Report to the

Legislative Commission on Minnesota Resources

WATER ALLOCATION AND MANAGEMENT

1985 - 1987

VOLUME I

THE VALUE OF WATER TO MINNESOTA

Department of Natural Resources

Division of Waters

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1985 - 1986

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1987

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Completion of an extensive project such as this would not have been possible without the assistance and dedication of project staff. Hedia Adelsman must be credited with the insight, devotion, and ambition to make this project happen. Only after her departure were those who continued to work on the project able to fully appreciate her role. Senior project staff, Patricia Olson and Gil Young, were primarily responsible for thoughtful integration of components of the project in the final report and for preparation of other project reports, DNR technical staff, Diane Desotelle, Henry Drewes, Eric Larson, Monte Rude and Steve Woods, assisted in study design, data collection, and interpretation. Their assistance and enthusiasm are greatly appreciated. The contractors, including the DNR Office of Planning; University of Minnesota, Water Resources Research Center; University of Minnesota - Duluth, Natural Resources Research Institute; U.S. Geological Survey; Minnesota Center for Survey Research; and Center for Urban and Regional Affairs, are to be commended for their active participation in the coordination of this undertaking and for their patience and perseverance in meeting project goals. Thanks go to Eric Mohring, Jeanette Leete, and Laurel Reeves for their review, editing, and encouragement in the preparation of project documents. A final note of thanks must go to our secretaries, Tami Brue and Felicia White. Their tireless efforts on endless drafts of the many project products, along with their willingness to tackle new and strange word processing software, are greatly appreciated.

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PART ONE
INTRODUCTION

BACKGROUND

The State of Minnesota is known for its abundant supplies of clean, fresh water. Minnesota boasts that it is the land of 10,000 lakes. The state is also the headwaters for the Mississippi River and the head of the Great Lakes system. Many Minnesota citizens derive their livelihood directly from the state's abundant water supplies. Water is Minnesota's most important natural resource.

The perception that Minnesota is *water-rich* has resulted in complacency. Our rivers and streams always have water; our wells never go dry. The only price you pay for water is the cost of the pumps and pipes to deliver it; the water itself is *free*. The water may be free to the individual but what are the costs to society? Since water is perceived to be free, what are our incentives to use it wisely and avoid waste?

Is Minnesota really water-rich? Looking at the state as a whole, it would appear that we have abundant supplies - the only problem is uneven distribution. Contrary to popular belief, some high-capacity wells have caused other wells to *go dry*. In western and southwestern Minnesota, there are instances where the lack of an adequate water supply has stopped economic development. Should northeast Minnesota then pump its *surplus* water to the western part of the state? Would promoting economic development in one part of the state be done at the expense of our highly prized recreational areas? And this perceived *surplus* of our water-richness - can it be diverted to the arid western states to satisfy a national priority for water for development?

Clearly we have the engineering skills to deliver water where we want it. Such allocation of water must, however, be tempered by wisdom bred from an understanding of the hydrologic, social, and economic consequences. The impacts on the affected society will be heard in the political arena. The hydrologic impacts can be analyzed by water budget modeling. A goal of the Water Allocation and Management project is to address the final question: what are the economic impacts of water allocation?

INSTITUTIONAL ARRANGEMENTS

The Water Allocation and Management project was funded by the Legislative Commission on Minnesota Resources for the 1985-1987 biennium. It was an ambitious project which combined two independent project proposals. The first was a cooperative effort between the Department of Natural Resources (DNR) and the University of Minnesota - Duluth's Natural Resources Research Institute (NRRI) to assess the value of Minnesota's water. The second was to look at the geographic information system (GIS) data needs for the elements of the hydrologic cycle and to assess the utility of *off-the-shelf* models for dealing with the elements of the hydrologic cycle. The second phase of the project was performed by the University of Minnesota's Water Resources Research Center. The results of the economic analysis including the hydrologic inputs are reported in Volume 1 of *Water Allocation and Management,* part 1 of which contains the hydrologic inputs while part 2 contains the economic analysis. Volume 2 of *Water Allocation and Management* contains the results of the GIS and *off-the-shelf* model phase.

THE INPUTS

Before we can analyze the economic impacts of water allocation decisions, we must quantify and determine the balance among water availability, offstream uses, and instream uses of water. Part 1 of this volume summarizes the analyses, findings and recommendations regarding these input variables. Part 2 summarizes the economic analyses, findings, and recommendations for further policy analysis.

THE ANALYSIS

Computer simulation models are a fairly common method used for answering the types of questions raised by this project. Input-output and linear programming models such as those used here can estimate the value of a commodity like water for which no real market exists. The flexibility of these models allows the researcher to simulate events which occur infrequently, such as droughts or floods. They are also able to provide insight into events which have never occurred, such as the diversion of water out of Minnesota. Finally, the models can evaluate the impacts of various allocations of water and determine which allocation will achieve the greatest benefit to the economy.

The statewide models were not completed in time to explore their full potential as tools for managing the water resources of the state. One scenario, an examination of drought, is evaluated. Five regional models were not available for use before the project's end date. Delays in the development of the models were caused by the unexpected amount of data collection required to update the original model from its 1977 data bases to 1982, the chosen year for the start of this analysis. Further complications resulted from the incompatibility of data bases gathered from a number of sources. Because of their confidence in the results which can be and will be obtained, both the Department of Natural Resources and the Natural Resources Research Institute have agreed to proceed with their work after the official project deadline. Additional analysis using the statewide model and completion and analysis of the regional models are planned.

The results of any computer simulation must always be treated with some caution. A number of simplifying assumptions were necessary in order to produce a model which has a reasonable level of complexity and flexibility. The results, therefore, are only as valid as the assumptions used in their derivation. Nonetheless, the model has already generated some significant findings. For instance, ground water has a higher value to Minnesota's economy than surface water. In fact, for each dollar of output generated by use of one acre-foot of surface water, $12.80 is generated from use of an acre-foot of ground water.

While computer simulations are effective methods for analyzing the value of water to the various economic sectors of the state, they can never measure the smile on a seven-year-old's face after catching her first walleye. Many Minnesotans believe that the true value of water accrues while it is still in the lake or river. There is no doubt that society places a value on water far beyond its usefulness to industries. One way to look at this value is in terms of the benefits that are generated from a recreational experience. While these benefits are very difficult to measure, they are very real.

It is extremely important for policy makers to appreciate both the tangible and intangible benefits when they choose between allocating water to industry or to recreation. The same argument can be made when the decision concerns the allocation of funds in the state budget. Should tax dollars be spent to encourage recreation and tourism or should they be spent to encourage a new industry to locate in Minnesota? One way to improve the decision-making process is to attempt to assign a dollar value to the benefits of recreation. Thus, when the policy-maker must decide whether to allow a wetland to be drained in order to build a new factory, the value of that wetland, in terms of the benefits which would be lost, can be estimated.

There are actually two different values which can be assigned to water for recreation. The first is the economic impact of goods and services purchased for recreational activities. Recreators purchase fishing equipment, food, lodging, gasoline, and the like. Not only do these purchases provide income to the seller of the goods and services, but also this income trickles down through the local economy as the seller restocks shelves and makes purchases for personal use.

The second value, intangible benefits of a seven year old's smile, are estimated through surveys of water-related recreational users. Rather sophisticated survey procedures allow the analysts to assign a value to each recreational experience and, from that information, to estimate the value of the water itself.

CONSTRAINTS

A number of assumptions are made for this project because of the following constraints:

1. Data on surface water availability is limited. Minnesota has thirty-nine principal watersheds (Figure 1) and, of these, only twenty have or have had continuous gaging of streamflow at the mouth of the watershed. Water availabilities are estimated for the remaining nineteen watersheds. The maps of water availability presented in the following chapter are gross generalizations suitable for a statewide assessment but unsuitable for site specific decision-making.
2. Ground water availability was assumed to be a multiple of 1985 ground water use in each of the economic regions (Figure 2) as follows:

Metropolitan	3 times 1985 use
Southeast and Central	2 times 1985 use
Northeast and West	1.5 times 1985 use

Given the lack of more precise data, this was the method used to estimate available supplies. The availability of ground water is further constrained by regulatory requirements (e.g. land ownership). Again, these assumptions are adequate for a statewide assessment but should not be used for site-specific decision-making.

3. Water in storage in lakes is available for use but is not necessarily included in the availability analysis. Minnesota allocation policies do allow for appropriation of 6 inches of water from lakes greater than 500 acres in size. If a lake has an outlet to a stream, the amount is indirectly accounted for in our analysis. If the lake does not have an outlet, the 6 inches in storage are not accounted for. This simplifying assumption is adequate for the statewide assessment.
4. The water in Lake Superior is not considered as available for use in this analysis because volume of water in the lake overwhelms the economic model. Thus, Lake Superior must be considered an infinite supply. As a practical matter, the legal and institutional constraints, including those among the Great Lakes states and two Canadian provinces, preclude use of this water source to satisfy water needs in other areas.
5. Whenever it was necessary to choose between various methods of analysis during this project, the researchers consistently selected that method which appeared to be the most conservative in terms of protecting the water source. This approach evolved from a common belief that it is preferable to err in favor of the resource than to make a choice which will later result in compromise or loss of that resource.

Figure 1: Minnesota's 39 principal watersheds.

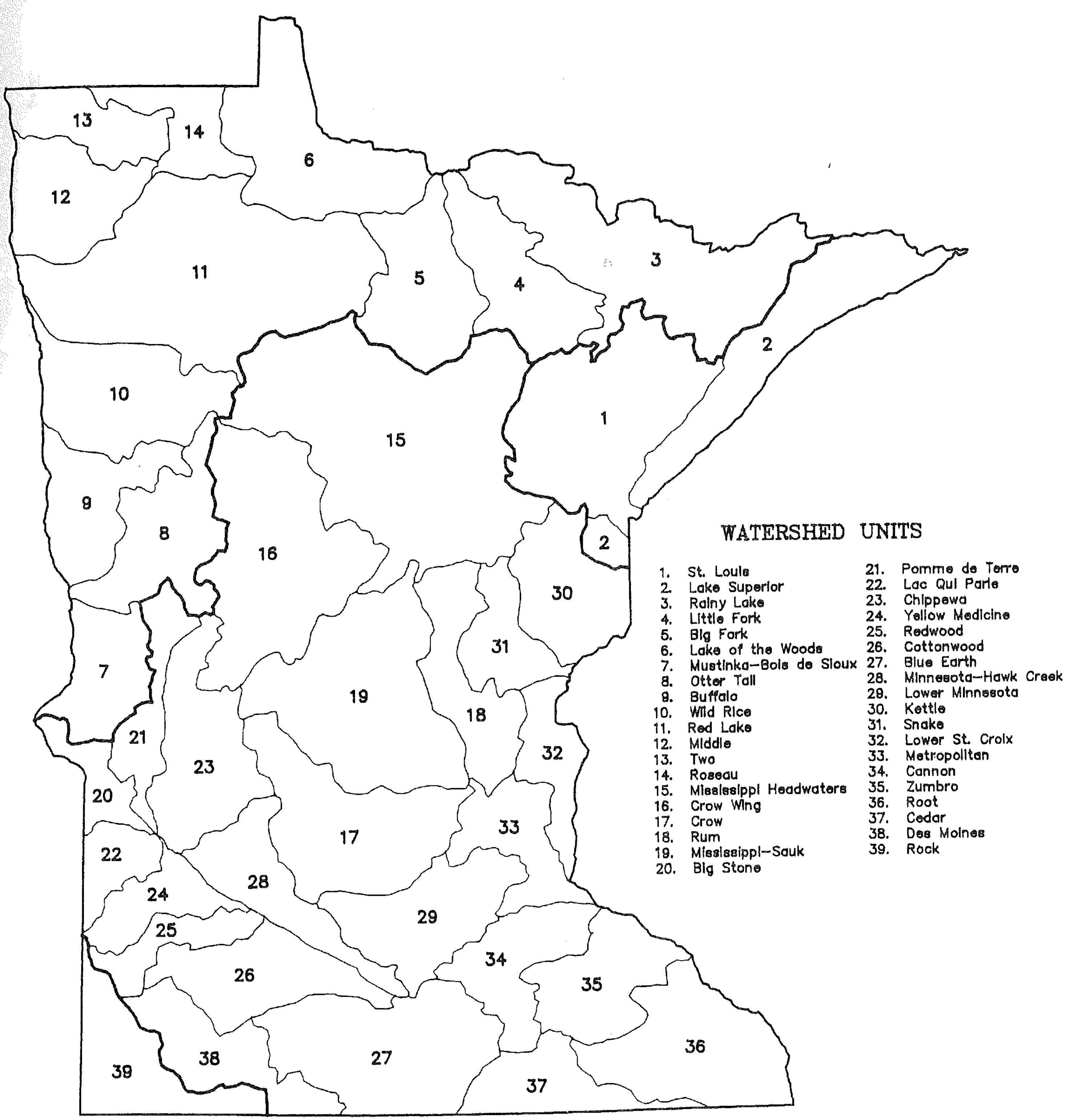
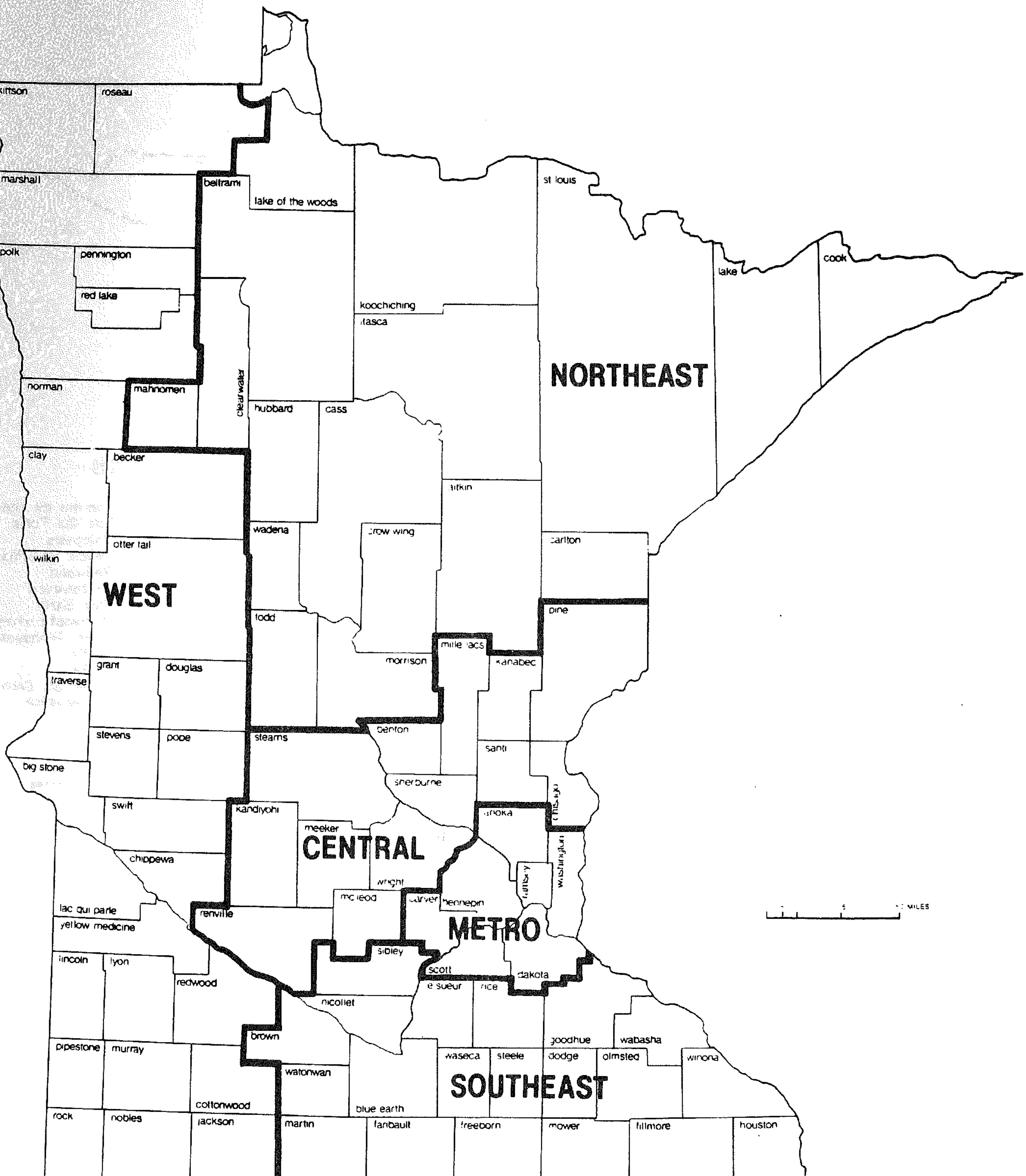


Figure 2: Minnesota's Economic Regions.



WATER AVAILABILITY

OBJECTIVE

To determine surface water availability in Minnesota for *dry, normal,* and *wet* hydrologic years. Water availability is determined for the state as a whole as well as for five economic regions.

INSTITUTIONAL ARRANGEMENT

This portion of the project was completed by the U.S. Geological Survey (USGS). The principal investigator was Jim Jacques. Other investigators included Dave Lorenz and Allen Arntson. The project funding, $95,000, was added to the existing cooperative agreement between the Department of Natural Resources and the USGS. Project deliverables are a report on Water Availability and a report on the Blue Earth Watershed Model. Both reports are completed and proceeding through the USGS review process; copies will be provided when published. Appendix A contains a discussion of the Blue Earth Basin modeling study.

ANALYSIS

Minnesota's surface-water resources are dynamic; extremes of availability occur within short time periods. Analysis of gaged data allows a historical perspective through the computation of statistics such as seasonal means, flow duration, and occurrence frequencies.

SURFACE WATER RUNOFF

This study is a statewide and regional interpretation of the amount and availability of streamflow in Minnesota. The regional perspective is politically as well as hydrologically based. The NRRI portion of this project uses five economic regions while the Department of Natural Resources (DNR) defines regions as the State's 39 principal watersheds.

One hundred and one (101) continuous record discharge measurement stations with 10 or more years of record were selected for use in this study. High and low flow statistics and basin characteristic data were compiled and formed the data base for the analyses.

One way of addressing the need for independence from hydrologic boundaries in regional analyses is to use spatially normalized statistical data. Frequency and duration statistics are difficult to use this way because they describe a single point. Although relationships can be found to estimate these statistics at other sites, they are valid only for the location of interest, and they are not spatially additive. However, mean daily flows can be used and regionalized on any special basis. For this study, the mean annual daily flow datasets for each gage are used because the NRRI and DNR studies use an annual basis.

The definition of *dry, normal,* and *wet* hydrologic conditions is complicated. It can be political, subjective, or scientific. There is not one correct answer. For the purpose of this study, the median of the mean annual daily flow dataset is deemed a *normal* occurrence. The seventy-fifth and twenty-fifth percentiles are defined as *dry* and *wet*, respectively.

Analyses of flow data at gaging stations can develop summary statistics such as average and mean flows and flow-duration curves. Not every site had a sufficiently long flow record for analysis. Many data transfer methods, including extrapolation or interpolation between two sites on the same stream and complicated statistical extra-basin transfers, were used. The most promising method used multiple regression to relate streamflow characteristics to topographic and climatic characteristics of the drainage basins as done previously for flood flow frequencies in Minnesota. Because the driving mechanisms of low and high flows are different, watershed characteristics which explain the variability in flood flows may not sufficiently explain the variability in low flows.

Regional low flow studies generally have included the use of hydrogeologic characteristics to explain part of the variability of low flow data sets. To accommodate this need, the basin characteristics data base was expanded to include wetland and lake areas and sustained aquifer yield data. The characteristics added specifically for low flow analysis, lake area and aquifer yield, were not as successful and did not explain as much variance as had been hoped. Wetland and lake areas from the Planning Information Center's 40 acre grid cell database were evaluated for accuracy and added for about 60 basins. The most valuable information came from the Aquifer Yield Map (Roman Kanivetsky, Minnesota Geological Survey, 1979). Even so, the standard error of estimate was over 100 percent for the equation describing the seventy-fifth exceedance percentile. Regionalization was not possible because the 60 station dataset was not large enough to work with confidently. Interpretation of the results for the economic regions was difficult. Therefore, the analysis was dropped.

The method of generalizing these flow characteristics is contouring, or isolines (lines of equal runoff), for the *dry, normal,* and *wet* conditions. Statistically, these conditions represent the seventy-fifth, fiftieth and twenty-fifth exceedance probabilities respectively and are presented in Figures 3 to 5.

The computation and summation of volumes for each area between contour lines of Figures 3 through 5 reveals that the state can expect 15.6, 22.3, and 31.4 million acre-feet of runoff under *dry, normal,* and *wet* conditions respectively. The volume increases from west to east. The wettest area is northeastern Minnesota in each scenario. In absolute terms, runoff is most variable in northeast Minnesota, a difference of about six inches of runoff between the *dry* and *wet* scenarios while the rest of the state varies about three inches. Table 1 lists the annual volumes, expressed in inches, of the 39 principal watersheds for each hydrologic condition. These values were estimated from Figures 3 through 5. Table 2 lists values for the economic regions in inches and acre-feet.

These maps are a statewide characterization of runoff conditions under *dry, normal,* and *wet* hydrologic conditions. The underlying analysis, although presented as a statewide map, is a collective history of one hundred and one individual stations. It is important to realize it is unlikely that these scenarios will happen statewide at the same time and that samples represent a specific date which does not correspond with dates for other data.

Figure 3: The 75% exceedance annual discharge, in inches, for the principal watersheds in Minnesota.

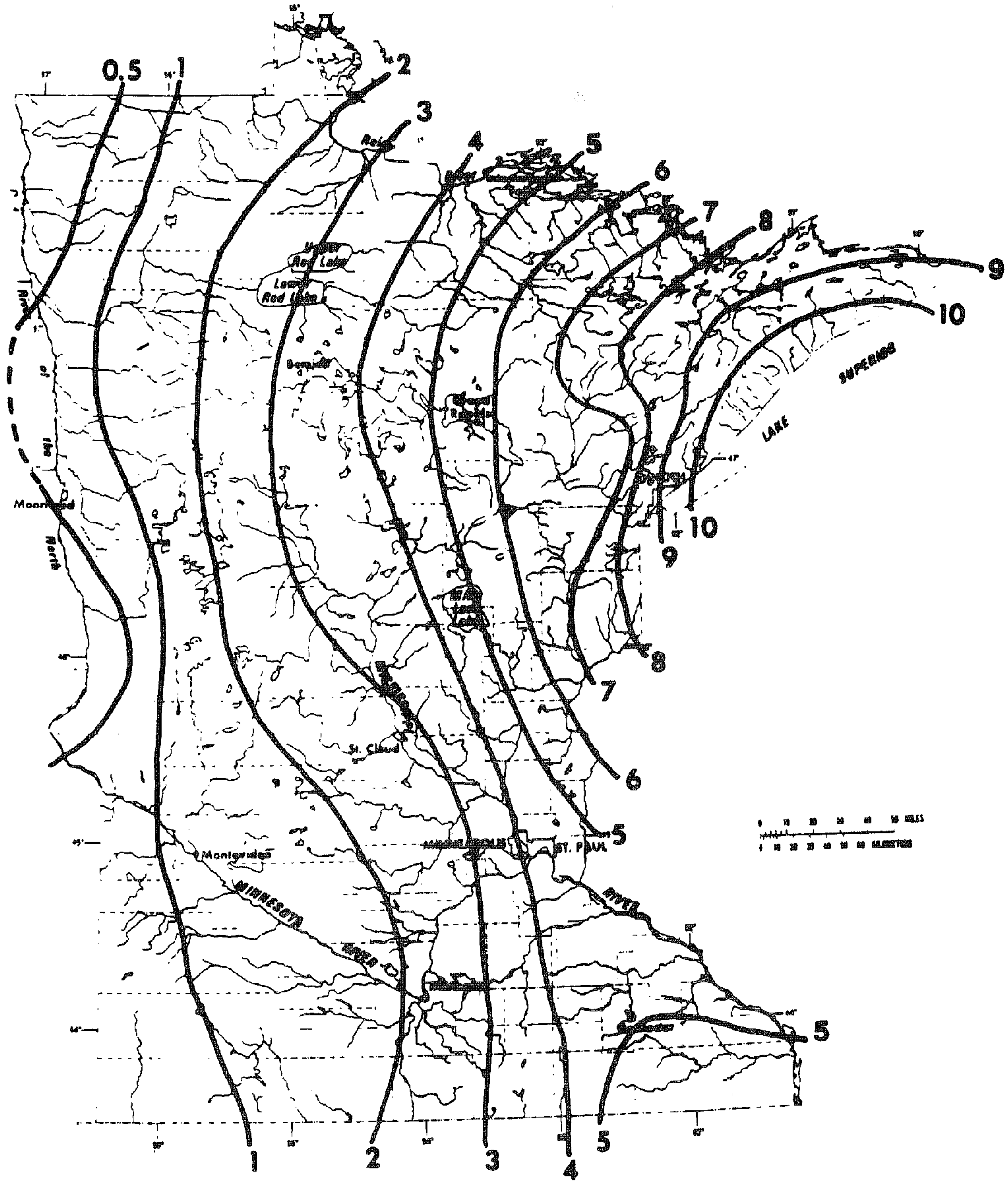


Figure 4: The median annual (50% exceedance) discharge, in inches, for the principal watersheds in Minnesota.

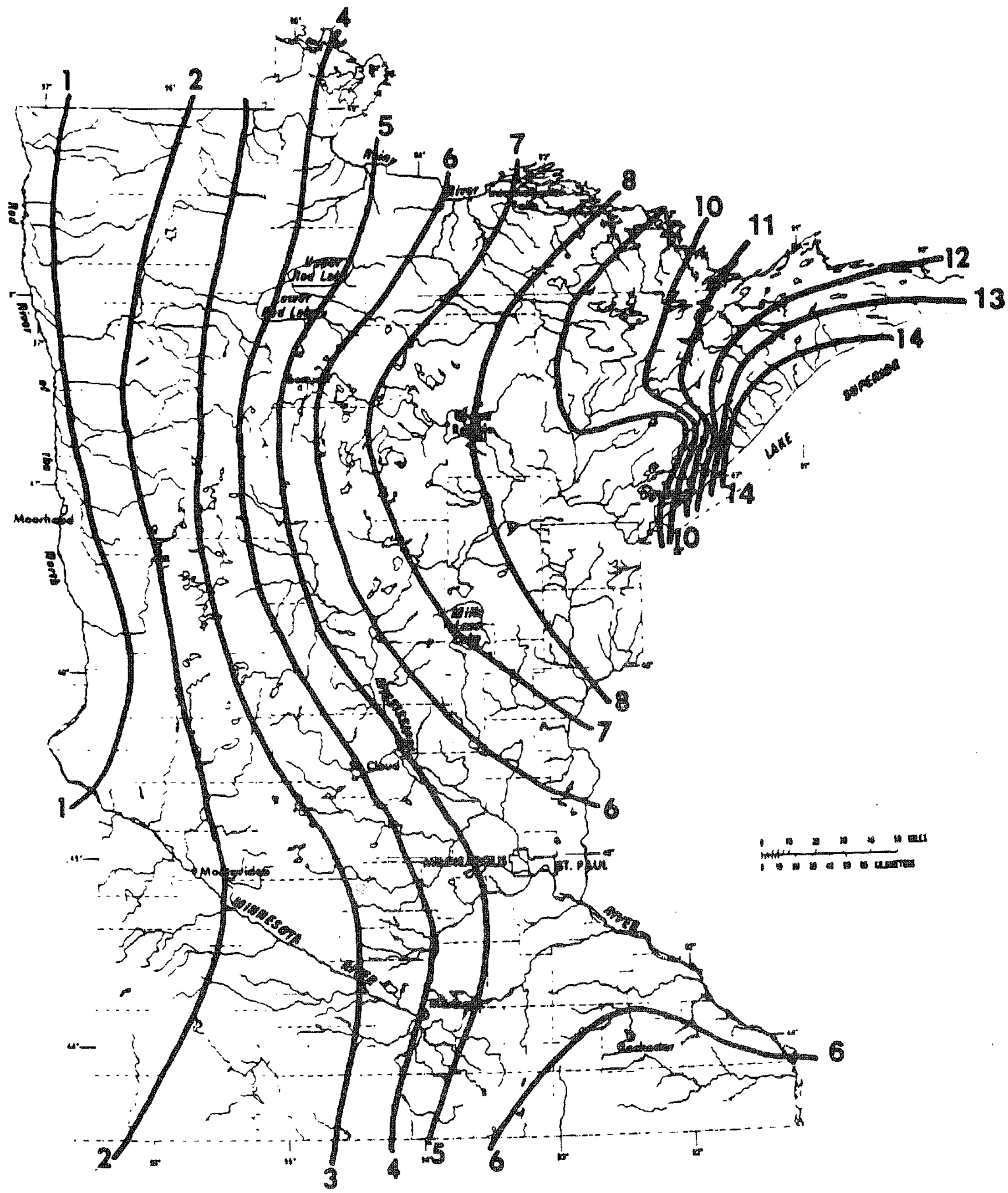


Figure 5: The 25% exceedance annual discharge, in inches, for the principal watersheds in Minnesota.

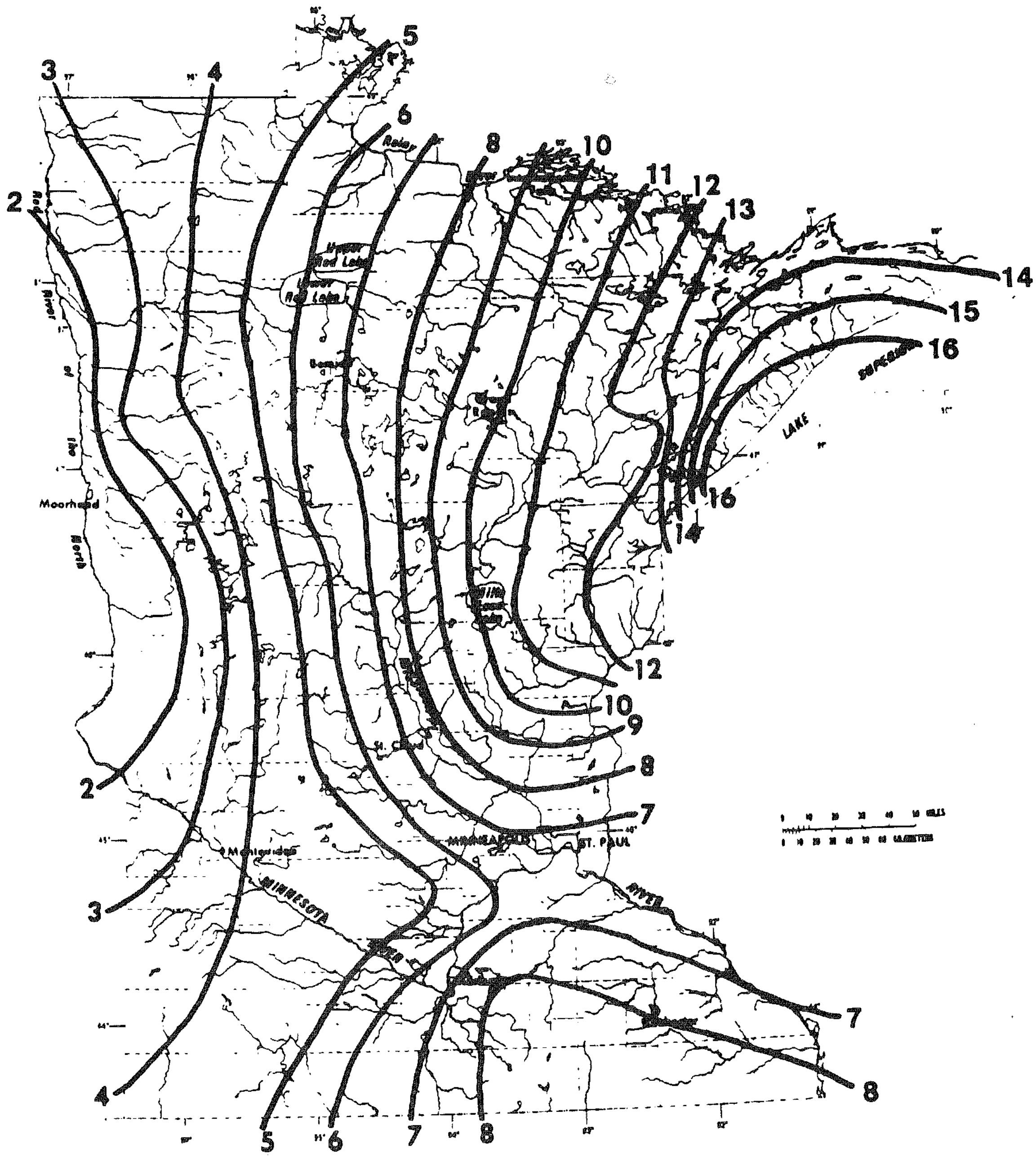


Table 1: Annual volumes, in inches, for dry, normal and wet conditions for each of Minnesota's 39 principal watersheds.

MN ID	NAME	DRY	NORMAL	WET
1	St. Louis River	8.5	8.9	11.9
2	Lake Superior	10.0	14.0	15.5
3	Rainy River	8.0	9.9	12.0
4	Little Fork River	6.0	8.2	10.0
5	Big Fork River	4.8	7.1	8.5
6	Lake of the Woods	2.8	4.1	5.9
7	Mustinka-Bois de Sioux	0.6	0.9	1.8
8	Otter Tail River	1.5	2.4	2.9
9	Buffalo River	0.8	1.2	1.9
10	Wild Rice River	1.4	2.0	3.6
11	Red Lake River	2.0	3.0	4.8
12	Middle River	0.6	1.5	2.8
13	Two Rivers	0.6	1.4	3.3
14	Roseau River	1.2	2.4	4.2
15	Mississippi Headwaters	5.0	7.3	9.1
16	Crow Wing River	3.0	5.0	5.6
17	Crow River	3.3	3.5	5.5
18	Rum River	4.4	6.4	9.0
19	Mississippi-Sauk	2.8	4.9	7.7
20	Big Stone Lake	0.8	1.2	2.2
21	Pomme de Terre River	1.1	1.6	2.6
22	Lac Qui Parle River	0.9	1.4	3.0
23	Chippewa River	1.6	2.2	3.8
24	Yellow Medicine River	1.1	1.7	3.7
25	Redwood River	1.1	1.9	3.9
26	Cottonwood River	1.5	2.4	4.7
27	Blue Earth River	2.2	4.1	7.0
28	Minnesota River-Hawk Creek	1.6	2.5	4.6
29	Lower Minnesota River	2.8	4.1	5.9
30	Kettle River	7.0	8.1	12.1
31	Snake River	5.5	7.1	11.1
32	Lower St. Croix	5.5	6.0	8.2
33	Metropolitan Area	4.2	5.5	6.6
34	Cannon River	3.8	5.4	7.6
35	Zumbro River	4.4	5.8	7.5
36	Root River	5.2	6.2	8.1
37	Cedar River	4.0	6.1	8.5
38	Des Moines River	1.3	2.4	4.7
39	Rock River	0.8	2.0	4.2

Table 2: Discharge by economic region.

Region	Runoff (inches)	Runoff (ft^3 per $mile^2$)	Total (millions of acre-feet)
Median Discharges on an Annual Basis			
West	1.94	0.143	2.72
Northeast	7.34	0.541	12.77
Central	5.05	0.372	2.59
Metro	5.22	0.385	0.86
Southeast	5.05	0.372	3.34
State	4.97	0.366	22.28
25% Annual Exceedance Discharges			
West	3.51	0.259	4.93
Northeast	9.50	0.700	16.53
Central	7.87	0.580	4.04
Metro	6.91	0.509	1.14
Southeast	7.23	0.533	4.78
State	7.01	0.516	31.43
75% Annual Exceedance Discharges			
West	1.12	0.083	1.57
Northeast	5.27	0.388	9.17
Central	3.67	0.270	1.88
Metro	3.88	0.286	0.64
Southeast	3.49	0.257	2.31
State	3.47	0.256	15.56

COMPARISONS OF ACTUAL VS. PREDICTED.

Water year (WY) 1982 in Minnesota is thought of as a wet year. Runoff in 1982 (Figure 6) does exhibit the same general pattern as the *wet* scenario from Figure 5. The WY82 runoff conditions in western and central parts of the state are very close to the *wet* scenario, while the northeastern and southeastern portions of the state are much *wetter* than the scenario. So, WY82 was in fact *wet* all over Minnesota and eastern Minnesota was exceptionally wet.

Water year 1976 is generally perceived as a *dry* year in Minnesota (Figure 7). WY76 runoff compares well with the *dry* scenario with the exception of northeastern Minnesota. Northeastern Minnesota is wetter than the *dry* scenario, but drier than the *wet* scenario. Therefore, WY76 may be characterized as a *dry* year everywhere except northeastern Minnesota where it was close to *normal*.

CONCLUSIONS

This study assesses the surface-water resources of the State of Minnesota. Two analytic techniques of regionalization were explored, regression analysis and isolines. The basic data to describe *dry, normal,* and *wet* hydrologic conditions are the seventy-fifth, fiftieth, and twenty-fifth annual exceedance runoff probabilities.

The isoline maps provide a basic tool which can be used to assess areal variability of runoff under varying hydrologic conditions. Any geographic subdivisions can be superimposed upon the maps, in spite of its basis in hydrologic subdivisions. These maps are also useful in assessing not only the relative frequency of statewide runoff for any year but also its regional characteristics.

It is not possible to refine the analysis of water availability without a considerable expansion of the state's stream gaging program. At the current time, only 20 of the 39 principal watersheds have continuous stream gages at their mouths. Accurate estimates for specific watersheds requires data from within those watersheds. If accuracy of the hydrologic response is important, additional gages should be installed and maintained.

ADDITIONAL PROJECT PRODUCTS

Arntson, A. and D. Lorenz, *Low Flow Statistics at Stream Gaging Locations in Minnesota* - pending publications as a USGS Water Resources Investigations Report.

Lorenz, D., *Peak Flow Statistics at Stream-Gaging Locations in Minnesota* - pending publication as a USGS Water Resources Investigations Report.

Jacques, J. E., *Surface Water Availability in Minnesota* - awaiting publication as a USGS Water Resources Investigations Report.

Figure 6: 1982 water year runoff map, in inches.

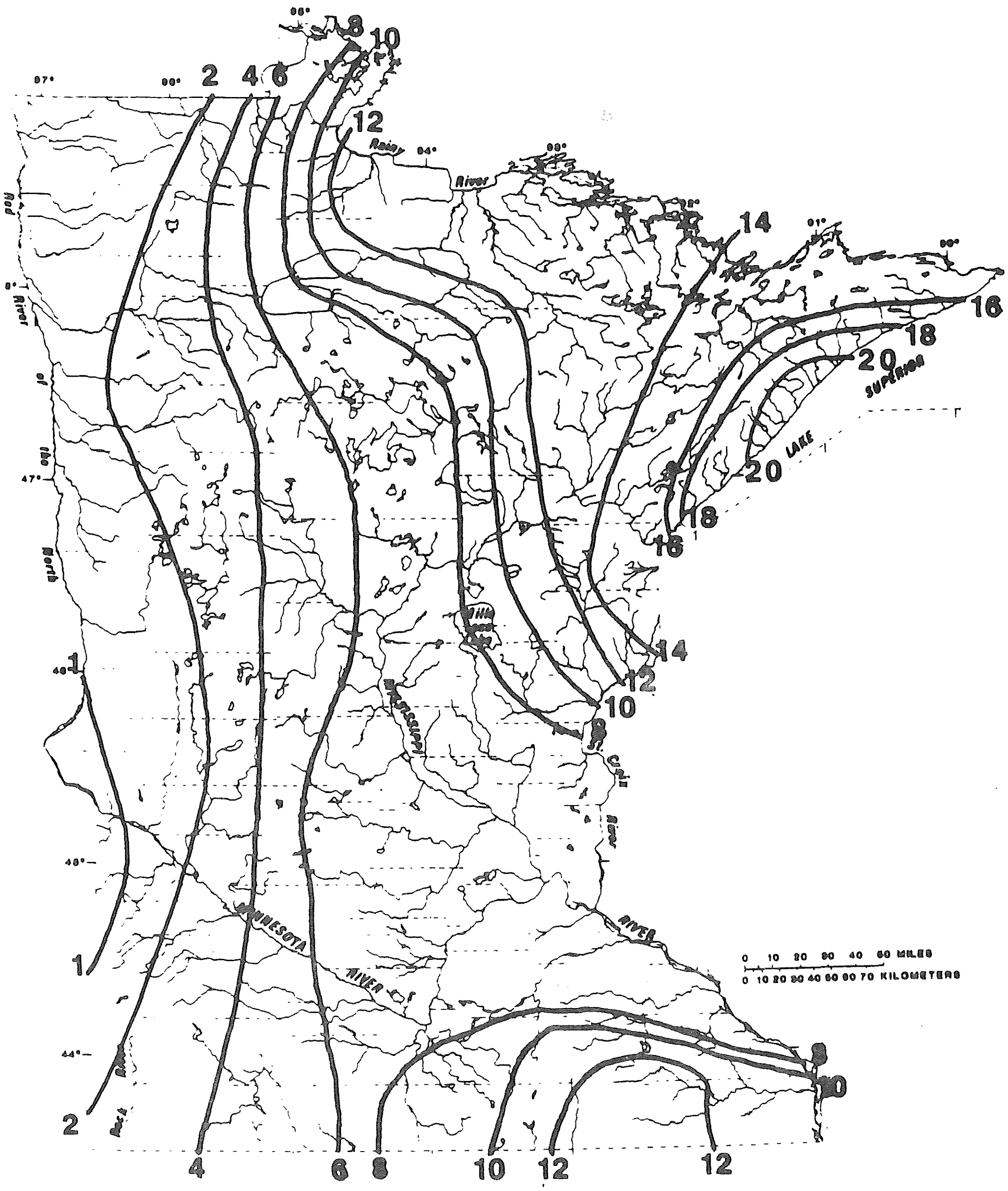
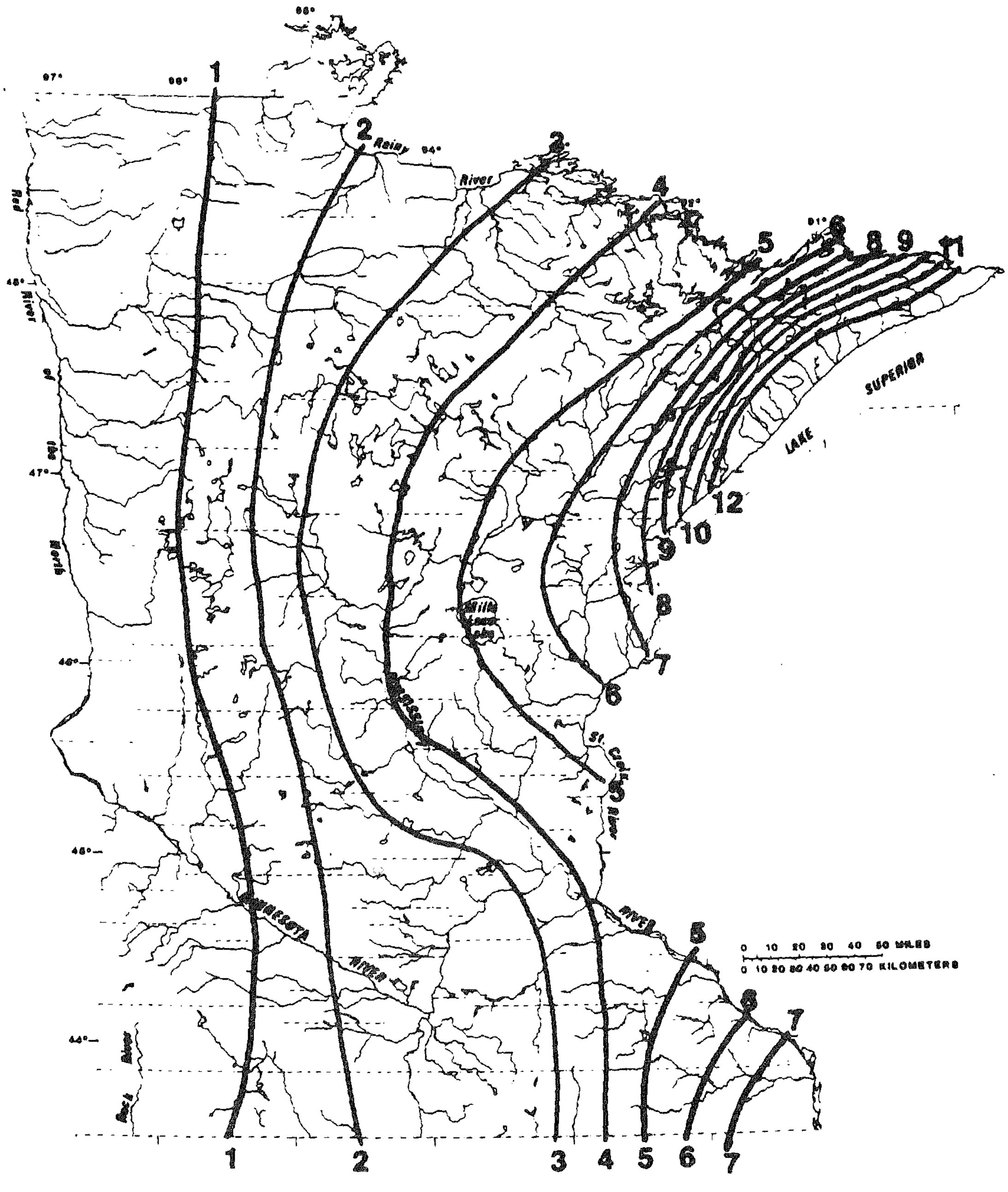


Figure 7: 1976 water year runoff map, in inches.



WATER USE SUMMARY

OBJECTIVE

Identify the quantities of ground and surface waters required by the various sectors of the economy and by households for each of the 39 watersheds, five economic regions, and the state as a whole, so that these requirements can be used in the economic valuation of water.

INSTITUTIONAL ARRANGEMENT

$87,000 was budgeted for this task and used by the DNR to fund staff. Gil Young, Research Analyst in the Division of Waters was the primary staff person responsible for compiling the water use data. The *Water Use Technical Report* and the *Water Use in Minnesota Agriculture Report* are the project products.

ANALYSIS

The (DNR) regulates the withdrawal of ground and surface waters through its water appropriation permit program. The right to the reasonable use of water is limited to the owners of land adjacent to, or, in the case of ground water, overlying the source (riparian ownership). A permit is required for the taking of more than 10,000 gallons of water per day or one million gallons per year. Domestic uses serving fewer than twenty-five persons are exempt from permit requirements.

Permit holders must record their water use monthly and report these volumes annually to the DNR. These pumpage reports were the primary source of data for this analysis. All withdrawals were codified by Standard Industrial Classification according to their end use. These amounts were then aggregated into seventy-four economic sectors for evaluation by the Interactive Policy Analysis Simulation System (IPASS) simulation model at the NRRI. Municipal water supply withdrawals were disaggregated and assigned to their end uses among the seventy-four sectors or included in residential water use.

Estimates of the volumes of water used were made for non-permitted and permitted but non-reported water withdrawals. Non-permitted withdrawals included unauthorized appropriations and appropriations below permit requirements such as most rural domestic and livestock water use. Estimates of these uses were based on county populations and average per capita water consumption. Livestock water use coefficients were taken from the USGS. Secondary data sources, including Minnesota Pollution Control Agency (MPCA) discharge permit records, were used to estimate unauthorized water appropriations. Estimates of permitted but non-reported water withdrawals were based on previous or subsequent years of reported use or on permitted volumes.

The volumes of water required for residential use were not included in the aggregations of the economic sectors but were instead treated as a final demand in the IPASS simulation model. Estimates of these water withdrawals were subtracted from the total amount of water available to obtain a net volume available for production. The effect of this procedure was to assign residential use a higher priority than economic production, since this residential demand must be satisfied first.

The decision to analyze volumes of water withdrawn rather than volumes of water consumed has significant impacts on the evaluation of water in the IPASS simulation model. Consumptive use, as defined by the USGS (Circular 1001, 1983), is "water that is no longer available because it has been evaporated, transpired, incorporated into products or crops, consumed by man or livestock or otherwise removed from the water environment". Volumes of water consumed vary from virtually nil for most cooling operations to practically all of livestock drinking water. Consumption data underestimate total water needs; the fact that cooling water is returned to a river or lake does not diminish its value to production. The analysis of consumptive water use is also hampered by a lack of primary data; these volumes must be estimated from withdrawal data, adding another level of uncertainty to their accuracy. Withdrawal data reflect the actual amounts of water required for each activity. However, aggregations of withdrawal data overestimate water requirements because they do not account for water which is returned to the source and thus made available for future use.

After weighing the two alternatives, the DNR chose to use withdrawal data because doing so increased the likelihood that this analysis would identify areas in the state where the amount of water available is not sufficient to meet the demands placed upon it.

FINDINGS

Over three million acre-feet of water were withdrawn in Minnesota in 1985 (Table 3). Nearly one-half of this water was used by electric utilities, which require large volumes of surface water for cooling at their coal and nuclear power plants.

The largest industrial water user (other than electric utilities) was iron ore mining, followed by the pulp and paper industry and primary and fabricated steel manufacturing.

Table 3: Minnesota water withdrawals by type - 1985 in acre-feet.

	Ground Water	Surface Water	Total
Thermoelectric	36,068.6	1,555,666.5	1,591,735.1
Industrial/ Commercial	429,116.4	670,292.9	1,099,409.3
Irrigation	110,332.3	44,474.9	154,807.2
Livestock	59,794.2	10,551.9	70,346.1
Residential	302,858.8	134,741.0	437,599.8
Total	938,170.3	2,415,727.2	3,353,897.5

Private households were the second largest users of ground water in the state. Slightly over one-half of this water came from municipal supply systems, while most of the remaining water came from private wells. Irrigation accounted for a much larger percentage of the total ground water used than surface water used. Over 70% of all irrigation water came from wells.

From a regional perspective, (Table 4 and Figure 1) the metro region used more water than any other region. It also had the most varied water use . Electric utilities, pulp and paper mills, sand and gravel washing operations, and a wide variety of manufacturing sectors used large volumes of water in the metro region. Over twenty percent of all water withdrawals was used by private households.

Water use in the southeast, central, and west regions was dominated by the agricultural and electric utility sectors, with residential water uses also requiring substantial portions of the total water. The west and central regions include the major irrigation areas in the State. The southeast had less irrigation, but used a substantial amount of water for livestock production and food processing. Virtually all residential and agricultural users took ground water in these regions, while electric utilities used mostly surface water.

The northeast region required large amounts of water to develop its natural resources, particularly iron ore and forests products. The northeast was the only region which used more surface than ground water for irrigation, primarily because of the significant amount of wild rice production, which depends entirely on surface water.

Table 4: Minnesota Water Withdrawals by Region - 1985 (acre-feet).

Region	Ground Water	Surface Water	Total
West	125,783.2	78,400.3	204,183.5
Northeast	115,691.4	631,054.1	746,745.5
Central	114,929.3	423,118.2	538,047.5
Metro	403,065.3	758,767.9	1,161,833.2
Southeast	178,701.3	524,386.6	703,087.9
Total	938,170.5	2,415,727.1	3,353,897.6

RECOMMENDATIONS

The largest source of uncertainty in determining the volumes of water used in the state is the unknown number of users who appropriate water without a DNR permit. The agency should expand its enforcement efforts so that all unauthorized users are brought into compliance with state statute.

While Minnesota is far ahead of most other states in collecting and analyzing water use data, there are some water measures which are not collected but would be useful for analysts in evaluation of individual permit applications and utilization of computer simulation models such as IPASS. The DNR should obtain information regarding the actual costs of water withdrawal from a variety of ground and surface water sources, and the withdrawal and consumptive water requirements for various industrial processes in terms of engineering efficiency. This would enable the DNR to more realistically develop standards for *reasonable use* and water conservation.

ADDITIONAL PROJECT PRODUCTS

Young, G. and S. Woods, 1987, *Water Use in Minnesota Agriculture* - in press.

Young, G., 1987, *An Analysis of Minnesota Water Use* - unpublished technical report.

INSTREAM FLOW

OBJECTIVES

The objective of the instream flow component of the water allocation study is to analyze and quantify approximate volumes of flow necessary to maintain instream uses (fish and wildlife habitat, recreation,...) in each of the 39 DNR watershed units, the 5 economic regions, and statewide so that these instream flow approximations can be used in the economic evaluation of water and water balance analysis.

INSTITUTIONAL ARRANGEMENTS

The $245,000 budgeted for this phase of the project was used by the Department to support staff. Patricia Olson, Senior Hydrologist in the Division of Waters, was the primary staff person. Products of this effort include a Technical Report entitled *Statewide Instream Flow Assessment* and draft watershed reports. Watershed reports for the Rainy, Crow Wing, and Blue Earth Watersheds are included in Appendix B of this report.

ANALYSIS

Protection of instream uses such as fish and wildlife habitat, recreation, aesthetics, waste water assimilation, navigation and conveyance to downstream users have been identified as significant social issues, especially during periods of water shortages. Instream flow protection is addressed in the Minnesota statutes and, since 1977, permits issued for appropriation of water from streams or lakes are limited in order to maintain and protect instream uses. Withdrawals are not allowed when flows or water levels are below the protected limits. Ground water uses can also be subject to maintenance of instream flow levels where ground water contributes to stream levels.

The term *instream flow approximation* is used in this study to indicate the estimated volume of water needed at the outflow point of river basins to support aquatic life forms and recreation. Instream flow approximations were identified for the 39 watersheds, the five economic regions, and statewide for both dry and normal hydrologic conditions. The purpose of these approximations is to identify instream flow use of water as part of the water allocation planning process. The study does not identify specific instream flow requirements on individual streams nor does it accommodate final decisions on water allocation proposals in a specific watershed. The approximations do provide an indication of potential conflicts between instream uses and existing and future offstream uses (appropriation uses). Conflict is determined by comparison of hydrologic conditions of available surface water for streams, instream flow approximations, and present and future water use for each study area.

The instream flow approximations are generally conservative (high), and more water may be reserved for instream uses than future site-specific studies may justify, because the approximations must apply over a broad geographic area and encompass a whole range of environmental conditions, instream uses, and issues. Many variables are important in determining the amount of water necessary to maintain existing and potential uses. These include flow quantity parameters (spatial and temporal variability, and availability), water quality (temperature and chemical composition), fish and wildlife habitat requirements, and recreation needs.

From a management perspective, the conditional terms used to define instream flow protection levels, such a minimum flow, maximum flow and optimum flow which may include provisions for flow variability as related to seasonal needs and existing hydrologic conditions, are also important. In Minnesota, due to lack of primary data and complexity of issues, a narrow management perspective of solving instream flow issues has been to establish a minimum flow. A minimum flow is the ultimate minimum that offstream users must leave in the stream. Using a minimum flow for instream flow protection can lesssen the conflict between instream and offstream uses, but it has generally done so at the expense of instream uses.

Most streams have more than one instream use, and *minimum flow* cannot accommodate the variability in needs. Just as water requirements for offstream uses vary, instream flow requirements also vary. Requirements for instream uses cannot be easily generalized. Fish and wildlife maintenance requirements differ by species and season. Aesthetic enjoyment is a subjective measure. White-water boating requirements are different than swimming or power boating requirements. Some uses, such as fisheries and riparian wetlands, require variability in flow to maintain optimum production whereas other uses, such as navigation, benefit by less or no variation in flow. Figure 8 shows a hypothetical array of varying instream and offstream needs through time. Thus the issue is not what minimum must be left in the stream but rather what does it take to meet the management objectives for the uses being promoted.

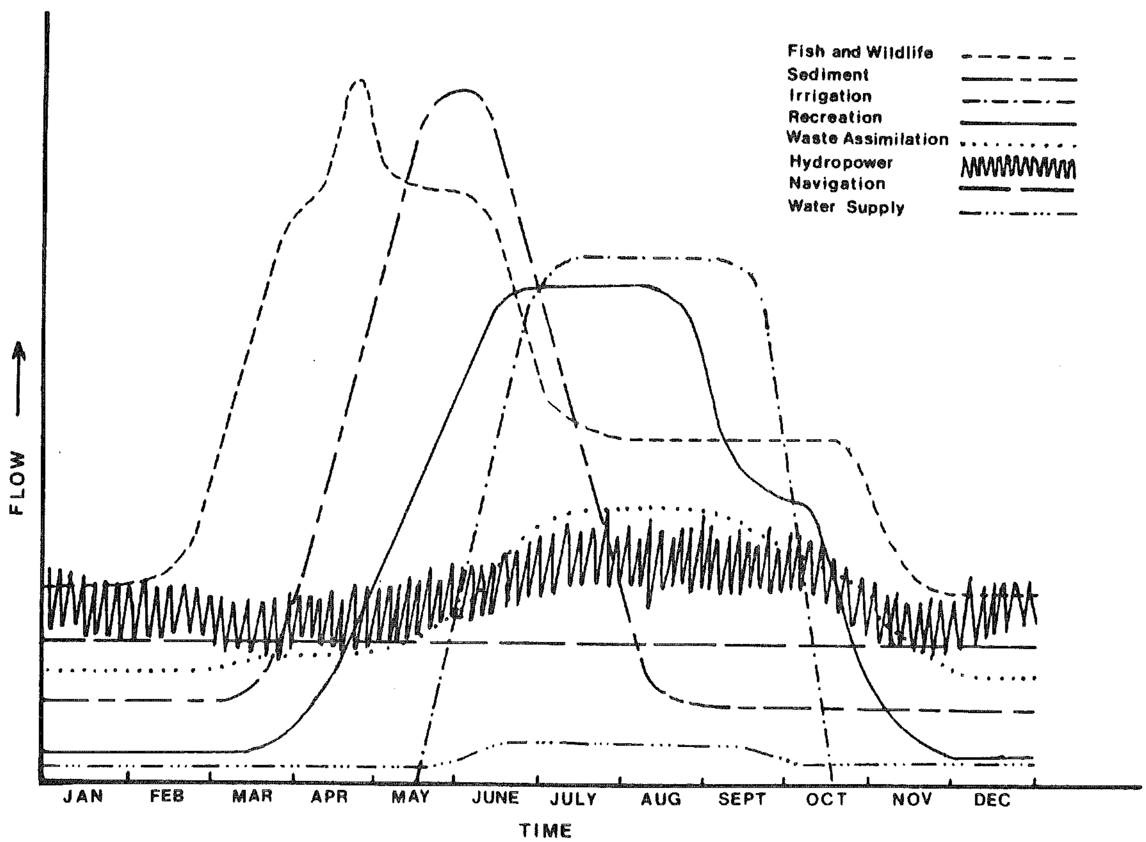
The instream flow analysis attempts to avoid the minimum flow problem and allow for greater flexibility in management scenarios by using a method that provides estimates that are closer to optimum flow requirements. Exact requirements cannot be identified without detailed study. The approximations justified during this study cannot be used as protected flows for any stream.

The instream flow approximations were developed through a multistep process as outlined in Figure 9. The approximations were based on measured field data, existing and potential instream uses, and hydrologic records. The results were reported in a format consistent with the water availability information.

The method used to determine the approximations required hydraulic simulation of field data. The hydraulic simulation techniques provided a means to estimate change in hydraulic parameters such as depth, velocity and wetted perimeter (streambed in contact with water) as discharge changed. The results were compared with hydrologic statistics. This method, the wetted perimeter method, is based on the assumption that maintenance of flow through riffles sustains important food production areas, maintains other stream habitat components less sensitive to river level changes and supports water-based recreation uses. The method allowed general analysis of three elements (food production, flow regime, and physical habitat structure) important to fish populations and survival. The wetted perimeter method permitted a more accurate depiction of instream flow needs than other planning assessment methods, which focus only on flow regime as the primary limiting factor. A detailed discussion of the methods for obtaining instream flow approximations is found in the *Statewide Instream Flow Assessment.*

Although the wetted perimeter method is an improvement over hydrologic-based methods, other important variables such as water quality, temperature, and biotic interactions (predation and competition) that influence distribution and abundance of stream fish could not be considered. Thus the results are only reflections of approximate needs and their inaccuracy precludes use as protected flows.

Figure 8: Hypothetical array of instream flow and offstream requirements for several uses.



The less accurate a method is in predicting changes in existing instream flow uses, and the less complete the assessment, the more conservative (high) the flow recommendations need to be. Thus the yearly instream flow approximations determined are conservative in order to accommodate existing and potential uses, allow flexibility in evaluating management alternatives, identify potential conflict areas before conflict occurs, and provide yearly instream flow numbers for the economic model. This approach is consistent with water quantity projections, which are based on economic growth needs for offstream water uses and not on survival needs. The probability of not identifying an area of conflict prior to its occurrence is reduced. Table 5 shows the instream flow approximations by each economic region and for the state as a whole.

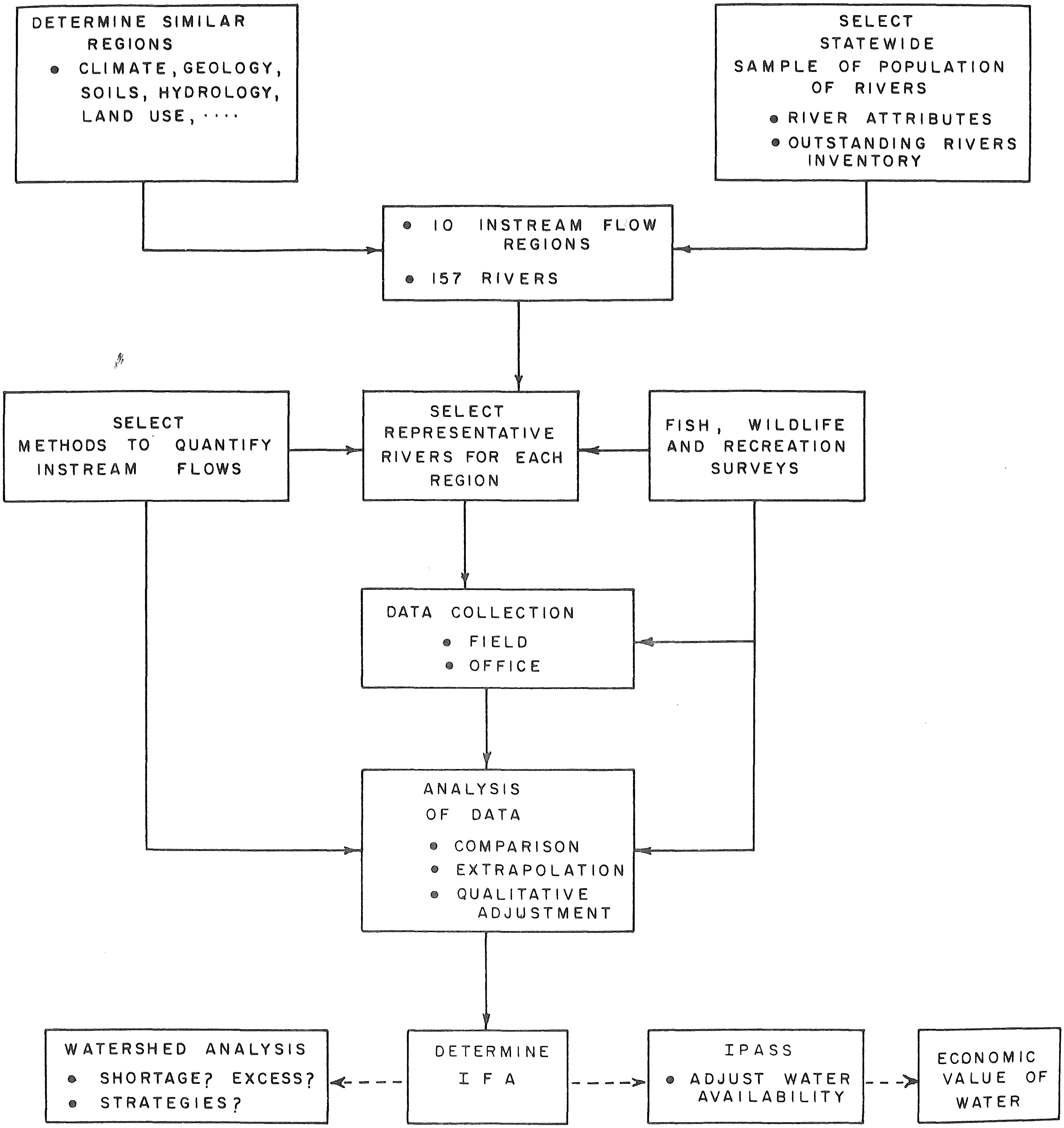
Table 5: Instream flow approximations in acre-feet for 5 economic regions and statewide.

	Normal Hydrologic Condition		Dry Hydrologic Condition	
	IFA acre feet (millions)	IFA % of available	IFA acre feet (millions)	IFA % of available
West	2.49	92	1.53	97
Northeast	11.48	90	8.30	90
Central	2.00	77	1.45	77
Metro	0.59	67	0.31	48
Southeast	2.41	72	1.72	74
Statewide	18.97	85	13.31	86

INSTREAM USES

The 1978 DNR SCORP recreation surveys were updated and expanded as part of the Water Allocation and Management Study. Recreation use trends are similar to the 1978 trends. Use of lakes for recreation is higher than use of rivers; however, use of both is still growing. Many factors may attribute to the low recreation use levels of rivers, including personal preference. Generally accessibility and distance from population centers attribute to use levels. Many of Minnesota's rivers and streams are some distance from larger population centers and are not readily accessible. Other possible contributing factors are that management emphasis has been on lakes and not rivers; and generally lakes are promoted more than rivers for recreation opportunities. Some rivers in the state, such as the St. Croix River sustain high levels of recreational use. These levels of use are generally attributed to lake recreation however, even though the "lake" is only a widening in the river.

Figure 9: Flow chart showing instream flow approximation process.



Lack of primary data and surveys regarding the specific values of instream uses to the state and resource users limit any economic analysis of instream flow uses. Recreational use and navigation are the only instream flow uses that can be valued in economic terms. In terms of strict economics, or outdoor recreation as an economic resource, rivers are of less value than lakes because rivers are used less than lakes. Recreation, however, is not the outdoors, but our reaction to it. No one would doubt that the river paddler's or trout angler's reaction is not as viable as the lake recreator's.

The instream flow approximations for some areas of the state are higher than existing recreational use levels would seem to warrant, but recreation is only one of several instream uses. Recreation use and fisheries use are more easily substantiated than preservation and aesthetics. The discussion of instream uses which follows emphasizes the recreation and fisheries opportunities.

In order to fill some of the large gaps in primary data concerning instream flow uses, a survey of DNR regional and area fisheries, wildlife and recreation managers was conducted in 1986. The survey provided information on existing and potential fish, wildlife and recreation opportunities, and limitations affecting those uses. The survey results are based on the resource managers perceptions and not on recreation surveys participation. Many of the following statements on potential fish, wildlife and recreation opportunities and limitations are based on the results of the resource managers survey.

Minnesota's streams and rivers provide valuable habitat for aquatic organisms, maintain riparian habitat for a variety of wildlife and support numerous recreational uses. The resource manager survey results indicate that the use of rivers for fishing, hunting, boating and other recreation is widespread throughout the state and there is potential for improving fish, wildlife and recreation opportunities along rivers.

SOUTHEAST AND WEST ECONOMIC REGIONS

Lakes are important statewide, but in a number of watersheds, most notably in the southeastern and western economic regions of the state, natural lakes are scarce or absent. In these areas, the stream resources are important for fisheries and water-based recreation, even though many of the rivers, especially in the southwest and Red River Valley, are affected by extremes in flow variability and availability, and water quality. In the survey, regional resource managers emphasized the potential for improving the riverine use opportunities as a management objective.

In these economic regions of the state the most important instream uses are fish and wildlife maintenance, waste assimilation, and conveyance to downstream users. Fishing and hunting are the primary recreational activities along the river corridors. According to the manager's survey, the Minnesota River and its tributaries support high levels of recreational use throughout the year. Recreational activities include canoeing, fishing, hunting, trapping, and camping. Rivers in this region support valuable wildlife habitat which is otherwise somewhat limited in this part of the state.

A number of rivers in these two regions are considered by the resource managers to have high fisheries potential which is not being realized due to water quality and quantity problems. Important gamefish species such as the smallmouth bass have been virtually eliminated due to land-use practices and dam operations. Other factors limiting the recreational use in these regions include sedimentation and erosion, nutrient loading, water quality and temperature, and extremes in flow variability. Stream channelization, wetland drainage, and dams have altered the natural flow regimes. All these are related to the flow quantity issues and most can be remedied through appropriate management actions.

Recreational use on smaller rivers in the western and southern regions appears limited in a statewide analysis, but the rivers are important locally. The high instream flow approximations reflect the local and regional importance of these stream resources (Table 5).

CENTRAL ECONOMIC REGION

The eastern portion of the central economic region supports a diverse spectrum of water-based recreation opportunities. Mille Lacs Lake is the major lake resource in the region and an important recreational resource. The St. Croix, Kettle, Snake, and Rum Rivers are all outstanding stream resources. Canoeing, fishing, camping, whitewater boating, tubing, and hunting are the major recreational uses associated with these streams. The proximity of these streams to major population centers has attracted increasingly larger numbers of recreational users annually.

The streams have not been heavily influenced by man's activities. Poor land use has contributed to localized erosion and nutrient loading problems in some areas but generally is not a major problem. Discharge from municipalities has at times been a problem on the Rum River. Naturally occurring low flows are infrequent; but at times have created problems in some watersheds. Collectively, these stream resources constitute a valuable recreation and fisheries resource to the region.

Water based recreation opportunities are somewhat limited in the western part of the central economic region. Natural lakes are not nearly as abundant as in some of the surrounding areas. With the exception of the Mississippi River and the North Fork of the Crow, both designated wild and scenic rivers, most of the streams in this region do not constitute significant river recreation resources. Survey results indicate that popular recreational uses on these rivers include canoeing, fishing, hunting, and camping. In the southern portion of the region, the rivers provide and maintain valuable wildlife habitat which is otherwise relatively scarce in this intensively cultivated portion of the state.

Although the Crow River system is close to a large population center, recreational use is not as high as on the Rum, Cannon, St. Croix, or Mississippi Rivers. The recreational potential of this stream resource is not being realized due to problems relating to water quality and quantity. Existing land use practices, intensive agriculture in particular, have reduced water quality through accelerated erosion and nutrient loading. Stream channelization and wetland drainage have altered the natural storage capacity in the region. The loss of storage has contributed to flooding problems and accentuated low flow events. These problems are most acute in the southern portion of the region where lakes and wetlands are infrequent. Toxic contaminants (i.e. pesticides and PCB's) from agricultural and industrial sources are also a concern. Management options, including improvements to existing land use practices and non-point pollution controls, could enhance the value of the streams. The instream flow approximations indirectly consider the importance of maintaining water quality.

METRO ECONOMIC REGION

Instream flow uses in the Metro economic region are varied and maintenance is important due to the proximity to the largest population center in the state. The Minnesota and St. Croix Rivers have their confluences with the Mississippi River in this region. These three rivers supply the greatest instream flow values and the highest levels of river use occur within this region. The statewide importance of these three rivers account for the high instream flow approximations in this region.

NORTHEAST ECONOMIC REGION

The water resources in the northeastern economic region include numerous lakes, reservoirs, several major rivers and some of the largest tracts of uninterrupted peatland in the world. With the exception of the larger rivers and designated trout streams, very little is known about the river resources and uses in this region. Historically, regional management efforts have emphasized the lake resources.

The river resources in the northeast are varied and support a diverse spectrum of river-based recreation activities which include canoeing, white-water boating, fishing, hunting, trapping and camping. Many of the rivers such as the Little Fork, the Big Fork, the St. Louis, the Crow Wing, the Mississippi, Cloquet, and Rainy offer excellent river fishing and canoeing opportunities. However, they are not heavily used due to the large number of lakes in the region. The Straight River in the Crow Wing watershed is one of the best trout streams in the state. Many of the rivers in this region are interconnected with lakes and are important for supplying water to these numerous lakes.

The streams tributary to Lake Superior constitute an extremely valuable resource to the State of Minnesota. The aesthetic appeal of these streams and their spectacular valleys attract large numbers of visitors to the north shore annually. The major water contact activity is fishing, with steelhead and salmon commanding the attention of anglers below the falls, and smaller stream trout in the upland reaches.

Several of the rivers have been affected by man's influences. Toxic contaminants from industrial sources remain a problem in the Mississippi and Rainy River systems. The St. Louis River has a series of hydropower facilities in operation which have altered the natural flow regime. At times, diversions from the river dewater the falls within Jay Cook State Park, thus reducing the aesthetic qualities of the area. Agricultural development and forest product operations have contributed to localized erosion problems but are for the most part not a major issue in this region. Naturally occurring low flows are problems on some of the rivers but in general flow quantity is not a major issue throughout the region.

The major factor limiting the recreational potential of many of these streams is their small size, distance from population centers, and lack of accessibility. Erosion and nutrient loading are problems in local areas. Low pH, fertility and flow in the northeastern portion of this region reduce the ability of the streams to support large populations of sport fish.

Existing laws permit only temporary water appropriations from designated trout streams. In order to meet the intent of these laws, the study assumes that the trout streams require at least the mean annual flow. Hence the instream flow approximations in regions with a high percent of area drained by designated trout streams such as the northeast and southeast economic regions, have been increased to reflect this high flow need. For example, approximately 45 percent of the northeastern portion of state is drained by designated trout streams. If trout streams are not considered as a special case, the instream flow approximation for the region would be estimated at 8.94 million acre-feet for a normal hydrologic year. With trout streams considered, the instream flow approximation is estimated to be 11.48 million acre-feet for a normal hydrologic year. The presence of other specially designated rivers such as canoe and boating routes and wild and scenic rivers are also reflected in the approximations.

SUMMARY

The instream flow component of the study provides a statewide scoping mechanism for developing management decisions for futher study and estimates to be used in the economic analysis. The *instream flow approximations* provide environmental constraints for the economic model and are generally considered a non-market value. However, hydropower, navigation and other non-consumptive users provide an economic value to instream flow, as does recreation use.

The resource manager survey results suggest that the resource potential for most river-based recreation activities is under-utilized. The results indicate that there could be improvements in the management of the state's rivers, thus greater potential for instream uses, if man-induced limiting factors such as erosion, flow-fluctuations from dam operations and from withdrawals, and non-point pollution, were controlled or eliminated. Naturally-caused limitations to instream uses such as flow-variability need to be addressed in terms of management options also.

A substantial amount of information is required within a specific watershed in order to address the issues of instream flow. The instream flow issues are not clear-cut. Developers, regulators and resource managers commonly see instream uses and offstream uses as being in conflict and exclusive. Most of the conflict is based on preconceived perceptions of the user's needs. The issues are clouded by misunderstanding of instream criteria and by reliance on traditional concepts of *minimum flow*. Greater interagency participation is necessary to ascertain and resolve conflicting issues.

The concerned agencies must develop detailed policy guidelines and establish specific criteria for decision-making. This study provides the ground work for directing attention to those areas most in need of specific analysis.

RECOMMENDATIONS

1. **Determine appropriate methods for site-specific instream flow analysis.** In most cases, office and single transect instream flow analysis methods do not provide adequate information to make the instream flow determinations for specific water allocation decisions. More detailed methods need to be examined and evaluated to facilitate water allocation strategies, provide for efficient allocation during shortages, and provide resource protection. Methods should be examined in terms of output accuracy, flexibility, time and budget commitments, complexity, and management options.

2. **Conduct site-specific instream flow studies in watersheds identified as areas of concern.** Site-specific studies are necessary to determine instream flow requirements and management alternatives. Limiting factors such as water quality, temperature and sedimentation need to be integrated into the studies where appropriate. The studies must evaluate management alternatives such as augmentation, land-use zoning, erosion control, and non-point pollution controls and should consider impacts for the entire watershed, not just the specific reach being studied.

3. **Develop primary hydrologic, biologic and instream use data.** There is a lack of primary data necessary for instream flow analysis on rivers and streams.

a) Hydrologic data are more readily available than any other necessary data, but it is not always available in the watersheds requiring instream flow implementation. The gaging network should be re-evaluated and/or expanded to provide hydrologic data for instream analysis. The DNR's hydrologic modeling capabilities for predictive and time series models should be expanded and improved. The interactions between stream flow and ground water need to be defined.

b) Biologic data on riverine species habitat requirements and preferences is limited. This data is essential to determining instream flow requirements. Studies should be conducted to obtain necessary biologic information on the population dynamics and habitat requirements for various stream species.

c) Little is known of the instream flow requirements for wildlife. Studies addressing the interaction between riparian habitat and change in stream flow should be performed.

d) River use surveys should be conducted on rivers as identified in the water balance recommendations to substantiate their levels of use and importance to river users.

4. **Involve other DNR disciplines, state and federal agencies, and developers in the instream flow determination and implementation.** The DNR, Division of Waters, has responsibility for establishing and implementing instream flow requirements; however, instream flow issues are interdisciplinary. In order to resolve issues and conflicts, and promote more efficient management, other DNR disciplines such as Fish and Wildlife, Trails and Waterways, and Planning, and, other agencies such as the U.S. Fish and Wildlife Service, U.S. Army Corps of Engineers, U.S. Geologic Survey, and Minnesota Pollution Control Agency should be involved in the studies and the decision-making process. Water users, such as the electric utilities and irrigators, also should be included.

5. **Develop management options for implementing instream flow recommendations.** Actions taken on specific river systems should consider the capacity of the resource, its relationship to other water sources, and the water use demands. Management options based on the above analysis could include augmentation of stream flow through reservoir operation plans and ground water; re-evaluation of fish, wildlife, and recreation management priorities; development of water conservation plans for offstream users; development of public education on the benefits of curtailing non-point pollution; development of incentives to reduce non-point pollution; and change in land-use zoning to lessen water quality and erosion impacts.

6. **Re-evaluate existing protected flow requirements and reservoir and hydropower operation plans.** Protected flows (instream flows) have been established on thirty-six rivers in the state. In many cases, these flows are inadequate to protect the resource. Fish kills have occured at flows higher than the protected flow level. There are numerous dams and hydropower operations in the state and most do not have operation plans that address the downstream flow requirements. These plans should be re-evaluated, especially in areas of concern. Several hydropower operations will need to apply for relicensing by December, 1993. Many of these operations do not have downstream flow requirements or only low minimum flow requirements. Some hydropower operations, such as on the Otter Tail River, are not licensed currently and do not have formal operation plans.

7. **Consider instream flow analysis as a tool for resource enhancement and multiple use optimization.** Physical habitat in channels is defined by two equally important characteristics: channel characteristics, such as substrate and structure, and streamflow. A stream with adequate streamflow but poor channel characteristics will not support fish any more than a stream with inadequate flow. Available instream flow methods have capabilities to model the effects of habitat modification on streamflow requirements. Enhancement can include modeling potential changes in reservoir operations in order to augment downstream flows while providing for reservior values such as flood control and wildlife.

8. **Establish instream flow procedures and guidelines.** A formal process addressing procedures and policies for developing instream flows needs to be developed in order to maintain consistency in the program.

ADDITIONAL PROJECT REPORTS

Blue Earth Watershed Report

Rainy River Watershed Report

Crow Wing Watershed Report

Olson, P. L., D. Desotelle, and H. G. Drewes, 1987, *Statewide Instream Flow Assessment* - an unpublished Technical Report.

WATER BALANCE

OBJECTIVES

Compare available surface water supplies with present offstream and instream water use demands and identify water shortages and excesses for each of the 39 watersheds, five economic regions, and the state as a whole. Develop priority areas for recommending future instream flow studies.

INSTITUTIONAL ARRANGEMENT

This component of the study was funded under the $245,000 budgeted for the instream flow analysis. Patricia Olson, Senior Hydrologist, and Gil Young, Research Analyst, of the DNR Division of Waters were the primary staff persons responsible for developing water balance ratios and discussion.

ANALYSIS

Minnesota's water resources contribute greatly to the economic and social prosperity of the state. Given Minnesota's apparent abundance of water, it is difficult to imagine that the amounts of water available are not always adequate to meet the competing demands. A major goal of this project is to identify the locations where water shortages are most likely to occur, so that the DNR can concentrate its water use management activities in the areas where they are most needed. Water balance evaluations were made statewide for the 39 principal watersheds (Figure 1, page 5) and the five economic regions (Figure 2, page 6) to compare available surface water supplies with present water demands.

Evaluation of the supply and demand, as a gross water budget, required the integration of three separate phases of the project. Water supply data were provided by the USGS from its water availability study. Water demand consisted of two other components: offstream uses, based on an analysis of water withdrawals, and instream uses, based upon the instream flow evaluation.

In this evaluation, the total water demand for each geographic subdivision was determined by summing the instream and offstream water requirements. The instream flow approximations are assumed to be a constraint on additional water available for offstream development. This assumption implies that the benefits accrued from providing water for instream flow uses equal the opportunity costs (benefits foregone) of diverting water for offstream use (agriculture, manufacturing, etc.).

In order to compare water supply and demand, two water balance ratios were calculated for each area. One ratio evaluated the availability and use of water under normal conditions (median flows), and the other ratio evaluated availability and use under dry conditions (75% exceedance levels). The volumes used for the ratios are annual averages of supply and demand as determined from the water availability, water use, and instream flow components of this study. These water balance ratios were defined as:

Normal conditions:

$$\text{Water Balance}_{50} = \frac{\text{Water Availability}_{50}}{\text{Total Use}_{50}}$$

Total Use_{50} = Water use + instream flow approximation for the normal hydrologic condition.

Dry Conditions:

$$\text{Water Balance}_{75} = \frac{\text{Water Availability}_{75}}{\text{Total Use}_{75}}$$

Total Use_{75} = Water use + instream flow approximation for the dry hydrologic condition.

The geographic region is defined as having a positive water balance (+), if the water balance ratio is greater than or equal to 1.10. A neutral water balance (0) is defined as a ratio between 0.95 and 1.10. A ratio less than or equal to 0.95 is defined as a negative water balance (-).

The use of water balance ratios provides an indication of the potential for a constraint on water supplies in a given area. Since the ratios were derived theoretically rather than empirically, historical records of water constraints were not considered in their determination. At best, they provide a means of comparison among geographic areas and a preliminary basis for determining areas of conflict.

Situations where the amount of water available is not sufficient to meet demand are most likely to occur in areas with a negative water balance. However, given the natural changes in water supply and demand and the uncertainty in the determinations of the ratios, constraints are also possible in regions with a positive water balance. Table 6 (page 36) shows the water balance ratios for the state. Ratios for the five economic regions and the 39 principal watersheds are shown in Table 7 (page 38) and Table 8 (page 41).

The primary sources of uncertainty in the water balance ratios come from the assumptions made in deriving the three components of the equation. Obviously, the direct comparison of supply and demand is a gross simplification of the natural system. Instream and offstream water uses are not directly additive.

The values used to calculate water balance ratios reflect annual averages of supply and demand. However, the amount of water available exhibits daily, seasonal, annual, and longer-term fluctuations. Similar changes occur in the volumes of water withdrawn for offstream uses. For instance, seasonal variations are typical in withdrawals for agricultural irrigation. Instream flow requirements also vary. For example, optimal habitat for fish species may have different flow requirements for different life stages.

Estimates of water availability are based on annual historical stream flow records and surface water runoff. The amount of water available from water basins and ground water is not included in these totals. The water availability estimates for the economic regions are based on area within the region and do not include runoff from upstream regions. Thus some regions may show a conflict based on the estimated water water availability for that region, however, conflict may not occur if all inflow were included in the analysis.

Estimates of instream flow requirements are based on a percentage of the median flow of the streams within the study areas. Since these areas usually include more than one stream reach, the estimates are an average of the instream flow requirements for the total area.

Offstream demands for water are taken from DNR records of water withdrawal by permitted appropriators. Aggregations of withdrawal data overestimate total demand because, for most users, a significant percentage of the water withdrawn is later returned to the source for further use downstream. This is particularly true for larger water users such as electric utilities and mining operations, which account for over 50 percent of all surface water withdrawals.

An additional source of uncertainty in the water balance ratios comes from the amount of error introduced into the analysis. Calculations of water availability have a mean squared error of one inch of water at the statewide level. This error can be generalized to the three maps of water availability (Figures 3, 4, and 5). The statistical bias of these maps is approximately zero. Degrees of error for the economic regions and watersheds were not determined.

The amount of error involved in developing the instream flow approximations could not be determined due to the variety of methods used in the analysis. Error was introduced in data collection, hydraulic modeling, site selection bias, and data transference. The amount of error varied with each watershed depending upon the degree to which primary data needs were satisfied.

The main source of error in the analysis of offstream use is in data collection. Dependence upon the water user to provide withdrawal data means that a variety of measurement techniques of undetermined accuracy are used. On the average, ten to fifteen percent of permitted users do not report their water use. Another unknown number of users are not under permit. While some effort was made to estimate unreported water use, an undetermined amount of error is associated with this lack of primary data.

The ratio results, management issues and recreation, fish and wildlife potentials were used as criterion for developing a tentative statewide list of watersheds for future specific instream flow studies. The priority rating and list of watersheds (Table 9) are described in the Findings and Management Issues section.

FINDINGS

Minnesota is considered to be a water abundant state; however, seasonal and geographic elements in the state result in disparities in water availability and create localized water shortages. Shortages and water conflicts have occurred mostly in the agricultural areas and in population centers that rely on surface water for municipal water supply.

Statewide, water availability is much greater than offstream water use. Withdrawals are only 11 percent of the water available under normal hydrologic conditions and 16 percent under dry hydrologic conditions. There is no indication of conflict under normal hydrologic conditions (Table 6), if the statewide supply of water is considered without regard to distribution, variability and quality. Hydrologic conditions are extremely variable throughout the state as is illustrated in Figures 3, 4, and 5.

Table 6. Statewide water supply data and water balance.

Hydrologic Condition	Water Availability acre-feet (millions)	Instream Flow acre-feet (millions)	Water Use acre-feet (millions)	Water Balance
Normal	22.28	18.97	2.41	+
Dry	15.51	13.31	2.41	0

Hydrologic conditions change spatially and in time. The same hydrologic conditions do not always occur at the same time throughout the state. For example, in the spring and early summer of 1985, most parts of the state were experiencing excessively high water levels, while the southeast area was experiencing a 50-year drought and low surface water levels. Historically, droughts do not occur all over the state at the same time. During the 1930's, drought conditions prevailed throughout most of the state; however, the northeast was relatively unaffected by the drought. Hence, the probability of statewide conflicts occurring simultaneously is not high.

The water balance ratios are only an indication of annual constraints. Water balance needs to be considered in more detail on a monthly or seasonal basis. Peak municipal, irrigation and power requirements are higher in the summer months, as are instream flow needs. Water supplies are generally lower, however, during the peak demand periods.

Contamination of ground and surface water supplies creates further limitations. The effects of water supply contamination were not addressed under water availability. Water quality is closely related to water availability and it can determine the actual usability of water for specific purposes. Water available for domestic supply may be constrained due to contamination of existing supply sources. Water quality conflicts have occurred in localized areas of the metro and southeast economic regions. Conflicts caused by poor water quality affect not only domestic water supply, but also can affect other offstream and instream uses.

Policies regarding instream flow are a management constraint on water available for offstream development. In this study, the instream flow approximations are conservative (high) estimates. Thus the water balance ratios may indicate that instream flow needs are a greater constraint to future water development than they really are. The application of instream flow methods, with improved, site specific data collection, will yield more realistic numbers and may reduce or eliminate conflicts in some areas.

WESTERN REGION

The western economic region illustrates the possible conflicts. The regional water balance ratios indicate a potential for conflict (Table 7); yet water withdrawal is only 3 percent of total water available during normal hydrologic conditions and 5 percent of that available in dry conditions.

The watershed water balance analysis (Table 8) facilitates better understanding of the conflicts in the economic regions. The greatest concentration of watersheds with negative and neutral water balance ratios occur in the western economic region (Figure 10). In this region, flow is highly variable; runoff is 10 to 20 percent of the precipitation. Annual flow fluctuations are large, ranging from floods to low or no flow. Low flows occur when offstream demands are the greatest. Even when the rate of water withdrawn from a river is small in comparison to the average flow, there are times when water withdrawn is greater than water available. Numerous localized conflicts for surface water and ground water have been documented. Periodic fish kills due to low flows and/or water quality are documented on the Buffalo, Wild Rice, Pelican and Des Moines Rivers. Water allocation plans have been implemented on the Buffalo and Clearwater Rivers where there is a high number of users. Offstream withdrawals have been restricted during low flow periods.

The positive water balance ratio in some watersheds in the western region does not reflect seasonal needs. Most of the available water occurs during spring floods. Even when flood flows are used, there are conflicts in drier periods.

The issues in the western part of the state include low flows, extreme flow fluctuations, water quality, erosion and sedimentation, non-point pollution, nitrate contamination of ground water, and hydropower peaking. Management options should consider land use management practices, flow augmentation, and re-evaluation of management priorities.

Numerous streams in the southwest and western portion of the state have protected flows, however these flows were based on the flow exceeded or equaled 90 percent of the time. In many cases, the existing protected flow is not adequate to meet management expectations. They will need to be re-evaluated according to in-stream uses, management priorities, and studies that will be done on hydropower facilities for licensing.

Table 7. Water supply data and water balance for five economic regions.

Economic Region	Hydrologic Condition	Water Availability acre-feet (millions)	Instream Flow acre-feet (millions)	Water Use acre-feet (millions)	Water Balance
West	Normal	2.72	2.49	0.078	0
	Dry	1.57	1.53	0.078	0
Northeast	Normal	12.77	11.48	0.631	0
	Dry	9.17	8.30	0.631	0
Central*	Normal	2.59	2.00	0.423	+
	Dry	1.88	1.45	0.423	0
Metro *	Normal	0.86	0.59	0.759	-
	Dry	0.64	0.31	0.759	-
Southeast*	Normal	3.34	2.41	0.524	+
	Dry	2.31	1.72	0.524	0

* Water Availability does not include inflow from upstream watersheds

NORTHEAST REGION

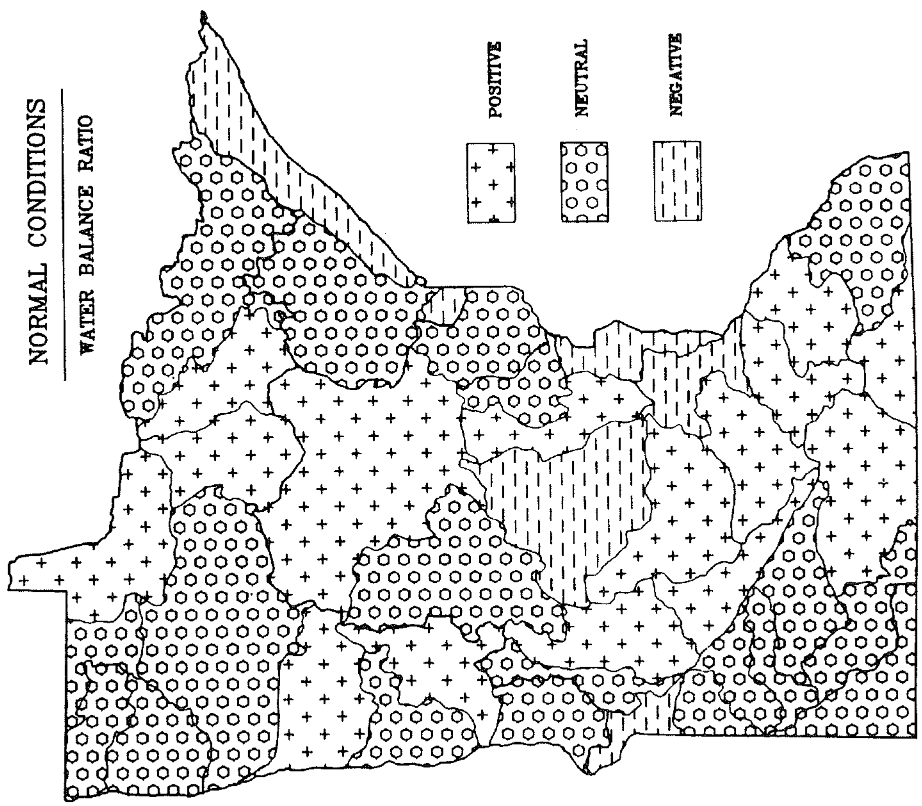
The water balance ratio for the northeast economic region indicates a potential for conflict even though water withdrawals are only 5 percent of the water available for normal conditions and 7 percent for dry conditions. With the exception of a few watersheds, water variability and low flows are not issues. The indicated conflict is more a function of management constraints concerning in-stream flow. Approximately 45 percent of the region is drained by designated trout streams. Only temporary water appropriations are allowed from designated trout streams; therefore, this study assumes that trout streams require 100 percent of the median flow.

The Lake Superior watershed has a negative ratio for both the normal and dry hydrologic conditions. The rivers in the lower portion of the watershed have little storage and generally have quick response to rainfall events. They have very low-flow during the drier periods of the year. One hundred percent of the watershed drainage area is drained by designated trout streams, hence the in-stream flow approximations are very high. Water use is relatively high due to mining activities, however, some of the larger mines have shut down which may lessen water use in the future. The watershed is very important to recreation, tourism and cold-water fisheries. Areas of special concern and where water diversion or consumption are proposed should be considered for site-specific study.

The water balance in the St. Louis watershed has a neutral ratio of approximately one for both scenarios. The instream flow approximations are high because 45 percent of the drainage area is drained by designated trout streams. The largest offstream uses are mining and electric utilities. Mining use is lessening somewhat, but other uses such as wood processing are increasing. A conflict associated with the mining industry is the pumping of water from the tailings basins into the stream systems. As the mines close and the tailing basins become inactive, water will have to be pumped out of the basins and the temperature, quality and quantity of this pumped water may negatively affect the stream systems. Site-specific studies, including temperature and water quality modeling, may be necessary for some of the tailing basin dewatering permits. Five hydropower plants along the St. Louis River will require re-licensing from the Federal Energy Regulatory Commission (FERC) in December, 1993. FERC requires the state to be involved in the re-licensing process. Site-specific studies dealing with the hydropower operations should commence within the next two years.

The neutral ratio of water availability to total use for the Kettle River watershed approaches 1.0. The streams in this watershed have naturally-occurring low flows. There is little storage and bedrock is close to the surface, thus the streams tend to be flashy, responding quickly to precipitation levels. The streams of the Snake River watershed have similar characteristics. The amount of water appropriated in the Kettle River watershed is very low, and there is no known water appropriated in the Snake River watershed. There have been some conflicts with recreation due to naturally occurring low-flows. Both watersheds are important recreation resources for canoeing and fishing. The Snake River and Kettle River are state canoe and boating routes, and the Kettle River is a state wild and scenic river. Determinations on any future water appropriation permits should include an analysis of the instream flow requirements to protect these recreational features.

Figure 10: Map of water balance results.



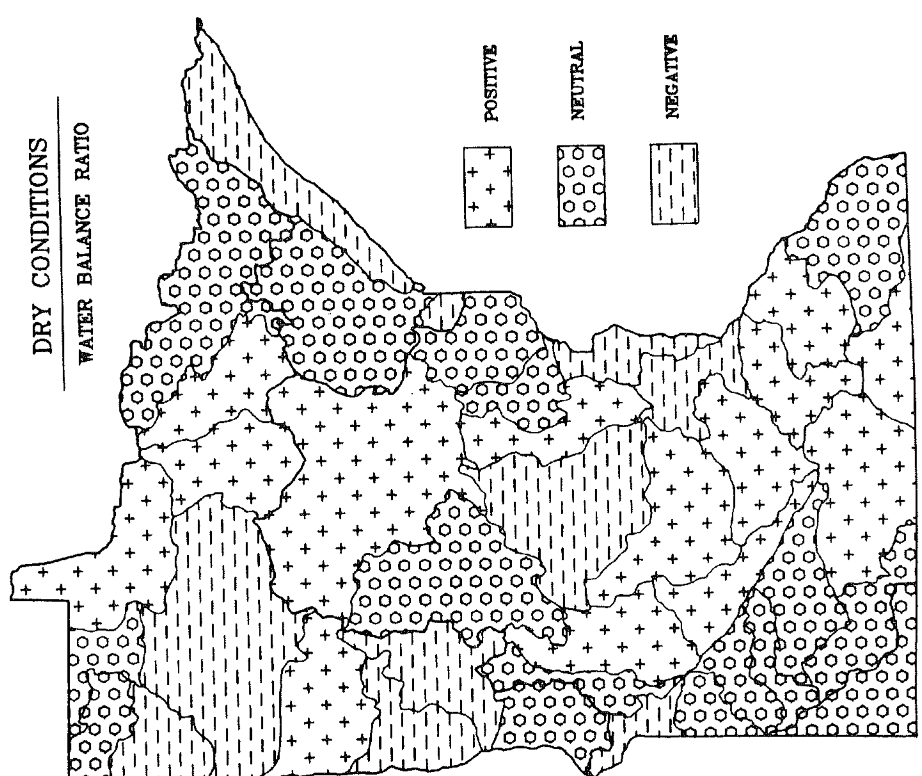


Table 8. Water supply data and water balance for the 39 watersheds.

Watershed		Hydrologic Condition	Water Availability	Instream Flow	Water Use	Water Balance
			million acre-feet			
1	St. Louis	Normal	1.724	1.547	0.199	0
		Dry	1.647	1.311	0.199	0
2	Lake Superior	Normal	1.910	1.892	0.128	-
		Dry	1.364	1.288	0.128	-
3	Rainy Lake	Normal	2.370	2.370	0.058	0
		Dry	1.915	1.867	0.058	0
4	Little Fork	Normal	0.819	0.614	trace[1]	+
		Dry	0,592	0.446	trace	+
5	Big Fork	Normal	0.781	0.616	trace	+
		Dry	0.528	0.441	trace	+
6	Lake of Woods	Normal	0.635	0.535	trace	+
		Dry	0.433	0.311	trace	+
7	Mustinka-Bois de Sioux	Normal	0.074	0.071	trace	0
		Dry	0.048	0.048	trace	0
8	Otter Tail	Normal	0.246	0.166	0.044	+
		Dry	0.154	0.125	0.044	-
9	Buffalo	Normal	0.076	0.076	0.003	0
		Dry	0.051	0.051	0.003	-
10	Wild Rice	Normal	0.277	0.241	trace	+
		Dry	0.194	0.172	trace	+
11	Red Lake	Normal	0.958	0.958	0.032	0
		Dry	0.639	0.634	0.032	-
12	Middle	Normal	0.117	0.117	0.003	0
		Dry	0.058	0.058	0.003	-
13	Two Rivers	Normal	0.092	0.092	0.0	0
		Dry	0.030	0.039	0.0	0
14	Roseau	Normal	0.144	0.104	0.0	0
		Dry	0.072	0.072	0.0	0
15	Mississippi Headwaters	Normal	2.752	1.956	0.200	+
		Dry	1.885	1.312	0.200	+
16	Crow Wing	Normal	1.004	0.943	0.003	0
		Dry	0.602	0.602	0.003	0
17	Crow	Normal	0.514	0.190	0.002	+
		Dry	0.485	0.146	0.002	+
18	Rum	Normal	0.530	0.361	trace	+
		Dry	0.364	0.232	trace	+
19	Mississippi -Sauk	Normal	1.017	1.017	0.415	-
		Dry	0.581	0.572	0.415	-
20	Big Stone	Normal	0.049	0.049	0.003	-
		Dry	0.032	0.032	0.003	-

Table 8 (cont.): Water supply data and water balance for the 39 watersheds

Watershed		Hydrologic Condition	Water Availability	Instream Flow	Water Use	Water Balance
			----------million acre-feet----------			
21	Pomme de Terre	Normal	0.083	0.079	trace	0
		Dry	0.057	0.057	trace	0
22	Lac qui Parle	Normal	0.057	0.057	trace	0
		Dry	0.037	0.037	trace	0
23	Chippewa	Normal	0.243	0.204	trace	+
		Dry	0.177	0.154	trace	+
24	Yellow Medicine	Normal	0.096	0.096	0.001	0
		Dry	0.062	0.062	0.001	0
25	Redwood	Normal	0.072	0.068	trace	0
		Dry	0.042	0.042	trace	0
26	Cottonwood	Normal	0.240	0.240	trace	0
		Dry	0.150	0.150	trace	0
27	Blue Earth	Normal	0.689	0.481	0.033	+
		Dry	0.370	0.251	0.033	+
28	Minn.-Hawk Cr.	Normal	0.197	0.1510	trace	+
		Dry	0.126	0.110	trace	+
29	Lower Minnesota	Normal	0.438	0.244	0.086	+
		Dry	0.299	0.178	0.086	+
30	Kettle	Normal	0.676	0.663	0.002	0
		Dry	0.585	0.550	0.002	0
31	Snake	Normal	0.384	0.384	0.0	0
		Dry	0.298	0.298	0.0	0
32	Lower St. Croix	Normal	0.296	0.296	0.260	-
		Dry	0.271	0.271	0.260	-
33	Metro	Normal	0.506	0.300	0.790	-
		Dry	0.386	0.107	0.790	-
34	Cannon	Normal	0.421	0.212	0.003	+
		Dry	0.296	0.139	0.003	+
35	Zumbro	Normal	0.518	0.410	trace	+
		Dry	0.393	0.321	trace	+
36	Root	Normal	0.850	0.850	trace	0
		Dry	0.713	0.694	trace	0
37	Cedar	Normal	0.392	0.213	trace	+
		Dry	0.257	0.139	trace	+
38	Des Moines	Normal	0.198	0.198	trace	0
		Dry	0.107	0.107	trace	0
39	Rock	Normal	0.191	0.176	trace	0
		Dry	0.076	0.076	trace	0

[1] Trace refers to less than 1,000 acre-feet are withdrawn per year.

CENTRAL REGION

In central Minnesota, the Crow Wing watershed and the Sauk-Mississippi watershed show potential for conflict between water uses. Conflicts between existing uses and available water have occurred in both watersheds during the drought of 1976-77. Water quality problems associated with municipal and industrial effluent discharges are exacerbated by low flows. Local water appropriation conflicts have occurred on the Long Prairie, Sauk, Straight, and Elk Rivers The issue in many of these rivers involves the interaction between ground water appropriation and the water quantity and temperature of the streams. A study of the Straight River is being funded by LCMR to determine the relationship.

Protected flows on a number of streams in the Crow Wing and Sauk-Mississippi watersheds were established during 1977. The protected flows are the flow exceeded or equaled 90 percent of the time. In most cases, this is not adequate to protect the stream resource. The protected flows on these streams will need to be reevaluated in terms of protection and management priorities. Site-specific studies may be necessary before issuing additional water appropriation permits within these watersheds.

A neutral water balance ratio for the Rainy River watershed and a negative water balance ratio for the Lower St. Croix watershed are also a reflection of the manner of determining the water availability for these watersheds. Water inflow not originating in the state is not considered as part of the water available for use by the state. Inflow from upstream watersheds of the Lower St. Croix watershed are not included in the water availability volumes either.

The water withdrawal in the Lower St. Croix River is 88 percent of the normal hydrologic water availability. The largest water user is electric utilities. This use in not totally consumptive and the percent of water use to water availability is misleading. Although both watersheds are very important recreational resources, the threat of water depletion is not imminent. Specific studies do not need to be considered in the near future.

METRO REGION

The metro region and watershed exhibits a very large negative ratio in both the normal and dry hydrologic conditions. Conflicts with municipal water supplies occurred during the drought in 1976 and 1977. The deficit, however, is more in response to the manner of determining the water availability and instream flow approximations for this region. Both do not include the inflow from the watersheds upstream of the region which is considerable (Mississippi, the Minnesota, and the St. Croix Rivers). The volume of water available when the upstream areas are included is approximately 7.7 million acre-feet under normal hydrologic conditions. The instream flow needs would be approximately 5.3 million acre-feet. Under dry hydrologic conditions, the water availability including inflow, would be approximately 5.1 million acre-feet. The estimated instream flow needs would be 2.5 million acre-feet. As water supply conflicts have occurred during drier periods, it is still reasonable to assume there could be a deficit during the dry hydrologic condition.

Most of the municipalities in the metro region have drought contingency plans and have developed ground water supplies to supplement their water supplies. However, there are ground water and surface water contamination issues which affect the availability of water for domestic use and instream use.

SOUTHEAST REGION

No water supply conflict is indicated for the southeast economic region. Only the Root River Watershed shows any potential for conflict for both normal and dry hydrologic conditions. This is due to the numerous designated trout streams within the watershed causing the instream flow approximations to be high. Offstream water use in the watershed is less than 1,000 acre-feet per year.

Although no conflict is indicated within the region, the water balance does not consider water quality conflicts. Water availability for domestic supply is constrained in many areas due to ground water contamination. There are hazardous waste sites such as Spring Valley which have contaminated numerous domestic wells. Pesticides and nitrates from fertilizers, feedlots, and septic systems can be transmitted rapidly through solution channels in the karst area. The ground water is directly connected to surface water supplies. The contaminants in the ground water flow toward areas of discharge, such as streams and springs, thus affecting surface water quality.

The streams and rivers of this region are important surface water resources since there are few lakes in the region. The Minnesota, Mississippi, Root, Zumbro, Straight, and Cannon Rivers are canoe and boating routes. The Cannon River is a wild and scenic river. Hydropower development is an issue of concern along the Mississippi, Blue Earth, Cannon, Root and Zumbro Rivers. Two hydropower dams, Zumbro Lake and Lanesboro, are not licensed by FERC, and additional hydropower development is proposed for the lock and dams on the Mississippi River. Fish kills have occurred on the Cannon River and the Blue Earth River due to hydropower dam operations. In order to protect the existing surface water resources, dam operation plans need to be developed or updated.

Numerous streams in the southeast region have established protected flows, however these flows may be inadequate to meet management expectations. They will need to be re-evaluated in terms of surface water appropriations and hydropower and reservoir operations.

AREAS FOR FUTURE STUDY

The water balance ratio results were used as the primary criteria to identify and develop a tentative statewide priority list for future instream flow studies. The water balance ratios are a planning tool that provide guidance to identifying areas of potential conflict. Watersheds that show a neutral or negative water balance indicate a need for additional watershed specific scoping to define the extent of additional studies.

In addition to indicated potential for conflict from the water balance ratios, management issues were considered as important criteria in determining the priority for future study. Management issues are existing conflicts between instream and offstream uses, hydropower licensing and re-licensing, local water planning, and reservoir operation plans. The existence of these issues and the need for developing a mechanism for resolving the issues while enabling allocation and development of water resources, were the primary impetus for the LCMR funding of the Water Allocation and Conservation Study (accelerated instream flow study) for the 1987-1989 biennium. The management issues were influential factors in developing a tentative priority list. None of the issues were given more weight than the others in the priority determinations. However, a higher priority was given to watersheds based on the number of issues occurring within the watershed.

The third criterion used in establishing the priorities was the recreation, fisheries and wildlife potentials. The potentials for each watershed were based on existing recreational resources, such as wild and scenic rivers and canoe and boating routes, and results of the DNR regional resource managers survey that indicate rivers with existing or potential recreational and fisheries value.

The following priority list (Table 9) is tentative and subject to change as additional scoping occurs. The list serves as a first approximation of rivers to study for the LCMR funded Water Allocation and Conservation study. Three priority classifications were used to expedite choice of study areas. Priority 1 is the highest classification. All watersheds in this priority class have at least two management issues occuring and have relatively high recreation or fisheries potentials. However, any waterhsed listed under all three priorities could be considered for study under the instream flow project.

Table 9: Priority areas for instream flow studies.

Priority	Watershed	Issues
Priority 1:	St. Louis	hydropower re-licensing, reservoir operations, mining, recreation
	Otter Tail	hydropower licensing, reservoir operations, existing conflicts, local water planning, recreation, fisheries
	Root	local water planning, hydropower, fisheries, recreation
	Cannon	hydropower, local water planning, recreation, fisheries
	Upper Minnesota	reservoir operations, water quality, local water planning, hydropower licensing, recreation, wildlife, fisheries
	Mississippi-Sauk	existing conflicts, reservoir operations, hydropower, local water planning, fisheries
	Mississippi Headwaters	reservoir operations, hydropower, local water planning, fisheries, recreation
Priority 2:	Crow Wing	existing conflicts, ground-surface water interactions, fisheries, recreation
	Red Lake	existing conflicts, proposed diversion, local water planning
	Blue Earth	hydropower operations, local water planning, recreation, fisheries
	Zumbro	hydropower, reservoirs, local water planning, recreation, fisheries
	Crow	local water planning, water quality, recreation
	Des Moines	local water planning, conflict potential, recreation
	Buffalo	existing conflicts, re-evaluate protected flow
Priority 3:	Wild Rice	proposed flood control, local water planning
	Cottonwood	water quality, local water planning, fisheries
	Lake Superior	hydropower, mining, fisheries, recreation
	Roseau	conflict potential, flood control, local water planning, wildlife

SUMMARY

Water supplies are more than adequate to meet existing water uses, however, water is not always available when and where needed. Actual availability and quality of water is determined by the manner of resource development and management. The resource available for development, either for instream or offstream use is a function of the existing legal structures and institutions that control or regulate the use.

In some areas of the state, availability is highly variable and water supply is more vulnerable to drought. Vulnerability can be lessened through management of existing surface and ground water resources. Management of the resource is based on allocation or reallocation of water among users or regions. Improving existing reservoir operations and water supply forecasting, and developing drought contingency and water allocation plans are traditional management options. For instance, in the areas of high flow variability, where conflict arises from either to much water or to little water, multiple-use of appropriately sized flood control projects could reduce flood conflicts and enhance low flows and water delivery through augmentation during periods of withdrawal. Augmentation can also be used to enhance instream uses.

Interbasin diversions or transfers are other management options for supplying additional water where needed. The use of such methods is clearly governed by economic, social and environmental factors. The feasibility of this option depends on how much recipients are willing to spend on developing the public works. Costs of development must include the social and environmental costs, including impact studies and mitigation. The costs may not allow water to be delivered at economically realistic prices. The social and environmental cost of increasing water supply in one area may be at the expense of water supply and environment in another area. Diversions aggravate dewatering impacts since the withdrawals have no return flow to the basin of origin.

AREAS OF CONCERN

Insufficient water supply during critical low flow periods occurs most often in the western and central economic regions (Figure 10). Future conflicts in water supply development are anticipated in these regions. Water quality deficiencies in lakes and streams are also prevalent in these regions. Water quality is an important component in developing instream flow recommendations and for some offstream uses; however, water quality was not directly integrated into this study. Where water quality is unsatisfactory, more detailed approaches, including water quality modeling need to be considered.

Mining and hydropower development are issues of concern in the northeastern economic region. Although there are more than abundant water supplies, quantity and quality are locally affected by mining discharges and reservoir operations.

Ground water degradation from landfills, hazardous waste sites, and nitrates is a statewide problem. The quality of ground water is closely linked to surface water because stream flow is supplemented by ground water. Ground water quality effects on streamflow is especially pronounced during low flow periods.

RECOMMENDATIONS

1. **Site-specific instream analysis of watersheds based on conflict, existing management priorities, instream and offstream use and local water planning should be conducted to provide management alternatives in allocating the water supply among instream and offstream users.** Based on this recommendation and information obtained in this project, potential study areas have been identified (Table 9).

2. **Evaluate gaging network and establish gages at mouths of watersheds of concern.** The gaging network has been steadily reduced because of budget constraints. The existing gaging network should be reviewed and modified to include a program for monitoring watersheds of concern.

3. **Establish a water conservation program. Water conservation is a potentially effective means of managing water supply in areas of water use conflicts or shortages.** There should be an interagency

effort to assist communities and public utilities by providing guidelines, information and techniques on water conservation and emergency and drought preparedness planning. A community technical assistance program for water conservation and emergency water supply planning should be established.

4. The DNR should develop a surface-water data base and management information system. A information system could coordinate accessible data files for surface water appropriations, protected flows, fisheries and recreation data, flow data, study areas, and sources of further information. This would enable more efficient decision-making on water appropriation permits, especially in water conflict areas.

5. The DNR should re-evaluate existing water appropriation laws in regards to the distribution of water resources. The Water Planning Board recommended that policy be adopted regarding the use of lease-easement arrangements to allocate water. Such a policy must consider water availability, environmental needs, and the demands of the specific situation. Re-evaluation should focus on the legal, institutional, social and environmental issues, and could consider the possibility of water sales or transfers, either private or public.

PART TWO
ECONOMIC WATER VALUATION AND EVALUATION OF SCENARIOS

OBJECTIVE

To determine the economic value of water for the state and selected industrial sectors and using the Interactive Policy Analysis Simulation System (IPASS) model, provide projections of future water demands, and evaluate scenarios and strategies for water allocation.

INSTITUTIONAL ARRANGEMENT

The Natural Resources Research Institute, with Richard Lichty as principal investigator, was contracted to perform the economic modeling and related activities. $280,000 was budgeted for this task. Specific contractual objectives include:

* determine the economic values of water to 75 economic sectors and the State economy.
* evaluate allocation strategies and investment decisions.
* recommend changes in policy directives, legislation and management actions.
* develop analytical tools for planning, policy development and management evaluation.

Other investigators who participated in this project include:

Mr. Miguel Garcia
Graduate Research Associate
University of Minnesota, St. Paul

Dr. Curt L. Anderson
Assistant Professor
University of Minnesota, Duluth

Dr. Wilbur R. Maki
Professor of Agriculture and Applied Economics
University of Minnesota, St. Paul

Dr. Jerrold M. Peterson
Professor of Economics
University of Minnesota, Duluth

Ms. Patricia Q. Dalton
Former Research Associate
University of Minnesota, Duluth

Mr. Mason Chen
Computer Programming Consultant

One of the unique features of the research program was the extensive use of undergraduate research assistants in the data collection and organization phases of the project. The work of these students was invaluable to the project and provided an undergraduate research experience for the students that is difficult to find under normal circumstances. The participating undergraduate research assistants were:

Mike Hoelscher
Lynda Komplien
Kaithin Lim
Tan Kok Hui
Mike Durand
Kurt Jusczak
Steven Hallgren
Jan Page
John Odegard
Scott Kelly
Thomas Elbert
and Gail Carlson.

INTRODUCTION

The general problem of valuing resources in order to determine optimal allocations has been the focus of numerous studies, especially with respect to water. These valuation exercises imply a need to allocate water. Allocation schemes have been found to be necessary throughout the world as water scarcities become more and more evident. This is a far cry from the condition throughout most of the world up through the last century where water was seen to be a *free* resource in plentiful supply.

In addition, when nations have developed laws relating to water resources, these laws often emphasize withdrawal rights as opposed to instream needs. To the extent that these laws view water consumption as an inherent right, most of them require equal sharing of the burden when water supplies are short. If persistent shortages exist, the tendency has been to construct facilities geared towards increasing supply, often resulting in significant instream effects.

From the point of view of economy efficiency, there are numerous indications that water is being over-used in this country. Instead of conserving withdrawals, cities are attempting to increase water supplies to meet demands. Only recently have people begun to recognize the value of keeping water in rivers to maintain fish and wildlife habitat or for aesthetic or recreational purposes. Major aquifers are being depleted at alarming rates in many sections of the country. Other ground water reserves have been made unusable through contamination. Because of this overuse, water is becoming increasingly scarce in economic terms, if not in physical terms. In other words, there is not enough water to meet all of the demands at the current price.

When scarcity presents itself, allocations must be made in the short run. In order for these allocations to be efficient, the resource should go to the highest and best uses as defined in identified objectives. Where an allocation scheme is based on across-the-board reduction of consumption, right of prior appropriation (first users of the resource have first claim), priority of withdrawals over instream uses, or where the allocation is based on households having first claims while the remaining resource is allocated according to one of the above schemes, it must be done with an understanding of the implications and costs of such allocations.

One of the clear results of the analyses conducted for the state of Minnesota is the realization that the state's water is not presently scarce from an economic point of view. In fact, water supplies are almost double what is required for production, even when a substantial amount of available water is withheld from production for other purposes (e.g., environmental or recreational purposes). From a pricing point of view, water in Minnesota is essentially treated as a free resource. Thus, water will be used in Minnesota as a substitute for other resources that are not free whenever such substitutions are possible. A second result is that water will be used an an input to production to a much greater extent than would be the case in those regions of the country experiencing relative water scarcities.

With continued economic growth in the state, with increased use of water for irrigation, with short-term variations in weather leading to possible drought conditions, with increased possibilities for contamination of ground and surface water supplies in the state, and with the possibility for diversion of Minnesota waters to other states where scarcities do exist, the possibility of future needs for allocating state waters is always present. Should water become a constraint to economic growth for any or all of these reasons, efficient allocation of the water that is available becomes desirable.

Given these concerns, it was recognized that without a comprehensive model to evaluate Minnesota's water policy options, the state could be seriously disadvantaged in the developing national and regional water policy struggle. This project is the result of that concern.

METHODOLOGY

This research project has as its major goal the evaluation of water allocation schemes for the State of Minnesota. Most evaluations of this type attempt to do so through the estimation of relative values associated with alternative allocation possibilities. No one single measure of value can always be used for such allocation evaluations. The measure used depends primarily on the objective of the evaluator.

Three objective functions will be employed in this analysis: the maximization of gross state output, the maximization of state income (earnings), and the maximization of state employment. The results of this analysis will highlight the direct and indirect effect on output, earnings, and employment from the direct and indirect increase in water use to satisfy new final demands for the state's output.

In other words, this analysis provides the user with an allocation ranking for the identified industries in the state. This ranking is interpreted as follows: If there is not enough water to satisfy the production requirements of the state's levels of final demand and if the maximization of earnings (for example) is the state's objective, then any additional water that might be found should be allocated first to that industry exhibiting the largest direct and indirect earnings effect per direct and indirect intake of one acre-foot of water. Once that sector's final demand is satisfied, the next unit of new water should go to the industry exhibiting the next largest ratio, and so on.

To continue such an allocation across all industries would be to maximize the possible earnings out of a given supply of water. No other allocation would increase earnings, and in this sense the resulting water allocation would be deemed to be efficient. In addition to evaluating alternative allocation schemes, this project has as one of its goals the examination of the change in the value of water as it becomes more scarce. Like labor, capital, steel or any other input to production, as a resource becomes scarce, its value relative to other inputs becomes greater. Simulation of this event under an allocation scheme which maximizes output, for instance, can yield a *shadow price* for water. Such a technique is a common way of measuring the value of a resource like water for which no market exists to assign a price.

A third goal of the project is to be able to analyze the potential economic impacts of various situations in which the supply of water is not sufficient to meet the demand placed upon it by the economy. The computer models used can simulate the effects of drought, contamination of surface or ground water, diversion of water within or outside the state, or increased demand for water caused by economic growth.

GENERAL CONSIDERATIONS

It should be pointed out at the beginning that there are a large number of important assumptions and definitions associated with an exercise of this type. First of all, extreme caution must be observed before applying the results of this or any other simulation model to the *real world* economy. While every attempt has been made to induce all variables in the model - labor, investment, etc. - to respond to change in ways which approximate their real world counterparts, they are simplifications of the economy and should be regarded as such. Furthermore, while the model can be run from 1982 until 1987 or any year in the future, IPASS is not a predictive model. It was not designed to forecast the future state of the economy, but instead to show the ways in which changes in one or more inputs affect other variables and the economy as a whole.

All water measures are in terms of water withdrawals. The research team discussed the alternatives at some length in this regard with the other options being engineering estimates of water requirements per dollar of output and water consumption. Water withdrawals were chosen due to the wealth of data on such withdrawals for Minnesota and to the particular concerns of the DNR that the largest measure of water use be considered so that any potential for conflict over water resources be identified through the use of the IPASS simulation model.

Another implication of the use of current withdrawal data is that the existing allocation of water is somehow efficient. In other words, this project does not purport to evaluate the efficiency of the current use of Minnesota's water or the re-allocation scheme that would be required to make such an allocation more efficient. The current water use pattern is taken as given.

Also taken as given is the institutional arrangement by which water is allocated in Minnesota. By institutional factors we mean the current arrangement of laws, ownership arrangements, and markets that are operating in the state.

The system of prices of water in the state is also ignored in this analysis. The values being estimated in this work are values relative to stated objectives and are not estimates of ideal water prices. In fact, like most input-output techniques, this work takes prices as given.

Another variable not addressed here is the cost of providing water to the identified highest and best uses. New investments in water production technology (for example, the construction of dams or drilling for new ground water supplies) are not analyzed in this work.

Finally, while the total project looks not only at the state of Minnesota but also at five sub-state regions, the analysis in this report will look only at the state as a whole. Similar analyses and tables will be prepared for the five sub-state regions. The characteristics of the generalized model and the caveats presented here carry over to the sub-state evaluations.

Two analytical tools were used in this evaluation of water in Minnesota. The first, The Interactive Policy Analysis Simulation System (IPASS), is a dynamic input-output simulation model. IPASS was used to develop alternative water allocation schemes and to evaluate the economic impacts of a constraint placed on available water supplies. Second, a shadow price of water was evaluated using the input-output matrix and a linear programing model.

IPASS is a dynamic simulation model capable of estimating a number of socioeconomic variables in the state over time. Numerous algorithms (grouped into eight basic modules: investment, final demand, production, regional output, employment, labor force, population, and primary input) are used to calculate and project these variables. IPASS is capable of interactive analysis, i.e., analysis where the user is allowed to change parameters and to simulate impacts from these parameter modifications on regional economic and demographic variables.

The base year for Minnesota's systems is 1982. Once the data base is inserted for that base year, the interaction of the command program and the various modules of the system simulate variable values for subsequent years.

A special purpose water module has been developed for this project. The water module takes on a form very much like that of the other modules. Water demand is estimated on the basis of ratios of water use to output on an industry by industry basis. When the level of industrial production of the state is conditionally forecast in the earlier modules, water use is also forecast on the basis of these water to output ratios.

Efforts were made to enable IPASS to reflect the natural system by limiting the amount of water available for production to that which is actually present during dry, normal, and wet years. Surface water supplies were estimated by the U.S. Geological Survey based on average runoff from precipitation under these conditions. A fairly substantial portion of this water is held back from production in order to satisfy the need to maintain an acceptable amount of surface water for non-withdrawal uses. This water is required for the maintenance of fish and wildlife habitat for recreation, for navigation, for hydroelectric power generation, and for waste assimilation. Estimates of these instream flow requirements were made by the DNR. Estimates of the amount of recoverable ground water were also made based on existing rates of withdrawal.

The amount of water available for production is further constrained by subtracting the volumes required for household consumption from the total water supply. In effect, residential water use (and instream uses) were assigned a higher priority than economic production, because the model is forced to satisfy these demands first before water is allocated to the various sectors of the economy. As is true in the investment and labor force modules, if the surface or ground water supply is inadequate to meet the estimated water demands, water becomes a constraint against production; income and employment suffer as a result.

In order to determine a value for water in the various uses (sectors) we must ask what the objective is to be. Suppose the objective is to maximize earnings. Consider the following ratio:

$$U_j/H_j$$

U_j measures the change in regional earnings given a unit change in the final demand for commodity j, while H_j measures the amount of water required to actually make this change. The ratio indicates the change in regional earnings per unit of water allocated to serve the needs of sector j (which, of course, includes water allocations to those sectors from which sector j purchases intermediate inputs).

These ratios represent a measure of the value of water in the following sense. Suppose the economy is currently utilizing all available water supplies while other primary inputs are not fully employed (which is usually the case for labor and for capital, since plants typically are run below capacity) and unfilled final demands exist in some sectors. In other words, suppose that water is constraining the level of economic activity in the region. Now assume z units of new water supplies are acquired. How should these be allocated? If the objective is to maximize regional earnings, it should be allocated so that the sector with the highest U_j/H_j ratio can meet all its unfilled final demands, then so that the sector with the next highest ratio can meet its unfilled final demands, and so on. In other words, the water should be allocated to its most highly-valued use which, in this case, is the use that leads to the generation of the most regional earnings. Clearly the procedure above results in the greatest increase in gross regional income per unit of water allocated and so results in an efficient allocation of the new supplies given the objective chosen. Again it should be noted that when allocating the water so that the first sector (say, sector j) can meet its final demands, this necessarily implies, due to the inter-industry linkages that some water must also be allocated to sectors from which sector j makes purchases so that they may increase their outputs to service the increased needs of sector j.

Conversely, suppose all final demands are currently being met by all sectors and that again all available supplies of water in the region are being utilized. Now assume a shortage of z units of water occurs (due to a drought, for example, for example). Where should the cuts in water use be made? Given the same objective of maximizing regional, those sectors with the lowest U_j/H_j ratios (and so, those sectors serving them) should be cut back first. This would insure the smallest loss in gross regional earnings possible.

Table 10 shows the ratio values relative to ground water along with industry rankings under three objectives: maximizing output, employment, and earnings. The relative rankings are the most important aspects to note out of those tables.

For example, if the state objective is to maximize production in the form of gross output, the gas utility sector would be given the first new unit of ground water when ground water is short relative to demand. This same sector would continue to receive water until its own output and that of its direct and indirect suppliers increase to the point of satisfying final demand.

However, if the objective is to maximize employment, the gas utility sector would be the thirty-third industry to start to receive new ground water. This same industry would be the forty-fifth industry if maximizing earnings were the objective.

Since the rankings are based on both the direct and indirect output, employment, and earnings effects from a dollar of final demand, the rankings not only depend on the absolute activity in the industry being analyzed (gas utilities in our example), but also on the level of interaction between that industry and the other identified industries in the economy. In the cases of employment and earnings, it is not only the interaction between industries that is important but the interaction of industries with each other and with the labor force. In other words, even if gas utilities were a small employer per dollar of output, it may still be ranked high relative to the employment objective if it interacts heavily with other Minnesota industries that are labor intensive relative to output.

The same computations were made with respect to surface waters. The results of these computations along with relative industry rankings appear in Table 11. Once again, the gas utility industry is seen to rank number one with respect to the output objective. However, it can be seen that the different pattern of water use relative to output results in a slightly different pattern of rankings among the industries.

One industry that ranks fairly high for both ground and surface water is business services. While business services is not itself a major user of water, its interaction with other industries in the state in terms of output, employment, and earnings makes water going to this sector of higher value than is true for many competing industries.

Table 10: Economic sector rankings: Ground water.

SECTOR	NAME	OUTPUT	EMPLOY-MENT	EARNINGS	AVERAGE RANKING
55	TRUCK TRANSIT	3	1	1	1.7
67	BUSINESS SERV.	5	2	7	4.7
64	FINANCE/INSUR.	9	4	2	5.0
58	COMMUNICATIONS	7	8	3	6.0
45	COM/OFFICE MACH	8	12	4	8.0
53	RAILROAD TRANS	4	7	16	9.0
62	WHOLESALE TRADE	11	15	8	11.3
24	APPAREL/FABRICS	10	14	15	13.0
72	EDUC/NON-PROFIT	20	3	17	13.3
54	LOCAL TRANSIT	14	5	23	14.0
15	ORDNANCE & REL	22	18	6	15.3
56	AIR TRANSPORT.	13	23	11	15.7
51	OPT.OPHTH.PHOT.	16	26	9	17.0
50	PROF/SCIENTIFIC	38	10	5	17.7
69	AUTO REPAIRS	12	19	22	17.7
71	HEALTH SERVICES	28	13	12	17.7
25	LOGGING	6	21	28	18.3
63	RETAIL TRADE	37	6	13	18.7
26	SAWMILLS	23	20	14	19.0
65	REAL ESTATE	2	24	31	19.0
43	MACHINE SHOPS	26	25	10	20.3
68	EAT/DRINK ESTBL	24	16	36	25.3
44	NONELECT. MACH.	30	30	18	26.0
60	GAS UTILITIES	1	33	45	26.3
52	MISC.MANUFACTUR	19	32	30	27.0
70	FILM/RECREATION	48	9	25	27.3
13	NEW CONSTRUCTN	15	34	34	27.7
27	WOOD PRODUCTS	36	28	20	28.0
14	MAINT. & REPAIR	18	35	32	28.3
28	FURNITURE	34	27	24	28.3
46	SERV. IND. MACH	21	40	27	29.3
42	FARM MACHINERY	40	31	19	30.0
47	ELECTRIC MACH.	31	36	26	31.0
35	LEATHER PRODUCT	43	22	29	31.3
23	TEXTILE GOODS	35	39	21	31.7
18	CANNED & FROZEN	29	29	44	34.0
4	OTHER CROPS	33	11	59	34.3
66	HOTELS/SERVICES	50	17	39	35.3
48	MOTOR VEHICLES	25	48	38	37.0
49	OTHER TRANSPORT	32	44	35	37.0
57	OTHER TRANSIT	27	43	41	37.0
5	FOR./FISH PROD.	51	37	33	40.3
20	BAKERY PRODUCTS	39	42	40	40.3
31	PRINT & PUBLISH	44	41	37	40.7
32	CHEMICAL/ALLIED	41	49	42	44.0
33	PETROL REFINING	17	63	57	45.7
21	BEVERAGES	46	50	46	47.3
34	RUBBER PRODUCTS	49	51	43	47.7
17	DAIRY PRODUCTS	45	47	54	48.7
16	MEAT PRODUCTS	42	52	55	49.7
22	OTHER FOOD/TOB.	47	45	58	50.0
36	CLAY/STONE/GLAS	56	53	49	52.7
1	DAIRY & POULTRY	53	46	60	53.0
19	GRAIN MILLING	54	55	51	53.3
30	PAPERBOARD CONT	52	59	50	53.7
6	AG/FOR/FISH SER	65	38	62	55.0
40	OTHER METALS	57	62	47	55.3
41	FABRIC. METALS	58	60	48	55.3
61	WATER & SANIT.	60	58	53	57.0
73	ALL GOVERNMENT	59	57	56	57.3
2	MEAT & ANIMAL	55	56	63	58.0
38	IRON/STEEL FOUN	61	61	52	58.0
39	PRIMARY COPPER	64	54	61	59.7
29	PULP & PAPER	62	65	64	63.7
3	FOOD/FEED GRAIN	63	64	65	64.0
8	NONFERROUS MINE	66	66	66	66.0
7	IRON ORE MINING	67	67	67	67.0
11	STONE & CLAY	69	68	68	68.3
37	PRIM STEEL PROD	68	69	69	68.7
59	ELECTRIC UTIL.	70	70	70	70.0
9	COAL & PEAT	NOT APPLICABLE			
10	OIL & NAT. GAS	NOT APPLICABLE			
12	OTHER MINING	NOT APPLICABLE			
74	SCRAP	NOT APPLICABLE			

Table 11: Economic sector rankings: Surface water.

SECTOR	NAME	OUTPUT	EMPLOY-MENT	EARNINGS	AVERAGE RANKING
67	BUSINESS SERV.	5	1	1	2.3
62	WHOLESALE TRADE	11	3	3	5.7
55	TRUCK TRANSIT	3	8	8	6.3
13	NEW CONSTRUCTN	15	5	5	8.3
58	COMMUNICATIONS	7	13	7	9.0
25	LOGGING	6	6	16	9.3
45	COM/OFFICE MACH	8	15	6	9.7
26	SAWMILLS	24	4	2	10.0
53	RAILROAD TRANS	4	10	19	11.0
24	APPAREL/FABRICS	10	12	12	11.3
54	LOCAL TRANSIT	14	2	22	12.7
69	AUTO REPAIRS	12	14	15	13.7
43	MACHINE SHOPS	26	16	4	15.3
63	RETAIL TRADE	17	11	18	15.3
15	ORDNANCE & REL	23	19	9	17.0
64	FINANCE/INSUR.	9	20	24	17.7
72	EDUC/NON-PROFIT	21	7	25	17.7
57	OTHER TRANSIT	28	17	17	20.7
52	MISC.MANUFACTUR	20	22	23	21.7
46	SERV. IND. MACH	22	25	20	22.3
68	EAT/DRINK ESTBL	25	9	33	22.3
44	NONELECT. MACH.	31	24	14	23.0
56	AIR TRANSPORT.	13	27	29	23.0
51	OPT.OPHTH.PHOT.	16	33	21	23.3
50	PROF/SCIENTIFIC	39	21	13	24.3
5	FOR./FISH PROD.	52	18	11	27.0
14	MAINT. & REPAIR	19	30	32	27.0
23	TEXTILE GOODS	36	40	10	28.7
65	REAL ESTATE	2	42	44	29.3
48	MOTOR VEHICLES	27	38	27	30.7
27	WOOD PRODUCTS	37	28	28	31.0
49	OTHER TRANSPORT	33	37	30	33.3
60	GAS UTILITIES	1	46	53	33.3
42	FARM MACHINERY	40	35	26	33.7
28	FURNITURE	35	32	35	34.0
31	PRINT & PUBLISH	45	26	31	34.0
20	BAKERY PRODUCTS	38	31	34	34.3
71	HEALTH SERVICES	29	41	40	36.7
47	ELECTRIC MACH.	32	43	38	37.7
70	FILM/RECREATION	49	23	41	37.7
73	ALL GOVERNMENT	59	29	36	41.3
30	PAPERBOARD CONT	53	39	37	43.0
18	CANNED & FROZEN	30	49	51	43.3
32	CHEMICAL/ALLIED	43	45	42	43.3
35	LEATHER PRODUCT	44	44	46	44.7
33	PETROL REFINING	18	61	57	45.3
66	HOTELS/SERVICES	51	36	52	46.3
4	OTHER CROPS	34	47	62	47.7
39	PRIMARY COPPER	64	34	50	49.3
34	RUBBER PRODUCTS	50	50	49	49.7
19	GRAIN MILLING	54	55	41	50.0
40	OTHER METALS	57	54	39	50.0
17	DAIRY PRODUCTS	42	56	54	50.7
41	FABRIC. METALS	58	51	43	50.7
38	IRON/STEEL FOUN	61	53	45	53.0
61	WATER & SANIT.	60	52	48	53.3
21	BEVERAGES	47	59	56	54.0
22	OTHER FOOD/TOB.	48	57	58	54.3
1	DAIRY & POULTRY	46	60	59	55.0
16	MEAT PRODUCTS	41	63	61	55.0
36	CLAY/STONE/GLAS	56	58	55	56.3
29	PULP & PAPER	62	48	60	56.7
2	MEAT & ANIMAL	55	65	65	61.7
6	AG/FOR/FISH SER	65	62	68	65.0
3	FOOD/FEED GRAIN	63	64	69	65.3
7	IRON ORE MINING	67	67	63	65.7
11	STONE & CLAY	69	66	64	66.3
8	NONFERROUS MINE	66	68	66	66.7
37	PRIM STEEL PROD	68	69	67	68.0
59	ELECTRIC UTIL.	70	70	70	70.0
9	COAL & PEAT	NOT APPLICABLE			
10	OIL & NAT. GAS	NOT APPLICABLE			
12	OTHER MINING	NOT APPLICABLE			
74	SCRAP	NOT APPLICABLE			

On the other hand, the electrical utilities industry, a very important industry in the state that also uses a great deal of water, ranks at the bottom of the pack when it comes to all three objectives and for both ground and surface water requirements. In other words, the business services industry generates more output, employment, and earnings for the water it and its direct and indirect suppliers utilize to satisfy final demand than does the electric utility industry, and thus the water has a higher value for the business services sector.

In fact, all of the largest water users in the state, including electric utilities, iron ore mining, primary steel production, sand and gravel operations (stone and clay, on the list), and irrigation (crop production) appear at or near the bottom of the rankings. Upon reflection, this seems reasonable. Logically, the larger water users will have a relatively low output per unit of water used. Thus, they will value each unit of water less than those sectors which require fewer units of water for each dollar of output.

The policy implications of these results are intriguing, to say the least. Simply put, these results indicate that if the goal of society is to maximize output, employment, or earnings, then the water demands for the smallest users (in general) should be satisfied first before allocating water to larger users. Fortunately, the top twenty-five sectors in the surface water rankings account for less than one percent of all water used. Given Minnesota's extensive water supplies, it seems unlikely that a situation would arise where no water was available to the large users.

Careful examination of the rankings also shows that many of the sectors at the top of the list, such as business services, wholesale and retail trade, and some manufacturing industries generally purchase their water from public utilities. This would seem to indicate that any allocation scheme should include this sector as a high priority use of water. It should be noted that IPASS does not treat sector sixty-one, water and sanitation, differently from any other sector, although this sector includes public water utilities. The water demand for this sector includes only that water required for treatment of water supplies and for personal use by utility employees.

The way in which IPASS treats two agricultural sectors also requires some discussion. Sectors three and four together make up all crop production in the state. However, the water demand for these sectors was based solely on the use of water for irrigation. Since less than two percent of all cropland in the state is irrigated, the figures used grossly overstate the output per unit of water withdrawn. Precipitation is ignored as a direct input to crop production. Thus it is difficult to interpret the implications of the ranking of these sectors.

When considering these results, it must also be remembered that it is possible - even likely - that the state of Minnesota may wish to choose a water allocation scheme which maximizes some objective other than output, employment, or earnings. This study acknowledges other objectives by allocating water for residential use and instream flow needs before providing any water for economic production. While there are valid arguments for doing so, these arguments are not universally accepted. Instream flow requirements have only been officially recognized during the latter half of this century. Residential water requirements include such *non-essential* uses as watering lawns, washing cars, and filling swimming pools.

Other objectives may also be valid. Minnesota has traditionally placed a high priority on its agricultural sectors. This objective is reflected in the current water allocation scheme which was established by the state legislature and gives agriculture a priority over all other industrial water uses. The state may also decide that it wishes to promote tourism and should therefore provide more water to those sectors related to recreation. The primary contribution of the model comes from it ability to predict the loss of output, employment, and earnings that would result from any allocation scheme which did not maximize these objectives. Given this information, it is hoped that policy-makers will thus be able to make better decisions regarding our water resources.

There is obviously a wealth of information in the Tables 10 and 11. This approach to water valuation, however, does suffer from some of the limitations forced upon it by the input-output structure and assumptions. These would include constant commodity and input prices, fixed-proportion production relationships subject to constant returns to scale, and the static nature of the model. These assumptions limit the model's ability to capture such possibilities as the existence of alternative production techniques which might be less water intensive or the substitution of other inputs from water. While this may not be much of a concern in the short run, it limits the model's reliability in the long run. In addition, given the current implicit price of zero for water in Minnesota, the water use ratios likely overstate actual water needs to the extent that there is no incentive for firms to efficiently use a zero-priced resource. In other words, it is likely the case that a significant reduction in water use could be achieved by most sectors at no or very little cost. This could lead to a misrepresentation of the true water needs of each sector in meeting its final demands.

The input-output view of value does not take actual water supplies into account. Linear programming provides a second view of water values which does. With the analysis summarized in this section and the next, a reasonably complete view of the planning approaches to water valuation is offered.

LINEAR PROGRAMMING AND THE VALUE OF WATER

A mathematical programming approach attempts to determine the most efficient allocation of a resource relative to some chosen objective function and subject to constraints with respect to production technologies and resource availability. While the objective function and constraints may be nonlinear, the mathematical difficulties of solving such systems usually lead analysts to only consider linear specifications and take advantage of established linear programming solution techniques. Since constant returns to scale and fixed input ratios are standard assumptions in input-output models, such formulations are well-suited for the linear programming format to describe the production technologies.

Solving such a problem would directly yield the allocation of water (and the other resources as well) which results in the maximum gross regional income possible. In other words, it would determine the economically efficient allocation of water given the objective chosen and the other constraints of the model. The principal measure of the value of water which may be drawn from such an approach is the *shadow price* of water. This *price* indicates the change in the optimal value of the objective function given a change in the water availability.

While the shadow prices provide an overall value for a region's total water supplies, they do not provide sectoral water values which may serve as allocation guidelines. However, since solving the problem directly yields the *best* allocation of water in order to maximize gross regional income, such values are not necessary. If sectoral water values are desired, the model can be reformulated to generate such values.

The specific model used is restricted to the analysis of water withdrawals in quantity terms. In this regard, a linear programming (LP) and an input-output (I/O) model are integrated under various assumptions concerning water availabilities. Shadow prices for water (the marginal values of water under various levels of water scarcity in terms of water's contribution to maximizing the objective function) are computed and reported.

The components of the model may be described in general terms as follows: a technical coefficient matrix describes production technologies available in the region; a set of direct water requirements per dollar of output for the given production processes is also required. It is assumed that for each production process, the quantity of water needed to produce a unit of output is given by a linear relation. Regional water supply constraints require that the quantity of water entering or used in economic production from all sources must be no more than the total quantity of water available.

The capabilities of water bodies to meet specified demands for recreation and to support fish and wildlife are assumed to imply maximum permissible levels for consumptive use. These water demands are specified exogenously and enter the model through specific bounds in consumptive parameters used by the region.

The LP and I/O combination resulted in a series of values that are summarized in Table 12. As can be seen in that table, water is not constraining until the level of water availability falls to 3,500,000 acre feet. Up to that point, the shadow price of water is equal to zero. This is due to the fact that water is not a constraining factor and that there is plenty to allow the economy to maximize its gross output. At a supply level of 3,500,000 acre feet, however, water must be allocated in order to get the highest level of gross output possible. At that time, water's contribution to meeting that objective makes its value equal to $2,070 per acre foot. This value makes sense only in relation to the gross output maximizing objective. It represents water's contribution towards meeting that objective.

Table 12: Water related shadow prices under alternative supply levels with moderate (5%) economic growth

Water Supply (acre-feet)	Water Used (acre-feet)	Gross Output ($ Million)	Shadow Price ($)
5,444,434	3,544,925	125,572	0
3,811,104	3,544,926	125,572	0
3,500,000	3,500,000	125,479	2,070
2,000,000	2,000,000	108,057	30,830
1,000,000	1,000,000	73,411	37,760
50,000	50,000	53,380	51,140
25,000	25,000	38,093	73,150
10,000	10,000	9,739	329,000

As water supplies continue to be reduced, the value of water in meeting the objective increases substantially. In fact, once water is reduced to 2,000,000 acre feet, the value jumps to $30,830 per acre foot. It then continues to jump to a high (out of the levels chosen for this analysis) of $329,000 per acre foot.

Another important point demonstrated in Table 12 is the effect of the water constraint on gross output. Again, when water is not constraining, gross output remains the same. However, when water does become constraining, gross output falls rapidly. It should be remembered that the gross outputs reported in this table are the maximum gross output that can be achieved given available water supplies. Future simulations should also look at other constraining factors, such as labor and capital. In such cases, a series of marginal values may be found dealing with each constraining factor individually or in some combinations.

WATER VALUATION

A dynamic value not unlike the "shadow price" from the linear programming model can also be generated using IPASS. To accomplish this, the model user notes the total water use and regional income level in the unconstrained baseline run and the same variables for the constrained case (using the best allocation scheme possible). The difference in regional income between the two model runs divided by the difference in water use provides an indication of the value (measured with respect to the regional income objective) of additional water supplies. By further constraining the water availability and again finding the best allocation possible, a full set of shadow prices can be derived.

Figure 11 shows the results of this analysis for surface water. The X axis shows the percent of water required for production which is made not available (diverted out of state, contaminated, etc.). Zero percent on the X axis means that there is adequate water for economic production and thus no impact on output (the Y axis). As you move to the right, water is taken out of production, and gross output is decreased by the amount shown on the Y axis.

Figure 11: Value of surface water.

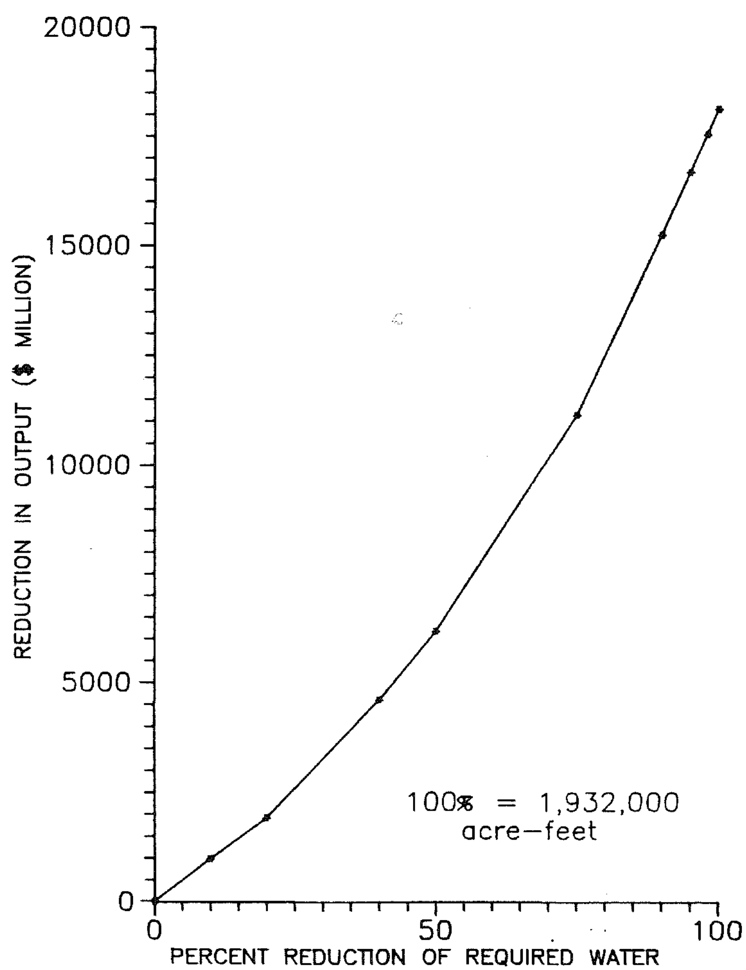
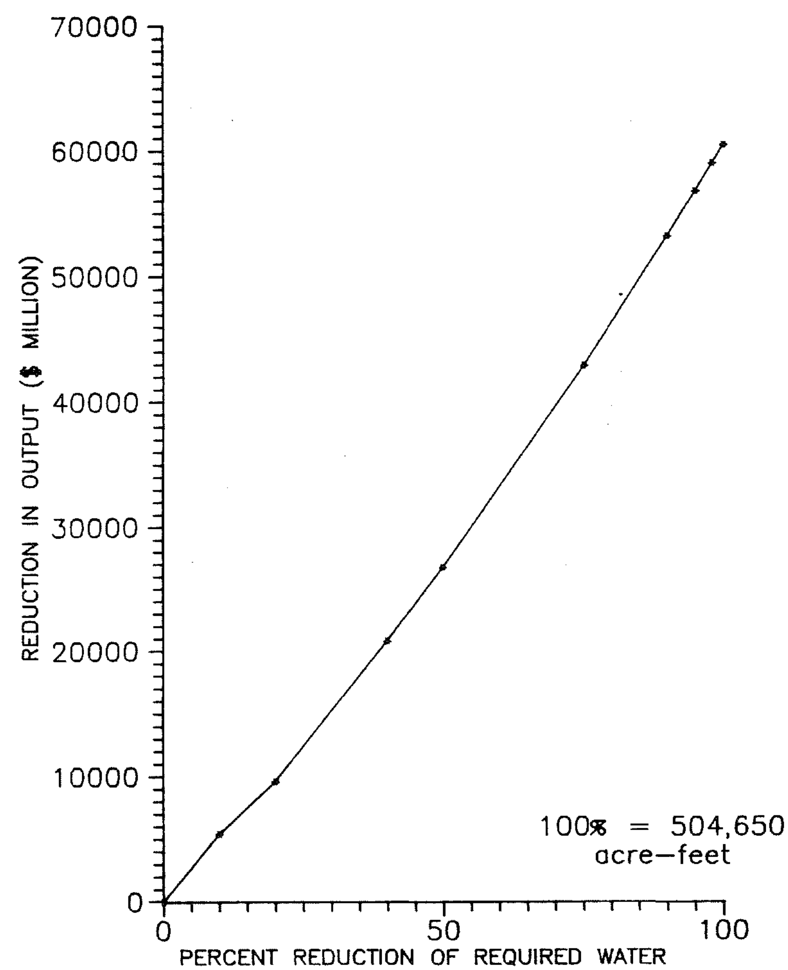


Figure 12: Value of ground water.



When all of the water is gone (100%, or about two million acre-feet), output is reduced by about $18 billion.

The results of the analysis for ground water are shown in Figure 12. Note that while the total amount of water required for unconstrained production, about 500,000 acre-feet, is one fourth the volume required for surface water, the total impact on output is much larger. In fact, the maximum reduction in output per acre-foot of ground water is 12.8 times the maximum reduction in output per acre-foot of surface water. In other words, each unit of ground water produces 12.8 times as much output as each unit of surface water.

Although time constraints limited the number of water conflict scenarios which could be evaluated by IPASS, it is possible to obtain a gross estimate of the potential economic impacts of various types of water shortage directly from Figures 11 and 12. From Figure 11, if ten percent of the demand for surface water is not met, due to drought, out-of-state diversion, or contaminated supplies, total output in Minnesota would be reduced by about one billion dollars. Similarly, from Figure 12, if forty percent of the demand for ground water is not met (approximately the amount of water required for the Twin Cities metropolitan area), output would be reduced by about twenty billion dollars.

These analyses can only determine the best allocation possible given the current water use technologies employed in the state. Since these technologies may not necessarily be the most efficient uses of water, the shadow price measures will likely overstate the value of water to the extent that the actual change in regional income is overstated. They would however serve as useful upper-bound estimates. Finally, it should be noted that although conceptually similar, these prices would not be directly comparable to those derived in the static linear programming approach.

A SCENARIO: SEVERE DROUGHT IN MINNESOTA

A very simple version of a drought scenario was run using the state IPASS and attending water models. Specifically, the model was run from its base year of 1982 to 1990 with no adjustments to establish the baseline against which the drought scenario will be compared. The modified run simulated the economy from 1982 to 1987, as in the baseline. In 1987, the available (net) water supply was decreased by almost 45% in the case of surface water and by 14% for ground water. While such reductions may seem severe, they were necessary in order to activate water as a constraint. Such necessity, in itself, demonstrates the relative richness of Minnesota's water resources.

Sector constraints were allowed to operate based on allocating total water supply according to past uses. Therefore, the various economic inputs from such a constraint come from a few sectors bumping against their assigned water supplies.

Table 13 lists some of the aggregate impacts from such a scenario. As can be seen, the impacts from such large reductions are not exceptionally large (150 direct and indirect employees, almost six million dollars in gross output, three million dollars in state exports and four hundred plus dollars in earnings per person in the state).

However, at this point the water constraint takes hold. In other words, any further reduction in water supplies would find the impacts increasing exponentially.

Table 13: Employment, output, export and earnings impacts: drought scenario.

Type of Impact	Value of Impact
	(1982 dollars)
Employment	150 Employees
Output	$5,660,000
Exports	$3,072,000
Earnings Per Person	$420

While we called this a drought scenario, we might also label it as a diversion or contamination scenario. Any of these would find reduced water supplies exerting the same types of effects on the economy, a reduction of employment, output, earnings, etc.

As mentioned earlier, this scenario was run for demonstration purposes only. A more sophisticated run might use the drought index option to simulate water conservation, increase or decrease the water held out of production option, etc., to better understand the sensitivity of the state's economy to decreases in water supply.

FINDINGS

- Computer simulation models can be valuable tools in analyzing the impacts of various shortages of water on economic production and the effect of alternative allocation schemes in achieving policy objectives.
- When water supplies are limited, economic production, as measured by output, employment, and earnings, is maximized when the demands for smaller water users are met before the demands of larger users.
- In terms of its direct impact on economic production, the water demand for the electric utility industry, the largest water user in the state, should be satisfied after that of all other economic sectors in order to maximize output, employment, or earnings.
- To the extent that municipal water utilities are important sources of water for a majority of small water users, the above measures of economic production can be enhanced by an allocation scheme which gives municipal utilities a high priority of use.
- For each dollar of output generated by one acre-foot of surface water, up to twelve dollars and eighty cents are generated from one acre-foot of ground water in the state.

- The marginal value of one acre-foot of water toward maximizing gross output for the state's economy is $2,070.
- A moderately severe drought can result in a loss of 150 jobs, a $5.7 million reduction in gross output, and a $3.1 million reduction in state exports.
- The current allocation schemes for water use in Minnesota, which assign a high priority to the agricultural sectors and electric utilities, do not correspond to the optimal allocation schemes outlined here. Therefore, alternative allocations exist which would achieve greater economic production.

RECOMMENDATIONS:

- The current allocation of water should be re-evaluated.
- Any allocation of water use should take into consideration the following:
  - Electric utilities have the lowest dollar value of output per unit water of any economic sector in the state. Given the strong dependence upon electricity among economic sectors and households, the assignment of a lower priority to electric utilities should be made contingent upon the availability of dependable supplies of electricity from sources out of state.
  - Municipal utilities provide water to the majority of those water users which produce the greatest output per unit of water consumed.
  - Regional differences in water use exist; there may be advantages to water allocation schemes which recognize this fact.
  - Ground water is a much more highly valued resource than surface water, both for economic production and for residential use. It may be preferable to have different allocation priorities for each.
  - Given that many of the conflicts over water use occur not among economic sectors but between instream and off-stream uses, the relative priorities of these different demands should be more clearly defined.
- The allocation of the state's financial resources should be reviewed to assure that the much higher value placed on ground water in comparison to surface water is reflected in management and regulatory activities. This recommendation is reinforced in light of the very real threat of extensive ground water contamination.
- The concept of drought contingency planning should be expanded in order to incorporate plans for responding to water supply contamination and increased water demand caused by economic growth.
- While water is relatively plentiful in the state, supplies are not infinite and water shortages have occurred. Before seeking new or additional water supplies, water users should be encouraged to investigate water efficient technologies, conservation, and substitution of other resources for water.

- The analytical capabilities of the computer models developed for this project have yet to be fully exploited. Since these models have shown promise for useful results, the DNR Division of Waters should allocate staff and funds so that improvements can be made to the model and much more analysis carried out.

ECONOMIC VALUE OF WATER FOR RECREATION

OBJECTIVE

To estimate the economic impact of recreation and tourism in Minnesota and the non-market benefits (consumer surplus) of water for recreation.

INSTITUTIONAL ARRANGEMENTS

The Continuous Survey of Participation and Expenditures in Outdoor Recreation by Minnesota Residents (DNR Continuous Survey) was conducted for the Minnesota Department of Natural Resources (DNR) by the Minnesota Center for Survey Research (MCSR) in association with the Center for Urban and Regional Affairs (CURA). Both MSCR and CURA are administrative divisions of the University of Minnesota. The project funding, $88,000, was transferred by a contract executed between the Department and the University. Bill Becker, DNR Office of Planning, was contract manager for the Department. R. Michael Madell was project manager for the University.

The Natural Resources Research Institute (NRRI), in cooperation with the DNR Office of Planning, was contracted to use the survey data to estimate the economic impacts and non-market benefits of recreation. Funding for this phase of the project was $165,000. Donald N. Steinnes was principal investigator for the NRRI. Product deliverables are reports on the survey methodology by R. Michael Madell of the University of Minnesota, the economic impacts by Tim Kelly of the DNR Office of Planning, and non-market benefits by Donald N. Steinnes.

ANALYSIS

The need for an analysis of the dollar value of water for recreation stems from the strong belief that knowledge of this value facilitates and improves decision-making in allocation and management of water resources. Conservation organizations such as the American Wilderness Alliance found studies of monetary values of recreation use helpful in placing amenity resources of natural environments (wilderness areas, etc.) in an analytical framework that make it possible to compare them with commodity resources. Also, the economic value of water for recreation use should prove helpful to natural resource managers in determining the level of investment required to maintain or enhance the resources and the trade-off values involved when in-state and out-of-state developments are proposed. The economic value of water for recreation use gives us a means to carefully weigh these values, along with irrigation, hydropower and other uses. Until now, we could only guess at the total worth of our water resources.

Several states have conducted similar documentations of the recreation use and the non-use preservation value of natural environments to the general public. However, most of these states have long been concerned about their water supply. These concerns have not been as urgent in Minnesota, but they are becoming more so, especially as other states begin to look to us as a source of water to meet their growing needs.

The value of water for recreation is generally considered to be comprised of two distinct components. The market value of recreation is defined as the direct and indirect impacts of purchases made for goods and services used for water recreation. These impacts are a measure of the significance of recreational expenditures on the local, regional, or state economy. The non-market benefits of recreation are the intrinsic values placed on the recreational experience itself. Intrinsic benefits are accrued by users and non-users of the water resource, but only user benefits are analyzed in this study. Since non-user "option" benefits and existence (preservation) values were not measured, the economic value of water for recreation obtained in this analysis represents a conservative estimate of the total value to society. This fact should be recognized when making allocation and management decisions regarding Minnesota's water resources.

Both the market and non-market values can be estimated using surveys of recreational activities. This study incorporated the results of two surveys. The State Comprehensive Outdoor Recreation Plan (SCORP) survey of resident and non-resident tourists was conducted by the DNR in 1978. The Continuous Survey of Participation and Expenditures in Outdoor Recreation by Minnesota Residents (DNR Continuous Survey) was commissioned by the DNR to update and supplement SCORP, since the Water Allocation and Management Program required resident expenditure information not collected in the 1978 survey.

Despite their different methodologies and scopes, the DNR Continuous Survey and SCORP complement each other well, while providing valuable information in their own right for recreation planners. SCORP surveyed Minnesota residents and non-residents tourists visiting the state during the summer of 1978. Recreation-related expenditure data were collected for non-residents but not for residents. Resident expenditure data were collected as part of the DNR Continuous Survey. This survey sampled Minnesota residents over a twelve month period regarding water-related recreational activities and associated expenditures. The Continuous Survey also attempted to determine the value of each recreational outing by asking how much more money (in addition to out-of-pocket expenses) the user would be willing to pay to take the recreational trip again.

MARKET VALUE OF RECREATION

This analysis included both water-based and other water-related recreational activities. Water-based activities include fishing, boating, canoeing, and all other activities typically associated with water recreation. Water-related land-based activities were determined by the survey respondent's answer to the following question: "Was a lake or river important to the decision of where to recreate?" If the answer was yes, then the land-based activity was categorized as water-related, and travel expenses were collected. Whole outings and their associated expenses were taken as water-related if any outdoor recreation activity on the outing was water-related. This categorization procedure, by design, is intended to produce a high estimate of recreation and expenses related to water resources.

The direct economic impacts of water-related recreational activities (Table 14) were calculated by allocating the cost of each expense item to various sectors of the economy. In some cases, the amount of a single expenditure was broken down and allocated among several sectors in order to reflect the various inputs required to generate the good or service. For example, all lodging expenses were applied to one sector, but gasoline expenses were allocated among refining, transportation, and wholesale and retail trade sectors.

Table 14. Direct impact of water-related recreation.

	High Estimate	Low Estimate	Low as a Percent of High
	(millions of 1985 dollars)		
Travel-Related Expenses			
Non-residents	$350.6	$293.6	83.7
Residents	$511.7	$431.0	84.2
TOTAL	$862.3	$724.6	84.0
Equipment Expenses			
Residents	$310.8	$310.8	not applicable
GRAND TOTAL	$1173.1	$1035.4	88.3

Nearly $1.2 billion, or nearly $300 per Minnesota citizen, was spent annually by recreators in the pursuit of water-related activities (Figure 13). Most was spent for travel (74%), with the remainder for equipment (36%). Residents make up 59 percent of travel expenses and non-residents 41 percent. The bulk of travel expenses is accounted for by food, lodging and transportation (mainly gasoline). Non-residents allocate a much smaller share of the food dollar to groceries than residents, and a greater share to restaurants. Non-residents spend a larger share of their travel dollar on shopping and personal items than residents.

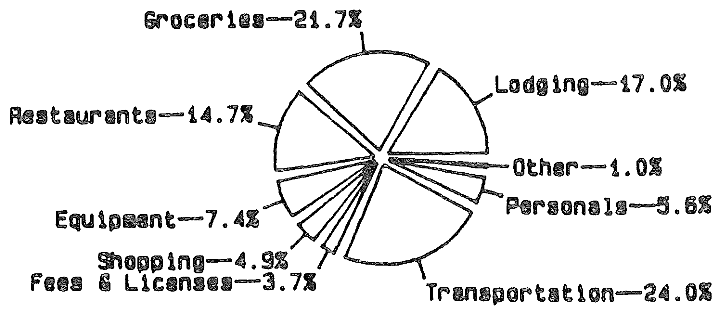
Resident equipment purchases are dominated by boats, trailers and boat accessories (77% of total equipment dollars). The next largest expense category is boat motors (6.9%).

Most of the water-related recreation activity time is spent, not surprisingly, on water-based activities (Figure 14). For all recreators, fishing is the largest activity. It is followed by swimming, boating and camping. Fishing is also the largest activity for both residents and non-residents. Non-residents spend a greater share of activity time on fishing, camping and canoeing than residents. Residents spend a greater share of activity time on remaining activities, especially swimming.

Figure 13: Statewide annual water-related outdoor recreation expenditures. (1985 Dollars)

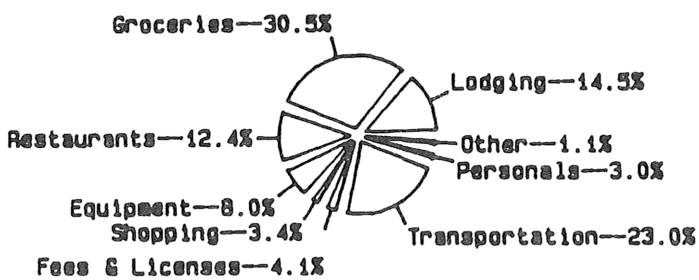
Travel-Related

All Spenders



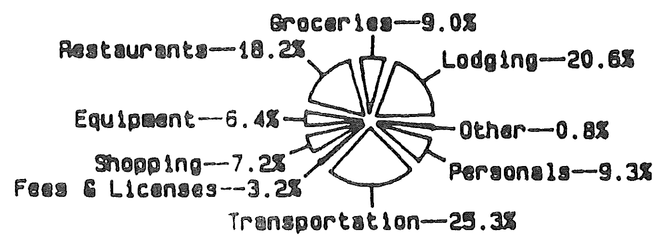
Total = $862.3 million

Minnesota Spenders



Total = $511.7 million

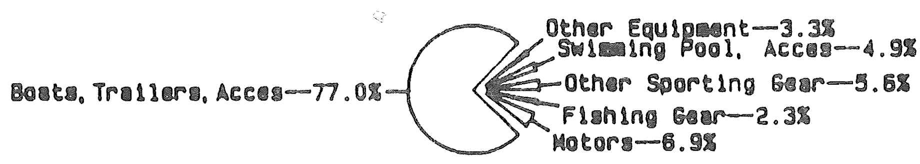
Nonresident Spenders



Total = $350.6 million

Equipment

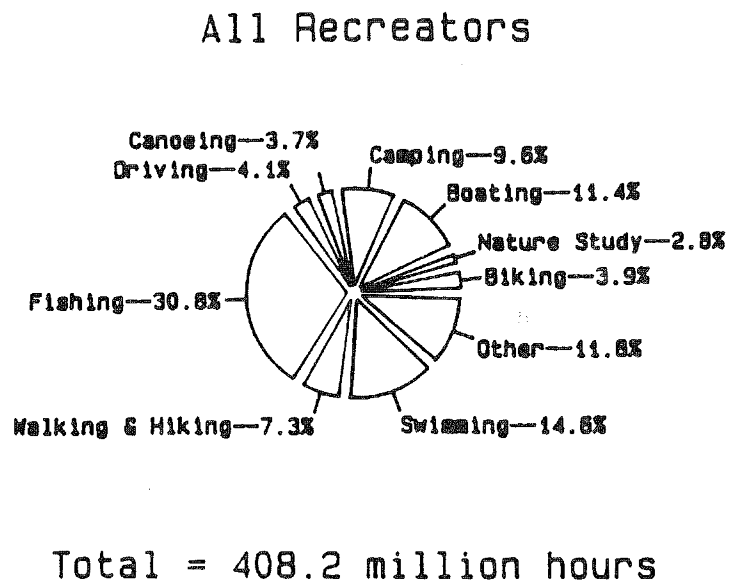
Minnesota Spenders

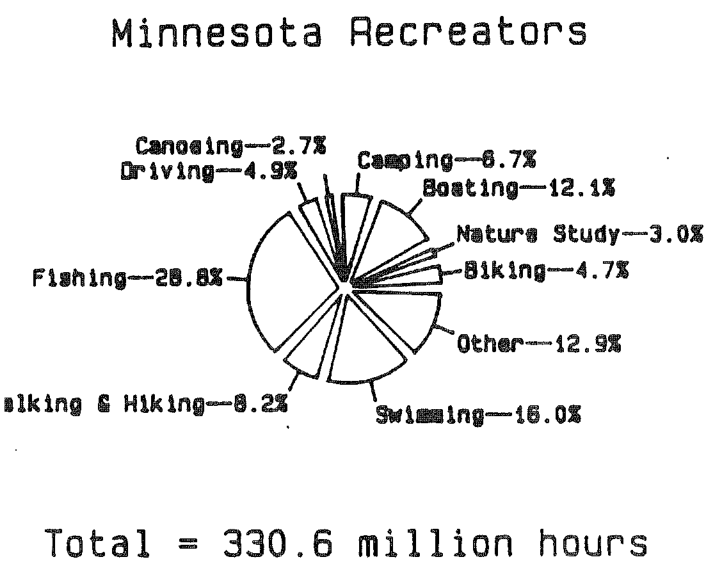


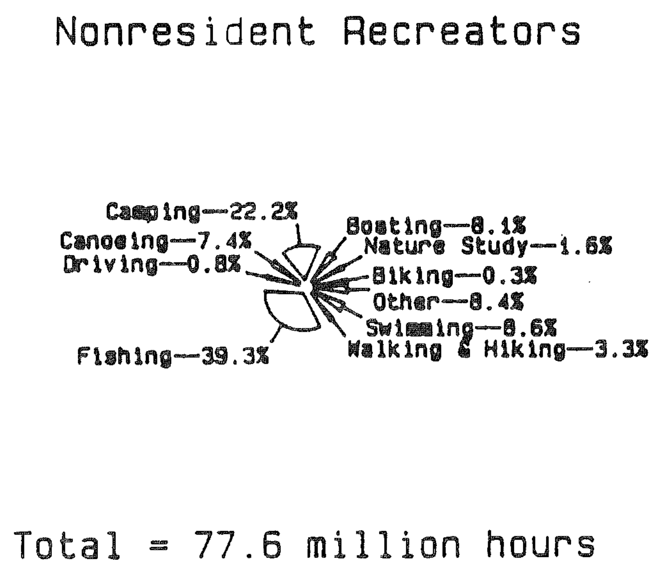
Total = $310.8 million

Source: Minnesota DNR Outdoor Recreation and Expenditure Survey of Residents (1985-86) and Nonresident Summer Motor Vehicle Visitors to Minnesota (1978). (Note: 1978 nonresident expenditures were inflated to 1985 dollars using inflation factors that are specific to each of the 74 economic sectors that represent the Minnesota economy in the IPASS Input/Output Simulation Model.)

Figure 14: Statewide annual water-related outdoor recreation activity time.







Source: Minnesota DNR Outdoor Recreation and Expenditure Survey of Residents (1985-86) and Nonresident Summer Motor Vehicle Visitors to Minnesota (1978).

Residents account for 81 percent of statewide activity time, but they only account for 59% of travel expenses. The closer-to-home recreation trips of residents are less expensive, for the same amount of recreation, than the longer distance trips of non-residents.

The six economic sectors most affected by recreational expenditures are shown in Table 15. Together these sectors account for almost 71 percent of the direct impacts of water-related outdoor recreation.

Table 15: Direct impacts on selected economic sectors.

Economic Sector	Percent of Total Water-Related Outdoor Recreation Impact
Retail Trade	18.1
Petroleum Refining	14.1
Hotels, etc.	11.6
Other Transportation Manufacturing	10.9
Eat and Drink Establishments	10.1
Wholesale Trade	6.1
TOTAL	70.9

The dollar value of all consumer expenditures does not represent the total impact of water-related recreation on the economy. In order to provide a good or service, a business must purchase goods and services which are inputs to its final products. These intermediate purchases also generate economic activity as the business suppliers require inputs to produce their goods and services, and those businesses must purchase inputs for their goods, . . . and so on throughout the economy. The combined effects of these inter-business purchases are the indirect impacts of consumer purchases for water-related recreation.

IPASS, the computer simulation model developed to analyze the economic value of water in a separate phase of this project, can also be used to measure the indirect impacts of recreation. The input/output tables from IPASS were used to trace the amount of gross output, value added, and employment required to satisfy the demand for goods and services purchased for recreational activities. The results of this analysis are shown in Table 16. Gross output represents the total value of all Minnesota business sales both inside and outside the state. Value added, a portion of gross output, is the income generated in the state by the production and sale of Minnesota products. It includes employee compensation, indirect business taxes, and property-type income. Employment is the number of jobs required to satisfy the demand for recreational goods and services. The major sector groupings used in Table 16 are aggregations of the 75 economic sectors used in IPASS.

Table 16: Impact profiles due to water-related outdoor recreation by type of impact for major sectors

MAJOR SECTOR	TYPE OF IMPACT (Column percents)			
	Direct	Direct & Indirect		
		Gross Output	Value Added	Employment
Agriculture, Forestry, Fisheries	0.7%	5.1%	3.9%	4.3%
Mining	(<0.05)	(<0.05)	(<0.05)	(<0.05)
Construction	0.0	1.1	1.2	0.3
Manufacturing	46.4	42.0	24.0	14.9
Transportation, Utilities, & Communications	1.2	5.9	6.6	3.5
Wholesale & Retail Trade	24.3	18.5	29.8	32.5
Finance, Insurance & Real Estate	(<0.05)	4.2	6.9	1.7
Services	27.1	22.5	26.9	42.1
Other	0.3	0.8	0.8	0.8
TOTAL PERCENT	100.0%	100.0%	100.0%	100.0%
ABSOLUTE TOTAL	$1087 million	$1753 million	$760 million	37,533
	(1982 Dollars)			(Jobs)

The total combined direct and indirect impacts from Table 16 account for 1.7 percent of the state gross output, 1.5 percent of the state value added, and 1.9 percent of state employment. Nearly one-third of of each of these impacts is export-based; that is, the impacts result from non-resident spending in Minnesota. Most of the impacts are concentrated in three major sectors: manufacturing, wholesale and retail trade, and services.

The economic impacts per acre of lakes with permanent fish populations, which are the state's prime water resource for outdoor recreation, were as follows:

	1982 Dollars Per Acre*
Consumer purchases (direct impacts)	479
Direct and Indirect Impacts on:	
Total Gross Output	771
Total Value Added	334
Direct and Indirect Impacts on:	Jobs per Thousand Acres
Total Employment	16.5

*Acreage is 2,274,669: excludes acreage of Lake Superior, Upper and Lower Red Lake, and any portion of a lake outside of the state; includes acreage of river lakes and pools.

NON-MARKET VALUE OF RECREATION

It is intuitively obvious that individuals place a value on water-related recreation which is at least as great as the amount of money that they pay for recreational activities. If this were not the case, it would be difficult to explain why so many choose to crowd the beaches at Minnesota lakes on a hot afternoon in July. By foregoing other possible activities, these recreators are making decisions in the opportunity "marketplace" which indicate that they place a value on recreation which is higher than the value they place on participating in some other activity, such as staying home and mowing the lawn. Another indication of the value placed on recreation is the amount of time and effort recreators are willing to expend to participate in a recreational activity. Consider, for example, the positive value of recreation which must outweigh the monetary and non-monetary expenses incurred while heading north on Highway 10 on the Friday before the fishing opener.

Economists refer to the value placed on recreation over and above the costs of participation as the "consumer surplus". It is this value which we attempt to determine here.

Other non-market values of recreation exist, but these are beyond the scope of this project. Among these values are those which are not directly associated with the use of recreation. Some individuals have intrinsic sentiments about the existence of a water resource. These are evidenced by the establishment of requests which can be used to endow the resource in the future, or the willingness on the part of some to contribute funds to ensure the preservation of certain marine species such as whales or sea lions. Other individuals do not use the resource at present, but they wish to maintain the option of using it in the future. A review of the literature on non-market value indicates that option values are, on average, 60% of the consumer surplus values of participants.

The two methods most commonly employed to measure the use values of non-market recreation benefits are the travel cost method (TCM) and the contingent valuation method (CVM). Attempts were made to utilize both methods for this project. CVM values were collected as part of the DNR Continuous Survey. TCM was applied to the 1978 resident and non-resident SCORP surveys. However, the 1978 non-resident SCORP survey did not include a question regarding contingent valuation, so the CVM values for non-residents were estimated from the DNR Continuous Survey. CVM was the primary method of analysis for this study, and TCM was used to verify the CVM results where possible.

The contingent valuation method (CVM) relies upon a survey response to a hypothetical question. For the DNR Continuous Survey, the interviewee was asked, "what is the most additional amount of money you would be willing to pay if you were to take (a specific) recreation trip again?" From the range of responses to this question, a value can be assigned to the water resource. For publicly owned resources, willingness to pay for access is expected to result in a more conservation estimate of value than that obtained by the travel cost method. Thus, the CVM can be used to determine a lower bound for the value of water recreation which can be compared to the more liberal value estimated by the TCM.

The basis for the travel cost method is the recognition that the use of recreational services of a particular site requires the user to incur not only expenditures for entry fees and equipment, but also the expenses associated with traveling to the site. The cost, or price, to an individual of using services at the site will vary according to the travel time and expenses incurred in getting to the site. Moreover, the farther the users must travel to reach the site, the greater the implicit price of recreation. Survey information on travel costs for a cross-section of users can be used to construct demand curves for a single site, and consumer surplus can then be calculated from the demand curves.

A summary of the results of the Contingent Valuation analysis is shown in Table 17. As would be expected, both travel expenses and consumer surpluses are greater for recreation activities involving an overnight stay than those which took less than one day. Similarly, non-Minnesota residents experienced greater expenses and consumer surpluses than did residents. On average, the consumer surplus was forty-four percent of the expenditures for each category. This figure did not vary significantly when statistical tests were used across counties for the DNR Continuous Survey.

Table 17. Average water-related recreation travel expenses and consumer surpluses in Minnesota (Contingent Valuation Method)

	Travel Expenses (Dollars per Person per Day)	Consumer Surplus (Dollars per Person per Day)
Residents		
Day Trips	$1.43	$0.63
Overnight Trips	$18.53	$8.07
Day and Overnight Trips	$6.23	$2.72
Non-Residents		
Overnight Trips	$26.39	$11.61
Residents and Non-Residents		
Overnight Trips	$21.40	$9.36
Day and Overnight Trips	$9.03	$3.95

Regional differences in water-related recreation are shown in Table 18. Note that the differences in value among the regions are much less significant than the differences between day and overnight trips and between residents and non-residents as shown in Table 17. The distribution of both aggregate expenditures and consumer surplus among the regions is primarily due to differences in recreation days, rather than differences in expenditures or consumer surplus per day.

Table 18: Travel expenditures and consumer surpluses for water-related recreation - Contingent Valuation Method.

Economic Region	Total Recreation Days	Fishable Water Acres	Total Travel Expenses	Total Consumer Surplus	Expenses Per Recreation Day	Consumer Surplus Per Recreation Day	Expenses Per Acre	Consumer Surplus Per Acre
West	11,535,541	237,305	$127,596,365	$59,052,819	$11.06	$5.12	$538.37	$249.16
Northeast	30,365,674	1,583,700	$503,281,601	$203,598,939	$16.57	$6.70	$317.79	$128.56
Central	11,395,741	225,059	$81,107,014	$37,501,260	$7.12	$3.29	$360.38	$166.63
Metro	33,743,049	61,909	$100,900,223	$57,060,180	$2.99	$1.69	$1,629.82	$921.68
Southeast	8,431,792	166,996	$49,400,782	$20,219,786	$5.86	$2.40	$295.82	$121.08
State	95,471,797	2,274,569	$862,285,985	$377,432,984	$9.03	$3.95	$379.08	$165.93

*Includes both day and overnight trips by Minnesota residents and non-residents.

Some of the differences among regions in Table 18 can be explained by the types of recreational activities which take place in each region. The Northeast accounts for over one-half of all recreation days which involve an overnight stay. These trips tend to have higher expenditures and consumer surplus than day trips. Over one-half of the day trips occurred in the Metro region, which explains its relatively low values per recreation day.

When the expenditures and surpluses are viewed on a per acre basis, the values are almost reversed. The Metro region, with its relatively small number of lakes, has the highest expenditures and consumer surplus. In economists's terms, there is a high demand for water in the Metro region and a low supply, so the price (per acre) is high.

From a policy stance, Table 18 can be quite useful for evaluating alternative sites for development within the state. For example, consider an industrial use of water which would eliminate 100 acres of water for recreation. According to Table 18, such a loss would be much greater in the Metro area than the other regions. This would suggest that the state should consider policies that would encourage outstate industrial development since the loss in water based recreation would be less than if future development occurs outside the Metro region. Of course, it should be noted that the gains in each region from the proposed industrial development might also vary, but this could be analyzed using the regional economic impact models prepared as part of this project. However, it seems reasonable to assume that the differences in recreation (per acre) indicated by Table 18 are greater than the differences in economic impacts between regions. Therefore, the policy conclusion is still valid that industrial development which might adversely impact recreation would be best encouraged outside the Metro region.

Table 19 shows a comparison of the results from the travel cost and contingent valuation methods. TCM values are first calculated using units of vehicle miles of consumer surplus. To convert from vehicle miles to dollars of consumer surplus requires knowledge of the average number of occupants per vehicle (3.03 persons, in this case), and an assumption regarding the costs of travel per mile. Operating costs, not total costs, are used so vehicle depreciation is not included. The Internal Revenue Service allows $0.09 per mile deductions for operating costs, so Table 19 includes calculations based on a range of $0.05 to $0.10 per mile. If $0.08 per mile is used, the TCM and CVM methods both yield the same state average consumer purchase of $9.36 per day. The closeness of the results obtained by the two methods adds confidence to their validity.

Table 19: Comparison of consumer surplus values for water-related recreation by contingent valuation and travel costs methods*

Economic Region	Contingent Valuation Method	Vehicle Miles of Consumer Surplus	Travel Cost Method (Travel Costs) $0.08 per mile	$0.05 per mile	$0.10 per mile
West	$11.55	$40.00	$3.20	$2.00	$4.00
Northeast	$8.79	$113.20	$9.05	$5.66	$11.32
Central	$7.99	$108.56	$8.68	$5.43	$10.86
Metro	$13.22	$318.61	$25.49	$15.93	$31.86
Southeast	$7.81	$78.06	$6.24	$3.90	$7.81
State	$9.36	$117.05	$9.36	$5.85	$11.71

*Includes Minnesota residents and non-resident trips involving an overnight stay.

Statistical analysis of the results shown in Table 19 revealed that the differences in the average daily consumer surplus values among the economic regions in the state are not significant. Similar tests were also used to determine whether differences existed in the values that recreators placed on various types of activities. Results showed that there were no significant differences in the average daily consumer surpluses among all water-related recreational activities. Thus, we cannot say that recreators value one activity, such as fishing, boating, water-skiing, or swimming, over another.

FINDINGS

In addition to its value as a sustainer of life and an input to economic production, water provides market and non-market benefits to Minnesota as a source of recreation. These benefits can be measured using commonly accepted procedures.

Annual consumer purchases associated with water-related outdoor recreation totaled nearly $1.2 billion (1985 dollars), of which $512 million were resident travel expenses, $351 million were non-resident travel expenses, and $311 million were resident equipment purchases.

The combined direct and indirect impacts of these consumer purchases were, in 1982 dollars, $1.75 billion in total gross output (total sales by Minnesota businesses) and $760 million in total value added (total income to Minnesotans). These impacts are linked to 37,600 jobs in the state, of which 12,000 result from non-resident travel expenditures.

The direct and indirect impacts of water-related recreation account for 1.7 percent of Minnesota's total gross output, 1.5 percent of total value added, and 1.9 percent of employment. Most of these impacts are concentrated in the manufacturing, wholesale and retail trade, and service sectors.

The average value of consumer purchases for recreation is $479 per acre of lakes with permanent fish populations. These lakes are the state's prime water resource for outdoor recreation.

The following findings are the result of survey analysis using the contingent valuation method:

- The average dollar value of the benefits received from water-related recreation in excess of out-of-pocket expenditures (the consumer surplus) was $9.36 per recreation day for activities which involve an overnight stay.
- The average consumer surplus for water-related recreation for day trips and trips involving an overnight stay (combined) was $3.95 per recreation day.
- The total value of the consumer surplus for water-related recreation in Minnesota is $377 million.
- The average consumer surplus per acre of lake area in the state is $166.
- In Minnesota, consumer surplus values are approximately 44% of consumer expenditures per recreation day.
- The average consumer surplus for non-Minnesota residents is significantly larger than the surplus for Minnesotans, and the average consumer surplus for trips involving an overnight stay is significantly larger than that for day trips.
- The Northeast region accounts for almost sixty percent of the total value of the consumer surplus for water-related recreation in the state. Over one-half of all recreation trips involving an overnight stay occur in this region.
- Over one-half of all water-related recreation day trips in Minnesota occur in the Metro region.
- The average consumer surplus per recreation day is highest in the Northeast region and lowest in the Metro region.
- The average consumer surplus per acre of lake area is highest in the Metro region ($922 per acre) - more than three times the average surplus per acre of any other region of the state.

The values obtained for the average consumer surplus for water-related recreation using the travel-cost method are approximately the same as those obtained using the contingent valuation method.

No significant difference in daily consumer surplus values were found among the various types of water-related recreation activities or among the five economic regions in Minnesota.

RECOMMENDATIONS

Although they are difficult to measure and therefore often ignored, the market and non-market benefits of water for recreation are significant. These benefits should be considered when making decisions regarding the allocation of water among competing uses.

Water provides more market and non-market recreational benefits to Northeast Minnesota than to any other region in the state. Policy options which protect or enhance the water resources in this region should be given high priority.

When considered in terms of the benefits provided per unit area, the lakes of the Twin Cities metropolitan region are significantly more important than are any other water bodies in the state. Great caution must be observed before allowing these water resources to be diverted to other uses.

Due to time constraints, the indirect impacts of expenditures for recreational activities were not calculated for each economic region in the state. The results of such an analysis would be very useful for making decisions regarding the allocation of water among competing uses. DNR resources should be allocated so that this analysis can take place.

The values obtained by this study to describe the benefits of water recreation are not directly comparable to those obtained to describe the impacts of water on economic production. Efforts should be made to enhance their comparability by evaluating the significance of the volume of water in lakes and streams on their value as sources of recreation.

Other benefits of water recreation, such as existence and option values, are important but were not evaluated here. These benefits should be analyzed, particularly with regard to the relative value of urban and non-urban water resources.

CONCLUSIONS

MINNESOTA WATER RESOURCES AND WATER LAWS

Minnesota's location in the geographic middle of the United States, sandwiched between the (relatively) wet East and the dry West is clearly reflected in its water laws and water resources. Minnesota water law adheres to the Eastern concept of riparian rights to water resources, although users must demonstrate that the water is put to a "reasonable use." While most of the state generally has adequate water supplies, the western third exhibits characteristics similar to the semi-arid Great Plains: low normal precipitation amounts, intermittent stream flows during summer months, and frequent drought-like conditions.

The riparian rights doctrine typically functions well when water supplies are adequate, but serious consequences arise when the demands from off-stream users exceed the available supplies. Consider, for example, the Clearwater River in northwest Minnesota. Eight wild rice growers have a total of seventeen DNR appropriation permits to draw water from the river in order to flood their fields each spring. This water is essential to the production of wild rice, and thus to the growers' livelihoods. Even in an normal year, spring flows in the river, augmented by snow melt, are barely adequate to provide enough water to flood all of the rice paddies. When the flow falls below a pre-determined level, (72 cubic feet per second), an allocation scheme is implemented by the DNR or the Red Lake Watershed District which strictly governs the timing and amounts of withdrawal by the growers.

The allocation of water to each user is determined by the amount of land owned that is riparian to the river. This allocation scheme changes whenever anyone purchases undeveloped land along the river and thus lays claim to a portion of the available water supplies. If an existing wild rice grower wishes to expand his/her acreage or a new grower wishes to start production, he/she may purchase riparian land, request a DNR appropriation permit, and thus force a reallocation of the river "pie" to include one more slice of water. Under low flow conditions, this would mean that all other water users would then be forced to reduce their withdrawals in order to maintain the minimum stream flow. In theory, the number of appropriators could reach a point where wild rice production would cease because no share of the pie would provide sufficient water to adequately flood the fields. Since wild rice irrigation is considered a "beneficial use", and since all wild rice growers have the same priority rights of withdrawal, the DNR cannot prevent the use of water by one or more growers in order to authorize adequate volumes of withdrawal to others.

If Minnesota followed the prior appropriation doctrine employed by most western states, the original water users would have priority over any land owners who began pumping at a later date. In this way, the original water users would be assured of a more stable water supply, less affected by other users. Such assurance provides a more stable economic environment for the water user, thus encouraging the users to remain as viable contributors to the local economy.

Discussion of the advantages of the prior appropriation doctrine does not imply endorsement of this concept; there are major problems associated with prior appropriation, the most significant of which is the "use it or lose it" philosophy, which discourages any attempts at conservation of water. Instead, mention of the prior appropriation doctrine merely suggests that other water allocation policies are available which may achieve more efficient and equitable solutions to water conflicts.

Similarly, the possibility exists to improve the priorities of water use which were established by the State Legislature. In descending order, these priorities are:

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

Application of these priorities can often result in allocations of water which are inequitable, inflexible, and even illogical. The assignment of domestic use to the highest priority does not restrict uses of water which at best can be considered non-essential: watering lawns, washing cars, and filling swimming pools. Assigning power production fourth priority ignores the fact that many water users among priorities one, two, and three use electric pumps to withdraw water. The loss of electricity would prohibit their pumpage despite the fact that water might be available for their use.

FINDINGS

1. Minnesota is blessed with abundant supplies of both surface and ground waters. In a normal year, the total amount of available surface water is 22.28 million acre-feet (about seven trillion gallons). This amount does not include the waters of Lake Superior or numerous land-locked lakes within the state. The total amount of available ground water was estimated to be 2.2 million acre-feet (700 billion gallons).

2. An average of 85% of the total surface water available in the state is required for the maintenance of instream flows. This water is needed for fish and wildlife habitat, recreation, hydroelectric power generation, navigation, waste assimilation, and sediment transport.

3. Approximately ten percent of available surface water and fifty percent of available ground water are required for the production of goods and services in the state and for use by private households. Major surface water users include: electric power utilities, municipal water utilities, iron ore mining, and pulp and paper

milling. Major uses of ground water included municipal water supplies, irrigation of agricultural crops, and food processing.

4. Despite Minnesota's water abundance, situations have occurred where available supplies were not sufficient to meet demand. Natural fluctuations in surface water supplies are often a major cause of the shortages. Streams display seasonal and long-term fluctuations in flow rates. On occasion rates are sufficiently low that the entire volume of water in the stream is required to maintain instream uses. Under these conditions, withdrawals for off-stream uses are curtailed or severely restricted.

Withdrawals for off-stream uses exacerbate low-flow conditions, particularly when the volumes withdrawn constitute a significant portion of the flow of the stream. On a few streams in the state, particularly the Clearwater and Buffalo Rivers, the combined pumpage by all withdrawal uses may constitute 75% or more of the total flow. This magnitude of pumpage presents a significant threat to the ecology of the local watershed.

5. When water supplies are limited, economic production, as measured by output, employment, and earnings, is maximized when the demands for smaller water users are met before the demands of larger users.

6. For each dollar of output generated by one acre-foot of surface water, up to twelve dollars and eighty cents are generated from one acre-foot of ground water in the state.

7. The marginal value of one acre-foot of water toward maximizing gross output for the state's economy is $2,070.

8. A moderately severe drought can result in a loss of 150 jobs, a $5.7 million reduction in gross output, and a $3.1 million reduction in state exports.

9. In addition to its value as a sustainer of life and an input to economic production, water provides market and non-market benefits to Minnesota as a source of recreation. The direct and indirect impacts of water-related recreation account for 1.7 percent of Minnesota's total gross output, 1.5 percent of total value added, and 1.9 percent of employment. Most of these impacts are concentrated in the manufacturing, wholesale and retail trade, and service sectors.

10. The total value of the consumer surplus (the value of the recreational experience over and above the costs of participation) for water-related recreation in Minnesota is $377 million.

RECOMMENDATIONS

1. Re-evaluate the current water allocation framework.
While no water allocation policy can be expected to resolve all problems arising from a constraint on water supplies, Minnesota's combination of water laws under the riparian doctrine and established priorities of use have proven to be inadequate in addressing a wide variety of water constraints. Therefore, current statutes and rules should be re-evaluated and more appropriate guidelines and procedures should be established.

Any new allocation policy must:

a) *Include an objective*, clearly stated, which can be used as a guide in resolving conflicts for which explicit procedures have not been established and in providing justification for policies and procedures which are defined by statute or rule.

b) *Incorporate a degree of flexibility* sufficient to reflect the diversity in the availability and use of water in the state.

These two requirements are important enough to warrant further discussion.

One possible objective, economic efficiency, is discussed at length in this report. However, a water allocation policy guided solely on the concept of economic efficiency would inevitably conflict with other stated goals of the DNR as well as commonly accepted principles of equity. For instance, if economic efficiency, defined here as the maximization of gross output, employment, or earnings, were the primary objective of Minnesota's water allocation policy, one could not justify the dedication of 85% of all surface water supplies for instream flow uses. The value of these uses, as measured by the direct and indirect impacts of water related recreation, accounts for less than two percent of the state's output employment and earnings. Strict adherence to the principal of economic efficiency would also imply giving a low priority to the use of water for agricultural production. While such a policy could be justified at the state or even regional level, it ignores the great importance of the agricultural economy in many rural communities in the state. Finally, it is difficult to imagine where water for domestic use would fit into an economically efficient allocation plan, other than opening the possibility for higher prices for drinking water.

The incorporation of some flexibility in Minnesota's water allocation policy would expand the number of options available in addressing the diversity in the State's water supply and demand. For instance, significantly variations in water use among the State's economic regions could require different priorities of water use. Differences in the relative availabilities of surface and ground water among the regions could also demand different priorities of use. Greater flexibility could permit the possibility for designating individual ground or surface water sources to specific uses. A precedent for such a step was taken with the designation of certain streams in the state for trout production. Other possible options include the designation of pumpage from entire aquifers, such as the Mount Simon-Hinckley, to municipal utilities exclusively. This restriction would greatly reduce the possibility for overuse and contamination of this valuable aquifer. Similarly, surface water sources with little or no instream use potential could be allocated almost completely to withdrawal uses.

In many ways, the results of the Water Allocation and Management Program substantiates and reinforces the recommendations made by the Water Planning Board in 1979. In its report, *Toward Efficient Allocation and Management: A Strategy to Preserve and Protect Water and Related Land Resources*, the Board suggested the following priorities of use in Minnesota:

1. Water for basic necessities (domestic use);
2. Water for environmental protection (primarily maintenance of instream flows and lake levels); and
3. Water for economic production.

While these categories of use are quite broad, they reflect many of the concerns raised in this report. Obviously, category three must be refined, possibly by incorporating many of the findings resulting from our rankings of economic sectors and an appreciation for regional differences in the supply and demand for water in the state.

The Water Planning Board also described several modifications of the riparian doctrine which would allow for the sale or leasing of "water rights" in Minnesota. At the time of their report, there was serious question as to the constitutionality of such a transfer of rights. Recent actions in the courts regarding similar transfers in some Western states imply that such sales are possible.

2. Improve data collection activities.
The availability of primary data is crucial to informed and effective planning and management of water resources. The current emphasis on local water planning serves to reinforce this need. The DNR should strive to improve its basic data collection activities in the following areas:

a. A minimal understanding of surface water supplies requires the establishment of a stream flow gage at the outlet of each of Minnesota's thirty-nine principal watersheds.

b. With the exception of several sand plain aquifers in central Minnesota and the Twin Cities metropolitan area, the yield potential of most ground water sources in the state have not been thoroughly explored. There is a need for detailed mapping of surficial and buried aquifers of the entire State of Minnesota.

c. An understanding of the instream flow requirements for a stream requires the collection and analysis of site-specific hydrologic, biological, and use data. The DNR should maintain its support for the collection of these data which is essential for the establishment of protected flows on streams with important instream uses. Funding provided by the LCMR for the continuation of this project is an important step toward this goal.

d. The methods used in the collection, storage, and analysis of water withdrawals in Minnesota are exemplary, as evidenced by the number of state and federal agencies which are using our procedures. The DNR should ensure that the momentum established over the last five years is not lost as the appropriation permitting responsibilities are decentralized to the six DNR regional offices. Instead, this recent shift should be used as an opportunity to improve the agency's enforcement of statutory requirements for water withdrawal.

3. Review the allocation of State resources.
The allocation of the state's financial resources should be reviewed to assure that the much higher value placed on ground water in comparison to surface water is reflected in management and regulatory activities. This recommendation is reinforced in light of the hydrologic, social, and economic impacts of reduces supplies due to contamination or depletion of available supplies.

4. Expand drought contingency planning.
The concept of drought contingency planning should be expanded in order to incorporate plans for responding to water supply contamination and increased water demand caused by economic growth.

5. Require efficient use of water.
While water is relatively plentiful in the state, supplies are not infinite and water shortages have occurred. Before seeking new or additional water supplies, water users should be encouraged to investigate water efficient technologies, conservation, and substitution of other resources of water.

6. Explore further use of the economic model.
The analytical capabilities of the computer models developed for this project have yet to be fully exploited. Since these models have shown promise for useful results, the DNR Division of Waters should allocate staff and funds so that improvements can be made to the model and many more analyses carried out.

7. Recognize the economic benefits of recreation.
Although they are difficult to measure and therefore often ignored, the economic and non-economic benefits of water for recreation are significant. These benefits should be considered when making decisions regarding the allocation of water among competing uses.

APPENDIX A

THE BLUE EARTH WATERSHED MODEL

U. S. GEOLOGICAL SURVEY

THE BLUE EARTH WATERSHED MODEL

OBJECTIVE

To develop a deterministic model which adequately simulates watershed processes and does not require extensive field work and data collection.

ANALYSIS

The Blue Earth Basin was chosen as the study area. The model developed can be used to evaluate the effects of changes in watershed, such as increased drainage or changes in land use, on the quantity and quality of runoff. It can also be used to assess the effects of changes in water use, such as stream flow appropriations or transfers, on runoff.

DATA SOURCES

Meteorologic, hydrogeologic, hydrologic, and land cover data were gathered from various sources for this project. Meteorologic data from 1980 through 1984 were obtained from the Waseca Agricultural Experiment Station of the University of Minnesota where solar radiation, air temperature, and wind speed were measured. Other data were obtained from the National Oceanic and Atmospheric Administration's Environmental Data and Information Service location in the National Climatic Center (NCC) at Asheville, North Carolina. NCC data included daily precipitation, and maximum and minimum temperatures at eleven sites. Hydrogeologic data were taken from Anderson's 1974 Hydrologic Atlas for the Blue Earth Basin. Land cover information was derived from the Department of Agriculture's Inventory Report on the Blue Earth Basin. Continuous record streamflow information was taken from the USGS Watstore database.

METHODS

The USGS has used several deterministic, distributed parameter runoff models which were developed to evaluate the impacts of various combinations of precipitation, climate, and land use on streamflow, sediment yields, and general basin hydrology. The one chosen for this project is the Hydrologic Simulation Program - Fortran (HSPF). The model was written for the Environmental Protection Agency and is based Crawford and Linsley's Stanford Watershed Model. It is modular in design, which provides flexibility for continued enhancement and hydrologic-modeling research and development. HSPF can be customized for Minnesota.

Streamflow hydrographs are the end product of areal and time distributions of precipitation, evapotranspiration, physical watershed characteristics, and soil and moisture conditions. For the purpose of modeling, it is useful to develop separate logical functions to represent hydrologic effects such as infiltration, interflow, surface runoff, groundwater movement, evapotranspiration, and the flow dynamics of the stream system.

RESULTS

WATERSHED CHARACTERIZATION

The basin (Figure 1) was divided into three parts, reflecting the locations of the continuous record gages. These are the Le Sueur River, the Watonwan River, and the Blue Earth River, including the Watonwan. Water years 1981 and 1982 were used in the calibration of each. Water year 1983 was used to verify the calibration.

CALIBRATION RUNS

Figures 2 through 4 are the observed and simulated hydrographs for water years 1981 and 1982 for each of the basins. The HSPF simulation used the aforementioned model parameters and watershed characterization. Table 1 contains the observed and simulated runoff volumes in each basin for each year.

VERIFICATION RUNS

Figures 5 through 7 are the observed and simulated hydrographs for water year 1983. These simulations used the same initial conditions and parameterization as the calibration runs. Table 1 contains the observed and simulated runoff volumes in each basin for water year 1983.

Figure 1: Location of the Blue Earth Watershed in Minnesota.

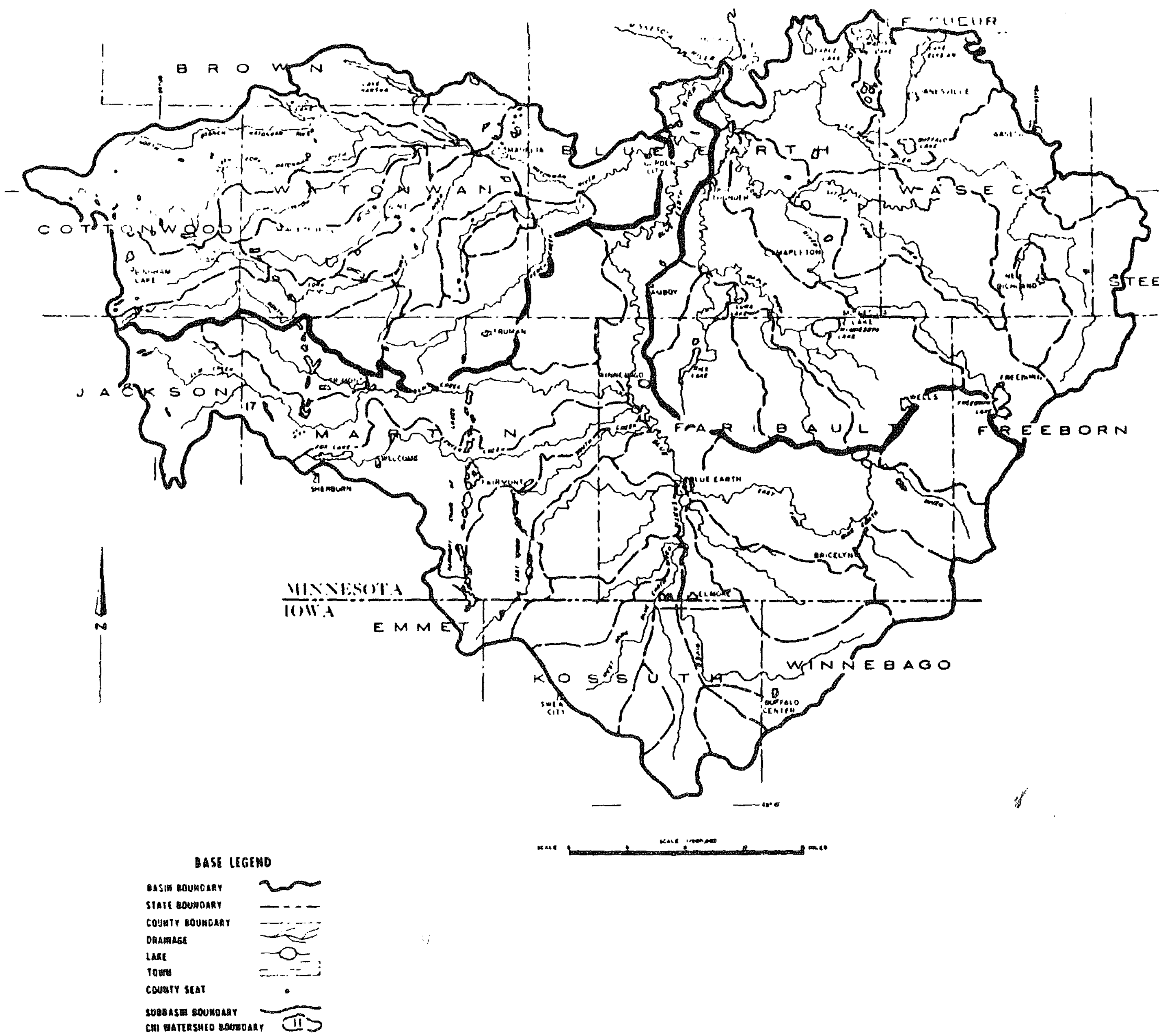


Figure 2: Watonwan River: HSPF simulation run.

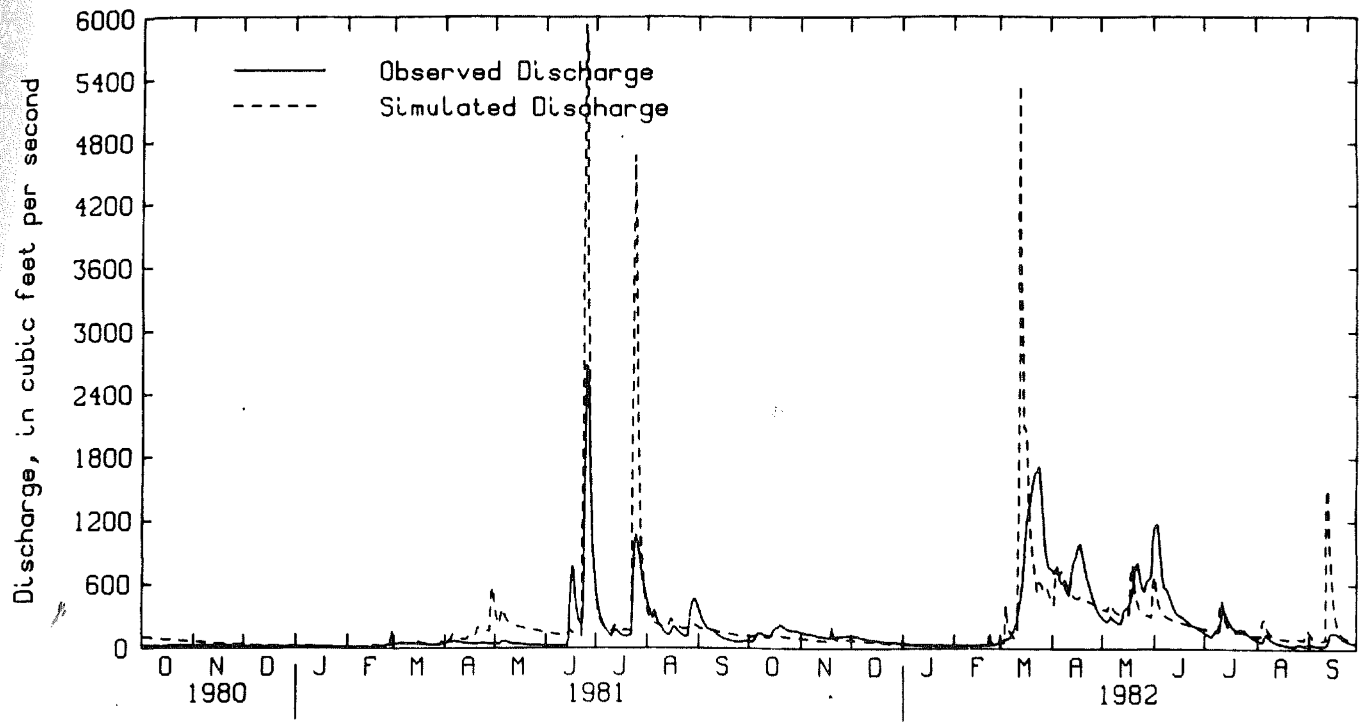


Figure 3: Blue Earth River: HSPF simulation run.

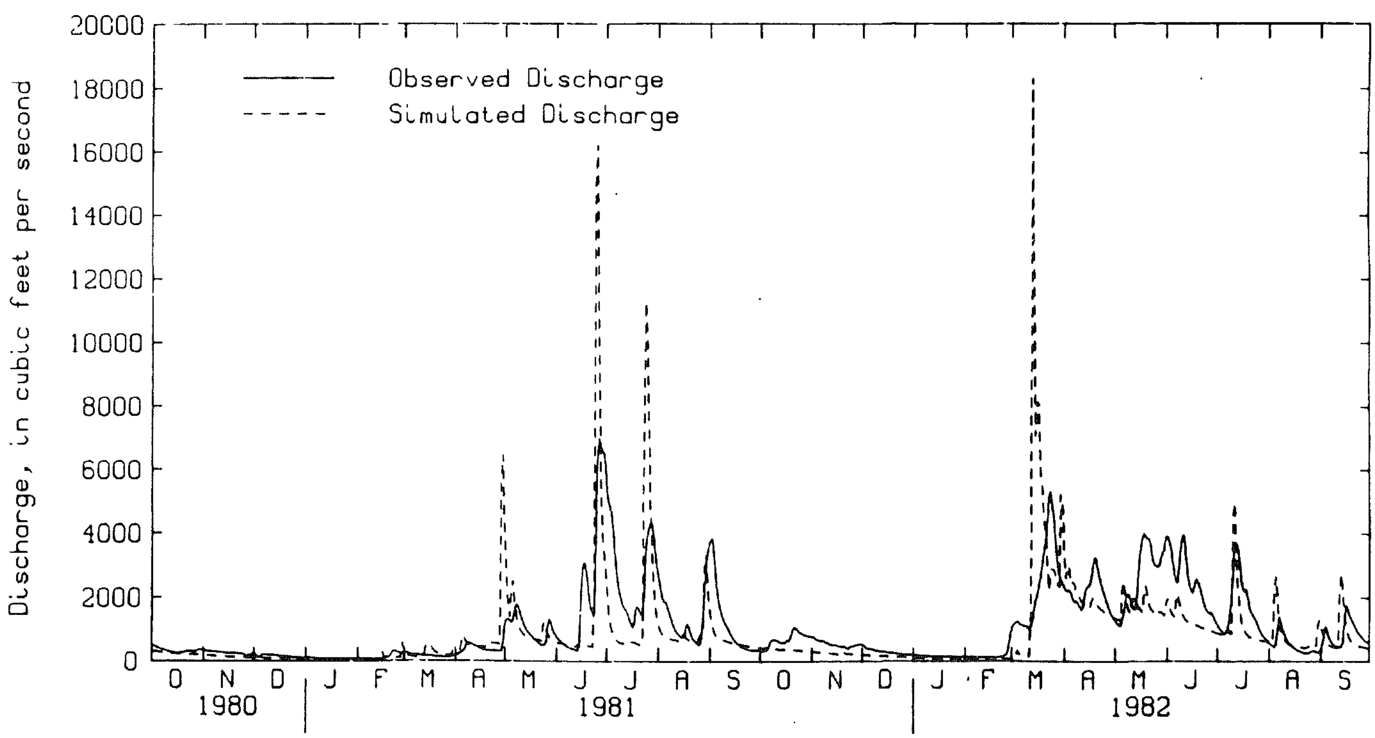


Figure 4: LeSueur River: HSPF simulation run.

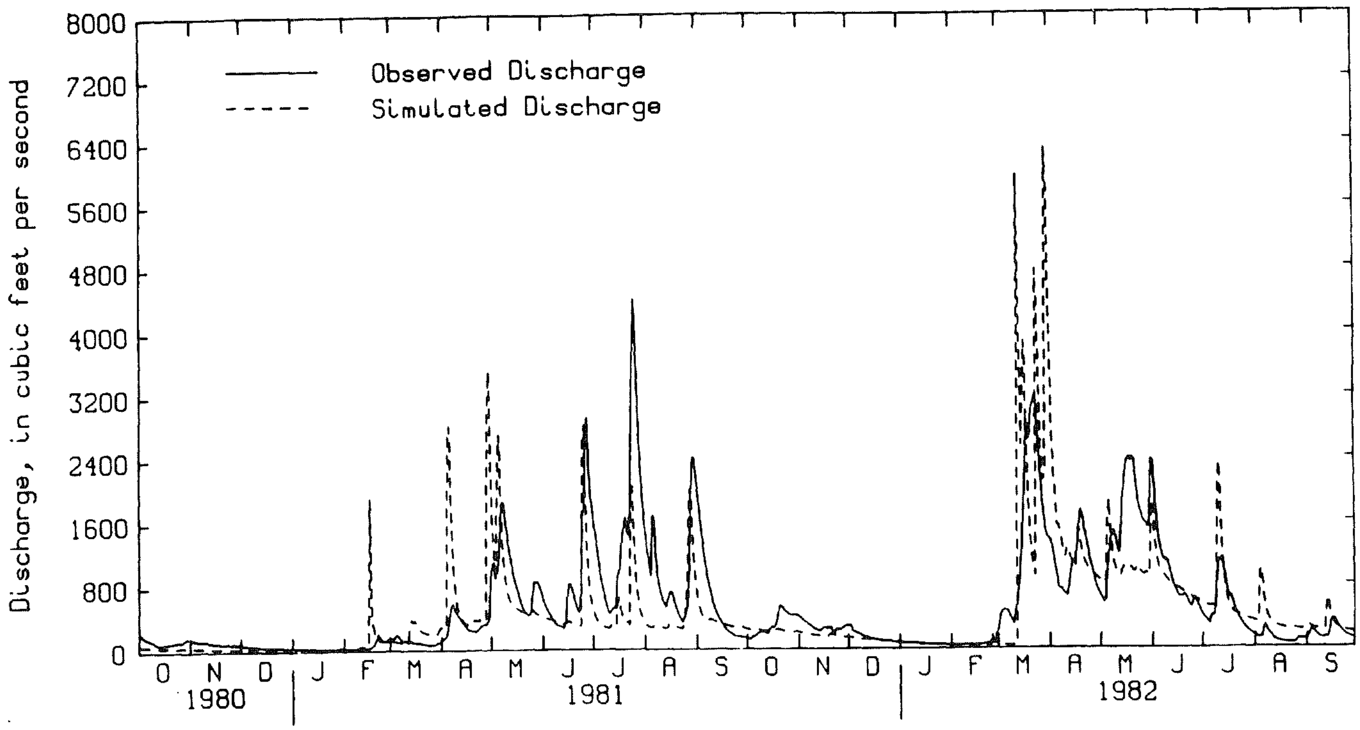


Figure 5: Watonwan River: HSPF verification run.

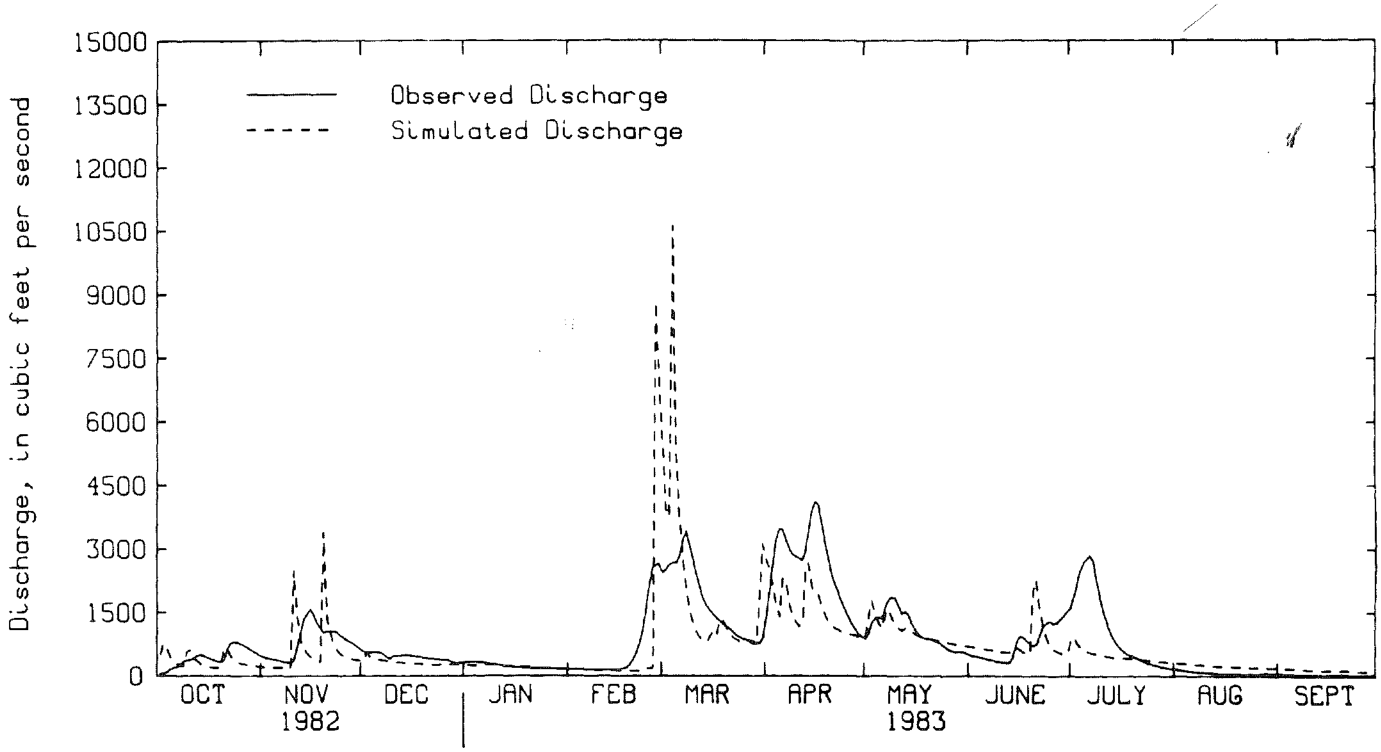


Figure 6: Blue Earth River: HSPF verification run.

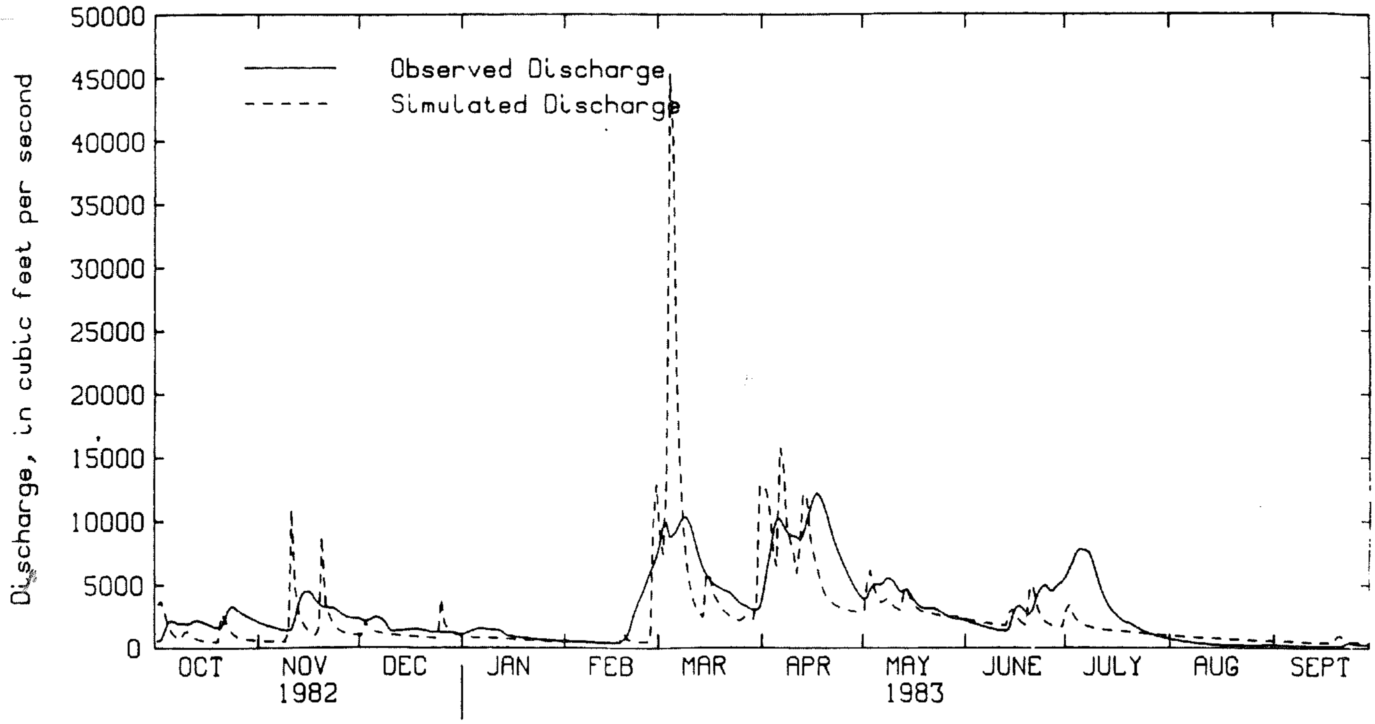


Figure 7: LeSueur River: HSPF verification run.

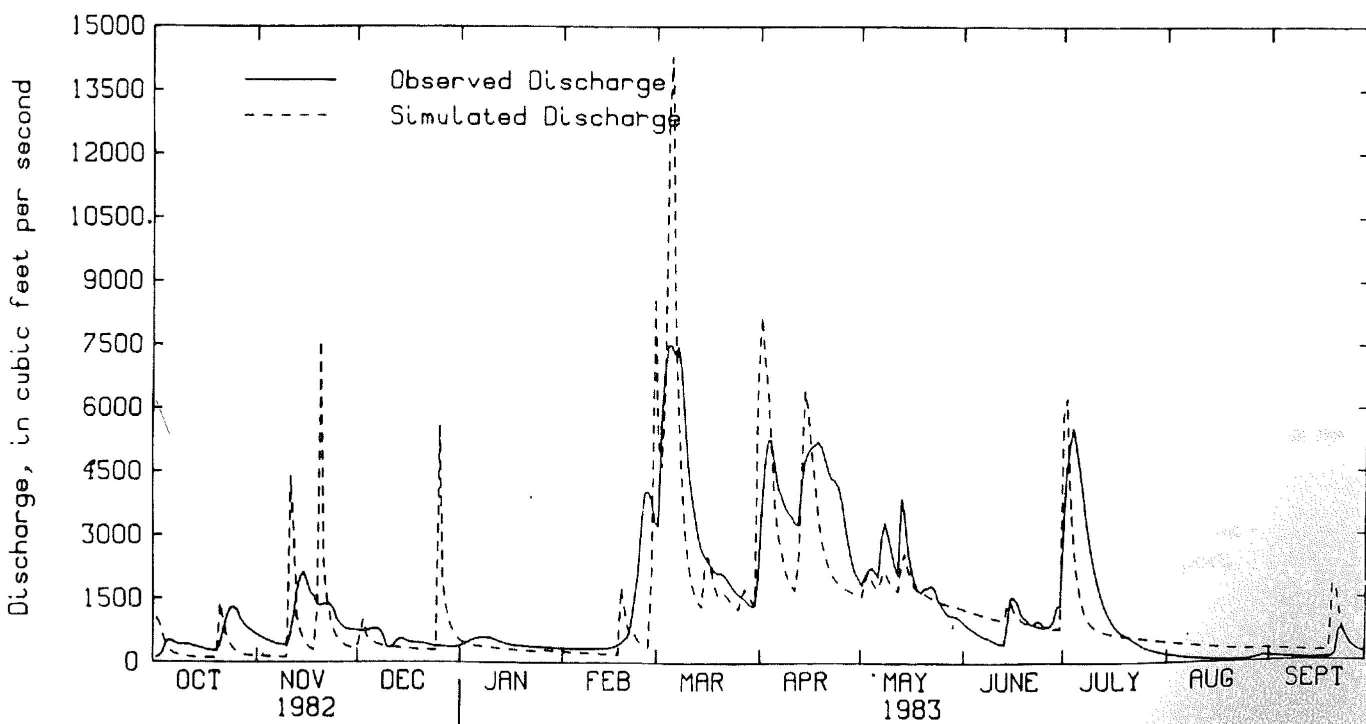


Table 1: Observed and simulated runoff for water years 1981 to 1983 in the three subbasins.

Watershed Basin	Observed	Simulated
	1981	
Watonwan River	2.04	3.48
Blue Earth River	4.71	4.28
LeSueur River	5.92	4.43
	1982	
Watonwan River	4.18	4.04
Blue Earth River	6.80	5.81
LeSueur River	6.87	7.30
	1983	
Watonwan River	13.68	11.75
Blue Earth River	16.07	14.23
LeSueur River	16.51	15.20

*Blue Earth basin includes Watonwan River drainage area.

DISCUSSION

The calibration and verification models of the Watonwan, Blue Earth/Watonwan, and the LeSueur may be evaluated by comparison of observed versus simulated hydrographs, as well as a comparison of annual volumes. It is important to remember that no channel routing was performed in any of these models.

Table 1 shows the observed versus simulated runoff for each water year in each basin. The differences between observed annual runoff volumes and the simulated volumes are generally less than 25 percent with simulated volumes usually less than observed. However, the model over-estimated the observed runoff of the Watonwan river in water year 1981 by nearly 75 percent. 1981 was a very dry year in the Watonwan river basin, runoff was 2.04 inches compared with an average of about 4.8 inches. Other investigators have noted that HSPF over-predicts in dry hydrologic conditions. It appears that extended dry spells can change a watershed's runoff response mechanism much as the winter-summer transition does. For example, in an extended dry period, the surficial aquifer can be depleted to a point where available water will fill the surficial storage to some thrshold level before the "normal" runoff response occurs. HSPF parameters can be changed to respond to such changes in watershed characteristics as was done here to make the transition from summer to winter and back again. However, HSPF cannot detect and dynamically react to basic changes in a watershed's runoff characteristics which cannot be seasonally anticipated.

Individual simulated peaks which are much larger than the observed peaks can be found in each calibration and verification hydrograph. The most consistent of these differences are in the spring of 1982 and 1983 for all simulations. However, two significant oversimulations occurred on the Watonwan and Watonwan/Blue Earth simulations of June and July, 1981. A comparison of bulk rain gage sampling and the Thiessen polygon distributions revealed nothing which would explain this. Examination of the HSPF output showed that both periods were characterized by large volumes of surface runoff. The LeSueur model did not oversimulate in this period and the rainfall there was much less. As previously noted, that runoff was not attenuated by channel routing. Much the same is true for the spring simulations. An additional factor in those simulations was the changing characteristics of the watershed as winter gave way to spring. As discussed previously, these changes are not dynamically treated within the model. Therefore the modeler may make ill-timed changes in parameters which may, for example, result in the model seeing frozen ground whien in fact it has thawed.

CONCLUSIONS

With the exception of the 1981 simulation in the Watonwan River, the models reasonably reflect the general runoff mechanisms of a watershed. Consideration should be given to expanding the model to include channel routing, sediment, and chemical transport.

Anomalies such as extended dry spells and seasonal changes are not handled well in these models. The capability by changing input parameters is there but these are user defined at specific times. The HSPF model cannot anticipate and make these changes itself. This is a potential area of research and development which would enhance the model.

While it is possible to create a "desk-top" model using HSPF, it requires an experienced hydrologist who can develop an intuitice understanding of the simulation modules as well as the complex interactions and interdependence of the variables used.

ADDITIONAL PROJECT REPORTS

Jaques, J. E., 1987 *Watershed Model of the Blue Earth Basin in Minnesota* - awatiting publication as a USGS Water Resources Investigation Report.

APPENDIX B

WATERSHED REPORTS

DEPARTMENT OF NATURAL RESOURCES

DIVISION OF WATERS

BLUE EARTH RIVER WATERSHED

Introduction

The Blue Earth River Watershed is located in south central Minnesota encompassing approximately 3153 square miles in Minnesota and 450 square miles in Iowa, which are not included in this study. The watershed in Minnesota includes all or most of Faribault, Watonwan, Blue Earth, Martin and Waseca Counties and portions of Brown, Cottonwood, Freeborn, Jackson, Le Sueur and Steele Counties (Figure 1). The surface topography includes morainal hills, glacial lake beds, outwash and till plains, and glacial and recent valleys. The watershed has a well developed drainage pattern, which has been altered by stream channelization and wetland drainage. Most of the natural lakes are shallow and subject to precipitation fluctuations; but, two unique lake chains of glacial origin are still identifiable. The Blue Earth River and its tributaries, the Le Sueur and Watonwan Rivers, are the major sources of surface water. Ground water from the glacial aquifers and several bedrock aquifers is readily available. Electric power production using surface water and public water supply using ground water are the major water uses in the watershed.

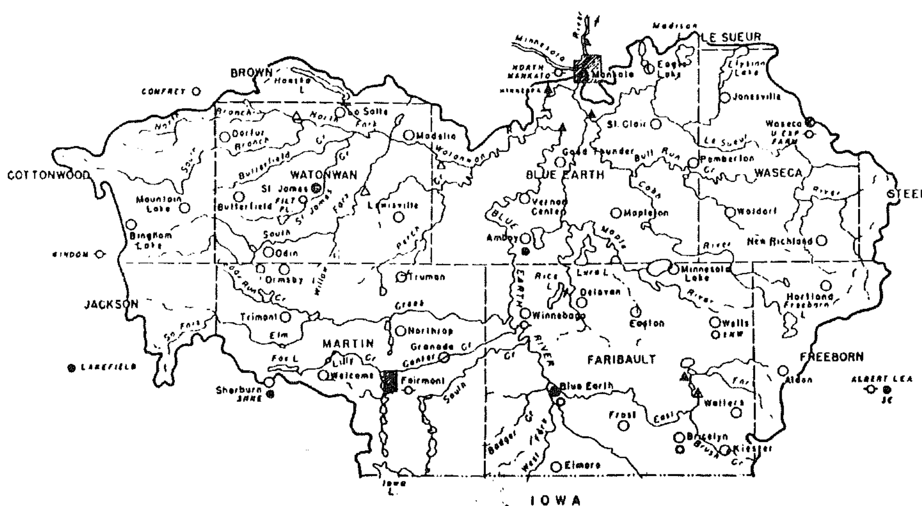


Figure 1 - Blue Earth River Watershed

Physical Characteristics

Landforms

The Blue Earth River Watershed is dominated by two major landforms, end moraine and till plain. Several separate moraines, which are nearly level to steep, surround the watershed on the west, south and east. Between the moraines is a till plain which is also found toward the center of the watershed. The till plain, known as the Blue Earth Till Plain, is characterized by gently rolling topography. Closed depressions, ice remnant features, form lakes and peat bogs on both the moraines and till plain. The most notable ice remnant features are two chains of connected lakes, trending north-south in the southwest corner of the watershed. A glacial lake basin, the Minnesota

Lake Plain, is the main landform in the central portion of the watershed. The topography and type of deposits, both lake clay and till, indicate the lake plain may have formed on and around disintegrating ice blocks; thus clean-cut, flat lake-bed topography is not present. Some outwash terraces and plains are found along the river valleys and at random locations. Several rivers have eroded deep valleys in the till plains in which recent alluvial terraces are found.

Geology

Thin, Recent alluvial sand and gravel deposits are found along the river valleys; however, most of the watershed is covered by Quarternary glacial deposits which in turn overlie bedrock. The surficial glacial deposits are from the most recent glacial advance, the Des Moines Lobe. Remnants of older glaciations may be found beneath the Des Moines age deposits. Des Moines end moraines, in a concentric series of ridges, surround the watershed on the west, south and east. Both the moraines and the till plain, found between the moraine ridges and in the center and north portions, consist primarily of unconsolidated, unsorted till deposits. Some sand and gravel lenses and layers are found randomly within the till. The till plain is covered in the center of the watershed by a glacial lake plain. The lake plain deposits, consisting of silt and clay, form a thin veneer over the till. The Quarternary glacial deposits are 0 to 100 feet thick in the northwest corner, 400 to 500 feet thick in the southwestern corner and 200 to 300 feet thick over the rest of the watershed. Deposits of outwash sand and gravel are found along river valleys and at other random locations within the other glacial deposits. These deposits are generally not very extensive except along the edge of the Glacial River Warren valley in the northwest portion. The two chains of lakes found in the southwest are an indication of buried outwash channels and ice disintegration.

Cambrian, Ordovician and Devonian age sedimentary bedrock underlies the glacial deposits in the central and eastern portion of the watershed. Exposures of bedrock may occur in the deepest eroded river valleys. The sequence of sedimentary rocks increases in age from east to west. The youngest, the Devonian Cedar Valley Limestone, is found only in a small area in the southeast corner. From youngest to oldest the formations found are the: Cedar Valley Limestone; Maquoketa, Dubuque and Galena Limestones; Decorah Shale; Platteville Limestone; Glenwood Shale; St. Peter Sandstone; Shakopee and Oneota Dolomites; Jordan Sandstone; Galesville, Eau Claire and Mt. Simon Sandstones. Glacial deposits in the western area are underlain by the Precambrian Sioux Quartzite. Thin, discontinous Cretaceous shales and sandstones cover both the quartzite and the older sedimentary rock in the western half of the watershed.

Land Use

Agricultural cultivation and pasture land are the largest land uses (Figure 2). Extensive drainage has reduced substantially the amount of original wetland areas.

Soils

The moraine areas are loam to clay loam with little sand and gravel. Till plain soils are limy, loam to clay loam. Poorly drained depressions and nearly level areas are common in the till plain. Generally less than three feet of loamy sand to silt loam overlie sand and gravel in the outwash areas. Soils in the lake plain range from silty clay loam to silty clay. Organic soils are found in the depressions and along the lakes and watercourses.

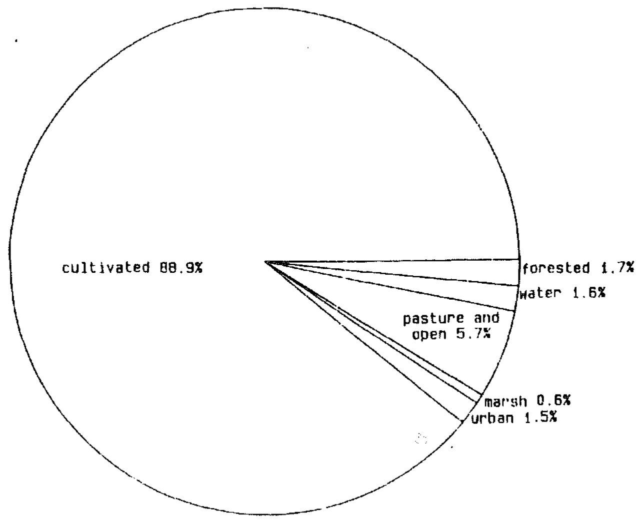


Figure 2 - Blue Earth River Watershed Land Use

Habitat

Intensive agricultural use has altered the original landscape of the watershed. Most of the native prairie has been replaced by cropland and pastures. Wetland drainage and stream channelization have been extensive throughout the watershed. These changes have reduced the availability of quality wildlife habitat. The remaining wetlands, grasslands and forested river corridors are important habitat.

Fisheries resources are somewhat limited. Most of the natural lakes are highly eutrophic and susceptable to winterkill The numerous streams have the potential to support an excellent population of sport fish; however, extreme flow fluctuations, low flows, and siltation problems collectively reduce the quality of the fishery. The Blue Earth River below Rapidan Dam represents an excellent fishery resource. The quality of this important fishery is reduced by the peaking operations of the Rapidan Dam hydropower facility. Land use practices aimed at controlling erosion and nutrient loading have a positive influence on the fish and wildlife resources.

Climate

The watershed experiences temperatures from -37 to 109 degrees Farenheit with an average temperature of 45.7 degrees. An average precipitation of 29.2 inches falls on the watershed including mean annual snowfall of about 40 inches. The mean annual runoff is around 4.8 inches and the mean annual evapotranspiration is 22 to 23 inches with a mean potential evaporation of 25 inches. The annual growing season is 156 days.

Water Resources

Surface Water

Quantity

The Blue Earth River flows for 92 miles from its headwaters in north-central Iowa to its mouth at the Minnesota River near Mankato. The average fall of the river is about 5 feet per mile and the greatest fall is nearly 10 feet per mile in the reach below Rapidan. The Le Sueur and the Watonwan Rivers are the main tributaries to the Blue Earth River. They are nearly as long as the Blue Earth River and have similar stream gradients and physical characteristics (Table 1).

Table 1. Continuous Gaging Stations

Gage Number	River	Location	Period of Record (yrs)	Area (mi2)	Mean Flow (cfs)	Max Flow (cfs)	Min 7-day Low Flow Flow (cfs)	2-yr (cfs)	10-yr (cfs)
531800	East Br. Blue Earth	Bricelyn	20	132	41.2	1320	0	0	0
531950	Watonwan	Garden City	14	812	324	5620	1.9		
532000	Blue Earth	Rapidan	44	2430	895	43100	6.9	42.3	14.5
532050	Le Sueur	Rapidan	41	1100	457	24700	1.6	17.1	4.91

The flow duration curves indicate similar hydrologic characteristics for the Blue Earth and the Le Sueur River near Rapidan, except at the lower end where the operation of Rapidan Reservoir gives the curve for the Blue Earth River a slightly flatter slope. The flow duration curve for the East Branch Blue Earth near Bricelyn indicates little or no natural storage (Figures 3 & 4).

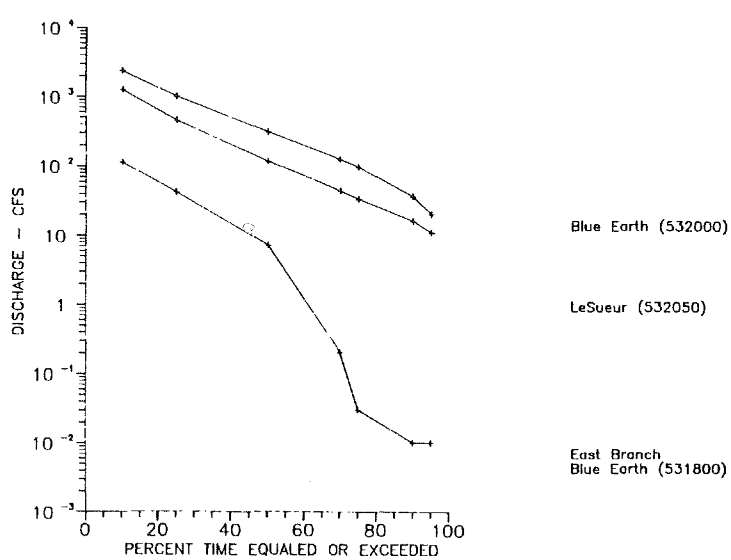


Figure 3 - Duration Curves for Selected Gages

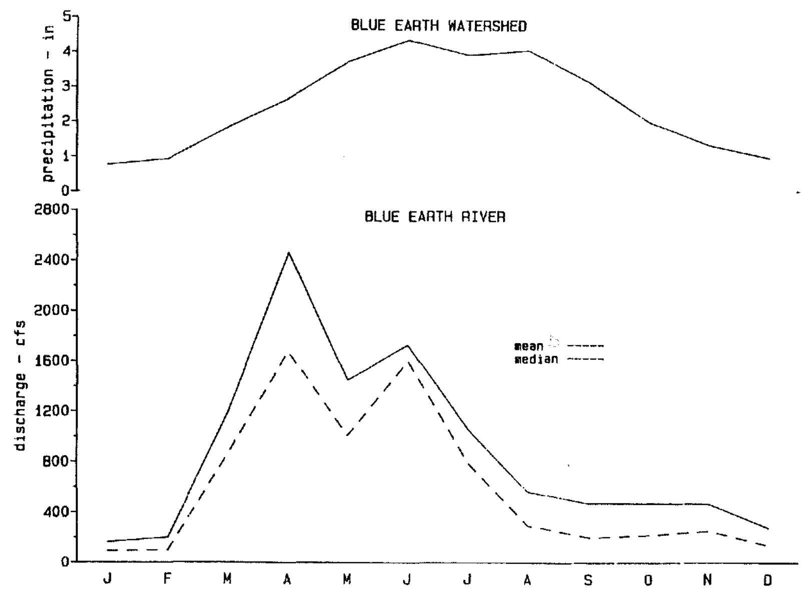


Figure 4 - Precipitation vs. Discharge of Blue Earth River

Quality

Water quality problems are generally the result of municipal and industrial discharges and runoff from agricultural lands. Municipal point source pollution problem sometimes result in effluent which exceeds the Minnesota Pollution Control Agency (MPCA) permit requirements for biochemical oxygen demand, suspended solids, or fecal coliform. Water quality problems associated with point source pollution will continue to be reduced, provided that wastewater treatment facilities are completed. Occasional violations of ammonia and copper standards also have been identified. Problems associated with nonpoint source pollution will worsen as long as sediments, nutrients, and pesticides continually enter watercourses. The 1984-85 MPCA report on water quality indicates that 19.4 miles of Center Creek by Fairmont does not support the fishing standards set by MPCA. Furthermore, 3.4 miles of the Blue Earth River at Mankato and 19.4 miles of Center Creek by Fairmont do not support the swimming standards set by the MPCA and 12.9 miles of the Watonwan River west of Garden City only partially support the swimming standards.

Major surface water discharges are limited to larger municipal treatment facilities and thermal electric cooling water. The major authorized municipal discharges are: 10.0 million gallons per day (mgd) to the Minnesota River from Mankato; 2.34 mgd to Center Creek from Fairmont; 1.33 mgd to the Watonwan River from Madelia; and a proposed 1.4 mgd to the Watonwan River from the new St. James municipal treatment facility. The Interstate Power Company Fox Lake Plant is authorized to discharge 40.0 mgd of cooling water to Fox Lake. The primary impact of this type of discharge is thermal. Numerous minor dischargers are permitted including small municipalities, water treatment facilities and manufacturing processing sites. The MPCA reports (1985) that effluent water quality standards generally are being met by authorized dischargers.

Ground Water

Quantity

In addition to the sand and gravel aquifers in the glacial deposits, six different bedrock aquifers are found in the watershed. Several of the bedrock formations, although they have separate geological identities, have similar hydrologic characteristics and are considered one aquifer. These aquifers include the Cretaceous, Cedar Valley-Maquoketa-Dubuque-Galena, St. Peter, Prairie du Chien-Jordan, Franconia-Ironton-Galesville, and Sioux Quartzite.

Lenses of sand and gravel buried within the till are the most widely accessible and most widely used shallow aquifers especially in the western part of the watershed. The saturated thickness of glacial deposits ranges from less than 100 feet to greater than 500 feet. These buried sand and gravel lenses are commonly thin and discontinuous, but generally provide water supplies adequate for private domestic use. Locally, water is available from surficial outwash and Recent alluvial deposits.

In the western part of the watershed, few wells obtain water from the bedrock. Toward the east, increasing numbers of wells obtain water from Ordovician and Cambrian rocks. The Jordan, St. Peter, and Galena Formations are parts of three separate aquifers. These three formations are the most reliable and widely used portions of the aquifers in the central and eastern areas. Cretaceous rocks are limited in extent and, therefore, are of limited value as an aquifer.

The Cedar Valley-Maquoketa-Dubuque-Galena aquifer, interlayered beds of limestone, dolomite, sandstone and shale, can be from 300 to 600 feet thick. Well yields range from 150 to 300 gallons per minute. This is the uppermost bedrock aquifer in the southeast portion of the watershed.

Immediately to the west of the Cedar Valley-Maquoketa-Dubuque-Galena aquifer the first bedrock aquifer is the St. Peter Sandstone aquifer. The St. Peter averages about 100 feet thick and has a well yield of 100, to as much as 1000, gallons per minute.

The Prairie du Chien-Jordan aquifer is the uppermost bedrock aquifer in the east central section. The Prairie du Chien is a sandy dolomite and the Jordan is a sandstone. This aquifer can be 350 feet or more thick and has well yields of 50 to 1000 gallons per minute.

The Franconia-Ironton-Galesville aquifer is primarily sandstone with a thickness up to 600 feet or more. Well yields can vary from 100 to 1000 gallons per minute. This aquifer is the first found west of the Prairie du Chien-Jordan aquifer and east of the Sioux Quartzite.

The Sioux Quartzite yields water from weathered and fractured zones within the quartzite and from sandstones found within the quartzite. Well yields are highly variable, ranging from 1 to 450 gallons per minute, but typically yielding 1 to 25 gallons per minute.

Quality

The ground water has high concentrations of salt, carbonate, sulfates, chlorides, nitrogen and phosphorous. The water quality in the surficial aquifers is not only influenced by agricultural production, but also by the chemical composition of glacial materials. Ground water in both glacial deposits and bedrock is high dissolved solids-sulfate type water in the west and lower dissolved solids-bicarbonate type water in the east.

Water Use

Water Withdrawal

Thermal electric cooling is the largest water use in the Blue Earth River Watershed (Figure 5). Interstate Power Company withdrew over 10.0 billion gallons of surface water for cooling purposes at their Fox Lake Thermal Production Plant in 1985. The Fairmont Public Utilities Thermal Power Facility is now closed, but was in operation in 1985; no estimates of water use for cooling purposes at that facility were recorded.

Only one hydroelectric facility, the Rapidan Dam, exists in the watershed. The Rapidan Dam is operated by Blue Earth County on the Blue Earth River, producing 4.9 megawatts (MW). This facility is run as a peaking operation, where water is stored and released when power is produced to meet peak demands.

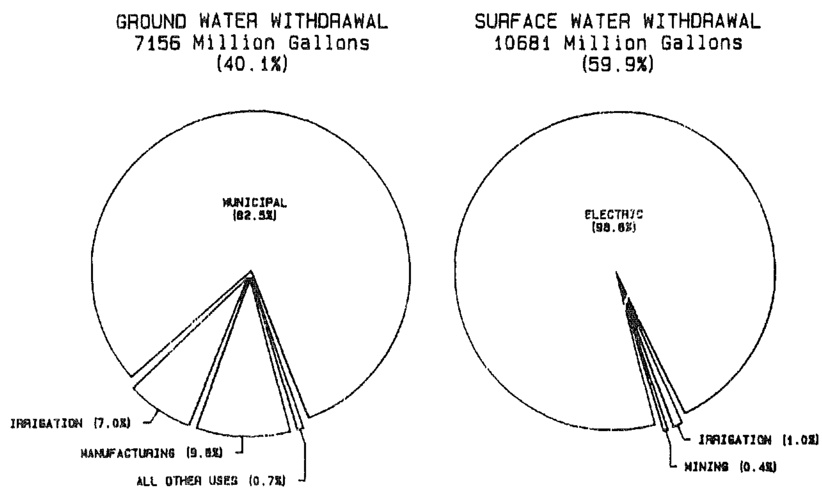


Figure 5 - Blue Earth River Watershed Water Use

The largest ground water use is for municipal public supply. In all, 47 cities have public supply systems, using ground water exclusively to meet their supply needs. Major cities in the watershed include: Mankato, with a population of nearly 30,000; North Mankato, Waseca and Fairmont, with populations between 8,000 and 12,000; and St. James and Blue Earth, with populations around 4,000. Industrial water use is centered around larger cities and consists primarily of food processing operations which used approximately 700.0 million gallons (2,100 acre feet) of ground water in 1985. Additional unrecorded ground water appropriations occur locally for private rural domestic supply.

Other large water uses include irrigation and mined material processing operations. Almost 4,000 acres of corn, soybeans, canning produce, and other field crops are irrigated from ground water annually, with an additional 1,200 acres irrigated from surface water sources. Sand and gravel washing operations withdrew nearly 50.0 million gallons (1,500 acre feet) of surface water in 1985.

Recreation

Recreational opportunities are primarily associated with the major streams. The Blue Earth River and its two primary tributaries, the Watonwan and Le Sueur Rivers, constitute the major recreational resources. The rivers and their associated valleys support a diversity of recreational activities which include fishing, hunting, canoeing, camping, hiking and picnicking. There are very few natural lakes, which accentuates the value of the stream resources.

Wildlife Management Areas (WMA) and Waterfowl Production Areas (WPS) encompass some 15,000 acres public land (Table 2). These areas protect important wildlife habitat and provide recreational opportunities for the public. The 2,000-acre Walnut Lake WMA is one of the major WMAs in the south-central Minnesota. This area receives exceptionally high levels of use during the hunting and trapping seasons.

Table 2 - Recreational Resources of the Blue Earth River Watershed

Resource	No.	Acres*	Features
State Parks	--	--	
County Parks	15	892	
Wildlife Management Areas	70	16,120	
Waterfowl Production Areas	--	400	
Federal Lands (excluding WPAs)	--	--	
State Forests	--	--	
Lakes	133	31,832	
Wetlands	86	4,318.5	
		Miles	
Designated Trout Streams	--	--	
Wild and Scenic Rivers	--	--	
Canoe and Boating Routes	--	--	

*Acreages for state forests, wildlife areas and all federal lands are approximated from 40-acre parcels.

The Blue Earth River between Rapidan Dam and its confluence with the Minnesota River is an extremely valuable recreational resource to the region. The recreational activities associated with this reach of river, fishing and canoeing in particular, are being adversely affected by the hydropower peaking operations of Rapidan Dam. Throughout the watershed, existing land use practices have had a negative impact on the water-based recreation opportunities.

Fisheries resources are somewhat limited. There are no designated trout streams in this watershed. Very few natural lakes support good populations of sport fish. Most of the lakes tend to be shallow, eutrophic and highly susceptible to winterkill. The Blue Earth River is the most significant fishery resource. The stretch of river below Rapidan Dam has high quality fish habitat and supports an excellent population of channel catfish. Channel catfish are also the principal sport fish species above Rapidan Dam and in its major tributaries. In addition, northern pike, walleye, sauger and panfish contribute to the fishery value. Smallmouth bass were once a major component of the sport fishery, especially in the Blue Earth River. Extreme fluctuations in stream flow, a result of the storage loss associated with extensive wetland drainage, stream channelization and ditching greatly reduced the smallmouth bass' spawning success during the early summer months. Erosion and nutrient loading are also major problems affecting water quality and the availability of fish habitat. Siltation serves to smother the coarse stream substrates that are essential to the production of food organisms for the smallmouth. Overall, biologists rate the rivers in the watershed as having the potential to support excellent populations of sport fish. This potential is not being realized due to the water quality and quantity problems.

Some of the most productive farmland in the state is found in this region; therefore, agricultural development has been extensive. Only fragments of the once expansive native tall grass prairie remain and wetland loss estimates run as high as 90 percent. At one time the Big Woods vegetation type, consisting of scattered maple, basswood and oak forests, extended southward into the northeastern corner of the area. Numerous wetlands were scattered throughout the region and bottomland hardwoods were common along all of the major watercourses. Forested areas have been cleared for cropland and hundreds of miles of streams have been altered by channelization and ditching. These changes have drastically reduced the availability of wildlife habitat. The WMAs and WPAs provide habitat for a variety of wildlife and are especially important for waterfowl and pheasant nesting. The river corridors provide valuable furbearer and waterfowl habitat and serve as wintering areas for white-tailed deer and various upland species.

Hunting and trapping are popular recreational activities, especially along the river corridors and on the public hunting areas. Important game and furbearing species include white-tailed deer, pheasants, waterfowl, hungarian partridge, rabbits, squirrel, fox, beaver, muskrat, mink and raccoon. The Heritage Program has catalogued plant and animal species in need of special consideration, those of special interest, and priority species. Of those species, 19 have been documented to occur in the watershed (Table 3).

Table 3 - Species of Special Interest

Species	Code #	Status*	Occurrences
Wood turtle	CD.639	THR	1
King rail	DM.449	SPC	2
Burrowing owl	DV.455	END	2
Loggerhead shrike	EK.424	THR	2
Spotted skunk	FS.517	SPC	2
Rock clubmoss	EA.426	THR	1
Goldie's fern	EF.P21	SPC	1
Buffalo grass	GH.BB1	SPC	2
Tumblegrass	GH.GP6	SPC	1
Snow trillium	GT.A74	SPC	1
White lady's slipper	GY.K52	SPC	3
Moustail	HH.GS6	SPC	1
Rattlesnake masten	L3.932	SPC	12
Species of black snakeroot	L3.C68	SPC	1
Prairie bush clover	LD.BC9	END	3
Sullivant's milkweed	ND.BA9	THR	5
Valerian	NW.A06	THR	4
Cacalia tuberosa	NX.E02	THR	5
Three lobed coneflower	NX.GL6	SPC	1

THR* - threatened SPC - special concern END - endangered

Water Availability

Shortages in both ground water and surface water have been experienced in the Blue Earth River Watershed. The 1976-77 drought created water supply problems in eleven cities. All of the cities drilled new wells to provide a more reliable water supply. Peaking operations at the Rapidan hydropower dam with the resulting low flows have been detrimental to the high quality fish habitat below the dam. The few lakes in the area are highly eutrophic due to nutrient loading and siltation problems, making them susceptible to winterkill. Fish kills have occurred in the past on a small scale due to low flow conditions. Protected flows have been set on the Blue Earth River, Center Creek, and Judicial Ditch #5 draining into the Little Le Sueur River. These flows are based on the 90 percent exceedance level, which may be inadequate for instream flow needs.

Surface Water Budget

The water budget equation, when solved using United States Geological Survey (USGS) and Minnesota Department of Natural Resources (MDNR) estimations, indicates that water availability will meet water needs (Table 4). A dry year is defined as the one-in-four drought event or those flows exceeded 75% of the time. A normal year is defined as the median flow or those flows exceeded 50% of the time. A wet year is defined as flows exceeded 25% of the time or the one-in-four year flood event. The area is defined as having a positive water balance (+) if the water balance is greater than or equal to 1.10, a neutral water balance (0) if the ratio is between 0.95 and 1.10 and a negative balance (-) if the ratio is less than or equal to 0.95. These numbers may contain significant error, but can act as indicators for the surface water balance equation of the watershed.

Table 4 - Surface Water Budget

Year	Available (A) acre feet	Needs (N) acre feet	Use (U) acre feet	Balance A/N+U
normal/ wet	689,000	481,000	33,000	+
dry	370,000	251,000	33,000	+

The USGS has approximated the total surface water available within the watershed from historical records of precipitation and runoff and from estimates of evapotranspiration. Runoff is difficult to model which increases the chance for error in the data.

The MDNR has approximated the total surface water necessary to maintain instream uses within the watershed based on existing and potential resources and recreational activities. This volume is a general assessment of the total flow needed at the mouth of the watershed sufficient to support aquatic life and recreation. These numbers were extrapolated from a single measurement made on the Le Sueur River. They should not be applied to specific streams. Rather they act only as indicators for the watershed.

The MDNR has also estimated water use from annual pumping reports sent in from water users. Table 4 shows the total annual appropriations for the watershed according to the 1985 water use data. Water use data is based on measurements made by appropriators which may contain error. In addition, nonpermitted appropriators use an unrecorded amount which is not included in these estimates.

Given the inherent error in the USGS water availability estimates and the MDNR's instream flow and water use approximations, these numbers can not be used to draw detailed conclusions. They should only be used as an indication that water shortage problems exist.

Conclusion

Water quality and quantity problems have had negative affects on the water supply, fisheries, wildlife, and recreational resources. Low flows, fluctuating water levels, and siltation are major problems in the surface waters. Improved land use practices, such as erosion control and reduced nutrient loading, could increase the surface water's recreational value.

Cities using ground water have already experienced water supply problems. Development of emergency water supply plans would be beneficial to better manage water use during draughts.

The gradual conversion of native prairie land to agricultural use has resulted in reduced availability of surface water habitat. The remaining wetlands and forest river corridors are very important habitat areas. Additional precautions must be taken to protect the ground water resources from contamination. In order to maintain the water resource of the watershed proper planning of the surface and ground water resources is essential.

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CROW WING RIVER WATERSHED

Introduction

The Crow Wing River Watershed comprises 3,764 square miles of west-central Minnesota, including all of Wadena and parts of Hubbard, Becker, Ottertail, Douglas, Todd, Cass, Crow Wing, and Morrison Counties (Figure 1). The area is covered by glacial deposits forming upland till plains, morainal hills and ridges, and outwash plains. Lakes and wetland predominate in the northern half of the watershed. The southern half has a well defined drainage pattern and is susceptible to summer flooding. The Crow Wing River drains the largest area of any river in the watershed. It's major tributaries are the Shell, Leaf, Partridge, Long Prairie and Gull rivers. The abundant water resources and natural character of the watershed offer fine recreational opportunities. Irrigation and public supply, both from ground water, are the major water uses within the watershed.

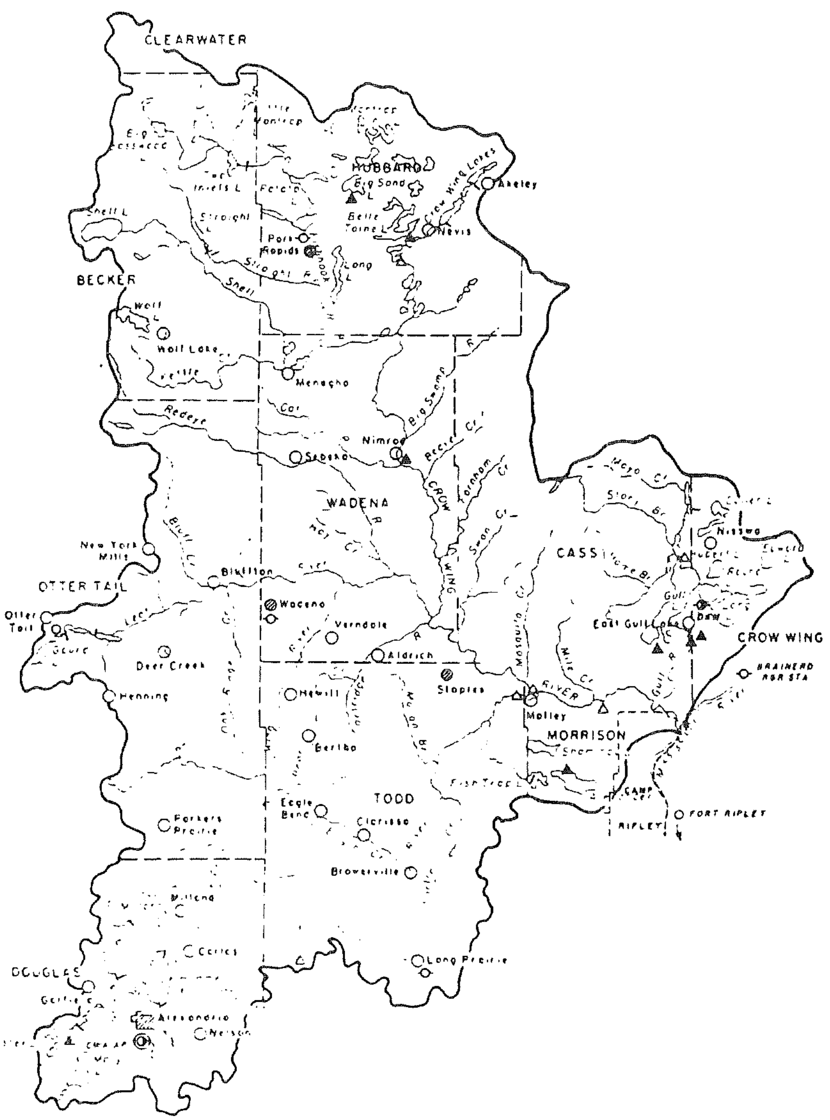

Figure 1 - Crow Wing River Watershed

Physical Characteristics

Landforms

The Crow Wing River Watershed is covered by glacial moraines, till, and outwash, which create a slightly undulating to undulating topography with an average local relief of 50 feet. Elevations range from 1,650 feet above sea level in the northwestern morainal hills to 1,150 feet at the mouth of the Crow Wing River. Outwash plains, exposed in the northern half of the watershed, cover 47 percent of the watershed. End moraines and drumlins cover about forty-three percent of the watershed and are characterized by a rolling to steep, knob and kettle topography. The drumlins are oriented north to south or northeast to southwest parallel to the original direction of ice movement. Peat bogs and wet depressions lie between the drumlins and moraines. Till plains, exclusive of drumlins, make up nine percent of the watershed and are characterized by moderately undulating relief.

Geology

The general geologic profile of the watershed is glacial drift overlying bedrock. Recent alluvial deposits overlie the glacial drift along watercourses, lakes and depressions.

The glacial drift was deposited primarily during the Late Wisconsin glaciation. Deposits associated with the Wadena, Rainy, Superior and Des Moines lobes all are found. The watershed is bounded by Wadena moraine on the north, Rainy moraine on the east and Des Moines moraine on the west.

The till plains of the Wadena lobe, the oldest of the four, were covered by Rainy lobe and Superior lobe outwash in much of the northern part and in an east-west trending belt across the south-central portion. Wadena lobe till plains are present in the central and southern areas. Drumlins in the till plain have been partially or completely buried by subsequent outwash. Moraines of the Des Moines lobe were deposited over the outwash and the till plains along the west side.

The composition of the alluvial deposits depends on the characteristics of the water features in which the alluvium was deposited, i.e. fine grained material in slow moving or stagnant water, or sand and gravel in higher velocity watercourses.

The outwash is comprised of stratified sand and gravel and ranges from 0 to 135 feet thick. The outwash is underlain by undifferentiated glacial drift, predominantly till, which extends to the bedrock. The moraines are primarily unstratified sandy till with some sand and gravel ice-contact features. The drift thickness in the moraine areas is commonly 200-400 feet, increasing to 600 feet locally. The till plain is also sandy till with varying amounts of outwash sand and gravel layers and with thickness ranging from 0 to 400 feet, usually 150-200 feet.

The bedrock is buried deeply across most of the watershed. The glacial deposits are thinnest near the western edge where bedrock lies about 200 feet below the surface. The bedrock consists mostly of Precambrian slate, graywacke, granite, gneiss, and schist. Scattered Cretaceous rocks (limestone, sandstone, shale) overlie the Precambrian rock only in the northern half of the watershed.

Soils

The outwash area is characterized by loam to loamy sand soils. Soils in the drumlin and moraine areas consist of limey sandy loams with many surface and subsurface cobbles. The till plain soils are similar to those in moraine and drumlin areas; however, they may contain more silt and clay. Organic soils are found in the peat bogs and depressions and around the lakes and watercourses.

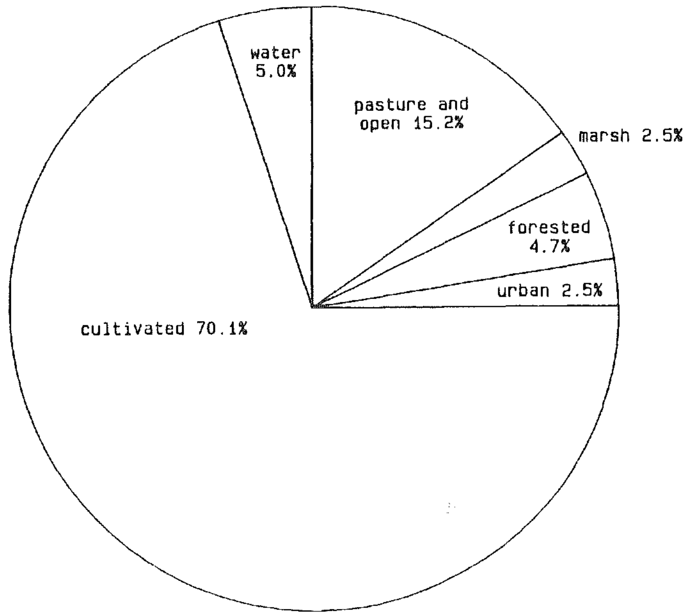

Figure 2 - Crow Wing River Watershed Land Use

Land Use

The majority of the watershed area is under agricultural cultivation. Forests, lakes and open lands also are prevalent (Figure 2).

Habitat

The watershed is comprised of a mixture of pine and hardwood forests, croplands, grasslands, bogs and swamps. The diversity of landscape offers suitable habitats for a variety of wildlife. Fisheries resources are somewhat limited due to the physical characteristics of the watershed. There are numerous natural lakes; however, many are too shallow to be of value as fishery resources. The rivers that dissect the watershed are classified for the most part as warmwater streams, but several ground water-fed, coldwater streams support trout populations.

Climate

Data from the Park Rapids, Wadena, and Alexandria weather stations indicate a mean annual precipitation of 25 inches including a mean annual snowfall of 46 inches. Average precipitation across the watershed ranges from 24 inches in the southwest corner to 26 inches in the northeast (Figure 3). Water budget calculations estimate runoff at the mouth of the Crow Wing River to be about 3.9 inches and evapotranspiration for the watershed to be about 21 inches (Lindholm et al, 1972). Cultivated crops benefit greatly from irrigation due to the high evapotranspiration from the sandy soils. Major recharge to the surficial aquifer comes from precipitation and averages 5.1 inches per year. The annual growing season varies from 143 days in Aitkin and Itasca Counties to 148 days in Crow Wing County. Temperatures in Wadena, Wadena County, have varied from a maximum of 112 degrees Farenheit in July, 1936 to -43 degrees in February, 1933.

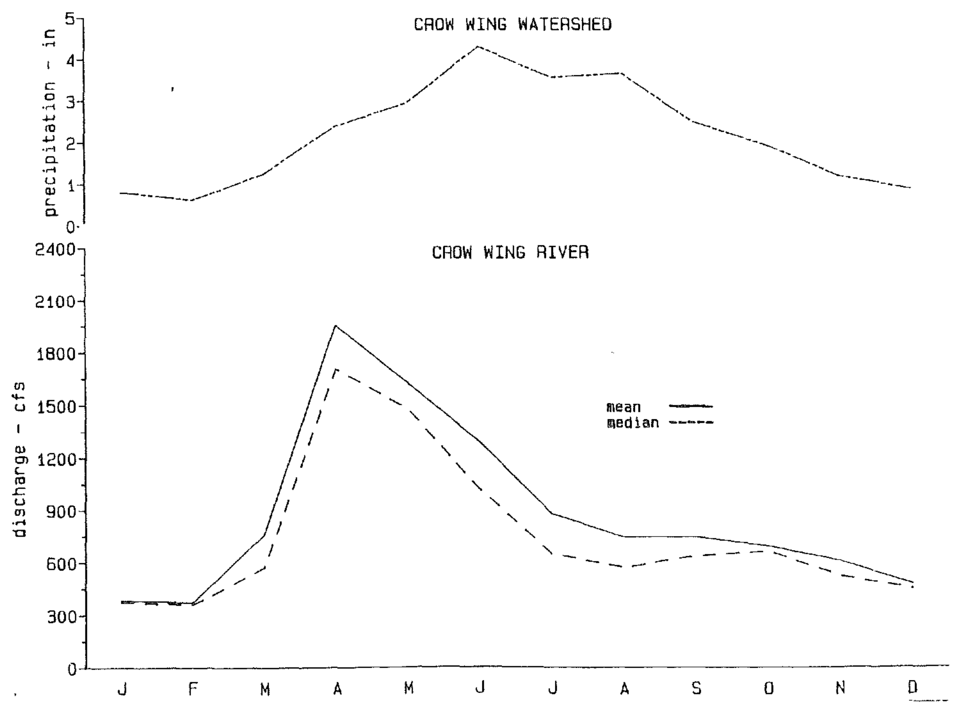

Figure 3- Mean Monthly Precipitation Data From Park Rapids, Wadena, and Alexandria Weather Stations and Median Monthly Flows for the Pillager Gage on the Crow Wing River

Water Resources

Surface Water

Quantity

The northern and southern halves of the Crow Wing River Watershed differ in their surface water characteristics. The northern half is underlain by porous glacial outwash and contains an abundance of small lakes, wetlands and forests. These features tend to help maintain a more constant streamflow throughout the year by retarding accelerated flows and limiting low flows. In contrast, clayey glacial till predominates in the southern half. The low permeability of the till and a well integrated drainage pattern make the region more susceptible to frequent summer flooding.

The Crow Wing River drains the largest area of any river in the watershed. The river rises in the Crow Wing Lakes of southern Hubbard County and flows 87 miles to its confluence with the Mississippi River in Morrison County. The width of the river ranges from 175 feet to 500 feet. Its major tributaries are the Shell, Leaf, Partridge, Long Prairie, and Gull Rivers.

About five percent of the watershed area is covered by natural lakes that lie near the watershed's perimeter. Many of these lakes are the headwaters or sources for streams and rivers and tend to regulate high and medium stream flows.

Geologic and hydrologic characteristics are reflected in the flow duration curves (Figure 4) and the gaging station data (Table 1). The relatively flat slope at the lower part of these curves indicates perennial storage in the lakes and glacial deposits. The steepness of the curve for the Long Prairie River indicates that the base flow (ground water inflow) component is smaller than that of the Crow Wing River.

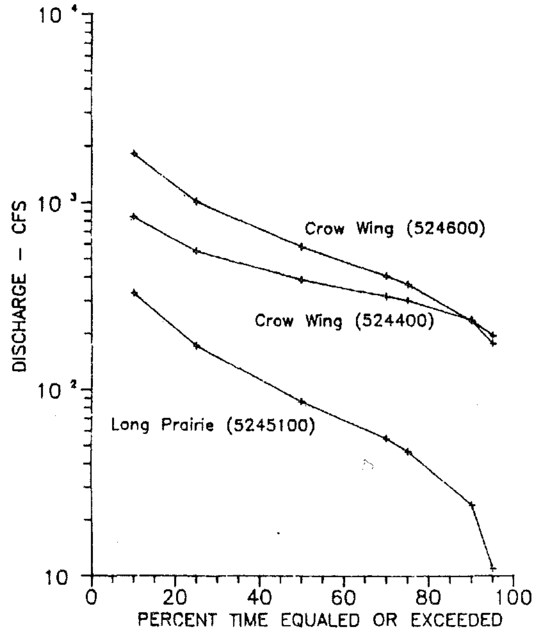

Figure 4 - Duration Curve for Selected Gages.

Table 1 - Continuous Gaging Stations

Gage Number	River	Location	Period of Record (yrs)	Area (mi2)	Mean Flow (cfs)	Max Flow (cfs)	Min Flow (cfs)	7-Day Low Flow 2-yr (cfs)	7-Day Low Flow 10-yr (cfs)
524400	Crow Wing	Nimrod	55	1010	471	3700	45	249	159
5245100	Long	Long	15	432	144	3270	0.84	-	-

Quality

Surface water in the watershed is the calcium bicarbonate type and is moderately hard and nutrient rich. When base-flow conditions exist, water quality is fairly uniform throughout the watershed. The majority of the watershed lakes are eutrophic and lakes with signs of advance eutrophication are found in the southwest corner. Several lakes in the intermediate stages of eutrophication exist in the northeast portion.

The Alexandria Lake Area Sanitary District, authorized by the Minnesota Pollution Control Agency (MPCA) to discharge 2.55 million gallons per day to Winona Lake, is the only major discharger within the watershed. There are many minor dischargers including municipal sewage treatment plants, water treatment plants, and industrial processing sites. Permitted dischargers must meet effluent water quality standards as outlined by the MPCA.

Groundwater

Quantity

Accessible ground water is primarily limited to glacial drift aquifers. Ground water in the glacial drift is available from surficial outwash and from buried sand and gravel aquifers within the till. Surficial outwash deposits generally are capable of yielding large quantities of water to wells. Water yields in the moraine and till plain areas vary widely. Most wells in the moraine and till areas are completed in buried sand and gravel deposits which yield large quantities of water. The till itself has low permeability due to high clay content and yields little water. The water table in the surficial outwash areas is usually less than 10 feet below the surface. The saturated thickness of the outwash ranges from 0 to 130 feet. The thickest surficial outwash aquifer is found in the northern part of the Pinelands Sand Plain area of Hubbard, Becker and Wadena Counties. Well yields of 500 gpm are obtainable with yields exceeding 2,000 gpm in some northern sections.

Precambrian igneous and metamorphic bedrock is generally a poor aquifer. The small amount of available water is limited to fractures and weathered zones in the rock. The only known bedrock production wells are those in Cretaceous limestone.

Quality

Ground water quality is suitable for most purposes. Total hardness ranges from 60 mg/l $CaCO_3$ in the southwest to 180 mg/l $CaCO_3$ in the central part. Water from the surficial outwash generally is suitable for irrigation; however, continued irrigation over an extended period may lead to a saline problem. Aquifers found at or near the surface are especially susceptible to contamination. Locally, surficial outwash aquifers are vulnerable to high nitrate concentrations. The water in the buried sand and gravel aquifer usually is mineralized more highly than water in the surficial outwash due to slower water movement through finer grained, glacial drift materials. Several areas with ground water pollution have been identified near solid waste disposal facilities.

Water Use

Water Withdrawal

Major water use within the watershed is for irrigation and public supply (Figure 5). The largest consumptive use of water is the irrigation of agricultural crops. Nearly 35,000 acres are irrigated using ground water, and another 6,000 acres are irrigated with surface water. Sandy soils and ample water supplies make the region highly suitable for the cultivation of potatoes, as well as field corn, soybeans, and alfalfa.

Municipalities, the second largest water users in the watershed, use ground water exclusively for their water supply systems. Alexandria, Wadena, Park Rapids, Staples, Long Prairie and Nisswa are the only cities with populations greater than 1,000. These cities account for the majority of publicly-supplied water. There are numerous small cities within the watershed. The major industrial water users are three dairy processing plants, one potato processing plant, and several sand and gravel washing operations. Other water users include mobile home parks, resorts, and rural domestic water supply. Additional ground water is used on the White Earth Indian Reservation, part of which is located in the northern portion of the watershed.

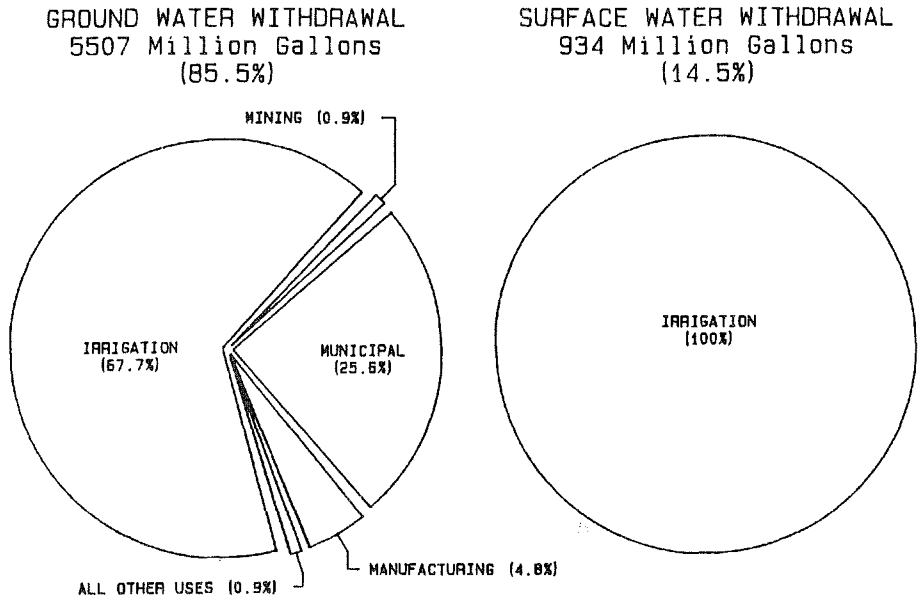

Figure 5 - Crow Wing River Watershed Water Use

The Minnesota Power Company operates two hydroelectric facilities on the Crow Wing River: Sylvan Dam in Cass County, and Pillager Dam in Morrison County. These facilities are operated as a run-of-the-river operation where no storage or water quality change occurs. Their combined output is 3.3 megawatts (MW).

Recreation

The abundant resources and natural character of the watershed offer fine recreational opportunities (Table 2). Canoeing, fishing and hunting are the major recreational uses. Other activities which are often associated with these uses include camping, hiking and wading. Wild rice harvesting, swimming and tubing are also locally popular.

By far the most notable recreational features are the Crow Wing and the Straight Rivers. The Crow Wing constitutes one of the major systems in Minnesota managed primarily for recreation. The stable water levels, clarity and scenic beauty of the Crow Wing make it an excellent canoeing stream. The Straight River is well known for its trophy brown trout fishery and receives heavy angling pressure in the early spring and during the insect hatches that occur in late June and early July. The Straight River is one of the twenty-five designated trout streams in the watershed.

Table 2 - Recreational Resources of the Crow Wing River Watershed

Resource	No.	Acres*	Features	
State Parks	1	1,250	Lake Carlos State Park	
County Parks	7	463		
Wildlife Management Areas	44	21,040	State Forests	Acres
			Badoura	3,320
Waterfowl Production Areas	-	2,08	Foothills	7,120
			Huntersville	15,440
Federal Lands	1	200	Lyons	5,920
(excluding WPA's)			Paul Bunyan	20,240
			Pillsbury	8,000
			Smoky Hills	14,560
State Forests	9	91,800	Two Inlets	14,560
Lakes	650	135,214	White Earth	2,640
Wetlands	671	22.943		
		Miles	Chippewa National Forest	
Designated Trout Streams	--	25		
Wild and Scenic Rivers	--	--	Crow Wing River Canoe Route	
Canoe and Boating Routes	1	110		

*Acreages for state forests, wildlife areas, and all federal lands are approximated from 40-acre parcels.

Other rivers within the watershed also offer fine angling opportunities. Overall, biologists rate the rivers in the watershed as having a moderate ability to support a community of sport fish. The northern pike is the principal sport fish species, but walleye, rockbass, and trout also contribute to the fishery. Fisheries trend data indicate that, while conditions have improved within the last ten years, the resource potential is not being realized due to limiting factors. These factors include naturally occurring low flows, flow fluctuations caused by diversions and dam operations, and erosion and nutrient loading problems resulting from land use practices. Many of the numerous natural lakes are too shallow to be of value as a fishery resource.

Wildlife species characteristic of a mixed farm and forest areas in the coniferous forest zone are present. Hunting and trapping are popular recreational uses. Important game species include white-tailed deer, ruffed grouse, woodcock, various waterfowl, rabbits, and squirrels. Important furbearers include beaver, raccoon, muskrat, mink and red fox; hunting and trapping for these animals is an economic asset to the area. The forested river corridors provide valuable nesting cover and feeding areas for waterfowl, and serve as wintering habitat for deer and upland animals. The Natural Heritage Program has catalogued plant and animal species in need of special consideration, those of special interest, and priority species. Of these species, eight have been documented to occur within the watershed (Table 3).

Table 3 - Species of Special Interest

Species	Code #	Status*	Occurrences
Blanding's turtle	CD.641	THR	4
Eastern hognose snake	CQ.G54	SPC	2
Bald eagle	DF.416	THR	13
Osprey	DF.435	SPC	11
Greater prairie chicken	DH.659	SPC	1
Prairie vole	FL.489	SPC	2
Ginseng	L2.480	SPC	1
Cooper's milk vetch	LD.865	SPC	2

*THR - threatened SPC - special concern END- endangered

Water Availability

Water availability problems have been experienced in the Crow Wing River Watershed in both surface water and ground water. Some cities experienced water supply problems during the 1976-1977 drought. All of them drilled new wells in order to provide a more reliable water source. Protected flows have been set on Bluff Creek, the Crow Wing River, Little Moran Creek, and the Straight River. Site specific studies have not been completed on these waterways. The protected flows are often set at the 90 percent exceedance level which may not be the best level to provide adequate aquatic habitat. The Sylvan and Pillager hydropower dams are located on the Crow Wing River in Cass County and Morrison County respectively. Malfunctions of the dams' operations occasionally have caused severe fluctuations in normal flows, thereby reducing the ability of the affected waters to reach their aquatic habitat potential. Many of the lakes are not very deep and have little water level stability during dry periods.

The change in land use from dry land farming to intensive crop irrigation is the most obvious recent change in water use. In 1974 only five farmers were irrigating; today, there are sixty-six irrigators in addition to the four municipal wells for the City of Park Rapids.

Regional hydrogeologic studies involving modeling of future pumping indicate that the water resources of the Pineland Sands Plain and other surficial outwash aquifers will support increased development (Helgeson, 1977). However, heavy pumping in some areas could lower the water table and some lake levels. A potential decrease in streamflows and lake levels also may exist because of the current increase in ground water appropriations for irrigation. The heaviest irrigation takes place within two miles of either side of the Straight River. Ground water provides the base flow to this river helping to ensure the cooler temperatures which are necessary for trout survival. Resource specialists believe that increased appropriations have decreased the base flow contribution to the Straight River, a trout stream. The decreased base flow has caused a decrease in water levels, an increase in temperatures, an increase in the potential for higher nitrate concentrations and pesticide contamination, and a reduced oxygen-carrying capacity. A study, in progress, will collect data, develop a model, and quantify the ground water withdrawal effects on the quality and quantity of the flow of the river. When the results of the modeling studies are available, it will be possible to develop innovative water use management in order to balance ground water use and the need to maintain the Straight River as a recreational resource.

Surface Water Budget

The results of the water budget equation, using the United State Geological Survey (USGS) and Minnesota Department of Natural Resources (MDNR) estimations discussed below, indicate there is small surplus of water during normal/wet years and a small deficit during dry years in the Crow Wing Watershed. The error in these figures is exaggerated due to estimations and extrapolations within and between the variables. A dry year is defined as the one-in-four drought event or those flows exceeded 75% of the time. A normal year is defined as the median flow or those flows exceeded 50% of the time. A wet year is defined as flows exceeded 25% of the time or the one-in-four year flood event. The area is defined as having a positive water balance (+) if the water balance is greater than or equal to 1.10, a neutral water balance (0) if the ratio is between 0.95 and 1.10 and negative balance (-) if the ratio is less than or equal to 0.95. These numbers may contain significant error, but can act as indicators for the surface water balance equation (Table 4).

Table 4 - Surface Water Budget

Year	Available (A) Acre Feet	Needs (N) Acre Feet	Use (U) Acre Feet	Balance A/N+U
Normal/ Wet	1,004,000	943,000	tr*	0
Dry	602,000	602,000	tr*	0

*tr - estimate less than 10,000 acre feet

The USGS has approximated the total surface water available within the watershed from historical records of precipitation and runoff, and from estimates of evapotranspiration. Runoff is difficult to model and this increases the error in the data.

The MDNR has approximated the total surface water necessary to maintain instream uses based on existing and potential opportunities, and recreational activities. This volume is a general assessment of the total flow needed at the mouth of the watershed to support aquatic life and recreation. The instream flow data was based on these two measurements made on the Crow Wing and Straight Rivers. These two rivers were modeled to determine the amount of water needed for instream use. This information was extrapolated to the mouth of the watershed, which also increases the chance of error.

The MDNR also has estimated water use from annual pumping reports sent in by water users. Table 4 shows the total annual surface water appropriations according to the 1985 water use data. Water use data is based on measurements made by appropriators which may contain error. In addition, nonpermitted appropriators use an unknown amount of water which is not included in these estimates.

Given the inherent error in the USGS water availability estimates and the MDNR's instream flow and water use approximations, these numbers cannot be used to draw detailed conclusions. Rather, they should be used only as an indication that there is limited surface water available for future developmental needs.

Conclusion

In the past, surface water resources within the watershed have met society's needs; however, many problems have affected water quality and quantity. Often, the 90 percent exceedance level is not a sufficient protected flow to maintain the recreational resources. Site specific instream studies should be done in order to develop a reasonable protected flow regime for dam operators and water appropriators to follow.

Ground water is the major source of water appropriated in the watershed. Some cities experienced water shortages during the 1976-1977 drought. Emergency water supply plans would be beneficial for managing water use in future droughts. Attention must be given to protecting the ground water from further contamination, preventing withdrawals in excess of recharge, and controlling withdrawal where surface water resources may be adversely affected by lowered ground water levels.

Because of continued use and alteration of the resource, proper planning is necessary to protect the water supply, fisheries, wildlife, and recreation opportunities.

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RAINY LAKE WATERSHED

Introduction

The Rainy Lake Watershed encompasses 4,489 square miles of the northeastern corner of Minnesota. The watershed includes parts of Koochiching, St. Louis, Lake and Cook Counties. The watershed borders on Canada and drains toward Hudson Bay. Several state parks and the nation's only wilderness canoe area, the Boundary Waters Canoe Area (B.W.C.A.), are within the watershed. The terrain and geology are quite variable with many irregularly shaped lakes and short broken streams. Bedrock is at or near the surface throughout. The majority of the watershed consists of forests, bogs, lakes and streams. Surface water appropriations provide most of the supply for the major water users. The low buffering capacity of the surface waters makes them sensitive to changes in pH; the surface waters are considered at risk from the effects of acid precipitation. Ground water resources are limited because of the extensive bedrock formations and thin, irregular deposits of glacial drift. The average annual temperature throughout the watershed is quite cool with high annual variation. The wilderness terrain and abundant, high quality water resources within the watershed provide unique recreational opportunities of state, national and international importance.

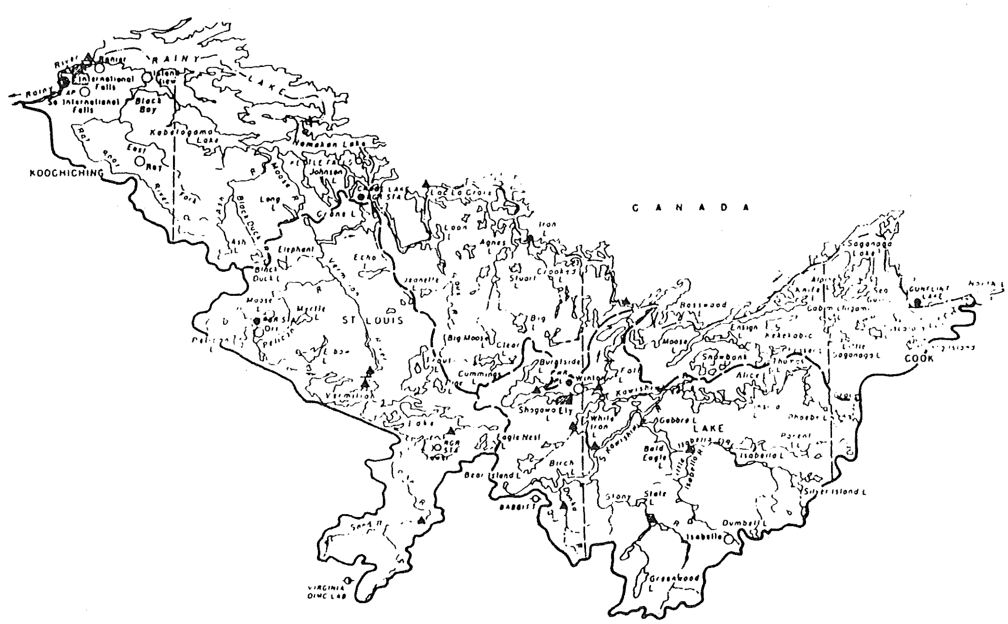

Figure 1 - Rainy Lake Watershed

Physical Characteristics

Landforms

The Rainy Lake Watershed is characterized by many irregularly shaped lakes and numerous short broken streams occupying depressions in forested, rocky terrane. In general, the slope is 12 to 15 feet per mile. The northern boundary is the chain of border lakes extending from Gunflint Lake on the east to Rainy Lake on the west. The Continental Divide, which follows morainic hills and bedrock ridges, is the southeastern boundary. The southwestern boundary is also moraines.

Altitudes range from more than 2000 feet in the hills along the southeastern boundary to about 1100 feet near Rainy Lake on the west

The majority of the watershed is dominated by rolling highlands with irregular slopes and craggy outcrops of bedrock. Numerous long, narrow peat bogs occur between the ridges. A lacustrine plain is located in the northwestern portion of the watershed. A few outwash plains are found, especially in the southern areas.

Geology

Bedrock outcrops are the primary geologic feature. The bedrock consists of a variety of Precambrian igneous and metamorphic rocks. The eastern third is the Upper Middle Precambrian Duluth Complex, North Shore Volcanic Group and the Animikie Group. The rest of the area is Lower Precambrian. The watershed lies entirely on the Canadian Shield, a broad plain of eroded ancient rock covering much of central Canada and some of the northern United States.

During glaciation, the glaciers scoured out the weathered, weakened rock along fractures and other linear features. Glacial drift then filled the depressions between bedrock ridges. The glacial drift is from the Rainy Lobe and is primarily brown, acidic, cobbly and gravelly glacial till. Intermixed with the till are lenses and layers of cobbly, gravelly sand. Some sandy outwash and ice contact areas are found in the southern portion. A Des Moines age lake formed on the western end of the watershed and deposited clayey and silty lake-washed till.

Land Use

The majority of the watershed is included in the Superior National Forest and contains most of the Boundary Waters Canoe Area Wilderness. Nearly all of the land previously logged is reforested and contains numerous lakes and rivers (Figure 2).

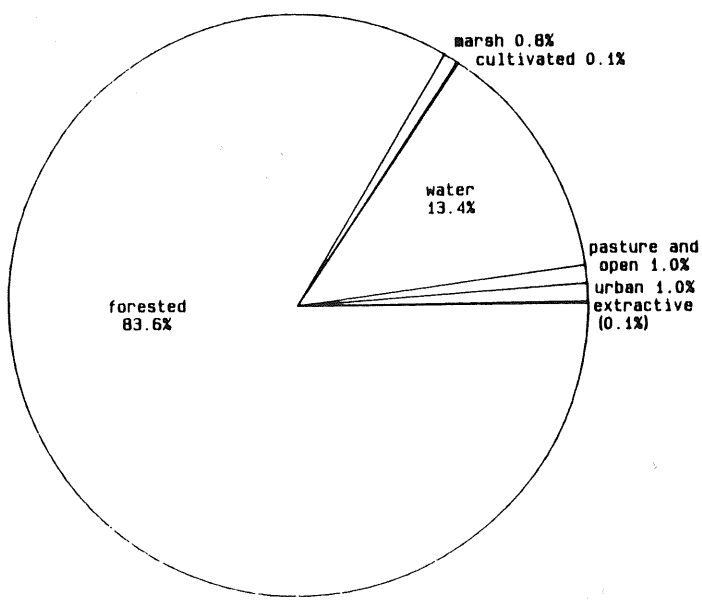

Figure 2 - Rainy Lake Watershed Land Use

Soils

Where bedrock is exposed or very near the surface, the soils are decomposed bedrock. The soil particle size depends on the degree of weathering. Soils in the till areas are coarse loamy sands and sandy loams. The outwash area soils are medium to strongly acidic, sandy and in some places quite gravelly. In the lacustrine plain, the soils are usually poorly drained and are quite variable within short distances. The sandy soils are often underlain by 50 to 150 feet of clayey or loamy sediments within 2 to 4 feet of the surface. Peat bogs are found throughout the watershed.

Habitat

The watershed is comprised of a mixture of dense forests, bogs, lakes and streams Most of the watershed consists of wilderness lands. The aquatic resources are abundant and relatively unaltered by mans' influences. The lakes and streams offer a variety of angling opportunities for both warmwater and coldwater species.

Climate

The mean annual precipitation determined from the International Falls and the Babbitt weather stations is 26.4 inches with a range of 25 to 28 inches. Snowfall varies from 55.0 to 62.7 inches with an average of 58.9 inches. The mean annual temperature is 37.6 degrees, however, annual temperatures can fluctuate greatly. At International Falls the maximum recorded high temperature is 98 degrees Farenheit and the minimum low is -46 degees. Runoff is estimated to be 9.8 inches from gaging stations on the Vermilion and Basswood Rivers. Annual runoff variations tend to be more subdued than those for precipitation, probably due to the natural regulating effect of the many lakes. According to the average annual water budget from 1931 to 1980, approximately 65 percent of all water lost is due to evapotranspiration. This assumes that underflow is zero since the ground water system is recharged and discharged within the watershed.

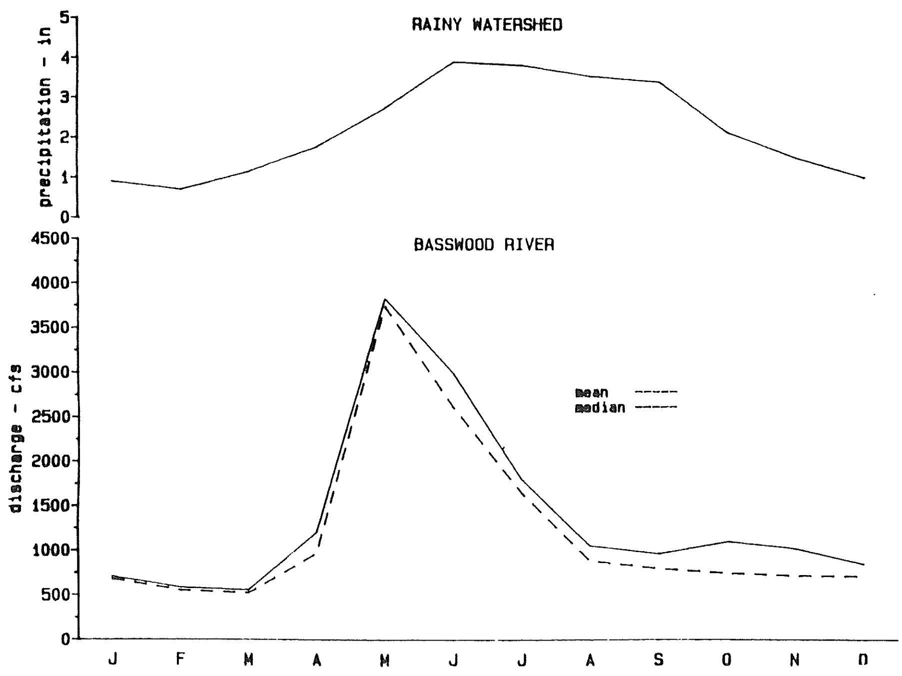

Figure 3 - Mean Monthly Precipitation Data from the International Falls and Babbitt Weather Stations and Medium Flows for the Basswood River Gage (512750) near Winton.

Water Resources

Surface Water

Quantity

The Rainy River Watershed has excellent surface water resources. The density of lakes is high; exceptions occur in the extreme southern and western parts, where the Pike and Rat Root River basins contain few or no lakes. A large percentage of the lakes are interconnected by river channels that form the surface water drainage network. The drainage pattern is partly rectangular, as evidenced by many nearly right-angle bends in streams which follow structural weakness (joint and faults) in the bedrock. Drainage is northward to the border chain of lakes and then westward into Rainy Lake. Similarly, many lakes are controlled by the bedrock. In the northeast, lakes run east to west in the weak zones parallel to the banding of the rock.

Geologic and hydrologic characteristics of the watershed are reflected in the flow duration curves (Figure 4) and the gaging station data (Table 1). The moderate slopes of the duration curves indicate most streams in the basin are not flashy.

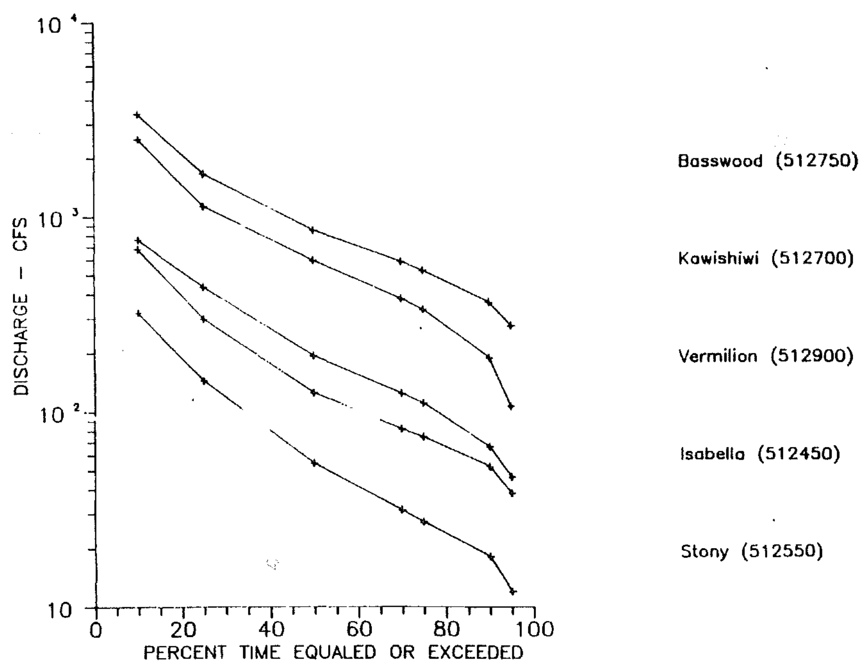

Figure 4 - Duration Curves for Selected Gages

Table 1 - Continuous Gaging Stations

Gage Number	River	Location	Period of Record (yrs)	Area (mi2)	Mean Flow (cfs)	Max Flow (cfs)	Min7-Day Low Flow Flow (cfs)	10-yr. (cfs)	2-yr. (cfs)
512448	Kawishiwi	Ely	18	253	219	1720	4.5	47.6	31.3
512450	Isabella	Isabella	12	341	272	3900	24	54.4	39.6
512550	Stony	Isabella	13	180	127	2040	5.6	14.7	7.65
512550	Stony	Babbitt	7	219	173	2490	6.7	--	--
512700	Kawishiwi	Winton	71	1229	1033	16000	0	200	43.4
512750	Basswood	Winton	53	1740	1402	15600	55	396	214
512900	Vermilion	Tower	62	483	319	2710	0	76.7	19.4

Quality

The wilderness waters are generally of excellent quality, but are quite sensitive to pollution. The low alkalinity and hardness of the water reduce the buffering capacity of the chemical system and make the water very susceptible to changes in pH. The water also tends to be low in conductance and nutrients and have a slightly acidic pH. The unusual softness of the water also increases the susceptibility of aquatic organisms to deleterious substances (the impacts of harmful substances are generally greater in soft water than in hard water).

More than 60 percent of the state's lakes larger than ten acres are in the Boundary Waters Canoe Area (BWCA). The BWCA's primitive character is maintained in accordance with the Wilderness Act of September 3, 1964. Most water quality data is from the Superior National Forest. Data indicate low concentrations of most chemical and bacterial constituents; however, much of the watershed is susceptible to contamination. Bedrock outcrops and thin soil immediately over the bedrock permit direct or nearly direct introduction of contaminants into ground or surface water.

Major dischargers to surface water are limited to treated municipal waste-water facilities and the Boise Cascade Corporation's International Falls Paper Plant. Major municipal discharges include: 2.3 million gallons per day to the Rainy River by the North Koochiching Sanitary Sewer District and 1.5 million gallons per day to Shagawa Lake by the City of Ely. The Boise Cascade Corporation is authorized to discharge 28.0 million gallons per day of treated industrial processing water to the Rainy River. Although overloading of degrading effluents to the Rainy River has occurred in the past, the Minnesota Pollution Control Agency (MPCA) (1985) reports that all major dischargers currently meet established effluent discharge standards.

Ground Water

Quantity

The crystalline bedrock is relatively unproductive, even for a minimum domestic supply of 5 gallons per minute. Wells in bedrock are commonly several hundred feet deep; but, little or no water is found at depths exceeding 300 to 500 feet. Yields are limited by the extent of interconnected fractures.

Glacial drift is the most favorable source of ground water; however, because the drift is irregular and thin, its reliability is limited as a source of water. Well yields in glacial drift vary from 2 to 250 gallons per minute.

Quality

Much of the watershed is undeveloped; therefore, very few wells are available from which to draw conclusions on water quality. Most of the ground water is the calcium bycarbonate type, is commonly hard, and in the northwestern part often contains amounts of iron and manganese in excess of the recommended limit for domestic consumption. Water from the bedrock may be more mineralized than water in the drift, but the bedrock water appears to have less iron and manganese. Dissolved solids in water from drift generally increase with depth. No relation between depth and amount of dissolved solids is apparent for bedrock water. The chemical characteristics of water from bedrock are likely to be derived largely from the overlying drift. Data is insufficient to make a correlation between bedrock type and water quality.

Water Use

Water Withdrawal

The majority of water used within the Rainy Lake Watershed is appropriated for industrial processing and mining operations (Figure 5). The Boise Cascade Corporation in International Falls appropriated nearly 15.0 billion gallons (45,000 acre feet) of water in 1985 for paper production, accounting for the largest surface water withdrawal in the watershed. The predominate water use for mining operations is in mine dewatering. Combined, mine processing and mine dewatering use was 3.7 billion gallons (11,100 acre feet) in 1985; of this, 3.6 million gallons (108,000 acre feet) of water is attributed to dewatering.

International Falls, South International Falls and Ely are the largest cities in the watershed, each with populations exceeding 3,000. These cities account for the majority of publicly supplied water use. The Cities of International Falls and South International Falls currently receive water from the Boise Cascade Corporation. However, the City of International Falls is undertaking plans to provide for its own municipal water supply source. The proposed city system will also provide municipal water for the City of South International Falls.

Two hydroelectric facilities exist in the watershed. The Boise Cascade Corporation in International Falls operates the Rainy Lake Dam on the Rainy River, producing 10.1 megawatt (MW), and the Minnesota Power Company operates the Winton Dam on the Kawishiwi River in Lake County, producing 4.0 MW. Both dams are run as "peaking" operations, where water is stored and released to provide power generation to meet peak electrical demands.

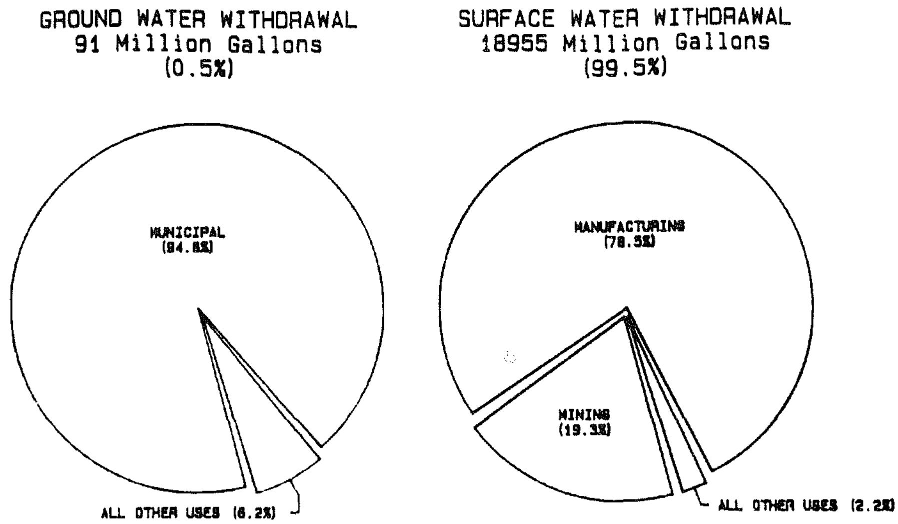

Figure 5 - Rainy Lake Watershed Water Use

Recreation

The watershed includes some of the most significant natural resources in the state. The numerous lakes and picturesque topography make it an area with unique recreational values of national importance. The recreational features include the B.W.C.A., Voyageurs National Park, Superior National Forest, all or portions of eight state forests and two state parks (Table 2). Nearly two million acres of land (about 57% of the watershed) are under public domain and provide substantial recreation opportunities. The numerous lakes are well known for their wilderness appeal and clear sparkling waters. Only a few rivers of significance are in this region. Most of the streams are small and act as connecting routes between the numerous lakes. Important recreational activities include boating, canoeing, fishing, camping, hiking, hunting, swimming and photography. Popular winter activities include skiing, snowshoeing, hunting, snowmobiling and winter camping.

The abundant water resources offer high quality fishing opportunities for a variety of species. The lakes are characteristically deep, rocky and clear. The larger lakes are Rainy, Vermilion, Kabetogama, Lac La Croix, Basswood, Namakan and Pelican Lakes. The principle sport fish species include walleye, northern pike and smallmouth bass. The Minnesota border lakes consititute the only substantial group of lake trout waters in the contiguous 48 states. Important stream resources include the Basswood, Isabella, Kawishiwi, Rat Root, Pelican, Stony and Vermilion Rivers. The principle game fish species are the same as those found in the lakes. There are 39 designated trout streams which provide coldwater angling opportunities.

Table 2 - Recreational Resources of the Rainy Lake Watershed

Resource	No.	Acres*	Features	
State Parks	2	5,675		acres
County Parks	--	--	State Forests	
			Bear Island	21,440
Wildlife Management Areas	1	--	Burntside	26,520
			Finland	26,760
Waterfowl Production Areas		--	Insula Lake	640
			Kabetogama	119,080
Federal Lands	3	1,630,640	Lake Isabella	160
(excluding W.P.A.s)			Lake Jeanette	1,520
State Forests	8	196,720	Sturgeon River	600
Lakes	1,590	629,415	Rainy Lake (reservoir)**	54,140
			Vermilion Lake	49,110
Wetlands	43	848	Kabetogama Lake (reservoir)	25,760
			Lac La Croix Lake**	19,820
		Miles	Basswood Lake**	14,610
Designated Trout Streams	39	--	Namakan Lake (reservoir)**	14,050
			Pelican Lake	11,944
Wild and Scenic Rivers	--	--		
			Boundary Waters Canoe Area	795,000
Canoe and Boating Routes	--	--	Superior National Forest	668,040
			Voyageurs National Park	167,600

*Acreages for state forests, wildlife areas and all federal lands are approximated from 40-acre parcels.

**Figures reflect surface area of lakes lying within state boundaries.

Vegetation is largely boreal forest with the prominent species consisting of jack pine, white and black spruce and balsam fir. A significant portion of the area is second growth aspen and birch. The watershed provides valuable habitat of a variety of wildlife species, many of which are either uncommon or non-existent in the remainder of the state. These species include bald eagle, osprey, timber wolf, moose, black bear, fisher, lynx and pine marten. Hunting and trapping are popular recreational activities. Important game and furbearing species include white-tailed deer, moose, black bear, waterfowl, ruffed and spruce grouse, snowshoe hare, otter, beaver, mink and muskrat. The lakes and streams provide valuable habitat for waterfowl, with diving duck species being especially abundant. Wild rice paddies provide important feeding areas for a number of species of waterfowl. The Natural Heritage Program has catalogued certain plant and animal species in need of special consideration, those of special interest and priority species. Of these species, 25 have been documented to occur within the watershed (Table 3).

Table 3 - Species of Special Interest

Species	Code #	Status*	Occurrences
Bald eagle	DF.416	THR	42
Osprey	DF.435	SPC	73
Keens' myotis	FD.495	SPC	1
Clustered bur reed	GB.GUO	END	1
Vasey's pondweed	GC.H61	SPC	9
Marsh arrow grass	GE.H63	SPC	1
Twin bentgrass	GH.GN5	SPC	1
Sedge sp.	GJ.123	SPC	2
Sooty beak rush	GJ.BB8	SPC	2
Sedge sp.	GJ.CK8	THR	13
Twig rush	GJ.E41	SPC	1
Spike rush sp.	GJ.J60	SPC	1
Bog rush	GS.BC8	SPC	2
Dragon's mouth	GY.051	SPC	4
Small white waterlily	HF.CM3	THR	1
Floating marsh marigold	HH.GS5	THR	2
Lapland buttercup	HH.GS8	SPC	1
Large leaved sandwort	JN.Y43	THR	2
Carolina spring beauty	JP.808	SPC	1
New england violet	KH.JX4	SPC	6
Awlwort	KP.BD6	END	3
Pygyweed	LA.Y47	END	3
Baked apple berry	LC.GT2	THR	1
Northern Comandra	LN.N61	SPC	2
Littorella americana	NM.CN1	END	19

*THR - threatened SPC - special concern END - endangered

Water Availability

Maintenance of the resources in this watershed will help to prevent conflicts or problems and allow the water resource availability to reach its potential. The water is naturally soft and susceptible to large pH changes, such as acid precipitation. Acid rain has already caused problems in some lakes. This area does not have natural buffering resources such as lime to neutralize the acid. Dams which run peaking operations have the potential to cause low flows. Hydropower peaking dams are located on the Kawishiwi River in Lake County and on the Rainy River in Koochiching County. Conflicts over water levels behind dams and fish advisories from pollution have caused problems on the Rainy River.

Surface Water Budget

The water budget equation, when solved using United States Geological Survey (USGS) and Minnesota Department of Natural Resources (MDNR) estimations, indicates that water availability does meet water needs (Table 4). However, the deficit is small and it was assumed that the water budget balances. A dry year is defined as the one-in-four drought event or those flows exceeded

75% of the time. A normal year is defined as the median flow or those flows exceeded 50% of the time. A wet year is defined as flows exceeded 25% of the time or the one-in-four year flood event. The area is defined as having a positive water balance (+) if the water balance is greater hatn or equal to 1.10, a neutral water balance (0) if the ratio is between 0.95 and 1.10 and a negative balance (-) if the ratio is less than or equal to 0.95. These numbers may contain significant error, but can act as indicators for the surface water balance equation of the watershed.

Table 4 - Surface Water Budget

Year	Available (A) acre feet	Needs (N) acre feet	Use (U) acre feet	Balance A/N+U
normal/ wet	2,370,000	2,370,000	58,000	0
dry	1,915,000	1,867,000	58,000	0

The USGS has approximated the total surface water available within the watershed from historical records of precipitation and runoff and from estimates of evapotranspiration. Runoff is difficult to model which increases the chance for error in the data.

The MDNR has approximated the total surface water necessary to maintain instream uses within the watershed based on existing and potential resources and recreational activities. This volume is a general assessment of the total flow needed at the mouth of the watershed which is sufficient to support aquatic life and recreation. These numbers were extrapolated from a single measurement made on the Stony River. They should not be applied to specific streams. Rather they act only as indicators for the watershed.

The MDNR also has estimated water use from annual pumping reports sent in from water users. Table 4 shows the total annual appropriations for the watershed according to the 1985 water use data. Water use data is based on measurements made by appropriators which may contain error. In addition, nonpermitted appropriators use an unrecorded amount which is not included in these estimates.

Given the inherent error in the USGS water availability estimates and the MDNR's instream flow and water use approximations, these numbers can not be used to draw detailed conclusions. They should only be used as an indication that water shortage problems can exist.

Conclusion

The Rainy Lake Watershed is protected by legislation to maintain its primitive quality. The environment is very sensitive. Improper use of the resource due to mining, acid deposition from precipitation and unnatural water level fluctuations will be detrimental to the water quality and quantity. In order to protect this wilderness the long range affects from any potential alterations to the resource must be considered.

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