as water levels fall; (c) the intensification of well-interference problems; (d) reduced discharge of ground water to surface water, thereby affecting surface-water uses; and (e) increased drawdown of lakes through the withdrawal of ground water.

In general, we would expect the economic impacts resulting from these problems to operate through the following channels:

(1) Water shortage problems affect the costs of firms, thereby affecting the output, profits, employment and earnings of each firm.

(2) Each firm and its employees have impacts upon other firms and individuals in the economy through both market and non-market relationships.

(3) Public policies and institutions affect the allocation of and availability of water to firms and individuals and, therefore, affect the impacts discussed in (1) and (2) above.

Water-withdrawing firms may be affected by water-shortage problems through increases in the costs of intake water because: (a) falling ground-water levels could result in increased energy requirements for pumping groundwater and could force firms to invest in lower drop pipes, in new pumps, in deepening their existing wells, or in drilling new wells in order to retain their access to ground water; (b) less water may be available from surface water sources requiring greater reliance on intake water from other sources at higher costs; (c) in extreme circumstances, a firm may not be able to obtain intake water at all; (d) the concentration of pollutants and suspended and dissolved substances of natural origin in a river or lake could increase because of additional competition for water or drought, resulting in a firm withdrawing water incurring costs of upgrading the quality of its intake water, seeking alternative supplies, or make other adjustments.

In response to these initial effects, firms may, in the short run, have the following options at their disposal:

** They may emphasize more heavily those processes (in their operations) which depend less upon water or which produce less effluent wastes. This may involve both product and input substitution since the processes involved will probably use inputs and produce outputs in different proportions.

** They may be able to exercise tighter controls on leaks, wastes, and/or spills. This can reduce withdrawals, consumption, and/or effluent waste concentrations.

** In some circumstances firms may be able to reduce their unit costs by reducing their rates of output.

** In some circumstances firms may be able to raise their prices to at least partially cover the increases in their costs.

** In some circumstances, firms may be able to reduce the prices they pay for raw materials.

** Firms may close down.

** Firms may do nothing.

If water-shortage problems appear to be recurring or chronic, firms may be able to invest in various types of capital equipment, such as new wells, pumps, piping, pollution abatement equipment and/or industrial processes which require less water or which give off fewer pollutants.

New technology could include the more extensive use of water recycling. Water recycling is expected to be widely adopted in industry in response to federal pollution control legislation. However, firms which have adopted extensive recycling to comply with this legislation will have less scope to react to increases in the cost of intake water by conserving water. Such firms may be more vulnerable to the adverse economic effects of water intake cost increases. A firm will make investments in water or waste saving equipment only if the expected present value of alleviating the expected problems plus any other expected benefits are equal to or greater than the costs of the investment required. If this is not the case, the firm will not make the investment. Then the firm may continue to operate at a lower level of earnings or, alternatively, it may shut down.

Responses of individual firms to water problems have economic ramifications upon the rest of the economy through secondary impacts. These impacts occur through forward linkages (those market channels through which products of the affected firm travel) and through backward linkages (those market channels through which the affected firm purchases its supplies of goods and services, through which suppliers of the affected firm obtain their supplies, and so forth).

The magnitude of the economic impacts of a water shortage may to some extent be mitigated with the passage of time or over space. In general, the larger the geographical perspective, the less severe will be the monetary value of economic losses. If, for example, output, employment, and earnings in a particular area decline due to a drought, these losses may at least in part be made up in another area of the state or country where conditions of water availability are relatively more favorable.

The adverse economic effects of a drought may also be mitigated with the passage of time. Reductions in output may be made up by operating at higher rates at a later date. Reduced demand by individuals and firms adversely affected by the water shortage may in part be deferred demand which will be exercised later. The demand for certain products, such as irrigation equipment, pumps, and the services of well drillers are stimulated during water-shortage conditions. Eventually investments in water-saving capital equipment, cooling towers, process-water recycling equipment and the like will stimulate the industries supplying these products, as well as other industries which support them.

The degree to which increased output in alternative times or places and water-shortage-induced investment will offset economic losses in the water-short area will depend upon the availability of unemployed resources (primarily labor) in the alternative times or places. If the increased output draws resources from other activities in the alternative times or places, the offsetting effects will be reduced as input prices are driven up.

Finally, if the output of heavy-water-using sectors decreases in an area, and heavy-water-using firms close down, they may eventually be replaced with new industries seeking to take advantage of idled resources in the area. This would in some respects be a desirable outcome since it would reduce the pressure on water resources in the area while still providing economic benefits.

Efficiency and Distributional Equity

Within the context of specific water storage problems in specific places and in conformity with widely held social and economic goals, efficient allocation of water can minimize economic, environmental, and other costs of water shortage by achieving the maximum benefits from water use given the available supply. An example may make this concept clearer. Suppose it were possible to reallocate water in such a way as to make some groups or individuals better off without making any other group or individual worse off. Clearly, society would be better off if such a reallocation were to take place, provided that the cost of making the reallocation did not exceed the increase in benefits from having made it. Now, suppose the allocation of water were such that no such reallocation could take place. In order words, that it were impossible to make one group or individual better off without making another group or individual worse off. If such an allocation were to be achieved, efficiency will have been reached.

Within the discipline of economic theory it has been shown that water can be most efficiently allocated if water is transferred, or re-allocated, from uses which, in terms of the benefits received by water users and by society as a whole, are low value relative to the costs of using it to uses where the water is high value relative to the costs of using it. Laws, policies and institutions which do not exhibit or which promote such transfers are, from the standpoint of efficiency, more desirable than laws, policies and institutions which inhibit such transfers.

Note that moving toward more efficient allocation could involve the reallocation of water away from industrial uses toward keeping it instream for environmental and recreational purposes. Thus, the concept of efficiency does not necessarily favor activities commonly thought of as "economic" ones.

In practice, there are costs to making such reallocations in the form of the administrative, planning, and material costs necessary to bring it about (the installation of meters, the laying of pipes to transfer water, etc.). The costs of such reallocations must be compared with the benefits of expected increases in efficiency from reallocations in deciding to pursue a particular policy.

In addition, it is not always possible to compensate those from whom water has been reallocated. Sometimes individuals or firms from whom water is allocated are those who had been receiving unjustified subsidies for their water use in the form of real costs of water use imposed upon others. A reallocation of water may involve forcing such individuals or firms to internalize (assume) all of the costs of their water use. Clearly, this makes them worse off. A decision to reallocate water in this way also involves a distribution decision. That is, it is implicitly decided to make these parties worse off by removing their subsidies.

The concept of efficiency relates to the total "package" of benefits received, not to the distribution of these benefits. The concept of distributional equity is concerned with the distribution of these benefits. There may be many alternative allocations in water with different benefit distributions which satisfy the criterion of efficiency. There is no objective way to determine the best allocation of water from the point of view of distributional equity. Planners and decision makers must use their judgment to determine that a distribution which will be most widely acceptable.

Allocation Under Current Minnesota Water Law

So far, current water law and policies of the Department of Natural Resources have worked reasonably well. However, there is reason to believe that in severe water-shortage conditions, particularly ones of long duration, some of these laws and policies could inhibit efficient and equitable water allocation. In particular:

** The riparian doctrine, which is the basis of current Minnesota water law limits the use of water to riparian land. Thus, water allocation under the riparian system is primarily determined on the basis of location and not on its values and costs in alternative uses as would be required to attain the efficient allocation of water. Under current state law, transfers to non-riparians by water utilities and arrangements for some transfers on a case-by-case basis have been permissible, but wider use of such transfers may be necessary to secure efficient water allocation in water-shortage circumstances.

** During a water shortage, the current Minnesota priority system as established in M.S. 105.41 could inhibit the efficient and equitable allocation of water. This is because the priority classifications have little relevance to the marginal values and costs of water in alternative uses and because they do not reflect the values of many segments of the public. It can be argued that under this priority system unjustifiable discrimination in favor of certain classes of users may take place. In addition, the current priority system is statewide in nature and does not take into account regional and local differences in the hydrological features and in the costs and benefits of water use.

The current Minnesota water allocation system does, however, have some advantages which should not be overlooked. Among these are the following:

** It is politically acceptable.

** Since domestic use has the highest priority under this system, basic necessity uses are for the most part protected vis-a-vis most other uses.

** The system is relatively inexpensive to administer and the administrative structure is currently in place.

** Alternatives could be technically difficult to implement and expensive to administer. Legal and constitutional problems could be encountered and extensive statute changes required if the system were to be altered significantly.

In spite of this last point, certain suggestions are presented in this report for securing more efficient and equitable allocation of water during water shortages and for permitting more regional (this term does not necessarily refer to state Regional Development Commissions) flexibility in water allocation policy. Options for water allocation are presented which could be considered for implementation at specific hydrologically-defined areas. Such considerations would necessarily require more in-depth consideration of the options, particularly with regard to: (1) the expected benefits and costs of each option where applied; (2) how the program would be implemented and administered; and (3) the legal and constitutional issues involved.

In all of the options considered, it is assumed that the Department of Natural Resources would retain responsibility to: (1) assess the capability of the hydrological system to sustain withdrawals and (2) control the total amount of water which is withdrawn and consumed from a hydrological system in order to protect the environment and the rights of all affected parties.

Alternative Priority Options

Over the years, Minnesota has modified the basic Common Law Riparian Doctrine into what is known as the American Reasonable Use Doctrine of Riparian Rights. Under this doctrine, each riparian land holder has a privilege to make a reasonable beneficial use of the available water supply, provided that such use does not necessarily interfere with the beneficial use of others. The Department of Natural Resources is responsible for making decisions relating to reasonableness and interference through the Water Appropriation Permit Program.

The State of Minnesota has required a permit to appropriate water since 1937. Under the present statutory provisions (M.S. 105.41, Subd. 1) and DNR policy, a permit is required of any appropriator withdrawing any surface or ground water, unless for a domestic use serving less than 25 persons or unless the withdrawal is less than 10,000 gallons per day and less than one million gallons per year. The Commissioner of Natural Resources has the power to cancel or modify the terms of permits previously issued.

A priority system for granting water appropriation permits is established in Minnesota Law (M.S. 105.41, Subd. 1A). It is a five-tier priority system under which domestic water supply (excluding industrial and commercial use of municipal water supplies) is the first priority; any consumptive use of less than 10,000 gallons per day is the second priority; agricultural irrigation and agricultural processing the third priority; power production, the fourth; and all other uses, the last priority. The practice of the Department of Natural Resources has been to issue permits based on the Reasonable Use Theory, subject to statutes setting forth controlling guidelines including this priority system.

The present priority system may be criticized on the basis that (1) it does not necessarily promote allocational efficiency since the priorities do not objectively allow for the fulfillment of water consumption needs in the order of their value to individual users and the rest of society, nor does it take into account the relative costs of supplying these needs; (2) in some cases the priority system may be infeasible since water consumption in lower priority uses may be necessary for the operation of higher priority uses; and (3) it is not necessarily equitable since higher priority uses (e.g., domestic use) could include uses of water which are frivolous (e.g., long, hot showers) compared to uses in lower categories (e.g., energy production).

In addition to the current priority system, two options are available. They are:

** Broad priority classifications. This priority system would consist of three main priority classes: (1) basic necessity, (2) environmental, and (3) economic and other uses. The basic necessity category would be fulfilled before any other during a water shortage. It would consist of basic allotments for drinking and sanitation, special health needs, electric power production, and so forth. The purpose of the environmental classification is to prevent the degradation of the environment through protection of water levels and flows. The economic class would consider the needs of firms in various sectors in the state economy, as well as residential uses beyond those allowed in the basic necessity category. Importantly, this system is highly adaptable to localized conditions.

Each of the two highest categories would have to be satisfied up to a minimum level before water would be allocated to the next highest category. Thus, the categories are not open-ended as are those in the current Minnesota priority system. The exact magnitude of each ceiling could be estimated and established on a regional basis. Water use in each category beyond its ceiling would have to be justified on a case-by-case basis before additional water use within the category could be given priority over use in lower categories. When this ceiling was satisfied, additional water would be allocated to the next highest priority category.

** No priority system. With no priority system, all allocation decisions would rest on Department of Natural Resources permit decisions. If pricing or free trading of shares were adopted, water would be rationed based on willingness to pay. The public would be depended on to reduce domestic consumption and other non-permitted uses as shortages became more severe.

The current priorities system cannot be neglected as an option. While problems have been identified, the current system does have positive attributes. First, since domestic use has the highest priority under the existing system, basic necessities are for the most part protected vis-a-vis most other uses. Second, the system is relatively inexpensive to administer. Third, alternatives could be technically difficult to implement and more expensive to administer. Finally, in most cases, priority classes have not been in conflict (although there are exceptions such as the Crookston case).

Distribution options need to be examined in terms of general appropriations policies, policies for dealing with extreme shortages, and municipal policies (espcially in pricing).

Ideally, the purpose of water appropriations policies is to distribute the right to consume water in such a way as to achieve efficient use of the water consistent with widely held social goals. Water is allocated efficiently where it produces a desired effect without waste, or -- more technically -- when it is impossible to change the allocation without making at least one individual worse off. Consequently, many efficient allocations are possible. The particular allocation toward which the state will move should depend on the values held by the citizens of the state. This tempers the efficiency of the allocation policy with equity.

While to date the basic water law of the State of Minnesota and the policies of the Department of Natural Resources have served the state reasonably well, there is reason to believe that in severe water shortage situations (particularly ones of long duration), these laws and policies could inhibit efficient and equitable water allocation. Specifically, the American Reasonable Use Doctrine of Riparian Rights, the basic water doctrine applied in Minnesota, by itself is not necessarily conducive to efficient or equitable allocation because allocation is determined on the basis of location and not on its values and costs in alternative uses. Further, the current priority system (M.S. 105.41) could inhibit the efficient and equitable allocation of water because priority classifications have little relevance to the marginal values and costs of water in alternative uses and because the priorities do not reflect the values of many segments of the public.

<u>Options for Making More Water Available to Non-Riparian Users</u>

Subject to the Department of Natural Resources' prerogative to regulate the total withdrawals from any source, efficient transfers of water from riparians to nonriparians should be encouraged as a means of alleviating problems of uneven water distribution. Such transfers are already carried out by municipal water utilities and rural water supply systems. Consideration should also be given to bringing about transfers of nonpotable water by means of (1) lease-easement arrangements, (2) sales of water by riparians, and (3) mutual water companies.

1. <u>Lease-easement arrangements</u>. Under this approach, a non-riparian obtains a lease from a riparian neighbor to a small amount of riparian land on which he sinks a well or installs surface water intake equipment, depending upon the type of water source. In addition, he obtains as easement from the riparian landowner to run a line to his own property. The lessee then acquires a permit to withdraw water for his purposes.

   Under this arrangement, the tenant water withdrawer could potentially be in competition with the riparian landowner for water during a water shortage. Thus, it is in the interest of the landowner to charge a high enough rent to offset the expected costs of such a risk. On the other hand, the rent cannot be so high that it causes the total costs of the arrangement to exceed its benefits to the tenant.

Because of the lease and easement arrangement, the investment on the part of the tenant in water withdrawal and transmission equipment will be protected, at least until the lease expires. Unless, of course, the DNR drastically changes the total amount which may be transferred to the nonriparian.

This arrangement would allow a transfer of water from land where most of the time the marginal value in use of water relative to the costs of using it was relatively low to land where this ratio was higher. Thus, it has the potential to improve the efficiency with which water is allocated, particularly in areas where access to water is unevenly distributed.

Under this system, the DNR would retain the obligation of assuring that the use to which water would be put under each permit was reasonable. Administrative costs would be incurred in reviewing the application of the lessees. Such costs would have to be considered in light of the efficiency gains of the water transfers. Most of the responsibility for initiating and carrying out the arrangement would rest with the parties involved. The DNR would continue to retain its responsibility to see that the water source was not over exploited, and to protect the rights of third parties.

2. <u>Sale of water by riparians to non-riparians</u>. A second approach somewhat along the same lines as that suggested above would have the DNR granting permits to riparians which allowed the riparian to withdraw water for the purpose of selling it to other riparians or to non-riparians.

The reasoning behind this suggestion is as follows: a permit is in fact permission to withdraw water which is subject to modification by the DNR. Obviously this permission results in economic and other benefits to the riparian, even if he does not own the water.

Under the lease-easement arrangement discussed above, the riparian who leases land for his neighbor's well has no control over the amount of water the neighbor withdraws. Thus, in a water-shortage situation, this tenant would be in competition for water with the riparian. This could tend to discourage such arrangements.

Thus, riparians might be more willing to participate in water transfers if they were given the right to obtain compensation for any reduction in their own ability to withdraw water resulting from the transfer of water to non-riparians.

One way of doing this would be for the DNR to stipulate that the withdrawal of water from a given water source for the purpose of selling it to non-riparians was a reasonable use of the water and would, therefore, be permissible within the maximum withdrawal limits of the riparian's current permit. This permission could be conditional upon the types of uses the transferees made of the water, although from the standpoint of efficiency, this would not be necessary.

It would be necessary to provide some protection for the transferee against unfair practices by the riparian seller. In particular, the transferee could make large investments in irrigation equipment expecting to receive water at a particular price and then find that the price had been raised precipitously after his investment had been made. This problem could be avoided by adequate contractual safequards; however, the contract would have to be contingent upon the DNR's right to manage the maximum amount of water which would be withdrawn under the riparian's permit and its right to modify that amount or to not grant the permit at all.

The main additional administrative cost of this approach would be for processing applications to sell water if such applications were deemed necessary so that the DNR could scrutinize the nature of the uses to be made of the transferred water by the transferees. In considering this option further, a determination would have to be made concerning whether such additional costs would be worth the benefits of moving water from less productive to more productive uses.

Clearly the legal and constitutional implications of this proposal would have to be explored in depth in its further consideration. In addition to constitutional questions raised by the proposed transfer of water from riparian to non-riparian land, the question can be asked as to whether the permission to sell water implies ownership of the water on the part of the seller. It could be argued that it does not because the state retains ultimate control through its ability to modify the terms of the permit which the water seller must have.

A second issue concerns the doctrine of reasonable use. Under this arrangement, the DNR would delegate control over the distribution of the water allowable under the permit along the riparian and those to whom he sold water. The DNR would make a determination as to whether or not the types of uses made of the water were reasonable but would make no such determination with regard to the quantities of water going to each use. The question arises, "can the DNR determine that use made of the water is reasonable if it does not know the exact amount going to each use?" It can be argued that by promoting the more efficient use of water, this option will lead to the more beneficial use of water than under the current system where the DNR puts a limitation on the quantity of water withdrawn by each specific user. In other words, that water that is efficiently allocated is more reasonably used than water which is not.

3. Mutual water companies. One way in which nonriparians could take advantage of either or the previous two options would be to form mutual water companies. Such entities exist in California and are a means by which any number of land owners may secure and distribute a common water supply.

   A newly formed mutual water company could secure a water supply by either buying or leasing riparian land, or by contracting to purchase water from a riparian land owner if this were permitted. The mutual water company would issue shares, each entitling its owner to some share of the water which the company could withdraw by virtue of its permit, or could purchase through the option above.

The shares would not imply that the shareholders owned the water but rather that they owned the mutual water company and had the right to use a percentage of the water withdrawn by the mutual water company by virtue of its permit or by virtue of the permit of a riparian land owner who sold the water to the mutual water company.

The shares would be traded on the market so that a competitive price could be administered by the staff of the mutual water company. As with the joint permit share trading option, water would be allocated to those uses which were at least as highly valued as the market price of the water, so that an efficient allocation among the members of the mutual water company would be established.

Such an arrangement would also promote efficient allocation because it would be a means of securing efficient transfers of water to non-riparian land owners.

The costs of administering and operating the mutual water company would be assessed against the shares of its members. Thus, it would be necessary to secure a sufficient number of members to prevent the cost burden on any single share owner from being too high. Nevertheless, this could be a viable means of securing water for non-riparians in areas where the geographical distribution of water was highly uneven. For such landowners, the benefits of having a reliable source of water could offset the costs assessed against the shares.

The same legal and constitutional questions discussed in the above option and, perhaps, additional ones could be raised with regard to mutual water companies. The DNR would have to delegate control over the specific quantities of water going to different users of the shareholders. Water would be transferred from riparian lands and permission to use it would be traded among the shareholders.

Allocation During Water Shortages

As noted previously, current state law and policy may not function sufficiently well during periods of water shortage. The options relating to more efficient transfers, while helpful, may not be sufficient in extreme shortage situations. Therefore, it is necessary to consider a means of adequately protecting resources during extreme shortages while promoting efficient use. Three major options should be considered: (1) pro-rata rationing policies, (2) benchmark water shortage pricing, and (3) trading in joint permit shares.

1. Pro-rata rationing. Pro-rata rationing involves apportioning available water among permitted users at a source according to their past withdrawals or the maximum allowable withdrawals under the terms of their permits. This approach would tend to result in inefficient water allocation, but it would be relatively easy to administer. Thus, it could be more appropriate for use during a severe temporary water shortage of short duration where the costs of misallocation would not have time to accumulate.

2. <u>Benchmark water-shortage pricing</u>. This approach involves establishing a per-unit water price for withdrawals from a water source when the level of the water (of a ground-water source or lake) approaches a predetermined benchmark level or, in the case of a river or stream, the flow of the water approaches a benchmark flow. The benchmark flows would be determined on the basis of environmental and hydrological considerations. As the benchmark level or flow is approached, the price is raised to discourage water use. If levels or flows are well above the benchmark parameters, the per-unit price would be set at zero.

   This approach would tend to produce efficient water allocation at the source because individual withdrawers would be forced to take into account the value of the resource in their withdrawal decisions.

   The establishment of benchmark water-shortage pricing at a given water source would depend upon the ability of the water management authority to monitor hydrological conditions and adjust the price charged per unit of water accordingly. Thus, in many areas it may not be technically feasible to implement at this time. In addition, it would be more expensive to operate and administer than pro-rata rationing. It would, therefore, probably be most suitable for areas suffering from chronic water shortage problems where the costs of misallocation would accumulate over time.

3. <u>Trading in joint permit shares</u>. One way to avoid the inefficient allocation which would take place under pro-rata rationing and to avoid the trial and error approach of benchmark water-shortage pricing would be to establish a system of trading in joint permit shares. This would involve the issuing of a joint permit to all current permit holders as a particular water source. The maximum current withdrawal allotment specified in each individual permit would be converted to shares in the maximum allotment attached to the joint permit. These shares would then be tradable. In essence, a mutual water company would be established among all withdrawers on the source.

   As with a mutual water company, an equilibrium share price would be established and water would be allocated more efficiently.

   During water shortages, the maximum allotment attached to the joint permit would be reduced so that each share would command a smaller absolute amount of water. Thus, during water shortages the competitively established price of shares would rise, encouraging conservation.

   The costs of administering this arrangement would be assessed against the share of the joint permit holders. Thus, it would be necessary to secure a sufficient number of members to prevent the cost burden on any single share owner from being too high. This arrangement would, therefore, be most suitable for use at water sources supplying a large number of withdrawers where chronic or recurring water-shortage problems existed.

   Obviously the legal and constitutional implications of this option require exploration.

Zoning and Land Use Planning

In general, zoning and land use planning also provide options for avoiding excessive pressures on surface- and ground-water sources during periods of drought and water shortage. These options seek to locate new water intensive industries in areas where water resources are relatively more plentiful.

There are certain costs associated with the implementation of land use and zoning policies, however. Among these are the following:

** Water is only one resource which is used in the production processes of industrial firms. Even if the cost of using water is high in an area because of limited water resources, a firm might choose to locate there because of the availability of raw materials and the relative costs of other inputs such as labor. Thus, if heavy water using industries are prevented from locating in an area, the local benefits which might be derived from the industry are lost.

** Use of water in the area by local residents and industries to the exclusion of industries which would locate there in the absence of zoning ordinances imposes a cost upon the excluded industries and their customers. Thus, the cost of the residents' use of water is undervalued; that is, they do not bear the full cost of their usage and the allocation of water between these residents and local industries and the excluded industry is not efficient.

Prohibiting industries from an area which might otherwise choose to locate there constitutes an income distribution decision in favor of the local residents, and local industries and their customers, and against the excluded industries, its employees and its customers.

An argument for zoning can be made, however, on the negative basis that other water allocation options may not be applicable to a particular source for technical and/or political reasons. Zoning does provide a means of protecting against the possibility of over-committing available resources with resulting economic and environmental costs.

Allocation by Water Utilities

In moving toward efficient use of water resources, pricing policies of water utilities are potentially a major consideration. In general, water is allocated by water utilities (e.g., municipal water utilities and rural water supply systems) through some type of pricing scheme. The rate structures selected affect both the allocation of water within the service area of the utility and at the source from which the utility draws its supplies. Thus, there are two primary reasons why the rate structures selected by utilities should be of concern if the State of Minnesota is concerned with achieving the maximum benefit from water supplies of the state.

(1) The water utility acts as an "agent" for individuals and certain firms in its service area when it competes for water supplies with other potential users. The rates charged by water utilities affect the total demand for water consumption. Therefore, the total satisfaction of all users of water at or from each source depends on how water is allocated within the utility's service area.

(2) Water provided through water utilities directly provides satisfaction of personal needs and desires. It indirectly provides satisfaction to individuals by permitting firms to provide goods and services, and jobs and income. Thus, the way in which water is allocated in a utility's service area affects the satisfaction derived from its use.

Water utilities in Minnesota charge for water delivered to each customer, rather than for water consumed. (Some utilities also provide sewage treatment services and charge for these services). At least five approaches have been employed in the state.

** <u>Service charges</u>. Service charges are charges which no not vary with the quantity of water delivered. They are imposed in addition to per-unit water charges in a water rate structure.

** <u>Flat charges</u>. The flat charge is a fixed bill which is levied independently of the amount of water used. For example, a customer might pay $10 per month for water service, regardless of the volume of water used.

** <u>Single block rate</u>. The single block, or uniform rate, is a constant rate charged per unit of water (e.g., the customer pays $2.00 for every 1,000 gallons of water used). This rate may vary according to different classes of users.

** <u>Declining block rates</u>. The declining block rate structure is usually instituted with a minimum demand charge. A declining block rate structure without a minimum demand charge is a structure in which a specified rate is charged per unit of water up to a specified amount. Water consumed beyond this specified amount is charged at a lower rate up to the next plateau, and so forth. When this structure is combined with a minimum demand charge, the customer is billed a flat charge for all water consumed up to the first specified level.

** <u>Increasing block rates</u>. This type of rate structure is the reverse of the declining block structure. In this case, the rate charged increases with successive blocks.

Because the existing rate structures employed in Minnesota are not directly based upon the short-run marginal cost conditions of supplying water to individual users and because they do not reflect differences in these conditions among uses and users, the current rate structures of municipal utilities tend toward inefficient use of water and toward unnecessary capacity expansions. One alternative to the existing structure is:

** The marginal cost approach. This approach is based on the marginal costs imposed upon water supply systems by identified groups of users. Identified groups of users would consist of customers who impose similar costs on the system (e.g., those who use water during peak periods, live at higher elevations, etc.). The rate structure imposed on each group would consist of initial charges (to cover those increments to the costs of the system which can be attributed to each new connection); service charges (to cover the fixed costs of the water utility directly attributable to each individual connection, the ongoing marginal costs of maintaining capacity for the peak needs of identified groups, and to distribute the economic gains or losses of the water utility); and commodity charges (a rate for each unit of water delivered which reflects the "true" short-run marginal costs of supplying water to groups of consumers).

Well Interference Problems

Finally, in considering major options relative to the allocation and distribution of water resources, it is necessary to consider what should happen when, in the distribution of the resource to one individual, another individual's access to the resource is affected. Of particular (and increasing) concern to Minnesota are ground-water related well interference problems.

The most common problems involving ground water are well-interference conflicts between irrigators and other users. Well-interference problems occur when the withdrawal of ground water by one user causes the level of the ground water in the vicinity of his well to fall, interfering with the ability of one or more neighboring well owners to draw water. The frequency of these problems depends on the spacing of wells drawing from an aquifer and on the overall availability of ground water in the aquifer. An individual whose water supply is affected by well interference may have to deepen his well, install a pump (in the case of an artesian well which stops flowing), and/or lengthen his drop pipe. In addition, he must use more energy in drawing the water.

In economic terms, well-interference problems may be described as follows: When an individual or firm decides to invest in a well, or, in the case of farmers, in irrigation facilities, it is because the individual or firm implicitly or explicitly expects a stream of benefits to arise over time due to the investment. If the individual or firm believes that the present value of this stream of benefits will be greater than the present costs involved, the individual or firm will make the investment. But such investors may not always take into account all of the costs of their investments.

Consider, for example, a certain Farmer A who invests in a water-table irrigation well. Suppose his well, when operating, lowers the level of the ground water under the property of his neighbor, Farmer B. Then Farmer A's well may result in costs which, in the absence of redress, must be borne by Farmer B if Farmer B has an existing well, or if B decides to put in a new well at a future date.

Suppose, for example, that Farmer B has an existing well. If Farmer A's well, when operating, lowers the level of the ground water under B's well to a depth below B's drop pipe, then B will not be able to draw water from his well. To assure himself a continuously available supply of water from this well, B will have to incur costs such as lengthening his drop pipe, deepening his well, or drilling a new well.

If Farmer B does not initially have an existing well, but subsequently decides to install one, he will have to drill the well to a greater depth or take other measures in order to obtain water. In this case too, a cost is imposed upon him by Farmer A.

Conclusions and Recommendations

Within the bounds of the above discussions, several recommendations are offered to deal with the distribution of available resources.

1. Accurate data. To efficiently manage the state's water resources, especially during water shortages, accurate data concerning water withdrawals is necessary. To obtain this information, withdrawal meters should be required of all permitted appropriators, except in cases where users can demonstrate that the use of such meters is technically infeasible or too costly. In the exceptional cases, alternative means of accurate withdrawal measurement should be required. To help secure compliance with this recommendation, intake meters could be required on all new permitted wells and water installations and the installment of such meters could be required on wells and other water intake installations undergoing modification, unless the permittee could demonstrate that the use of such meters would be technically infeasible.

2. Priority system. The current Minnesota priority system should be replaced with one which protects generally recognized basic needs, takes into consideration widely held social values, and allows a greater measure of regional flexibility in the setting of water allocation policy.

   Such a priority system should consist of:

   (a) A basic necessity category to protect minimum water needs for drinking and sanitation, needs of individuals with health problems, minimum needs for electric power production to provide for basic personal energy requirements, hospital needs and any other uses deemed basic by the water allocation authority.

   (b) An environmental category designed to present the degradation of the water environment by protecting lake levels and instream flows.

(c) An economic category which covers the water use of firms in various sectors of the economy and residential uses beyond those allowed for the basic necessity category. Allocation within this category could be administered on a regional level, perhaps making use of some of the options presented in this report.

Each of the two highest categories would have to be satisfied up to a minimum level before water would be allocated to the next highest category. Thus, the categories are not open-ended as are those in the current Minnesota priority system. The exact magnitude of each ceiling could be estimated and established on a regional basis. Water use in each category beyond its ceiling would have to be justified on a case-by-case basis before additional water use within the category could be given priority over use in lower categories. When this ceiling was satisfied, additional water would be allocated to the next highest priority category.

To fully define and refine the major priority classes for "basic necessity uses" and "environmental protection requirements," the coordinating body, in consultation with appropriate agencies, shall quantify these classes prior to the submission of any legislation to repeal the present priorities system. Basic necessities and environmental protection levels should be based on local demographic, hydrologic, environmental, and regional dependencies.

Economic production allocations should be based on economic, social, and hydrologic considerations relevant to the area involved. Local and/or regional water management plans should be developed -- consistent with state policies and guidelines -- to guide such decisions. Pending development and approval of localized water and related land use plans, regional development commissions shall be authorized to develop regional "economic production" class priorities, which shall be advisory to the Commissioner of Natural Resources in permit issuance. Where an RDC elects not to establish regional priorities, the Commissioner may establish priorities for the region within the "economic production" class.

3. Improving distribution of water resources. It is recommended that the State of Minnesota adopt as an explicit policy the use of lease-easement arrangements to improve efficiency in the allocation of its water resources. This arrangement would allow a transfer of water from land where most of the time the marginal value in the use of water relative to the costs of using it is relatively low to land where the ratio is higher. While this option does not promote the greatest efficiency in water use among the options considered, it is the option most consistent with riparian doctrine.

The sale of water from riparians to non-riparians and mutual water companies should continue to be studied in Minnesota. Specifically, the study should focus on (a) the expected benefits and costs of adopting the option, (b) how such a program would be implemented and administered, and (c) the legal and constitutional constraints.

4. Allocation during critical shortages via pro-rata rationing. Because most critical shortages in Minnesota are likely to be of limited duration and because this policy could be easily implemented, it is recommended that the State of Minnesota consider adoption of a policy of pro-rata rationing during periods of critical shortages.

5. Well interference disputes. Rules and guidelines for the settlement of well interference disputes shall be based on the following responsibilities: (1) all appropriators of water shall be responsible for making a reasonable effort to obtain water sufficient in quantity and quality for their needs; (2) all appropriators shall be responsible for meeting the well code requirements of the Minnesota Department of Health; and (3) if further development of the aquifer causes interference with existing appropriators who are meeting their responsibilities, the new appropriator (or appropriators) shall be responsible for the cost of corrective measures, including any needed treatment facilities. The Department of Natural Resources shall, by rule, define the concept of "a reasonable effort to obtain" an adequate water supply.

6. Allocation by utilities. The Water Planning Board makes the following recommendations for improving the efficiency and equity of water allocation by water utilities:

   A. To bring about the more efficient allocation of water among the customers of intermediate water suppliers and to prevent excessive demand for water at the source and uneconomic capacity expensions, it is recommended that the state encourage and assist water utilities to adopt rate structures based on marginal cost principles. A specific three-part rate structure is suggested. To this purpose, the state should consider subsidizing a pilot project whereby such rate setting practices could be tested through actual application by a water utility.

   B. In order to make sure that low income families can afford the water necessary to meet their basic needs and still be included to treat water as a resource with value, it is recommended that such families recieve lump-sum subsidies to cover some part of the cost of obtaining water for basic necessities and that they be charged the same rates (based on marginal cost pricing) as all other users.

   C. In considering the merits of rural water systems, attention should be given to their potential ability to bring about more efficient allocation of water. Rural water systems have the ability to transfer water from places where it is relatively plentiful and, therefore, less highly valued, relative to the costs of using it, to places where it is relatively scarce and, therefore, more highly valued relative to the costs of using it. They provide a means of establishing efficient allocation among their customers and reduce the possibility of well-interference problems between irrigators and domestic users.

EFFICIENT USE OF WATER RESOURCES

Water supply shortages are not always due to a lack of sufficient annual precipitation. They may be due to non-uniform seasonal availability and irregular regional distribution. Shortages may arise because of community growth, facility obsolescence, capacity constraints and limitations due to competing uses, water quality problems, and rising costs of distribution and treatment.

Traditionally, water planning for the future has been concerned chiefly with the problem of acquiring and developing additional supplies. Water conservation in water supply planning has only relatively recently come to the fore, usually as the result of an extreme shortage. In 1972, when wastewater flow reduction was included in the federal Clean Water Act (P.L. 92-500), water conservation became a formal part of water management policy. In 1978, President Carter went a step further in his national water policy message, proposing a financial assistance program for states to incorporate water conservation into planning activities through public education, information discrimination, and technical assistance. Under this program, up to $347,000 could be made available to Minnesota annually.

The term "conservation" is often used to mean the protection of a resource from being used completely. More recently, conservation has taken on an efficiency connotation, referring to the production of a desired effect without waste. The Supply, Allocation, and Use Work Group refers to conservation of water resources in terms of an efficient use/anti-waste concept, rather than a purely conservation/ anti-use design.

Conservation is important to Minnesota because, while Minnesota is a relatively "water-rich" state, it is also experiencing a number of the same water-related problems which are occurring nationwide. These problems generally appear in localized shortages. Three factors contribute to localized shortages. First, natural precipitation is unpredictable. Second, increasing population pressure expands the demand for water from municipal and domestic supplies. High density population also increases the demand for services using water and goods requiring water for manufacturing and processing. Finally, advancing technology and a rising standard of living are increasing water availability and encouraging new uses in agriculture, industry, municipalities, and homes.

Application of conservation technologies and adoption of a conservation ethic can mitigate the impacts of localized shortages, while providing benefits (e.g., reduced pumping costs, lower bills for heating water, and delayed capitol investments) for individual users.

The Present Situation

The Department of Natural Resources has been charged with the responsibilities to "develop a general water resources conservation program for the state" since 1947. While no conservation program has been delineated, water conservation considerations have been incorporated in the issuance of permits for water appropriation and use of the waters of the state. In 1977, the Legislature further specified conservation measures for requiring (1) public water supply authorities to restrict "lawn sprinkling, car washing, golf course and park irrigation, and other non-essential uses" under certain conditions and (2) contingency plans describing alternatives to be used by a surface water appropriator if his appropriation is restricted due to low streamflow or lake level. In addition, the Minnesota Department of Health has the authority to develop emergency plans to protect the public when declining water supply creates a health risk.

Aside from the measures to be taken in water quantity or quality shortage, a state posture toward water conservation as a management tool has not been identified. The Supply, Allocation, and Use Work Group recognized the need to examine potential promotion of efficient water use in water resource planning in the areas of irrigation, food processing and domestic/municipal water use. These three areas were selected for study because of a recognized potential for change in their customary water use. The methodology consists primarily of examining state-of-the-art water conservation options for their applicability in Minnesota as a part of the long range water resource management scheme.

1. Irrigation

The trend toward more widespread use of irrigation is well illustrated by Minnesota statistics. Agricultural irrigation in Minnesota has rapidly gained acceptance as a viable farm management technique since about 1960. Best estimates indicate that from 1960 to 1970, irrigated acreage doubled from 22,000 acres to 44,000 acres. From 1970 to 1975, this acreage increased to 174,000. One estimate for 1977 reports 433,000 acres irrigated in Minnesota.

The water withdrawal and consumption which these irrigated acreages represent are a substantial portion of overall Minnesota water use. In dealing with the topic of water conservation and irrigation in Minnesota, the potential to reduce total withdrawals and consumption can be seen in light of the vast amounts of water used in irrigation practices. In 1976, 60 billion gallons of water were withdrawn for irrigation, accounting for 4.4% of total withdrawals. Forty-eight billion gallons of this water were consumed, that is, unavailable for immediate reuse, or 22% of total water consumption in Minnesota.

To prevent waste, withdrawal volumes should be kept to the minimum required for the consumptive use demand of the crop irrigated. By minimizing withdrawal, the water saved remains available for other uses. Efficient water use is a major factor in waste prevention and water conservation and also offers potential economic savings from reduced pumping costs. Irrigation options for conservation include the use of equipment, sprinkler or drip irrigation methods, flow meters, soil moisture monitors, and technical assistance in scheduling.

It seems reasonable to assume that irrigation increases like those in Minnesota have a substantial impact on the state economy. Any impacts, whether economic or resource-related, will be strongly regional in nature because irrigation is limited to specific areas of the state. Because of the regional nature of irrigation development, it is emphasized that although state concern is imperative, the impetus for irrigation water conservation should be locally or regionally initiated. Cooperation at all government levels is strongly advocated to further educational and technical assistance programs to increase the awareness of conservation potentials.

2. Agricultural Processing Industry

Agricultural processing firms in the state include canneries, dairy processors, slaughterhouses, sugar refineries, and poultry producers. Each of these firms processes raw agricultural goods produced in the state. Although there has been a tendency for processing firms to become more centralized, the majority of firms are still located in rural municipalities. These firms are often the major or only industry in a locality. Water supplies and waste treatment services for these industries are either private operations or municipal systems. Plants decide to use these utilities on the basis of individual hydrologic, technical, and financial considerations. The demand for water by these plants is extremely large, often exceeding one million gallons per day. Requirements for waste treatment facilities are equally demanding due to the quantities of waste water and organic matter leaving the plants daily. Plants operating in both rural and metropolitan settings are capable of putting severe stress on local hydrologic conditions and on water-related capital equipment. Processing firms and municipalities alike have been feeling the financial pressure of increased water and waste treatment costs.

Food processing firms have always been aware of the need for vast amounts of water for their internal operations. However, this concern was (and is in many cases) primarily technologically rather than economically oriented. Water is needed to wash, cook, cool and transport the product, and to keep all the equipment and facilities clean and sanitary. Since water was deemed an inexpensive and often free resource, plant facilities were designed without regard to water use. In the days before the environment was viewed as a resource, water resource use for waste assimilation was not a major issue. Decisions on plant locations were based on water availability for technologic needs, not on the resource cost of supplying these needs.

As resource supplies and demands shift, so do their prices, both real and imputed. While there is always a cost associated with resource use, it is only now beginning to show up in a municipal and industrial fiscal statements. These costs go under the headings of water, energy, waste treatment, depreciation, and interest charges. Water has become a constraint on continued operations and projected growth.

Many food processing operations in the state are now adjusting their use rate of water in order to compensate for increased costs and diminished supplies. This change in the distribution of water use generally can be termed water conservation. Conservation can be accomplished by altering the input mix without deferring output and by deferring output with no change in input ratios. Conservation goals also can be reached through different technological means. Consequently, different patterns of use rates are achieved through adjustments to the technology and through different combinations of inputs and outputs.

One of the prime requirements of conservation attempts is a change in attitude. Adjusted use rates demand new patterns of thinking as well as different technologies. In many respects it is easier to construct a new machine than it is to change work habits or views on resources. However, an effective conservation program must link new technologies with new thoughts.

Food processing plant options may be guidelines which consist of any number of the following elements: recycling and reuse, organizational support, in-plant water surveys, elimination of waste, plant cleanup operations, dry conveyance of solid waste, minimization of fresh water use, and less water intensive transport of products.

3. Domestic Use

This discussion of water supply is limited to municipal and domestic use. Domestic water consumption is only an estimated seven percent of the state's total withdrawals and 4.4 percent of the total consumption. Even a dramatic cut in water use by households would add only a proverbial drop in the bucket of available water. The reason that domestic use can cause supply problems is the high concentration of domestic, commercial, and industrial demand. Municipal systems which show high per capita use values usually also serve some industrial user.

The benefits which are implied in a discussion of water conservation are decreased demand and maintenance of the environment. If the demand for water on a public water supply is reduced, the change will: 1) free presently developed supplies for other purposes; 2) prevent or delay the construction of costly water supply and treatment facilities; 3) decrease the amount of energy needed for pumping, treating, and heating water; and 4) reduce the required capacity for future wastewater treatment plants.

Conservation measures must be appropriate for the individual supply and circumstances. Implementation of conservation strategies might be accomplished with voluntary or mandatory participation. Two sets of conservation measures might be developed, one for drought conditions and one for normal precipitation. A water conservation program could include any number of the following strategies: information/education, water saving devices, metering, pricing, leak monitoring and control, legislative measures, and water management planning.

4. Changes in Attitudes

Central to all efficient use/anti-waste approaches is a change in the attitude of consumers of water. Adjusted rates of use demand new patterns of thinking, as well as implementation of new technologies. A key to success in achieving a change in attitudes may be initial concentration on water saving devices which can be installed without major disruption in lifestyles. An effective conservation program must link technologies with new thoughts.

Issues and Options

In examining the present situation in Minnesota and evaluating the state's future water resource demands and supplies, the Supply, Allocation, and Use Work Group has concluded that three important questions must be raised.

(1) Is water conservation an effective long-term strategy for holding down inefficient water withdrawals and consumption in Minnesota?

(2) What should be the general guiding principles in developing effective water conservation strategies and techniques in Minnesota?

(3) What actions need to be taken now? What questions require further study?

The question "Is water conservation an effective long-term strategy for holding down inefficient water withdrawals and consumption in Minnesota?" demands a "yes" or "no" decision. While the adoption of a conservation approach may not appear to have the immediacy in Minnesota it has in less "water-rich" states, conservation (1) frees additional supplies for other uses; (2) prevents or delays construction of costly water supply and treatment facilities; (3) decreases energy costs for pumping, treating, and heating water; and (4) reduces the required capacity of future wastewater treatment facilities. Importantly, development of a conservation program has been deemed necessary by the Legislature since 1947 (with reaffirmations in 1977) and, under virtually all estimates, has been estimated to be capable of reducing water consumption and withdrawal in Minnesota.

The major negative consideration is whether a state which likely faces primarily localized water shortage problems should employ its limited resources in a conservation program effort.

If the state elects to develop a conservation program, a number of principles should be considered. These include:

** Selection between a mandatory conservation approach with goals to be reached within a given period and a program of education and technical assistance;

** Identification of a single state agency as a clearinghouse for conservation functions;

** Determination of whether the program should be focused at the state, the regional, or the local level;

** Development of a water conservation example in state agencies;

** Provision of demonstration programs in a limited number of local communities;

** Preparation of education and school curriculum materials on wise water management; and,

** Enforcement of statutory provisions requiring that the Department of Natural Resources adopt rules to be followed by public water supply authorities in restricting lawn sprinkling, car washing, golf course and park irrigation, and other non-essential uses during periods of critical water deficiency.

The areas of domestic consumption, agricultural irrigation, and agricultural processing were examined by the Supply, Allocation, and Use Work Group for their conservation potential. Potential options in these areas include:

** Domestic consumption. Options include increased educational and informational activities, installation of water saving devices, increased metering, price increases and leak monitoring and control.

** Agricultural irrigation. Among the practices which could contribute to water conservation in agricultural irrigation are the practice of water stewardship as a general ethic, rehabilitation of inefficient irrigation systems, reduce incidental losses such as those caused by leaks and over-irrigation, installation of flow meters, the institution of multiple uses such as irrigating with sewage outflow, development of scheduling programs, and introduction of soil monitors.

** Agricultural processing. Options involve recycling and reuse of water supplies, organizational support, in-plant water surveys, elimination of waste, plant cleanup operations, dry conveyance of solid waste, minimization of fresh water use, and less water intensive transport of products.

Important options for future study are (1) conservation in other manufacturing sectors, (2) reduced water use in the mining industry, (3) conservation water-quality relationships in electrical generation, and (4) the potential impact of the adoption of water conservation approaches on municipal water charges and potentially appropriate state responses.

Conclusions and Recommendations

The Supply, Allocation, and Use Work Group concludes that water conservation makes sense for Minnesota in order to maintain water supplies for the future, to protect the quality of existing supplies, to reduce costs associated with energy demand, and to postpone development of untapped water supplies. Therefore, the Work Group recommends:

1. Technical assistance program. Water conservation programs are a potentially effective means of promoting efficient water withdrawal and consumption in Minnesota. The state should take the lead in obtaining, evaluating, and disseminating information on conservation techniques through an education and technical assistance program. The state coordinating body should be designated as the clearinghouse for water conservation activities. It should be responsible for disseminating this information to local and regional governments and for making educational materials available to schools through the Minnesota Environmental Education Board.* In addition, it should (1) administer funds which may become available under federal water policy initiatives and (2) monitor conservation demonstration programs at the local level.

   Adoption of conservation techniques and options by domestic and agricultural users, industry, and utilities would be voluntary.

2. Local programs. Conservation programs, including those required by statute, should arise at the local level. Where required by law, such programs shall be consistent with state rules.

3. Department of Natural Resources rules. The Department of Natural Resources should adopt rules necessary for operation of local programs to restrict non-essential water uses during critical periods and to implement the general conservation program required by Minnesota Statutes, Section 105.39 through the permit program. The conservation program should address such areas as mining, commercial and industrial domestic, agricultural and municipal conservation.

4. Metering. All permitted appropriators shall be required to measure their water use accurately. Flow meters shall be used, except in cases where users can demonstrate that employing meters is technically infeasible or too costly. It shall be the responsibility of the appropriator to demonstrate that a flow meter is infeasible or prohibitively costly. Where successfully demonstrated, an alternative means of accurate withdrawal measurement shall be required.

5. Studies. The Water Planning Board, in conjunction with affected state and local agencies, should carefully study (a) the impact of water conservation approaches on municipal water charges and

*It should serve to direct inquiries on water conservation practices to the appropriate agencies and technical service bodies, such as the Agricultural Extension Service.

state responses if conservation approaches result in increased water charges and (b) the ways in which the state plumbing code might be revised to promote water conservation.

6. State agencies. The Governor should require state agencies to initiate water conservation measures in state facilities and require agencies to encourage water conservation techniques in programs they administer.

FLOODING IN MINNESOTA

Flooding has been a steadily increasing problem as man's activities have encroached on the natural drainage system and the floodplain. Riverine flooding most commonly occurs in spring due to accumulated snowfall, rapid rises in temperature, spring rains, high soil moisture, or a combination of these factors. River flooding can also occur during the summer in localized areas due to severe thunderstorms. Two other types of flooding also occur. Lake flooding can be caused by high runoff, high ground-water levels or wave action; urban flooding is due to increases in amounts of impervious surfaces and to natural or man-made stormwater drainage systems that are insufficient during severe storms.

Major floods have occurred in almost every basin in the state. In recent years, severe floods have occurred regularly along the Red River and its tributaries and along the Minnesota, Mississippi, Cannon, Zumbro and Root Rivers.

The major damages caused by severe floods continue to be loss of lives, damage or destruction of homes and businesses in flood plain areas, and damages to agricultural crops and roads. In addition to these direct losses or damages, there are a number of indirect damages that are less obvious. These include emergency flood fighting and rescue costs and income losses to businesses not directly affected by flooding. In spite of the efforts of federal, state, and local agencies, flooding remains a major problem and the economic and social costs of flooding continue to rise.

The Economic Impacts of Flooding

The last major studies to determine the average annual damages caused by flooding were conducted during the late 1960's for most of the state. At that time average annual flood damages totalled over $23 million. Because of inflation and some continued development of flood plain areas, a conservative estimate of current average annual damages is over $54 million (in 1978 dollars). (See Table 5.)

Average annual damages consider the damage caused by both major and minor floods over a period of years. Thus, such a figure is significantly smaller than the damages caused by very severe floods, but substantially larger than the damages caused by minor flood events. Estimates of flood damages during the severe floods of 1978 may exceed $100 million. About $27 million of federal disaster assistance was provided to victims of these floods. These damages occur largely as physical damage to property by flood waters and are measured by the cost of restoring or replacing this property. These losses also include the reduction in earnings for agricultural and non-agricultural activities which are affected by flooding. (See Table 6.)

A more serious problem is the continued loss of life during major flood events. The development of flood forecasting systems and the increasing effectiveness of flood emergency activities have helped to reduce the number of deaths due to flooding, but deaths still occur particularly in areas that are subject to flash flooding.

TABLE 5. Estimated average annual damages in Minnesota, by basin (base year damages adjusted to reflect 1978 prices, only).

River Basin	Base Year	Average Annual Damages in Base Year	Damages Updated to 1978 Prices	Basin Damages as % of Total Minnesota Damages
		Damages Expressed in Thousands of 1978 Dollars		
Mississippi 1/	1966	15,369	37,163	68.76
Red River 2/	1967	7,367	16,257	30.08
Rainy River 3/	1967	149	338	00.63
Great Lakes 4/	1970	267	288	00.53
Total State			54,046	100.00

1. Existing Conditions

2. With existing projects, including those for which construction has been started or has been funded prior to December, 1967.

TABLE 6. Agricultural and non-agricultural average annual damage estimates, by basin.

River Basin	Agricultural Damages	Non-Agricultural Damages	Non-Agricultural Damages as % of Total Damages
	Damages Expressed in Thousands of 1978 Dollars		
Mississippi	15,501	21,662	58.29
Red River	10,773	5,484	33.73
Rainy River	193	145	42.90
Great Lakes	182	106	36.81
Total State	26,649	27,397	50.69

Sources: Upper Mississippi River Basin Coordinating Committee, 1970; Great Lakes Basin Commission, 1975; Souris-Red-Rainy River Basins Commission, 1972.

Flood Damage Reduction Measures and Programs

Historically three different approaches have been used to reduce the economic impacts of flooding: (1) decreasing flood losses by redirecting, modifying, or changing the probability distribution of flood flows through corrective measures; (2) decreasing flood losses by reducing the value of property exposed to flooding by preventative measures; and (3) reducing the economic hardship caused by flooding with compensation measures.

Until the late 1960's, various types of structural or corrective measures were the primary means of reducing flood damages. Reservoirs, levees, dikes, and small impoundments were constructed in many parts of the state to modify the frequency or the magnitude of floods or to protect property from flood damage. In spite of these measures flood damages continued to increase because of the continuing development of flood plain areas.

Since the late 1960's, the primary emphasis in flood damage reduction has switched from structural to non-structural measures at both the state and federal levels. Preventative and compensation measures including flood plain zoning, flood insurance, flood proofing, flood warning systems, land acquisition, disaster planning, land use controls, stormwater management, and others have become increasingly common means of flood damage reduction. Although the major emphasis is currently on non-structural measures, both structural and non-structural measures are recognized as essential components of a comprehensive flood plain management program.

Federal Flood Damage Reduction Program

The federal government is currently involved in almost every aspect of flood damage reduction and flood plain management. The following summary briefly describes some federal programs.

1. Programs of the Corps of Engineers

   The legislative authority for the involvement of the Army Corps of Engineers in the flood control began with the Flood Control Act of 1936. This Act gave the Corps the authority to conduct investigations and to construct flood control improvements on navigable waters and their tributaries, with the condition that improvements authorized under this Act or subsequent amendments would have to produce benefits in excess of all project costs.

   In addition to responsibility for major flood control projects, several laws permit special continuing authorities. These include:

   A. Small Flood Control Projects. Section 205 of the Flood Control Act of 1948 authorized the Chief of Engineers to build small flood control projects that have not been specifically authorized by Congress.

B. Snagging and Clearing. Section 208 of the Flood Control Act of 1954 provides for clearing and straightening of stream channels and for the removal of accumulated snags and other debris which may reduce channel capacities.

Since 1960, the Corps has become increasingly active in the area of flood plain management. Under Section 206 of the Flood Control Act of 1960, the Corps has established a flood plain management services program. Under this program the Corps provides flood plain information reports to localities, flood insurance studies, and technical assistance to state and local governments to aid them in the preparation of flood plain regulations and to evaluate flood hazards.

The Corps is also directly involved in a variety of flood emergency activities. Under Public Law 87-99, Congress authorized the creation of an emergency fund to be used for flood emergency preparations, flood-fighting and rescue operations, or for the repair or restoration of flood control structures threatened or destroyed by flooding. The Corps also furnishes flood forecasts under this authority. In addition, under P.L. 92-288, the Corps is authorized to cooperate with the Federal Disaster Assistance Administration in performing emergency work essential for the preservation and protection of life and property, conducting damage survey investigations after major floods, repairing and replacing public roads, and providing technical and engineering services.

2. Programs of the Department of Agriculture

The Watershed Protection and Flood Prevention Act of 1954 (P.L. 566) authorized the Soil Conservation Service (SCS) to carry out a program of structural flood damage reduction in upstream areas. Projects initiated under the P.L. 566 program are limited in size and restricted to upstream locations, or watersheds under 250,000 acres. The SCS also has a program for delineating flood hazard areas in upstream communities and distributing this information to local units of government.

By recent amendment to P.L. 87-639, SCS has been authorized to conduct joint investigations, with the Army Corps of Engineers, in watershed areas for purposes, including flood prevention. A joint investigation is underway in southern Minnesota.

3. National Flood Insurance Program

In 1968, Congress passed the National Flood Insurance Act (P.L. 90-488) which established the national flood insurance program. The objectives of this program are to (1) provide flood insurance at subsidized rates for existing structures and their contents, (2) provide coverage at actuarial rates for future properties located in the 100 year flood plain, and (3) promote appropriate land uses in areas subject to flooding in order to reduce flood hazards. To achieve the latter objective, state and local governments are required to adopt land use regulations to: (1) restrict the development of land exposed to flood damage; (2) guide the development of proposed future construction away from locations which are threatened by floods, (3) assist in reducing damage caused by floods; and (4) provide for proper land use and land management in floodprone areas by recognizing the degree of the existing flood hazard.

4. Emergency and Other Programs

The Disaster Relief Act of 1974 (P.L. 93-288) provides the basic authority for the Federal government to help local and state governments provide relief assistance to flood victims. Assistance to flood victims under this Act is contingent upon an emergency declaration requested by the Governor and issued by the President of the United States, or other appropriate federal authority. There are three different types of disaster declarations, including a Small Business Declaration, an Agricultural Declaration, and a Major Disaster Declaration. The types of assistance provided varies greatly depending on the type of declaration.

The National Weather Service Forecast Office located in the Twin Cities is responsible for all public weather service and hydrologic guidance forecasts in the State of Minnesota. Weather forecasts, watches, and warnings issued by the Weather Service are made by radio and television broadcast to allow residents as much advance warning as possible to take preventative measures. On a longer range basis, the Army Corps of Engineers maintains Operation Foresight. When data gathered during the winter months indicate an abnormally high snowpack, or when other conditions are present which indicate severe flooding, the Chief of Engineers is authorized to provide assistance to counties and communities to help identify problem areas and to begin planning for pre-flood emergency operations.

5. Recent Federal Policy Changes

Federal policy changes may have significant impacts on both state and federal flood plain management policy. President Carter's Water Policy Message proposed more stringent requirements for funding federal projects, and contained provisions for mandatory state cost-sharing for federal projects. Many of his proposals are already being implemented by Executive Order. Executive Order No. 11988 encourages the restoration and preservation of the natural and beneficial values served by flood plains and requires the consideration of alternatives to avoid adverse effects and incompatible development in the floodplain. This Order may have many far reaching effects on the state because it may affect many federally funded programs that are vital to the state.

State Flood Damage Reduction Program

1. Comprehensive Flood Plain Management Program

Under the Flood Plain Management Act of 1969, the Department of Natural Resources was directed to: (1) coordinate flood plain management activities at all levels of government; (2) provide technical information on flooding and flood plain management to counties and communities; and (3) assist local governments in developing their own flood plain management programs and ordinances to mitigate flood losses. The Act directs the Commissioner of Natural Resources to establish criteria for determining what flood plain uses are permissible and to establish various procedures and develop criteria for alternative and supplemental flood plain management measures (e.g., such as flood proofing requirements and subdivision regulations).

The program places primary emphasis on non-structural measures, while recognizing structural measures as a necessary component of the program. The major thrust of the program to date have been to identify flood hazard areas, to enroll flood prone individuals and businesses in the National Flood Insurance Program, and to implement local zoning ordinances that regulate additional development of flood plain areas. Other areas of emphasis include the establishment of flood proofing requirements in the state building code, public education, and emergency assistance.

2. Grant-in-Aid Pilot Program

This program was established in 1977 to provide financial assistance to local governmental units located in Minnesota River Basin Area in constructing floodwater retarding and retention structures. Grants under this program are administered by the Soil and Water Conservation Board on a 75 percent state/25 percent local cost-sharing basis. Project selection and evaluation is the responsibility of the Area II Action Committee, in cooperation with the Corps and SCS (both of which are currently participating in the P.L. 87-639 program in that area). To date, three small flood water impoundments (storage capacity: approximately 200 acre-feet each) have been identified for construction.

3. Emergency Programs

The Civil Defense, or "Calamity Act," of 1951 provides the authority for state government to intervene in cases of severe flooding. The Act authorizes the Executive Council to make expenditures of state funds in case of an emergency to prevent impending disaster, or to prevent the occurance or spread of any disaster. The Adjutant General has been appointed as the disaster Relief Coordinator for "Calamity Act" funds. State disaster relief efforts are coordinated by the Division of Emergency Services, which also has the responsibility for administering the individual and family grants made available by a major disaster declaration.

Principles and Criteria for Evaluating and Monitoring Flood Damage Reduction Programs and Projects

Federal flood damage reduction programs and projects are currently subject to examination according to certain principles and criteria. Currently, state programs and projects do not receive this type of evaluation. Criteria are needed to monitor the effectiveness of current programs and to evaluate proposed flood damage reduction measures. Four principles that can be used to establish criteria for evaluating flood damage reduction programs are: (1) economic efficiency, (2) environmental quality, (3) community and regional development, and (4) social welfare. Criteria based on these principles are needed for the state to establish priorities for flood damage reduction programs and projects.

1. Economic Efficiency

The goal of economic efficiency is to ensure that the state does not allocate too few or too many resources for flood damage reduction programs and projects. This is achieved by selecting programs and projects which maximize the amount of benefits over costs. It is not necessary that programs be economically efficient, but it may be a goal for the state to strive to attain. A similar approach can be used to determine the amount of state cost-share for various programs and projects. To ensure that the level of protection sought by local groups is consistent with state interests, local cost-shares should be based on the ratio of local benefits to total benefits. If local costs are zero, local groups will choose a measure that provides the highest level of protection. If local groups are paying a share based on the amount of benefits they will receive, they will opt for more economically efficient measures.

2. Environmental Quality

The goal of environmental quality is to ensure that valuable environmental resources receive consideration and are not destroyed when other measures having fewer environmental consequences may be available. This is achieved by selecting programs and projects that minimize environmental destruction or that enhance some component of the natural environment.

The destruction of the environment represents a "cost" to society that has in the past not received very much consideration in flood damage reduction programs and projects. It has been argued that if these "environmental costs" could be accurately measured, many large projects would never have been built. In cases where alternatives exist, programs and projects with few negative environmental impacts should be selected. In any case, the trade-offs between environmental quality and economic efficiency should be considered.

3. Community and Regional Development

The goal of community and regional development is to stimulate the economic growth of a local area. This is achieved by establishing programs or projects that will provide jobs or additional income in areas that are economically depressed. This principle is frequently misused and can result in projects that are not economically efficient or environmentally acceptable. Programs other than flood damage reduction projects are available that will transfer income to local areas in a more efficient manner so this criteria should be used cautiously.

4. Social Welfare

The goal of the social welfare principle is to reduce the loss of life and threat to health caused by flooding. This is probably best achieved by implementing land use controls and flood warning systems, although this principle can be used to justify programs and projects that are not economically efficient or environmentally feasible. It is difficult, if not impossible, to realistically place a value on human life and health. Where it is practical to accomplish this, it is the primary goal of current flood plain management policy. Social welfare should be considered as a factor in an examination of the economic efficiency of a flood damage reduction project, but social welfare can not realistically be the only factor in project selection.

5. Summary

This brief discussion of principles for the evaluation of flood damage reduction programs is important because the state currently has no criteria for prioritizing or selecting programs and projects. Similar criteria should be used to evaluate the effectiveness of current programs. It was not the intention of this discussion of principles to advocate any of the principles, but merely to point out how the criteria can be used and what they can tell you about different flood damage reduction measures.

Implications of the Current Situation

The floods in Rochester during 1978 illustrated that the current flood plain management program can be effective. Structures built in the flood plain in accordance with standards adopted by the local government were generally protected from major damage. However, over the last decade, several shortcomings of the existing state program have been identified. These include (1) the failure to provide supplemental funding for the implementation of both non-structural and structural flood damage reduction measures and (2) the failure to expand the flood plain program into areas authorized in the Floodplain Management Act due to a lack of priority and staffing and funding constraints.

Land use changes outside of the immediate flood plain area are not considered by the Floodplain Management Act. Some of these changes -- such as wetland drainage and increasing urbanization -- have detrimental effects on flood-rpone areas because they increase flood states above established protected elevations. A closely related concern is the relatively undefined responsibility of a landowner or developer to manage the water which falls on or flows over his property to prevent damage to others.

Finally, federal policy changes may have significant impacts on Minnesota's flood plain management strategy.

Conclusions and Recommendations

Because of the magnitude of current urban and agricultural damages, it is concluded that additional flood damage reduction measures should be adopted in order to enhance the state's approach to flood damage reduction.

1. Expanded state program. Because of the magnitude of the current urban and agricultural damages occurring in Minnesota and the numerous opportunities for action, it is recommended that the flood damage reduction program of the state be expanded and improved.

2. Program emphasis. The primary emphasis of the State of Minnesota should continue to be on non-structural means of floodplain management. Local flood-plain zoning, flood-proofing, and selected land use controls continue to be the most effective means of long-term flood damage reduction.

   There are, however, areas of the state where structural flood damage reduction measures are needed and can be effectively implemented as a part of a comprehensive flood-plain management program. These structural measures should receive full consideration when they are found to be economically and environmentally feasible.

3. Statewide grant-in-aid program for flood damage reduction. Minnesota Statutes, Chapter 104 should be amended to provide for a statewide program of cost-sharing to implement both structural and non-structural components of approved comprehensive flood plain management plans. This program is intended to replace other specific flood damage reduction cost-sharing programs that are currently authorized and funded. The program should be jointly administered by the Department of Natural Resources and the Soil and Water Conservation Board based on a formal agreement between the two agencies. The purpose of the program is to provide incentives to local units to implement flood plain management measures. The amount of the local cost-share should be proportional to benefits which accrue to the local area; the amount of the state cost-share should be proportional to the benefits received by society as a whole from the flood damage reduction project (e.g., benefits which are too widespread to permit identification of direct beneficiaries).

4. Establishment of criteria for evaluating and ranking programs. The Department of Natural Resources and the Soil and Water Conservation Board in cooperation with other state and local agencies should develop joint criteria for evaluating and ranking the

structural and non-structural components of approved comprehensive flood plain management plans. The criteria to be drafted should include but not be limited to: (1) types of programs and projects eligible for funding; (2) percentages or amounts of cost-sharing; (3) environmental and economic considerations; and (4) requirements for evaluation of alternatives.

5. Mandatory disclosure of flood hazard information. Minnesota Statutes, Chapter 104 should be amended to require mandatory disclosure of flood hazard information prior to any property transactions. Persons purchasing land or homes in flood plain areas have not always been able to obtain adequate information about flood hazards. For areas in which studies have been completed, flood hazard information is available through county or municipal zoning administrators and should be provided to the prospective buyer by the realtor or seller before contracts or purchase agreements are signed.

6. Technical and education assistance. Technical assistance for flood proofing, for assistance with applications for state and federal aid, and for information dissemination and education programs are currently authorized by Minnesota Statutes, Chapter 104, but has not received sufficient funding. Training is also needed for local officials responsible for adopting and implementing local flood plain management ordinances. Additional funding should be provided to expand these components of the flood plain management program.

   Many individuals do not fully appreciate the risks of locating in flood hazard areas and do not fully understand the benefits to be gained by purchasing flood insurance or by flood-proofing their residences. A similar situation exists with some small communities, which may be unaware of the types of state and federal acquisition and redevelopment funds or disaster assistance that are available. The economic value of information related to flooding and the steps which can be taken to reduce flood losses is potentially great. The cost of providing this information is low when compared to the reduction in flood losses that can be achieved with increased access to proper information.

7. Evaluation of the effects of drainage on flooding. The State of Minnesota, in cooperation with the appropriate federal agencies, should immediately begin to define the effects of wetland drainage and filling in basins subject to severe flooding. All actions affecting wetlands should be considered in the context of the cumulative effects of wetland drainage and filling on flooding in order to evaluate the true costs and benefits of wetland drainage activities.

8. Flood-warning devices. Information on flash flood-warning devices should be collected and be made available to areas subject to flash flooding and to areas located downstream from dams with possible safety hazards. These devices allow timely evacuation of flood plain areas and help to prevent loss of life. Relatively inexpensive and simple devices are in use in some areas and their use in Minnesota should be encouraged.

9. <u>Mandatory urban stormwater management plans</u>. Minnesota Statutes, Chapter 104 should be amended to include provisions for mandatory urban stormwater management plans meeting minimum statewide standards in urbanizing areas. One function of flood hazard studies is to identify an elevation above which structures will be protected except for the most severe flood events. Increases in urbanization upstream from flood plains may cause flood stages to rise higher than the protected elevation causing increased damages to otherwise protected structures. By retaining the water or delaying it until after peak flood periods, this problem can be alleviated. Maintenance of natural storage areas, provision of on-site or in-line storage areas, and minimizing the amount of impervious surface are all means of reducing flood stages downstream and may also improve water quality. It is easier and less expensive to plan for these features before development occurs than to establish an effective stormwater management program after an area has been extensively developed. (This recommendation also involves water quality benefits.)

WATER QUALITY:
ACTIVITIES AND CONCLUSIONS

Because Minnesota is a headwaters state, control of man-induced water quality problems is a special responsibility. Minnesota has not only its own interests in preserving water quality, but also an ethical obligation to protect the quality of water which reaches downstream users.

While recognizing both the state's interests and its responsibilities, the Water Planning Board and the Supply, Allocation, and Use Work Group are confronted with the fact that the Minnesota Pollution Control Agency and the Metropolitan Council, working under Section 208 of the federal Clean Water Act, are addressing major water quality issues. These activities are being carried on separate from, but in coordination with, the Framework Water and Related Land Resources Plan program.

Through its water quality planning program, the MPCA is beginning to address issues related to water pollution from non-point sources and potential abatement measures. The Metropolitan Council is preparing a plan for achieving federal water quality goals in the metropolitan area through adoption of a sewer system plan and a program for managing and regulating water quality-related facilities. When complete, these efforts will become the water quality elements of the state water resources strategy.

In the interim, the role of the Supply, Allocation, and Use Work Group is to address the present quality of the state's waters; to explore relationships between state water quality programs; and to examine limited, specific issues which might otherwise "fall between the cracks" of the major planning efforts. Because the major water quality elements of the state strategy will await completion of the MPCA and the Metropolitan Council efforts, the water quality selection of this report discusses only the present situation in Minnesota and conclusions and recommendations in limited areas suggested by the public and the Water Planning Board's Water Interests Advisory Committee.

The Current Situation

The quality of Minnesota waters is generally good, but continued and improved careful management is essential if this quality is to be preserved.

The quality of surface and ground-water resources depends in a larger part on natural conditions. Water picks up materials from the air, the ground over which it flows, and the soil through which it infiltrates. Variations in the chemistry of soils and underlying rocks have a strong impact on the quality of the waters that pass through them over time. As water flows in lakes and streams, it is affected by the life forms in the waters (just as the life forms are affected by the quality of the water). Thus, even in the absence of man's activities, there would be "natural" variations in water quality.

However, man's activities have significantly affected the "natural" state. Air pollution has changed the material picked up in the air. Agricultural chemicals and urban construction add contaminants to the ground over which water flows. Disposal of hazardous waste has the potential for influencing water as it infiltrates the soil.

Surface waters are subject to comparatively rapid changes in quality because they are easily reached by natural and artificial contaminants. As a result, many of Minnesota's lakes are now impacted to some degree by the effects of eutrophication. Naturally eutrophic lake examples are found within the prairie-grassland regions of southwestern, western, and northwestern Minnesota. Man-induced eutrophication results from industrial, municipal, or commercial waste system discharges and from erosion or drainage or cultivated farmlands, urban runoff, and septic tank systems. In general terms, lake clarity decreases moving from the northeast to the southwest.

Studies of the Minnesota Pollution Control Agency in 1976 indicated that the majority of the rivers in the state are currently in conformance with national goals for "fishable" and "swimmable" waters. However, large areas of particular rivers and a substantial number of localized areas appeared to be in noncompliance with applicable goals. Twenty-three percent of the 75 water quality monitoring stations assessed in the report were considered to be in noncompliance with one or both of the national goals. Rivers or reaches of rivers in this category were the Mississippi River below Minneapolis-St. Paul; the Zumbro River below Rochester; the Cedar River below Austin; Buffalo Creek below Glencoe; Center Creek below Fairmont; and the headwater tributaries of the Missouri and Des Moines Rivers.

Studies of water quality in Minnesota based upon chemical data collected for municipal water supplies have shown marked deviations depending upon whether the water was supplied from a surface or a ground-water source. These studies indicate that ground water supplying communities in southwestern Minnesota deviated most from currently accepted quality criteria. In addition, the Karst area of southeastern Minnesota faces special problems in relation to ground-water contamination. (In general, however, ground water is considered to be a more dependable source of municipal supplies and is the source of supply for over 93 percent of the municipal suppliers in the state).

Three state agencies are principally involved in the resolution of water quality problems: the Pollution Control Agency, the Department of Health, and the State Soil and Water Conservation Board. In addition, the Minnesota Department of Agriculture, Natural Resources, and Transportation and the state Water Resources Board and watershed districts are involved to a lesser degree.

The state water quality activities involve some 30 separate permitting authorities, non-permitting regulatory activities, and monitoring and study programs targeted on controlling pollution of the state's waters.

There are overlapping jurisdictions in a number of these programs, although this is not necessarily undesirable or damaging. The number of programs and the overlapping jurisdictions tend to highlight the necessity of coordinated, goal-oriented management of programs if water quality objectives are to be met at the least cost to the public.

The costs of pollution control are high in any case. In a June 1977 report to Congress, the MPCA estimated total needs for municipal treatment systems in Minnesota at $1.6 billion (including sewer systems and infiltration/inflow corrections). Soil Conservation Service estimates of agricultural non-point source pollution control for Minnesota are in the neighborhood of $1.2 billion, with lakeshore and streambank erosion controls possibly adding another $700 million to this figure.

However, the benefits of high quality water to Minnesota are also substantial. Beyond the essential health and safety factors, high quality water is central to the tourist industry of the state (which generated expenditures of $1.3 billion in 1976 and produced 115,000 jobs), to many industries, to commercial fishing in the state, and to the overall quality of life enjoyed by citizens of the state.

Conclusions

The review and analysis undertaken by the Supply, Allocation, and Use Work Group led to 10 major conclusions relative to the quality of the state's water and the efforts to maintain water quality.

** The quality of Minnesota waters is generally good, but continued and improved careful management is essential if this quality is to be preserved. Where quality is impaired, it must be improved to ensure the health and welfare of the citizens of the state.

** With the completion of the "208 Plan," the state will have the opportunity to adopt effective programs to address most water quality problems. However, there will be an urgent need to coordinate water quality program goals with the other water resource interests of the state.

** While the Minnesota Pollution Control Agency and several other agencies regularly collect information on the quality of a variety of Minnesota waters, there is no coordinated system for collecting it or disseminating it to potential users. As a result, the State of Minnesota is obtaining far less benefit from available information than could be achieved. At the same time, there is insufficient data to answer many of the specific questions raised by planners, organizations, and individuals.

** To a limited extent, industries which practice water conservation in order to reduce their water costs might also benefit through reduced waste treatment and disposal costs. However, in the future new power plants will consume more water in order to protect waters from thermal pollution.

** There is a need to ensure proper construction and maintenance of on-site waste disposal systems in many areas where no regulation currently exists. (On-site systems include subsurface soil treatment and disposal, as well as alternatives such as composting toilets.)

** The runoff of stormwaters from urban areas creates significant levels of water pollution in some areas. Solutions to such problems are likely to be costly and must be tailored to each locality.

** There is a need for continued close attention to the problem of ground water quality in the Karst (sinkhole) region of southeastern Minnesota. Major efforts may prove necessary to protect ground water resources in the region.

** Maintenance of navigation on the Mississippi River and other commercial waterways will continue to pose water quality problems.

** A few Minnesota cities have historically discharged their treated wastewaters just upstream of lakes. Due to the high cost of reducing the amount of phosphorus in the wastewater -- a measure necessary to the protection of lake water quality -- in a few specific situations these cities have found it more economical to remove their discharges from those lakes, sometimes even into another drainage area. More such situations are expected to arise in the future. Appropriate agencies (e.g., the Minnesota Department of Natural Resources) may find it necessary to take into consideration the potential effect of such moves on water availability.

** There is a substantial body of Minnesota law enabling Minnesotans who live outside incorporated cities to establish rural sewer systems for their communities. Some of this law is not being utilized. A number of districts are created by special legislation, when other authority exists. Revisions in the existing body of law are warranted. In making revisions, care must be taken not to overlook linkages to rural water systems nor the land use implications of rural sewerage. Further, coordination of various state and federal requirements for funding rural sewer systems should be improved.

Recommendations

Within the limited issue areas suggested during public meetings and by the Water Interests Advisory Committee, the Supply, Allocation, and Use Work Group makes the following recommendations:

1. Program management. Because of the number of water quality programs and their overlapping jurisdictions with other programs designed to protect both the quantity and the quality of state waters, it is recommended that these programs be managed in a

coordinated and efficient manner including consideration of geographic variations, in order to achieve state quality-quantity objectives. The Water Planning Board structure may be used to address quantity-quality issues emerging from Framework Plan and "208 Plan" development.

2. Coordination of water quality monitoring. It is recommended that information being collected for management studies and to revise and update a water data catalog be aggregated and used to address the issue of the coordination of water quality monitoring in Minnesota. In addressing this issue, the fact that water quality data are gathered from different purposes by different bodies must be considered. Key options which require examination are (a) centralization of monitoring control, (b) development of a coordinating mechanism between agencies monitoring water quality, and (c) continuation of present approaches, but under memoranda of agreement between agencies. The study of these options should be initiated by the coordinating body and carried forward by the involved agencies. Increased non-point source monitoring must be an element in any case.

3. Trade-offs between effluent standards and conservation measures. Targeting on areas where water conservation measures have a potential impact on water quality, it is recommended that future efforts be made to address issues relating to trade-offs between effluent standards and water conservation measures. The PCA and the DNR must actively coordinate activities in this area.

   In a related area, it is recommended that water quantity concerns continue to be given high priority in power plant siting, specifically including considerations of greater consumptive requirements due to closed system cooling.

4. Strategy for on-site waste disposal. In order to realize the full potential of recent on-site waste disposal rules (sometimes cited as the septic tank rules) adopted by the state in protecting public health as well as water quality, it is recommended that a statewide management strategy for on-site waste disposal be developed. Such a strategy should address: (a) certification of installers and inspectors of on-site systems; (b) proper maintenance of existing systems; (c) adoption of regulations for on-site disposal in all localities in which need is established; and (d) control of adverse land use impacts resulting from non-uniformity among localities in the adoption of regulations. The strategy should be developed under the joint leadership of the Pollution Control Agency and the Department of Natural Resources, coordinated by the state coordinating body, and include the Department of Health and local and regional entity participation.

   The Metropolitan Council has adopted on-site waste disposal policies as a part of its water quality ("208) planning effort. These policies essentially reflect the four-part strategy outlined in this recommendation.

5. Reduction in runoff. Stormwater runoff -- including its effects in areas undergoing construction activities and on overflow from combined sewers -- has been identified as a significant contributor to water quality problems in the metropolitan area and in developing areas across the state. It is anticipated that the MPCA and the Metropolitan Council will make recommendations for actions by other entities (e.g., counties, soil and water conservation districts, watershed districts, and municipalities) in their "208" plans. These responsibilities are expected to include developing plans and programs for the abatement of pollution through runoff controls and adoption and enforcement of erosion and sedimentation controls. It is recommended that the MPCA and the Metropolitan Council place additional emphasis on measures to reduce runoff and increase infiltration of non-polluted water, on erosion and sediment control measures, and on measures to deal with pollutants other than sediment. Further it is recommended that proposals resulting from the "208" plans be carefully reviewed and adopted by the state, as appropriate.

6. Dredging and channel maintenance. With regard to dredging and channel maintenance, it is recommended that (a) the findings of GREAT I (an investigation and development of a management plan for the Mississippi River, with particular emphasis on a balanced plan for maintaining the 9-foot navigation channel) be carefully reviewed and adopted as appropriate; (b) where GREAT I leaves unanswered questions, the authorized "Master Plan" for the Upper Mississippi River carry out additional priority studies, including economic and energy-related studies; and (c) that the Corps of Engineers -- in coordination with the state -- fully examine the environmental consequences or its dredging and disposal at each site prior to dredging and use mitigating measures as necessary to comply with state requirements.

7. Management strategy for rural sewerage. It is recommended that a statewide management strategy for rural sewerage be developed in coordination with the rural water system recommendations in this report. This management strategy must balance potential land use impacts of expanded sewer systems; the potential effect on agriculture; environmental benefits; and other social considerations, including impacts on area growth strategies.

   Further, it is recommended that (1) the existing waste disposal system laws be examined to determine what revisions might be made to reduce special local enabling acts (while retaining sufficient flexibility at the local level) and (2) coordination of various state and federal requirements for funding rural sewer systems be improved.

8. Development of minimum protected flows. The Water Planning Board recommends that the Department of Natural Resources and the Pollution Control Agency, in consultation with other interested bodies (e.g., the Environmental Planning staff of the SPA), coordinate actions to develop minimum protected flows guidelines,

reflecting both quantity and quality concerns, for high-priority rivers and streams in Minnesota. The process of developing such guidelines must take into account the purposes for which protection is being provided, recognizing that the same protected flows may not be appropriate for all purposes.

9. Funding. The Water Planning Board recommends that full attention be given to balancing point source and non-point source pollution control abatement efforts. While funds have been available for dealing with control of point sources, a signficantly lesser amount has been available for non-point source abatement.

As indicated above, the Supply, Allocation, and Use Work Group recommends that the water quality planning program recommendations of the Minnesota Pollution Control Agency and the Metropolitan Council be fully reconciled with the Framework Water and Related Land Resources Plan strategy and become the principal water quality elements of the state water resources strategy. Similarly, the findings of the Soil and Water Conservation Board resulting from efforts related to carrying out the Resource Conservation Act in Minnesota should be integrated into the framework plan strategy, as appropriate.

LAKE MANAGEMENT

Minnesota harbors much of the nation's wealth of lakes, not only in abundance but in variety. Because the physical and biological characteristics of a lake are an expression of topography, climate, geology, and soils, Minnesota's lakes range from the deep, cold, nutrient-poor lakes of the northeast to the shallow, eutrophic, warm-water lakes of the southwest, including acid bogs, nearly saline prairie potholes, glacial lake remnants, beaver-dam impoundments, and ox-bow lakes. This natural variation influences the use of lakes and requires recognition of the natural limitations of any given lake. The individuality of a lake -- or a group of lakes -- has important implications for its protection and management.

Minnesota's Lake Resources

The topography of Minnesota and its lake resources have been shaped by four glaciations. In southeastern and southwestern Minnesota, the ancient glacial material is thick and has been untouched by the more recent glaciers responsible for lakes in the rest of the state. Erosion in the intervening years has produced steep-walled valleys and eliminated nearly all the glacial basins which once existed, so that few natural lakes now exist in these areas (Figure 15). The remainder of the state owes its rich lake inheritance to the Wisconsin glaciation, considered recent in geologic terms. These lake basins are the result of depressions in ground moraine, pre-glacial valleys dammed by moraine, "kettles" created by melting blocks of ice in glacial material, or by irregular depressions in the beds of ancient glacial lakes (such as Red Lake in glacial Lake Agassiz). Although some Minnesota lakes have resulted from stream processes (erosion and deposition), most of the 15,291 lake basins larger than ten acres are of glacial origin. More than 3,250 of these basins in the agricultural zone and in ancient glacial lake beds have been lost to agricultural drainage.

The geological origin of a lake and its watershed influence its shape, water chemistry, and biota. Lakes gouged in bedrock by passing glaciers are often deep, steep-sided, and have nutrient-poor watershed soils. As a result, the oxygen-rich deep water, limited littoral zone, and lack of dissolved material limit productivity, inhibit the development of aquatic plants, and enable maintenance of a cold-water fishery. In contrast, saucer-shaped depressional lakes in ground moraine with rich soils have a large littoral zone, nutrient-rich warm water, and extensive production. These shallow lakes may support dense aquatic plant beds and warm-water fisheries with lower oxygen requirements.

Climatic conditions also determine the characteristics of lakes. The relationship between precipitation and evaporation influences both the chemical content of lakes and their water level stability (Figure 16).

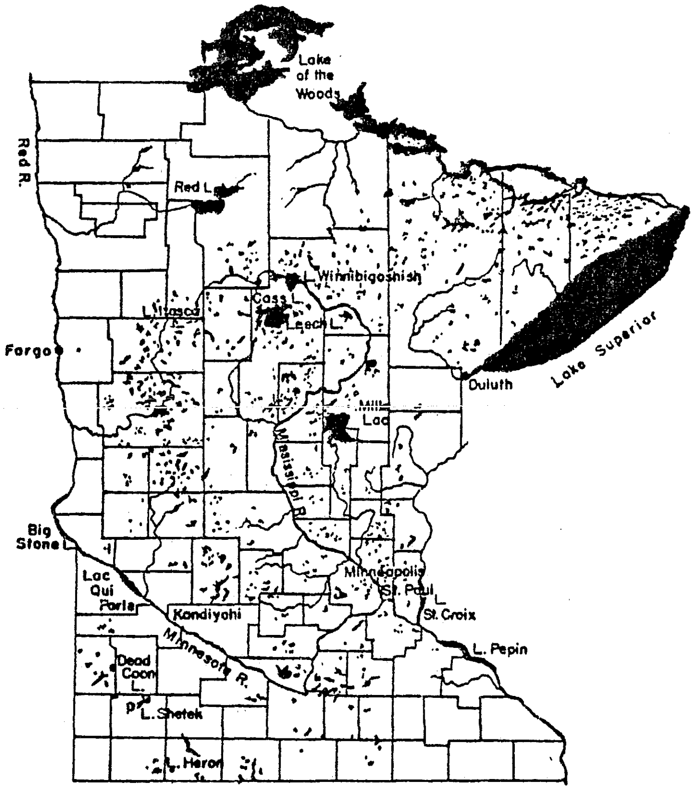


FIGURE 15. General distribution of lakes and major streams in Minnesota (Eddy, 1966).

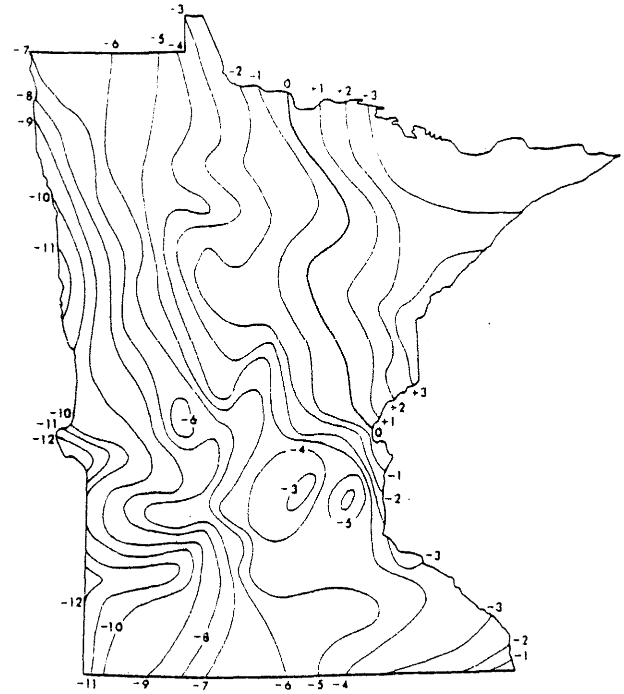


FIGURE 16. Annual precipitation minus evaporation, in inches (Bright, 1968).

"If precipitation significantly exceeds evaporation, as in northeastern Minnesota, lakes will have outlets and therefore relatively low mineral concentrations, because of a continual flushing action. If, on the other hand, evaporation exceeds precipitation, as in southern and western Minnesota, the local soluble minerals are likely to become concentrated in lake water. Lakes in these areas lose relatively little water through their outlets" (Lundquist, 1975, p.9).

The existence of an outlet for a lake also influences the stability of water levels, as does the size of the watershed and the source of water. Lakes dependent on surface water, rather than ground water inflow, are more likely to fluctuate rapidly in response to precipitation, and larger watershed to lake area ratios increase the effect. Lakes with large watersheds are often found in flat, ditched regions (such as glacial lake beds) rather than rolling, irregular terrain. Lake outlets act as natural elevation controls, but land-locked lakes must fluctuate in response to water supply.

Regional Trends

Regional trends in lake characteristics are evident. They are due principally to gradations of soil and climate. However, local variations within a region usually exist.

Generalized trends of a number of lake parameters (including alklinity, nitrogen, phosphorus, dissolved constituents, lake clarity, and related biological indicators) exhibit increases southward and westward from the very low concentrations of the bedrock lakes in Cook and Lake Counties (Figure 17 exhibits isolines for phosphorus, the element assumed to be the limiting factor for the productivity of most lakes). This pattern is also reflected in Lundquist's generalized map of lake types (Figure 18).

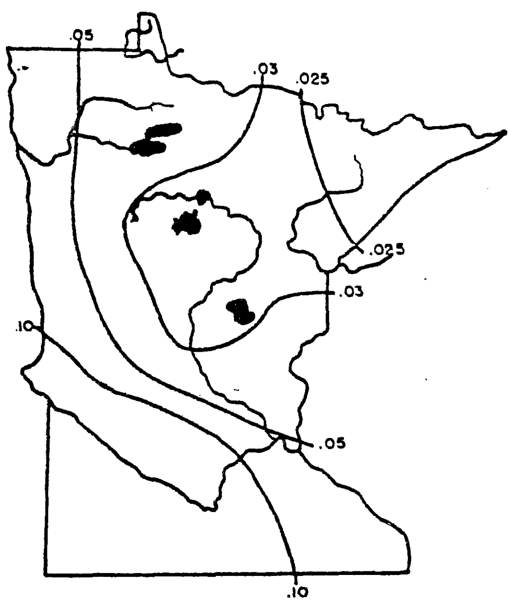


Figure 17. Isolines for mean concentration of total phosphorus in ppm for surface waters of Minnesota (Eddy, 1966).

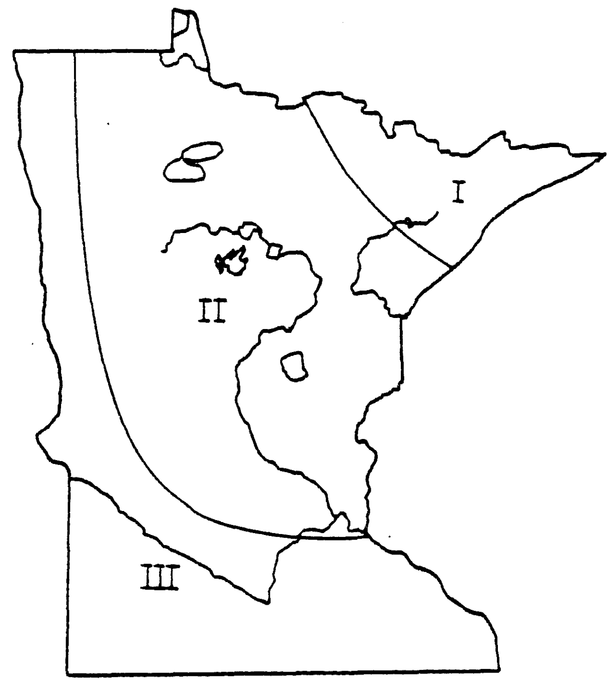


Figure 18. Distribution of lake types in Minnesota (Lundquist, 1975).

The distribution of lake types in Minnesota can be described in terms of three areas:

** <u>Area I</u>. The water basins of northeastern Minnesota are deep, steep-sided basins carved by glaciers in pre-Cambrian rock. Glacial drift is thin, the land is forested, and the limited flow of nutrients from watersheds to lakes limits productivity. The oxygen-rich waters of deep lakes permit a cold-water fishery (e.g., lake trout and whitefish). Shallow lakes house pike, walleye, and perch which tolerate lower winter oxygen levels. Most lakes are oligotrophic or mesotrophic.

** Area II. Lakes in north-central Minnesota occupy depressions in glacial till with ample nutrient supply. They are considered mesotrophic or eutrophic. Most are very productive, have extensive and gently-sloping littoral zones, and may undergo summer oxygen depletion. The large fish populations may include walleye, bass, crappie, pike, and perch, but exclude lake trout and other cold-water fish.

** Area III. Most lakes in southern and western Minnesota are considered eutrophic. Soils are fertile, agriculture is the dominant land use, and high evaporation rates concentrate dissolved materials in lakes. Dense growths of aquatic plants, blooms of blue-green algae, and poor water clarity can be expected. The decomposition of large quantities of organic matter cause oxygen depletion. Fish present include the species common to Area II, plus carp and bullheads.

Lake Management Problems

Several of the principal problems related to Minnesota's lakes have been alluded to in other sections of this paper and in other water resource-related assessments. However, no comprehensive assessment of lake problems or practical lake improvements has been compiled by state lake management authorities.

In assessing lake management problems, it is important to recognize that problems involve the perceptions of the user. The natural limitations of lakes may require that users alter their expectations for the resource, rather than alter the resource itself.

For Minnesota, general problems relating to lake management include (1) eutrophication, (2) water level fluctuations, (3) surface use conflicts, (4) lakeshore development, (5) public access, and (6) drainage.

1. Eutrophication

Eutrophic lakes are highly productive as a result of abundant nutrient supplies, which may be either natural or man-induced. High rates of organic production can result in extensive weed beds and poor water clarity, but also provide a large biomass of fish.

Man-induced, or "cultural" eutrophication, can result from both point sources and diffuse (i.e., non-point) sources of nutrients. Cultural eutrophication is of greatest interest because it is subject to control. Point-source discharges are now under regulation, although many lakes still receive such effluent. Approximately 150 to 200 communities still discharge secondary effluent to lakes, subject to effluent standards. Non-point sources are presently subject only to limited voluntary control.

Cultural eutrophication can be retarded by controlling the movement of both nutrients and water from land surfaces. Some mitigating land management techniques involve nutrient retention (e.g., manure storage, erosion controls, proper septic tank installation, and sediment ponds), while others focus on offsetting the increased runoff from urbanization and agricultural drainage. These preventative "best management practices" are fundamental to the protection of lakes from accelerated eutrophication.

The restoration of culturally eutrophic lakes has been undertaken in several areas in Minnesota. The primary emphasis has been in urban areas where land use decisions are largely irreversible. Restoration techniques are extremely expensive and have been supported largely by state and federal funds, in part because restoration techniques demonstrate an evolving technology with national applications. Restoration, however, is a last resort involving considerable expense and ecologic manipulation, with no guarantee of achieving the desired effect. In addition, simultaneous application of protective measures is required.

There has been no comprehensive effort to classify Minnesota's lakes by trophic state, although the Minnesota Pollution Control Agency is accelerating its efforts in this area. Some indication of the extent of the problem is provided in Figure 7 (Chapter 1) and in the water quality section of this report.

2. Water Level Fluctuations

Lake levels fluctuate as a result of natural variations in precipitation, runoff, water table elevation, evaporation, and related hydrologic conditions. Many man-induced factors, such as outlet modifications, withdrawals and diversions, and land use changes (e.g., urbanization and agricultural drainage) can be significant. The usual effects of low water levels are aesthetic, such as exposure of the lake bed, although extreme cases can impair recreational use, water supply, and disrupt wildlife habitat. Elevated water levels can inundate lakeshore homes, accelerate shoreline erosion, and cause septic tank failure.

Where water-level fluctuations are not man-induced, a preventive and educational effort may be relied on to reduce conflicts. Determination of extreme and natural high water elevations, coupled with a notification of these levels to buyers in real estate transactions, may help lakeshore residents recognize the lake's natural limitations.

Man-induced water level changes can only be evaluated on a case-by-case basis. Case-by-case evaluations are currently being carried out through the Department of Natural Resources' Lake Hydrology Program.

3. Surface Use Conflicts

Many of the recreational uses of lake surfaces create conflicts under the present uncontrolled water surface use system. The principal conflicts are those between activities which require large areas because of high speeds (e.g., motorboating and water-skiing) and activities which are low-speed (e.g., canoeing, sailing, and fishing). However, an important related issue is the respective use right of the riparian and the non-riparian, for which no state or local policies exist.

Surface use management is becoming increasingly important in the metropolitan region. A study by Wietecki and Orning (1973) found that nearly 70 percent of boat owners in Ramsey County believed water surface use regulations were needed on county lakes. Of the 85 lake basins studied, nineteen received 90 percent of the water-recreation use.

The interrelationship of lakes in providing recreation throughout Minnesota suggests that an important surface water use concept is the management of related lakes as a single system, since changes in the use of one lake in the system affect the uses of other lakes in the system. As demand increases, it is likely to become increasingly apparent that a given lake cannot fulfill the needs of all users and that lake characteristics must be considered in regulating use.

Authority exists for local units of government in Minnesota to segregate and intensify surface uses through regulation of public facilities, accesses, and lake-surface-area and time-for-use zoning. Perhaps because of the lack of organization of lake users and the absence of state guidance and policy recommendations, very few counties have enacted controls.

4. Lakeshore Development

Ten years ago, the University of Minnesota carried out a comprehensive study of Minnesota's lakeshore (Borchert et al., 1970). No revision of this basic study has been undertaken, although the implementation of shoreland zoning in the interim has certainly affected many of the study's observations. The failure to monitor current lakeshore development is an obvious deficiency in statewide lake management.

The 1970 study found that the growth rate of seasonal homes was lower than generally estimated, but that most development was concentrated on only about 14 percent of the lakes. Though hundreds of miles of lake shoreline were found to be undeveloped, lakeshore homes on developed lakes reached densities nearly urban in character. A major factor in the density of development was proximity to urban centers (Figure 19).

Development of lakeshore property can modify both the quality of the resource and the character of the recreational environment. Some of the most important related effects include: (1) problems with waste disposal systems which may fail or be improperly installed; (2) clearing of vegetal cover, increased erosion, and loss of natural character; (3) increased surface use requirements; (4) incompatible land uses; (5) stormwater runoff and pollution from urban areas; and (6) dissatisfaction of residents with natural conditions of the lake (e.g., algae blooms, aquatic plant growth, and fishing). Recent studies indicate increasing lakeshore development devoted to permanent dwellings and planned unit developments, with undetermined effects on recreational demand (surface use conflicts) and related urban development.

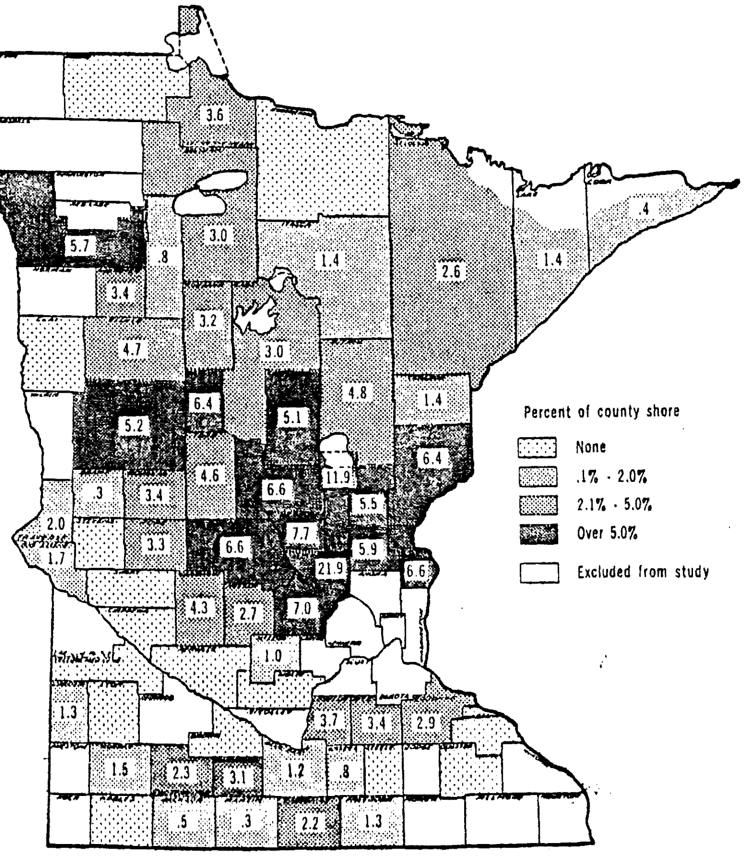


FIGURE 19. Percent of county shoreline with excessive development (less than 100 feet of shoreline per dwelling), from Borchert et al. (1970).

The Shoreland Zoning Act was intended to alleviate some of these problems. Unfortunately, there is no reliable assessment of its success, and no monitoring of lakeshore development. Some adverse effects of shoreland development are clearly beyond the scope of the present program. The 1970 Lakeshore Study projected a decrease in the rate of lakeshore development, but no statewide data has been gathered to verify this estimate. Additionally, the granting of variances by county administrators has not been monitored for consistency with state criteria.

5. Public Access

The provision of public access is essential to the use and enjoyment of over three million acres of open space already in public control (i.e., the surface area of Minnesota's lakes). Although the total acreage of lakes which are not accessible to the public is unknown, the Department of Natural Resources does provide data on the existence of public accesses. Of 1,700 public accesses, 1,000 are owned by the state, 500 by local units of government, and 200 by the federal government.

The Department of Natural Resources is required by law to acquire public access to lakes, except on lakes less than 150 acres. There are about 2,700 such large lakes in Minnesota. Thus, there are at least 1,000 large lakes without public access and perhaps 10,000 smaller lakes subject to state control but not readily accessible to the public. Although it is unreasonable to expect to provide universal public access, there is no definition of state interests in lakes with which to guide the purchase and development of lake access.

Public access development has become a particular issue in the metropolitan area, where energy conservation demands may dictate the provision of increased lake recreation opportunities in proximity to the bulk of the state's population. Public use of many state-owned lakes in the metropolitan area is prohibited or discouraged by self-interested riparians or municipalities fearful of disruption by unregulated lake users. Though adequate authority exists to control lake uses, local lake management agencies have not assumed leadership and the state has not exerted pressure to open metropolitan lakes to controlled public use.

6. Drainage

Agricultural drainage and wetland conversion are considered in some detail in other sections of the Work Group report. However, the direct impact of drainage on relatively large lake basins cannot be ignored (Figure 20). This is true particularly in south-western Minnesota where few natural lakes existed even prior to settlement. In general, drainage of wetlands within a lake's watershed may alter lake quality and quantity through increased runoff and probable loss of nutrient and sediment retention.

7. Other Problems

Because of the relationship between a lake and its watershed, many land use modifications will have some impact on lake quality or hydrology, including urbanization, construction, agricultural practices, and wetland filling. Most such modifications are under consideration in the Pollution Control Agency's Water Quality Management Planning Program.

Additionally, lakes, reservoirs, and river pools are an important water supply source in Minnesota. Over 41 percent of all water withdrawn for use in Minnesota in 1976 was withdrawn from lakes. About 250 active appropriators withdraw from lakes, including Reserve Mining and several power plants. Maintenance of "protected" lake elevations has been mandated by the Legislature, although such an elevation has been established only for one lake.

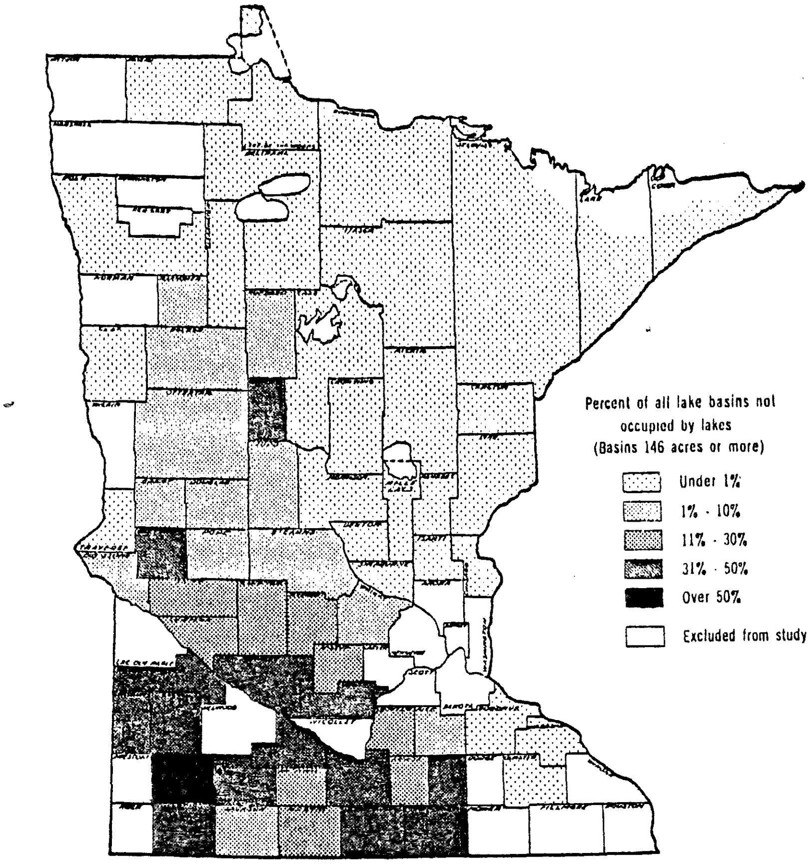


FIGURE 20. Concentration of dry lake basins (Borchert, 1970).

Conclusions and Recommendations

As in many other water-related issue areas, information from which to draw detailed conclusions and recommendations about lake management in Minnesota is limited. This limitation may be especially critical because:

** Minnesota relies heavily on its lake resources to support a $1.3 billion tourist travel industry;

** The recreational opportunities provided by Minnesota lakes are a key to the high quality of life found in the state;

** Energy conservation measures may require readjustment of recreational patterns, placing expanded pressures on lake resources in the metropolitan area; and

** Lakes are an important water withdrawal supply for many industries in the state (e.g., mining and electrical power) which are highly consumptive now and may be more so in the future.

Therefore, to focus on central issues, information needs, and optional solutions in the major problem areas, it is recommended that the State of Minnesota sponsor a major lake management conference within the next 12 months. The conference should be coordinated through the Water Planning Board and should involve local, state, and federal entities, special districts, interested organizations, and concerned citizens. The conference should address the conclusions and recommendations which follow.

In problem-related areas, the Work Group, drawing both on its own studies and those of the Management Work Group, concludes:

1. Current lake management programs in the state lack comprehensiveness and direction toward common goals. Lake management authority is fragmented among many state and local institutions, leading to independent decision-making which may not produce unified results. Therefore, it is recommended that:

   A. The state establish goals for lake management and develop policies for programs to effectuate those goals. These goals must consider the roles of both state and local units of government.

   B. Diverse lake management programs be examined to consider their cumulative effects on a lake. Lakes may be considered as basic management units affected by many independent programs. This consideration could be accomplished through development of comprehensive lake management plans for individual lakes or groups of interrelated lakes, carried out by state agencies or by local/regional agencies meeting minimum state requirements.

   C. Lake management programs interrelate program plans and implementation to achieve common objectives. Programs often lack a clear and precise statement of purpose and fail to incorporate interactions with related programs. Acknowledgement of and formalizing the interrelationships among programs could achieve mutual objectives more efficiently. For example, state financial assistance to lake management authorities (counties, lake improvement districts) could be tied to compliance with shoreland management, urban stormwater management, or enactment of erosion controls.

   D. Lakes be classified and a group of high-priority lakes, or lakes of particular state interest, should be identified. Several programs need a common lake classification -- or a common data base -- with which to establish priorities and allocate program efforts. These activities include public access development, lake improvements, non-point source abatement, surface use zoning, and establishment of lake protection elevations. Divergence of individual program priorities should clearly reflect divergent program objectives.

   E. Efforts be made to segregate lake uses and determine lake "carrying capacity," due to increasing demands on lake resources. Because many lake surface and lakeshore uses are incompatible, increasing demand will render multiple-use management an inefficient allocation of lake resources. As lake uses intensify, the ability of a lake or a group of lakes to sustain a particular use -- surface use, nutrient loadings, lakeshore development, or water withdrawals -- must be considered by lake management authorities prior to irreversible commitments.

2. Measures to insure the protection of lakes must be established. Lake rehabilitation technology is expensive, relatively unproven, and is rarely undertaken without federal financial assistance. Although restoration is desirable, it is prohibitively expensive without subsidy. Public funds will usually provide greater water quality benefits through protection rather than rehabilitation.

   Most lake protection measures involve land management practices, and are being considered by PCA's Water Quality Management Planning Program. Additionally, increased authority for the planning, control and/or permitting of urban stormwater discharges is necessary.

3. Lake data should be consolidated and some data-gathering efforts should be accelerated. Although the abundance of Minnesota's lakes is a rich inheritance, their management is also a tremendous administrative burden. Data collection activities require considerable financial and personnel commitments, and many state and local lake management programs base decisions on less than adequate information. This situation has resulted in cases where the "tail of available data wagged the dog of management policy" (Bryden, 1977, p. 807), as evidenced by classification of lakes and streams for the Shoreland Management Program. There is a clear need either to establish a common lake data base or to ensure that independent lake data-gathering activities provide computer-storage in a universal format.

   Several efforts have begun to provide a structure for housing lake-related data, including the Lakeshore Development Study, Clean Lakes Inventory File, Minnesota Land Management Information System, USGS Metro Area Lake Data Base, and the Water Planning Board/DNR Water Use Data Base. However, deficiencies exist and these structures need a means of interrelating (e.g., a common lake identifier), which would also facilitate lake classification. Additional data is required for monitoring shoreland development, determining lake nutrient budgets, and assessing the impact of non-point sources.

   Particular research needs have been identified to (1) improve understanding of lake hydrogeology for determining lake hydrologic budgets, and (2) to document a method of establishing Natural Ordinary High Water Elevations.

4. A state/local cooperative relationship must be established to effectively manage lakes. Local units of government, including counties and special purpose districts (lake improvement, lake conservation, watershed, and soil and water conservation districts) have been delegated considerable lake management authority by the state. Delegated lake management functions include surface use zoning, shoreland zoning, septic tank inspection, and some kinds of permit issuance. Local units of government also provide proximity to lake users, can tax properties, and have familiarity with the potential and problems of an individual lake.

   The state is the ultimate protector and developer of Minnesota's lake resources, and as such retains most of the lake management authority and houses resource data and expertise. State government can reflect concerns of greater than local significance and can transcend local special interests.

   Several programs have already attempted to implement the concept of state/local shared authority, involving the state's provision of minimum standards followed by local adoption and administration. The Shoreland Management Program exemplifies both the strengths and weaknesses of this approach; the county ordinance reflects local needs, is administered by responsible local officials, and protects the county's interests in lake quality and tourism. From the State's perspective, a minimum degree of protection is being afforded all lakes, and a local awareness of lake protection has evolved. However, two inadequacies are apparent -- the lack of state assistance to perform inspection and aid local administration, and the failure of the state to adequately monitor local performance. These deficiencies may be largely the result of limited financial support from the legislature.

   This state/local cooperative relationship should be the cornerstone of other lake management programs, particularly those involving lake protection -- such as erosion control, urban stormwater management, and other non-point source control measures.

5. Increased effort should be made to carry out and enforce existing lake management legislation. Minnesota's legislature has mandated several lake management programs which have progressed slowly due to either insufficient funding and staffing or low priority given by the responsible agency. Among these are the following:

   ** Failure to develop rules and regulations for lake improvement districts (DNR, 1974, M.S. 378.41 Subd. 2), surface use zoning (DNR, 1975, M.S. 361.36 Subd. 1a), and appropriations from lakes (DNR, 1975, M.S. 105.41 Subd. 1a). Several postponements have been granted in development of these, but no final regulations exist at this date. (Editor's note: Since completion of the original draft of this report, DNR has begun development of these rules and regulations.)

** Failure to develop a statewide plan for water and related land, including provisions dealing with lakeshore development, control of water weeds, regulation of lake water levels, regulation of water surface use, and management of fish resources (DNR, 1975, M.S. 105.403).

** Delay in implementation of municipal shoreland zoning (DNR 1975, M.S. 105.485 Subd. 6) and failure to monitor the consistency and administration of enacted ordinances. DNR has not been able to meet this large burden in a timely manner, and no data base exists by which to judge the impact of delayed implementation.

** Failure to complete an assessment of the need for lake improvements (DNR, 1975, M.S. 105.484) and to provide criteria for the allocation of state aid. The responsibility was assigned to the DNR with the intended assistance of PCA and the State Planning Agency.

Many other lake management activities have not been undertaken or have progressed at a reduced level -- including establishment of lake protection levels (DNR), coverage of lakes in the Lake Monitoring Program (PCA), and the public waters inventory (DNR). Each case may have unique factors causing the lag in implementation, but the end result is continued inactivity. This situation is further aggravated by the lack of knowledge on the consequences of such delays.

WETLAND MANAGEMENT

The modification of wetlands through agricultural drainage and urban development is perhaps the most emotional and pervasive issue in Minnesota's management of water resources. The controversy crosses many units of government, where decision-making often has been based largely on political considerations rather than on applied research and resource inventories. The issue is significant not only because it addresses the bounds between public and private rights, but because wetland resources influence agricultural production, flooding, water quality, wildlife, and water supply throughout the state.

This chapter provides an overview of the state of wetland values and management in Minnesota, relying extensively on existing documentation available to the Water Planning Board. Wetland management issues involve a range of complex scientific, economic, legal and political problems which deserve a more thorough analysis. However, the concepts reflected in this chapter and the supporting materials produced by the Management Work Group provide a sufficient basis for recommending several improvements in wetland management.

The Nature of Wetlands

Discussion of wetland management issues has been complicated by a lack of information and imprecision in terms. Those areas which are not clearly either land or water may commonly be referred to as "wet land", "wet soils" or "poorly drained soils," and some of the confusion regarding the extent of wetland drainage in Minnesota results from this problem. A definition of wetlands may rely on any of several characteristics, including type of natural vegetation, relationships to ground water or surface water, size, and soil type. For purposes of this report, a wetland is considered to be an area with shallow surface water and/or waterlogged soil capable of naturally supporting moist-soil vegetation. The classification system referred to is that described in U.S. Fish and Wildlife Service Circular 39 (Shaw and Fredine, 1971), which is also cited by relevant passages of the Minnesota Statutes. The eight types of inland fresh areas (adapted by Johnson, 1976) are:

Type 1 Seasonally Flooded Basin or Flat - A type of wetland which is covered with water, or is waterlogged during some seasons but is usually well-drained during most of the growing season. Vegetation on this type of wetland is quite variable -- ranging from bottomland hardwood forests to open meadows. This type of wetland may be found in an upland depression or in an overflowed bottomland.

Type 2 Fresh or Wet Meadow - A type of wetland which is not covered with standing water, but is waterlogged within a few inches of the surface during most of the growing season. Characteristic vegetation on this type of wetland includes grasses, sedges, rushes and various broad-leaved plants. Representative plants are sedges, rushes, redtop grass, reed grasses, manna grasses, prairie cordgrass, and mints. This type of wetland may occur in a shallow lake basin, slough, farmland sag or on the edge of a shallow marsh.

Type 3 Shallow Marsh - A type of wetland which is usually waterlogged during the growing season and often is covered by water six or more inches deep. Vegetation characteristic of this type of wetland includes grasses, sedges, bulrushes, burreed, spikerushes, cattails, arrowheads, pickerelweed and smartweeds. This type of wetland may occur in a shallow lake basin or slough, on the edge of a deep marsh, or as a seep area on irrigated land.

Type 4 Deep Marsh - A type of wetland which is covered with 6 inches to 3 feet or more of water during the growing season. Vegetation characteristic of this type of wetland includes cattails, bulrushes, spikerushes and wild rice. This type of wetland may occur in a shallow lake basin, a pothole, limestone sink, slough or on the edge of open water.

Type 5 Open Water - A type of wetland which is covered with three to ten feet of water and has emergent vegetation along its edges. Vegetation characteristic of this type of wetland includes pondweeds, waterlilies, wild celery, coontail and water milfoils. This type of wetland includes shallow ponds and reservoirs.

Type 6 Shrub Swamp - A type of wetland which is usually waterlogged during the growing season and which is often covered with as much as six inches of water. Vegetation characteristic of this type of wetland includes alders, willows, and dogwoods. This type of wetland may occur along a sluggish stream, on a floodplain, or on a disturbed wet meadow or shallow marsh.

Type 7 Wooded Swamp - A type of wetland which is waterlogged within a few inches of the surface during the growing season and which is often covered with as much as one foot of water. Trees characteristic of this type of wetland include American elm, silver maple, tamarack, white cedar, black spruce, balsam, red maple and black ash.

Type 8 Bog - A type of wetland on acid peat which is waterlogged. Vegetation characteristic of this type of wetland includes health shrubs, sphagnum moss, sedges, black spruce and tamarack. This type of wetland may occur in a lake basin, along a sluggish stream, or on a watershed divide.

A Historical Perspective

In the last century the ownership, management, and public perception of wetlands have changed dramatically. Wetlands were viewed in the late nineteenth century as a menace and a hindrance to land development, stimulating both state and federal action to encourage land reclamation. In 1860, the provisions of the Swamp Act were extended to Minnesota, granting to the state the federally-owned wetlands and inundated land not sold to settlers or otherwise transferred. The unsold swampland could be claimed by the state and sold, with the proceeds used to finance levees and drainage works. The prevailing attitude was reflected by the Supreme Court (Johnson, 1976, p. 30):

> "If there is any fact which may be supposed to be known by everybody and therefore by courts, it is that swamps and stagnant waters are the cause of malaria and malignant fevers, and that police power is never more legitimately exercised than in removing such nuisances."

The federal government transferred over three and one-third million acres of wetlands to Minnesota in this manner. Although the specific history of these lands has not been researched, most States abused the Swamp Land Act by bartering the land for unrelated purposes, giving it to railroad companies, or otherwise subverting the purposes. Most lands were put into private ownership, often at a price of pennies per acre.

In Minnesota many original wetlands have been put into useful agricultural production. The ditching of wetlands was unregulated until formation of the Drainage Commission in 1893, and was readily undertaken until regulatory authority was housed in the Department of Drainage and Waters in 1919. In this period there was a ready market for land, counties promoted private ownership and an increasing tax base, and mechanization facilitated the construction of large ditches. It was a "boom" era of land promotion, optimism, and growth, and by 1920 the Agricultural Census showed that nearly one-fourth of Minnesota had been drained.

The drainage activity soon slowed. Some drainage projects, particularly in northern Minnesota, failed economically and the lands were forfeited for taxes; the State paid the ditch bonds, took title to the lands, and although much of the better agricultural lands were returned to private ownership, some are now held as State Forests and Wildlife Refuges. The drought years of the 1930's imperiled agriculture and served to restrain drainage activity, and some of the first legislation restricting drainage was passed by the State.

The 1940's and 1950's brought an increased demand for farm products, favorable prices, and the stimulus for additional wetland drainage. The growing awareness of the value of wetlands for wildlife production heightened the controversy over continued agricultural drainage. By 1955, the waterfowl production capabilities of southwestern Minnesota (Cottonwood, Wantonwan, Jackson, Martin, Faribault, Murray, and Nobles counties) had been virtually destroyed, and drainage projects in Redwood, Brown, Nicollet, Sibley and Renville counties were rapidly decreasing wildlife values (Mann, 1955). Much of this activity was subsidized by federal cost-sharing assistance to landowners.

In the subsequent years the trend of increasing scrutiny of drainage projects has continued, including statutory changes requiring permits for new projects affecting public waters, review of large projects in Type 3 wetlands, and consideration of environmental impact in improvements to ditch systems. Federal and State acquisition and "water bank" programs have been provided for wetland protection, and in Minnesota federal assistance is no longer available for cost-sharing drainage of Type 3 (or deeper) wetlands. Nevertheless, drainage projects continue to be undertaken, legally and illegally, although much of the activity involves improvements or rehabilitation of systems in disrepair.

This change in perception, reflected in both public opinion and governmental programs, results from a growing awareness of the public benefits provided by wetlands in a natural state. Although documentation of these values is far from complete, there was sufficient evidence to prompt Minnesota's Legislature to recognize the "beneficial public purposes" provided by wetlands, including recharge of ground water, mitigation of flooding, nutrient and sediment entrapment, and provision of wildlife habitat and recreational enjoyment.

Wetland Values

Wetlands provide benefits in both natural and modified conditions. Among the most important are the following:

1. Biological Functions.

   Several types of benefits are related principally to the biota in a wetland community and have been well documented elsewhere. They include:

   A. Primary and secondary production.

   Wetlands are the most productive ecosystems known, having very high rates of photosynthesis. The conversion of solar energy is the fundamental source of stored chemical energy for higher trophic levels, including such economically valuable species as migratory waterfowl and sport fish.

   B. Provision of habitat and reproductive sites.

   In addition to providing habitat for resident species, wetlands are seasonally important to migratory species, and provide nesting/spawning and cover sites for waterfowl, upland game and fish.

   C. Genetic diversity and ecosystem stability.

   Wetlands serve as "refuges" which harbor considerable genetic variation in the species present. It is a general concept in ecosystem theory that diversity provides stability, such that a wide range of responses are available to dampen the effects of any perturbation. These benefits become increasingly important as a landscape approaches uniform land use (e.g., farmlands in monoculture).

D. Refuges for endangered or rare species.

2. Water Quality Effects.

Wetlands are often considered to be highly valuable for the removal of pollutants from influent water. While the generalization is valid, wetlands differentially affect various constituents, and the removal efficiency varies with seasons and loading rates.

Suspended solids (sediment) are perhaps most efficiently removed by wetlands, accomplished by (1) reduction in the velocity of influent water, (2) filtration through vegetation and litter, and (3) ionic attractions. Some deposition provides nutrients and other benefits to a wetland, but excessive sediment loads will likely alter the natural species and functions. Nutrients are less efficiently removed, but the significance of any removal must be judged in relation to the total nutrient load of the receiving water. Most studies have shown a wide range of nutrient removal due to differences in wetland types, season, and length of observation.

Removed nutrients are incorporated in the organic soils and vegetation of the wetland. Nutrient removal is probably greatest during the active growing season when stormwater loads are low, and nutrients are flushed from decaying plant litter in spring.

Very little research has been performed on the retention of other constituents by freshwater wetlands.

3. Hydrologic Functions

Wetland hydrology is an emerging science, but the few existing studies have provided evidence of the value of wetlands for reducing flood peaks and, to a lesser extent, providing groundwater recharge. However, their value for maintenance of base flow has not been substantiated in the scientific literature, and not all wetlands provide recharge.

Wetlands may be simply categorized as surface-water-supported or ground-water-supported, based on the source of water (Novitzki, 1979). Surface-water wetlands receive water as precipitation, runoff from surrounding uplands, or from flooding rivers or lakes, and are wettest in spring. Their levels fluctuate in response to precipitation and evaporation. Wetlands supported by ground water are more stable due to the dependency on relatively constant ground-water levels.

Research in both Wisconsin and Minnesota has provided strong evidence that the existence of a small percentage of lakes or wetlands in a watershed significantly reduces peak flows. Wetlands affect flood peaks by retarding water, reducing energy through friction, and temporary storage and release of flood water. Although wetlands retain water long enough to attenuate flood peaks, the retention is not of sufficient duration to increase base flows. Novitzki's research suggests that wetlands lose water through evapotranspiration (reducing ground-water recharge) which could otherwise appear in base flow.

Although some upland wetlands occupying depressions (rather than slopes) recharge ground water, many do not substantially contribute to underlying aquifers. Wetlands not only lose water through evapotranspiration, but organic sediments can restrict downward movement. However, the extent of recharge is highly dependent on the particular characteristics of a wetland (e.g., soil permeability and hydraulic "head").

Wetlands are not usually used as water supplies, due to their fluctuating water levels and varying quality. However, where recharge does occur they contribute to ground-water supplies, and where hydraulically connected to ground water they serve as indicators of water supply.

Although wetland hydrology has provided some useful documentation of beneficial effects, the science has not progressed sufficiently to reveal the water relations of a particular wetland without extensive field research.

4. Recreational/Cultural Values

The value of natural wetlands for recreation is easily perceived but not fully quantified. Consumptive recreational pursuits, such as hunting, fishing, and trapping, have been examined most extensively. Economists have undertaken numerous studies to determine the economic impact of waterfowl hunting; for example, Hertsgaard (1976) found that hunter expenditures annually generated over $50 million (1973) as gross business volume in North Dakota's economy, over half of which was attributed to the existence of wetlands.

Non-consumptive recreational uses have received less scrutiny, but the recent growth of canoeing, hiking, birdwatching and similar activities suggests that the dominance of consumptive recreation may be challenged. Quantification is complicated by the spontaneity and lack of organizational structure in such pastimes. However, the concentrations of wildlife in Minnesota's wetlands appeal to photographers, birdwatchers, and artists; water-related activities such as canoeing and sailing are very significant. Although wetlands are highly prized for many of these activities, the resulting recreational demand may focus intense developmental pressures to "improve" access or boat storage and consequently endanger the wetland.

Other cultural values are even more difficult to document. Wetlands provide aesthetic "refuges" in monotonous landscapes, and man's affinity for riparian environments has led to the importance of some wetlands as archaeological and historical sites.

5. Agricultural Uses

Wetlands have contributed substantially to the economic well-being of Minnesota's farmers. Most agricultural uses require the removal of excess moisture through drainage practices -- particularly for the production of cultivated crops, but wetlands also have provided peat, pasture land and hay crops, wild rice, and some forest resources.

A. Cultivated crops.

In the three "Lake States" of Minnesota, Wisconsin, and Michigan, thirty-eight percent of cropland occupies wet soils. The principal crops are soybeans, corn, hay, oats, barley, vegetables, and wild rice; all but the latter require the drainage of wetlands. Drainage allows more precise planning for tillage, planting and harvesting; promotes more efficient crop production; can reduce equipment repairs by reducing the stress on equipment operating in wet fields; and may lead to better distribution and rotation of field crops. There are numerous other benefits associated with the use of drainage, including the following:

** Less risk of destroying soil structure due to working wet soil;

** Longer growing season due to earlier planting dates;

** Reduced erosion on a well-drained soil, from the increase in the capacity to hold rainfall and consequent reduction in runoff;

** Deeper root development, enabling plants to better withstand summer droughts. High water tables in the spring due to poor drainage cause shallow root development and a smaller soil volume from which plants can obtain moisture and nutrients;

** Increased crop yields and improved crop quality resulting from favorable soil moisture conditions;

** Savings of time, labor, and fuel from the avoidance of wet spots;

** Reduced year-to-end yield variability; and

** Improved market value of land.

Drainage systems are classified according to how the water is removed, either through surface drainage or subsurface drainage. With surface drainage, land surfaces are reshaped to eliminate ponding and to establish slopes sufficient to induce gravitational flow overland and through channels to an outlet. Subsurface drainage employs installed ditches and buried drains within the soil profile to collect and convey excess ground water to a gravity or pumped outlet. The drop in pressure resulting from discharge forces the flow of excess ground water through the soil into the drains.

Surface drainage problems typically occur on flat or nearly flat areas of land due to: (1) uneven land surfaces which prevent or retard natural runoff; (2) low-capacity-disposal channels within the area which remove water so slowly that high water levels in the channels cause ponding; and (3) outlet conditions which hold the water surface above ground level. These lands generally suffer from slow infiltration, low permeability, or restricting layers in the soil profile which prevent the percolation of rainfall, runoff, or overflow from streams through the soil to deeper strata.

Surface drainage is accomplished either through the collection and removal of excess water within the affected area, or by the diversion of water away from the area to be protected. A surface drainage project consists of: (1) a collection system which collects the water from the land (bedding, field ditches, row ditches or diversion ditches); (2) a disposal system which receives water from the collection system and conveys it, usually in an open ditch, or the outlet; and (3) the outlet, which is the terminal point of the drainage system.

B. Pasture land and hay crops.

Many wetlands are dominated by grasses and other vegetation edible by livestock. Although some wetlands are dry enough for grazing, other very wet marshes have been drained to produce pasture, and this is an extensive use of wetlands throughout the Great Lakes region. Problems such as poor footing and hoof rot beset animals, and the difficulty of machine usage contributes to relatively low per-acre values for this use.

C. Peat extraction and energy production.

Peat, which is the partially decomposed vegetative matter characteristic of bogs and other wetland types, has important commercial values. Since peat harvesting normally involves draining and the operation of heavy equipment, destruction of wetlands is almost inevitable. However, since drainage and peat removal may prepare the land for agriculture, other values are involved. This use is of particular concern to Minnesota, which has the largest area of patterned peatlands in the contiguous United States.

Extracted peat has many potential uses, the most important of which is fuel. Considerable research has been performed regarding the use of Minnesota's peatlands for either direct burning or gasification as alternative fuel sources. Although the energy content of peat is lower than that of coal, it contains less sulphur and may be competitive in some situations. Harvested peat is also used for horticultural purposes, as a mulch, soil conditioner, and germinating medium. Small amounts of specific types of peat are useful for water purification, processing of iron ore, and other industrial applications.

D. Fiber and pulp production.

Some wetland areas have retained high proportions of timber resources, due to difficult access, unsuitability for conversion to cropland, and dominance by less desirable tree species. In Minnesota the most common tree species on wetlands are black spruce, tamarack, and white cedar. The harvesting of black spruce as a major pulpwood species is fundamental to the forestry economy of north-central Minnesota.

The possibility of harvesting cattails or other biomass for the production of methane gas or alcohol has received increasing attention. Research on the economic feasibility of such energy sources is in progress, but the probability of widespread harvesting is undetermined.

6. Water Treatment

The newest use for "altered" wetlands is that of stormwater and wastewater treatment. Although the process involved are mentioned above under "Water Quality Effects," there is a clear distinction to be drawn between the water quality benefits provided by natural wetlands and the intensive management of particular wetlands as biological treatment units. Wetlands exposed to high loading rates of nutrients and suspended solids have been shown to be very effective in pollutant entrapment in the short-term, evidenced by extensive research at the University of Michigan on wetland application of secondary effluent from a municipal wastewater treatment plant. In Minnesota, Hikok, Hannaman and Wench (1977) documented extremely high efficiency of sediment and nutrient removal by a wetland near Lake Minnetonka receiving urban stormwater.

These results are encouraging for the improvement of wastewater quality, and suggest that wetlands in urban areas should be preserved as an alternative to costly methods of physical and chemical treatment. However, two important considerations are (1) the degree to which a wetland can sustain pollutant removal in the long term, particularly if the structure of the ecosystem is altered, and (2) the possible elimination of other beneficial attributes (particularly biological and aesthetic) in a wetland used intensively for pollutant removal.

7. Development

The ultimate "use" of a wetland is its destruction. Although much of this section has dealt with the extensive alteration of Minnesota's wetlands through agricultural drainage, no other activity so thoroughly eliminates the natural values of wetlands as does the filling of wetlands for urban expansion and riparian development. Such encroachment not only eliminates the natural values but increases surface-water runoff, resulting in non-point source pollution, higher peak streamflows, and greater fluctuations in lake levels. Even where wetlands are not filled, construction activities generate suspended sediment loads capable of serious ecological impairment of adjacent wetlands.

Wetland Inventories

There has been no definitive inventory of the existence, modifications, or uses of Minnesota's wetlands, although many attempts and partial surveys have been made. Most efforts have been undertaken to assess the need for cost-sharing of agricultural drainage practices or to protect valuable areas of waterfowl production. Although the general trend of substantial alteration of wetlands is apparent (Figure 21), the information is not sufficient for other purposes, such as hydrologic modeling and permit evaluation. Within specific areas, many of the inventory estimates differ substantially (Quade, 1979).

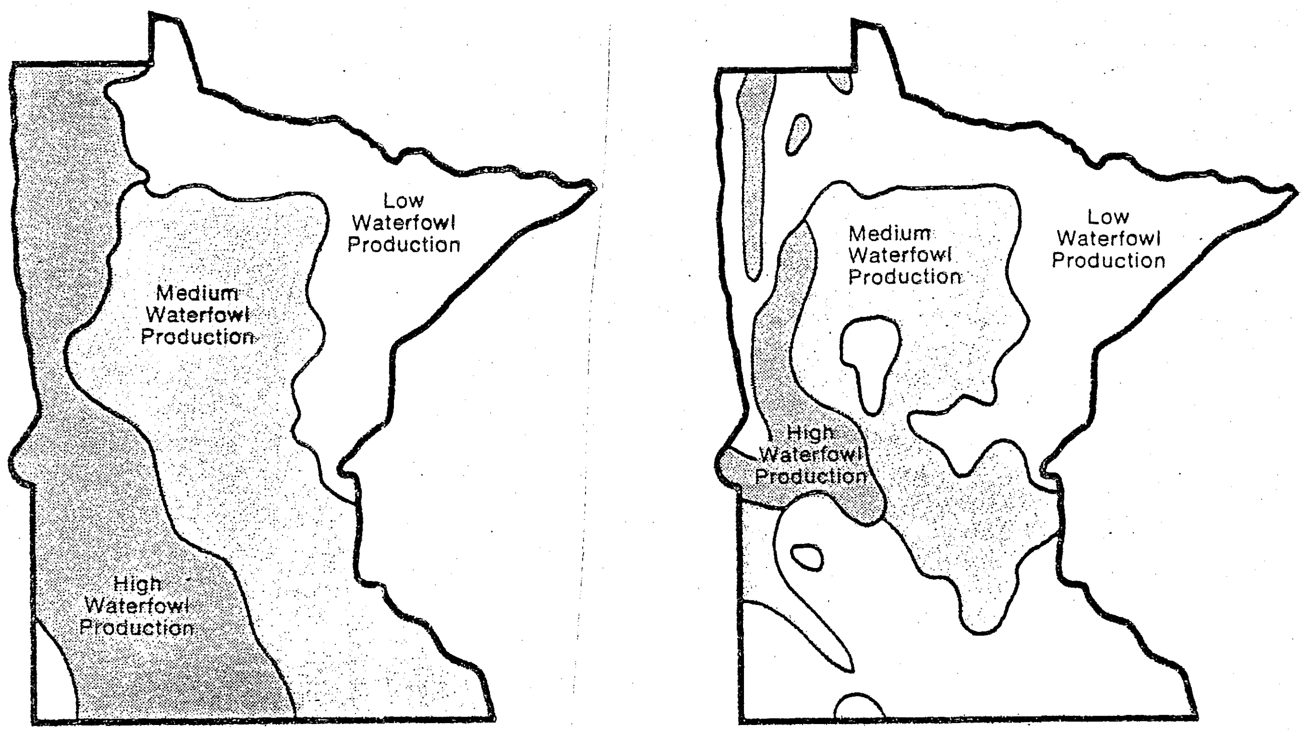


FIGURE 21. Waterfowl production areas at time of settlement (left) and in 1975 (right), from Walton (1975).

There are serious obstacles to assessing the extent of agricultural modifications of wetlands. Many areas lack reliably mapped data, and the quality of information available from county engineers is variable. Unauthorized ditches and private tiling are outside the realm of normal record-keeping. Most attempts to establish an inventory of agricultural modifications have been forced to rely on secondary indicators or the opinions of knowledgeable local officials.

The general picture which emerges from several studies (Table 7) is that of extensive loss of wetlands in southwestern and northwestern Minnesota (Figures 20 and 22). The Legislative Auditor (1978) has estimated that 4,300 of approximately 20,000 originally wet basins larger than ten acres have been drained. Estimates of the acreage affected range widely, due to differences in inventory methodology, date of completion, and difficulty of precisely determining "affected acreage." The Agricultural Census (United States Department of Commerce, 1959) indicated that in 1920 more than twelve million acres, nearly 24%, of Minnesota's land had been drained. More recent estimates (United States Department of Commerce, 1969; Allred and Geiser, 1978) suggest that six million acres of wet crop and pasture land are presently artificially drained.

FIGURE 22. Major areas of drainage.

Estimates of wetland acreage are dependent on many variables, most importantly the definition employed. Mann (1955) and Shaw and Fredine (1971) reported slightly more than five million acres of wetland types 1-8 in Minnesota in the early 1950's. In contrast, the 1967 Conservation Needs Inventory (Minnesota Conservation Needs Committee, 1971) indicated that over 11.6 million acres of cropland and pasture have "wetness" problems, more than half of which have received some form of drainage. These estimates are not comparable, but exemplify the problem of identification of altered wetlands. Although completion of the State's Public Waters Inventory may resolve some data limitations, there is likely to remain insufficient data with which to judge past or present wetland loss from both agricultural and urban activities.

TABLE 7. Estimates of existing wetlands and drainage activity in Minnesota.

DATE	SOURCE	ESTIMATE (Acres)	COMMENT
DRAINAGE ACTIVITY			
1920	1	9,232,709	Benefited acres; includes organized drainage enterprises and individual farms.
1930	1	11,474,683	
1940	1	10,990,409	Benefited acres; organized drainage enterprises only.
1950	1	11,269,962	
1960	1	11,688,201	Benefited acres; organized drainage enterprises larger than 500 acres.
1969	2	6,005,243	Benefited acres; same as above, except mail census of farms with sales of $2,500+
1978	3	6,043,888	Artificially drained cropland and pasture.
1978	4	180,000-220,000	Drained basin acres, excluding adjacent (wet) land.
WETLANDS/WET SOILS			
1954	5	5,044,900	Types 1-8 wetlands
1967	6	11,600,000	Cropland and pasture with wetness problems.
WETLAND PROGRAMS			
1935-1976	-	5,000,000	Area benefited by cost-sharing from Agriculture Conservation Program for drainage and land shaping.
1978	4	~240,000	Wetlands acquired by state (largely fee purchase).
1978	4	43,660	Federally-purchased wetlands.
1978	4	33,000	Wetlands under federal easements.
1978	4	16,763	Wetlands in Federal Water Bank.
1978	4	795,582	Wetlands and adjacent lands under all state and federal protection programs.

Sources:

1. United States Department of Commerce (1959)
2. United States Department of Commerce (1969)
3. Allred and Geiser (1978)
4. Legislative Auditor (1978)
5. Shaw and Fredine (1971)
6. Minnesota Conservation Needs Committee (1971)

Economics of Wetland Management

Decisions regarding the management or fate of wetlands are usually made in response to a recognizable economic influence. The value of wetlands for some purposes, such as agricultural production and urban development, can be readily established in the functioning markets for land; others, such as flood reduction and water quality maintenance, cannot. Comprehensive economic decisions regarding wetlands are hampered by several problems:

1) Many benefits from unaltered wetlands are not readily quantifiable, since there is no conventional "market" value.

2) Benefits provided by wetlands are often "fugitive" in that they do not accrue to the owner of the resource, but to other members of society (hunters, downstream communities, etc).

3) There is no economic incentive for the owner of wetlands property to consider the "external" economic effects of altering wetlands, except for a limited number of compensation programs, including easements and water banks. (Editor's note: In 1979, state legislation was passed providing a tax credit for owners of wetlands in Minnesota.)

Efforts have been made to impute economic values for several of the non-market benefits from wetland preservation, including waterfowl production, ground-water recharge, and flood reduction. Although these studies succeeded in quantifying the wetland benefits foregone by altering wetlands, their site-specific nature limits applicability to other individual wetlands. Such studies are beneficial for developing state programs and policies, but do not assist in determining the benefits and costs of altering a specific wetland.

In contrast, the benefits from wetland alteration usually accrue to the owner and are more readily quantifiable. Expansion of cropland through drainage is based primarily on the following economic choice: If land can be reclaimed by drainage for crop production at a lower cost than additional farm land acres can be purchased, it is economically sensible to drain. Drainage projects are eligible for investment credits and rapid tax write-offs, providing a greater incentive to drain.

A decision to drain must be based on whether the projected benefits exceed the projected costs. The benefits of a drainage system depend upon the yield response, crop price, risk aversion and time premiums. Increased yields with strong prices can quickly pay off a drainage system investment; when prices are lower, the payback period will be extended. The value of risk aversion is a function of the enterprise's financial ability to absorb risk and the owner's personal aversion to risk. Drainage costs depend upon the tile spacing required, tile depth required, amount of required land-forming, type of outlet system, and the opportunity cost of money. Bringing land into cultivation and "improving" previously undrained lands require increased agricultural input costs. These costs and benefits vary greatly by farm; yield responses are affected by soil type, soil fertility, amount of fertilizer applied, tile spacing, precipitation, and other factors. Cost conditions are equally variable.

A similar situation exists for converting wetlands to urban land uses - the benefits and costs to the landowner are easily quantified, but those to society are neither quantified nor represented in the marketplace. This failure of the marketplace to represent society's interest in wetlands has led to governmental intervention through various programs for wetland management, principally through regulation, compensation, and acquisition.

Wetland Management Programs

The institutional framework which addresses drainage and wetland protection, described in documents produced by the Management Work Group, reflects the ambivalence of the legislature and changing attitudes toward wetlands.

State legislation is characterized by vague terms and the absence of clear guidelines for decision-making, and sections of the statutes are specifically designed to represent the divergent interests. Although this may be intended to achieve the required balancing of interests, resolution of problems through administrative and judicial processes has been time-consuming, ineffective, costly to taxpayers, and has heightened the controversy. (Editor's note: Since the original drafting of this section, the Legislature has amended relevant portions of Minnesota Statutes, Chapter 105, to specifically define "public waters" to include "wetlands" as type 3,4, and 5 wetlands larger than 10 acres in unincorporated areas and 2.5 acres in incorporated areas.)

Public drainage projects may be initiated legally through Watershed Districts but are more frequently undertaken under the drainage code, set forth in Chapter 106. The procedure is initiated by the filing of a petition with the County Board by local landowners. The proposed project is surveyed and submitted to DNR for comment and review, which is strictly advisory. The County Board holds a public hearing and determines if the project will be of public benefit and will promote the public health as set forth in the statutes. This process has given landowners access to the power of the state, including eminent domain, to aid drainage projects. Unless the project substantially affects public waters, no state approval is required. The local character of Chapter 106 decision-making probably has a strong pro-drainage bias, and there is little representation of conservation or state-wide interests (Bryden, 1973).

The principal regulatory programs are DNR's Public Waters Inventory program, which has not been successful, and the permit requirements for works in designated public waters. The Corps of Engineers 404 permit requirements for filling of wetlands have generally not been extended to drainage activities. Wetland preservation programs cover about 800,000 acres of wetlands and adjacent uplands in Minnesota, funded largely by the State Acquisition Program, U.S. Fish and Wildlife Acquisition and Easement Programs, and under compensation provided by the Federal Water Bank (Legislative Auditor, 1978). The State Water Bank has not yet disbursed funds.

Conclusions and Recommendations

The wetland drainage issue is extremely complex, as it straddles the boundaries between land and water, public and private interests, conservation and development, and tangible and intangible benefits. Progress toward its resolution requires consideration of many related concerns.

The cumulative effects of wetland drainage must be dealt with by government, since individual decisions are based largely on personal economic return. There is no consideration in the marketplace of the "external" public benefits provided by wetlands for flood damage reduction, sedimentation, and other public benefits described previously. Only government can adequately consider benefits foregone and damages incurred by wetland modification throughout a watershed.

Concern with property rights and financial effects are implicit in either wetland preservation or drainage. The policy of the Legislature and the state seems to favor wetland preservation and just compensation of landowners where private rights must be sacrificed, but the adequacy of the compensation must be examined. The Public Waters Program appears to be well designed to compensate owners even though the program has performed poorly. Acquisition programs have raised concerns regarding loss of tax base, but studies of wildlife areas by the Upper Minnesota Valley RDC suggest that federal and state payments in lieu of taxes, when considered collectively, provide more revenue than if the lands were included on local tax rolls (Jorgens and Dorf, 1979).

The conflict between wetland preservation and agricultural production is often mentioned, but cannot be precisely evaluated because of data deficiencies. Available information on the extent and nature of agricultural modifications to wetlands (including drainage and tiling) is sparse, and that which exists is conflicting and probably inaccurate. The limited research documenting the effects of these modifications has frequently been site-specific and based on "synthetic" hydrologic techniques, which restricts generalization. The need for Minnesota's agricultural production must be viewed in the context of national agricultural economics, but decisions are made by individual farmers maximizing the return on their investments. However, the large "set-aside" acreage which has previously been taken out of production in Minnesota questions the need for continued drainage.

An essential consideration is the rapidity of resolving this issue. The Legislative Auditor has suggested that those remaining wetlands which can be feasibly drained probably will be drained within twenty years, and that awaiting the development of case law to clarify statutory language will likely provide a solution by default. (Editor's note: Recent statutory changes have eliminated the need to demonstrate "beneficial public purpose.") Restoration of wetlands has been attempted and is an evolving technology, but restored wetlands are likely to be primitive ecosystems lacking most of the values of the original.

Public understanding and rational discussion are also essential to successful decision-making. The DNR must make the rationale, and the overriding public interest, apparent when wetlands are preserved. An authoritarian image hinders cooperation and is often ineffective; the DNR has experienced serious enforcement problems in the restoration of illegally-drained public waters. Conversely, decisions made in the public interest and based on careful analysis should not be sacrificed for politically powerful special interests.

A final conclusion concerns the management of wetlands in developed areas, where major problems result from urban encroachment and stormwater disposal. The protection of urban wetlands is a unique situation complicated by the inapplicability of existing compensation programs, high property taxes, and the unknown effect of "model ordinances" set forth by the Metropolitan Council. Federal and state acquisition programs have been of limited value in preserving urban wetlands. Further study is warranted to suggest alternatives and to consider creation or reorientation of compensation programs for urban areas.

In response to these concerns, the Work Group recommends the following actions:

1. Determination of wetland values. Several related actions should be undertaken:

   a) The Department of Natural Resources should identify state goals for wetland management.

   b) With financial assistance provided by Section 22 funds from the Corps of Engineers, the Department of Natural Resources should determine specific characteristics of wetlands providing flood control, nutrient and sediment retention, groundwater recharge, and other public benefits.

   c) The DNR, in consultation with other concerned agencies, should undertake a statewide inventory of wetlands which reflects the characteristics and values of wetlands providing public benefit. The inventory should include mapping of high-priority wetlands for flood control, water quality, recharge, and agricultural suitability as has been performed for wildlife values.

d) Information on the extent of drainage activity should be evaluated for validity by the DNR and reliable data should be used to assess the extent of the drainage-preservation conflict.

e) An aggressive education program should be undertaken to inform the public of the determined values and to receive public comment.

2. Accelerated implementation of DNR's Public Waters and Water Bank Programs, and support of improved funding for the federal water Bank Program. When Recommendation (1) has been completed, priorities for compensation and acquisition programs can be established. Water Bank programs should provide adequate compensation to encourage wetland preservation.

3. Further study of modifications to the drainage code to protect assessed landowners and environmental concerns. Although there is evidence that strictly local control of drainage improvements may not lead to impartial decision-making, further investigation is necessary before specific recommendations can be made.

4. Evaluation of the adequacy of wetland incentive and acquisition programs, including consideration of:

a) In-lieu-of-tax payments for state and federally-owned wetlands, and the distribution of payments among local units of government;

b) Financial incentives for wetland preservation, including tax credits and Water Bank compensation; and

c) Wetland acquisition programs, and the relationship between purchase and regulatory control of valuable wetlands.

5. Development of a program for the protection of urban wetlands. The first step should be a cooperative study of urban wetland protection by the Metropolitan council and the state coordinating body, considering the need for protection of urban wetlands excluded from existing compensation and acquisition programs.

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