# The Use of Prescribed Percentages of Mean Annual Discharge to Recommend Instream Flows for Fish in British Columbia

## (The Montana Method Revisited)

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# Prescribed Percentage of the Mean Annual Discharge

## Introduction

When there is a need to make quick appraisals of the instream flows required for fisheries, an empirical method based on prescribed percentages of the mean annual discharge can be useful. Properly applied, this method is based on field observations of streams that are like the ones for which instream flow recommendations are to be made. These observations document the suitability of instream flows for fish (and other users of instream flows) at various instantaneous discharges representing a broad range of percentages of the mean annual discharge, from less than 10% to 200%.

The method assumes that the condition of fisheries habitat on other streams --large or small--in similar biogeoclimatic zones is comparable when the instantaneous discharges, expressed as percent of the mean annual discharge, are the same. If this assumption is valid, the consequences of proposed short-term changes in a stream's discharge can be known beforehand. The proven capacity to make such predictions gives this method credibility and makes it a logical successor to the method most widely used today--raw subjective assessment.

The success of a method based on prescribed percentages of the mean annual discharge is assured by a fundamental principle of hydrology: stream width, as well as mean depth and velocity, vary as a function of mean annual discharge (Figure 1), (Leopold and others, 1964). Widths tend to increase as the square root of the mean discharge, thus the relationship can be written symbolically as

$$W = \rho D^{0.5}$$

Where W is width, D is discharge, and $\rho$ is a constant.

Because of the fixed relationship between width and percent of mean annual discharge, generalizations can be made about the quality of instream flows for fish. In streams that have not been studied, generalization can be based on the few streams that have. In eleven streams in Montana, Wyoming, and Nebraska (Fig. 1), an increase in percent mean annual discharge from 0 to 10 causes an increase in the percent of wetted width from 1 to 60. Thus, in the

American mid west, and probably in most of the world's streams, a very small portion of the mean annual discharge (10%) generates more than half the wetted width (Fig. 1).

Even so, about 40% of the wettable width remains exposed. Under these conditions, fish must seek refuge in pools, and riffles are too shallow for fish to pass (Tennant, 1976; Orth and Maughan, 1981). Thus, a discharge that is 10% of the mean annual discharge ought to be considered the minimum for short-term survival of fish and other aquatic organisms (Table 1). In this context, short term means a few days to a week. At less than 10% of the mean annual discharge, the stream should be regarded as severely degraded.

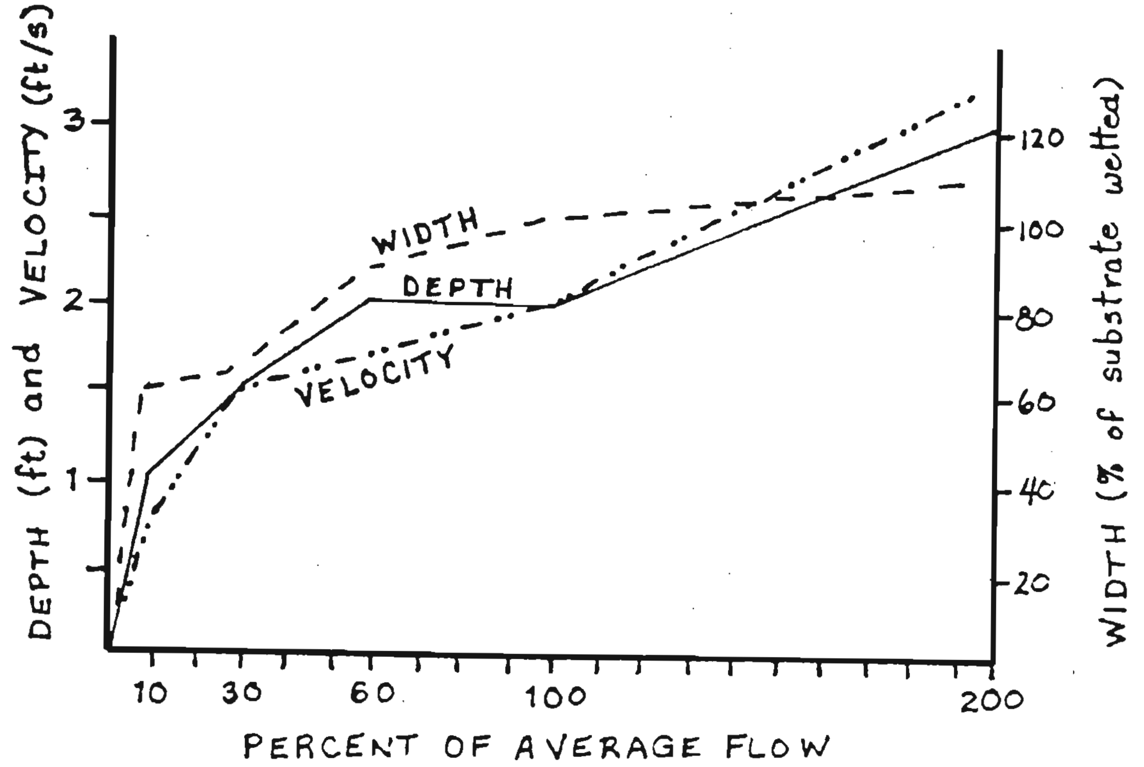

Figure 1. Relationships between width, depth, and velocity to percentages of the average annual flow for 11 streams in Montana, Wyoming, and Nebraska (Redrawn from Orth and Maughan, 1981; originally published by Tennant, 1976)

In the range from 60% to 100% of the mean annual discharge, wetted width ranges from 90 to 100%. Thus, in this flow range, most of the width is wetted, and the rate of change of width is small even when changes in discharge are large. Thus, conditions in the stream favour the development of stable benthic communities and healthy fish populations, well protected against the ill effects of sporadic changes in stream discharge (Table 1).

Discharges in the range of 200% of the mean annual cause minor changes in the wetted width of the stream, but velocities increase from 2 feet per second to 3 feet per second (Fig. 1). These increased velocities are believed to be beneficial for fisheries when they occur infrequently and for short periods of time. Discharges in these ranges (200% of the mean annual discharge) tend to disturb gravel in the stream bed, removing the fine particles and flushing them downstream.

## The Montana Method

The first well documented example of a method using prescribed percentages of the mean annual discharge was developed by the U.S. Fish and Wildlife Service in Montana (Tennant, 1976). Tennant's "Montana Method" is popular because it is quick, cheap, easy, reliable, and objective. The calculations are simple and can be based on published stream-flow records, or estimates of the mean annual discharge, if records are not available.

The following description of the "Montana Method" and instructions in its use are quoted from Tennant, 1976:

The Montana Method is so brief it can be typed on a 3 x 5 inch card. It can be applied rapidly to many segments of thousands of streams by referring to Table 1 of this paper and surface water records of the U.S. Geological Survey (U.S.G.S.).

Table 1

Instream Flow Regimens for Fish, Wildlife, Recreation and Related Environmental Resources

| Narrative Description of Flows 1/ | Recommended Base Flow Regimens Oct.-Mar. | Apr.-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 zero flow | |

1/ Most appropriate description of the general condition of the streamflow for all the parameters listed in the title of this paper.

The following intensive use of this method will produce a factual, conclusive streamflow study on any stream. First, determine the average annual flow of the stream at the location(s) of interest (listed as AVERAGE

DISCHARGE by U.S.G.S. and herinafter called average flow). If the average flow isn't published by the U.S.G.S., they can quickly calculate it for you. Visit the stream and observe, photograph, sample, and study flow regimens approximating 10%, 30%, and 60% of the average flow. Other flows can be studied, but these three regimens will cover a flow range from about the minimum to near the maximum that can normally be justified and recommended to protect the natural environment on most streams.

The average flow of a stream (or any given portion or percent of the average flow) is a composite manifestation of the size of the drainage area, geomorphology, climate, vegetation, and land use. These relationships have also been evaluated and reported by other biologists and hydrologists.

On uncontrolled streams, study U.S.G.S. records for daily, monthly, and annual flow patterns, then go to the field and check their gage(s) until you can view and study natural flows approximating 10%, 30%, and 60% of the average flow.

If flows are controlled, begin by having the highest flow you wish to study released first, then regulate so that each succeeding lower flow will begin the following midnight. Photos taken early the next morning will reveal the difference in exposed substrate or wetted perimeter. This is photographic "regression analysis." An 8-10 hour interval will normally be sufficient to negate any appreciable differences in flow levels due to bank storage.

Pictures may be the best data you will collect for selling your recommendations to the general public, administrators of construction agencies managing water development projects, and judges or juries adjudicating water laws. Black and white photographs and 35 mm. slides of key habitat types (e.g., riffles, runs, pools, islands, and bars) from elevated vantage points like bridges and high stream banks will give results superior to ground level shots or photos from aircraft high above the stream. Record appropriate, vital information on all photographs and slides as soon as they are received.

U.S.G.S. monthly measurements of width, depth, and velocity cover a variety of flows at most of their stream gage or cable crossing. Obtain cross-sectional data on width, depth, and velocity measurements from the local U.S.G.S. field office for flow regimens under study. Use this information to plot and compare water widths, depths, and velocities to known requirements for aquatic resources. As manpower and money permit, U.S.G.S. will make specific cross-sectional measurements of width, depth, and velocity for government agencies at any point on any stream. It requires proper experience, equipment, and plenty of time for others to make the necessary cross-sectional measurements. Study average daily, monthly, and annual stream-flow regimen tables and previous historic low-flow data published by U.S.G.S. to learn the base flow patterns of the climatic year and help determine flows that mimic nature and justify your final recommendations. Recommend the most appropriate and reasonable flow(s) that can be justified to provide protection and habitat for all aquatic resources.

Ten percent of the average flow: This is a minimum instantaneous flow recommended to sustain short-term survival habitat for most aquatic life forms. Channel widths, depths, and velocities will all be significantly reduced and the aquatic habitat degraded (fig. 1). The stream substrate or wetted perimeter will be about half exposed, except in wide, shallow riffle or shoal areas where exposure could be higher. Side channels will be severely or totally dewatered. Gravel bars will be substantially dewatered, and islands will usually no longer function as wildlife nesting, denning, nursery, and refuge habitat. Streambank cover for fish and fur animal denning habitat will be severely diminished. Many wetted areas will be so shallow they no longer will serve as cover, and fish will be crowded into the deepest pools. Riparian vegetation may suffer from lack of water. Large fish will have difficulty migrating upstream over riffle areas. Water temperature often becomes a limiting factor, especially in the lower reaches of streams in July and August. Invertebrate life will be severly reduced. Fishing will often be very good in the deeper pools and runs since fish will be concentrated. Many fishermen prefer this level of flow! However, fish may be vulnerable to overharvest. Floating is difficult even in a canoe or rubber raft. Natural beauty and stream esthetics are badly degraded. Most streams carry less than 10% of the average flow at times, so even this low level of flow will occasionally provide some enhancement over a natural flow.

<u>Thirty percent of the average flow</u>: This is a base flow recommended to sustain good survival habitat for most aquatic life forms. Widths, depths, and velocities will generally be satisfactory (fig. 1). The majority of the substrate will be covered with water, except for very wide, shallow riffle or shoal areas. Most side channels will carry some water. Gravel bars will be partially covered with water and many islands will provide wildlife nesting,

denning, nursery, and refuge habitat. Streambanks will provide cover for fish and wildlife denning habitat in many reaches. Many runs and most pools will be deep enough to serve as cover for fishes. Riparian vegetation will not suffer from lack of water. Large fish can move over riffle areas. Water temperatures are not expected to become limiting in most stream segments. Invertebrate life is reduced but not expected to become a limiting factor in fish production. Water quality and quantity should be good for fishing, floating, and general recreation, especially with canoes, rubber rafts, and smaller shallow draft boats. Stream esthetics and natural beauty will generally be satisfactory.

*Sixty percent of the average flow:* This is a base flow recommended to provide excellent to outstanding habitat for most aquatic life forms during their primary periods of growth and for the majority of recreational uses. Channel widths, depths, and velocities will provide excellent aquatic habitat (fig. 1). Most of the normal channel substrate will be covered with water, including many shallow riffle and shoal areas. Side channels that normally carry water will have adequate flows. Few gravel bars will be exposed, and the majority of islands will serve as wildlife nesting, denning, nursery, and refuge habitat. The majority of streambanks will provide cover for fish and safe denning areas for wildlife. Pools, runs, and riffles will be adequately covered with water and provide excellent feeding and nursery habitat for fishes. Riparian vegetation will have plenty of water. Fish migration is no problem in any riffle areas. Water temperatures are not expected to become limiting in any reach of the stream. Invertebrate life forms should be

> varied and abundant. Water quality and quantity is excellent for fish and floating canoes, rafts, and larger boats, and for general recreation. Stream esthetics and natural beauty will be excellent to outstanding.
>
> A flow of two to three times the average flow is often best for kayaks and whitewater canoeing. A flow of this magnitude is also preferable for larger boats with inboard or outboard motors, like those many people use on the annual Missouri and Yellowstone River floats held in June and July in Montana.

This completes the quotation from Tennant, 1976.

These percentages proposed by Tennant are based on the mean annual discharge of a stream in its pristine state. Thus, when a substantial portion of the instantaneous discharge is licenced for diversion, the actual quantity diverted must be added to the instream flow to obtain a reliable estimate of the mean annual discharge. Failure to include the volume of water already being diverted would result in prescribed discharges that are less than the appropriate amount. Also, since the mean annual discharge is a variable, fluctuating from year to year, the mean on which instream flow recommendations are based should include as many years of record as possible.

Users of the Montana Method recognize that it is based on a substantial amount of field data. Thus it has become widely recognized and accepted in places where the relationship between fish production and stream discharge is reasonably well known.

In British Columbia this relationship has not been established, and there are no empirical correlations suitable to calibrate the Montana Method for use here. Conceptually, the Montana Method is sound, and, when it is properly calibrated it ought to be very useful. There are numerous biogeoclimatic zones in the province, and it is conceivable that each of these will require different fractions of the mean annual discharge to maintain fisheries habitats at the level of quality indicated by Tennant's work.

The few opinions now available suggest that it would be appropriate to reduce the prescribed percentages to less than 30% of mean annual discharge for "good" survival conditions, and to less than 60% for "excellent or outstanding", (Okanagan Basin Agreement, 1974; R. Ptolemy, file data; Pat Slaney, pers. comm.).

In a setting where there is serious competition for a scarce and dwindling supply of water, the suggestion that fish in British Columbia might require less water than is prescribed by the widely accepted "Montana Method" seems absurd. In fact it is not. But, any proposed alteration to the percentages should be based on adequate study. Also, it would probably be safest not to tamper with the prescribed 10% to "sustain short-term habitat".

The percentages of mean annual discharge recommended by the "Montana Method" reflect the unique terrain, climate, and runoff characteristics of drainages used in the development of this method. In British Columbia, our terrain is steeper, our climate colder in the winter, and our streams subject to flooding that is worse and more frequent than most of the streams on which the Montana Method is based. Also, the timing of various life-history phases of fish in British Columbia may differ from the timing specified by the Montana method. Thus, some alterations seem to be required.

Although it is beyond the scope of this paper to modify the Montana Method for use in British Columbia, there is merit in a conceptual discussion of the matter:

1. A Common Criticism of the Montana Method

   The Montana Method is criticized in British Columbia because the flows it recommends exceed the flows found under natural conditions in the pristine stream. Firstly, this criticism is unwarranted because it is always the duty of the agency making the recommendations to examine its predictions based on a model (e.g. Montana Method), in the proper real-life context. Secondly, the instream flows recommended by the Montana Method might represent an improvement over natural conditions in settings where the actual instreams flows are less than those recommended by the model.

   It is conceiveable that when the model recommends instream flows greater than are actually found, it has identified an opportunity for fisheries enhancement, and the need for water storage to augment instream flows at certain times of the year. There are many examples of such streams on the east coast of Vancouver Island.

2. Modifications to the Prescribed Percentages

   The tendency for the Montana Method to recommend instream flows that exceed natural flows might reflect fundamental differences in the shape and infrastructure of annual hydrographs in British Columbia compared with those elsewhere. Skeptics of this suggestion argue that the Montana

Method is based, in part, on studies of streams in the eastern Rockies of the U.S.A. and imply, therefore, that the Montana Method ought to work here in British Columbia.

But, the eastern slope of the Rockies is in a rainshadow and it is possible that the streams in this zone are less prone to flash floods and have, in general, a more placid runoff season than is found in most of British Columbia.

In this regard, the more erratic the annual hydrograph--that is, the worse the floods, and the more frequent they are--the greater the need to modify the prescribed percentages of the mean annual discharge used in the "Montana Method". When floods account for a large proportion of the annual volume of water carried by a river, the discharge in the remainder of the year will be a relatively small fraction of the mean annual discharge. It is perhaps in recognition of this phenomenon that the following untested modification of the Montana Method was proposed in the Canada-British Columbia Okanagan Basin Agreement, 1974:

a) flow adequate for short-term survival; 10% of mean annual flow
b) flow adequate for long-term survival between October and March; 15% of mean annual flow
c) flow adequate for long-term survival between April and September; 30% of mean annual flow.

In another part of the province, Vancouver Island, fish census data suggest a mean monthly flow of not less than 20% of the mean annual discharge, and mean daily flows of not less than 10% of the mean annual discharge, as a requirement for survival of cutthroat trout fry. Cutthroat trout apparently depend on the availability of habitat for fry in riffle areas, and on the production of aquatic insects in the riffles. Presumably, as mean monthly discharge decreases below 20% of the mean annual discharge, the riffles shrink quickly, causing rapid loss of habitat and food supply essential to the fry.

### 3. Pools

The tendency of a stream to flood more violently and more frequently than the ones studied by Tennant is not the only justification for recommending smaller percentages of the mean annual discharge. Tennant himself has stated, in his personal correspondence (Tennant-Newcombe, 1983), that streams with large pools separated by short riffles would provide adequate habitat for long-term survival at discharges significantly less than 30% of the mean annual discharge. The empirical observations of the Fisheries Branch suggest that 20% of the mean annual discharge is sufficient (Ron Ptolemy, file data). If large pools can affect the prescribed percentages of mean annual discharge, so too might stream gradient and the ratio of various components such as riffles, pools and glides.

### 4. Season of Low Flow

The Montana Method divides the hydrological year into two equal parts representing, 1) the six month period of lowest stream flow, and; 2) the six months of the rest of the year. In the American midwest where the model was developed and calibrated, the time of lowest stream flow is winter and early spring (Fig. 2), (Stalnaker and Arnette, 1976). This season corresponds to Tennant's set of instream flow recommendations for October to March (Table 1). For obvious reasons, the instream flow recommendations during a season of low flow must be less than the recommended flows for the remainder of the year. However, the base flow of not less than 10% of the mean annual discharge applies year round.

The Hydrological Atlas of Canada identifies two seasons of low flow in British Columbia (International Hydrological Decade, 1969). On the West Coast of Vancouver Island, lowest stream flow occurs in late summer and fall; in the rest of the province it occurs in winter, (Fig. 3). The species of fish that are important varies from one region to the next. And, in the course of a year, the life history phases most likely to be vulnerable to low flows also vary. Thus, when this information is available, instream flow recommendations can be tailored to give the best possible protection to the most valued species, or to the most vulnerable, and perhaps to both.

Although the Hydrological Atlas seems to indicate that most of the province is characterized by streams that have their lowest flows in winter, the most northerly streams seem to have the most protracted period of low flows. These last until late spring and are followed, within the space of a month, by the highest flows of the year. These dramatic changes in stream flow seem to suggest the need for different

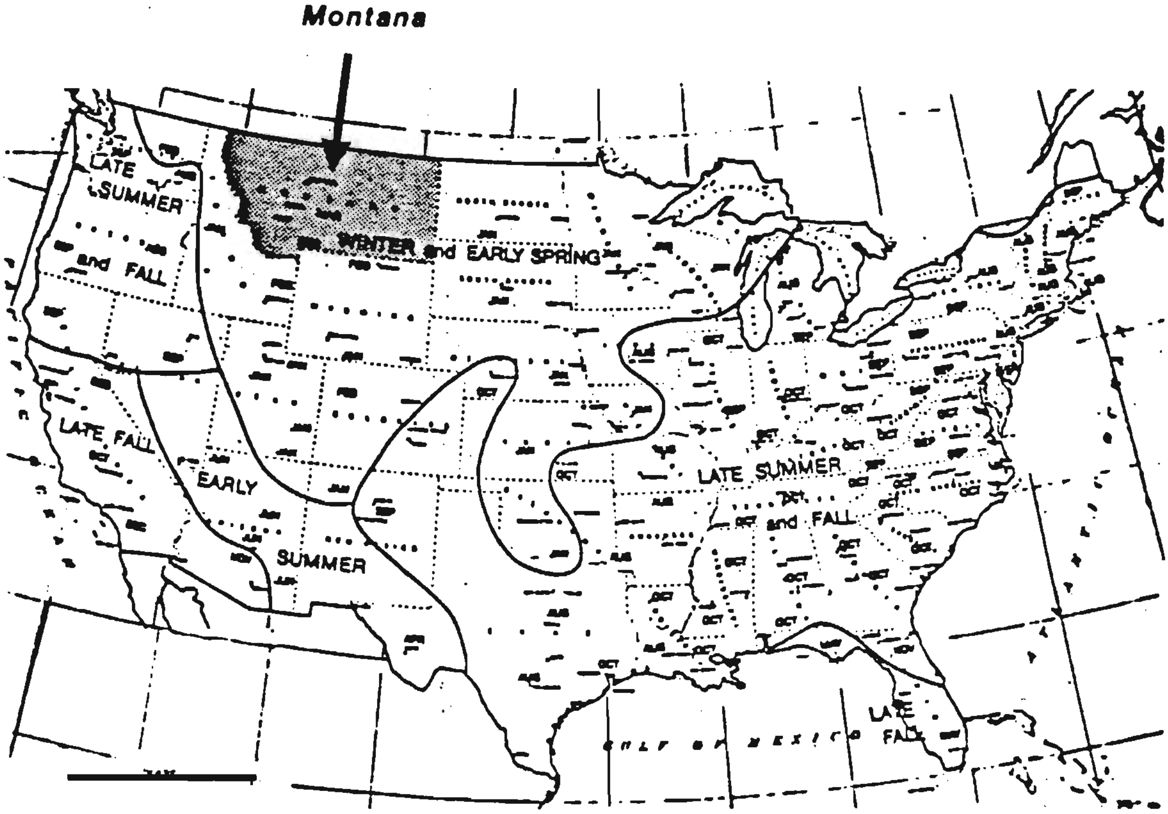

Figure 2. Seasons of lowest stream flow in the United States of America, including Montana (Stalnaker and Arnette, 1976)

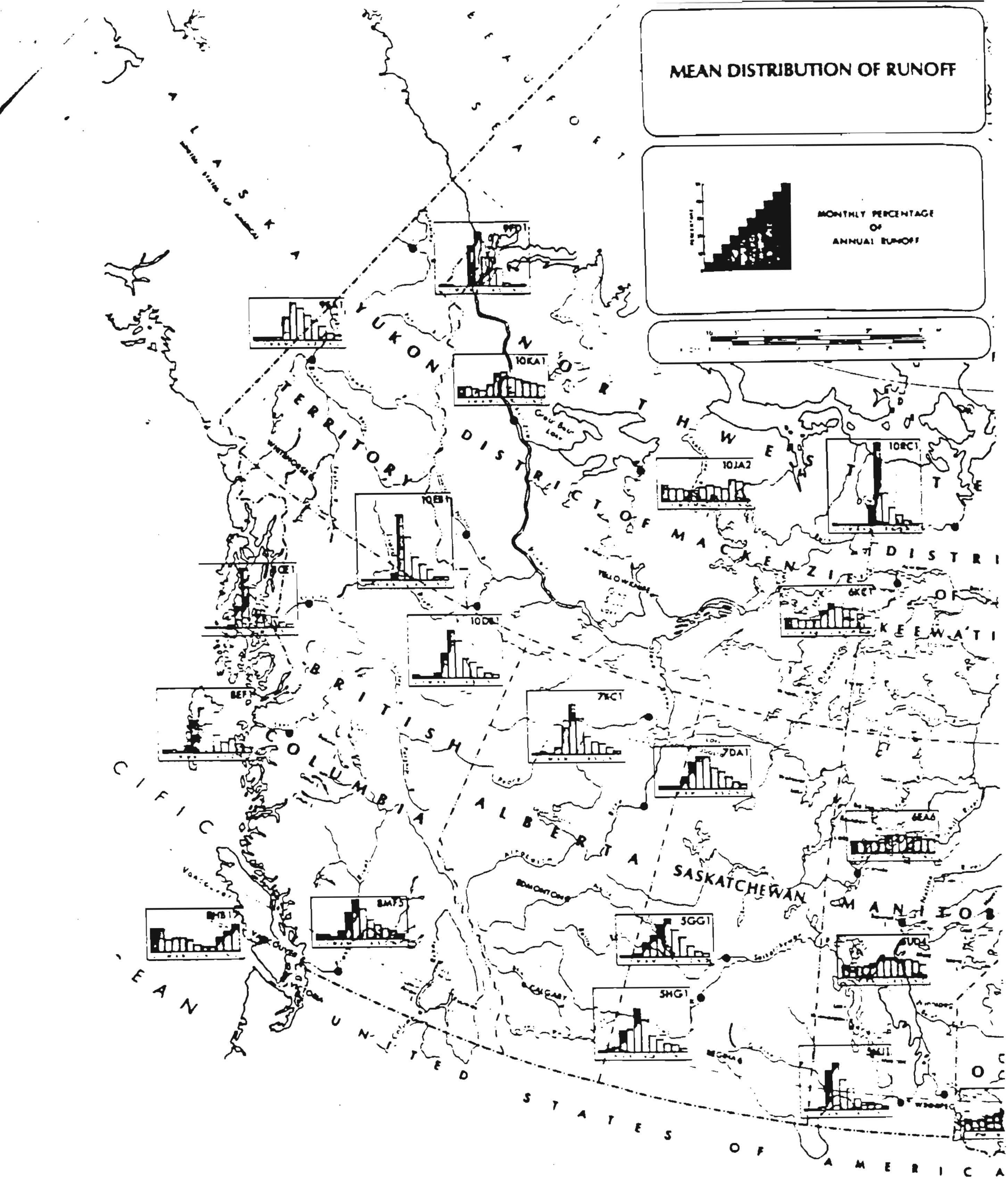

Figure 3. Mean distribution of runoff for Western Canada, including British Columbia (International Hydrological Decade, 1969)

modifications to the Montana Method than would be required in the southern parts of the province.

The information presented by the Hydrological Atlas is too sparse to permit the drawing of boundaries around regions with similar annual hydrographs; however, there are sufficient data to do this using files of the Water Survey of Canada and the provincial Water Rights Branch. The data from these sources would generate a detailed map, even though the majority of streams in the province have never been gauged. With this map, fisheries agencies could make inferences about the shape of the annual hydrograph on streams that have not been gauged. Even so, such inferences would not be totally reliable and might only be useful at the reconnaissance level. The low flow characteristics of streams in adjacent basins may differ, yet the differences can not be predicted on the basis of known characteristics of the drainage basin, or from the shape of the annual hydrograph of streams in an adjacent basin (Riggs, 1972).

## 5. Credibility of the Montana Method

Other work which tends to increase the credibility of Tennant's 10 percent mad survival flow and 30% mad preservation flow has been done by Elser (1972) and Wesche and Richard (1971). The results of these studies indicate that below approximately 30% mad there is a significant reduction in hydraulic parameter values (e.g. velocity) and available habitat (e.g. riffles). Under proper conditions, in the locales where they were developed, approaches using records of flow seem to provide an adequate assessment of preservation flows for the level of study for which they were intended (reconnaissance grade).

6. Other Aspects

A complete discussion of modifications to the Montana Method ought to include aspects not mentioned above. Some of these are:

- instream flows required to prevent the formation of ice and ice crystals in a stream bed where incubating fish eggs are found.
- the need to identify the life history phases of the various species of fish present in the stream during periods of low flow.
- the need to identify the single most vulnerable life history phase from among all the ones found in a stream during periods of low flow.
- the need for prescribed percentages of the mean annual discharge to coincide with the timing of various life history phases throughout the year.
- are streams with headwater lakes less prone to flooding and therefore more likely to fit the Montana model better than streams that do not have a headwater lake?

## Conclusion

Here is a final word of encouragement to those who have an immediate and pressing need to make quick appraisals of the instream flows for fisheries, and who know that a modified version calibrated for conditions in British

Columbia may not be available for a long time. Begin the process on your own initiative. Use the available methods and learn their strengths and weaknesses. Document your experience in writing and take plenty of photographs. The weight of such documentation by individuals throughout the province ought to produce a modified version of the Montana Method faster and cheaper than any formal effort. The adoption of informal modifications at the field level might prompt a formal review leading to a validation of your findings. This is the essence of empiricism--the accumulation and formalization of practical experience. In the absence of explanatory theory, there's no better substitute than reliable field data.

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