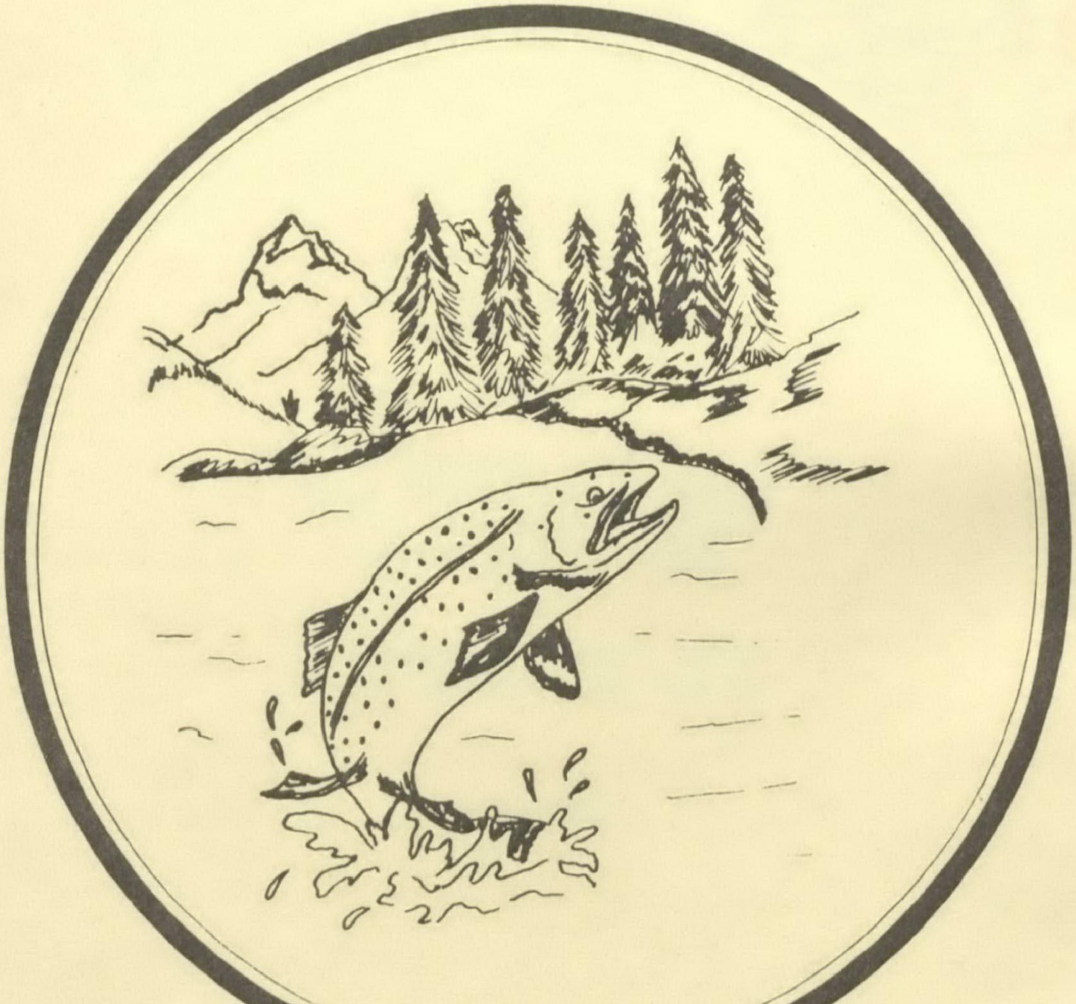
EPA-908/4-78-004B

FIELD TESTING AND ADAPTATION OF A METHODOLOGY TO MEASURE "IN-STREAM" VALUES IN THE TONGUE RIVER, NORTHERN GREAT PLAINS (NGP) REGION

EXECUTIVE SUMMARY



U.S. ENVIRONMENTAL PROTECTION AGENCY

ROCKY MOUNTAIN-PRAIRIE REGION

OFFICE OF ENERGY ACTIVITIES

DENVER, COLORADO

APRIL, 1978

FIELD TESTING AND ADAPTATION OF A METHODOLOGY TO MEASURE "IN-STREAM" VALUES IN THE TONGUE RIVER, NORTHERN GREAT PLAINS (NGP) REGION

EXECUTIVE SUMMARY

by

Ken Bovee
James Gore
Dr. Arnold Silverman
University of Montana
Missoula, Montana

for the

U.S. Environmental Protection Agency
Rocky Mountain-Prairie Region
Office of Energy Activities
Contract No. 68-01-2653

OEA Coordinator: Denis Nelson
Project Officer: Loys Parrish

April, 1978

DISCLAIMER

DISTRIBUTION

Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

ABSTRACT

A comprehensive, multi-component in-stream flow methodology was developed and field tested in the Tongue River in southeastern Montana. The methodology incorporates a sensitivity for the flow requirements of a wide variety of in-stream uses, and the flexibility to adjust flows to accommodate seasonal and sub-seasonal changes in the flow requirements for different uses. In addition, the methodology provides the means to accurately determine the magnitude of the water requirement for each in-stream use. The methodology can be a powerful water management tool in that it provides the flexibility and accuracy necessary in water use negotiations and evaluation of trade-offs.

In contrast to most traditional methodologies, in-stream flow requirements were determined by additive independent methodologies developed for: 1) fisheries, including spawning, rearing, and food production; 2) sediment transport; 3) the mitigation of adverse impacts of ice; and 4) evapotranspiration losses. Since each flow requirement varied in importance throughout the year, the consideration of a single in-stream use as a basis for a flow recommendation is inadequate.

The study shows that the base flow requirement for spawning shovelnose sturgeon was 13.0 m^3/sec. During the same period of the year, the flow required to initiate the scour of sediment from pools is 18.0 m^3/sec., with increased scour efficiency occurring at flows between 20.0 and 25.0 m^3/sec.

An over-winter flow of 2.83 m^3/sec. would result in the loss of approximately 80% of the riffle areas to encroachment by surface ice. At the base flow for insect production, approximately 60% of the riffle

area is lost to ice. Serious damage to the channel could be incurred from ice jams during the spring break-up period. A flow of 12.0 m^3/sec. is recommended to alleviate this problem. Extensive icc jams would be expected at the base rearing and food production levels.

The base rearing flow may be profoundly influenced by the loss of streamflow to transpiration. Transpiration losses to riparian vegetation ranged from 0.78 m^3/sec. in April, to 1.54 m^3/sec. in July, under drought conditions. Requirements for irrigation were estimated to range from 5.56 m^3/sec. in May to 7.97 m^3/sec. in July, under drought conditions. It was concluded that flow requirements to satisfy monthly water losses to transpiration must be added to the base fishery flows to provide adequate protection to the resources in the lower reaches of the river.

Integration of the in-stream requirements for various use components shows that a base flow of at least 23.6 m^3/sec. must be reserved during the month of June to initiate scour of sediment from pools, provide spawning hibitat for shovelnose sturgeon, and to accommodate water losses from the system. In comparison, a base flow of 3.85 m^3/sec. would be required during early February to provide fish rearing habitat and insect productivity, and to prevent excessive loss of food production areas to surface ice formation. During mid to late February, a flow of 12 m^3/sec. would be needed to facilitate ice break-up and prevent ice jams from forming. Following break-up, the base flow would again be 3.85 m^3/sec. until the start of spawning season.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

FIELD TESTING AND ADAPTATION OF A METHODOLOGY TO MEASURE "IN-STREAM" VALUES IN THE NORTHERN GREAT PLAINS (NGP) REGION

EXECUTIVE SUMMARY

Introduction

The western United States may be described as a water poor region by virtue of the fact that the potential rate of evaporation far exceeds the annual precipitation in large areas of the region. Surface water occurs primarily as the result of storage of water (in lakes and reservoirs) and from importation from high precipitation areas, such as mountain ranges. The importance of surface waters to the development of the West is recognized by the kind of economic activity and population distribution that found in the region. Virtually all major population centers are located near a lake or river.

Because the availability of water is paramount for development, there may be intense competition for water by different interests. Historically, water was considered to be used beneficially only if it was diverted for irrigation, municipal use, or industry. Commonly, applications for water rights exceeded the total annual flow of the river. It was later recognized that there also existed certain water demands which required the presence of a discharge within the natural channel. This discharge was termed an "in-stream flow", and has only recently been given legal standing as a beneficial use of water.

Stated simply, an in-stream flow reservation is a water right held by a state or federal agency, for the beneficial use of fisheries, maintenance of water quality, maintenance of channel form and process, and protection of complex riverine-riparian relationships of the ecosystem.

The presence of many simultaneous, and often conflicting water demands, both in- and off-stream, implies the need for a systems approach to water planning and management. This means not only the identification of the system to be analyzed, but objectives, boundary conditions, and constraints associated with each system (Stalnaker and Arnette, 1976). Unfortunately, the pattern of water planning has often resulted in fragmentation rather than consolidation of water uses. This has been particularly true in the case of in-stream flow determinations. While many in-stream flow methodologies address the problems of water quality, sediment transport, or riparian vegetation requirements, the final flow recommendation is invariably based on fishery requirements. Thus, it is implied that satisfaction of the basic requirements for the fishery will adequately protect all other in-stream values.

Most of the methodologies used in the assessment of fishery requirements were developed for cold, high gradient, salmonid fisheries. Experiences gained from the experimental dewatering of small trout streams may not be entirely adequate for dealing with a large, complex, warm-water fishery. Therefore, the validity of extrapolating a salmonid oriented methodology to a warm water system has been called into doubt.

Furthermore, many of these methodologies are based on the hydraulic, rather than the biological, characteristics of the stream. In addition, the methodology may contain assumptions about the biology of certain species, rather than the demonstrated physical requirements of the species. In some cases, however, the basis for biological assumptions are rather obscure.

It is further generally assumed that most in-stream uses have an extinction point; a volume of water below which a given use cannot exist. Methodologies which do not incorporate biological responses, or feedback, are frequently unable to define this extinction point. Because there is usually a demand on the planner to optimize the off-channel use of water, the determination of the extinction point becomes critical. In a negotiation situation over water rights, the option of a "fall-back position" (for in-stream flows, the extinction point) is not open. This in turn may either affect the defensibility and ultimate legal recognition of the flow reservation, or result in preserving a mere vestige of former aquatic resources.

The objectives of this study were designed to solve the types of problems discussed above. A primary objective was the development and field testing of a methodology to assess the minimum streamflow requirements for a warm water fishery. Another primary objective was the methodological development and assessment of minimum streamflow requirements of several non-fishery in-stream uses, and the adequacy with which the fishery flows meet these needs. A secondary objective involved the development and modification of data gathering and modeling techniques for large river assessments. Finally, the study attempts to show how a systems approach to in-stream flow requirements might be implemented and interpreted by a water resource planner.

The study was conducted in the Tongue River Basin in southeastern Montana. Selection of this river was made on the basis of its size, location, and composition of the fish community. The Tongue River is a medium sized stream, averaging about 50 meters in width, and draining an area of approximately 18,500 km^2. The upper river is typified by a fairly steep gradient and cobble bed, which grades downstream to a moderate to low gradient, and sand-gravel bed, near the mouth. Over 30 species of fish inhabit the Tongue River during part or all of the year.

Results and Conclusions

The methodology developed and implemented by this study can be a powerful management tool, and is a significant improvement over other methods in current use. The methodology incorporates a sensitivity for the flow requirements of a wide variety of in-stream uses, and the flexibility to adjust flows to accommodate seasonal and sub-seasonal changes in flow requirements for different uses. It also provides the means to accurately and reliably determine the magnitude of the requirement for each in-stream use.

It was found that different in-stream uses assume positions of greater or lesser importance during different times of the year. Flow requirements for fisheries are of highest importance (i.e. require the greatest amount of streamflow) only during certain portions of the year.

Winter ice is one condition which periodically requires a sufficient flow to prevent serious problems. The thickness of the surface ice sheet was found to be inversely related to the velocity of the water beneath it. Therefore, reduced streamflow would not only reduce the depth of water, but actually give rise to a greater thickness of ice. At the minimum fish rearing flow, up to 90% of the riffle areas of the stream could be solidly frozen from surface to bed. At the minimum flow requirement for maintenance of insect productivity, only about half of each riffle area would be so frozen.

During the spring break-up of the ice sheet, serious damage from ice jams may occur unless the streamflow is fairly high. These jams are virtually assured if the flow is at the minimum level defined for fisheries. It is estimated that a flow of approximately three times the fishery flow is needed to protect the stream and irrigation structures or equipment from damage by ice jams along the Tongue River.

Pool scour during the spring runoff period is considered essential to maintain stream habitat areas, and to remove silt from diversion structures and irrigation pump intake areas. The flow required to initiate the removal of coarse sediment from pools was found to be considerably higher than the flow required for spawning during the same time period. It was further determined that the efficiency of water use for this purpose could be improved by providing a flow above the base level for pool scour. Extreme care must be taken during this time period to avoid deposition of coarse sediment in areas where it doesn't normally occur, for this can lead to streambed armoring, a condition that makes the initiation of scour more difficult in succeeding years.

Perhaps the most striking discovery of this research was the determination that water losses must be added to the base in-stream flow to ensure that flow at all points of the river. The instantaneous flow requirements to satisfy evapotranspiration for riparian vegetation and irrigated crop land often exceeded the rearing flow for fisheries by 200 to 300 percent. If water is lost from the system, it is absolutely necessary to account for it. Failure to do so will result in large reaches of river with less discharge than required for other in-stream uses. In fact, approximately 50 km. of the lower Tongue River would have zero discharge if only a fishery rearing flow were released from the Tongue River Dam during July and August. However, this in-stream flow requirement applies primarily to losing rivers. Where a river is augmented by groundwater accretion, the problem is not so serious, for the groundwater will also supply a large part of the water for evapotranspiration. It is apparent that most in-stream flow methodologies were developed for gaining rivers, as no methodology in current use even metions or considers the problem of transpiration losses.

Methodological Development and Evaluation

The "In-Stream Flow Methodology" developed and implemented in this study, should be conceptualized as the end result of the application of several problem specific, component methodologies. The relationships between the component methodologies and the final flow recommendations are illustrated in Figure 1.

Some of the in-stream uses described in Figure 1 are considered complementary; that is, the streamflow requirement to satisfy one use will also satisfy several others. Under this framework, the complementary use with the highest flow requirement for a certain time period is considered critical.

Consumptive water uses, such as transpiration losses from natural riparian vegetation or irrigated cropland, are considered additive uses. Flow requirements determined for these water losses are summed, and added to the critical flow requirement as determined for the complementary uses. The total in-stream flow requirement for a given time period is then defined as the summation of the additive and critical complementary requirements.

The use of the comprehensive methodology to make a minimum streamflow recommendation is illustrated by the flow diagram in Figure 2. For the month of June, the flow requirement for pool scour was determined to be 18 m^3/sec., while the base flow for spawning shovelnose sturgeon is 13 m^3/sec. The flow required to flush fine sediment from gravel areas is only 11 m^3/sec. Thus, the critical streamflow requirement for all complementary uses is 18 m^3/sec. Total transpiration losses were calculated to be 5.58 m^3/sec. Therefore, the total in-stream commitment for June is 23.6 m^3/sec. This is the instantaneous flow to be released at the Tongue River Dam to ensure a flow of 18 m^3/sec. at the mouth of the river. The total monthly volume commitment would be 63.2 million cubic meters.

This methodology is based on the determination of the minimum streamflow requirement to satisfy each in-stream component; therefore, it is extremely important that each of these determinations is accurate and valid. Each

Figure 1: Component diagram of a comprehensive in-stream flow recommendation procedure. Components at the far left of flow diagram refer to minimum flow requirements for each component. For some months, certain components go to zero.

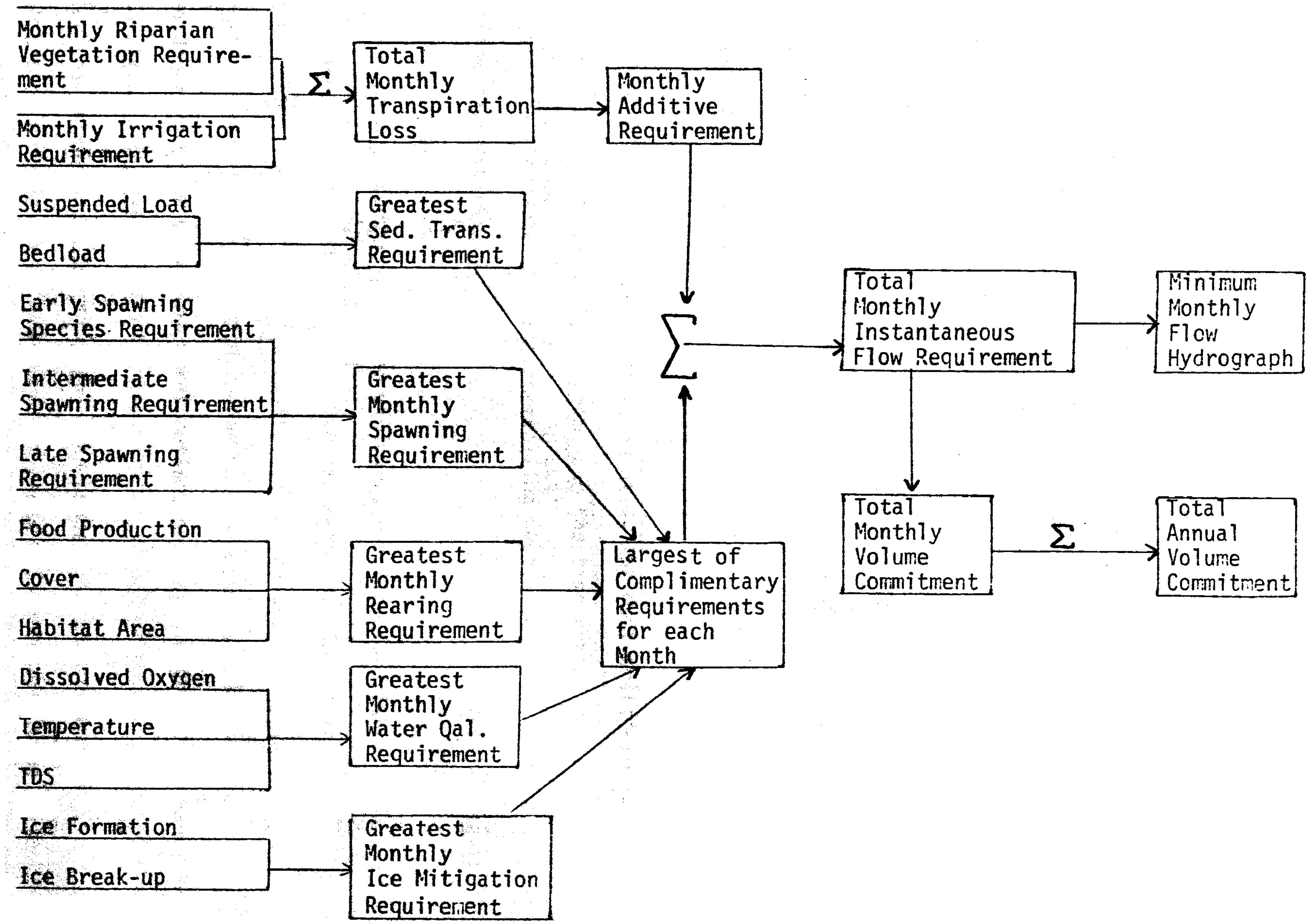
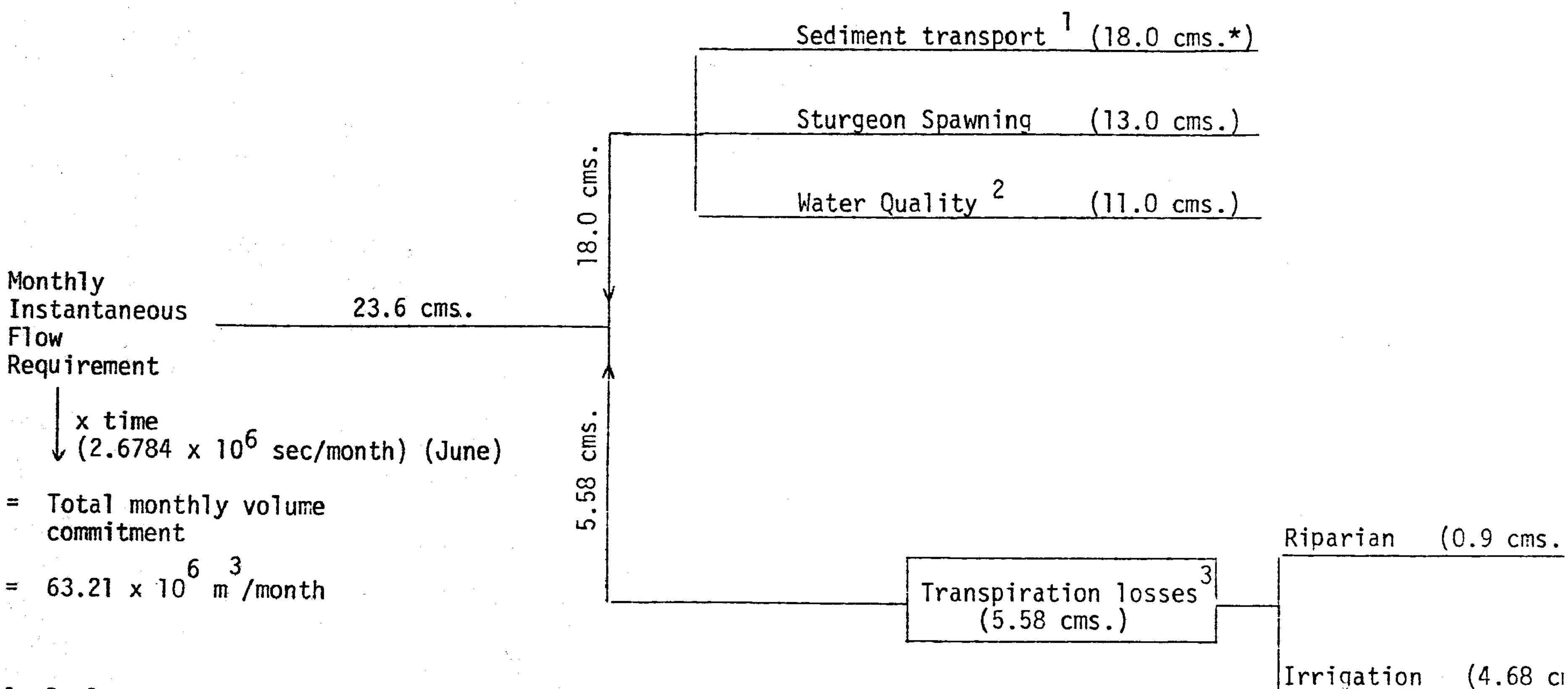


Figure 2: Example of integrated methodology used to determine the minimum streamflow requirement for the Tongue River during the month of June.



1. Pool scour requirement
2 Entrainment dishcarge of fine sediment
3 Corrected for rainfall
* cms. = cubic meters per second

methodology used in this study was evaluated by the criteria of accuracy, ground truth or biological feedback, and water availability. A brief description of each of the component methodologies, and an evaluation of their validity, are provided below.

Water Quality Component:

The methodologies employed in the determination of flow requirements to maintain water quality may be found in general sanitary engineering texts, such as Velz (1970), or in technical bulletins outlining specific water quality problems. The water quality component was not implemented or evaluated in this study due to constraints of manpower, and the general lack of pollution in the Tongue River. However, evaluations of the different water quality models are usually given with the model descriptions.

The importance of different water quality parameters will vary from stream to stream, depending on the waste loading, geology, land use, and water use. Therefore, it is important to identify the most critical water quality parameters for a particular stream, and the time period during which that parameter is likely to become a controlling factor in the determination of streamflow requirements.

Fisheries Component:

The methodology used to determine minimum streamflow for fisheries is designated the "Critical Area-Indicator Species Method". This method utilizes the high sensitivity of shallow water riffles and gravel bars to changes in streamflow. Because of the rapid change in hydrologic variables with change in discharge, these habitat areas reflect a greater degree of change than other stream habitats.

A logical extension of the critical area concept is that organisms which inhabit or utilize these shallow water areas will necessarily be more sensitive to changes in streamflow than will inhabitants of less sensitive habitat areas. Therefore, if suitable habitat is maintained in the critical area, for species using that area, it is assumed that conditions will be suitable for all other species in the river. This concept is used to define the criteria for an indicator species.

Under this methodology, the same indicator species is not used throughout the year. Rather, several indicator species have been identified for use during the migration and spawning phase of the life history, and others during the rearing phase. For the purposes of this study, the sauger and shovelnose sturgeon were selected as migration and spawning indicators. Rearing conditions were evaluated in terms of productivity (aquatic insect habitat) and balance (habitat diversity for fish). Maximum biomass and diveristy were utilized as criteria for maximum productivity. The stonecat was used as the indicator species delineating critical area habitats.

The fisheries component method involves two separate phases of field data collection. The first phase is the formulation of flow criteria for each indicator species. This flow criteria includes a determination of the velocity range, depth range, and bottom type most commonly associated with each indicator species.

The second phase evaluates a series of discharges across a critical area, or areas. This evaluation process requires the construction of planimetric hydrologic contour maps which delineate areas of equal depth or velocity. Field data for the maps were collected from four or more transects across a critical area. At specified intervals across each transect, measurements of depth, velocity, and bottom type are made. A depth contour map is prepared by transferring the transect depth measurements to their appropriate positions on a scale drawing of the channel. Lines of equal depth are then drawn on the map by interpolating to the desired depth contour between points on the same transect, or between corresponding points on adjacent transects. Figure 3 is an example of a depth contour map with the field data left on the transect lines. Velocity maps are similarly constructed on a separate planimetric map. These maps may be read in a manner similar to a topographic map.

The adequacy with which a given dishcarge provides habitat over the critical area for the indicator species may then be evaluated with the use of a composite map. Composite maps are constructed by superimposing the appropriate depth, velocity, and bottom type contours on the same map. Only the contours delineating the boundary conditions for the flow criteria of a given indicator species are presented. Areas which do not meet depth, velocity, and bottom type criteria are then cross-hatched. Areas remaining on the composite map meet all of the flow criteria for the indicator species. These areas may then be measured with a planimeter, and the total area meeting the flow criteria determined for each discharge. The area meeting this criteria is then plotted against discharge for each discharge "mapped" (Collings, et. al., 1972). This curve is used to determine the optimum and minimum streamflow requirements for the indicator species. An example of a composite map is given in Figure 4. Figure 5 shows a plot of preferred habitat area vs. discharge.

According to the widely used procedures, the minimum streamflow requirement is defined as 75% of the optimum, as determined by the peak of the curve. However, it was found that this was an invalid approach. The optimum flow has no direct bearing on the minimum flow requirement, and this procedure often results in a flow recommendation which does not meet the criterion of water availability. For example, the minimum rearing flow requirement as determined

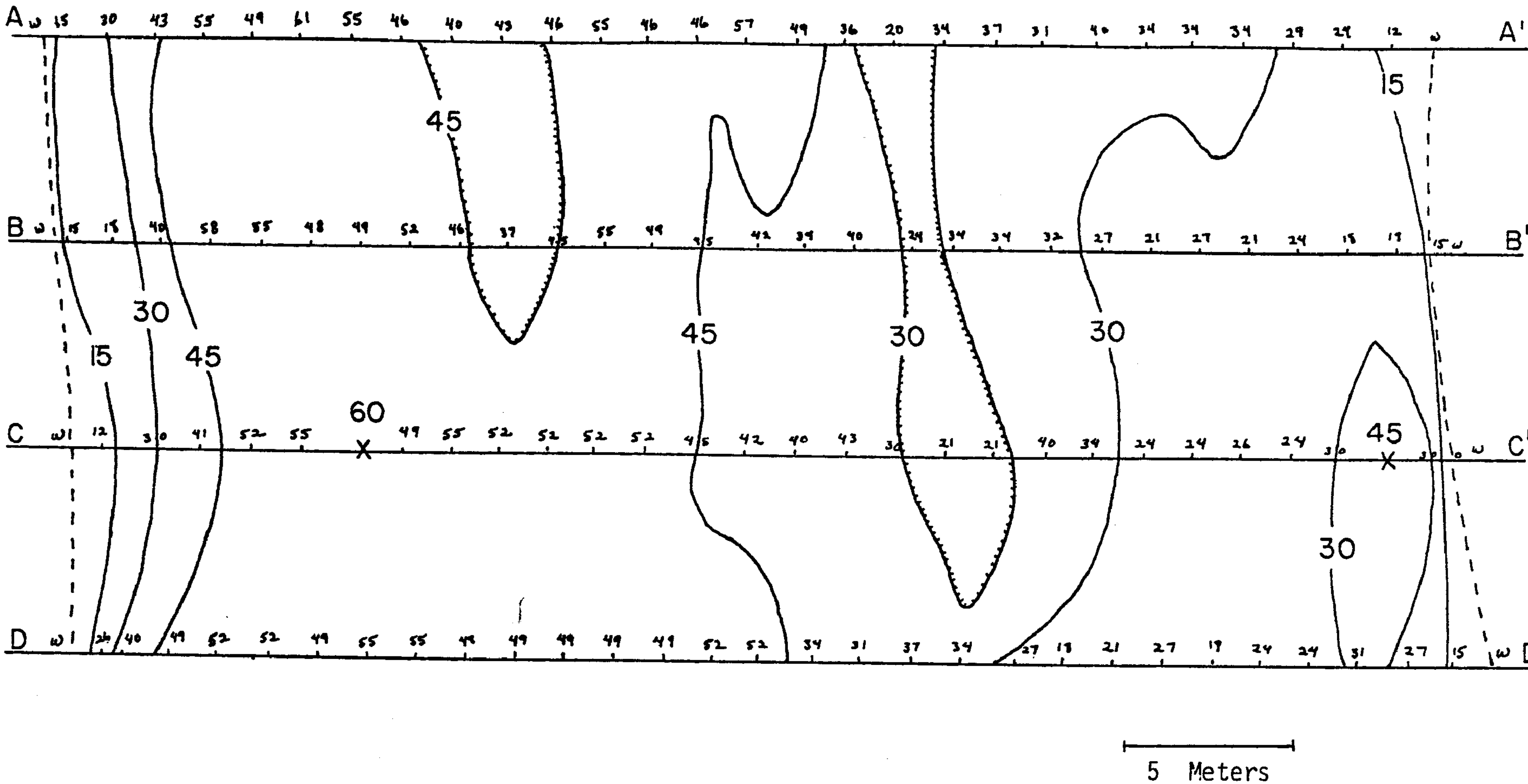


Figure 3 : Example of the construction of a depth contour map. Handwritten numerals are from field data; isolines of equal depth drawn by interpolation between data points; depths are in cm.

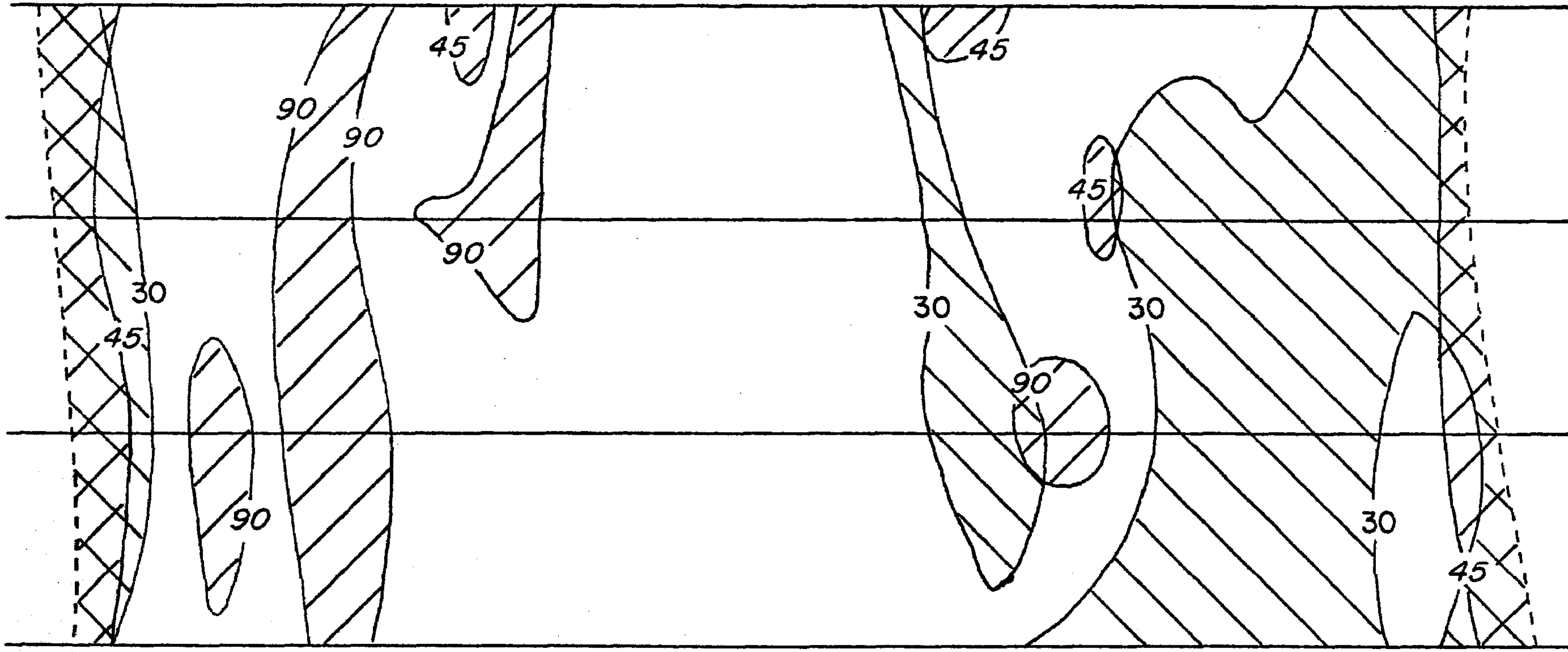
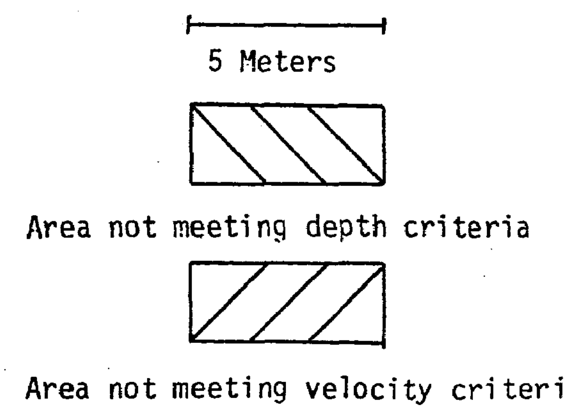


Figure 4 : Example of a composite map, showing areas meeting flow criteria.for the stonecat. Area with no cross hatching meets all criteria.

Total area meeting criteria: 425 m^2.

Discharge = 12.0 cms.



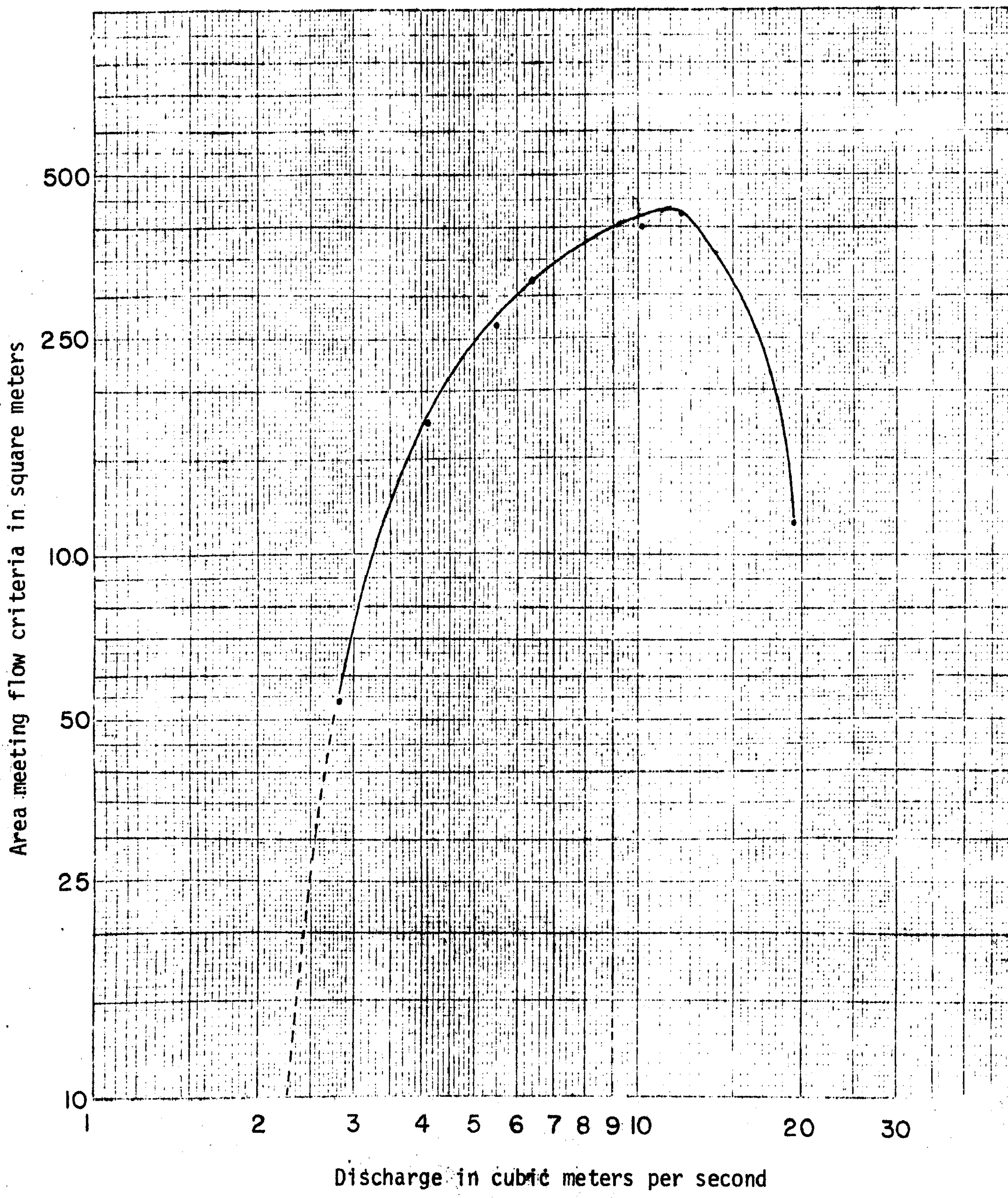


Figure 5 : Example of preferred area vs. discharge, or "peak of the curve" plot used to determine optimum and minimum streamflow requirements.

by the 75% method was found to be equalled or exceeded less than 40% of the time from 1961 to 1970 for the Tongue River.

Therefore, a new approach was developed to objectively identify the minimum, or base flow, requirement. The base flow is defined as that discharge which first provides some increment of preferred hydrologic conditions (i.e. meets the flow criteria of the indicator species) over the critical area. The base flow, thus defined, was equalled or exceeded more than 70% of the time between 1961 and 1970 for the Tongue River.

The field tests conducted to determine biological feedback for the methodology gave credence to both the concepts of optimum and base flow. As the base flow is approached, it would be expected that diversity and productivity might decline. In fact, these were the findings of the field tests. The change in diversity and productivity may be quite precipitous as the flow falls below base flow level. In addition, there were some subtle qualitative changes in the composition of the fish community, which had serious implications for recreational fishing. When the flow decreased below the base flow level, suckers and minnows became dominant, with a corresponding decline in the number of sport fish present.

Based on the findings of the field tests, it was concluded that the base flow concept, as used within the context of this methodology, was accurate, valid and met the criterion of water availability. However, the utility of this method is likely to be limited by the large time and manpower investment needed for implementation. Another potential objection to the methodology is that it is only applicable to small, wadeable rivers.

Both objections to this methodology may be effectively overcome through the use of specialized equipment and hydrologic flow prediction models. Two such models were field tested during this study. The Water Surface Profile Program (WSPP) is an energy balance model, utilizing the Manning equation to predict depths and average velocities of a channel cross section at different flows. The CONTOUR model, developed during this study, utilizes power functions based on hydraulic geometry to predict depths and water column velocities at specific points on the cross section. While neither model was able to predict the exact flow parameters, both show considerable promise as flow predicting tools. The CONTOUR model was designed especially for use in planimetric mapping, and was found superior to WSPP for velocity prediction within the constraints of the model. Output from the CONTOUR model may be used in conjunction with computer plotting programs, so it may be possible, in the near future, to use computerized simulation mapping as a technique for in-stream flow work. It is estimated that such simulation mapping will reduce the time requirement for the use of the Critical Area-Indicator Species Method by as much as 80 percent. This technique would be applicable to any river, although boat mounted stream gaging equipment would be required on larger streams.

Ice Formation Component:

At the outset of the study, it was recognized that ice formation played an important role in Northern Great Plains streams, but the extent and nature of its influence was not known. It was found that ice formation actually affects the river ecosystem in two ways: 1) by reducing the amount of habitable area by its physical presence, and 2) by disturbance of the bed during the break-up period.

Field measurements showed that the equilibrium ice thickness (the thickness at which heat loss from the top of the ice sheet equals the heat gained at the water-ice interface) was inversely related to water velocity. Thus, slower water velocities were invariably associated with a thicker surface ice sheet. As velocity decreases drastically with reduced discharge, it follows that a decrease in discharge would result in a greater equilibrium ice thickness.

The extent of habitat loss to the formation and thickening of an ice sheet depends not only on the discharge, but on the thermal regime of the region as well. The methodology used in this study to assess the area loss to ice utilizes an empirically derived relationship between ice thickness and current velocity. For a given water velocity, there is a corresponding expected ice thickness. Examples of this relationship are given in Table 1.

Table 1: Expected ice thicknesses according to current velocities at measurement locations.

Current velocity cm/sec	Equilibrium thickness cm.
60	19
50	21
45	21
40	22
30	25
20	29

Since the data from Table 1 was empirically derived, it is applicable only to the Tongue River, although the velocity-thickness relationship may hold for all rivers which experience surface ice conditions.

The extent of habitat loss may be evaluated for the same critical areas used in rearing flow determinations, by using the same depth and velocity contour maps prepared for those areas. Velocity contour lines are used to estimate the approximate thickness of the ice. This expected thickness is then superimposed on the depth contour map for the same discharge. Where the predicted ice thickness is greater than, or equal to the depth within a given contour interval, that area is assumed frozen to the bed. The approximate percentage of the riffle lost to ice formation may then be estimated, or actually measured if greater accuracy is desired.

The determination of the flow requirement to prevent ice jams from forming is considerably easier than determining the fishery flow. Since the greatest thickness of ice measured empirically was not much larger than 30 cm., it was assumed that most of the ice released from pool areas would be around 30 cm. thick. The depth contour maps for a given critical area were examined to determine the extent of the area less than 30 cm. in depth at various discharges. If the depth over the entire area is greater than the thickness of the ice floating through the area, the chances of ice jam formations are decreased considerably. Conversely, the probability of a serious ice jam over a critical area increases as more of the critical area is less than the required depth.

At this time, the relationship between ice thickness and current velocity can best be determined empirically. However, there are several thermodynamic models for the prediction of equilibrium ice thickness which may be of value in the near future (Paily, et. al., 1975; 1976). These models were developed primarily for the determination of ice cover in streams receiving thermal effluent. They may also be applicable to unheated streams if the heat production and abrasion of running water can be determined. These models are now unverified for in-stream flow use.

Transpiration Loss Component

Since transpiration losses along a river are additive, it is not possible to select a critical area for the determination of a satisfactory flow requirement. The methodology used to determine transpiration losses is essentially the same for riparian vegetation and irrigated cropland.

The first step, in either case, is the determination of the total canopy cover involved in the transpiration process. For irrigated crops, this area is usually available in the literature (i.e. U.S.G.S. streamflow records and gaging station descriptions). However, the area of riparian vegetation may be determined empirically through the use of aerial photographs. For this study, vegetated areas were traced from aerial photos onto a gridded tracing paper, in such a manner that each small square of the grid contained some canopy. The percentage of each square covered by canopy was estimated, and that vegetation area was given a weighting factor depending on the percentage cover. The total cover for each vegetation map so prepared was determined by measuring each vegetated area with a planimeter, and multiplying by the appropriate weighting factor. Total canopy cover was determined by summation of individual canopy cover areas as determined for each map. The construction of a weighted area vegetation map is shown in Figures 6 and 7.

The transpiration rate was then determined using the Penman equation, an energy balance equation, and local climatological data. Using the Penman equation, it is possible to determine the mean daily and maximum daily transpiration rates of the vegetation. These rates may be corrected for rainfall if desired.

Daily water volume requirements for transpiration may then be determined by multiplying the total canopy cover area (in square meters) by the transpiration rate (meters per day). Instantaneous flow requirements were estimated by assuming that groundwater recharge is constant over time. By dividing the mean daily water volume requirement by 86,400 sec/day, it is possible to calculate the instantaneous mean daily flow requirement for transpiration.

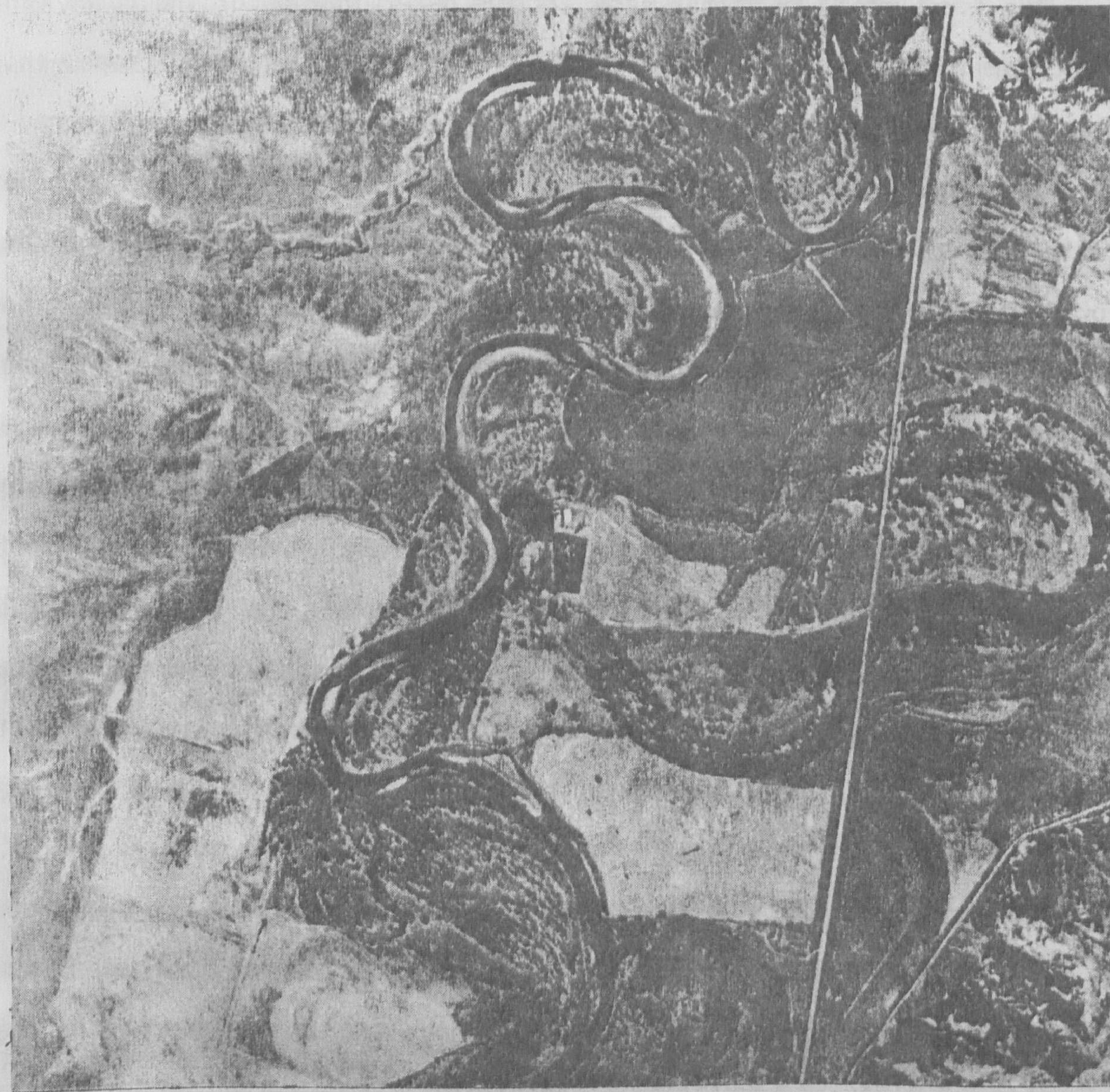


Figure 6: Aerial photograph showing canopy cover of the riparian vegetation of the Tongue River floodplain, in the vicinity of Ash Creek. Photo courtesy of the Montana Department of Fish and Game.

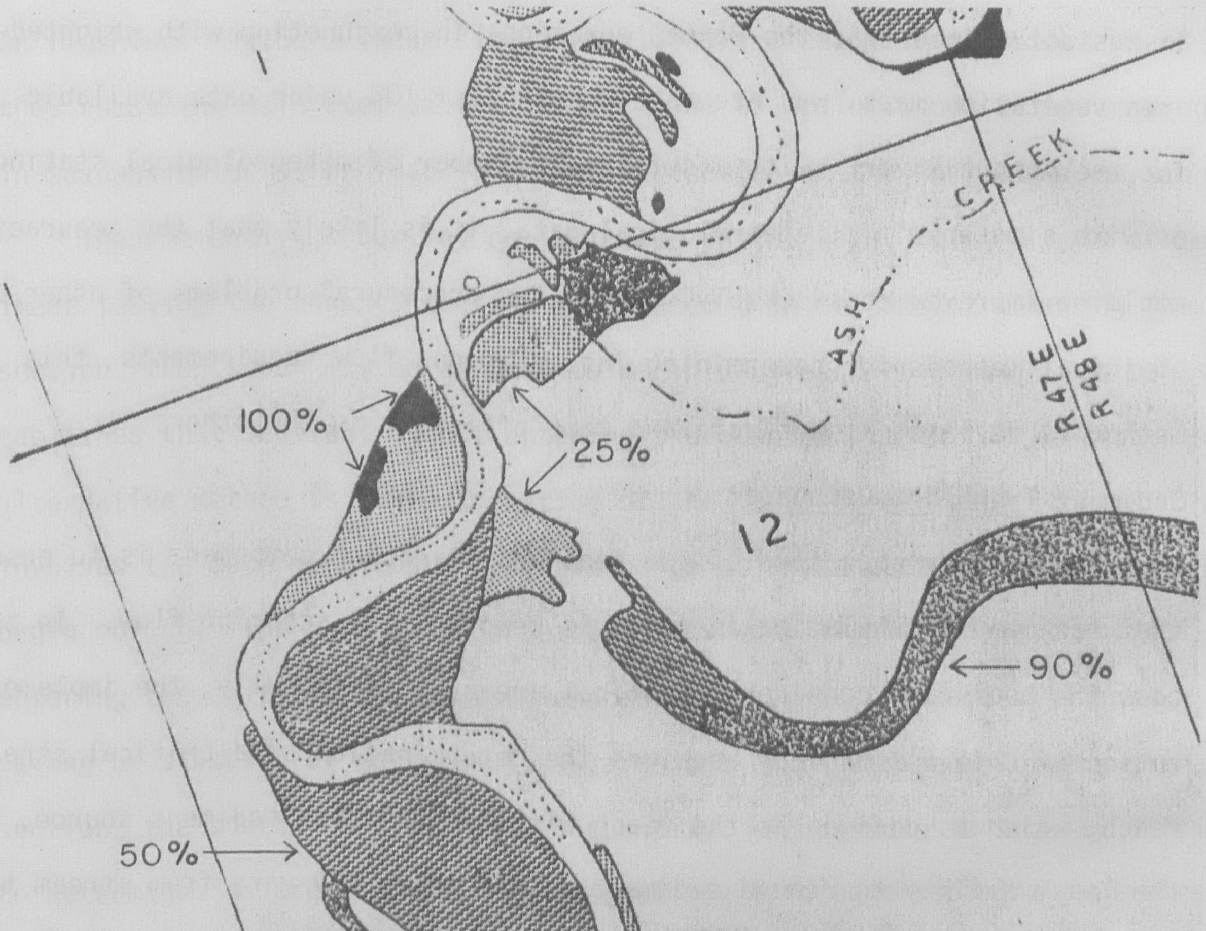


Figure 7: Vegetation map showing canopy cover density as estimated from the aerial photo (Figure 6) of the Tongue River floodplain near Ash Creek.

Predicted instantaneous flow requirements were tested against ground truth data as determined by stream gaging records for the Tongue River. It was determined that the Penman equation, in conjunction with weighted-area vegetation maps, was accurate to within ± 10% using data available for the Tongue River. With a sufficient number of meteorological stations, or with site specific meteorological data, it is likely that the accuracy could be improved considerably. Given the procedural problems of other empirical methods for determining instantaneous flow requirements, this method is at least as accurate and time efficient as the others.

Sediment Transport Component:

The primary objective of the sediment transport component is to ensure that sediment accumulation in pools is removed by a scouring flow. In this case the pools are considered critical areas. Additionally, the implementation of this methodology requires the determination of a critical stream reach, which is defined as the reach with the greatest sediment source, and the least ability to remove sediment. This reach may vary from stream to stream depending on the nature of the sediment inflow. For many streams, however, the critical reach for sediment transport will be in the lowest part of the basin, where the hydraulic gradient of the stream is at a minimum.

Sediment transport was evaluated empirically by taking both bedload and suspended sediment samples at the downstream end of a large pool in the critical reach for the Tongue River. Sediment rating curves for various size fractions of sediment were constructed by plotting the sediment load against the discharge. The interpretation of these sediment rating curves is often made more difficult by a scattering of the data points for a given discharge. This scattering phenomenon is most serious for particle sizes less than 62 microns in diameter. However, this size fraction may be omitted from the evaluation process because it does not reflect channel scour or flushing. Rather, these size particles are already in transport when they reach the main stem of the river. Fine to medium sand, either moving in suspension or as bedload is better indication of the initiation of scour.

Theoretically, scour may be indicated in two ways. If the load of sediment leaving the channel section is greater than the amount entering the section, then scour may be assumed to be in progress provided it can be established that sediment is not entering the channel within the section. An alternative method is the examination of the competence of the stream. This involves the determination of the discharge at which certain size fractions begin moving. The mass balance method works well if all sediment sources entering the critical stream section can be measured. However, if bank caving or slumping of material is a large source of sediment for the stream section, the source is difficult to quantify. Competence is equally difficult to determine, as areas within the channel may move some sediment particles at virtually all discharges.

The method used to evaluate sediment transport in this study is a combination of both the competence and mass balance methods. Numerous samples were taken at a relatively low flow, with no sediment entering the river from runoff. These samples were used to establish "background" levels of the load of the various size fractions of sediment. Subsequent samples at higher discharges, on the rising limb of the hydrograph, were then examined to determine whether the load appreciably exceeded the background level. Thus, a type of cluster analysis was used to interpret the initiation of scour in the pool. For example, the background level for fine sand moving as bedload was found to be around 3 metric tons per day for a number of flows below 18 m^3/sec.

The load at 18 m^3/sec. varied from 4 to 5 metric tons per day. However, from 18 to 20 m^3/sec. the fine sand load increased to 10 to 12 metric tons per day. This relationship is shown in Figure 8. It was therefore concluded that pool scour was initiated at about 18 m^3/sec. This flow was also substantiated by larger particle sizes moving as bedload, and by the appearance of fine sand in the suspended load.

It can be seen from Figure 8, that the value of 18 m^3/sec. is extremely conservative for a recommended pool scouring flow. Since pool scour is only initiated at this flow, it is suggested that a slightly higher discharge, perhaps 25 m^3/sec., would give a more efficient use of water for this purpose. Under the defined objectives of the study, 18 m^3/sec. is considered the base flow, and would be used as a fall back position in a negotiation situation.

There are numerous hydraulic models which could be implemented to determine the flow requirements needed for sediment transport. The simplest of these is the competence, or critical tractive force, model. This model derives the discharge at which a certain size of bed material begins to move. However, it can be seen from Figure 8 that some bed material is virtually always in motion, without the occurance of scour. Therefore, the competence model is considered to be of little value for in-stream flow work. Other sediment transport models incorporate a mass-balance aspect which could be of considerable value. These models require much the same type of field data as the Water Surface Profile Program, a factor which adds to the attractiveness of the mass-balance model.

Research Needs

In the foreseeable future it may be possible to simulate any of the components of Figure 1. The development and refinement of predictive tools which reflect real-world conditions accurately, should be given high priority

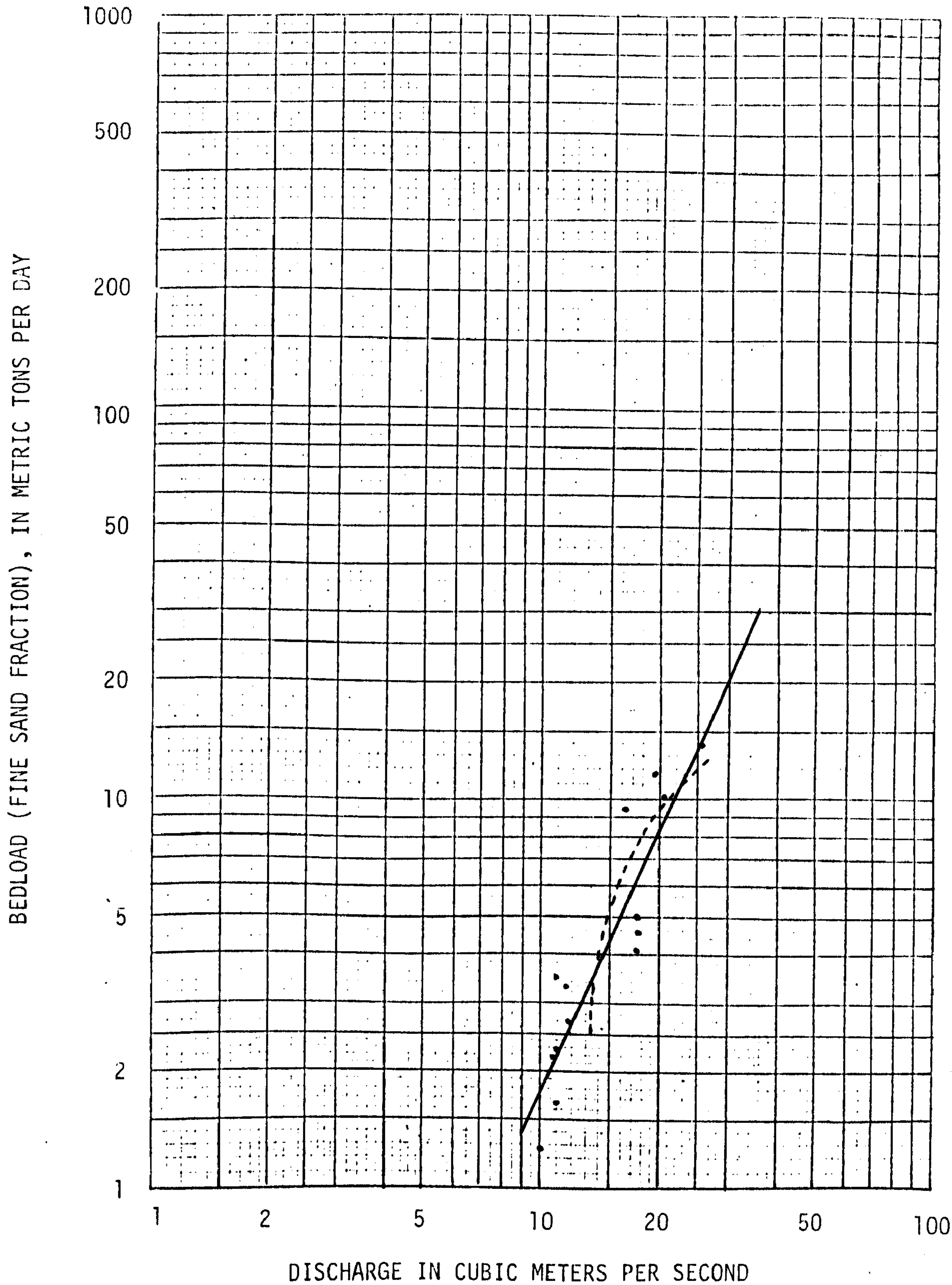


Figure 8 : Movement of Fine Sand (125 to 250 Microns) as Bedload in the Ft. Keogh Section, Tongue River, Montana

for future research. The use of computers for data simulation and for simulation mapping can reduce the time required to implement a large scale study from a year to two, to from one to three months. The benefits of such an approach in terms of cost and number of studies that can be completed in a limited time frame, is enormous.

Considerably more information regarding flow criteria for different species is needed. The techniques involved in the implementation of the Critical Area-Indicator Species approach are applicable in virtually every river. However, the important species in different regions, or in different sizes of streams, may change. There is no universal indicator species for in-stream flows. Therefore, it is important that indicator, or target, species for different regions be identified, and flow criteria for those species developed.

Further field testing of methodologies should continue on a long term basis. Important aspects of such studies should include the degree of depletion of a fishery under an incremental flow reduction below the base flow level, long term effects on the species composition and age class strength, for flows near or below the base level, long term effects on sediment transport and channel morphology, and long term effects on the zonation of riparian vegetation.

The mechanisms of surface ice formation and its relationship to discharge are only partially understood. Research into the prediction of equilibrium ice thickness and the thermodynamics of running water should be continued. Another unknown in terms of surface ice that merits study is the effect on stream organisms.

References

1. Collings, M.R., Smith, R.W. and Higgins, G.T., 1972, "The hydrology of four streams in western Washington as related to several Pacific salmon species", U.S.G.S. Water Sup. Pap. #1968. 109 pp.

2. Paily, P.P., Kennedy, J.F., and Dagan, G., 1975, "Effects of Large Thermal Discharges on Ice-Covered Rivers", Ia. St. Wat. Res. Inst. Ames, Iowa. ISWRRI-68. 10 pp.

3. __________., and Macagno, E.O., 1976, "Numerical prediction of thermal regime of rivers", J. Hyd. Div., ASCE, HY3: 255-274.

4. Stalnaker, C.B. and Arnette, J.L., 1976, "Methodologies for the determination of stream resource flow requirements: an assessment", USFWS, OBS, 199 pp.

5. Velz, C.J., 1970, Applied Stream Sanitation. Wiley Interscience, New York, 619 pp.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-908/4-78-004B	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Field Testing and Adaptation of a Methodology to Measure "In-Stream" Values in the Tongue River, Northern Great Plains (NGP) Region - Executive Summary		5. REPORT DATE April 1978 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Ken Bovee, James Gore and Arnold Silverman		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Geology Department, University of Montana, Missoula, Montana		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO. Contract No. 68-01-2653
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency, Region VIII, 1860 Lincoln Street, Denver, Colorado		13. TYPE OF REPORT AND PERIOD COVERED Final - Executive Summary 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

A comprehensive, multi-component in-stream flow methodology was developed and field tested in the Tongue River in southeastern Montana. The methodology incorporates a sensitivity for the flow requirements of a wide variety of in-stream uses, and the flexibility to accommodate seasonal and subseasonal changes in the flow requirements for different uses. In-stream flow requirements were determined by additive independent methodologies developed for: 1) fisheries, including spawning, rearing and food production; 2) sediment transport; 3) mitigation of adverse impacts of ice; and 4) evapotranspiration losses. Consideration of a single in-stream flow requirement is inadequate since flow requirements for each use varied throughout the year. The methodology can be an effective water management tool.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Stream flow, sediment transport, hydrology, fishes, benthos, aquatic biology, evapotranspiration, water management.	Instream flow requirements - benthos, fishes, life stages, sediment, scouring, riffles, ice, vegetation, seasonal, subseasonal, integrated methodology, water management.	

18. DISTRIBUTION STATEMENT Release unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 35
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

INSTRUCTIONS

1. **REPORT NUMBER**
Insert the EPA report number as it appears on the cover of the publication.

2. **LEAVE BLANK**

3. **RECIPIENTS ACCESSION NUMBER**
Reserved for use by each report recipient.

4. **TITLE AND SUBTITLE**
Title should indicate clearly and briefly the subject coverage of the report, and be displayed prominently. Set subtitle, if used, in smaller type or otherwise subordinate it to main title. When a report is prepared in more than one volume, repeat the primary title, add volume number and include subtitle for the specific title.

5. **REPORT DATE**
Each report shall carry a date indicating at least month and year. Indicate the basis on which it was selected *(e.g., date of issue, date of approval, date of preparation, etc.)*.

6. **PERFORMING ORGANIZATION CODE**
Leave blank.

7. **AUTHOR(S)**
Give name(s) in conventional order *(John R. Doe, J. Robert Doe, etc.)*. List author's affiliation if it differs from the performing organization.

8. **PERFORMING ORGANIZATION REPORT NUMBER**
Insert if performing organization wishes to assign this number.

9. **PERFORMING ORGANIZATION NAME AND ADDRESS**
Give name, street, city, state, and ZIP code. List no more than two levels of an organizational hirearchy.

10. **PROGRAM ELEMENT NUMBER**
Use the program element number under which the report was prepared. Subordinate numbers may be included in parentheses.

11. **CONTRACT/GRANT NUMBER**
Insert contract or grant number under which report was prepared.

12. **SPONSORING AGENCY NAME AND ADDRESS**
Include ZIP code.

13. **TYPE OF REPORT AND PERIOD COVERED**
Indicate interim final, etc., and if applicable, dates covered.

14. **SPONSORING AGENCY CODE**
Insert appropriate code.

15. **SUPPLEMENTARY NOTES**
Enter information not included elsewhere but useful, such as: Prepared in cooperation with, Translation of, Presented at conference of, To be published in, Supersedes, Supplements, etc.

16. **ABSTRACT**
Include a brief *(200 words or less)* factual summary of the most significant information contained in the report. If the report contains a significant bibliography or literature survey, mention it here.

17. **KEY WORDS AND DOCUMENT ANALYSIS**
(a) DESCRIPTORS - Select from the Thesaurus of Engineering and Scientific Terms the proper authorized terms that identify the major concept of the research and are sufficiently specific and precise to be used as index entries for cataloging.

    (b) IDENTIFIERS AND OPEN-ENDED TERMS - Use identifiers for project names, code names, equipment designators, etc. Use open-ended terms written in descriptor form for those subjects for which no descriptor exists.

    (c) COSATI FIELD GROUP - Field and group assignments are to be taken from the 1965 COSATI Subject Category List. Since the majority of documents are multidisciplinary in nature, the Primary Field/Group assignment(s) will be specific discipline, area of human endeavor, or type of physical object. The application(s) will be cross-referenced with secondary Field/Group assignments that will follow the primary posting(s).

18. **DISTRIBUTION STATEMENT**
Denote releasability to the public or limitation for reasons other than security for example "Release Unlimited." Cite any availability to the public, with address and price.

19. & 20. **SECURITY CLASSIFICATION**
DO NOT submit classified reports to the National Technical Information service.

21. **NUMBER OF PAGES**
Insert the total number of pages, including this one and unnumbered pages, but exclude distribution list, if any.

22. **PRICE**
Insert the price set by the National Technical Information Service or the Government Printing Office, if known.