STATEWIDE INSTREAM FLOW ASSESSMENT

TECHNICAL REPORT

1985 - 1987

Report to the

Legislative Commission

on

Minnesota Resources

Department of Natural Resources

Division of Waters

January, 1988

PREFACE

Minnesota's rivers and streams are important to its culture and life. They were the thoroughfares of Indians, early explorers and settlers and determined the present locations of most of our modern cities and towns. They still serve as major navigation routes and provide water supply for cities, industries, cooling, agriculture and power production.

The richness of our liquid assets goes beyond their economic utility; they are the foundation upon which our environmental well being is based. The taking of water from rivers and streams has to be balanced with the need to keep water within the rivers and streams for instream flow purposes. Instream flow needs include water-based recreation, fish and wildlife habitat, water quality, navigation and aesthetics. While the benefits of these purposes may not always be tangible, in an economic sense, they are, nonetheless, an essential element of our water-rich heritage.

Recent federal court decisions have presented a new imperative for improving our capability to define the water needed to satisfy instream flow requirements. This report summarizes work done under the Water Allocation and Management Study to develop statewide instream flow assessment criteria and develops a strategy for implementing the assessment.

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ACKNOWLEDGEMENTS

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CHAPTER 1. INTRODUCTION

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 flows or elevations. Protected flows or instream flows refer to the volume of water required to protect instream uses and downstream higher priority offstream users.

The major objective of the instream flow component of the LCMR funded Water Allocation and Management Project is to analyze and quantify a conservative (high) approximate range of flows necessary to maintain instream uses throughout the state. The results of this analysis were used as inputs to a computer simulation economic model (IPASS) for the economic evaluation component of the LCMR project. In the economic model, the instream flow approximations act as constraints on the amount of water available for offstream use.

The phrase 'instream flow approximation' (IFA) is used in this report to indicate an estimated range of instream flows. The U.S. Fish and Wildlife Service defined instream flow approximations as "flow regimes consisting of quantitative expressions of ... estimates of monthly flows at the outflow points of a basin or group of basins ... sufficient to support the habitat of aquatic life forms and outdoor recreation ..." (Bayha, 1978, p. 4). The phrase reflects the 'softness' of the assessment in that the study results do not specify instream flows on individual streams and are not used to make final decisions on water allocation. Instead the IFAs identify the volume of flow necessary to maintain instream uses within a watershed. Instream flow approximations were developed for the state, five economic regions as identified by the Department of Trade and Economic Development defined in the final project report, and each of 39 watersheds as defined in Department of Natural Resources, Division of Waters Technical Bulletin No. 10, (DNR, 1959).

Identification of these volumes of flow aids water allocation planning. The analysis is not intended to reveal site specific problems but to provide an indication of potential conflicts between instream uses and existing and future offstream uses. Conflict is determined by comparing dry and normal hydrologic conditions of available surface water for streams, instream flow approximations, and present water use demands for each watershed.

This "Statewide Instream Flow Assessment" report provides a detailed discussion of the methodology used in developing the instream flow approximations. The manner of integrating the IFAs with the economic model and determining areas of concern is discussed in the project main report, "Volume 1: The Value of Water to Minnesota."

1.1 LEVEL OF STUDY

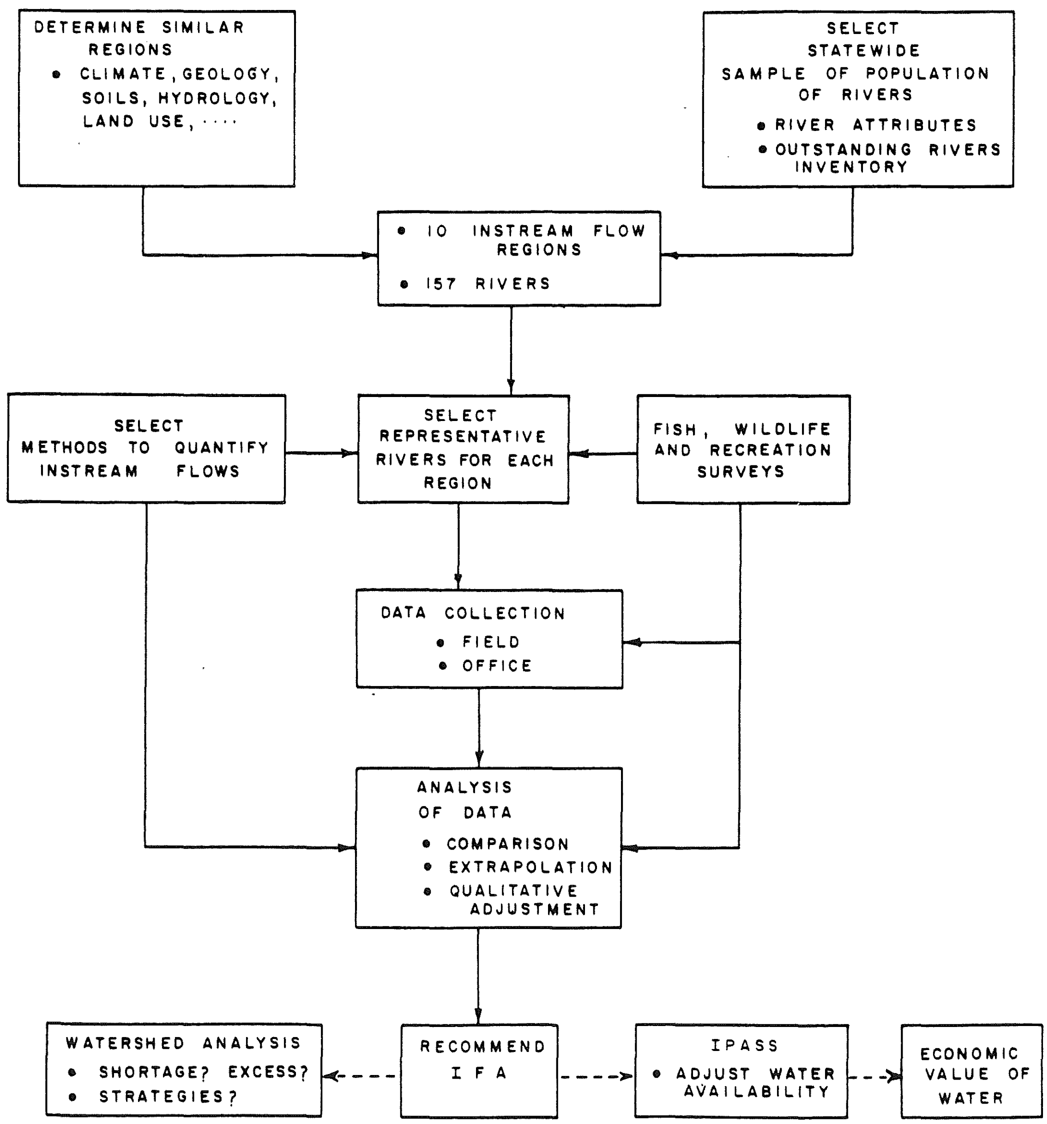
The level of study determines the extent of data collection and the methods to be applied in the instream flow analysis. The level of study for this report is analogous to a Level B planning process (Water Resources Council, 1973).

Level B planning represents an intermediate step between broad-scale Level A planning, such as Minnesota Water Planning Board's (1978) analysis of instream flow needs, and site-specific Level C studies. Planning objectives of Level B address economic development and environmental quality. During Level B planning, general and specific data are combined to develop policy and guidelines for forming alternatives and defining issues. Alternatives are evaluated and areas needing further site-specific study are identified.

Level B instream flow studies typically require a modest amount of field work, including some surveying and discharge measurements. Methods including hydraulic simulation techniques have often been applied (Bayha, 1980).

The instream flow approximations were developed through a multi-step process outlined below and in Figure 1. Each step is addressed in more detail in the technical report chapters.

Figure 1. Flow chart for instream flow approximation process.



1. Classify the state into similar regions based on criteria significant to instream flow management.
2. Select representative rivers within each region.
3. Select methods to quantify instream flows.
4. Select study sites on the representative rivers.
5. Collect office and field data.
6. Analyze data.
7. Determine instream flow approximations.

Figure 1 shows additional steps not addressed in this document. Separate reports on the economic value of water, watershed descriptions, water availability issues and analysis, and IPASS model discuss these components in further detail (refer to main report "Volume 1: The Value of Water to Minnesota").

1.2 ASSUMPTIONS AND CONSTRAINTS

During the course of this study, a number of simplifying assumptions were made. An overview of these assumptions and concurrent constraints follows.

Assumptions:

- Minnesota can be classified into instream flow regions based on physical, hydrologic and biologic data.

- It is possible to distinguish relatively homogeneous instream flow regions based on conditions characteristic to the region.

- Representative rivers can be selected within each region based on similar characteristics.

- Representative rivers are considered analogous systems and information obtained from measurements made on these representative rivers can be transferred to the other similar river systems in the region.

- Representative rivers should exhibit one or more instream flow uses in order to provide conservative instream flow approximations.

- Flowing river reaches include both unregulated and regulated reaches. Regulated rivers can be used as analogues if representative to the region.

- The hydraulic simulation model is based on Manning's equation and uniform flow, and works only in flowing water situations.

- Instream flow approximations for warmwater fisheries are a function of hydraulics, specifically depth at riffles, velocity, and wetted perimeter.

- The method used to integrate the hydrologic and hydraulic parameters to the biologic relates to only one level of biological relationships (riffle directed) and if this relationship is optimized then the other relationships will also be protected.

- Gamefish carrying capacity is proportional to food production, which is related to the wetted perimeter in riffles.

- Recreation is a function of velocity and depth of water.

- If fisheries and recreational uses are protected then all other instream flow uses will be protected.

- The water appropriation rules allow only temporary appropriations from trout streams, thus the mean annual flow in these streams is the required instream flow approximation.

- Water quality, temperature and other factors are not limiting to instream flow uses.

- Watersheds are in equilibrium.

Constraints:

- Due to the nature of data available for regional analysis, regional boundaries are somewhat subjective.

- Regions apply only to the instream flow component of this study.

- Not all relationships between the physical, hydrologic and biologic characteristics are linear.

- There is not always a linear relationship between different stream orders.

- Analysis is limited to only fluvial habitat and does not include reservoirs and lakes in the system.

- Both quantitative and subjective inputs with different degrees of error are required in the analysis.

- The project is limited to readily available data for office analysis.

- Stream hydraulics in riffles usually do not meet uniform flow assumptions of hydraulic models based on Manning's equation.

- Wildlife instream flow needs are considered only indirectly as a function of change in discharge as it affects riparian vegetation.

- Only measurable hydraulic factors (velocity, depth, wetted perimeter) are used for habitat parameters.

- Biological background data is insufficiently detailed to provide instream flow needs of many fish species.

- Methods treat water quantity impacts, but not water quality impacts.

- Instream flow approximations are treated as simply additive.

- Extrapolation of data between the natural analogue and other systems is not always constant due to the large number of influencing parameters.

- Instream flow requirements are not constant throughout the year and vary for use.

CHAPTER 2. CLASSIFICATION OF INSTREAM FLOW REGIONS

As G. K. Gilbert (1895), the eminent geologist and fluvial geomorphologist, suggested the first stage in a scientific investigation involves the grouping of facts according to common characteristics with the resultant classification serving as a framework for observation. Similarly, the first step in the instream flow approximation process was to classify the state into instream flow regions. The purpose of classification is to organize knowledge, simplify complex interrelationships by identifying similar areas, provide stratification to improve sampling, provide structure for aggregating and disaggregating data and information, and identify the elements responsible for variation and covariation. Classifying the state into instream flow regions provided a more manageable structure and data base for researching instream flow needs.

Based on criteria significant to instream flow management such as hydrology and biology, the state was classified into ten instream flow regions (Figure 2). The use of instream flow regions facilitated the choice of representative rivers and study sites for field investigation and provided information for transferring the field data to other stream systems. Systems of similar hydrologic, geologic, climatic, vegetative, land use, and soil elements are assumed to have similar runoff, flow patterns, fish and wildlife assemblages and recreation opportunities. Therefore, streams within a region should respond similarly to change in management practices and should require comparable instream flow regimes (Slack, 1955; Leopold and Miller, 1956; Ziemar, 1973; Platts, 1974, 1979; Burton and Wesche, 1977; Bayha, 1978; Dunne and Leopold, 1978). Relative homogeneity within a region allows transfer of information from one analogous basin to another. This in turn facilitates choosing representative streams within each region and conducting field studies on a smaller number of sites.

The general characteristics used to classify the state into instream flow regions were geology, climate, land use, vegetative associations, soils, and hydrology. Geomorphic indicators such as bifurcation ratios, stream frequency, drainage density, and elongation factors were considered during the first phase of the classification process. These indicators, however, did not appear to significantly differentiate between or among regions. This was probably due to the recent glaciation and poorly integrated drainage throughout most of the state.

2.1 CLASSIFICATION METHODS

Two standard methods of classification that have been frequently used to determine groupings of individuals (Armand, 1965) were used to classify the instream flow regions. The first method used to delineate the instream flow regions is based on the subdivision of a population into groups according to the presence or absence of two or more attributes. The attributes, as defined for this study, were physical, hydrologic, biological and cultural characteristics of the watersheds.

The subdivision method was used to determine preliminary groups and relied on mapped data, published materials, surveys and discussions with resource professionals. This method simplified diverse information, aided in elimination of variables not significant to classification for instream flow analysis, and permitted use of important, not easily quantifiable data, such as geology, to determine patterns of similarity and develop regional boundaries. During this

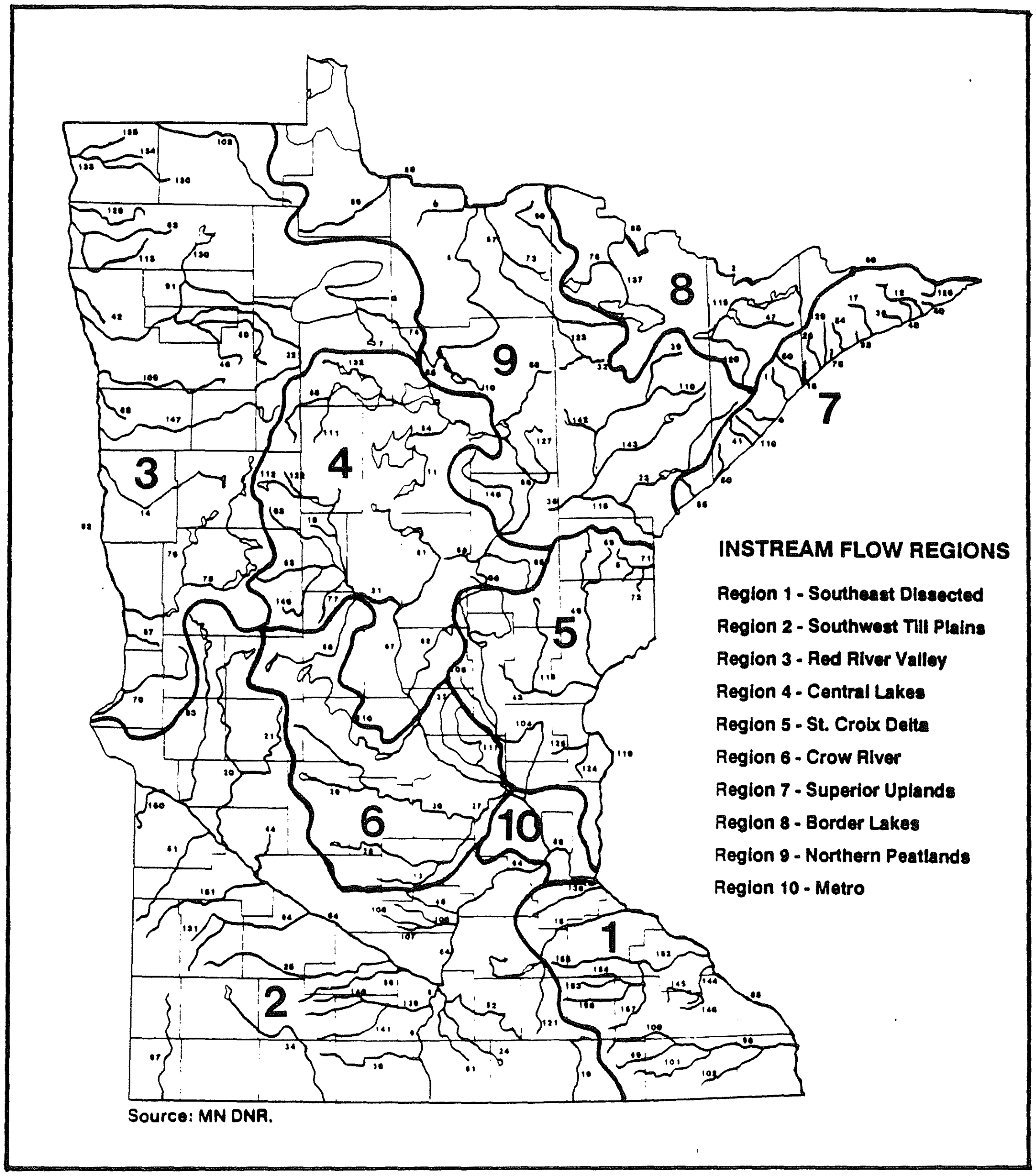


Figure 2. Instream flow regions.

stage, existing regions such as the physiographic regions (Wright, 1972), the biocultural regions (Kratz and Jenson, 1977), and Bailey's ecoregions (Bailey, 1980) were considered. These existing regionalizations were not used as none provided a delineation appropriate to instream flow considerations. The relied primarily on landscape features and vegetation associations, and did not consider hydrologic parameters.

After the preliminary regional boundaries were determined, the regions were analyzed using discriminant analysis, a multivariate statistical method.

This second method of classification enabled the grouping of rivers into classes through numerical analysis of continuous and quantifiable characteristics such hydrologic statistics. The purpose of this step was to numerically predict the proper regional boundaries and to assist in choosing representative streams within the regions.

Discriminant analysis identified relationships between qualitative variables (regions) and quantitative predictor variables such as hydrologic parameters. The regions were measured on the same set of predictor variables. The input matrix was similar to those used in multiple correlation and regression analysis. A stepwise procedure was used to eliminate intercorrelations among predictor variables and collinearity problems. Based on the relation of the predictor variables, discriminant functions were formed in such a way as to maximize the separation of groups, " ... the mathematical objective ... is to weight and linearly combine the discriminating variables ... so groups are statistically distinct as possible" (Klecka, 1975, pg. 435). The weighted combination of predictor values was used to assign the individual rivers to their most probable region. A reclassification function was used to evaluate the group delineations.

2.2 CLASSIFICATION DATA DESCRIPTION

Both classification methods used the watershed as the basic unit of aggregation and data collection. Watersheds share many characteristics that cause them to converge into a common system and be readily classified. A characteristic of importance is that watersheds have definite boundaries, and within the boundaries, the pattern of streams, vegetation, soils and associated flora and fauna exist in response to the climatic and geologic processes within the basin. These patterns tend to repeat in nearby basins of similar physical environment (Strahler, 1975).

Whereas the watershed is the basic unit of data aggregation, the streams are the individual units within the watershed. There are over 6,500 streams within the state. In order to develop a manageable population size, a sample population had to be determined.

The DNR project report "Statewide Oustanding Rivers Inventory" (Kimball, 1983) provided the sample population of rivers. This report identified 157 rivers to be studied for future consideration in river management programs (See Figure 2 and Appendix A). The attributes considered in choosing these 157 rivers were similar to those required for determining instream flow. During the outstanding rivers study, the rivers' resource characteristics were measured from Minnesota Land Management Information Systems (MLMIS) information on natural and scenic conditions, and urban and agricultural development potential, and, fisheries information from DNR Fisheries and Ecological Services inventories, recommendations and management designations. During the outstanding rivers inventory, user groups and resource management personnel were surveyed for stream recommendations and values of these recommended streams. Streams not having a minimum level of resources values were eliminated from further consideration in the inventory.

The streams within a watershed are the integrated results of all characteristics of their watershed. These characteristics include physical, hydrogeologic, biologic and cultural parameters.

2.2.1 Physical Characteristics. Geologic structure and lithology provide the basic make up of soils and influence water quality, permeability, groundwater characteristics, landforms and watershed morphology and topography, and to some extent, land cover and land use. The flows most critical to instream flow analysis are in the low to normal flow range. Low flows are primarily influenced by geology and climate.

Water yield and sediment yield are affected by the size, length, shape and relief of the basin, and the extent and character of the channels. The factors found important in regionalization and instream flow management were watershed slope, basin area, soils, basin storage, and surficial geology. All interact to influence the development and productivity within a watershed.

2.2.2 Hydrologic Characteristics. Hydrologic data such as runoff response and flow regime can be used in a classification process to show similarities or dissimilarities among regions and within regions. Numerous studies have shown that basin characteristics such as the mean and median streamflow appear to be representative of similar areas (Chorley, 1968; Morisawa, 1968; Dunne and Leopold, 1978; Smith and Stopp, 1982). Flow statistics can be used in relation to other physical characteristics, such as drainage basin area, channel length and storage, or as ratios to other flow statistics such as the median flow/mean annual discharge, the seven-day-ten-year low flow/mean annual discharge, and highest and lowest monthly mean discharges/mean annual discharge. Ratios such as the flow exceeded 75 percent of the time to the flow exceeded 25 percent of the time (Q_{75}/Q_{25}) can indicate the magnitude of variation in flows in the range of flows not affected by extreme events. These ratios can indicate relative stability of a stream system, which can indicate the ability of a stream system to support the various water uses.

Hydrologic data provide some of the better continuous variables for discriminant analysis. These variables are closely interrelated and controlled by the components of the morphological structures which are not easily quantified. There was high correlation among the individual hydrologic variables. Hence, in order to eliminate the autocorrelation between variables, ratios of these variables were used as discriminating variables. These ratios include mean annual discharge/drainage area, seven-day ten-year low flow mean annual discharge, base flow/two-year flood, and the Q_{75}/Q_{25}. Hydrology is an important parameter as it is the link between the biology of a watershed and its physical environment.

2.2.3 Biological and Cultural Characteristics. Biological and cultural data were used during the initial regionalization and not in the discriminant analysis. These are best expressed in the description of the biocultural regions (Kratz and Jensen, 1977) which include Marschner's (1932) vegetation types. Vegetation type and land use will affect both the water quantity and water quality. These in turn are important in determining instream flow uses and management. Generally these factors are related to the physical and hydrologic factors and thus, are indirectly addressed.

2.3 ANALYSIS

Two categories of variables were chosen as the best sets of discriminating predictor variables based on the output of the discriminant runs and the predictor variables reliability.

The two categories of variables used in the analysis were:

1. Combined watershed and river gage data - Watershed data was obtained from Planning Information Center data on the 81 'height of land' watersheds. The river gage data was from the U.S. Geological Survey (USGS) historical flow records and basin characteristics data. The best set of discriminating predictor variables of this combined data set were dominant soil type, watershed slope, mean annual discharge to basin drainage area ratio, base flow to the 2-year flood flow ratio, watershed surface storage, and 7-day 10-year low flow. Only seventy-six of the 157 rivers had sufficient gage data to analyze.

2. River gage data - The predictor variables considered as the best set of discriminating variables for the data set were mean annual discharge to drainage area ratio, 7-day 10-year low flow to mean annual discharge ratio, base flow to 2-year flood flow ratio, channel slope, and surface storage.

The results of the discriminant analysis using the combination of river gage and watershed variables reclassified 85.4 percent of the 76 rivers into the nine regions determined through the first classification method. Soil type and mean annual discharge to drainage area ratio accounted for 84 percent of the variation. Three of the six discriminant variables - soil type, watershed slope, and the mean annual discharge to drainage area ratio, accounted for 94.6 percent of the variation.

The discriminant analysis run for the river gage variables reclassified 69.7 percent of the 76 rivers into the preliminary regions. The mean annual discharge to drainage area ratio accounted for 81.5 percent of the variation. Mean annual discharge to drainage area ratio, the seven-day ten-year low flow to mean annual discharge ratio, and channel slope accounted for 91.6 percent of the variation.

Table 1 shows the percent of rivers correctly reclassified into their original regions.

Table 1. Results of discriminant analysis showing the percent of rivers correctly reclassified into the nine preliminary instream flow regions.

Discriminant Variable Groupings	Regions								
	1	2	3	4	5	6	7	8	9
River Gage and Watershed Variables	88.9	100	95.5	75.0	42.9	14.3	100	100	100
River Gage Variables	88.9	70.6	86.4	50.0	42.9	14.3	60.0	50.0	85.7
Number of Rivers in Each Region	9	16	20	3	6	5	4	3	10

As a result of the statistical analysis, an additional region (Region 10-Metro) was identified and the preliminary regional boundaries were adjusted. The final classification is shown in Figure 2.

Although individual elements within a regional unit may not resemble each other under close scrutiny, they are members of a continuous series when observed in a general sense. The following description of region two, the southwest region, is an example of the classification results. (For descriptions of the other nine regions refer to Appendix B).

In the preliminary regional analysis, the most important characteristics used in defining region two were surficial geology, hydrologic regime, vegetation associations and land use. Most of the region is covered by glacial till deposits physiographically classified as the Des Moines till plain.

The topography varies from nearly flat to gently undulating terrain, lacking strong moraines within the plain. The only areas of pronounced relief exist in the southwest corner on the Coteau des Prairies escarpment and along the Minnesota River bluffs.

The majority of the rivers flowing through the till plain are generally slow, meandering, alluvial streams where they have not been altered through drainage and channelization. Minor exceptions occur in the headwaters of streams flowing off the Coteau des Prairie escarpment, bordering end moraines, and where the streams flow into the Minnesota River Valley. The streams are rocky and swift in these areas.

The hydrologic regime is variable, with high flows in spring to low flows during late summer through winter, and very low flows, or no flow, during dry periods. Generally, groundwater and throughflow influence is limited except in the areas of alluvium and outwash deposits. Lakes and wetlands account for approximately 2.5 percent of the surface storage. Thus, the stream systems are the primary source of surface water in the region.

The original vegetation is big blue-stem prairie with floodplain tree species such as cottonwood along the stream corridors. The primary land use is intensive cultivation with scattered pastures.

During the discriminant analysis, sixteen streams were assigned to Region 2. In the discriminant run using the combination data set of watershed and river gage variables, all sixteen of the streams were confirmed to be correctly classified in this region.

In the discriminant run using river gage variable set, twelve of the streams were correctly re-classified in region two. The remaining 4 streams were classified into region three, the Red River Valley; although, the second best classification was region two. In analyzing region three data, the rivers incorrectly classified by the discriminant analysis method in this region were placed in region two. This indicates some similarities between the two regions. The mean discharge/drainage area and storage variables account for most of the similarities. The forces that physically formed the landscape such as glaciation, climate, native vegetation, and current intensive agricultural production in both regions are very similar and explain the classifications.

2.4 SUMMARY

Classification of the state into instream flow regions was a viable means of studying representative stream systems for large areas. It provided a data base to gather information on a statewide basis and to expedite the extension of field information. Subdivision and further refinement of the regions may provide a basis for determining appropriate instream flow methods for site-specific studies. Refinement of regions should include channel characteristics in the analysis.

CHAPTER 3. SELECTION OF REPRESENTATIVE STREAMS

As discussed in the classification chapter, the assumption of the existence of natural analogues simplifies data collection and permits data to be transferred to other systems. The natural analogues form the basis for understanding and predicting the behavior of other systems. For the purpose of this study, representative streams are the natural analogues that represent the hydrologic and ecologic processes of river systems of similar geology, climate, soils, vegetation, geomorphology, and land use.

The Water Appropriation Rules 6115.0630 and Minnesota Statutes § 105.417 require that rivers needing instream flow protection must exhibit some use or attribute worth protecting. These uses or attributes include fisheries, wildlife, recreation, waste assimilation, aesthetics, navigation, and preservation. The streams used for the statewide sample population for choosing representative streams are assumed to exhibit one or more of these uses or attributes.

Although not all streams within the regions have quantified instream uses, choosing streams that have at least one use or attribute allows us to err on the conservative side. The instream flow approximations identify higher volumes of water for instream uses than further site-specific study may justify. This approach is consistent with methods for economic water use quantity projections which are based on economic growth desired for offstream water uses, and not on survival needs for the human population.

This approach is also consistent with a holistic concept of instream flow management. In a holistic analysis, the watershed becomes the basic unit, and all stream networks within the watershed serve a purpose, even if only to supply water to those streams having specified instream uses. Thus, using conservative estimates reduces the possibility of not identifying a conflict or demand when it has a chance of occuring.

3.1 METHOD

Choosing representative rivers from the population of 157 rivers was facilitated by the discriminant analysis performed for the classification of regions. The discriminant analysis provided measures of similarity and dissimilarity among the rivers within each region. The cluster plots visually show if rivers within a region are closely aligned (Figure 3) or if there are anomalies (Figure 4). The discriminant analysis classification procedure also assisted in identifying congruity or variance among rivers in a region. For example, the Pine River is spatially in Region 4 but during the discriminant analysis it was often regrouped into Region 9. Thus it would be considered atypical of other Region 4 rivers.

Results from the statistical analysis in combination with biological information gathered from a survey of DNR resource managers provided information to select the population of representative rivers for field investigation. The survey is addressed in Chapter 5: Data Collection and Chapter 6: Data Analysis.

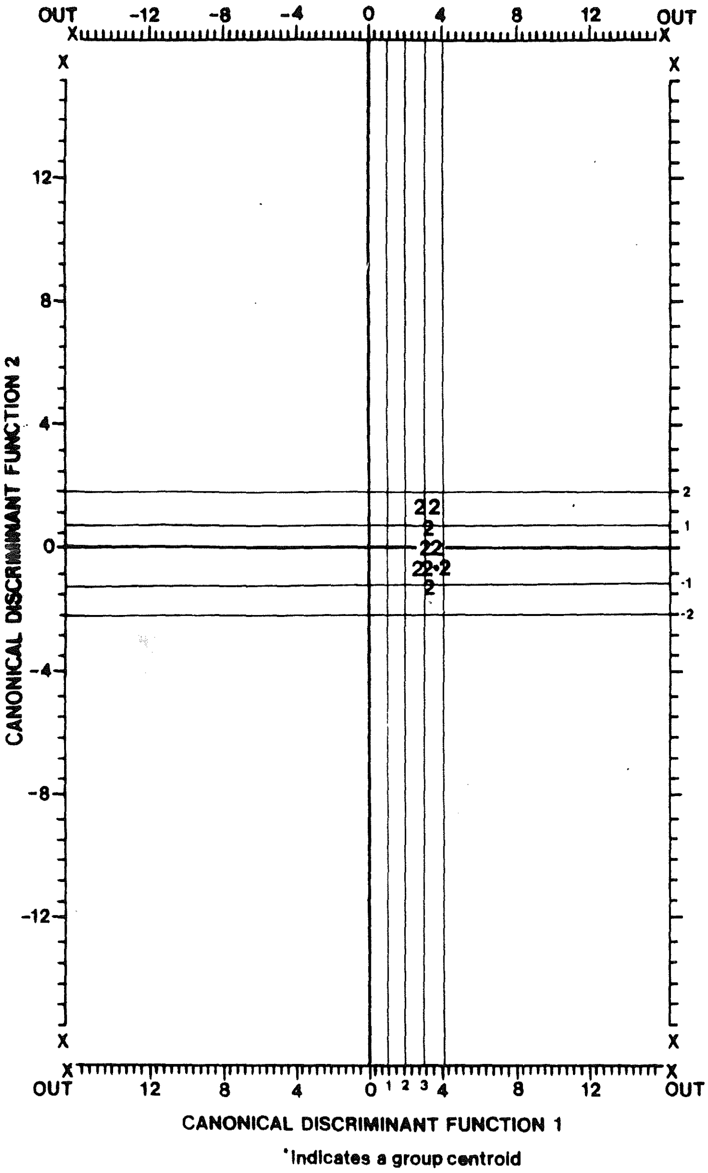


Figure 3. Cluster plot for region 2 showing tight clustering around centroid.

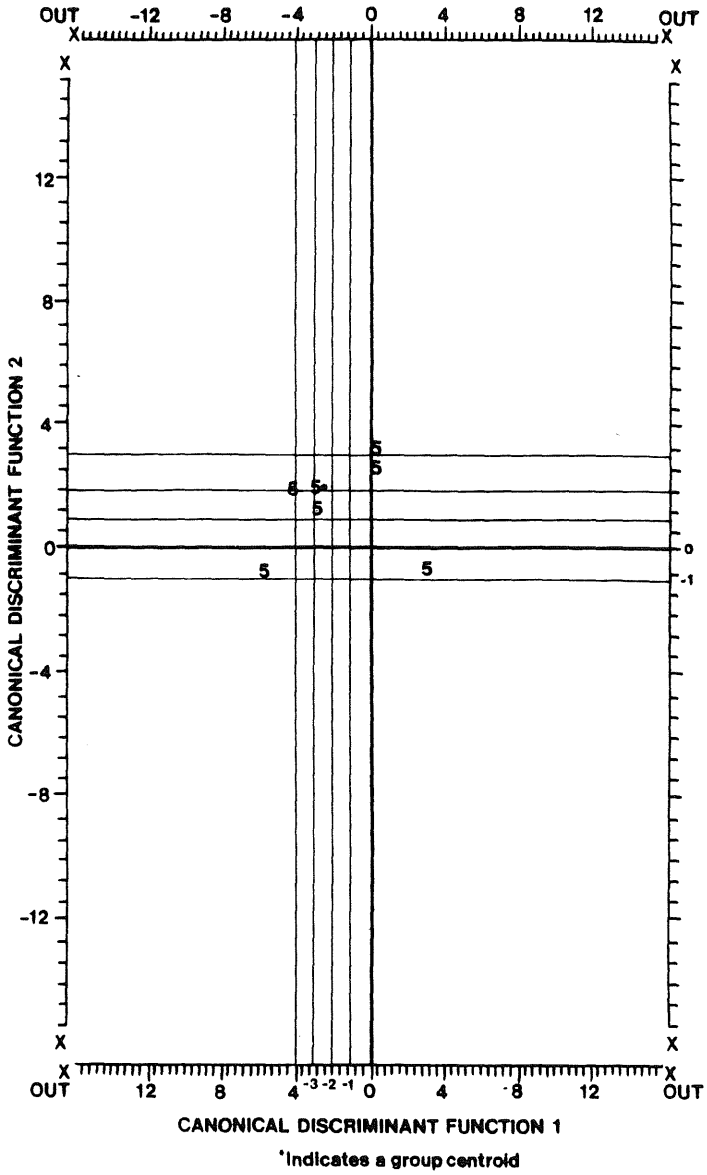


Figure 4. Cluster plot for region 5 showing deviation from centroid.

Selection criteria within regions include: degree of homogeneity among rivers, identification of subgroups, and identification of anomalies. The number of rivers surveyed in each region varied based on three categories:

1. In regions where the rivers are quite similar in regards to both the physical and biological characteristics, a minimal amount of field work was required. Rivers were selected on a random basis with strongest consideration given to accessibility.

2. In regions where there exists some degree of variation among rivers in regard to the physical characteristics, a moderate amount of field work was required. Several groups of rivers were identified in a region of this nature. Rivers selected for study included representatives from each of the identified groups. Chosen rivers received ecological scrutiny to ascertain whether they are "typical" of the region.

3. In regions where there exists a high degree of variation among rivers in regard to the physical characteristics, considerably more field work was required. Identification of subgroups using discriminant analysis may be difficult. In regions of this type, ecological criteria were important in selecting study rivers.

For example, in Region 3 some degree of variation exists among rivers in regard to the watershed and river gage information. The rivers appear to be grouped into three categories. The first subregion is the lacustrine area of the Red River Valley. This area encompasses the lower portions of all the rivers flowing into the Red River. Any of the lower portions of the Ottertail, Buffalo and Wild Rice Rivers would be typical of this subregion. The second subregion is the peat area of the Red River Watershed. The Roseau River and Clearwater River would be typical of this subregion. The third subregion is topographically an area of end moraines. Mostly the headwaters of Red River tributaries fall into this category. The Pelican River or the headwaters of the Wild Rice River, Clearwater River or Ottertail River are typical of this subregion. Thus the Ottertail, Pelican, Wild Rice and Clearwater Rivers were chosen as representative rivers for this region.

The representative rivers for each region are listed in Appendix C.

3.2 SUMMARY

Representative rivers act as analogues for the other systems in each region. Using representative rivers allows field data to be collected from a small sample of the entire population. This provides information that is very useful in determining instream flow approximations for the 39 DNR watersheds and the five economic regions. The data collected are also useful in a preliminary examination of the reliability of some instream flow evaluation methods.

CHAPTER 4. INSTREAM FLOW METHODS

In the last twenty years, numerous methods have been developed to assess instream flow needs, due to increasing public attention given to the values protected by leaving water in streams.

There are three basic categories of instream flow evaluation methods:

1) hydrologic methods that rely on water supply statistics;

2) hydraulic methods that predict hydraulic parameters through modeling habitat-discharge relationships, and;

3) regression methods that involve correlations of some measure of habitat productivity (e.g. standing crop) with some measure of streamflow.

Only methods in category one and two will be discussed as category three methods require more rigorous analysis than warranted for this study. Also the category three methods are limited to the measurement site. Only the methods in category one and two that are applicable to the level of study and warm-water streams will be discussed. There are numerous publications available that describe or evaluate other instream flow assessment methods (Stalnaker and Arnette, 1976; Orsborn and Allman, 1976 a,b; Wesche and Rechard, 1980; Loar and Sale, 1981; Hilgert, 1982; Morhardt, 1986).

4.1 REVIEW OF METHODS

Hydrologic methods rely on hydrologic data such as mean annual discharge, mean monthly discharge, or flow duration statistics. The hydrologic methods evaluated for this study were the Tennant Method, the New England Method or Aquatic Base Flow Method, and the Northern Great Plains Resource Program.

The Tennant Method is one of the quickest and easiest methods to use for calculating instream flows. Hence, it has been frequently used, especially in broad-based regional planning studies. The instream flows are determined as a percentage of the mean annual flow (MAF). The percentages range from 10 percent for degradation flow to 60-100 percent for optimal flow. Two hundred percent of the MAF is recommended for flushing flows, that is, the flows necessary to flush sediments from the channel bed (Tennant, 1975). The year is divided into two six-month periods and the percentages are specified for each period (Table 2).

Table 2. Tennant's recommended base flow regimes (from Tennant, 1976).

Narrative Description of Flows	Recommended Base Flow Regimes	
	Oct-March	April-Sept
Flushing or Maximum	200% of the Average Flow	
Optimum Range	60-100% of the Average Flow	
Outstanding	40%	60%
Excellent	30%	50%
Good	20%	40%
Fair or Degrading	10%	30%
Poor or Minimum	10%	10%
Severe Degradation	10% of Average Flow to 0 Flow	

Tennant based his recommendations on observations from streams in the northern United States. The percentages are based on observed discharge, velocity, depth, and width, and their relation to habitat and recreation conditions. Tennant recommends field observation and measurements at critical flows; however, the method has been applied where no supporting field work was done.

The Tennant Method has several limiting assumptions:

1) the method requires historical flow records;

2) the use of mean annual flow ignores seasonality or variability in flow, and may skew results due to rare, but significant, flow events;

3) The method assumes the percentages are appropriate and does not incorporate regional differences in hydrology and stream channel geometry, which can result in flow recommendations that are unattainable in lower flow months or, as in the case of stable streams, flow recommendations that are too low (Hilgert, 1982; Bayha, per. comm., March, 1985);

4) the method is more accurate when applied to non-regulated streams and streams that have records on consumptive withdrawal; and,

5) the method is more reliable if the hydrologic and biotic knowledge of the stream system is well known.

The Minnesota Water Planning Board prepared water allocation reports that considered instream flow (Water Planning Board, 1978). In the report Tennant's 30 percent of the mean annual flow recommendation for fair habitat conditions was used as the recommended base flow. These reports were framework studies and assessments which are similar to Level A planning. As they were the broadest level of planning, it was appropriate to use the Tennant Method. They evaluated flows on a broad basis of need without field validation as to effects. Without validation, however, there is no evidence that the recommended flows provided are either necessary or sufficient to meet biological or other instream use requirements for a particular stream.

A modified version of the Tennant Method would be appropriate to use in a Level B type study if field validation and regionality are incorporated into the flow recommendations. This would require measuring discharge, velocity, width, and depth over the specific flows of interest. Th percent of mean annual flow recommendations would need to be modified to account for regional differences in instream flow requirements. Due to this requirement, the Tennant Method was not used for three reasons:

1) during the study period, the streams throughout the majority of the state were constantly above average flows, thus the flows of interest were not available for measurement;

2) the field work would require more time than was available for this study; and,

3) in some regions, there are very few streams with sufficient hydrologic records.

The New England or Aquatic Base Flow Method (ABF) (U.S. Fish and Wildlife Service, 1981) requires the use of historical stream flow records in order to generate the ABF. The ABF is the median daily flow for August and is the yearly recommended flow for maintaining aquatic habitat. Streamflow records for at least a 25 year period are required to select the median. Only unregulated streams with a drainage area greater than 50 square miles were used in the analysis. A constant yield factor based on runoff per watershed area is calculated for streams not meeting the above criteria. The constant yield factor is applied to a specific site to estimate actual flow conditions.

The North Carolina Office of Water Resources adapted this method to the climatic and hydrogeologic conditions in North Carolina. They used the September median daily flow for their ABF for June through February because "... September is most frequently the month of lowest flow and greatest habitat stress" (Reed and Mead, 1984, p. 17). The ABF is used to rate the sites' suitability for fish habitat and provide flow requirements to correlate with field method flow recommendations. No constant relationship between the recommendations based on site-specific data and those based on historical flow records was found (Ibid, 1984).

As with the Tennant Method, the New England Method requires sufficient historical records. A major constraint of methods requiring flow records is the availability of the records and the suitability of their duration. Region 4 and Region 8 of the instream flow regions have no gages with 20 years or more of historical data. Only fifteen of the 81 major watersheds have gages with 25 or more years of record. Based on the criteria of 25 or more years of flow data, this method would have very limited application in Minnesota. The concept of constant yield was used during the extension of site specific data, however. This is discussed in detail in Chapter 6 on Data Analysis.

A hydrologic method proposed by the Northern Great Plains Resource Program (NGPRP) uses flow duration analysis (Anonymous, 1974; Loar and Sale, 1981). Flow duration curves are cummulative frequency curves showing the percent of time that specified discharges are equalled or exceeded. They do not measure length of time the flows persist and they only apply to the periods for which data were used to develop the curve. The NGPRP Method requires at least 20 years of daily flow records. The flow records are modified by using the 'student's t distribution' to eliminate abnormal high and low flow events for each month. The remaining daily values are arrayed into monthly flow duration curves. The instream flow recommendation for each month is the flow equalled or exceeded 90 percent of the time on the monthly curve.

Although this method was developed to satisfy assessment requirements on midwestern streams, it requires long periods of flow records. Flow duration curves can be extended to partial record gages along the stream system; however, it is suggested that duration data be given only for gaging stations (Riggs, 1968, 1972). Thus the paucity of gages with 20 years or more of recorded data limits the applicability of this method for Minnesota streams.

Like the two previous methods, the NGPRP method does not require field work; however, without field validation, the flow statistic or percentage chosen is arbitrary. This can produce error in the direction of not recommending sufficient flows. This is contrary to the assumption that in order to generate enough water for all existing and potential instream uses for planning purposes, conservative (high) estimates must be determined.

Field documentation for any of these methods would require observation of conditions and hydraulic parameters at the specific flows of interest. This is an expedient technique where discharge can be controlled, but on unregulated streams, flows of interest must be available during the study period. High water conditions and the two-year study timelines dictated that methods requiring less field time, and not requiring specific flow levels, be considered.

Hydraulic rating methods are not dependent on historical flow records and do not require field observation at specific flows. Hydraulic rating methods can be used to examine the relationship between stream flow, hydraulic parameters, and the physical parameters of the aquatic environment.

There are numerous hydraulic rating methods available (Stalnaker and Arnette, 1976; Wesche and Rechard, 1980; Bayha, 1980; Loar and Sale, 1981; Morhardt, 1986). Most are based on the assumption that biological conditions and productivity are dependent on flow and hydraulic characteristics. Discharge is assumed to be directly related to almost all the stream and hydraulic parameters that determine the activities of the aquatic organisms. Discharge determines stream physical characteristics such as width, depth, velocity and wetted perimeter. Studies (Hynes, 1970; Wesche, 1973, 1974; Beschta and Platts, 1986) have shown that these characteristics can affect fish production. Thus it is reasoned, discharge must also control the amount of spawning areas, food production areas (such as riffles), microhabitat and cover as these factors are related to the biological productivity of a stream. Hence, hydraulic rating methods can be used to predict potential change to stream habitat and aquatic production at various discharge levels. Flow recommendations can be made on the basis of change and needs of the species.

Hydraulic rating methods employ physical-process hydraulic simulation models. These models predict hydraulic parameters--wetted perimeter (distance of wetted stream bed), maximum, minimum and average depths, average velocity, slope, water surface width, water surface elevation, and cross-section area for the flows of interests. The models generally require collection of site-specific field data (discharge, velocity, water surface elevations, channel slope, and cross-section elevations) at one or more flows along the transects across a stream channel. In order to relate the parameters to the aquatic habitat, transects are selected to be representative of specific types of stream habitat, such as riffles, pools, and runs, that may be affected by alterations in flow. The field data obtained at the transects are used for calibrating the hydraulic simulation models. The response relationships between parameters descriptive of habitat conditions, and stream flow at unmeasured flows are estimated by hydraulic simulation. Thus flow recommendations are made on the basis of actual and simulated hydraulic conditions rather than on flow statistics.

Hydraulic rating methods range from simple to complex. The simplest methods employ single transect measurements at one flow. A U.S. Forest Service program known as R-2 Cross (Anonymous, 1974) was one of the most commonly used single-transect methods. The transect was usually placed at a critical area of the study site, based on the assumption that conditions must be met at these sites to protect the fishery or recreation. The hydraulic simulation model uses Manning's equation (Chow, 1964) to predict hydraulic properties, including discharge, velocity, wetted perimeter and cross-sectional area, at unmeasured discharges. Other single cross-section methods provide similar outputs with minor differences. Generally, instream flow investigators do not recommend using single cross-section methods for site-specific studies, however, they are acceptable methods for assessment of Level B type studies (Bayha, per comm., March, 1985; Bovee, per. comm, April, 1985).

More sophisticated methods use multiple transects with hydraulic simulation models capable of analyzing all cross-sections at any number of measured flows. One of the more well-known and complex hydraulic-habitat methods, the Instream Flow Incremental Method (IFIM), was developed by the U.S. Fish and Wildlife Service, Aquatic Systems Branch (formerly Instream Flow and Aquatics Group) (Bovee, 1982; Milhous, Wegner, and Waddle, 1984). Programs within this method, collectively called the physical habitat simulation model (PHABSIM), range from single to multiple transect analysis for one or more measured flows. The programs most commonly used rely on data obtained from multiple transects delineating a representative reach. Various hydraulic simulation models are available in this method with each model best suited to different physical conditions. The output of the hydraulic simulation models are used in conjunction with habitat suitability indices (weighted preference curves) to obtain a habitat availability index (weighted useable area) at specified flows.

Generally, this method is used in site-specific studies, however, it has been adapted for use on the Colorado River Level B study (Bayha, 1980). The method could not be used in the Water Allocation Study as it requires specific information on fish species and their various life stages. This information for most species in Minnesota is not readily available and requires further detailed study not warranted by the current level of study. Some of the hydraulic-simulation models can be used, however, separately from the habitat suitability curves to produce useful output.

4.2 METHOD

The limitations of information availability and study timelines dictated that a combination of hydrologic and hydraulic methods be developed for the instream flow approximation. The method includes a hydraulic model (Leete, 1985) designed to calculate a series of hydraulic parameters from data collected along single or multiple transects in riffle areas (Figure 5). The output of the model includes water surface elevation, wetted perimeter, cross-sectional

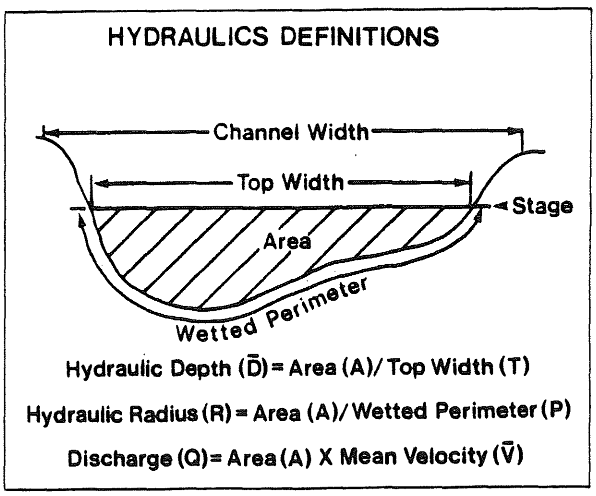


Figure 5. Hydraulic parameters calculated from hydraulic model.

area, average and maximum depth, and average velocity. The IFIM Water Surface Profile (WSP) and MANSQ hydraulic simulation models were used to supplement the main model where physical conditions warranted their use (refer to Bovee and Milhouse, 1978; Bovee, 1982; Milhouse, Wegner and Waddle, 1984; and Milhous, 1985 for describition of these models).

The Tennant Method was used in comparing the output obtained from the hydraulic models with available flow statistics. A modification of the constant yield concept from the Aquatic Base Flow Method was used to extend the data to unmeasured streams.

The study methodology uses the wetted perimeter-discharge relationship and depths generated by the hydraulic models as the decision variables for determining instream flow approximations. A direct relationship is assumed to exist between wetted perimeter of a riffle area and fish habitat or area for benthic insect production. Food production is assumed to be proportional to game fish carrying capacity. Depth of water across the riffle section is assumed important for fish and canoe passage as riffles are most affected by flow reduction (Figure 6). An additional assumption is that the maintenance of suitable riffle conditions will also result in suitable pool and run conditions also (Bovee, 1974).

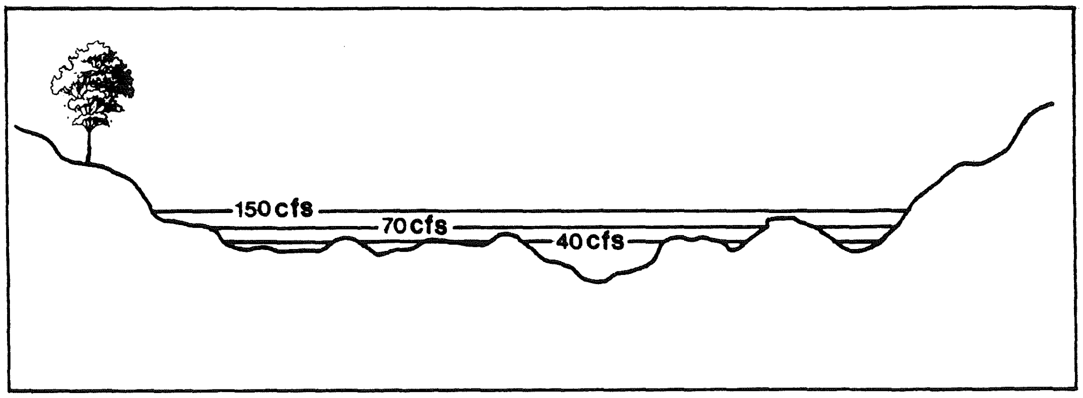


Figure 6. Riffle section at various discharges.

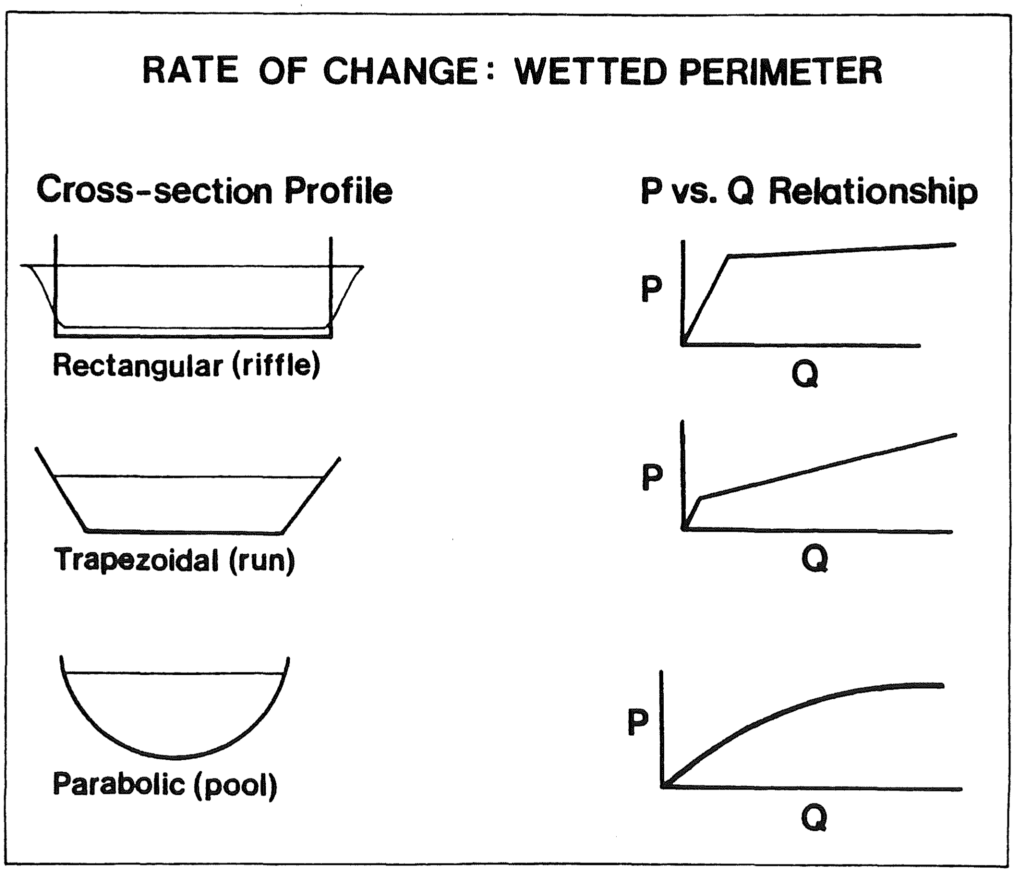
Studies have shown the wetted perimeter-discharge relationship to be valid for trout streams, where the relationship between food production in riffles and fish production is clearly understood (Collings, 1972; Wesche, 1973, 1974; Nelson, 1980; Randolph and White, 1984). This relationship is not nearly as well understood for cool and warm water species; however, researchers have found that the maintenance of riffle habitat in cool and warm water streams may be more critical to the aquatic communities than cold water streams (Waters, 1969; Bovee, 1974; Stalnaker, 1981; Orth and Maughn, 1983; Bovee, August, 1985, per. comm.).

Some recent instream studies in other states have used wetted perimeter methods to determine flow recommendations on warm water streams (Reed and Mead, 1984; Leonard et. al, 1986; Nelson, April, 1986, per. comm.). These investigations have indicated that a wetted perimeter method would be appropriate for this level of study.

The instream flow approximations are determined from the inflection point of the wetted perimeter versus discharge curve (specified in terms of water surface elevation) below which further reduction of flow results in an increased rate of wetted perimeter related habitat loss. The relationship shows that as discharge decreases, wetted perimeter decreases, but not at a constant rate. Decrease occurs much more rapidly at lower flows (Figure 7).

A major limitation of wetted perimeter methods is that inflection points are identified subjectively (Nelson, 1984; Annear and Condor, 1984; and Morhardt, 1986). Nondistinct inflection points or multiple inflection points and complex channels further complicate the interpretation of data. The use of a mathematical curve fitting function that determines when the second derivative of the curve changes sign (mathematical definition of inflection point) decreased the subjectivity in choosing an inflection point (refer to Chapter 6 Data Analysis). Choosing representative or critical transects where the riffle cross-section was rectangular and well-defined lessened the occurrence of the second limitation (refer to Chapter 5: Data Collection).

Figure 7. Relationship between wetted perimeter (P) and discharge (Q) for different shaped cross-sections.



Analyzing the flow recommendations from the model output in conjunction with available flow statistics and graphic representations of the cross-sections at inflection point flows provided the most reasonable numbers for the instream flow approximations. These instream flow approximations were then extended to unmeasured streams.

4.3 SUMMARY

There are many instream flow assessment methods available ranging from office methods to comprehensive field methods. For the LCMR Water Allocation Study a method that would allow the use of existing information in combination with field investigations was considered to be the most appropriate for this level of study (Bayha, 1980).

The wetted perimeter-discharge approach was considered useful in evaluating riffle areas where invertebrate food production is considered an important limiting factor. The method also has the advantage of being useable on warm water streams (Bovee, 1974; Stalnaker and Arnette, 1976).

The assessment method used in the study provided data that could not be obtained through office methods. Thus the instream flow approximations were determined on real information and not by arbitrarily choosing a flow statistic which may not provide an appropriate estimate of flow needs.

CHAPTER 5. DATA COLLECTION

Both field and existing biological and hydrologic data were used to determine the instream flow approximations. Field data were collected on 23 rivers. Field data on four additional sites was available from previous studies. Analyzing and compiling existing data consisted of three phases: 1) pre-field investigation of maps, hydrologic data, stream fishery surveys, and recreational surveys; 2) questionnaires sent to Department of Natural Resources regional and area managers to obtain biologic and recreation data; and, 3) compilation of specific hydrologic data, such as flow duration curves, for comparison with wetted perimeter results.

5.1 FIELD DATA

The wetted perimeter method requires some field data collection along transects at each study site. Selection of habitat transects at riffles was based on two criteria: 1) transects were representative of habitat conditions; and, 2) transects crossed relatively rectangular shaped cross-sections (Figure 8). Additional transects were measured on hydraulic controls allowing the use of the IFIM, WSP model where physical conditions warranted. Generally, a cross-section, either above or below the riffle, was selected for the discharge measurement. Selection of the discharge transect was based on the guidelines for the U.S. Geological Survey outlined by Rantz (1982).

Water surface elevations, channel bed and water surface slope, and cross-section profiles were measured along the habitat transects using differential and profile survey techniques as described by Davis et. al. (1981) and Bovee and Milhous (1978). All elevations were tied to a benchmark established at the study site.

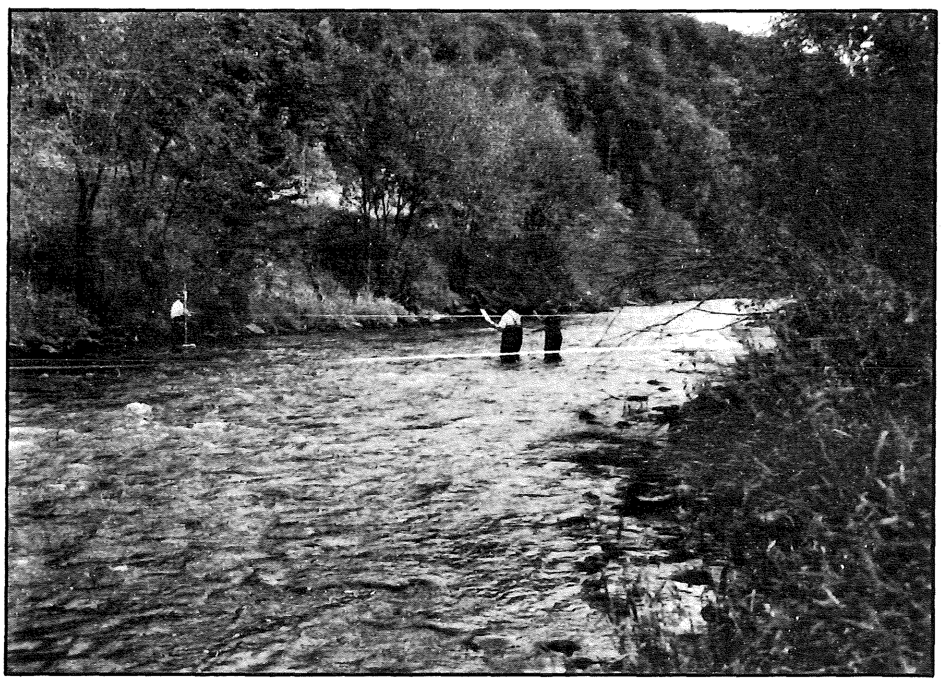


Figure 8. Stream reach with habitat transects

Incremental velocities were measured along the habitat transects using Price AA, Gurley and pygmy flow meters. Discharge was measured at the discharge transects following the guidelines of Rantz (1983) and the USGS (1980). Substrate size and percentage composition were estimated to indicate habitat conditions and to facilitate selection of Manning's "n" for the hydraulic simulation models. Numerous photographs were taken at each site.

5.2 OFFICE DATA

5.2.1 Site Selection

Study sites were selected on representative streams using a two-stage process. Potential sites were identified in the office using existing data sources. Final site selection occurred after a field inspection of the potential sites. Ultimately, one site was selected on each river with one exception. For those rivers which pass through distinctly different geologic formations, several sites were selected to represent the major regions. Multiple sites are necessary to discern differences in hydrologic characteristics associated with changes in geologic formations. Criteria considered in selecting study sites include: 1) suitability of the site for the wetted perimeter-discharge method; 2) biological significance of the river reach; and 3) site accessibility.

Various sources were utilized to identify potential sites. The geologic information from the hydrologic atlases was used to determine if single or multiple sites were necessary. Multiple sites were selected where distinct transitions in the surficial geology occurred. For example, in the Red Lake River Watershed there are three transition zones: end moraine, peat areas, and lacustrine. Thus, three sites were chosen. A stream gradient map and USGS topographic maps were useful in identifying river reaches where slope was conducive to locating good riffle areas. Riffle areas are necessary to facilitate the use of the wetted perimeter-discharge method. Aerial photographs, watershed studies, county maps, USGS stream gaging data, and biological surveys also provided useful information.

Biologic information for the most part was obtained from stream survey files, and personal communication with area managers. Information regarding species composition, location of critical reaches (e.g. spawning or food production areas, barriers to fish movement), factors limiting the fishery (e.g. low flows, flow fluctuation) and the location of popular fishing and recreation areas was collected. Five to ten potential sites were chosen. A standard form was used to record pertinent physical, hydrologic, and biologic information and the location of potential sites (Appendix D).

After a small number of candidate representative sites were selected, potential sites were evaluated during a site inspection. If all the sites were relatively similar then selection was based on stated criteria, logistics and landowner approval. Tentative transect location, a description of the stream morphologic characteristics and observation relating to the natural setting were recorded on a standard form (Appendix D).

5.2.2. Resource Survey

An important element of the instream flow approximation process was the identification of instream flow uses. "Use" in this context refers to describing the value of aquatic and riparian habitats for fisheries, wildlife, and recreation. This was accomplished using a series of mail surveys distributed to state resource managers. The mail survey technique was selected because it enabled collection of information from a large number of rivers in a relatively short period of time. An advantage of this technique, is that it allowed us to indirectly incorporate the knowledge of area personnel into the instream flow approximation process. A disadvantage of this technique is that only general information could be obtained, thereby limiting interpretation that could be made from the data.

Separate surveys were prepared for fisheries, wildlife, and recreation. The format of the three surveys was similar with the majority of the questions requiring objective responses. Respondents were given the opportunity to elaborate on certain questions, specifically on those requesting information regarding low or high flow issues. The respondents were requested to provide a general response with the entire river in mind. If they were knowledgeable of only a certain section of the river, or the river's character changed markedly, a general response could not be provided. In these instances, the respondent would indicate the upper and lower bounds of the section described.

Surveys were prepared for each of the 157 rivers identified in the "Statewide Outstanding Rivers Inventory", (Kimball, 1983). The surveys were sent to the regional offices for distribution to the area personnel best qualified to respond for each river. The fisheries surveys were directed to the Regional Fisheries Supervisors; the wildlife surveys to the Regional Wildlife Supervisors; and, the recreation surveys to the Regional Trails and Waterways Coordinators. Fisheries personnel were also requested to respond to the recreation survey. A brief description of the surveys is provided below.

River Fisheries Survey - The objective of the survey was to obtain information concerning fish habitat and resource potential. The river fishery survey was designed using the 1982 National Fisheries Survey (Judy et. al. 1984) as a model (Appendix E). The principal focus was on sportfish; this is not because sportfish are the only contributors to the value of the river, but because the majority of available fisheries information concerns these species, and their presence of absence generally indicates conditions of prevailing water quality.

The respondents were requested to provide information regarding the presence of sportfish species and species of special interest. If in the opinion of the respondent the use, survival or productivity of the fish community was adversely affected by man-caused or natural factors, they were asked to identify the limiting factors and indicate their probable source. Response categories included water quality, water quantity, useable habitat, and problems in the fish community. A series of questions were used to rank each river with respect to its ability to support fish, particularly sportfish. The respondents were asked to indicate the current conditions of the river and speculate on past and future conditions. This series of questions was designed to provide insight into trends in resource conservation and utilization.

Wildlife - For the most part, formal methodologies for determining instream flow requirements for wildlife do not exist. Four classes of effects of altering natural water flow regimes have been identified (Kadlec, 1976): a) removal of drinking water for terrestrial birds and mammals; b) altered flow patterns or volumes may directly affect aquatic wildlife such as beaver or muskrat; c) lowered water tables may alter riparian vegetation, eliminating essential elements of habitat for some species; and d) changed patterns of flooding may affect wetland habitats that depend on flood waters for their maintenance.

The most serious effects are likely to be from changed hydrologic and hydraulic regimes, including groundwater, and the resultant effects on vegetation and habitat. The objectives of the wildlife survey were: to obtain a description of the wildlife resources found along the river corridors; and, to identify the times of the year (seasons or months) during which stream flow (high or low) is critical to certain species within the wildlife community (Appendix E).

The respondents were requested to provide information regarding the importance of the river corridor for providing waterfowl and furbearer habitat and identify any unique wildlife uses that occur along the river corridor, such as, bald eagle nesting and feeding activity. Hunting and trapping are popular recreational uses frequently associated with rivers and their riparian zones. The respondents were requested to estimate the level of use for each activity (waterfowl, small game, big game hunting and trapping) and indicate the important species.

Recreation - The objective of the recreation survey was to obtain information concerning recreational opportunities associated with the river corridors. The survey consisted of a list of activities which included both contact (i.e. swimming, canoeing, wading) and non-contact (i.e. camping, hiking, picnicking) activities (Appendix E). Using a matrix, the respondent was requested to estimate the intensity of use (i.e. heavy, moderate, light) for those activities known to occur along the river corridors. Respondents were also asked to provide their opinion as to whether or not the river resource is sustaining the level of use that it may be capable of supporting (potential).

To supplement the surveys, additional information was obtained regarding trout streams and species of special interest. Trout streams in Minnesota receive special designation which affords them a high degree of protection. Streams receiving this designation include those with naturally reproducing trout populations and those which are maintained through stocking programs. The Department maintains an inventory of the designated trout streams which includes the Township, Range, and Sections through which each stream courses. For the purpose of this study, the trout streams were sorted into the 39 watersheds for inclusion in the watershed reports.

The Minnesota DNR-Natural Heritage Program has identified those species of plants and animals that are recognized as being rare, threatened or of special concern in the State of Minnesota. Known occurrences of most species of special interest have been catalogued and maintained on computer files by the Natural Heritage Program. For the purpose of this study the Natural Heritage records were sorted into the 39 watersheds for inclusion in the watershed reports. A number of rare and/or sensitive species are obligate or faculative riverine species thus requiring special consideration in the identification of instream flow needs. This is beyond the scope of this study, however, documenting the presence of these species is essential.

CHAPTER 6. DATA ANALYSIS

The instream flow approximations (IFA) were determined statewide, for five economic regions, and for each of the 39 DNR watersheds (DNR, 1959) for normal (median of the mean annual daily flows) and dry (75% exceedance level) hydrologic conditions. The approximations are based on analysis of hydraulic simulation model output, the resource survey results, existing and potential instream uses, and water availability. The results from modeling the field data for 28 study sites were extended to the 39 watersheds, five economic regions, and statewide. The resource survey results were used to identify the instream flow uses and adjust the approximations accordingly. The hydrologic records indicate the reasonableness of the approximations.

6.1 WETTED PERIMETER ANALYSIS

6.1.1. Data Processing

A file containing transect data (profile distance, stream bed elevation, velocity, substrate characteristics, discharge, bed and water surface slope, and water surface elevation) was prepared for each of the twenty-eight sites surveyed throughout the state. Computer models based on Manning's equation (Milhous, 1984; Leete, 1985) and a modified water surface profile, step-backwater progression (Bovee and Milhous, 1978; Milhous, Wegner, Waddle, 1984) were used to model the data. These models estimate wetted perimeter, depth, and velocity for various water surface elevations and discharges.

Output from the computer models was tabulated and displayed graphically. A graphic representation of the cross section (Figure 9) was used to visually assess changes in wetted perimeter and channel dimensions at various water surface elevations. A plot of wetted perimeter versus water surface elevation (Figure 10) was another method used to visually select critical flow levels for individual transects. Standard scales were chosen for each of these graphs in order to maintain scale consistency between rivers.

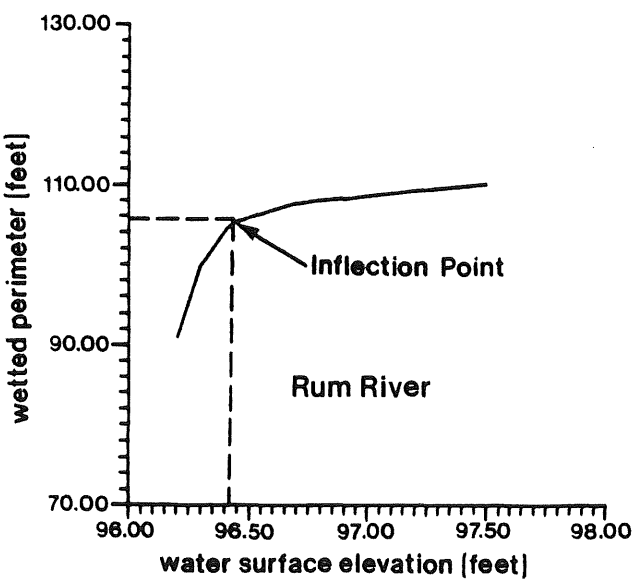


Figure 9. Cross-section profile.

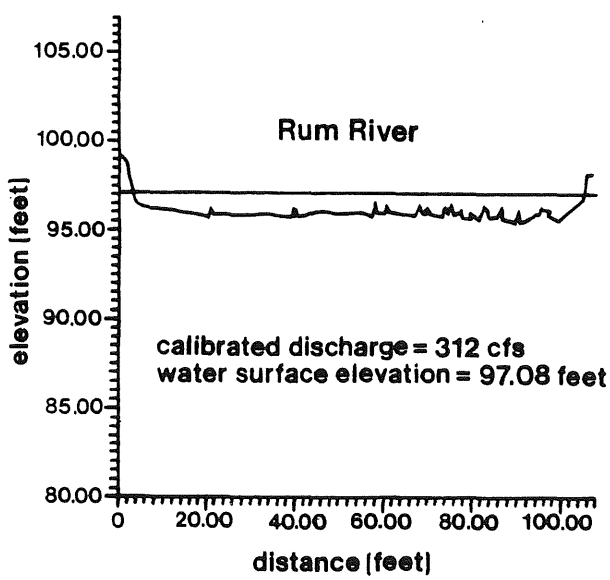


Figure 10. Plot of wetted perimeter vs. water surface elevation with defined inflection point.

One of the major criticisms of the wetted perimeter method is the subjective nature of the critical flow point selection. An attempt was made to reduce the subjectivity by using a mathematical solution. A computer program was developed (Lorenz, 1986) which first smooths a curve through the modeled points and then determines the degree of curvature at each point on the smoothed curve (Figure 10). The data were smoothed to reduce rounding and truncating errors associated with the modeled points. The smoothing function described a continuous function that was used to compute the degree of curvature. The point where the degree of curvature is at a maximum would theoretically corresponds to the inflection point and the discharge where the wetted perimeter decreases significantly.

6.1.2. Method

The output was analyzed and a range of instream flow approximations (IFA) for each site was chosen. The normal year flow recommendation is the high end of the range. The low end of the range is used for the dry hydrologic condition. The method of obtaining the IFAs is:

1) The mathematically defined inflection point on the wetted perimeter vs. water surface elevation curve was mapped on the cross-section plot.

2) A visually chosen inflection point was mapped on the cross-section plot. (Note: In 43 percent of the cases, both the mathematically defined and visually chosen inflection points were the same).

3) A discharge was determined for the water surface elevation corresponding to each inflection point.

4) The discharge where the average depth across the riffle was a half foot was determined. The half foot depth was based on professional judgement for canoe and fish passage criteria.

5) The mean annual flow (MAF) was calculated for each study site. When a gage was in close proximity, either upstream or downstream of the site, an area discharge ratio was used to calculate the MAF. For some cases, miscellaneous measurements were available and MAF could be determined through regression analysis with a nearby gage. Otherwise MAF was determined by a runoff equation developed by the U.S. Geological Survey:

   $0.07367 * A * RO$, SEE ± 25%

   Where, 0.07367 = empirical coefficient for converting runoff inches per square mile (volume) to cubic feet per second (rate)

   A = area in square miles

   RO = mean annual runoff

6) The discharges for each inflection point and half foot average depth were compared to the MAF to determine the reasonableness of the flow. If the inflection points were not the same and one was greater than the MAF, then the lower inflection point was used as the instream flow approximation. If the half foot average depth discharge was greater than the inflection point discharge, but less than the MAF, it was used as the normal year instream flow approximation. If all three points were greater than the MAF then the MAF was used.

7) The lowest discharge of the points was used for the dry hydrologic condition flow. In cases where the MAF was used as the normal year flow then a secondary inflection point was selected for the low range flow recommendation (Figure 11).

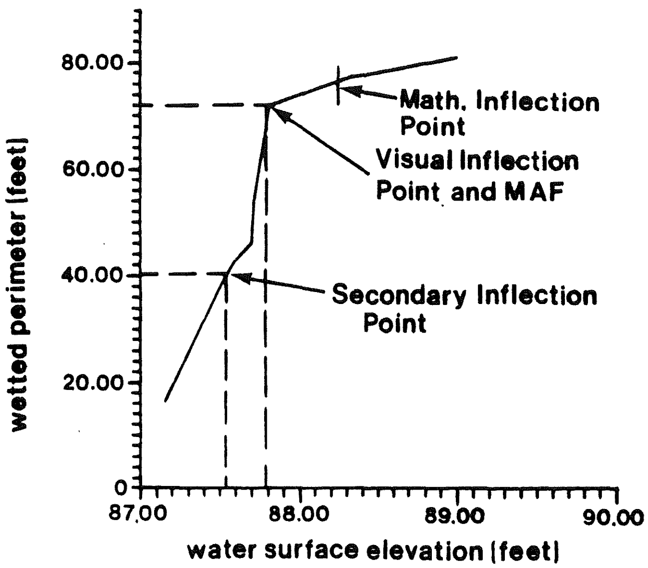


Figure 11. The mathematically defined inflection point is at a discharge higher than the MAF thus the MAF is used as the IFA. The dry year IFA is the lower inflection point.

8) On designated trout streams, the MAF was used as the instream flow approximation. As only temporary, short-time appropriations are permitted from designated trout streams, it has been assumed that all the flow is necessary to maintain the trout populations.

6.1.3. Method Error

The results obtained in the instream flow analysis are sufficient for the defined level of study. However, these results would not be appropriate for any more detailed analysis due to variability in instream use demands and errors inherent in the methods applied in developing the instream flow approximations.

The instream flow approximations determined for this study must apply over a broad geographic area and encompass a whole range of environmental conditions and instream uses. 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), channel morphology, water quality (temperature and chemical composition), fish and wildlife habitat requirements, and recreation needs.

Most streams have more than one instream use, and determining one annual instream flow for normal hydrologic conditions and one instream flow for dry hydrologic conditions 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 wetland maintenance, require variability in flow to maintain optimum production whereas other uses, such as navigation, benefit by less or no variation in flow. Exact requirements cannot be identified without detailed study.

Additional sources of uncertainty in determining the instream flow approximations comes from errors introduced into the analysis. Hydraulic simulation, data collection, sample size and hydrologic estimations of annual flow statistics were the primary sources of error in the study.

The use of hydraulic simulation and field data as a planning tool for determining instream flow approximations appears to be an improvement over hydrologic-based methods for this level of study. However, prediction of stage-discharge relationship through hydraulic simulation models is influenced by natural channel processes which may introduce numerous errors into the analyses.

The significance of the hydraulic simulation errors is related to the number of discharge measurements made. The errors become even more pronounced when simulating hydraulic parameters at flows outside the model range. When Manning's equation is the basis for the hydraulic model, the recommended range of extrapolation is 40-250% of the calibration discharge. The U.S. Fish and Wildlife Service conducted an error analysis (Bovee and Milhous, 1978) on various hydraulic models. A model based on Manning's equation had a mean error of 12-26 percent in predicting stage-discharge curves for 11 streams when discharges simulated were within .40-2.5 of the calibration discharge and only one set of calibration measurements were used. The mean error varied from 22-61 percent when no extrapolation limitations were used.

Four of 28 instream flow approximations for the normal hydrologic condition and four for the dry conditions were beyond the extrapolation limits. However, the difference between the mean of the 28 cases and the mean when the 4 cases are eliminated is insignificant at the 95 percent confidence level. There appeared to be no real difference in the variances between the two groups (P(.05)) either. Thus these points probably did not substantially increase the error.

A number of other errors can occur during hydraulic modeling. The one-dimensional model used to determine the instream flow approximations can not accurately predict real situations because water surface elevations are not flat. This is especially evident in more turbulent and steep sections of a stream. This approach assumes that flow variations caused by changes in channel configuration are negligible. In reality, the degree of change in the stage-discharge relationship is primarily a function of channel shape. Generally, the more uniform the channel, the more reliable the predicted hydraulic parameters. As the channel becomes less uniform, the error in predictions increases.

The use of a constant slope and Manning's n factor in the hydraulic simulation introduced another error. Slope and Manning's n do not remain constant in real situations when discharge changes. Analyses conducted by the Aquatics Systems Modeling Section of the U.S. Fish and Wildlife Service in Fort Collins indicate that using a constant slope and n factor commonly lead to an error of one-tenth of a foot in water surface elevation (Bob Milhous, November 1987, per. comm.).

Field data collection and survey methods are a typical source of error associated with instream flow analysis. The survey level of accuracy applied during this study was third order. The allowable error for this level of accuracy is 5 percent (0.5 $\sqrt{M}$, where M equals distance surveyed in miles).

The error associated with measuring velocities and discharge varies with channel characteristics and method of measurement. Carter and Anderson (1963) conducted statistical analysis of error associated with vertical-axis flow meters such as the Price AA current meter and pygmy flow meter. The investigators found that in measuring flow in natural streams, under average conditions, an error of 2.2 percent is likely when using the two-point method and an error of 4.9 percent is predictable for the one-point method. Heede (1974), in a study conducted for the U.S. Forest Service, found that discharge measurements in boulder strewn streams can have an error up to 20 percent. Most of the transects measured during the LCMR study had flow measurement errors in the 2-5 percent range.

Hydrologic data had to be simulated for 12 of the 28 sites. In the areas that were not gaged or had insufficient hydrologic data to develop mean annual flow statistics, the USGS formula for mean annual flow (pg. 28) was used. This formula has a 25 percent standard error of estimate.

The instream flow approximations have a combined error of 35-50 percent. This was considered an acceptable level of error for the study. The results are only reflections of approximate needs, however, and their degree of inaccuracy precludes their use as specific protected flows.

The total sample size (n=28) for field investigation was sufficient to provide reasonable estimates for planning. However, inferences can only be made for the state as a whole since the sample size for each region is generally insufficient to produce conclusive results on the regional use of instream flow methods. The following interpretation of results must be considered according to the errors inherent to the methods. Perhaps the results would differ significantly if a larger sample size was used and more diversity in size of sample streams existed within all the regions.

6.1.4. Interpretation of Results

Interpretation of the wetted perimeter results showed variation both within the regions and between the regions for the approximated normal and dry-year instream flows when compared as a percentage of mean annual flows (Table 3 and Figure 12). Throughout the state, the instream flow approximations ranged from 48-100 percent of mean annual flows for normal year scenario and from 30-73 percent of mean annual flows for the dry year scenario (Table 4).

As can be seen from Table 4, there are variations in the instream flow approximations as a percent of mean annual flow (MAF) within the regions also. For example, in Region 2, the instream flow approximations for normal year conditions ranged from 57 percent of the mean annual flow to 80 percent of the mean annual flow. The dry year instream flow approximations ranged from 30-68 percent of the mean annual flows.

Table 3. The mean annual flow, instream flow approximations, and percent of MAF for normal and dry year hydrologic conditions by region.

	MAF	Normal Year IFA (cfs)	% of MAF	Dry Year IFA (cfs)	% of MAF
Region 1					
Cannon	431	285	66%	185	43%
Zumbro	532	330	62%	240	47%
N.F. Zumbro	118	75	64%	65	55%
S.B. Root	168	130	78%	95	57%
			x̄ = 68%		x̄ = 50%
Region 2					
LeSueur	408	230	57%	120	30%
Cottonwood	277	244	88%	182	66%
Redwood near Redwood Falls	100	75	75%	65	65%
Redwood in Camden S.P.[1]	43	34	78%	30	68%
Rock	44	35	80%	20	45%
Des Moines	276	220	80%	190	69%
			x̄ = 76%		x̄ = 57%
Region 3					
Pelican	83	55	66%	45	55%
Otter Tail	311	200	64%	150	48%
Wild Rice	158	105	66%	75	47%
Clearwater	180	130	72%	72	40%
			x̄ = 67%		x̄ = 48%
Region 4					
Crow Wing	462	346	75%	231	50%
Pine	207	197	95%	104	50%
Straight[1]	44	35	80%	26	60%
Upper Miss.	38	30	79%	20	53%
			x̄ = 82%		x̄ = 53%
Region 5					
Kettle	127	105	83%	85	67%
Rum	320	195	60%	125	40%
Nemadji	50	41	82%	37	74%
			x̄ = 75%		x̄ = 60%
Region 7					
Knife[1]	42	25	60%	22	53%
Temperance[1]	138	83	60%	60	43%
			x̄ = 60%		x̄ = 48%
Region 8					
Stony	58	58	100%	41	71%
Region 9					
Cloquet	124	115	93%	60	48%
St. Louis	82	39	48%	30	37%
Swan	77	65	84%	41	53%
Little Fork	603	374	62%	270	45%
			x̄ = 72%		x̄ = 46%

[1]For comparing actual measured results as a percent of MAF the IFAs in the table are based on results of the wetted perimeter analysis only and do not include the management decision that 100% of the MAF is required for trout streams.

Table 4. The range of instream flow approximations in percent of MAF with average values for each region and statewide showing variation in the percent of MAF recommended.

Regions	1	2	3	4	5	7	8	9	Statewide
Range of Flow:[1]									
Normal year flows	62-78%	57-88%	64-72%	75-95%	60-83%	60%	100%	48-93%	48-100%
Dry year flows	43-55%	30-69%	42-55%	50-60%	40-74%	43-53%	71%	37-53%	30-74%
Dry-Normal means	50-70%	57-76%	48-67%	54-82%	59-76%	48-60%	61-100%	46-72%	46-100%
n =	4	6	4	4	3	2	1	4	28

[1]The ranges are based on actual results of the wetted perimeter analysis and do not include the management decision that 100% of MAF is necessary for trout streams.

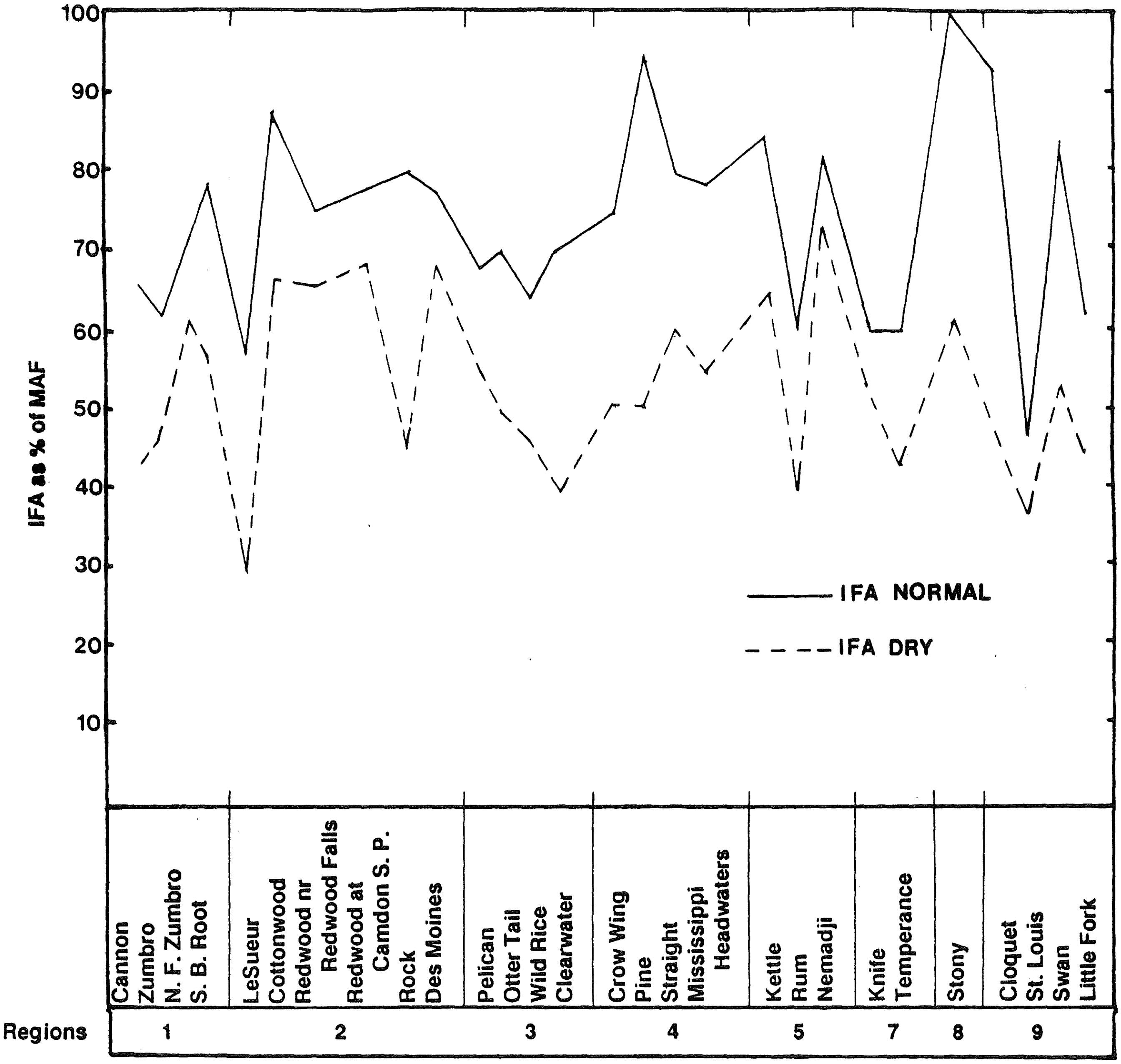


Figure 12. Variation in instream flow approximations for normal and dry year conditions as a percent of MAF.

Student's "t" distribution test was used to obtain a statewide estimate of the 95% confidence interval for the instream flow approximations expressed as a percent of MAF. Under normal hydrologic conditions, the 95 percent confidence was 68% $< \mu <$ 79% (Student's t value of 2.05) interval. The 95 percent confidence interval of values for dry hydrologic conditions was 98% $< \mu <$ 58% (Student's t value of 2.05). The majority of the sites do not occur within these confidence intervals indicating a significant degree of variability in results.

Statistical tests such as regression analysis, analysis of variance and Kruskal-Wallis analysis for non-parametric data were applied in an attempt to better understand the variability in the instream flow approximations as a percent of mean annual flow. The mean annual flow of a stream is a result of surface water runoff and groundwater interchange which are influenced by soils, topography, geology, vegetation, land use and drainage area to name a few. It is well known that many of the variables in natural systems are inter- and auto-correlated. The intertwining effects of the variables on stream flow and channel development and lack of independence among the variables limit testing for statistically significant differences. Significance tests were conducted, however, with the assumption of independence among the variables, in order to provide an indication of the strength of differences.

The regression analyses indicate that the wetted perimeter determined instream flow approximations are more a function of channel morphology and channel substrate size than mean annual flow. Channel morphology, substrate size and mean annual flow are all influenced by watershed characteristics such as soils, topography and geology. Mean annual flow and drainage area are correlated ($r = 0.76$). However, the instream flow approximations as a percent of mean annual flow are not correlated with drainage area (normal hydrologic condition: $r = -0.19$; dry hydrologic condition: $r = -0.21$). This indicates that mean annual flow and drainage area are not the determining factors for wetted perimeter derived instream flow in Minnesota.

The regression analysis resulted in a correlation between the instream flow approximations in cfs and mean annual flow (normal condition: $r = 0.97$; dry condition: $r = 0.95$) and drainage area (normal condition: $r = 0.62$; dry condition: $r = 0.79$). However, these correlations are probably more in response to increase in channel size. Usually as drainage area increases, discharge increases, and the channel width, depth and velocity increases with width increasing at a greater rate than depth and velocity (Leopold, 1962). As channel width, depth and velocity variables increase, instream flow approximations calculated through hydraulic simulation should also increase in order to accommodate the larger channel size.

Interpretation of these results led to the conclusion that relations between the instream flow approximations for the given habitat maintenance objective (riffle maintenance) as a percent of mean annual flow and drainage area are not linearly related as expected in the Tennant Method. Moreover, no correlation was indicated between the normal instream flow approximation as a percent of mean annual flow and the dry instream flow approximation as a percent of mean annual flow ($r = -.11$). These results signify the uncertainty associated with determining instream flows based on a fixed percentage of mean annual flow with no modification and field verification.

At least two hypothesis can be offered to explain the variability of results, lack of correlation, and low predictive ability for determining instream flow needs by a fixed percentage method. Both explanations are related to channel morphology and channel and basin development.

General laws of basin and channel development state that as streams progress downstream, stream gradients decrease, channel width increases, and stream bed particle size decreases (Hack, 1957; Leopold, 1962). The typical longitudinal profile is convex. These assumptions are most evident for streams flowing through uniform geology and climate. If a stream followed this orderly downstream progression, then, perhaps, the amount of instream flow required as a percent of a specified discharge would also show a consistent rate of change.

An orderly downstream change in stream gradients and bed particle size, however, is not always evident for Minnesota streams. Basin and channel development of the majority of streams is strongly influenced by the recent glaciation and variability associated with the surficial geology of Minnesota.

The surficial materials through which a stream flows influence channel form by determining bank strength, erosion thresholds and composition of bed materials. Since surficial methods influence channel substrate size they will influence the amount of flow required to cover the substrate in the channel. The variance in the results appears to be influenced by the heterogenous nature of surficial deposits, channel substrate variability and lack of an obvious orderly progression of development.

The wetted perimeter method and hydraulic model used in the study also appeared to cause variation in the results. The basic assumption underlying the method requires the use of riffles as the determining variable. Riffle channel form represents a balance between the frequency and magnitude of flows, sediment transport and other channel characteristics such as bank erosion or deposition that affect channel dimensions and substrate size. As noted above, the surficial geology exerts an influence on these variables. Thus, the development of riffles will be dependent on the surficial geology and topography through which the stream flows.

Channel dimensions, stream gradient and bed substrate size had an important influence on wetted perimeter calculations in the riffle areas. Wetted perimeter is equal to channel cross-section area divided by hydraulic radius (approximately equal to the water depth). Any change in channel structure (roughness factor) and slope will change velocities in a model driven by Manning's equation. Rate of change of particle size influences stream gradients. Longitudinal profiles can change as surficial geology changes. The composite profile of a stream flowing over various surficial landforms may show breaks where the stream flows from one surficial type to another. Any change in these variables will also change area and hydraulic radius, thus affecting the wetted perimeter variable. The heterogeneous nature of the glacial deposits made the streams and their longitudinal channel structure more difficult to classify and reduced consistency in the wetted perimeter results when the results were defined in terms of percent of mean annual flow.

Some investigators have found that the size of stream is related to the percentage of mean annual flow required for instream protection (Annear and Condor, 1984; Leonard, Orth and Goudreau, 1986). In order to test this hypothesis for the streams measured for this study, the data were classified into watershed size classes to ascertain if office methods could be more reliable using a different classification criteria. Table 5 shows the range of instream flow approximations for each watershed size class.

Table 5. The range of instream flow approximations in percent of MAF by stream size class.

	Stream Size Class (sq. mi.) 1-99	100-299	300-999	1000
Range of Flows:				
Normal year flows	51-100%	60-93%	60-95%	57-88%
Dry year flows	38-73%	43-68%	40-65%	30-68%
Mean dry and normal flows	57-73%	55-78%	49-71%	51-71%
n =	5	9	7	7

A visual analysis of the results in Table 5 indicates that watershed size classes do not provide a better grouping than the regions where the instream flow approximations are defined as a percent of mean annual flow (MAF). In order to explain how much of the variance in the instream flow approximations as a percent of MAF for normal or dry hydrologic conditions was explained by regional or watershed size groupings, two statistical tests for one-way analysis of variance (ANOVA) were applied to the data. The first test is for parametric data and the second, the Kruskal-Wallis test, is a non-parametric alternative. The first test has a normal distribution assumption while the second does not. The results of both tests indicate that, with 28 sample points, there was insufficient evidence to conclude that the regional or watershed size groupings were significant at any level of confidence in controlling the percent of MAF required for the instream flow approximations. The interpretation of these statistical tests also substantiated the hypothesis that instream flow as a percent of mean annual flow is not a viable method for determining specific instream flows within Minnesota. More data sampling points and diversity of stream size would provide greater opportunities to conduct additional statistical tests and observe spatial distributions of occurence. This would permit more detailed analyses of the relation of instream flow requirements to one or more physical factors.

The instream flow approximations were converted into percent of flow equalled or exceeded where flow records were available to see if there were any relationships between instream flow and other hydrologic statistics. The percent of flow equalled or exceeded was determined from the available flow duration information for the normal and dry instream flow approximations. Only sixteen of the sites had flow duration information available (Table 6).

The instream flow approximations expressed as a percent of flow equalled or exceeded varied between and within regions also. Only 43 percent of the sites for normal hydrologic conditions fall within the 95 percent confidence interval determined from the Student's "t" distribution. The number of sites that occur within the 95 percent confidence interval for the dry hydrologic condition decreases to 37 percent (Student's t value of 2.12).

From these results, we conclude, that in Minnesota, office methods relying on a specified flow duration statistics would not be appropriate for determining instream flows either. Use of flow duration or exceedance statistics is also limited to gaged sites. Simulation of flow duration curves at ungaged sites is not recommended (Riggs, 1968, 1972).

Table 6. The instream flow approximations converted to percent of flow equalled or exceeded from flow duration information.

Streams	Normal Year IFAs as % Equalled or Exceeded Flow	Dry Year IFAs as % Equalled or Exceeded Flow
Region 1		
Cannon	45%	56%
Zumbro	37%	50%
Region 2		
LeSueur	37%	50%
Des Moines	30%	35%
Rock	37%	50%
Cottonwood	26%	32%
Redwood near Redwood Falls	28%	32%
Region 3		
Otter Tail	54%	70%
Pelican	57%	60%
Wild Rice	26%	38%
Clearwater	34%	50%
Region 4		
Crow Wing	65%	75%
Pine	47%	72%
Region 7		
Knife	33%	36%
Region 9		
Swan	46%	60%
Little Fork	39%	45%

The regional groupings were useful for providing a rational manner of reducing field data collection and allowing transference of results. However, the above analysis implies that the existing regional delineation would not be appropriate for determining regional methods based on percentages of some flow statistics due to variability in results. The analyses also indicate that methods relying on flow duration statistics or fixed percentages such as the Tennant Method would not be reliable without modification and field verification on a case by case basis.

Additional errors in estimating the instream flow approximations as determined through office methods could arise from transferring estimated data of spatially variable events into regional and statewide instream flow approximations. One purpose of developing instream flow regions and selecting appropriate sample sites was to reduce this error.

Additional statistical testing was conducted on the sample population to determine if the regional groupings and chosen sample sites could still provide a valid method of transferring the point data to unmeasured watersheds. The instream flow approximations were normalized by eliminating drainage area from the analysis. Drainage area is usually eliminated as a variable by reduction to unit area. The unit area measure is used to compare or extend water yields within and between watersheds. An acceptable method of extrapolating mean annual flows is by drainage area relationships (Riggs, 1969, 1972). One of the relationships with a high correlation is the annual mean or median discharge to area ratio which provides the unit area measure of cubic feet per square mile (cfsm).

The instream flow approximations for each sample point were converted to cfsm. The mean annual cfsm was determined for each measured site also. Regression analysis was performed between the mean annual cfsm and the instream flow cfsm for both the normal hydrologic condition (r=.95) and the dry hydrologic condition (r=.90). This indicates that the factors influencing mean annual flow also influence the instream flow determined through the wetted perimeter analysis. Since it is acceptable to compare mean annual cfsm within and between watersheds or hydrologic regions, it was assumed that the instream flow cfsm could also be used in such a manner.

Two tests for analysis of variance (parametric and non-parametric) were applied to the instream flow approximations as cfsm to test the significance of the regional groupings when drainage area is eliminated. The results of both tests indicated that the regional groupings were significant (P(.01)) in controlling the amount of instream flow when described by a unit area measure. The percent of variation accounted for by the regional groupings was 65 percent.

The high degree of significance may have occurred due to lack of independence among the variables and random probability. However, it would seem probable that the regional groupings would still be significant. The results suggest that the factors that are important to runoff or flow per unit area such as soils, topography, geology, vegetation and land use, become important to instream flow per unit area.

Office methods based on channel and basin characteristics may prove more beneficial. Numerous investigators have shown that biological productivity is related to physical watershed characteristics controlling drainage pattern, flow rates, gravel sizes and shapes, channel gradients, stream and slope stability, and other channel and geomorphic parameters (Slack, 1955; Ziemer, 1971; Burton and Wesche, 1974; Marston, 1978; Platts, 1979; Beschta and Platts, 1986). Errors in estimating instream flows from these methods could be reduced through weighting point estimates. Weighting could be based on measureable physical parameters such as substrate size, channel slope, soil erodibility, percent riffles and pools, and other channel and basin characteristics. The instream flow regions could be more useful if subdivision is refined based on channel characteristics. Due to insufficient data, neither this type of method nor hypotheses regarding influence of channel of basin characteristics on instream flow could be further analyzed in this study. However, the potential for developing instream flow equations or office methods based on channel and basin characteristics needs to be further explored.

Until other office methods can be developed, the Tennant Method recommendations for optimum flow (60-100% of MAF) could be used as a guideline for planning level studies or possibly for interim protected flows where adequate hydrologic data and knowledge of the river system exists. There is approximately a 85 percent probability (n = 28) of any case occuring during normal flow conditions within the recommended 60-100 percent of mean annual flow. The median value of the instream flow approximations is 75 percent of the mean annual flow.

Tennant's recommendations for good to outstanding habitat conditions (40-60% of MAF) could be used as guidelines for drought planning. There is approximately a 61 percent probability (n = 28) of any case occuring within this range based on instream flow approximations for the dry hydrologic condition. The median value of instream flow approximation as a percent of mean annual flow is 53 percent. Thirty percent of the mean annual flow should be the absolute minimum during dry periods without further investigation. The results indicate that flows below 30 percent of the MAF are undesireable based on potential impacts on food production, bank cover, and spawning and rearing habitat. Extreme low flows can decimate warm water stream fish and invertebrates and higher flows may permit rapid recolonization (Larimor, et. al., 1959). Lower flows can also allow sand accumulation in riffles due to reduced ability of the stream to carry sediment. This in turn may decrease invertebrate and forage species which are food sources for game fish (Orth, 1987).

Any instream flow determined through the use of the Tennant Method or any other office method should be verified. This would require at least one visit to the stream and some measurements at the recommended flow.

6.2 EXTRAPOLATION ANALYSIS

The instream flow approximations as determined for the measured sites had to be extended to 39 watersheds, five economic regions and statewide for the economic analysis and IPASS model. The extension of the results of the geographical point data was facilitated by statistically defining instream flow regions. Within these regions, the results of the point-data analysis in cfsm can be averaged to best represent the characteristics of the whole region. Generally the average is applicable throughout the region for planning purposes (Chow, 1964).

As discussed previously, it is an acceptable method to use mean or median annual cfsm to extend flows throughout a watershed or hydrologic region. A priori assumptions had to be made for transferring the measured data to other watersheds. However, the regression analysis and ANOVA tests indicate that this method could be appropriate on this study level, for extending the measured instream flow data in the instream regions also. The instream flow cfsm can be averaged to provide a constant yield factor for all points within measured and unmeasured watersheds. In this manner, flow can be approximated for any point by multiplying the constant yield factor for that watershed by the drainage area above the point.

Instream flow approximations for each of the watersheds, economic regions and statewide were calculated from the water availability figures supplied by the U.S. Geologic Survey. The numerical results of both watershed analyses are in Appendix F. Instream flow approximations were determined and extended to unmeasured sites through a process of several steps:

1. The total watershed area for each of the 39 watersheds was proportioned into area drained by designated trout streams and area drained by non-designated trout streams. This division is necessary in order to ensure the assumption is met that trout streams require 100 percent of the MAF for protection.

   The area in each watershed drained by trout streams was estimated by identifying the townships through which the streams flowed. The locations were obtained from the Department of Natural Resources inventory of designated trout streams. The total area drained by the trout streams was calculated for each watershed and converted into a percent of the entire watershed.

2. For each of the 28 measured sites, the normal and dry instream flow approximations were converted into cubic feet per square mile (cfsm) for the non-trout streams using the following equations:

   a) $$\frac{IFA_{50}}{tDA} = qIFA_{50}$$ b) $$\frac{IFA_{75}}{tDA} = qIFA_{75}$$

   Where: IFA_{50} = flow in cubic feet per second (cfs) necessary at the transect for normal year instream flow needs

   IFA_{75} = flow in cfs necessary at the transect for dry year instream flow needs

   tDA = drainage area in square miles above the transect

   $qIFA_{50}$ = flow in cubic feet per second per square mile (cfsm) for normal years instream flow needs

   $qIFA_{75}$ = flow in cfsm for dry year instream flow needs

   If more than one stream was measured in a watershed then these values were averaged for the watershed.

3. The water availability flows provided by the U.S. Geologic Survey for normal (Q_{50}) and dry (Q_{75}) hydrologic conditions were converted into cfsm by the following equations:

   a) $$\frac{WA_{50}}{WDA} = qWA_{50}$$ b) $$\frac{WA_{75}}{WDA} = qWA_{75}$$

   Where: WA_{50} = the normal year water availability in cfs

   WA_{75} = the dry year water availability in cfs

   WDA = the drainage area of the watershed in square miles

   qWA_{50} = the normal year water availability in cfsm

   qWA_{75} = the dry year water availability in cfsm

4. The IFAs as a percent of the water availability for normal and dry hydrologic conditions were calculated as follows:

a) $\dfrac{qIFA_{50}}{q\ WA_{50}} \times 100 = iQ_{50}$ b) $\dfrac{qIFA_{75}}{qWA_{75}} \times 100 = iQ_{75}$

Where: iQ_{50} = the percent of the water availability in cfs needed for instream flow in a normal year

iQ_{75} = the percent of water availability in cfs needed for instream flow in a dry year

5. The total amount of flow needed for the instream flow approximations was determined by adding the trout instream flow, at 100% of the available flow, to the non-trout instream flows:

a) $[(qWA_{50})(100\ DAT)] + [(qWA_{50})(iQ_{50})(DAN)] = IFA_{50w}$
b) $[(qWA_{75})(100\ DAT)] + [(qWA_{75})(iQ_{50})(DAN)] = IFA_{75w}$

Where: DAT = the estimated watershed area in square miles drainged by trout streams

DAN = the estimated watershed area in square miles drained by non-trout streams

IFA_{50w} = the instream flows approximation in cfs for the watershed in normal years

IFA_{75w} = the instream flow approximation in cfs for the watershed in dry years

6. The flows determined in step 5 are converted to acre-feet for a yearly volume:

a) $IFA_{50w} \times 1.98 \times 365 = V_{50}$
b) $IFA_{75w} \times 1.98 \times 365 = V_{75}$

Where: 1.98 = the conversion factor for changing cfs to acre-feet

365 = days in year to convert acre-feet to a yearly volume

V_{50} = the yearly volume needed for instream flow in a normal year

V_{75} = the yearly volume needed for instream flow in a dry year

Figure 13 and Table 7 illustrate this process by example.

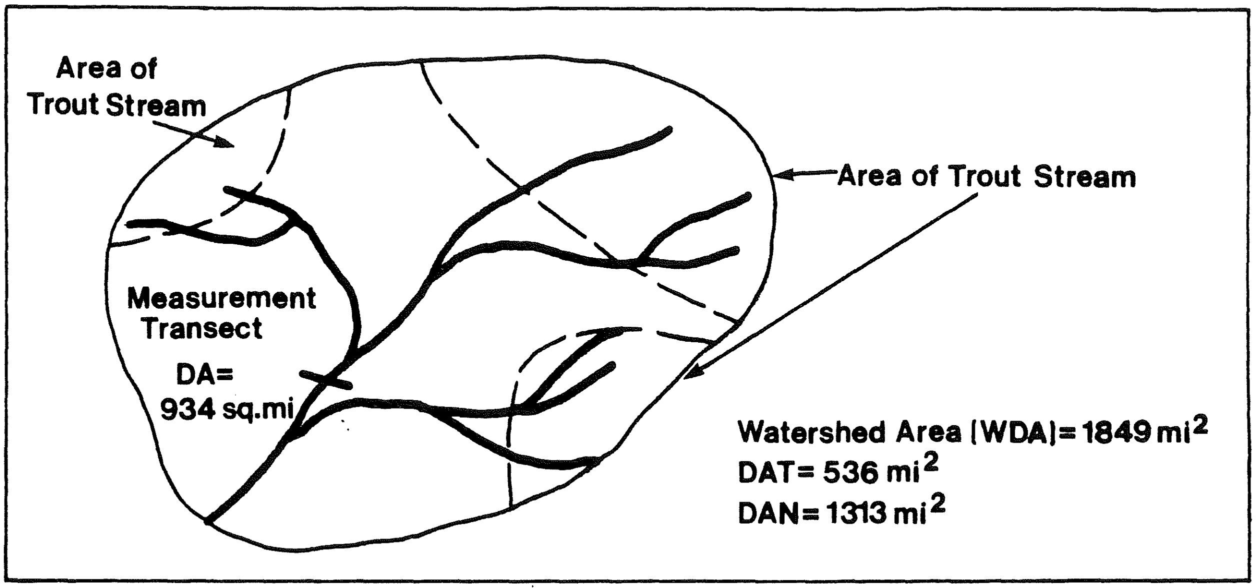


Figure 13. Hypothetical watershed showing total drainage area and proportion of trout stream area to non-trout stream area.

Table 13. Calculations for extending instream flow approximations.

IFA_{50} = 374 cfs

IFA_{75} = 270 cfs

WA_{50} = 1119 cfs

WA_{75} = 819 cfs

Calculations:

	Normal	Dry
Step 2.	a) $\frac{374 \text{ cfs}}{934 \text{ mi}^2} = 0.400$ cfsm	b) $\frac{270 \text{ cfs}}{934 \text{ mi}^2} = 0.289$ cfsm
Step 3.	a) $\frac{1119 \text{ cfs}}{1849 \text{ mi}^2} = 0.605$ cfsm	b) $\frac{819 \text{ cfs}}{1849 \text{ mi}^2} = 0.443$ cfsm
Step 4.	a) $\frac{0.400 \text{ cfsm}}{0.605 \text{ cfsm}} \times 100 = 66.2\%$	b) $\frac{0.289 \text{ cfsm}}{0.443 \text{ cfsm}} \times 100 = 65.2\%$

Step 5.
a) [(0.605)(536)] + [(0.605)(66.2%)(1313)] = 850 cfs
b) [(0.443)(536)] + [(0.443)(65.6%)(1313)] = 617 cfs

Step 6.
a) 850 cfs x 1.98 x 365 = 610,000 ac. ft.
b) 617 cfs x 1.98 x 365 = 440,000 ac. ft.

The 28 rivers surveyed using the wetted perimeter analysis represented 19 of the 39 Department of Natural Resources watersheds. For these watersheds, it was possible to directly extend the transect information throughout the watershed to determine instream flow approximations. For the remaining 20 watersheds, direct extension was not possible. For those watersheds, information was extrapolated from an analogous watershed. The particular watershed used for extrapolation was selected based on hydrologic and geologic similarities using the previously defined instream flow regions, flow duration curves, and hydrographs. After an analogous watershed was selected for extrapolation, the transect data from the measured site(s) in that watershed (instream flow approximations in cfs, for normal and dry conditions), and the corresponding drainage area of that site was then used to determine the instream flow approximations for the non-measured watershed. The watersheds that were selected for extrapolation have been indexed in the summary of results table (Appendix F).

Instream flow approximations for the five economic regions were similarly determined. The watershed areas within each region were calculated then partioned into trout stream drainage area and non-trout stream drainage area. The previous formulas were then applied for each economic region. The instream flow approximations for each region were summed to obtain the statewide instream flow volumes for normal and dry hydrologic conditions (Table 8). The watershed instream flow figures were not summed because the water availability for the watersheds has greater error than the water availability volumes determined for the economic regions.

Table 8. 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

6.3 RESOURCE SURVEY RESULTS

The resource survey sent to the DNR regional and area managers provided valuable information regarding the instream flow uses and needs within the state. The combined response rate for the three surveys was 95 percent (fisheries 92%, wildlife 97% and recreation 96%). Of the surveys that were returned 90 percent contained useable information. The remaining 10 percent (predominantly recreation surveys) were not completed due to a lack of information on the part of the respondents. Survey returns were coded and stored in computer files to facilitate analysis. For data stratification purposes each return was indexed by survey type, stream number from the "Statewide Outstanding Rivers Inventory" (Kimball, 1983), watershed number, DNR management region number and instream flow region number. Separate results have been prepared for each of the surveys and are presented below.

Fisheries - The results of the survey indicate that northern pike and walleye are the most prevalent sportfish species found in Minnesota rivers (79.4 and 65.8 percent respectively; Table 9). Other prevalent sportfish species, in descending order of abundance, are channel catfish, smallmouth bass, brook trout, rainbow trout, and brown trout. Largemouth bass, muskellunge, salmon and various panfish and bullhead species are also important sportfish in certain rivers of the state. Very little information was generated through the survey regarding the presence of species of special interest. Natural Heritage data indicates that there are 24 species of fish and 4 speices of mollusks that are recognized as being threatened, rare or of special concern in the State of Minnesota. Documented occurrences of these species have for the most part been from the southeastern and southwestern parts of the state. There are 623 designated trout streams in Minnesota representing 2060 miles of natural trout reproducing or hatchery maintained waters.

The resource managers estimated that the survivial, productivity or use by the fish community in 76.0 percent of the rivers surveyed is definitely (33.3%) or suspected (42.7%) to be adversely affected by natural or man-caused limiting factors (Table 10). In 21.4 percent of the streams, they estimated as doubtful (18.7%) or certain (2.7%) that these factors are not limiting the fishery. No assessment was provided for the remaining 2.7 percent of the rivers.

Table 9. Important sportfish species and estimates of abundance for the "Statewide Outstanding Rivers". Numbers represent the total responses for each category based on 145 survey returns.

	Abundance					Total	
Species	Abundant	Common	Uncommon	Rare	Expended	No.	%
Northern pike (Esox lucius)	22	72	14	2	6	116	79.4
Walleye (Stizostedion vitreum)	12	48	26	7	3	96	65.8
Panfish spp.	5	28	22	4	2	61	41.8
Channel catfish (Ictalurus punctatus)	5	21	8	3	3	40	27.4
Smallmouth bass (Micropterus dolomieui)	7	17	10	1	1	36	24.6
Brook trout (Salvelinus fontinalis)	13	7	6	4	1	31	21.2
Rainbow trout (Salmo gairdneri)	5	19	4	2	-	30	20.5
Brown trout (Salmo trutta)	4	17	5	1	-	27	18.5
Largemouth bass (Micropterus salmoides)	-	7	14	2	-	23	15.8
Bullhead spp.	4	7	3	-	-	14	9.6
Salmon spp.	2	9	2	-	-	13	8.9
Muskellunge (Esox masquinongy)	-	1	2	1	1	5	3.4

For the analysis of limiting factor and probable source information, certain categories were aggregated to account for some redundancy in the survey design. Twelve categories of limiting factors and 9 categories of probable sources were used in the final analysis. The categories relating to stream flow conditions were analyzed separately to specifically identify whether the sources for these

Table 10. Limiting factors and probable sources affecting the survival, productivity or use of the fish community for the "Statewide Outstanding Rivers". Numbers represent the total responses for each category based on 146 survey returns.

Limiting Factors	Major Concern	Minor Concern	Total No.	Total %
Low flows	64[a]	28[b]	92	60.5
Erosion/siltation	59	14	73	50.0
Flow fluctuation	19[a]	37[b]	56	38.4
Nutrient surplus	26	21	47	32.2
Temperature (high or low)	16	29	45	30.8
High flows	25[a]	9[b]	34	23.3
Toxic substances	11	20	31	20.4
Channelization	15	12	27	18.5
Fish kills	15	9	24	16.4
Dissovled oxygen	17	4	21	14.4
Nutrient deficiency	7	3	10	6.6
pH (high or low)	1	4	5	3.3

Probable Sources	Major Source	Minor Source	Total No.	Total %
Agriculture	55	18	73	50.0
Natural	33	23	56	38.4
Municipal	21	25	46	31.5
Feedlots	17	24	41	28.1
Urban	4	14	18	12.3
Industrial	12	6	18	12.3
Forestry	-	7	7	4.8
Landfills	-	4	4	2.7
Mining	-	1	1	0.7

[a]Responses indicating natural causes as the source of the problem.
[b]Responses indicating man-induced causes as the source of the problem.

problems are naturally occurring or man-induced. The most frequently reported limiting factors were low flows (63.0%), erosion/siltation (50.0%), flow fluctuations (38.4%), nutrient surplus (32.2%) and temperature (30.8%) (Table 10).

The most frequently reported sources for the limiting factors were agriculture (50%), natural conditions (38.4%), feedlots (28.1%), and municipalities (17.1%) (Table 10). Low flow and high flow problems were most often associated with natural causes, whereas, flow fluctuation problems were predominantly man-induced. The loss of storage resulting from wetland drainage, and, hydropower peaking operations were the most frequently cited causes for flow fluctuation problems.

Respondents ranked the status of each river with respect to its ability to support fish, particularly sportfish. Evaluations were made based on present, past, and future conditions. The results of this analysis indicate that present conditions are very similar to what they were 5-10 years ago (Table 11). Respondents also speculated on what the resource capability would be if man-induced limiting factors were eliminated. The results indicate that in the view of the respondents, there could be improvements in the state's rivers over present conditions if man-induced limiting factors were controlled or eliminated (Table 11). The number of streams ranked 0, 1, and 2 (those with minimal ability to support fish) would decrease with a concomitant increase in the number of higher ranked streams.

Wildlife - The survey results indicate that rivers provide and maintain valuable habitats for a variety of wildlife (Table 12). In addition to providing habitat for waterfowl and furbearers, the river corridors frequently provide critical wintering habitat for white-tailed deer and various upland species. This is especially true in the agricultural portions of the state. Respondents indicated that there are at least 257 parcels of public land, managed as wildlife habitat, that are directly influenced by rivers. These lands include Wildlife Management Areas, Waterfowl Production Areas and National Wildlife Refuges.

Table 11. Capability of the stream resources to support fish populations, with emphasis on sportfish species. Number represent the total responses indicated for each category.

Category	No. Fish	Roughfish Only	Minimum Ability	Moderate Ability	Excellent Ability	Maximum Ability	Total
Present conditions	0	1	35	58	49	6	149
Past conditions (5-10 years ago)	0	1	33	56	49	5	144
Future conditions (5-10 years from now)	1	11	37	49	47	6	151
Resource potential	0	0	16	47	66	20	149

Table 12. Important wildlife uses associated with the river corridors for the "Statewide Outstanding Rivers". Numbers represent the total responses, for each category use based on 170 survey returns.

Use	Number	%
Furbearer habitat[1]	170	100.0
Waterfowl nesting habitat	144	84.7
Waterfowl feeding area (includes brood rearing)	109	64.1
Deer wintering habitat	106	62.3
Waterfowl staging area	73	45.9
Bald eagle feeding area	60	35.3
Wintering habitat for upland species	37	21.8
Colonial nesting sites (i.e., heron rookeries)	31	18.2
Osprey nesting and feeding areas	21	12.3
Fisher and pine martin use	15	8.8
Bald eagle nesting and rearing	14	8.2
Sandhill crane use	11	6.5
Timber wolf use	10	5.9

[1]Furbearers (rated as abundant or common)

Mink	166	97.6
Beaver	163	95.9
Muskrat	155	91.2
Raccoon	139	81.8
Otter	84	49.4

The respondents were requested to provide information regarding the hunting and trapping opportunities found along the river corridors. Hunting was divided into separate categories for waterfowl, big game and small game. The results of the survey indicate that mallards, wood ducks and teal were the most common species sought by waterfowl hunters (Table 13). White-tailed deer were the predominant big game species, however, moose and black bear hunting were locally popular along some of the rivers in the northern part of the state. Important small game species include ruffed grouse, pheasants, rabbits and fox. Important furbearers include mink, muskrat, beaver, raccoon, fox and otters. The intensity of use of each category was estimated by the respondents. The results indicate that big game hunting is the most popular type of hunting associated with the river corridors (Table 13). Trapping is also an important activity as evidenced by the level of use estimates.

Table 13. Hunting and trapping opportunities associated with the river corridors for the "Statewide Outstanding Rivers". Numbers represent the total responses for each category based on 170 survey returns.

Activity	Important Species	Responses Number	%	Level of Use Heavy	Moderate	Low
Waterfowl hunting				53	68	47
	Woodduck	116	68.2			
	Mallard	115	67.6			
	Teal	67	39.4			
	Canada geese	34	20.0			
	Other[1]	41	24.1			
Big Game hunting				106	55	7
	White-tailed deer	147	86.5			
	Black bear	34	20.0			
	Moose	31	18.2			
Small Game hunting				29	113	28
	Grouse	91	53.5			
	Pheasant	59	34.7			
	Rabbits	48	28.2			
	Fox[2]	44	25.9			
	Squirrel	33	19.4			
	Woodcock	14	8.2			
	Hungarian partridge	14	8.2			
Trapping				73	84	5
	Mink	115	67.6			
	Muskrat	90	52.9			
	Beaver	83	48.8			
	Raccoon	75	44.1			
	Fox[2]	41	24.1			
	Otter	30	17.6			

[1] Predominantly diving duck species.
[2] Fox were identified as an important species for both small game hunting and trapping.

Recreation - The total number of responses for each of the recreational activities was calculated for both the current level of use and resource potential categories. Totals were based on the combined responses of fisheries and trails and waterways respondents. For this reason, the number of responses do not correlate with the number of rivers (i.e., there may be several responses for each river). Each response was numerically coded to indicate the respondents estimates of current level of use (1-heavy, 2-moderate or 3-low) and resource potential (1-potential reached, 2-resource underutilized or 3-resource potential unrecognized). Statewide estimates of current level of use and resource potential were calculated by averaging the response scores for each activity.

The survey results indicate that fishing, hunting, canoeing, camping, picnicking, hiking and swimming are the most frequently reported recreational activities associated with the river corridors (Table 14). Each of these activities was reported in at least 50 percent of the responses. Statewide estimates of the current level of use for these activities indicate that fishing, canoeing and camping are the most popular recreational activities. The current level of use estimates for all activities ranged from low to moderate.

In the opinion of the respondents, the resource potential for most of the activities listed is not being realized (underutilized; Table 14). Power boating and wild rice harvesting opportunities on the rivers are somewhat limited. Because these activities are popular, and the opportunities are limited, the current level of use approaches the resource potential.

Table 14. Recreational uses associated with the river corridors for the "Statewide Outstanding Rivers". Numbers represent the total responses for each activity based on 261 survey returns.

Activity	Responses Number	%	Current Level of Use[1]	Responses Number	%	Resource Potential[1]
Fishing	251	96.2	2.5	257	98.5	1.8
Hunting[2]	192	73.6	2.7	196	75.1	1.9
Canoeing	183	70.1	2.6	187	71.6	2.0
Camping	163	62.4	2.6	183	70.1	2.0
Picnicking	160	61.3	2.8	187	71.6	2.0
Hiking/walking	142	54.4	2.8	179	68.6	2.1
Swimming	131	50.2	2.9	149	57.1	1.9
Viewing	128	49.0	2.5	171	65.5	2.2
Wading	108	41.4	2.7	145	55.6	1.9
Observing flora/ fauna	106	40.6	2.7	158	60.5	2.1
Tubing	82	31.4	2.8	143	54.8	2.0
Power boating	79	30.3	2.5	110	42.1	1.5
Kayaking	76	29.1	2.8	142	54.4	2.0
Wild ricing	50	19.2	2.7	107	41.0	1.5
Rock collecting	37	14.2	2.9	111	42.5	2.0

[1] Average score for all responses reported for each activity is based on resource managers perceptions.
[2] Does not include trapping.

6.4 SUMMARY

As useful as the regions were for obtaining and transferring data, there appears to be reasons to further sub-divide for more detailed analysis. If the regions are reclassified or the existing subdivision is refined, channel and basin parameters should be included in the analysis. Parameters such as channel slope, channel pattern, dominant substrate size could be important classifiers.

The instream flow analysis provided reasonable but conservative (high) instream flow approximations. The Manning's driven hydraulic model is only valid within certain limits, however, this does not detract from its usefulness within those limits. The quality of the model does not depend on how realistic it is, but how well it performs in relation to the purpose for which it is built. The wetted perimeter hydraulic model provided appropriate information for this level of study.

Methods based on flow statistics or fixed percentages of mean flows such as the Tennant Method would have been inappropriate as the relationship between instream flow approximations, as a percent of mean annual flow, within stream size or regional groupings is not linear, but random. The hydrologic methods can be useful within the limits of adequate hydrologic data and knowledge of the needs of hydrologic and biological systems. Determination of these needs would require field investigation in many instances. However, the field validation required for the office methods can be more time-consuming than the field effort required for the hydraulic rating method and thus were not appropriate for this two-year study.

Using wetted perimeter and depth as habitat and recreation decision variables is an appropriate technique for the scope of this study. These variables, however, would not be sufficient to define needs in site-specific studies. Describing only riffle habitat is the major limitation. The data provides only passage information for fish and canoes, and habitat information for riffle-dependent species.

For site-specific studies, an instream flow method would need to encompass multiple transects that define the other available habitat found in pools, runs and transition zones. Generally pool species prefer slow, deep water, and are not as dependent on wetted perimeter since pools retain much of their depth at lower flows. A wetted perimeter analysis would answer only the food production needs of pool species, by providing flow recommendations for riffle species that may be a food source for the pool species.

As Figure 7, page 21 illustrates, the incorporation of pools and other habitat types other than riffles into a wetted perimeter analysis may present another limitation to the method. The inflection point of the wetted perimeter-discharge function will become less definitive due to the relationship between channel cross-section shape and wetted perimeter. Other investigators have encountered this problem (Annear and Condor, 1984; Nelson, 1984; Reed and Mead, 1986).

A mathematically defined formula such as the one developed by Lorenz (1986) may enable the objective determination of the inflection point. This technique has not been tested for pool or run cross-sections.

The instream flow approximations cannot be used for site-specific analysis. The error associated with the analysis is high. The evaluation only analyzed riffles and not other habitat. The instream flow approximations are for yearly instream flow volumes in order to accommodate the economic analysis which is based on yearly figures. For site specific recommendations, seasonal and monthly instream flow needs should be considered.

CHAPTER 7. CONCLUSIONS AND RECOMMENDATIONS

Decisions made regarding streamflow allocations require the evaluation of numerous decision variables. Instream flow implementation is one of the important decision variables that determine the benefits and liabilities of any management practice and streamflow allocation strategy.

In Minnesota, where there are over 6,500 streams and rivers, instream flow determination and implementation would be an enormous task without simplification. In order to simplify, a statewide identification of priority and conflict areas is necessary. Only after a statewide assessment is accomplished, can specific studies be conducted to determine instream flow needs as required by Minnesota laws. This project provided the initial statewide data and analysis to develop priorities for future studies and identify issues.

A previous study done on statewide instream flow needs used a fixed percentage of mean annual flow. More recent site-specific studies indicate that using a fixed percentage statewide may not be an adequate scoping mechanism to determine areas of concern and priority. This is primarily due to the diversity of the geologic, hydrologic and biological systems in the state. Thus a management decision to include field point data was made to more accurately describe the areas.

During this study, Minnesota was classified into 10 instream flow regions to facilitate the choice of representative rivers for field sampling. Twenty-four sites throughout the state were measured. Data from four previously measured sites were combined with these data to obtain "instream flow approximations".

A wetted perimeter analysis based on a Manning's equation driven hydraulic model was used to determine the specific instream flow approximations at each of the 28 measured sites. These instream flow estimates were then extended throughout the watersheds.

The results of the wetted perimeter analysis indicates that there is a significant degree of variation in instream flow as a percent of mean annual flow and as a percent of flow exceeded or equaled (flow durations). The variation may be due to the heterogeneous nature of surficial deposits which affect channel substrate and form. The wetted perimeter hydraulic model is influenced by substrate size and channel configuration. The results indicate that instream flow relationship is not linearly related to mean annual flow as assumed by instream flow hydrologic methods such as the Tennant Method or flow duration statistics.

The Tennant Method and other hydrologic methods attempt to circumvent the problem of variability or nonlinearity by assuming the average, or other flow statistics such as flow duration, prevail. These types of hydrologic methods do not appear to provide appropriate estimates without field verification and modification for the particular stream system.

The instream flow approximations provided the decision base for determining the approximate volume of flow necessary to protect instream uses at the outflow point of each of the 39 DNR principle watersheds. The instream flow approximations are generally conservative (high) because the approximations must apply over a broad geographic area and encompass a whole range of environmental conditions, issues, instream uses, and offstream uses.

The instream flow assessment does not take into account monthly or seasonal instream flow needs, management objectives, or water availability. The instream flow approximations are annual volumes only in order to accommodate the IPASS economic model. Thus the instream flow approximations cannot be used as protected flows for specific water allocation or appropriation issues. They are a planning tool to provide insight regarding potential area of conflict.

The watershed instream flow approximations were compared to existing offstream water use and available water supplies for dry and normal hydrologic conditions to identify areas of conflict or concern. As part of the instream flow evaluation, a survey of DNR resource managers was conducted. The survey results provided identification of instream uses throughout the state and a preliminary identification of management priority areas. This process is described in the Water Allocation and Management Study main report "Volume 1: The Value of Water to Minnesota".

Instream flow approximations were determined for each of the 5 economic regions, as identified by the Department of Trade and Economic Development, and the state as a whole. These annual volumes were used as inputs to a computer simulation model of the Minnesota economy developed by the Department of Agricultural Economics of the University of Minnesota and the Natural Resources Research Institute at Duluth. This Interactive Policy Analysis Simulation System (IPASS) model (formerly SIMLAB) analyzes the economic value of water to the state and the impacts of changes in water supply on economic production. The instream flow approximations act as a constraint on economic development in the economic model. Descriptions of these components and references to supporting reports are found in "Volume 1: The Value of Water to Minnesota".

In conclusion, the method of hydraulically modeling field data to obtain an instream flow decision variable (wetted perimeter) in combination with extension of sample points to determine instream flow approximations provided a relevant planning tool for statewide and watershed assessment. The analysis provided a preliminary comparison of potential instream flow methods for future site-specific studies and initial input for developing instream flow program procedures. The survey of resource managers furnished useful preliminary information on instream uses for the 157 rivers identified in the report entitled "Statewide Outstanding Rivers Inventory" (Kimball, 1983).

A relatively high degree of error was associated with the analysis and affected the results. Error was introduced through data collection, modeling, sample size and transference of instream flow approximations to unmeasured watersheds. The results varied significantly within and between the instream flow regions. Some of this variation may have been caused by the inherent errors. However, Annear and Condor (1987) found that methods yielding variable recommendations for different stream types or sizes may be more biologically accurate then methods with consistent tendencies.

7.1 RECOMMENDATIONS

Additional site-specific instream flow studies should be conducted to expand on the work already accomplished and to develop analytical and management tools.

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. Other more definitive instream flow methods can be used and results compared to determine the accuracy, reasonableness and usefulness of each method for developing protected flows.

The studies should evaluate management alternatives and options such as 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. Impacts should be considered for the entire watershed, not just the specific reach being studied. The results of the studies would provide information to develop specific procedures and policies concerning protected flow designation and to assist in other state programs such as local water planning.

The Instream Flow Incremental Method (IFIM), developed by the U.S. Fish and Wildlife Service, is considered the most comprehensive method for predicting changes in habitat from changes in hydraulic and physical parameters. This method should be used as the standard for comparing other methods and developing less intensive methods for non-conflict situations. The IFIM should be used in any conflict situation until other methods can be compared to this method. In comparing the methods, each should be examined in terms of flexibility, time and budget commitments, complexity, and management options.

A statewide instream flow program need to be developed to enable comprehensive management and decision making regarding instream flow issues. The assessment of appropriate instream flow methods and creation of the biological database should be a component of the program development. Promotion of constituency awareness and support should be an important aspect of the program development also. Interim and/or office instream flow assessment methods should be developed to facilitate the water allocation permit process until a program is implemented.

The lack of primary biological data on riverine fish species habitat requirements and preferences has limited past efforts in establishing adequate protected flows and developing a comprehensive instream flow program. The biological data is essential for determining instream flow requirements. Studies should be conducted to obtain necessary biological information on the population dynamics and habitat requirements for various stream species. The IFIM analysis requires biological data to be in the form of habitat suitability indices (fish preference curves) based on species seasonal preference for such variables as depth, substrate, temperature and velocity.

Hydrologic data is also necessary to conduct instream flow analyses. It is generally more readily available than any other necessary data, but 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.

During the process of developing the instream flow program, the adequacy of existing protected flows (instream flows) and reservoir and hydropower operation plans should also be evaluated. Protected flows have been established on forty-four 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 currently licensed and do not have formal operation plans. The Federal Energy Regulatory Commission is requiring these unlicensed hydropower operations to begin the licensing process.

Instream flow methods should be considered not only as a regulatory tool but also as a method to enhance existing resources. 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 reservoir values such as flood control and wildlife.

The DNR, Division of Waters, has responsibility for establishing and implementing instream flow requirements; however, instream flow issues are interdisciplinary and complex. 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 developing the program. One method of obtaining and integrating the concerns, knowledge and issues of other disciplines and agencies is to develop an interagency technical advisory group.

Not only should other governmental entities be involved in the process, but also interested public and private groups. Involving and educating these groups can help alleviate conflicts before they occur, and build support for program development and implementation. A means of integrating public (sporting groups, recreation clubs, etc.) and private interest groups (utilities, irrigators, mining companies, etc.) needs to be developed. A public participatory method developed by the Center for New Democratic Processes (Crosby et. al., 1986) and used to form the "Citizen Panel on Agriculture and Water Quality" provides one framework for developing citizen advisory groups.

Most of the above recommendations could be incorporated into the LCMR funded Water Allocation and Conservation Study (FY 88-90). There are additional issues, however, that should be considered for future study. Some of these issues are:

1. The effects of flow modification and changes in sediment loads on riparian wetlands.

2. The effects of severe northern winters and channel ice dynamics on fish survival and productivity.

3. The development of models that consider the influence of variables such as biotic interactions (predation and competition) on fish survival and abundance.

4. The use of instream flow techniques for channel and riparian wetland restoration.

5. The use of instream flow models as a tool for predicting habitat changes due to alterations in riparian land use (sedimentation, water quality).

6. The value of instream flow uses or the inplace value of leaving water in the stream.

7. The relation among the geomorphic processes of the watershed, stream development, and fish and wildlife productivity.

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APPENDIX A: 157 OUTSTANDING RIVERS (Kimball, 1983)

1 Baptism
2 Basswood
3 Battle
4 Beaver
5 Big Fork
6 Black
7 Black Duck
8 Blackhoof
9 Blue Earth
10 Bowstring
11 Boy
12 Brule
13 Buffalo Creek
14 Buffalo
15 Cannon
16 Caribou
17 Cascade
18 Cat
19 Cedar
20 Chippewa
21 Chippewa-East Branch
22 Clearwater
23 Cloquet
24 Cobb
25 Cottonwood
26 Cross
27 Crow
28 Crow-South Fork
29 Crow-Middle Fork
30 Crow-North Fork
31 Crow-Wing
32 Dark
33 Deer Yard Creek
34 Des Moines
35 Devils Track
36 East Savanna
37 Elk
38 Elm Creek
39 Embarrass
40 Flute Reed
41 Gooseberry
42 Grand Marais Creek
43 Groundhouse
44 Hawk Creek
45 High Island Creek
46 Hill
47 Isabella
48 Kadunce Creek
49 Kettle
50 Knife
51 Lac Qui Parle
52 Le Sueur
53 Leaf
54 Leech Lake
55 Lester
56 Little Cottonwood
57 Little Fork
58 Long Prairie
59 Lost
60 Manitou
61 Maple
62 Marsh
63 Middle
64 Minnesota
65 Mississippi (Lower)
66 Mississippi (Metro)
67 Mississippi (Upper)
68 Mississippi (Headwaters)
69 Moose Horn
70 Mustinka
71 Nemadji
72 Net
73 Nett Lake
74 North Cormorant
75 Onion
76 Otter Tail
77 Partridge
78 Pelican (North)
79 Pelican (South)
80 Pigeon
81 Pine
82 Platte
83 Pomme De Terre
84 Poplar
85 Popple
86 Prairie
87 Rabbit
88 Rainy
89 Rapid
90 Rat Root
91 Red Lake
92 Red River of the North
93 Redeye
94 Redwood River
95 Rice
96 Ripple (Mud)
97 Rock
98 Root
99 Root-Middle Branch
100 Root-North Branch
101 Root-South Branch
102 Root-South Fork
103 Roseau
104 Rum
105 Rum-West Branch
106 Rush
107 Rush-Middle Branch
108 Rush-South Branch
109 Sandhill
110 Sauk

APPENDIX A: 157 OUTSTANDING RIVERS (Kimball, 1983) (Cont'd)

111 Schoolcraft
112 Shell
113 Snake (West)
114 Snake (East)
115 N. & S. Kawashiwi
116 Split Rock
117 St. Francis
118 St. Louis
119 St. Croix
120 Stony
121 Straight (South)
122 Straight (North)
123 Sturgeon
124 Sunrise
125 Sunrise-North Branch
126 Swamp
127 Swan
128 Tamarac
129 Temperance
130 Thief
131 Three Mile Creek
132 Turtle
133 Two Rivers
134 Two Rivers-Middle Branch
135 Two Rivers-North Branch
136 Two Rivers-South Branch
137 Vermillion (North)
138 Vermillion (South)
139 Watonwan
140 Watonwan-North Fork
141 Watonwan-South Fork
142 West Swan
143 Whiteface
144 Whitewater
145 Whitewater-North Fork
146 Whitewater-South Fork
147 Wild Rice
148 Willow
149 Wing
150 Yellow Bank
151 Yellow Medicine
152 Zumbro
153 Zumbro (Middle Fork)
154 Zumbro (N. Br. Middle Fork)
155 Zumbro (North Fork)
156 Zumbro (S. Br. Middle Fork)
157 Zumbro (South Fork)

APPENDIX B: DESCRIPTION OF INSTREAM FLOW REGIONS[1]

REGION ONE

Instream flow region one, located in the southeast corner of the state, is mostly covered by loess and calcareous sandy loams, overlying Precambrian and Paleozoic sandstone, limestone, and dolomite. The eastern portion of this region is characterized by karst topography with steep valleys, hardwood forested slopes, and rocky bluffs. In the western part, relief is less steep and the glacial till soils are excellent for farming. Most of the native prairie lands have been converted to cropland and pasture and many of the wetlands have been drained.

Intensive agriculture, high rainfall, low evaporation, and minimal storage lead to flashy characteristics in the heavily dissected streams. The well defined drainage pattern, deeply incised streams, steep valley slopes and shallow soils contribute to a high runoff rate in the stream dissected area. This causes serious soil erosion and siltation problems. Streamflow is sustained by groundwater.

Eight out of the nine rivers placed in this region were correctly reclassified into this region for both the river gage and the combination river gage and watershed data base discriminant analysis. The regional boundary line cuts through the middle of the Cannon River Watershed and part of the Cedar River Watershed because in various discriminant analysis groupings, the Straight and Cedar Rivers were not grouped into region one. The Straight and Cedar Rivers are classified into region two. Both rivers flow through the Des Moines till plain making their physical and hydrologic character more similar to the southwest region.

REGION TWO

Most of region two, located in southwest Minnesota, is covered by glacial till deposits physiographically classified as the Des Moines till plain. The topography varies from nearly flat to gently undulating terrain, lacking strong moraines within the plain. The only areas of pronounced relief exist in the southwest corner on the Coteau des Prairies escarpment and along the Minnesota River bluffs.

The majority of the rivers flowing through the till plain are generally slow, meandering, alluvial streams where they have not been altered through drainage and channelization. Minor exceptions occur in the headwaters of streams flowing off the Coteau des Prairie escarpment, bordering end moraines, and where the streams flow into the Minnesota River Valley. The streams are rocky and swift in these areas.

The hydrologic regime is variable, with high flows in spring to low flows during late summer through winter, and very low flows, or no flows, during dry periods. Generally, groundwater and throughflow influence is limited except in the areas

[1]Map showing instream flow regions and representative study reaches is located in Appendix C.

of alluvium and outwash deposits. Lakes and wetlands account for approximately 2.5 percent of the surface storage. Thus, the stream systems are the primary source of surface water in the region.

The original vegetation is big blue-stem prairie with floodplain tree species such as cottonwood along the stream corridors. The primary land use is intensive cultivation with scattered pastures.

During the discriminant analysis, sixteen streams were assigned to region two. In the discriminant run using the combination data set of watershed and river gage variables, all sixteen of the streams were confirmed to be correctly classified in this region.

In the discriminant run using river gage variable set, twelve of the streams were corectly re-classified in region two. The remaining four streams were classified into region three, the Red River Valley; although, the second best classification was region two. In analyzing region three data, the rivers incorrectly classifed by the discriminant analysis method in this region were placed in region two. This indicates some similarities between the two regions. The mean discharge/drainage area and storage variables account for most of the similarities. The forces that physically formed the landscape such as glaciation, climate, native vegetation, and current intensive agricultural production in both regions are very similar and explain the classification.

REGION THREE

Instream flow region three is located along the upper western half of the state. The northwestern part of the state contains very flat terrain remnants of Glacial Lake Agassiz. Intensive agriculture predominates where native prairie once abounded. Thick glacial deposits consisting of loam and clay overlie the Early Precambrian bedrock. The lake plain is interrupted by the incised valleys of tributary streams and an extensive network of drainage ditches. Wetland drainage, impermeable soils, and low storage capacity contribute to flooding problems. Extended periods of low or no flow are common on many streams during periods of low precipitation. The only noticeable relief in this region is associated with the ridges of sand and gravel along former shorelines of Glacial Lake Agassiz and the Alexandria moraine complex. The northeastern portion of this region is abundant with marshes, swamps, bogs, and peatlands. Here stream flows are partially sustained by storage and ground water contribution from morainal areas.

In general, this region is homogeneous with similar land use, mean annual flows, and slopes. However, three distinct subgroups were identified. The western portion of the region is physiographically classified as Glacial Lake Agassiz. This lacustrine area is characterized by heavy clays and flashy seasonal flows. The second subgroup is the peatlands found in the northern portion. The peatlands are poorly drained. The base flow is only slightly sustained by water stored in the peat. The third subgroup located in the eastern part of the region, is part of the Alexandria moraine complex. The relief is rugged and the slopes heavily wooded. Numerous lakes dot the lanscape and regulate and stabilize streamflow.

Nineteen out of twenty-two rivers placed in this region were reclassified into this region for the river gage data base discriminant analysis. Twenty-one out of twenty-two rivers were reclassifed into this region for the combination river gage and watershed data base discriminant analysis. The three rivers not reclassified into region three were reclassified into region two. While this region is relatively homogeneous, four rivers were chosen to measure in order to incorporate the three regional subgroups.

REGION FOUR

Instream flow region four is located in the central part of the state. Geologically, central Minnesota is the most varied region in the state. At least four major ice advances created a complex mosaic of end moraines, eskers, drumlins, kames, glacial lake plains, and outwash plains. In general, the materials in the region consist of sandy and clayey glacial drift overlying Precambrian granitic rock, slate, and iron formations. The landscape is rugged and heavily forested. A large storage capacity exists in the numerous wetlands, lakes, and reservoirs. Flooding is not a major problem in this region and flow stability minimizes low flow impacts during dry periods.

Three out of four rivers placed in this region were reclassified into this region for the river gage data base discriminant analysis and two out of four rivers were reclassifed in this region for the combination river gage and watershed data base discriminant analysis. This region includes the northern Crow Wing Watershed, the western two thirds of the Upper Mississippi River Watershed, and the upper half of the Mississippi-Sauk River Watershed. The diversity of landforms, soils, and vegetation types found in this region, and the paucity of hydrologic data, reduced the resolution of the discriminant analysis.

REGION FIVE

Instream flow region five is located in the east central part of the state and it includes all of the Lower St. Croix, Snake, Rum, and Kettle River Watersheds and the southern tip of the Lake Superior Watershed. This region is characterized by rock outcrops, ground moraines, and end moraines in the northern part and sand plains in the southern part. Most of the streams flow through numerous rapids and boulder fields. The Kettle and Snake Watershed to the east have variable flows due to narrow basins, steep gradients, and shallow soils, whereas the Rum Watershed to the west has more stable flows due to lake regulation, less relief, and deeper soils. The Nemadji River Basin in the north eastern tip is the bed of an old glacial lake. The lacustrine deposits consist of heavy clays that are highly susceptible to erosion and slumping.

Three out of seven rivers assigned to this region were reclassified into this region for both the river gage and the combination river gage and watershed data base discriminant analysis. This area has lack of hydrologic data base. The heterogeneity within this region required additional site specific analysis in order to get a good representation of the area.

REGION SIX

Region six is located in central Minnesota, which lies in the transition zone between prairie and forest. It is a small area including all of the Crow River Watershed and the southern part of the Mississippi-Sauk Watershed. Surficial geology consists of a complex of moraines, drumlins, till plains, and sand plains. The bedrock ranges from cretaceous in the southwest to lower precambrian in the northwest. In the northern portion, numerous lakes create a large storage capacity and stable river flows. The rivers in the southern part, on the other hand, have prairie-type characteristics, with widely fluctuating flow regimes and problems relating to water quality.

Out of the seven rivers in the data set only one was reclassified to region six and the other six were regrouped into region three for the combination river gage and watershed data discriminant analysis. The river gage discriminant analysis regrouped one river into region six, one river into region two, and the other five rivers into region three.

Flows are more variable for streams assigned to region two and region three, then the streams assigned to region six. Therefore it seemed desirable to separate these rivers into different regions for analysis.

REGION SEVEN

This highland region lies along the shore of Lake Superior. The bedrock is Keweenawan basalt and diabase. The coast line is interrupted by points and bays that reflect the differential resistance of the igneous rocks. The topography is rugged, consisting of old mountain ranges with steep end moraines deposited along the uplands. A small portion south of Duluth called the Nemadji basin is an anomaly. Here the bedrock is metamorphosed sedimentary rocks and the surficial deposits are lacustrine. Drainage along the North Shore consists of numerous short, steep-gradient streams which flow directly into Lake Superior. Inland lakes are more numerous in the northern portion of this region which act to stabilize stream flows. Stream flows in the southern portion of this region tend to be flashy in nature.

All the rivers in the combination river gage and watershed data discriminant analysis were reclassifed into region seven and three out of five were reclassified into region seven for the river gage data discriminant analysis. These rivers are all short and steep and flow into the Superior Basin. The variation from north to south includes increases in lacustrine deposits and decreases in the number of lakes. The differences made it necessary to sample a river in the northern part and a river in the southern part.

REGION EIGHT

Located in the northeast corner of the state, this region retains its wilderness character and includes the Boundary Waters Canoe Area. The bedrock is Precambrian and Metamorphic rocks. Weak spots were ground out by moving glaciers leaving the region's most notable features, a myriad of lakes interconnected by a network of streams and rivers. The surficial geology is predominantly thin, discontinuous drift and the topography is varied and rugged. Rapids, boulder fields, and gorges are common on many of the rivers. Due to the regulatory effects of the lakes, the hydrology of the region is very stable.

There were only four rivers with data for this region. All of the rivers reclassified to region eight for the combination river gage and watershed data discriminant analysis and fifty percent of them were reclassified to region eight for the river gage discriminant analysis. Many of the streams in this region either flow within the BWCA or are designated trout streams. Both designations severly limit water withdrawals. Thus only one stream was chosen to represent the region for this study.

REGION NINE

Located in north central Minnesota, this region includes three subsections. The rivers in the northeastern part originate in the moraines and flow north through numerous lakes and marshes before falling onto the lake plain. The hydrology is relatively stable due to the regulatory influence of the lakes and groundwater contribution. In the northwestern section, the relief is low and the natural drainage is sluggish. Here the rivers are influenced by peat hydrology. Peat retains water and dampens peak flows, but does not contribute much flow to the system during normal and drier periods. The southern section is a flat lacustrine plain with extensive bog and peat areas. It is different from other lacustrine plains in that the streams flow through sandy stretches, pools, boulder fields, and large substrate riffles. Extensive drainage ditches exist throughout the region.

All of the rivers were reclassified into this region for the combination river gage and watershed data discriminant analysis and 85.7 percent were reclassified into this region for the river gage data discriminant analysis. These high percentages reflect the strong similarity between the three subsections within the region, therefore, fewer study sites were needed to represent the area.

REGION TEN

This region is centered around the Twin Cities metropolitan area where three major rivers, the Mississippi, the Minnesota, and the St. Croix, converge. The surficial deposits from the two major glacial lobes that crossed the area consist of materials from both Precambrian crystalline rocks in the north (Superior Lobe) and limestone and clay (Des Moines Lobe). The watershed is a complex basin of minor watersheds tributary to large segments of the Mississippi and Minnesota Valleys. The eastern, western, and southern boundaries are formed by hilly moraines, whereas the northern boundary is a poorly defined divide on a sand plain. The central portion is a broad area of glacial till and outwash plain crossed by hummocky moraines and dissected by wide, deep valleys of the trunk streams. The flow regimes of the major rivers are influenced by reservoir storage, hydropower, and navigation.

There was very little data for the small tributary creeks within this region and the three major rivers flow through other regions. Therefore, this region was not included in the discriminant analysis, however, qualitative analysis reflects homogeneity due to the high degree of urbanization.

APPENDIX C: LIST AND MAP OF REPRESENTATIVE RIVERS BY INSTREAM FLOW REGION

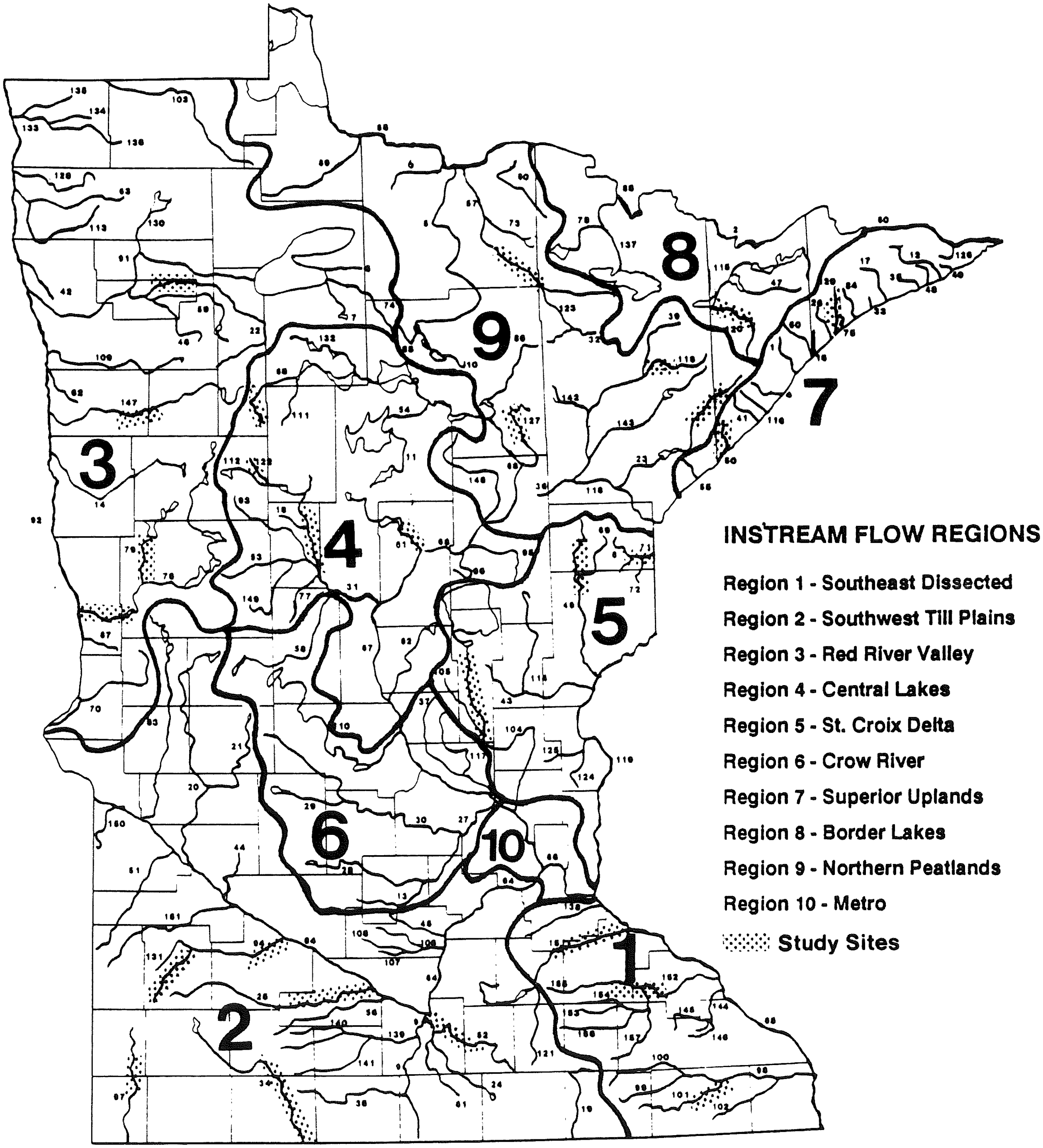
Region	Name	Representative River
1	Southeast	Cannon Zumbro North Fork Zumbro South Branch Root
2	Southwest	Le Sueur Cottonwood[1] Des Moines Rock Redwood[2]
3	Red River	Otter Tail[1] Pelican Wild Rice Clearwater[1]
4	Central Lakes	Crow Wing Straight[1] Pine River Mississippi Headwaters
5	St. Croix Delta	Kettle Rum Nemadji
6	Crow River	South Fork Crow[3] Sauk River[3]
7	Superior	Temperance Knife
8	Border Lakes	Stoney Isabella[3]
9	Northern	St. Louis Cloquet Little Fork Rapid[4]

[1]Data from previous studies were used in analyzing these rivers.

[2]Two sites were measured as there were distinct differences between headwaters of streams and lower reaches.

[3]These streams were not measured due to high water or lack of access.

[4]No measurements were taken as no appropriate measurement sites were found.



Source: MN DNR.

Instream flow regions and representative sites.

APPENDIX D: SITE SELECTION FORMS

The Preliminary Site Selection - Office form was used to determine the sites for field reconnaissance.

There are two Field Site Checklists - one for hydrologic descriptions and one for biologic descriptions. These were used to determine the most representative site for field data collection. Photographs were taken at each site investigated.

Preliminary Site Selection - Office

River Name: ______________________________

Counties: ______________________________

Reviewer: ______________________________

Date: ______________________________

1. General description of the river (i.e. land use, hydrology, recreational value).

2. Determine the number of study sites. Specify if:

   A) Multiple sites are necessary because discrete sections are evident (river courses through several geologic formations).

   OR

   B) One site sufficient because nor discrete sections are evident.

3. Choose stretches where stream gradient is conducive to finding good riffle areas.

4. Location of gaging stations.

5. Location of impoundments.

6. Available information (i.e. stream surveys, watershed studies, canoe and boating route maps).

7. Important sport fish species.

8. Important forage fish species.

9. Presence and location of threatened, endangered or species of special concern.

10. Location of critical reaches (i.e. spawning areas, barriers to fish passage, popular fishing/recreation areas).

11. Factors limiting survival, productivity or use of the fish community (i.e. water quantity or quality, available habitat).

12. Location of potential sites.

Site No. or Name	Mile	T	R	S	County	Access	Topo. Numbers

Field Site Checklist - Hydrological

Date: ____________ Reviewer: ____________

Stream: ____________ Description:

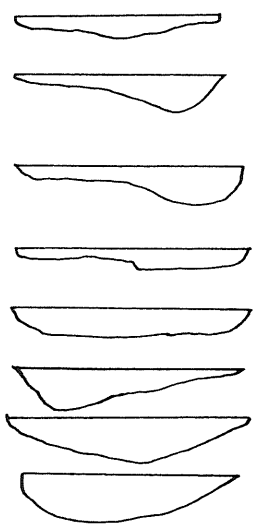
Site #: ____________ legal: ____________

Photos: ____________ discriptive: ____________

____________ ____________

____

1. Cross-Section profile shape:



a. rectangular (riffles) ☐

b. shelf w/ triangular channel ☐

shelf w/parabolic channel ☐

shelf w/rectangular ☐

c. trapezoidal (runs) ☐

d. triangular ☐

e. parabolic (pools & channelized) ☐

Thalweg on left side ____ center ____ right side ____

2. Length of riffle ________ ft./yd.

3. Discharge transect: upstream ☐

downstream ☐

distance from site _____ ft/yds.

4. Condition of discharge transect good ☐ fair ☐ poor ☐

obstacles in transect ☐ yes ☐ no

type of obstacle ____________

removal yes ___ no ___

5. Composition of bed: sand ☐ sand/gravel ☐ gravel/cobbel ☐

fines ☐ other ____________

____

6. Estimated number of transects: ____________

7. Average width ________ ft/yds.

8. Average depth ________ ft.

deepest transect depth ________ ft.

9. Average estimated velocity (float method) ________ f/s.

10. Obstructions to surveying elev.: yes ☐ no ☐

type ____________

11. Survey instrument set up: one ☐ ☐

estimated # _____

Sketch of site/transect locations

STUDY SITE EVALUATION - BIOLOGICAL

RIVER NAME: ______________________________

SITE NAME: ______________________________

GENERAL LOCATION: ______________________________

DATE: ______________________________

REVIEWER: ______________________________

I. Briefly describe the physical setting at this site (e.g. topography, vegetation, and land use).

II. Does this site represent the type of area within the stream which is most sensitive to changes in flow (e.g. gravel bars/riffles)?

III. What is the significance of this site to the aquatic community? Indicate for which species and life stages this stream reach is important.

IV. Complete pertinent components on the attached Habitat Evaluation Form (Items 2, 3, 5, 6, 7 and 10).

V. Recent meteorlogical events:

VI. Observations relating to wildlife:

VII. Additional comments:

Rating Item	Excellent	Good	Fair	Poor	Numerical Score
1. Stream Flow	Baseflows 60% of median annual flow. 0	Baseflows 30-59% of median annual flow. 3	Base flows 10-29% of median annual flow. 7	Base flow 10% of median annual flow. 10	
2. Stream Channel Capacity	Channel adequate to contain peak flows (W/D $\leq$ 7). Little or no evidence of active or recent erosion of the floodplain or channel during floods. 2	Most flows contained (W/D = 8 - 15). Some evidence of periodic erosion of the the floodplain and/or channel, but channel is essentially intact. 4	Normal flows are barely contained (W/D = 15-25). Considerable evidence of occasional erosion of the floodplain and/or channel. 6	Channel capacity inadequate (W/D $>$ 25). Floodplain severely eroded and degraded, stream, channel poorly defined. 8	
3. Stream Bottom Substrate and	Over 50% rubble, gravel or other stable substrate with 25% embeddedness 2	30-50% stable substrate; 25-50% embeddedness. 4	10-30% stable substrate; conditions less than optional, 50-75% embeddedness. 7	Less than 10% gravel, rubble or other stable substrate; embeddedness exceeds 75%. 10	
4. Sinuosity	2 2	1.5 - 1.9 4	1.2 - 1.4 7	1.2 10	
5. Streambank Vegetation and Soil Alteration	Stable banks not being altered by water flows or animals. Over 80% coverage by vegetation or stable material. 3	Stable banks, but maybe slightly altered, some stress present. 50-79% coverage by vegetation or other stable material. 5	Streambanks are being altered considerably. Eroding banks present 25-49% coverage of bank by vegetation or other stable material. 7	Severe alteration of streambanks. Banks may be false, brokendown or eroding. $<$ 25% coverage by vegetation or other stable material. 9	
6. Watershed Non-point Source Pollution	No evidence of sources or potential sources. Watershed is well managed. 2	No obvious problems but potential sources exist. Watershed is well managed. 4	Potential problems are evident. Intensive cultivation, drainage, runoff or impoundments. 8	Sources of pollution are evident and extensive. Poor land management is obvious. 10	
7. Watershed Erosion	No evidence of significant erosion. Watershed is well managed. 4	Some erosion may be evident, but few raw areas are present. Well managed watershed. 5	Moderate erosion with some raw areas present. Erosion from storm events obvious. 7	Severe erosion is obvious. Any runoff will result in heavy erosion. Many raw areas. Water levels fluctuate widely. 8	
8. Water Quality	Stream water unpolluted. No pollutants detected by standard methods. 0	Occasional above normal levels of one or more water quality constituents usually present, but detectable only by analysis. 3	Occasional visible signs of oversupply of nutrients. Periodic fish kills. 7	Grossly polluted waters with frequent fish kills. 10	
9. Barriers to Fish Movement	No man made obstructions to free passage of fish upstream. 0	No dams or other structures causing a vertical drop of more than 3 feet during low flow. 4	No dams or other structures causing a vertical drop of more than 10 feet during low flow. 8	One to several dams or other structures each causing a drop of more than 10 feet during low flow. 10	
10. Cover Available for Fish	Cover is abundant and diverse. A combination of overhanging banks, snags, boulders and/or aquatic vegetation is present. 2	Cover is adequate. Abundance and diversity of cover available for fish is adequate. 4	Cover is limiting. Abundance and diversity of available cover for fish is low. 6	Cover is virtually lacking. Overhanging banks, snags, boulders and aquatic vegetation sparse. 8	
Approximate ranges for scores:	$\leq$ 28	29-55	56-81	$\geq$ 82	Total:

APPENDIX E: RESOURCE MANAGER SURVEY FORMS

The River Fisheries Survey was sent to each DNR Regional Fisheries Supervisor. A copy of the survey with a list of rivers in each area was sent to the Area Fishery Supervisors.

The Recreational Use Survey was sent to DNR Regional Fisheries Supervisors, Regional Wildlife Supervisors, and Regional Trails and Waterways personnel. The surveys with list of rivers were sent to appropriate Area Managers.

The Wildlife Survey was sent to DNR Regional Wildlife Supervisors. A list of rivers and surveys were sent to the Area Wildlife Managers.

May 6, 1986

RIVER FISHERIES SURVEY

River Name ____________________

Respondent ____________________ Title ____________________

Area Office ____________________

Section of River Described ____________________

INTRODUCTION

The Division of Waters is currently conducting a study to approximate instream flow needs for Minnesota as part of a LCMR funded water allocation project. Documenting instream flow needs for Fisheries is an integral part of this process. Last year fisheries managers were sent a survey requesting basic information regarding the management of river fisheries. This follow up survey is designed to provide some additional information concerning fish habitat and resource potential. The questions asked of you in this survey were designed using a 1982 U.S. Fish and Wildlife survey as a model. The principle focus of this questionnaire is on sport fish; this is not because sport fish are the only contributors to the value of the river, but because the majority of available fisheries information concerns these species, and their presence or absence generally indicates conditions of prevailing water conditions.

While some rivers tend to be fairly homogeneous throughout their length, others are characterized by having distinct sections. Where possible please provide a general response with the entire river in mind. If your response is directed towards discrete sections of the river, indicate the upper and lower bounds of each section.

You have been asked to participate in this study because of your knowledge of the resources in your area. Please feel free to expand your response beyond this set of questions. The information that you provide will assist us in documenting instream flow needs for the State of Minnesota.

1. Please list the important sport fish species found in this river and assign an abundance rating using the subjective descriptors provided.

Abundance Rating

Species	Abundant	Common	Uncommon	Rare	Expected	Unknown
1)						
2)						
3)						
4)						
5)						

2. Are there any species found along this river that are recognized as being rare, threatened or of special concern in the State of Minnesota? If so, please indicate their presence by circling the species on the attached list, developed by the Minnesota Natural Heritage program.

3. Is the survival, productivity, or use of the fish community being adversely affected by natural or man-made conditions in this river? CIRCLE ONE NUMBER

Yes, definitely 1	If you answer 1 or 2 please complete all of question 4 and questions 5-9.	
Yes, suspected 2		
Doubtful 3	If you answer 3, 4 or 5 skip question 4 and complete questions 5-9.	
No, definitely 4		
Unknown 5		

4. Please complete the following tables by checking appropriate factors and sources. If possible, indicate if the factors and sources are of major or minor concern.

TABLE I.
WATER QUALITY

Check all applicable categories and circle 1 (Major) or 2 (Minor) in each category checked.

A. LIMITING FACTOR

	Major	Minor
1___Temperature too high	1	2
2___Temperature too low	1	2
3___Turbidity	1	2
4___Salinity	1	2
5___Dissolved oxygen	1	2
6___Gas supersaturation	1	2
7___pH too acidic	1	2
8___pH too basic	1	2
9___Nutrient deficiency	1	2
10___Nutrient surplus	1	2
11___Toxic substances	1	2
12___Other (specify below)		
______________________	1	2

B. PROBABLE SOURCE

	Major	Minor
41___Point source discharge	1	2
42___Industrial	1	2
43___Municipal	1	2
44___Combined sewer	1	2
45___Mining	1	2
46___Dam release	1	2
47___Nonpoint source discharge	1	2
48___Individual sewage disposal	1	2
49___Urban runoff	1	2
50___Landfill leachate	1	2
51___Construction	1	2
52___Agriculture	1	2
53___Feedlot	1	2
54___Silviculture/logging	1	2
55___Mining	1	2
56___Natural	1	2
57___Unknown	1	2
58___Other (specify below)		
______________________	1	2

TABLE II
WATER QUANTITY

Check all applicable categories and circle 1 (Major) or 2 (Minor) in each category checked.

C. LIMITING FACTOR

	Major	Minor
13___Below optimum flows	1	2
14___Above optimum flows	1	2
15___Loss of flushing flows	1	2
16___Excessive flow fluctuation	1	2
17___Occasional low flow	1	2
18___Other (specify below)		
______________________	1	2

D. PROBABLE SOURCE

	Major	Minor
59___Dam (power)	1	2
60___Dam (flood control)	1	2
61___Dam (storage)	1	2
62___Diversion (agriculture)	1	2
63___Diversion (municipal)	1	2
64___Diversion (industrial)	1	2
65___Natural	1	2
66___Other (specify below)		
______________________	1	2

E. If water quantity is a factor limiting fishery potential, please indicate the seasonality and nature of the problem (e.g. excessively high flows during May and June reduce spawning success of smallmouth bass or, extreme low flow conditions during August and September is limiting the recruitment of smallmouth bass into the fishery).

TABLE III
USABLE HABITAT

Check all applicable categories and circle 1 (Major) or 2 (Minor) in each category checked.

F. LIMITING FACTOR

	Major	Minor
19___Adult/juvenile habitat	1	2
20___Pools	1	2
21___Riffles	1	2
22___Undercut banks	1	2
23___Boulders	1	2
24___Snags	1	2
25___Overhead cover	1	2
26___Egg/larvae habitat	1	2
27___Gravel	1	2
28___Plants, plant debris	1	2
29___Other (specify below)		
______________________	1	2

G. PROBABLE SOURCE

	Major	Minor
67___Excessive siltation	1	2
68___Bank erosion/sloughing	1	2
69___Channelization	1	2
70___Other channel modifications	1	2
71___Migration blockage	1	2
72___Natural	1	2
73___Unknown	1	2
74___Other (specify below)		
______________________	1	2

TABLE IV
FISH COMMUNITY

Check all applicable categories and circle 1 (Major) or 2 (Minor) in each category checked.

H. LIMITING FACTOR

	Major	Minor
30__Fish kills	1	2
31__Contamination	1	2
32__Diseases/parasites	1	2
33__Tumors/lesions	1	2
34__Overharvest	1	2
35__Poaching	1	2
36__Underharvest	1	2
37__Fish stocking	1	2
38__Other (specify below)		
____________________	1	2

I. PROBABLE SOURCE

	Major	Mi
75__Heavy metals	1	
76__Pesticides	1	
77__Other noxious/toxic substances	1	
78__Crowding	1	
79__Other stress	1	
80__Natural	1	
81__Unknown	1	
82__Other (specify below)		
____________________	1	

The next few questions are a subjective but necessary part of this survey. To provide some standardization for response, a "ladder" is shown below describing the spectrum of conditions that could exist in an aquatic ecosystem in terms of the fish community. At the top of the ladder is the ideal situation of maximum ability to support a fish community of high interest, i.e., a community of sport fish or other species of special concern. The bottom of the ladder represents a river that is incapable of supporting any fish community. Please use this ladder as a reference in answering questions 5-8.

CHECK ONE BOX FOR EACH QUESTION

5. Using the scale shown at the bottom of this page, how would you rank the current conditions of this river?

   [ ] 0 [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5

6. Again using this scale, how would you rank the conditions of this river five to ten years ago?

   [ ] 0 [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5

7. If present trends on this river continue, how will it rank five to ten years from now?

   [ ] 0 [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5

8. Should the man-caused limiting factors (if previously indicated in question 4) be eliminated or controlled, how will this river rank five to ten years from now?

   [ ] 0 [ ] 1 [ ] 2 [ ] 3 [ ] 4 [ ] 5

—5— This river exhibits a maximum ability to support a sport fish community, species of special concern, or both.

—4— This river exhibits an excellent ability to support a community of sport fish, species or special concern, or both.

—3— This river exhibits a moderate ability to support a community of sport fish, species of special concern, or both.

—2— This river exhibits a minimum ability to support a community of sport fish, species of special concern, or both.

—1— This river has the ability to support a non-sport fish population only.

—0— This river has no ability to support any fish population.

9. Considering this river as part of a system, what tributaries would you consider to be of utmost importance in maintaining the integrity of the system? Please list those of major importance which may warrant further study.

Additional Comments:

Thank you! If you have additional comments or questions regarding this survey, feel free to contact Henry Drewes at (612) 296-0438. We request that these surveys be completed and returned by June 16, 1986.

Please return this survey to: Henry Drewes
Minnesota Department of Natural Resources
Division of Waters, Box 32
Water Allocation Unit/Instream Flow Team
500 Lafayette Road
St. Paul, MN 55146

MINNESOTA NATURAL HERITAGE PROGRAM

Fish Elements

SPECIES	COMMON NAME	MNHP STATUS
Acipenser fulvescens	Lake Sturgeon	Threatened
Hybopsis x-punctata	Gravel Chub	
Cycleptus elongatus	Blue Sucker	
Polyodon spathula	Paddlefish	Rare
Scaphirhynchus platorhynchus	Shovelnose Sturgeon	
Opsopoeodus emilae	Pugnose Minnow	
Notropis amnis	Pallid Shiner	
Notropis anogenus	Pugnose Shiner	
Notropis topeka	Topeka Shiner	
Notropis lutrensis	Red Shiner	
Carpiodes velifer	Highfin Carpsucker	
Moxostoma carinatum	River Redhorse	
Moxostoma valenciennesi	Greater Redhorse	
Moxostoma duquesnei	Black Redhorse	
Noturus exilis	Slender Madtom	
Anguilla rostrata	American Eel	
Fundulus sciadicus	Plains Top Minnow	
Ammocrypta asprella	Crystal Darter	
Percina evides	Gilt Darter	
Etheostoma chlorosomum	Bluntnose Darter	
Coregonus zenithicus	Shortjaw Cisco	Special Concern
Coregonus kiyi	Kiyi	
Clinostomus elongatus	Redside Dace	
Dionda nubila	Ozark Minnow	
Carpoides carpio	River Carpsucker	Undetermined
Aphredoderus sayanus	Pirate Perch	
Lepomis megalotis	Longear Sunfish	
Alosa chyrsochloris	Skipjack Herring	Extirpated

May 6, 1986

RECREATIONAL USE SURVEY

River Name ____

Respondent ____________________ Title ____________________

Area Office ____

Section of River Described ________________________________

INTRODUCTION

The Division of Waters is currently conducting a study to approximate instream flow needs for Minnesota as part of a LCMR funded water allocation project. Recreation is an important instream use which needs to be considered in this study. In order to properly represent the recreation component in these approximations, it is essential that we document as many recreational uses as possible. Information concerning the intensity of use for recreational activities is equally important. We are only interested in those activities which are directly related to the river corridor.

While some rivers tend to be fairly homogeneous throughout their length, others are characterized by having distinct sections. Where possible please provide a general response with the entire river in mind. If your response is directed towards discrete sections of the river, indicate the upper and lower bounds of each section. We are especially interested in identifying those activities which would be affected most by abnormally high or low flow regimes. Please do not limit your response to the list of activities provided. If there are particular activities associated with this river which are important and may be affected by high or low flow regimes, please identify them.

This questionnaire is being sent to those individuals who possess knowledge concerning recreational use of the aforementioned river. The information that you provide will assist us in documenting instream flow needs for the State of Minnesota.

RIVER ORIENTED RECREATION

ACTIVITY		CURRENT LEVEL OF USE: Heavy	Moderate	Light	Unknown	RESOURCE POTENTIAL*: Reached	Underutilized	Unrecognized
1) Fishing								
2) Hunting								
3) Swimming								
4) Wading								
5) Boating	Power							
	Canoes							
	Kayaks							
6) Floating	Rafts							
	Tubes							
7) Waterskiing								
8) Scuba Diving								
9) Collecting Wild Rice								
10) Picnicking								
11) Camping								
12) Hiking or Walking								
13) Driving								
14) Viewing								
15) Rock Collecting								
16) Observing Flora and Fauna								
17) Other:__________								

*The Resource Potential component was included so that the respondent can provide their opinion as to whether or not the river resource is sustaining the level of use that it may be capable of supporting. For this survey, please indicate for this river those activities which are: (1) currently sustaining a level of use at or near their potential (reached); (2) currently receive some level of use, but could see some expansion (underutilized); and (3) those which have received little or no attention, but have high potential (unrecognized).

Comments:

Thank you! If you have any additional comments or questions about this survey, feel free to contact Henry Drewes at 612/296-0438. We request that the surveys be completed and returned by June 16, 1986.

Please return this survey to: Henry Drewes
Minnesota Department of Natural Resources
Division of Waters, Box 32
Water Allocation Unit/Instream Flow Team
500 Lafayette Road
St. Paul, MN 55146

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July 7, 1986

WILDLIFE SURVEY

River Name____

Respondent____________________ Title________________________

Area Office____

Section of River Described______________________________

INTRODUCTION

The Division of Waters is currently conducting a study to approximate instream flow needs for Minnesota as part of a LCMR funded water allocation project. Documenting instream flow needs for Wildlife is an integral part of this process. The purpose of this survey is to obtain basic information concerning the biological setting along the river corridor. We are especially interested in identifying those situations where wildlife would be benefited or impacted by abnormally high or low flow conditions. This survey was designed to be completed in the office using existing information in your files and your best professional judgment.

While some rivers tend to be fairly homogeneous throughout their length, others are characterized by having distinct sections. Where possible please provide a general response with the entire river in mind. If your response is directed towards discrete sections of the river, indicate the upper and lower bounds of each section.

You have been asked to participate in this study because of your knowledge of the resources in your area. Please feel free to expand your response beyond this set of questions. The information that you provide will assist us in documenting instream flow needs for the State of Minnesota.

1. List the Wildlife Management Areas, Waterfowl Production Areas or National Wildlife Refuges in your area which are influenced by the character of this river.

2. If this river and adjacent wetlands are important habitat for waterfowl, please indicate the seasonality of use and the life stages for which it is essential (e.g. nesting, feeding, staging).

3. Please indicate the important furbearers usually found along this river corridor and assign an abundance rating using the subjective descriptors provided.

Species	Expected Abundance		
	Abundant	Common	Rare
Beaver			
Otter			
Mink			
Raccoon			
Muskrat			

4. Using the matrix below indicate what type of hunting and trapping opportunities exist along the river corridor and identify which species are important. Give an indication of the popularity of those activities by checking the appropriate Level of Use.

Type of Hunting Activity	Most Important Species	Level of Use		
		Heavy	Moderate	Low
Waterfowl				
Big Game				
Small Game				
Trapping				

5. Please identify any <u>unique</u> wildlife uses associated with this river corridor that may be affected by abnormal flow regimes (e.g. presence of rookeries; wintering habitat for deer and pheasants; feeding areas for bald eagles).

6. If there are any other rivers in your area which are of significant value to wildlife for which you have not received a survey, please list them and briefly state why they are significant.

Additional Comments:

Thank you! If you have any additional comments or questions regarding this survey, feel free to contact Henry Drewes at 612/296-0438. We request that the surveys be completed and returned by August 4, 1986.

Please return this survey to: Henry Drewes
Minnesota Department of Natural Resources
Division of Waters, Box 32
Water Allocation Unit/Instream Flow Team
500 Lafayette Road
St. Paul, MN 55146

APPENDIX F: NUMERICAL RESULTS OF INSTREAM FLOW ANALYSIS

Key to Table Headings

Watershed = one of the 39 principle watersheds

Transect Drainage Area (tDA) = area in square miles above the transect measurement site

IFA50 = instream flow approximation at transect site for normal year in cfs

IFA75 = instream flow approximation at transect site for dry year in cfs

qIFA50 = IFA50/tDA converts to cubic feet per square mile (cfsm)

qIFA75 = IFA75/tDA converts to cfsm

WA50 acft (cfs) = volume of water in acre feet (cfs) at mouth of watershed for normal hydrologic conditions based on USGS water availability

WA75 acft (cfs) = volume of water in acre feet (cfs) at mouth of watershed for dry hydrologic conditions based on USGS water availability

Watershed Drainage Area (WDA) = total drainage area in square miles of the watershed

qWA50 = WA50/WDA converts to cfsm

qWA75 = WA75/WDA converts to cfsm

iQ50 = qIFA50/WA50 (cfs) x 100 instream flow approximation at transect site for normal conditions as a percent of water available

iQ75 = qIFA75/WA75 (cfs) x 100 instream flow approximation at transect site for dry conditions as 2 percent of water available

DAT = the area in square miles drained by designated trout streams by watershed

DAN = the area in square miles drained by non-trout streams by watershed

IFA50W = instream flow approximation in cfs at mouth of watershed for normal conditions

IFA75W = instream flow approximation in cfs at mouth of watershed for dry conditions

V50 = instream flow approximation in acre-feet at mouth of watershed for normal years

V75 = instream flow approximation in acre-feet at mouth of watershed for dry years

Watershed	Representative River	Transect Drainage Area	IFA50 cfs	qIFA50 cfsm	WA50 acft	WA50 cfs	Watershed Drainage Area	qWA50 cfsm	iQ50 cfs	DAT sqmi	DAN sqmi	IFA50W cfs	V50 acft
St. Louis	St. Louis	96	39	0.409	1724831	2386.6	3634	0.657	62.3	1646	1988	1894.9	1369413
St. Louis	Cloquet	127	115	0.906	1724831	2386.6	3634	0.657	100.0	1646	1988	2386.6	1724831
	Average												1547122
Superior	Temperance	146	138	0.945	1909854	2642.7	2558	1.033	91.5	1944	614	2588.7	1870853
Superior	Knife	40	41	1.035	1909854	2642.7	2558	1.033	100.2	1944	614	2643.8	1910698
Superior	Nemadji	50	50	1.000	1909854	2642.7	2558	1.033	96.8	1944	614	2622.3	1895167
	Average												1892239
Rainy	Stoney	74	58	0.784	2370044	3279.4	4489	0.731	100.0	2764	1725	3279.4	2370044
Little Fork	Little Fork	934	374	0.400	808579	1118.8	1849	0.605	66.2	536	1313	850.1	614364
Big Fork	Little Fork	934	374	0.400	781141	1080.9	2063	0.524	76.4	217	1846	852.9	616379
Lake of the Woods	Clearwater	512	130	0.254	634750	878.3	2903	0.303	83.9	81	2822	741.0	535542
Mustinka	Wild Rice	832	105	0.126	71372	98.8	909	0.109	100.0	0	909	98.8	71372
Otter Tail	Otter Tail	1840	200	0.109	245745	340.0	1922	0.177	61.4	244	1678	225.6	163012
Otter Tail	Pelican	486	55	0.113	245745	340.0	1922	0.177	64.0	244	1678	233.1	168436
	Average												165724
Buffalo	Wild Rice	832	105	0.126	76091	105.3	1688	0.062	100.0	76	1612	105.3	76091
Wild Rice	Wild Rice	832	105	0.126	276889	383.1	2596	0.148	85.5	254	2342	333.1	240696
Red Lake	Clearwater	512	130	0.254	958340	1326.1	5988	0.221	100.0	389	5599	1326.1	958340
Middle	Wild Rice	832	105	0.126	116664	161.4	1823	0.089	100.0	0	1823	161.4	116664
Two Rivers	Wild Rice	832	105	0.126	91984	127.3	1232	0.103	100.0	0	1232	127.3	91984
Roseau	Wild Rice	832	105	0.126	144375	199.8	1128	0.177	71.3	25	1103	143.6	103800
Mississippi Hdwts	Mississippi	119	30	0.252	2751636	3807.4	7068	0.539	46.8	1569	5499	2231.5	1612707
Mississippi Hdwts	Swan	131	65	0.496	2751636	3807.4	7068	0.539	92.1	1569	5499	3573.7	2582721
Mississippi Hdwts	Pine	562	150	0.267	2751636	3807.4	7068	0.539	49.5	1569	5499	2312.9	1671536
	Average												1955654
Crow Wing	Straight	48.5	44	0.907	1003671	1388.8	3764	0.369	100.0	1035	2729	1388.8	1003671
Crow Wing	Crow Wing	1005	340	0.338	1003671	1388.8	3764	0.369	91.7	1035	2729	1305.1	943211
	Use Crow Wing												943211
7 Crow	Cottonwood	1260	244	0.194	514421	711.8	1250	0.569	34.0	54	1196	262.4	189605
8 Rum	Rum	616	195	0.317	529716	733.0	1552	0.472	67.0	50	1502	499.1	360688
9 Mississippi-Sauk	Rum	616	195	0.317	1016523	1406.6	3890	0.362	87.5	716	3174	1263.7	913240
0 Big Stone	Rock	257	35	0.136	49277	68.2	668	0.102	100.0	0	668	68.2	49277
1 Pomme de Terre	Redwood (Camden)	271	45	0.166	83365	115.4	966	0.119	100.0	7	959	115.4	83365
1 Pomme de Terre	Redwood	697	75	0.108	83365	115.4	966	0.119	90.1	7	959	104.0	75181
	Average												79273
2 Lac Qui Parle	Redwood (Camden)	271	45	0.166	57266	79.2	767	0.103	100.0	68	699	79.2	57266
2 Lac Qui Parle	Redwood	697	75	0.108	57266	79.2	767	0.103	100.0	68	699	79.2	57266
	Average												57266
3 Chippewa	Redwood (Camden)	271	45	0.166	243099	336.4	2072	0.162	100.0	93	1979	336.4	243099
3 Chippewa	Redwood	697	75	0.108	243099	336.4	2072	0.162	66.3	93	1979	228.0	164809
	Average												203954
4 Yellow Medicine	Cottonwood	1260	244	0.194	95829	132.6	1057	0.125	100.0	0	1057	132.6	95829
5 Redwood	Redwood (Camden)	271	45	0.166	72145	99.8	739	0.135	100.0	360	379	99.8	72145
5 Redwood	Redwood	697	75	0.108	72145	99.8	739	0.135	79.7	360	379	89.4	64618
	Average												68382
6 Cottonwood	Cottonwood	1260	244	0.194	240369	332.6	1878	0.177	100.0	173	1705	332.6	240369
7 Blue Earth	LeSueur	1073	230	0.214	689413	953.9	3106	0.307	69.8	0	3106	665.8	481158
8 Minnesota-Hawk	Redwood (Camden)	271	45	0.166	197188	272.8	1479	0.184	90.0	126	1353	247.9	179166
8 Minnesota-Hawk	Redwood	697	75	0.108	197188	272.8	1479	0.184	58.3	126	1353	168.8	122016
	Average												150590
9 Lower Minnesota	Cottonwood	1260	244	0.194	438399	606.6	1487	0.408	47.5	233	1254	337.9	244192
0 Kettle	Kettle	181	105	0.580	676470	936.0	1566	0.598	97.1	543	1023	918.0	663450
1 Snake	Kettle	181	105	0.580	384323	531.8	1015	0.524	100.0	54	961	531.8	384323

Watershed	Representative River	Transect Drainage Area	IFA50 cfs	qIFA50 cfsm	WA50 acft	WA50 cfs	Watershed Drainage Area	qWA50 cfsm	iQ50 cfs	DAT sqmi	DAN sqmi	IFA50W cfs	V50 acft
32 Lower St. Croix	Kettle	181	105	0.580	296301	410.0	926	0.443	100.0	267	659	410.0	296301
33 Metropolitan	Weighted Average			0.310	505968	700.1	1338	0.523	59.2	0	1338	414.8	299762
34 Cannon	Cannon	1165	285	0.245	421030	582.6	1411	0.413	59.3	83	1058	293.1	211819
35 Zumbro	N. Fk. Zumbro	240	75	0.313	518410	717.3	1676	0.428	73.0	515	1161	583.2	421501
35 Zumbro	Zumbro	1157	330	0.285	518410	717.3	1676	0.428	66.6	515	1161	551.6	398612
	Average												410056
36 Root	S. Br. Root	284	130	0.458	849760	1175.8	2568	0.458	100.0	2044	524	1175.7	849713
37 Cedar	Cannon	1165	285	0.245	391677	542.0	1204	0.450	54.3	4	1200	295.4	213459
38 Des Moines	Des Moines	1198	220	0.184	198388	274.5	1520	0.181	100.0	65	1455	274.5	198388
39 Rock	Rock	257	35	0.136	191241	264.6	1793	0.148	92.3	0	1793	244.2	176471

instream dry

Watershed	Representative River	Transect Drainage Area	IFA75 cfs	qIFA75 cfsm	WA75 acft	WA75 cfs	Watershed Drainage Area	qWA75 cfsm	iQ75 cfs	DAT sqmi	DAN sqmi	IFA75W cfs	V75 acft
1 St. Louis	St. Louis	96	30	0.313	1647310	2279.4	3634	0.627	49.8	1646	1988	1653.7	1195117
1 St. Louis	Cloquet	127	60	0.474	1647310	2279.4	3634	0.627	75.6	1646	1988	1974.8	1427171
	Average												1311144
2 Superior	Temperance	146	60	0.411	1364181	1887.6	2558	0.737	55.7	1944	614	1686.9	1219093
2 Superior	Knife	40	22	0.550	1364181	1887.6	2558	0.737	74.5	1944	614	1772.2	1280791
2 Superior	Nemadji	50	40	0.800	1364181	1887.6	2558	0.737	100.0	1944	614	1887.6	1364181
	Average												1288021
3 Rainy	Stoney	74	41	0.551	1915187	2650.0	4489	0.590	93.4	2764	1725	2582.8	1866579
4 Little Fork	Little Fork	934	270	0.289	591643	818.7	1849	0.442	65.3	536	1313	616.9	445818
5 Big Fork	Little Fork	934	270	0.289	528095	730.7	2063	0.354	81.6	217	1846	610.5	441210
6 Lake of the Woods	Clearwater	512	75	0.146	433488	599.8	2903	0.206	70.9	81	2822	430.1	310844
7 Mustinka	Wild Rice	832	75	0.090	47581	65.8	909	0.072	100.0	0	909	65.8	47581
8 Otter Tail	Otter Tail	1840	150	0.082	153590	212.5	1922	0.110	73.7	244	1678	163.8	118359
8 Otter Tail	Pelican	486	45	0.093	153590	212.5	1922	0.110	83.7	244	1678	182.4	131785
	Average												125072
9 Buffalo	Wild Rice	832	75	0.090	50727	70.2	1688	0.041	100.0	76	1612	70.2	50727
10 Wild Rice	Wild Rice	832	75	0.090	193822	268.2	2596	0.103	87.3	254	2342	237.4	171539
11 Red Lake	Clearwater	512	75	0.146	638893	884.0	5988	0.147	99.2	389	5599	877.6	634239
12 Middle	Wild Rice	832	75	0.090	58332	80.7	1823	0.044	100.0	0	1823	80.7	58332
13 Two Rivers	Wild Rice	832	75	0.090	39422	54.5	1232	0.044	100.0	0	1232	54.5	39422
14 Roseau	Wild Rice	832	75	0.090	72187	99.9	1128	0.088	100.0	25	1103	99.9	72187
15 Mississippi Hdwts	Mississippi	119	20	0.168	1884682	2607.8	7068	0.368	45.6	1569	5499	1503.1	1086294
15 Mississippi Hdwts	Swan	131	41	0.311	1884682	2607.8	7068	0.368	84.2	1569	5499	2287.4	1653084
15 Mississippi Hdwts	Pine	562	110	0.196	1884682	2607.8	7068	0.368	53.0	1569	5499	1655.2	1196228
	Average												1311868
16 Crow Wing	Straight	48.5	29	0.598	602202	833.3	3764	0.221	100.0	1035	2729	833.3	602202
16 Crow Wing	Crow Wing	1005	230	0.229	602202	833.3	3764	0.221	100.0	1035	2729	833.3	602202
	Average												602202
17 Crow	Cottonwood	1260	182	0.144	485026	671.1	1250	0.536	26.9	54	1196	201.7	145804
18 Rum	Rum	616	125	0.203	364180	503.9	1552	0.324	62.5	50	1502	321.0	232004
19 Mississippi-Sauk	Rum	616	125	0.203	580870	803.7	3890	0.206	98.2	716	3174	792.0	572389
20 Big Stone	Rock	257	20	0.078	32851	45.5	668	0.068	100.0	0	668	45.5	32851
21 Pomme de Terre	Redwood (Camden)	271	30	0.111	57314	79.3	966	0.082	100.0	7	959	79.3	57314
21 Pomme de Terre	Redwood	697	65	0.093	57314	79.3	966	0.082	100.0	7	959	79.3	57314
	Average												57314
22 Lac Qui Parle	Redwood (Camden)	271	30	0.111	36814	50.9	767	0.066	100.0	68	699	50.9	36814
22 Lac Qui Parle	Redwood	697	65	0.093	36814	50.9	767	0.066	100.0	68	699	50.9	36814
	Average												36814
23 Chippewa	Redwood (Camden)	271	30	0.111	176800	244.6	2072	0.118	93.8	93	1979	230.1	166263
23 Chippewa	Redwood	697	65	0.093	176800	244.6	2072	0.118	79.0	93	1979	195.5	141314
	Average												153788
24 Yellow Medicine	Cottonwood	1260	182	0.144	62007	85.8	1057	0.081	100.0	0	1057	85.8	62007
25 Redwood	Redwood (Camden)	271	30	0.111	41768	57.8	739	0.078	100.0	360	379	57.8	41768
25 Redwood	Redwood	697	65	0.093	41768	57.8	739	0.078	100.0	360	379	57.8	41768
	Average												41768
26 Cottonwood	Cottonwood	1260	182	0.144	150231	207.9	1878	0.110	100.0	173	1705	207.9	150231
27 Blue Earth	LeSueur	1073	120	0.112	369929	511.9	3106	0.164	67.9	0	3106	347.4	251039
28 Minnesota-Hawk	Redwood (Camden)	271	30	0.111	126200	174.6	1479	0.118	93.8	126	1353	164.7	118996
28 Minnesota-Hawk	Redwood	697	65	0.093	126200	174.6	1479	0.118	79.0	126	1353	141.1	101939
	Average												110468
29 Lower Minnesota	Cottonwood	1260	182	0.144	299395	414.3	1487	0.278	51.8	233	1254	246.0	177818
30 Kettle	Kettle	181	85	0.470	584603	808.9	1566	0.516	90.9	543	1023	760.9	549903
31 Snake	Kettle	181	85	0.470	297715	411.9	1015	0.405	100.0	54	961	411.9	297715
32 Lower St. Croix	Kettle	181	85	0.470	271610	375.8	926	0.405	100.0	267	659	375.8	271610
33 Metropolitan	Weighted Average			0.110	386376	534.6	1338	0.399	27.5	0	1338	147.2	106367

instream dry

Watershed	Representative River	Transect Drainage Area	IFA75 cfs	qIFA75 cfsm	WA75 acft	WA75 cfs	Watershed Drainage Area	qWA75 cfsm	iQ75 cfs	DAT sqmi	DAN sqmi	IFA75W cfs	V75 acft
34 Cannon	Cannon	1165	185	0.159	296280	410.0	1411	0.290	54.7	83	1058	192.1	138848
35 Zumbro	N. Fk. Zumbro	240	65	0.271	393277	544.2	1676	0.324	83.4	515	1161	481.7	348090
35 Zumbro	Zumbro	1157	240	0.207	393277	544.2	1676	0.324	63.9	515	1161	408.0	294894
	Average												321491
36 Root	S. Br. Root	284	95	0.335	712702	986.2	2568	0.384	87.1	2044	524	960.2	693951
37 Cedar	Cannon	1165	185	0.159	256837	355.4	1204	0.295	53.8	4	1200	191.7	138570
38 Des Moines	Des Moines	1198	190	0.159	107460	148.7	1520	0.097	100.0	65	1455	148.7	107460
39 Rock	Rock	257	20	0.078	76497	105.8	1793	0.059	100.0	0	1793	105.8	76497