SALMON STUDIES ASSOCIATED WITH THE POTENTIAL KEMANO II HYDROELECTRIC DEVELOPMENT

VOLUME 6

HYDROGRAPHICAL STUDIES ASSOCIATED WITH SALMON IN THE NANIKA AND MORICE RIVERS

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HYDROGRAPHICAL STUDIES ASSOCIATED WITH SALMON IN THE NANIKA AND MORICE RIVERS RELATIVE TO THE PROPOSED KEMANO II DEVELOPMENT

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Although the major part of the funding for these studies was provided by the British Columbia Hydro and Power Authority, the findings and opinions expressed within the report are solely those of the author agency.

<u>TABLE OF CONTENTS</u>

LIST OF FIGURES

Page

Page

LIST OF TABLES

INTRODUCTION

Hydrographical studies have been undertaken since 1971 by the Fisheries and Marine Service in the prime spawning areas of the Nanika and Morice Rivers. The purpose of the studies was to document the physical and hydraulic conditions under which spawning and incubation naturally occur and to determine the minimum flows necessary to sustain salmon in these two life stages. The studies were concentrated in the major sockeye spawning area of the Nanika River and the major chinook spawning area of the Morice River and are in each case representative of a substantial proportion of the total river spawning area within the system.

In 1974 the studies were expanded to include an assessment of reduced summer discharges on water temperatures within Nanika and Morice Rivers. Several cross-sections were established over the length of each river and the pertinent hydraulic information was monitored at each section under various discharges. These data were used in a simulation model developed by the International Pacific Salmon Commission to provide water temperature profiles over the length of the rivers under various discharges and meteorological conditions.

In addition to presenting the results of the studies discussed above, this report provides information on the hydrology of the Bulkley River system and outlines some of the potential effects of diversion of Nanika and Morice waters on the mainstem Bulkley. All studies discussed in this chapter were conducted independently of the program underaken on behalf of B. C. Hydro and were totally financed by the Fisheries and Marine Service.

1. Hydrology

The Bulkley River drainage basin (Figure 1) can be divided into two major physiographic components: the Interior Plateau region which takes in most of the 4,740 square miles of drainage area, and the Coast Mountains bordering the western boundary of the basin. Climate records by the B. C. Department of Agriculture indicate that the mean annual precipitation is relatively uniform over the plateau areas, with approximately 12 inches of rainfall and 75 inches of snowfall. Precipitation is much more intense in the Coast Mountains as indicated by the weather station near Tahtsa Lake. The mean annual precipitation at this station is 78 inches, which includes 36 inches of rainfall and 420 inches of snowfall.

The Morice-Nanika watershed is located in the southwest portion of the Bulkley River drainage basin, draining a portion of the Tahtsa Range of the Coast Mountains. The watershed varies in elevation from 2,600 feet to 7,200 feet above sea level and is extensively glaciated. Approximately 15 percent of the entire Bulkley River drainage area occurs above the outlet of Morice Lake. Nanika, Kidprice and Morice Lakes provide almost all of the lake storage in the Bulkley River system. The surface area of each of these lakes is 11.5, 3.0 and 36.0 square miles, respectively.

Discharge recording stations have been operated on the Nanika, Morice and Bulkley Rivers for a number of years by the Inland Waters Directorate of the Department of the Environment. The location of stations currently being operated and the period of continuous daily operation are as follows:

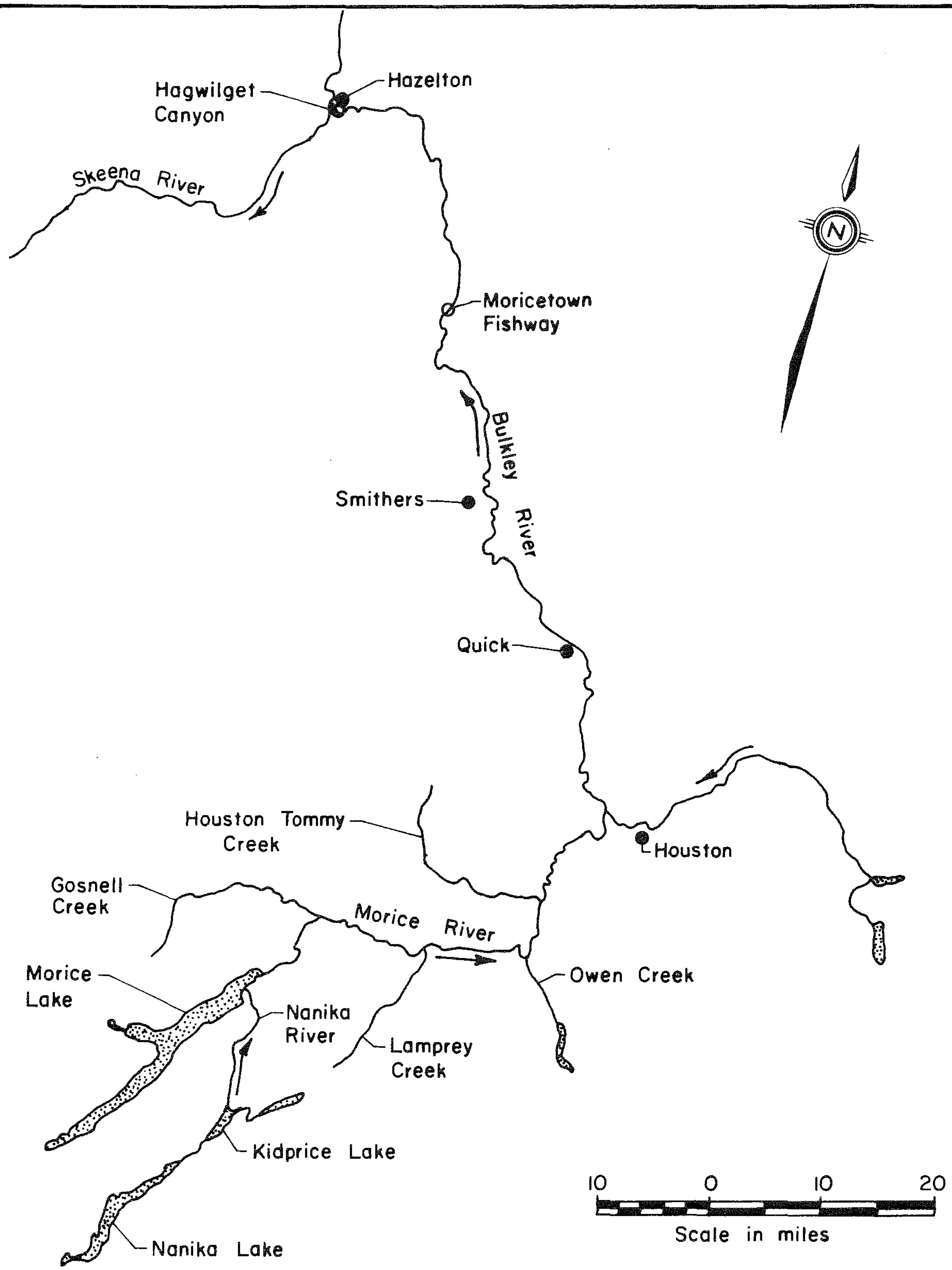


FIGURE I Map of Bulkley River Drainage Basin.

STATION	PERIOD OF OPERATION
Nanika River at outlet of Kidprice Lake	June, 1972 to present
Morice River near outlet of Morice Lake	Sept.,1961 to present
Bulkely River at Quick	1930 to present

Additional stations have been operated on the Bulkley River but were discontinued a number of years ago.

A seasonal recording gauge was also operated by the Aluminum Company of Canada on the Nanika River at the outlet of Kidprice Lake between 1950 and 1972. However, the daily discharge data provided by Alcan for the latter part of 1972 are substantially lower than those recorded by Inland Waters. On September 24, 1971, a discharge of 751 cfs was measured by the Fisheries and Marine Service in the Nanika River a short distance below Kidprice Lake. The Alcan records indicate a discharge of 385 cfs on that date. It is therefore concluded that the data recorded by Alcan are unreliable and they have not been used in this report.

The average discharge in the Nanika River at the outlet of Kidprice Lake during 1973 and 1974 was 1024 cfs.

Over the period 1962 to 1974, inclusive, the average discharge at the outlet of Morice Lake was 2744 cfs. The drainage area above this station is 729 square miles, resulting in a long term average unit discharge of 3.76 cfs per square mile. The Bulkley River at Quick, with an upstream drainage area of 2800 square miles, averaged 4971 cfs during this same period. Excluding the Morice Lake drainage area and discharge from these figures, the average unit discharge for the remainder of the drainage area above Quick is therefore 1.08 cfs/square mile. It is noted that the ratio of the above unit discharges compares reasonably well with the ratio of the mean annual precipitation of Tahtsa Lake and Smithers.

Hydrographs depicting the annual distribution of mean monthly discharges for the three recording stations being operated by Inland Waters are shown on Figure 2. The discharge pattern is seen to be relatively typical from year to year with peak flows occurring during the spring run-off period. A secondary freshet normally occurs prior to freeze-up.

The quantity of water which the drainage area above the outlet of Morice Lake contributes to the Bulkley River varies throughout the year, as shown on Figure 3. During the spring runoff, when other areas in the drainage basin are contributing a high rate of discharge from snow melt, the Morice watershed can represent as little as 16 percent of the the discharge at Quick. However, at other times of the year the Morice Lake outflow can represent as much as 96 percent of the total discharge at Quick. This is largely due to the storage capacity of Nanika, Kidprice and Morice Lakes.

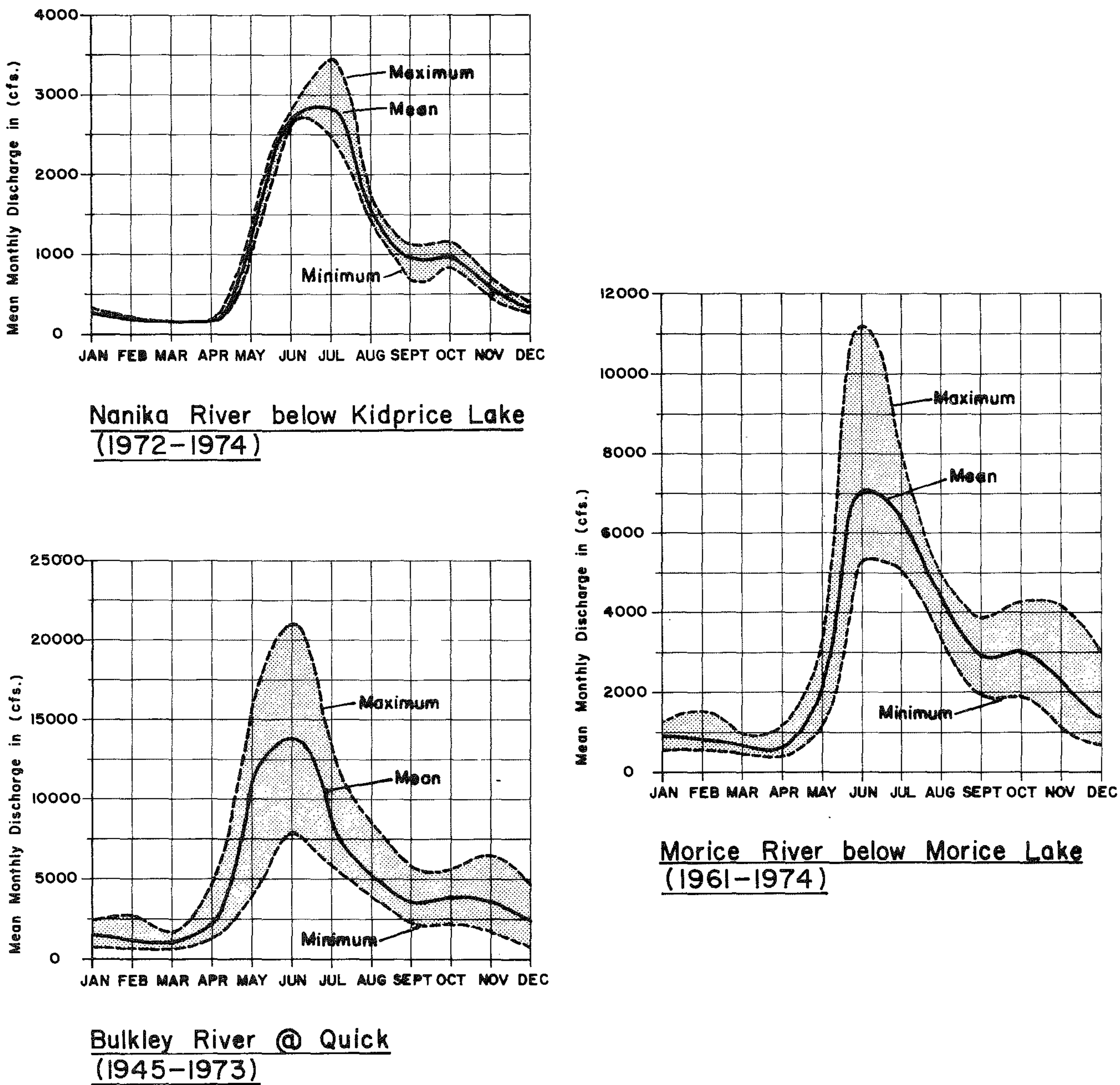
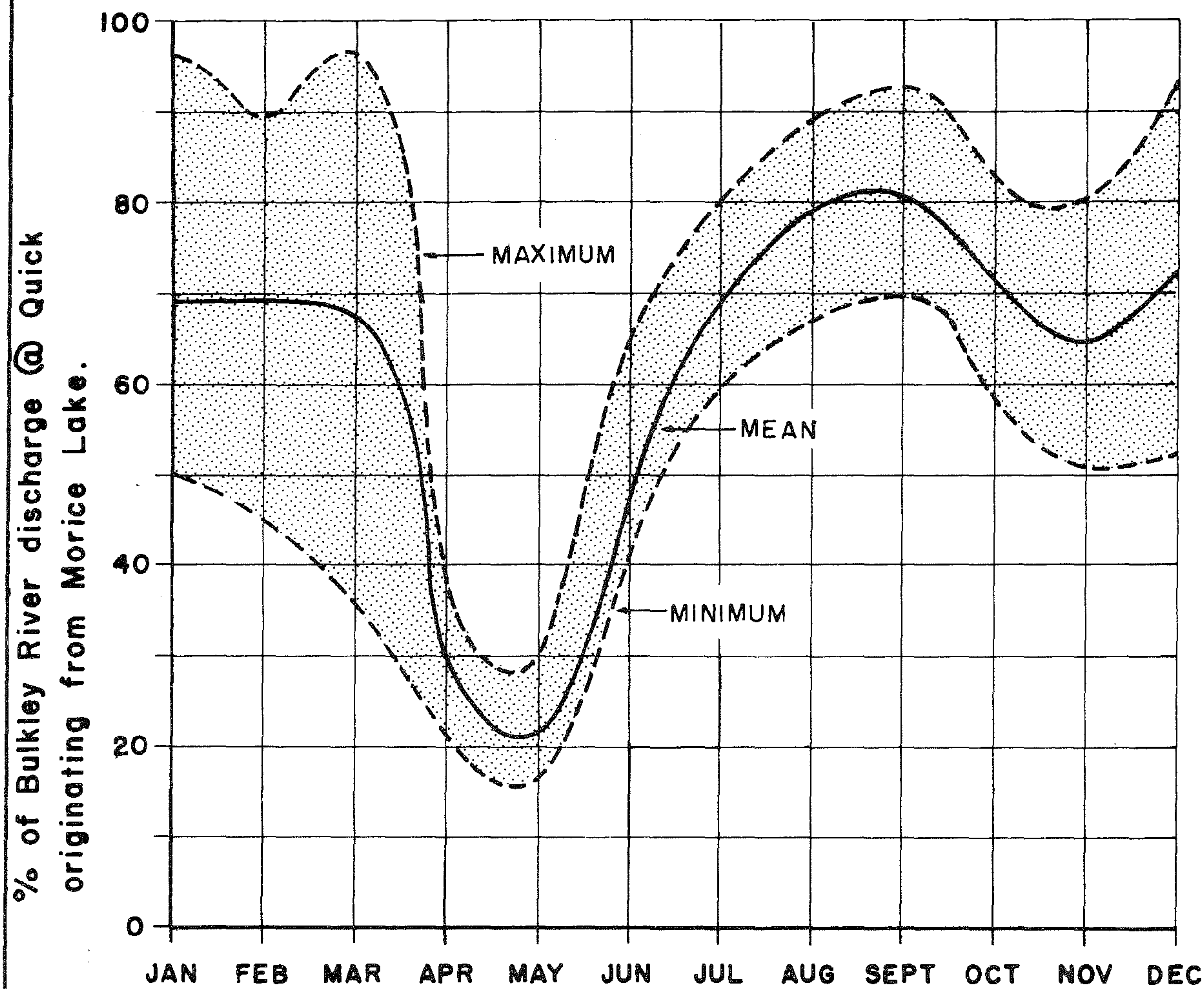


FIGURE 2. Annual distribution of mean monthly discharges Nanika, Morice, and Bulkley Rivers.

FIGURE 3.



Based on Mean Monthly discharges between January 1962 and December 1973.

FIGURE 3. Monthly contribution of flows from outlet of Morice Lake to the Bulkley River at Quick.

2. Spawning Studies

In assessing the relationship between discharge and available spawning area, depth and velocity contours are usually obtained within the spawning area over a range of discharges. These contours indicate the depth and velocity occurring at any point within the spawning area for a given discharge, which allows the delineation of areas falling within the velocity and depth ranges preferred by the species of salmon in question. The relationship between discharge and available spawning area can be readily determined by repeating this procedure over the desired range of discharges.

The ranges of velocity and depth preferred for spawning by various species of salmon has been investigated by several researchers, as summarized in Table 1.

TABLE 1: DEPTH-VELOCITY CRITERIA REQUIRED FOR SALMON SPAWNING

Source	Species	Depth (ft.)	Velocity (fps)
Burner (1951)	Chinook	0.25 - 1.5	1.0 - 3.5
	Chinook	0.33 - 1.5	1.0 - 3.0
Chambers (1955)	Chinook	1.25 - 2.25	1.00 - 1.75
	Chinook	1.00 - 1.50	1.00 - 2.25
	Chinook	1.25 - 2.25	1.50 - 2.50
	Sockeye	1.00 - 1.50	1.75
	Coho	1.00 - 1.25	1.20 - 1.80
Pitney (1963)	Chinook	0.8[1]	
Collings *et al.* (1970)	Chinook	1.00 - 1.50	1.00 - 2.25
Smith (1973)	Chinook	1.28[2]	0.61 - 2.64
	Chinook	0.79[1]	0.98 - 2.49

1 minimum depth

2 mean depth

Within an area of suitable spawning gravel, velocity near the riverbed is undoubtedly the most important factor influencing the selection of a spawning site by any of the salmon species. In the process of spawning, a shallow hole or redd is excavated below the general level of the river-bed. Eggs are deposited by the female, fertilized by the male and eventually covered by gravel as a result of subsequent spawning activity a short distance upstream. The redd is excavated by the female salmon by a vigorous swatting action of its tail. As a result, gravel particles are projected upward where they are caught by the current and moved downstream. Aside from this action, the salmon has no physical capability of moving gravel out of its redd. Therefore, water velocities must be of sufficient magnitude adjacent to the bed to allow the fish to successfully excavate its redd.

Gravel which is carried away by the current normally accumulates at the downstream edge of the excavation in the shape of a small dune. The presence of this dune is also considered to be of importance to spawning in that it induces a low velocity area or back eddy near the bottom of the redd. This would prevent many of the newly deposited eggs from being swept downstream before being covered by gravel from adjacent spawning activity. This is probably one of the major factors influencing the upper velocity limit of spawning salmon since excessive velocities would move the gravel too far downstream without allowing a dune to form.

Minimum flow studies have normally treated depth separately from velocity and then superimposed these parameters to establish preferred spawning area. However, the depth preferences reported by Chambers et al. (1965) are considerably shallower than the natural spawning depths in many B. C.

streams. In the main sockeye spawning ground in the Nanika River the majority of spawning occurs at depths of 3 to 5 feet. The shallower areas corresponding to the preferred depths cited above are characterized by silty beds and thus are totally unsuitable for spawning. For this reason, it is considered that depth in itself is not a major factor in the selection of a suitable spawning area and for purposes of this report, no limit has been placed on the maximum depth at which spawning can occur. Successful spawning is therefore assumed to be dependent only upon the availability of suitable gravel, adequate water velocities and a depth of water of at least one foot.

2.1 Nanika River

The lower Nanika River between Kidprice and Morice Lakes is approximately 14 miles in length and drops some 400 feet in elevation. Immediately below the outlet of Kidprice Lake, the river flows over Nanika Falls which is approximately 30 feet in height. This forms the upstream limit of all anadromous fish stocks. The majority of spawning occurs over the two miles of river immediately below the falls (Figure 4). In the first mile below the falls (a-b), the river is very turbulent and is comprised of a series of rapids, low waterfalls and interconnecting pools. Although this reach is not generally considered as being a highly productive spawning area, it does contain several pockets of suitable spawning gravel. Throughout the next one-quarter mile (b-c), the flow becomes quite laminar as the river widens over a relatively shallow and flat-bottomed riverbed. This reach contains approximately 65 percent of the total available spawning area. The next segment of the river (c-d) consists of a deep and relatively wide pool which does not contain

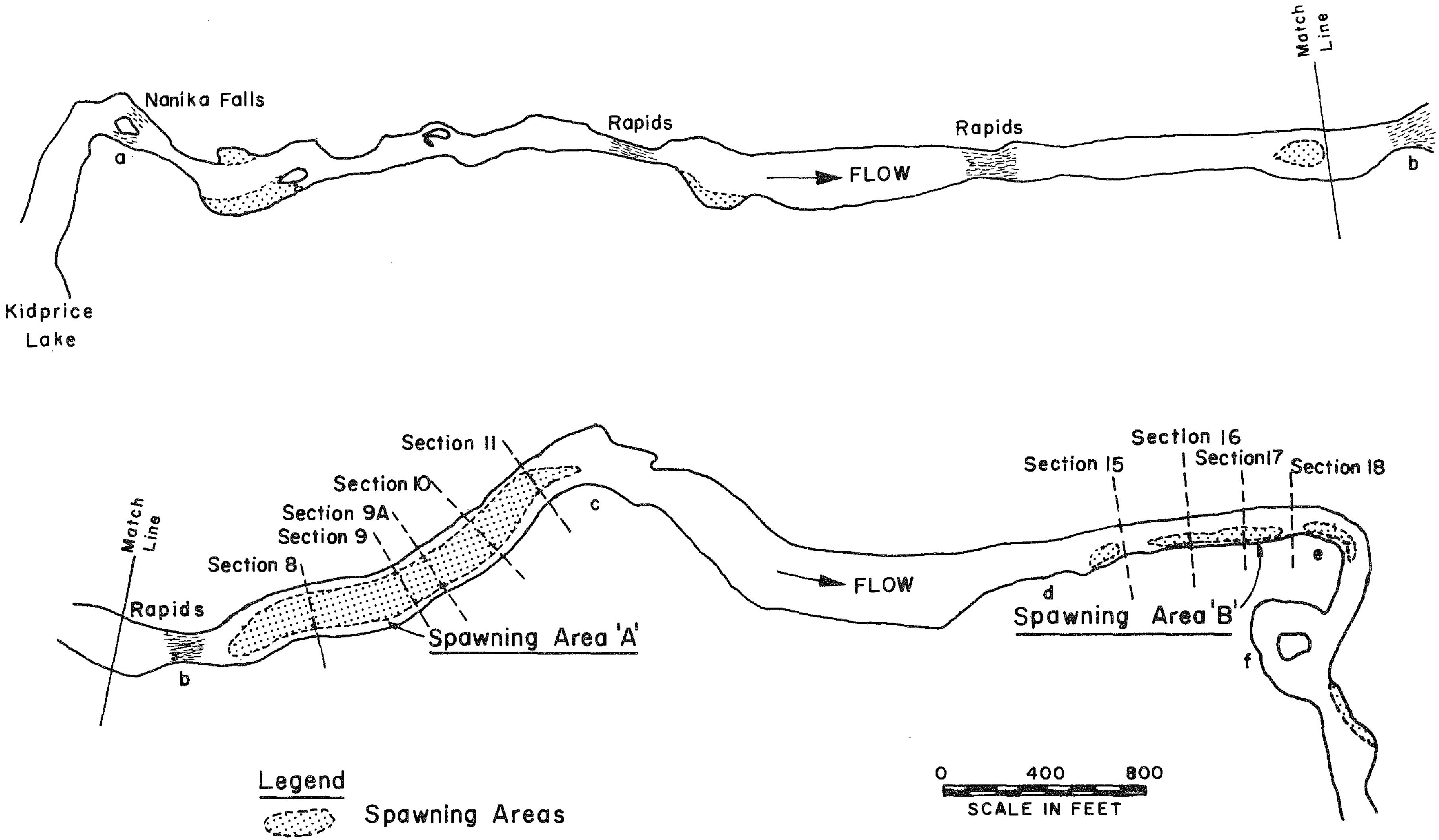


FIGURE 4. Location of Study Areas and Spawning Grounds in Upper Nanika River below Kidprice Lake.

FIGURE 4.

any suitable spawning gravel. Immediately downstream from this pool (d-e), the channel again narrows but the flow remains relatively laminar. Another productive spawning area is located adjacent to the right bank within this channel. Except for some minor amount of spawning gravel occurring slightly downstream of the oxbow bend (f), this forms the lower limit of the spawning area. Below this point, the river generally flows in single channel although it becomes quite braided in the lower few miles before reaching Morice Lake.

Of the several sockeye salmon spawning areas located in the upper two miles of the river, only the two major ones were studied in detail. However, it is considered that the information presented in this report should apply also to other spawning areas in the system. The locations of the two spawning areas, referred to as Spawning Areas A and B, are shown on Figure 4.

i) Spawning Area A

Spawning Area A represents the largest single spawning area within the system and was therefore studied in the greatest detail. The area contains approximately 20,000 square yards of suitable spawning gravel distributed over a length of approximately one-quarter mile. Spawning occurs within a relatively deep channel with a width of approximately 160 feet. Outside this channel the riverbed and banks are very silty and therefore unsuitable for spawning. The depth of water over the spawning gravel is deeper and the water velocities are generally much lower than found in normal sockeye spawning areas. However, a substantial depth of water also occurs over the entire spawning area during the winter when discharges are low and the spawn is not therefore subject to de-watering or freezing during the incubation period. For this reason, egg survival rates in this spawning area are expected to be quite high.

In order to quantify the sockeye spawning area in the Nanika River relative to discharge, five cross-sections were established within Spawning Area A, as shown on Figure 4, and monitored at discharges of 155, 830 and 2,000 cfs. Additional flow data were also collected during 1975 at discharges of 150 and 700 cfs. Section 10 was found to be representative of general flow and spawning conditions throughout the study area. The cross-section and its discharge rating curve are shown on Figure 5. Since the river channel is relatively uniform over the length of the spawning area and the water surface gradient is very low at all discharges, the rating curve is considered to be applicable to all cross-sections within the spawning area.

Riverbed contours were plotted within Spawning Area A from the cross-sectional profiles. Using these contours in conjunction with water surface elevations from the rating curve on Figure 5, the areas of suitable spawning gravel covered by various depths of water were determined for several discharges. The analysis was confined to the length of river from midway between Sections 8 and 9 to midway between Sections 10 and 11, as represented by Sections 9, 9A and 10. The results are shown on Figure 6 as a percent of the 9,500 square yards of suitable spawning gravel represented by these sections. It can be seen that the entire spawning area is covered by depths in excess of 1.8 feet for normal spawning discharges of 800 cfs or more. Similarly, at 800 cfs, slightly more than 15 percent of the area has depths in excess of 5 feet.

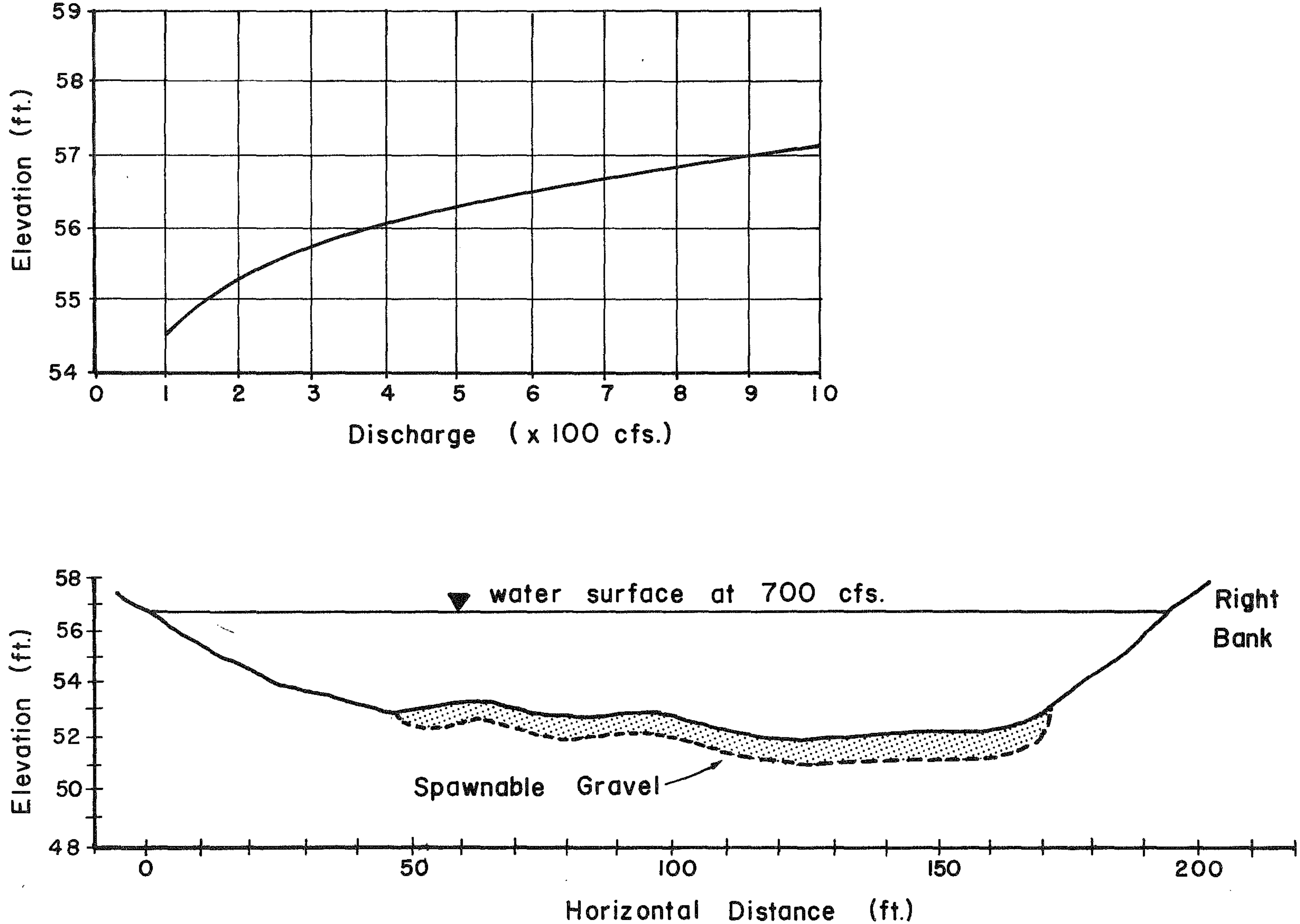


FIGURE 5. Nanika River.- Rating curve and cross-sectional profile for Section 10, Spawning Area A.

FIGURE 5.

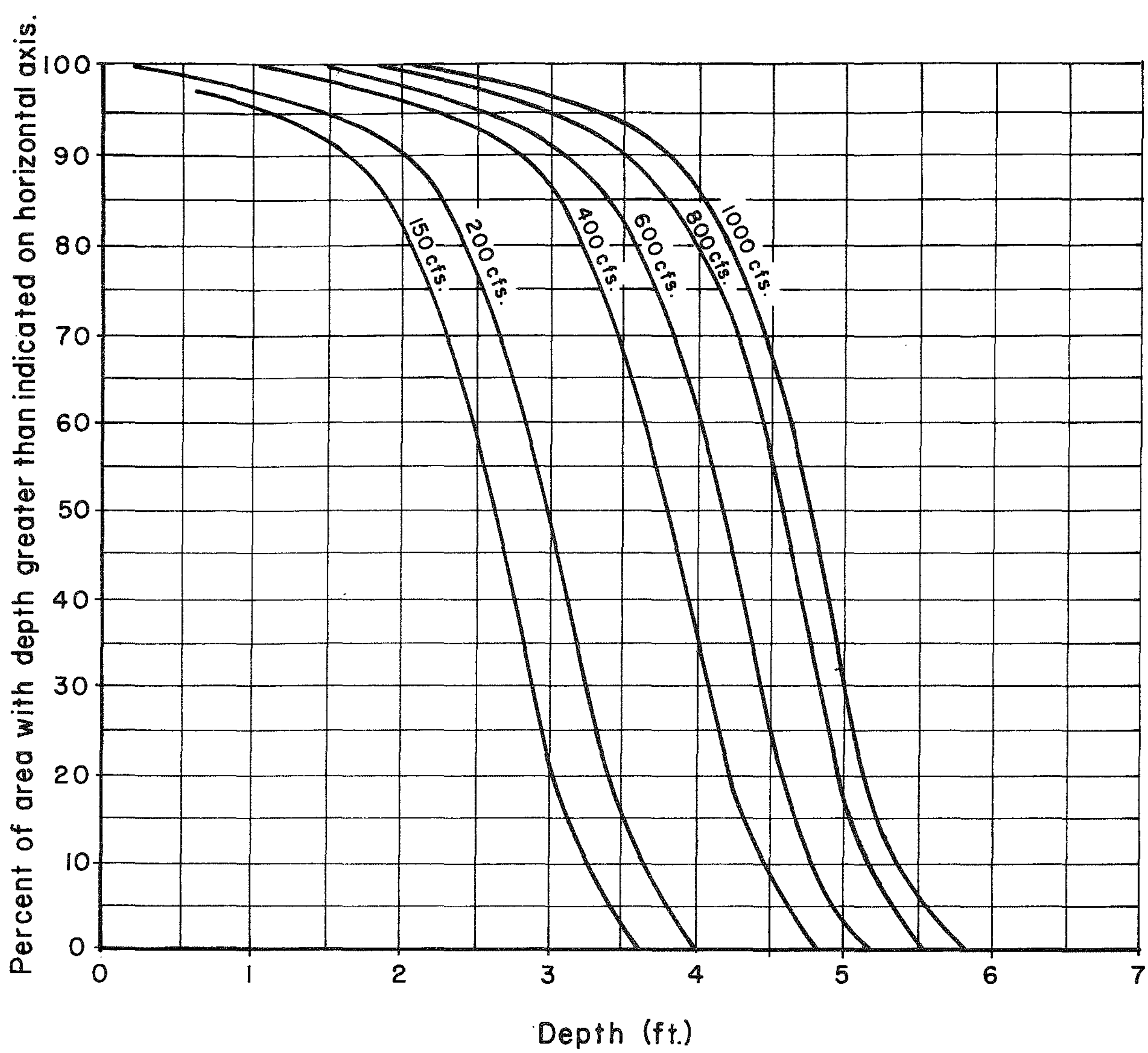


FIGURE 6. Nanika River – Relationship between area of spawning gravel and depth of water for various discharges, Spawning Area A.

Nose velocities (0.4 feet above the riverbed) and average velocities (at a distance above the riverbed of 40 percent of the depth of water) were measured within spawning Area A at discharges of 155, 700 and 830 cfs. The measurements were distributed over Sections 9A and 10 as well as randomly throughout Spawning Area A.

An analysis of cross-sectional and water level data for Sections 9, 9A and 10 revealed that the average velocity of the river can be closely represented by the relationship:

$V = C\ D^{2/3}$, where . . . . (1)

V = velocity at a distance of 40 percent of the depth above the riverbed.

C = a coefficient which is dependent upon the water surface gradient and frictional resistance of the riverbed.

D = depth of water.

The coeffieient C differs for each of the sections and varies with discharge as shown on Figure 7. For any given discharge the average velocity can be determined by applying the coefficient C from the appropriate curve on Figure 7 and the depth of flow to equation 1. Velocities computed in this manner compared reasonably well with the actual average velocities measured above the spawning gravel on Section 10 as illustrated on Figures 8 and 9. The large discrepancy at Station 30 is due to the fact that this point corresponds to the toe of the riverbank. The bank would impose an additional friction factor which is not included in equation 1.

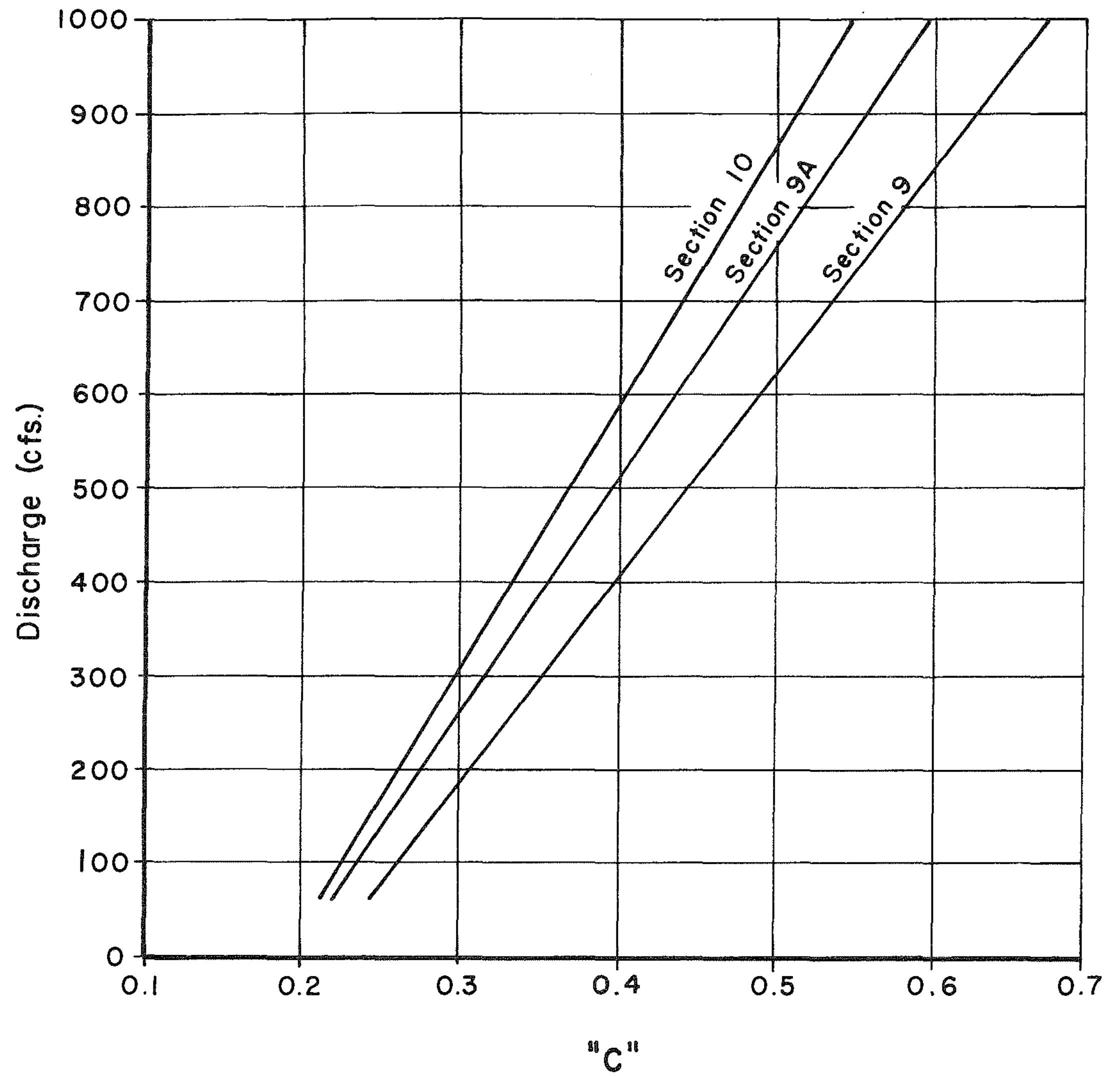


FIGURE 7. Nanika River–Relationship between discharge and coefficient "C" for determining average velocities at Section 9, 9A, and 10, Spawning Area A.

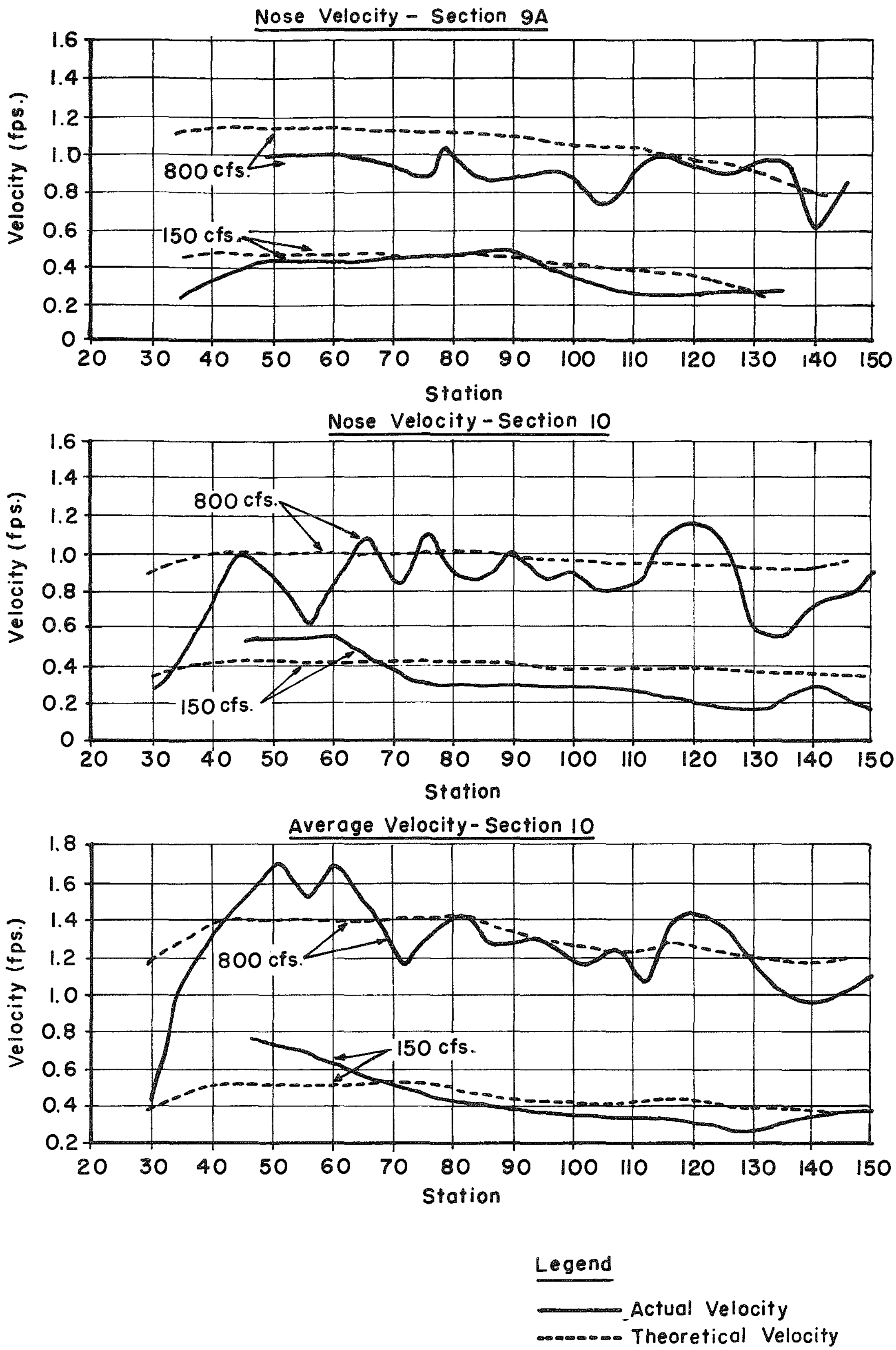


FIGURE 8. Nanika River-Comparison of measured and theoretical average velocities and nose velocities, Spawning Area A.

FIGURE 9.

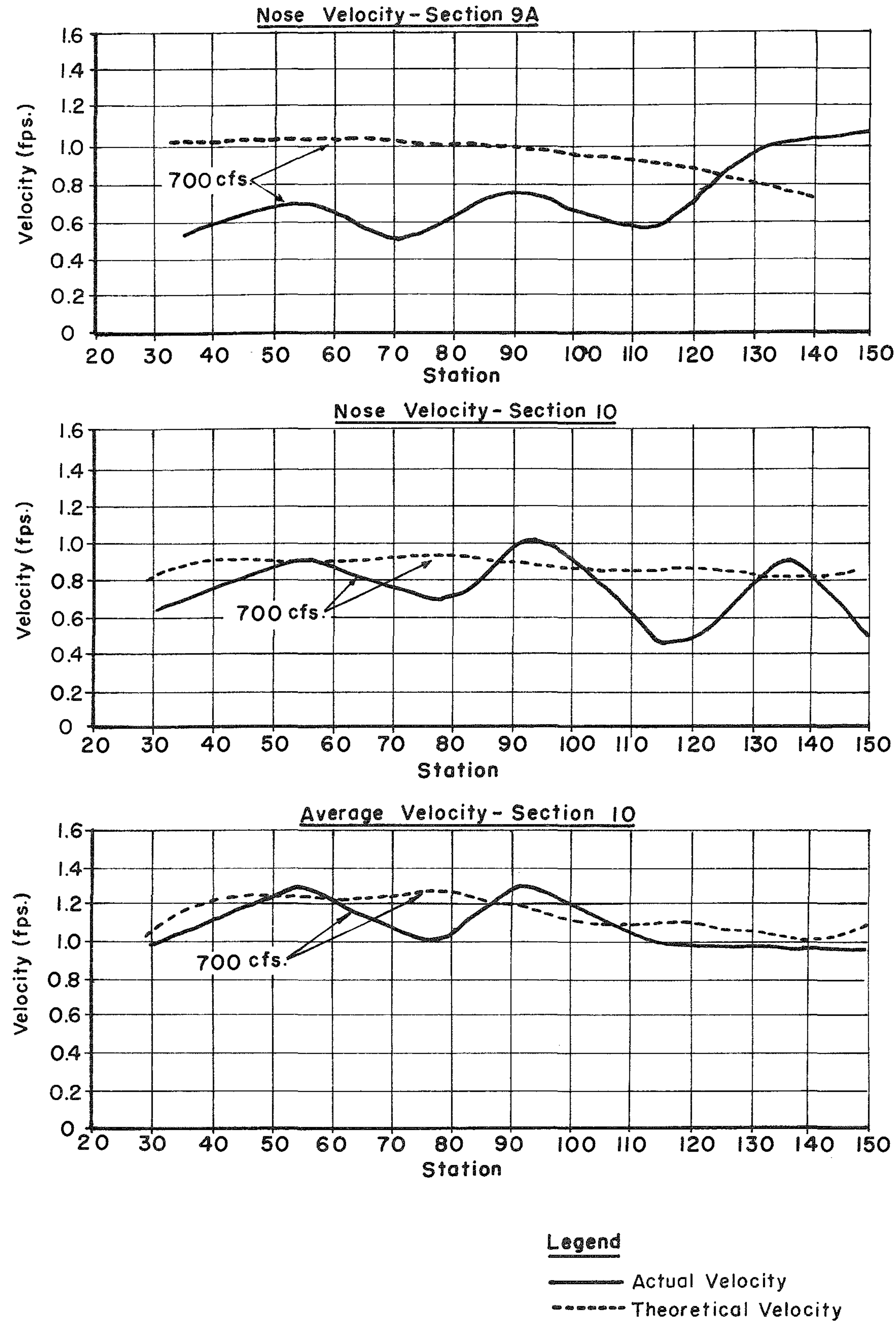


FIGURE 9. Nanika River – Comparison of measured and theoretical average velocities and nose velocities, Spawning Area A.

The average velocity occurs at approximately 3/5 of the water depth above the riverbed. However, to define suitable spawning area it is necessary to convert this velocity into the velocity at the depth of spawning. This is referred to as the nose velocity and is assumed to be 0.4 feet above the riverbed. The relationship between average velocity and nose velocity varies in accordance with depth of flow. Vertical velocity distributions have been recommended by Einstein et. al. (1955) for clear water and silt laden flows. An interpretation of the velocity distribution for clear water flow resulted in a relationship between depth of flow and the ratio of nose velocity to average velocity as shown on Figure 10. However, it was found that theoretical nose velocities computed on the basis of this curve were consistently higher than the actual nose velocities measured under various discharges at Sections 9A and 10. Therefore, the Einstein curve was modified so as to provide a reasonable correlation between theoretical and actual nose velocities at these sections. This modified curve is also shown on Figure 10. A comparison of the measured nose velocities and the theoretical nose velocities computed on the basis of this curve are shown on Figures 8 and 9.

Nose velocities were computed in the above manner over the width of the spawning area at Sections 9, 9A and 10 for several discharges between 150 and 1,000 cfs. These three sections represent 9,500 square yards of spawnable gravel or approximately 50 percent of the total area within Spawning Area A. Velocity distribution curves were then plotted for each of the discharges as shown on Figure 11. As an example of how these curves are interpreted, it can be seen that at 800 cfs, 100 percent of the area is subject to nose velocities in excess of 0.80 feet per second, whereas only 30 percent of the area has nose velocities in excess of 1.10 feet per second.

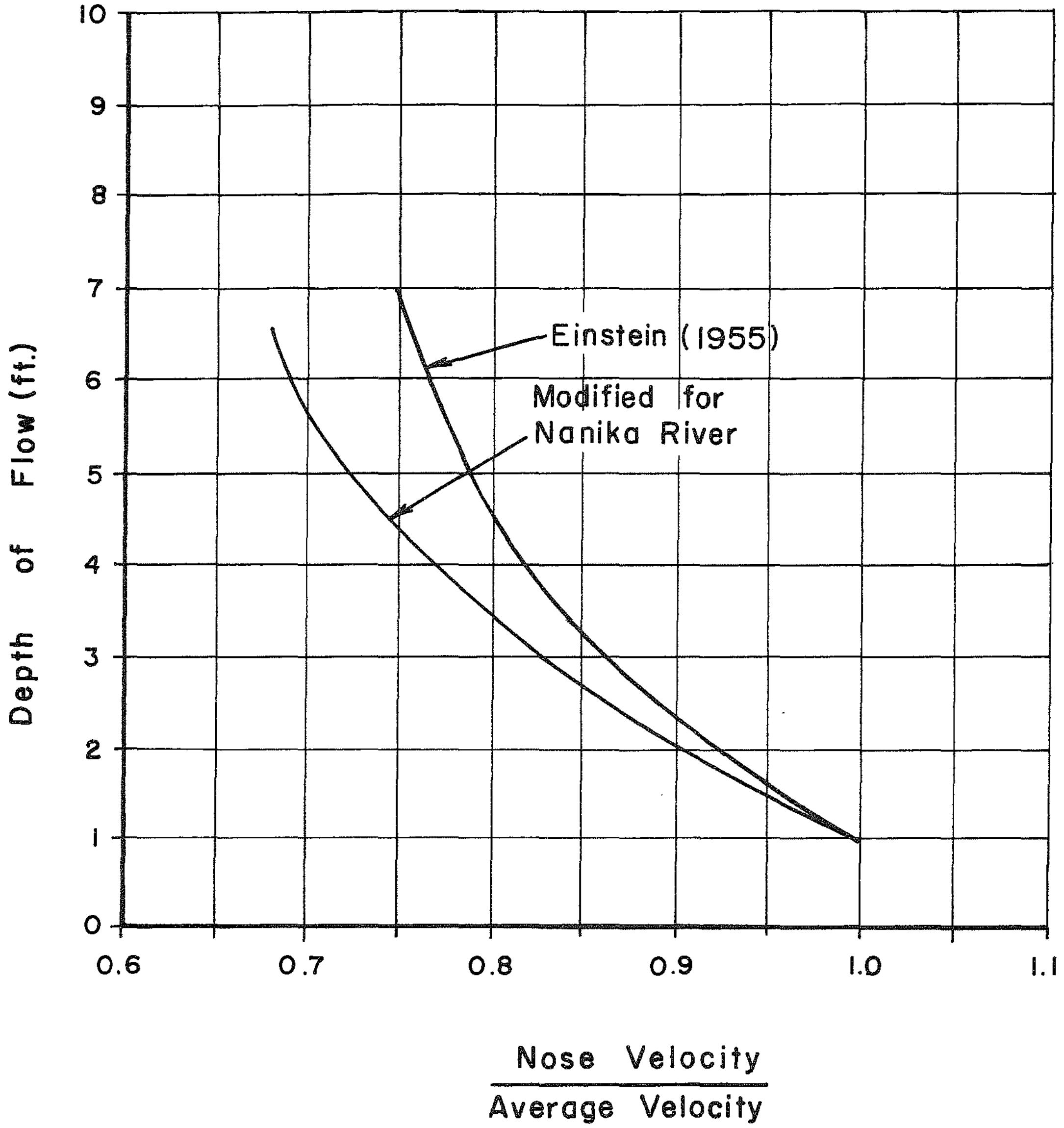


FIGURE 10. Nanika River – Ratio of nose velocity to average velocity relative to depth of flow.

FIGURE 11

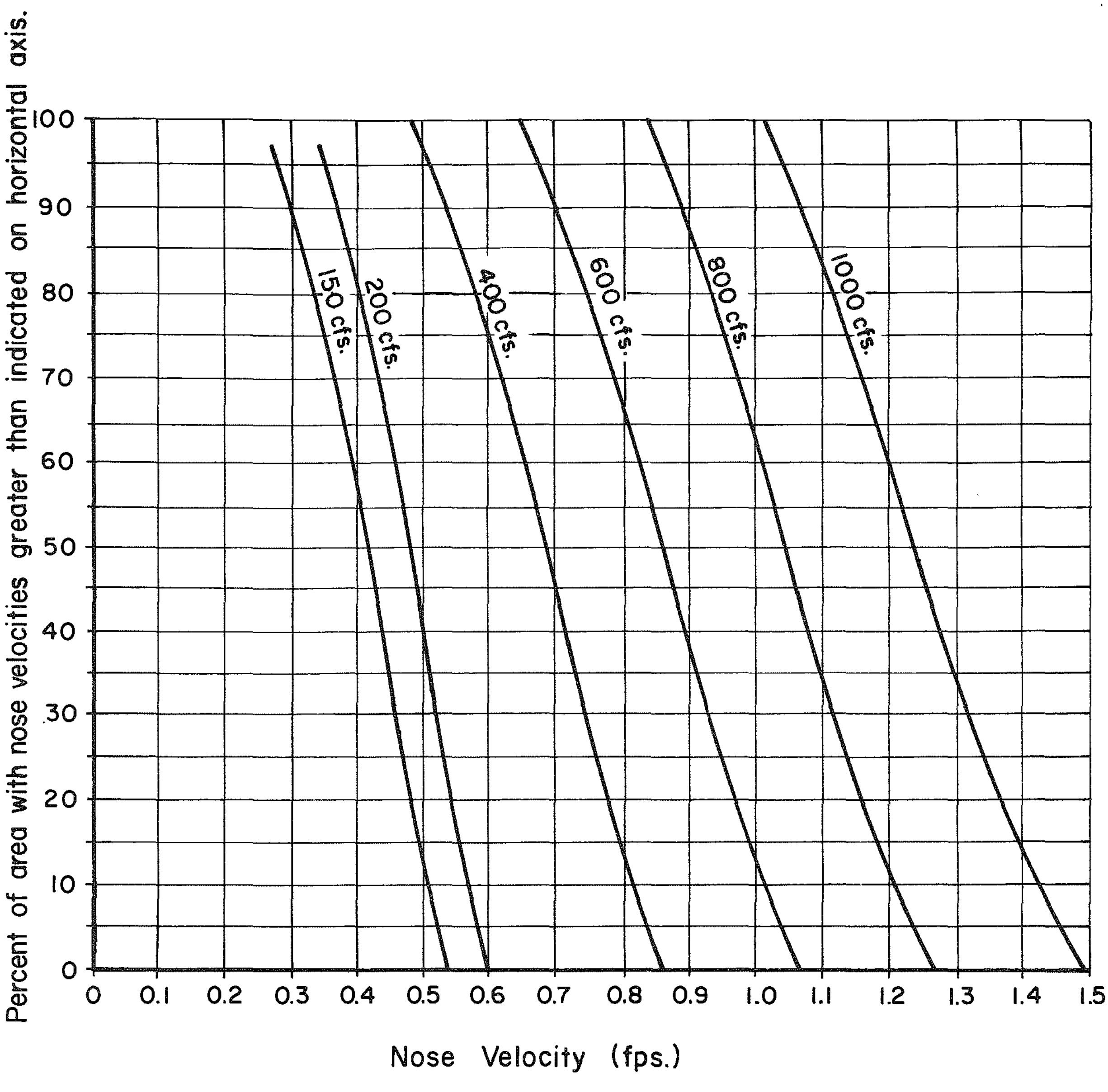


FIGURE 11. Nanika River - Distribution of nose velocities for various discharges, Spawning Area A.

As previously discussed, a velocity preference of 1.75 fps was indicated by Chambers *et al.*(1955) for sockeye salmon. A range was not specified as in the case of other salmon species. However, a review of the data contained in their report indicates that from a total of 278 observations of spawning sockeye, the vast majority spawned within a velocity range of 1.25 fps to 2.25 fps. A limited number spawned at velocities as low as 0.50 fps and as high as 2.75 fps. From Figure 11, it can be seen that only 3 percent of the Nanika River spawning area represented by Sections 9, 9A and 10 is subject to nose velocities in excess of 1.25 fps under a normal spawning discharge of 800 cfs. During the 1975 spawning season, nose velocities were measured at 39 active redds randomly chosen within Spawning Area A. All measurements were taken on the undisturbed gravel immediately adjacent to the redd where the induced turbulence would be minimal. The velocities ranged between 0.6 fps and 1.35 fps with an overall average of 0.95 fps. Average nose velocities measured in the Nanika River prior to 1975 were somewhat lower than this (0.82 fps), although these earlier measurements were taken amid groups of fish and were not necessarily located properly with respect to the redds.

From the foregoing data, it has been concluded that suitable gravel with nose velocities in excess of 0.9 fps will provide acceptable spawning habitat. Using these criteria and assuming that Sections 9, 9A and 10 are representative of Spawning Area A, the available spawning area was determined with respect to discharge by interpreting Figure 11. This is depicted graphically on Figure 12. To show how the extent of

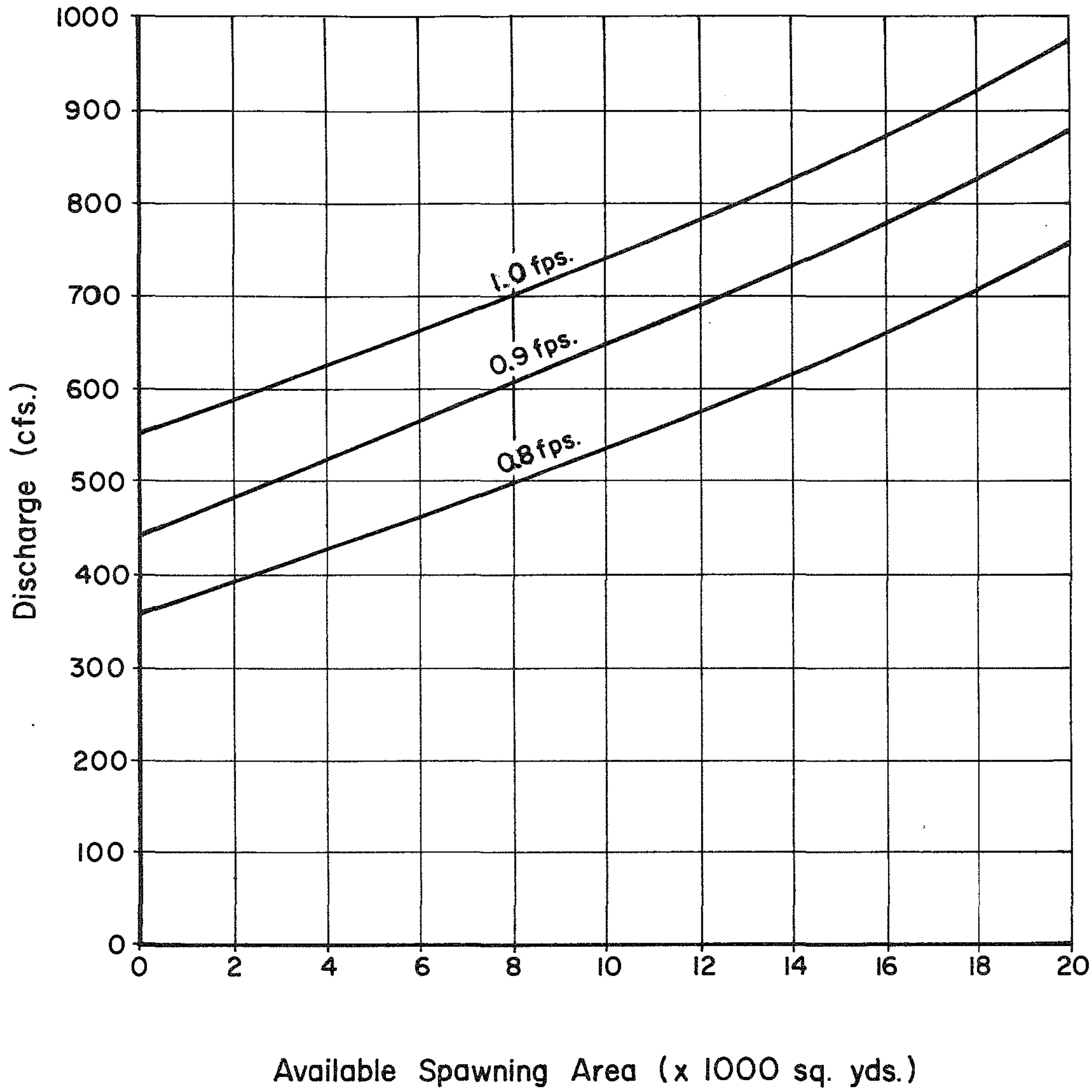


FIGURE 12. Nanika River - Relationship between available spawning area and discharge, Spawning Area. A.

spawning habitat is affected by changing the lower limit of nose velocity, curves are also provided on Figure 12 for minimum nose velocities of 0.8 fps and 1.0 fps.

ii) <u>Spawning Area B</u>

Spawning Area B (Figure 4) is much smaller, consisting of approximately 2,000 square yards of suitable spawning gravel. It is also quite different from Spawning Area A in that it is located adjacent to the right bank rather than across the width of the channel. This situation is more critical with respect to spawning and incubation as the gravel actually becomes dewatered with reduced discharges. In addition, velocities are considerably higher over the spawning gravel than in the case of Spawning Area A. This is apparent over the wetted spawning gravel even under low winter discharges. Therefore, the assessment of this area is based exclusively on the premise that spawning gravel is lost when subjected to a depth of water of less than one foot.

Cross-sections 15 to 18, inclusive, were established within the spawning area and monitored under various discharges. Cross-section 16 was found to be representative of general flow conditions throughout the area and was therefore used to determine the relationship between discharge and available spawning area. The cross-section and its discharge rating curve are shown on Figure 13. Using this rating curve and the depth contours of the riverbed, the total area of suitable spawning gravel covered by a depth of water of at least one foot was computed for several discharges. This is presented in Figure 14. It can be seen that even under a discharge of 1,000 cfs, approximately 250 square yards of suitable spawning gravel is unavailable for spawning due to a limited depth of water.

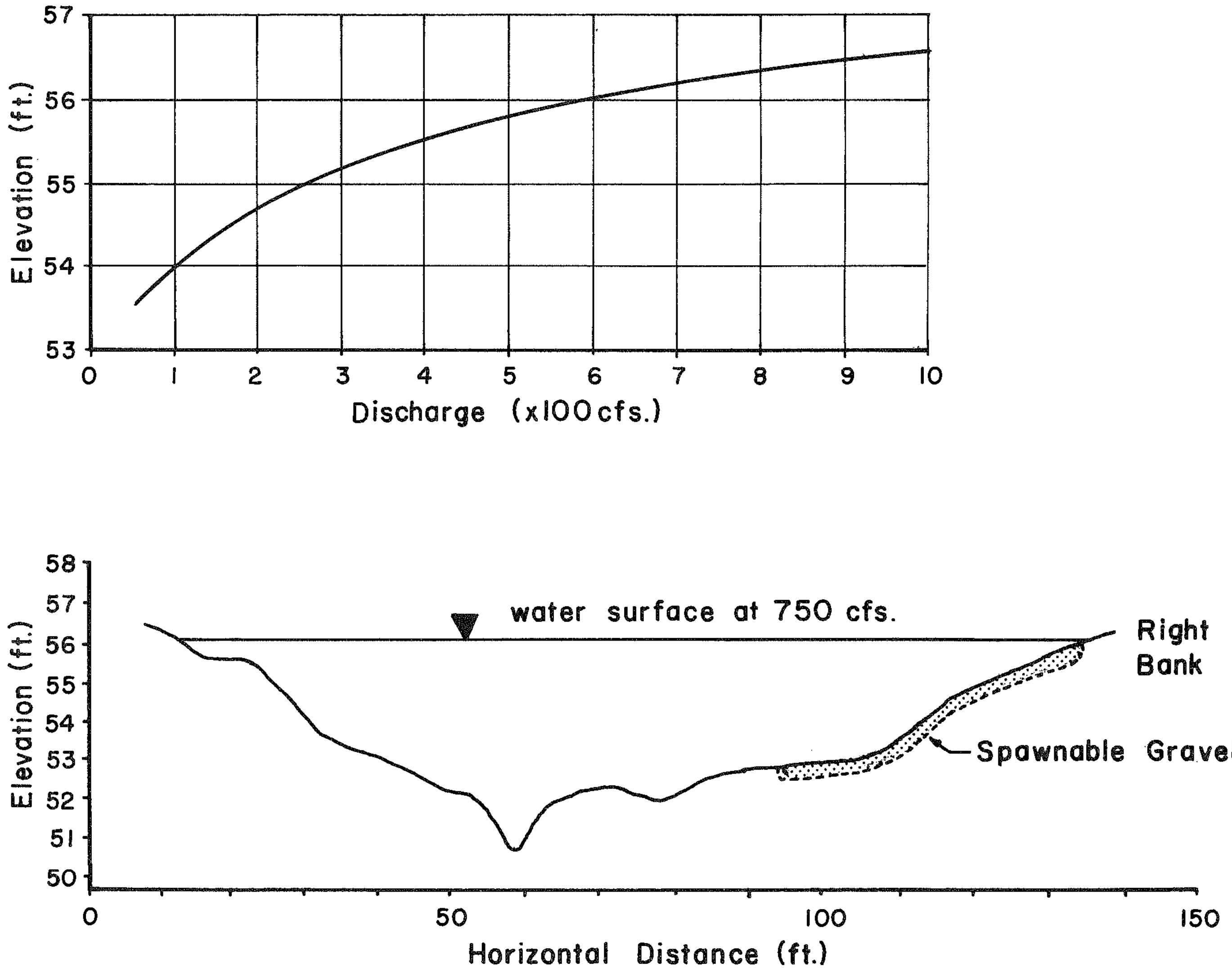


FIGURE 13. Nanika River- Rating curve and cross-sectional profile for Section·16, Spawning Area B.

FIGURE 13.

FIGURE 14.

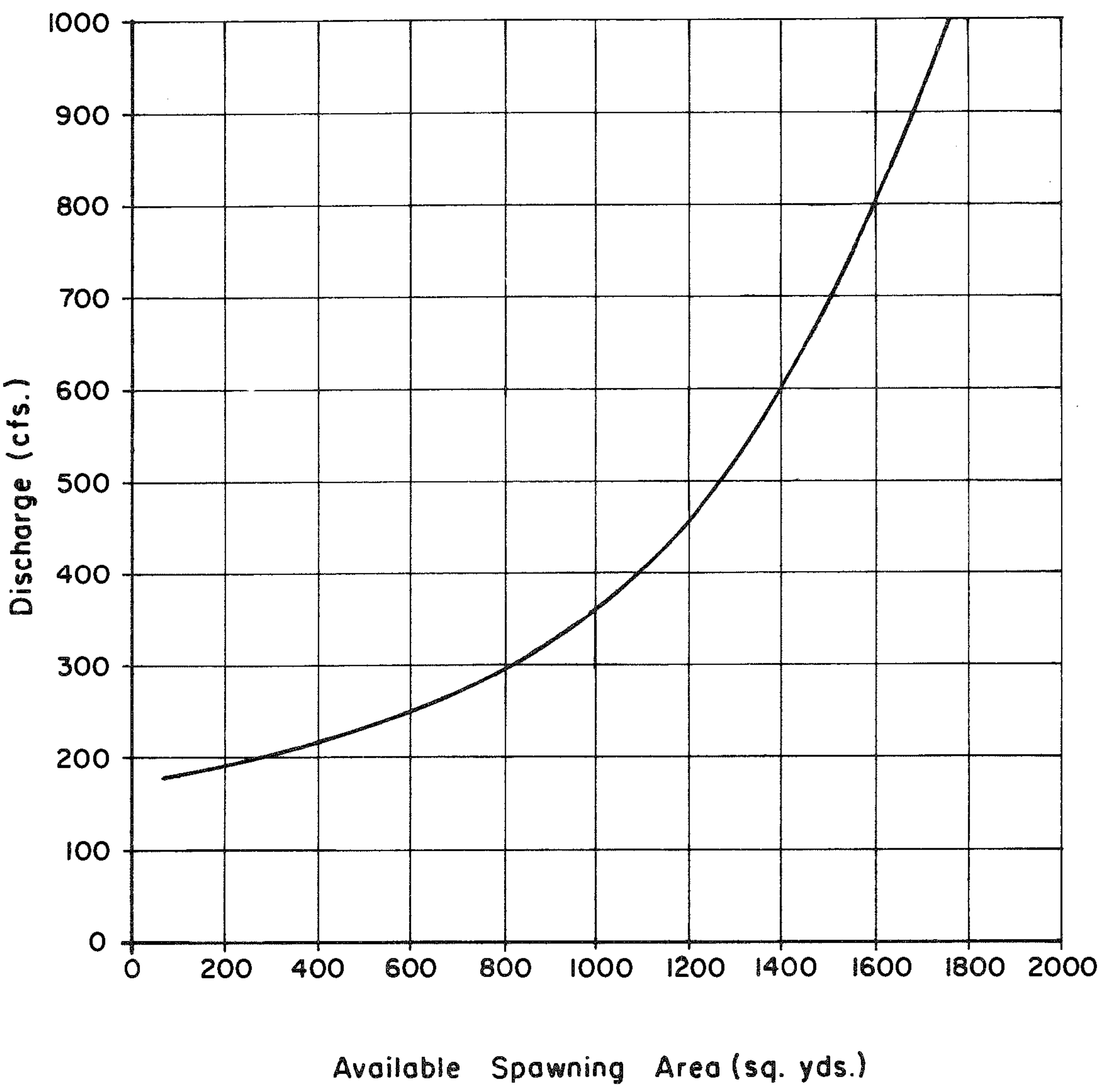


Figure 14. Nanika River – Relationship between spawning area and discharge, Spawning Area B.

(iii) Potential Spawning Populations, Spawning Areas A & B

As a result of studies conducted on the Columbia River system, Burner (1951) reported that a pair of sockeye salmon will defend an area of approximately 8 square yards against encroachment by other spawners. However, this area will be overlapped by subsequent spawners and upon completion of all spawning activity an average density of one pair of sockeye per 2 square yards of gravel can be expected. Assuming this is also applicable to the Nanika River, the potential spawning population in Spawning Areas A and B relative to river discharge would be as indicated in Table 2.

Within Areas A and B the gravel is generally excellent except for small pockets of silt and debris which has accumulated downstream from some of the small dunes. The river was inspected during 1975 and it was estimated that the area represented by these pockets of unsuitable spawning material would be less than 5 percent of the total spawning area.

In addition to Spawning Areas A and B, other gravel areas are scattered throughout the upper two miles of the river as indicated on Figure 4. It is estimated that an additional 10,000 square yards of suitable spawning gravel exists in these areas. Although not included in the study it was assumed that these areas would sustain the same ratio of loss in spawning area with reduced discharges as the combined losses determined for Study Areas A and B. On the basis of this, the potential spawning population which could be sustained in the upper Nanika River system relative to discharge is as presented in Table 3.

TABLE 2 SUMMARY OF AVAILABLE SPAWNING AREA AND POTENTIAL SOCKEYE SPAWNING POPULATIONS IN SPAWNING AREAS A AND B, AS A FUNCTION OF RIVER DISCHARGE.

Discharge (cfs)	Available Spawning Area (sq. yds.)			Percent of Total Suitable Spawning Gravel (22,000 sq.yds.)	Potential Sockeye Spawning Population
	Spawning Area A	Spawning Area B	Total		
1,000	20,000	1,750	21,750	100%	21,800
800	19,200	1,600	20,800	95	20,800
600	6,000	1,400	7,400	34	7,400
400	0	1,100	1,100	5	1,100
200	0	300	300	1	300
150	0	0	0	0	0

TABLE 3 SUMMARY OF AVAILABLE SPAWNING AREA AND POTENTIAL SOCKEYE SPAWNING POPULATIONS IN THE UPPER NANIKE RIVER, AS A FUNCTION OF RIVER DISCHARGE.

Discharge (cfs)	Available Spawning Area (sq. yds.)			Potential Sockeye Spawning Population
	Spawning Areas A & B	Additional Areas	Total Potential	
1,000	21,750	10,000	31,750	31,800
800	20,800	9,500	30,300	30,300
600	7,400	3,400	10,800	10,800
400	1,100	500	1,600	1,600
200	300	100	400	400
150	0	0	0	0

2.2 Morice River

Hydraulic studies were conducted in the Morice River on a prime chinook salmon spawning area some 2,000 feet in length and located approximately one-half mile below the outlet of Morice Lake (Figure 15). This area, designated Study Area A, comprises the highest density of chinook spawning within the river. The surveys were conducted at discharges ranging between 460 cfs and 2800 cfs and were comprised of the following operations:

- River channel cross-sections at 13 locations within the study area.
- Velocity measurements over the width of the river on several of the sections.
- Velocity measurements over the dune bedforms between sections 11 and 13.
- Velocity measurements at chinook redds during the spawning period.
- Measurements of water surface profiles throughout the length of the study area at flows ranging between 460 and 2800 cfs.
- Detailed topographical mapping of the riverbed in two study areas B and C within the main study area.

Miscellaneous water levels were also obtained within the study area at discharges between 1500 and 9700 cfs. In addition, several miles of the river below the outlet of Morice Lake was photographed from the air for reference purposes.

A topographical map of the study area with general riverbed contours, location of cross-sections and study area sites,

FIGURE 15. A Prime Chinook spawning area in the upper Morice River below Morice Lake. Photograph taken August 29, 1974. Discharge - 3800 cfs.

FIGURE 15

and the relative density of spawning is shown on Figure 16. Flow is split within the study area by an island. The ratio of flow between the right and left channels (facing downstream) on either side of the island was found to be 2 to 1 at 2,500 cfs and 3.5 to 1 at 675 cfs. Flow measurement below the island by the Fisheries and Marine Service agreed closely with discharges recorded a short distance upstream by the Inland Waters Branch, but were approximately 15 percent higher than the combined discharges measured in the channels on each side of the island. Some of this discrepancy may be due to errors inherent to the metering operation, but it is considered to be largely attributed to the occurrence of a substantial sub-gravel flow through the porous, granular materials in the island.

Most of the riverbed within the study area is characterized by a series of large gravel dunes generally oriented perpendicular to the direction of flow. Dunes are common in sand bed rivers where they are often the predominant mode of bedload transport under certain discharge regimes. However, they are not commonly found in gravel bed rivers and it is not known if their occurrence in the Morice River is due to hydraulic conditions alone, to the spawning activity of the chinook salmon, or to some combination of the two. Regardless of how they are formed, the existence of the gravel dunes undoubtedly contributes significantly to the maintenance of the large runs of chinook salmon in the Morice River. Studies conducted by the International Pacific Salmon Fisheries Commission (Cooper, 1965) concluded that the circulation of fresh water through the gravel was enhanced by the presence of a mound of gravel or dune on the surface of the riverbed. This would result in increased survival rates during the egg incubation period, which is discussed later in this report.

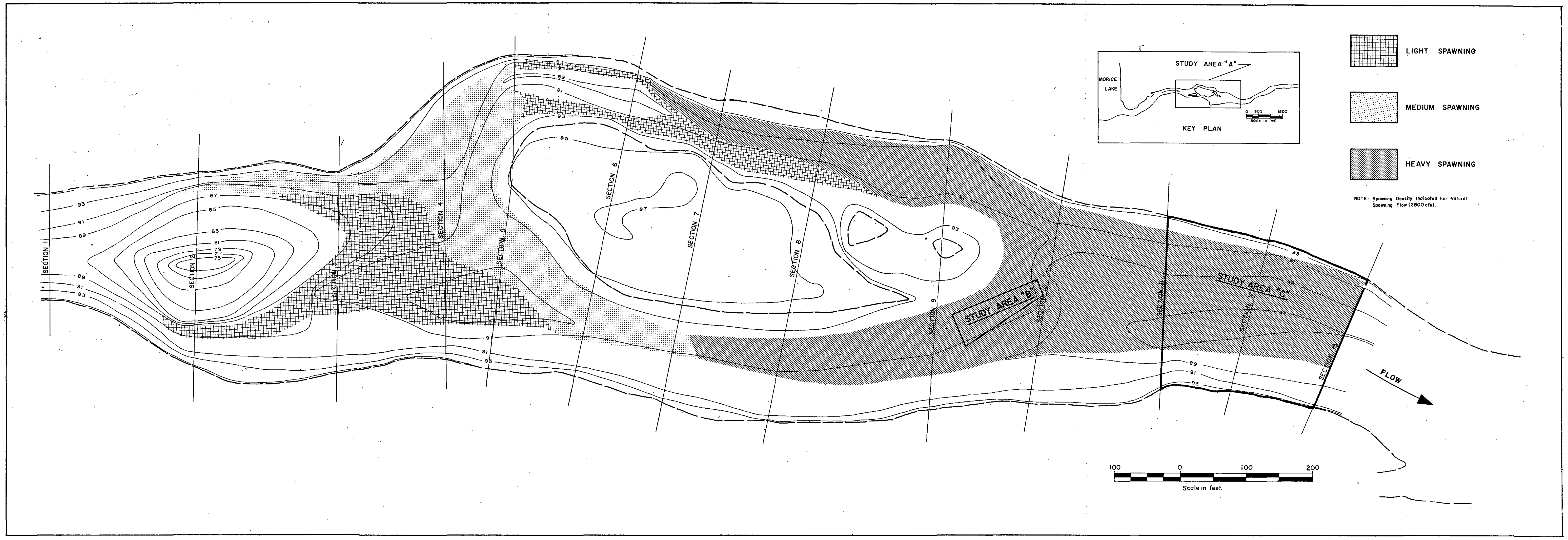


FIGURE 16. Map of river topography and spawning density, Morice River, Study Area A.

The dunes could possibly be broken down during periods of peak discharge, although this has not occurred during the past five years at discharges as high as 10,000 cfs. If the dunes are caused hydraulically, it is probable that they would be broken down at some discharge in excess of 10,000 cfs and then reformed as discharges recede. This is the normal sequence of events in the case of dunes in sand bed rivers. Such breakdown and subsequent reformation would have a cleansing effect on the gravel within the dunes, which would also be an important factor in ensuring high survival rates during the incubation period. In order to maintain the quality of this spawning area in the event of diversion of water from Morice Lake, high flow releases may be required every few years in the Morice River. The flow rate is unknown at this time.

Due to the complex hydraulic conditions created by these dunes, the relationship between spawning area and discharge could not be analyzed in a manner similar to the Nanika River. The relatively uniform riverbed in the Nanika River allowed the entire study area to be represented reasonably well by a few cross-sections. However, in the Morice River the irregularities of the riverbed required a complete topographical survey of the study area as well as extensive velocity measurements in order to delineate spawning areas.

Five cross-sections within the study area are shown on Figure 17 together with their respective discharge rating curves. Water levels are shown on each section for discharges of 675, 1350 and 2500 cfs. The irregular bottom profile of each cross-section is caused by the section being located across gravel dunes.

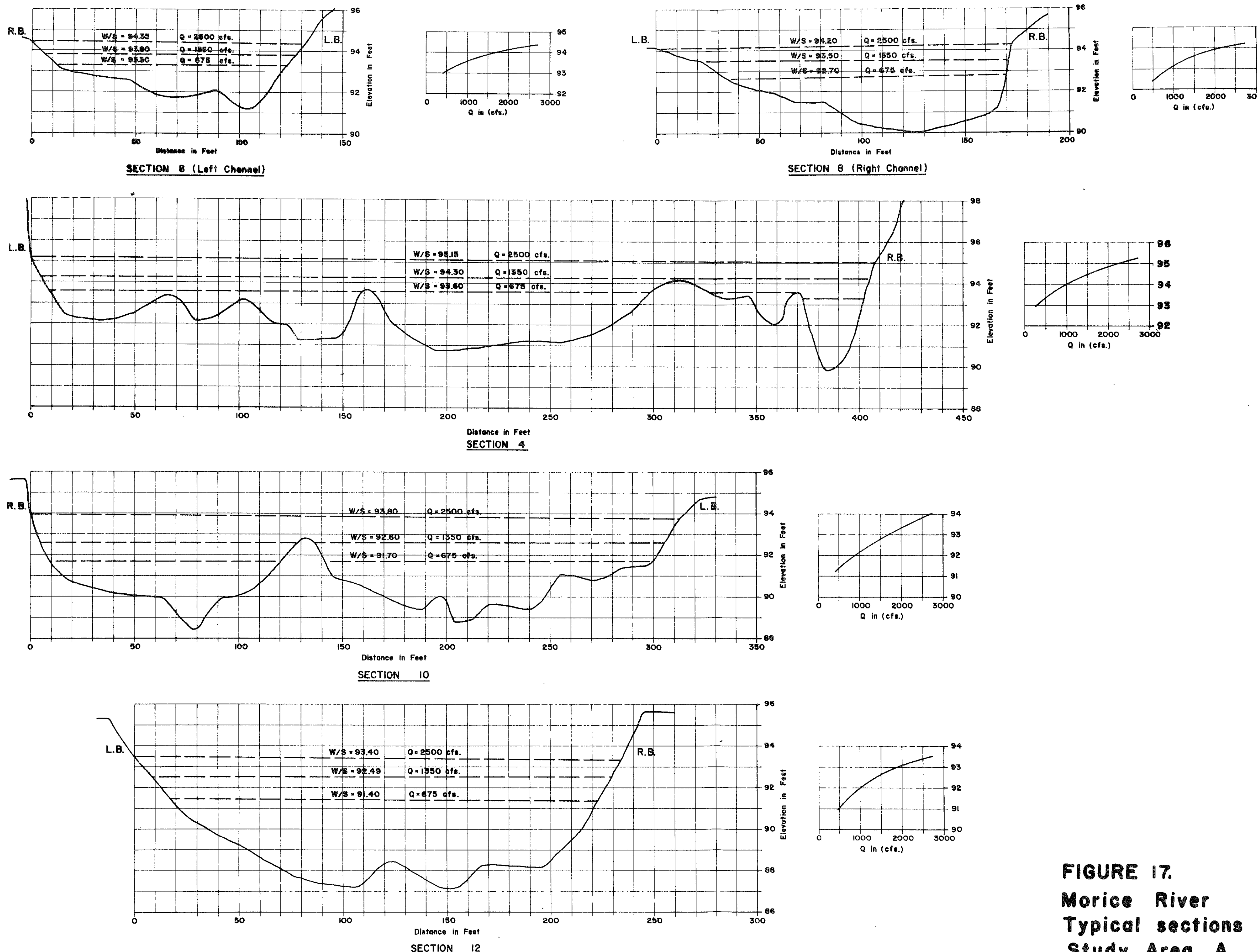


FIGURE 17.
Morice River
Typical sections in
Study Area A.

In assessing the effects of reduced discharges on spawning areas in the Morice River, it was assumed that an area is unacceptable to spawners if covered by less than one foot of water. Using this criterion, an analysis was carried out on the wetted area between sections 3 and 13, Figure 16. Sections 1 and 2 were not included as spawning is known to be quite limited in this area. The total wetted area between sections 3 and 13 is 57,600 square yards at a discharge of 2800 cfs. The percentage of this area covered by a depth of water of more than 1 foot at various discharges is summarized in Table 4.

TABLE 4

RIVERBED AREA COVERED BY MORE THAN ONE FOOT OF WATER BETWEEN SECTIONS 3 AND 13, MORICE RIVER STUDY AREA 'A'.

DISCHARGE (CFS)	AREA (SQ. YDS.)	PERCENT OF TOTAL WETTED AREA AT 2800 CFS
2800	40,610	71
2300	38,650	67
2000	36,760	64
1500	35,040	61
1000	31,190	54
460	17,860	31

The above table presents only the relationship between wetted perimeter and discharge within the study area and does not relate to available spawning area. Extensive dune formations occur throughout the lower half of the study area and a certain percentage of the surface area of a dune is unsuitable for spawning under any discharge due to variability in the composition of the gravel and the water velocities over the width of the dunes. To provide a relationship between total wetted area and available spawning area, a detailed topographical survey was conducted on a small area with typical gravel dunes immediately below the island and on a larger area located between sections 11 and 13. These study areas were designated Study Areas B and C, respectively, and are located as shown on Figure 16.

Study Area B was investigated during 1974. A detailed contour map and longitudinal sections of the area are shown on Figure 18. The maximum area of spawning gravel of proper size composition for spawning was found to be 189 square yards within the study area. On the basis of biological observations during the 1974 chinook spawning period, it was estimated that spawning would normally occur over approximately the upper 2/3 of the upstream face of a dune, if covered by a water depth of more than 1 foot. Based on this, the available spawning areas within Study Area B were determined for various discharges as shown in Table 5.

TABLE 5

AVAILABLE SPAWNING AREA IN MORICE RIVER, STUDY AREA B

FLOW (CFS)	AVAILABLE SPAWNING AREA, SQ. YDS.	PERCENT OF SUITABLE SPAWNING GRAVEL AVAILABLE FOR SPAWNING
2,500	189	100
2,000	180	95
1,500	164	87
1,000	117	62
675	46	24

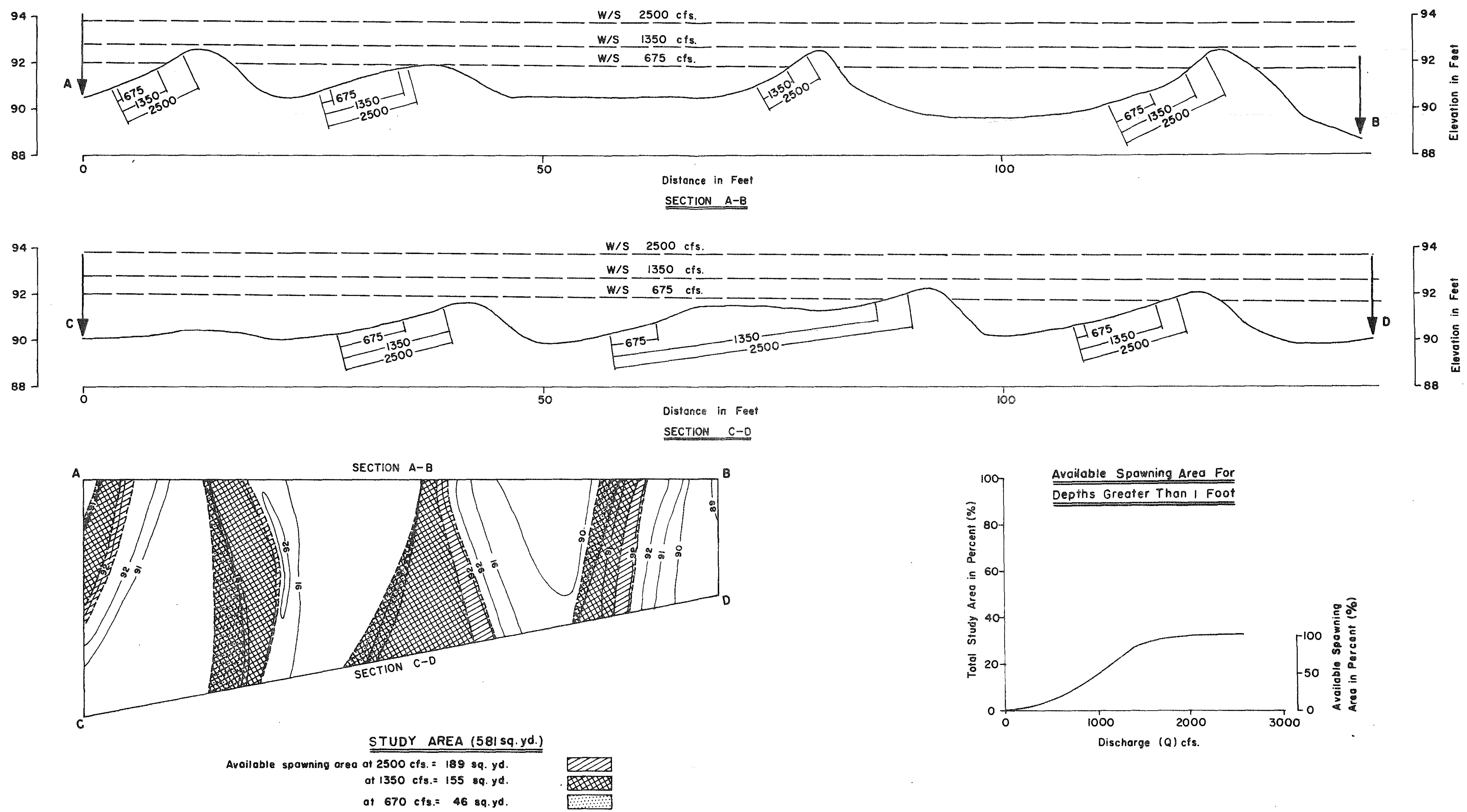


FIGURE 18. Morice River.
Available spawning area over dune bedforms in Study Area B.

In view of the fact that Study Area B is very small, representing only about 1 percent of the wetted area within Study Area A, and water velocities had not been considered in the analysis, it was decided to investigate a larger area during 1975. This area, designated Study Area C, was located downstream from the island between sections 11 and 13 and is one of the most densely spawned areas within Study Area A. It is also considered to be very representative of the large spawning area occurring further downstream.

Surveys were conducted on Study Area C at discharges of 460, 1500 and 2800 cfs. Average and nose velocities and water depth were measured at each discharge at close intervals on several sections oriented perpendicular to the dunes. The direction of flow was noted during each velocity measurement. Twenty active redds were also monitored for nose and average velocities. Nose velocities adjacent to the redds were found to range between 1.6 and 3.8 feet per second with an overall average of 2.2 feet per second. However, this does not necessarily indicate the acceptable range of spawning velocities since the observations were made during the initial stages of spawning and the earliest arrivals would tend to select the most ideal spawning areas on the upper part of the dunes. Consequently, a minimum acceptable nose velocity of 1 foot per second, as shown in Table 1, is assumed to be also applicable to chinook salmon in the Morice River.

Suitable spawning gravel was also mapped within the study area. This was done on the basis of gravel composition without regard for velocity or water depth. Only clean, silt-free gravel was considered as being suitable.

The first major difference between the 1974 and 1975 studies lies in the invalid assumption that spawning will occur anywhere on the upper 2/3 of the upstream face of the dunes if covered by more than 1 foot of water. This may closely represent the maximum area of available spawning gravel, since the downstream face, trough and lower portion of the upstream face of the dunes are generally laden with sand, silt and debris, which is not conducive to spawning. However, the 1975 studies revealed that significantly less area was available for spawning on the upstream face of the dunes because velocities over suitable spawning gravel were often less than the acceptable level. This was particularly the case at lower discharges.

The available spawning area within Study Area C for each discharge at which the surveys were conducted is shown on Figures 19, 20 and 21. The available spawning area is defined as that area of suitable spawning gravel which has a minimum cover of 1 foot of water with a minimum nose velocity of 1 foot per second.

Since velocities were measured only at three discharges, further velocity data were needed to define the limits of available spawning area at intermediate discharges. These velocities were subsequently obtained by linear interpolation between the actual field measurements. Due to the extremely complex nature of flow over the dunes, no other analytical method of obtaining intermediate velocities was considered practical. On this basis the available spawning area within Study Area C was determined for discharges of 2800, 2300, 2000, 1500, 1000 and 460 cfs as presented in Table 6. Discharge versus available spawning area is shown graphically on Figure 22.

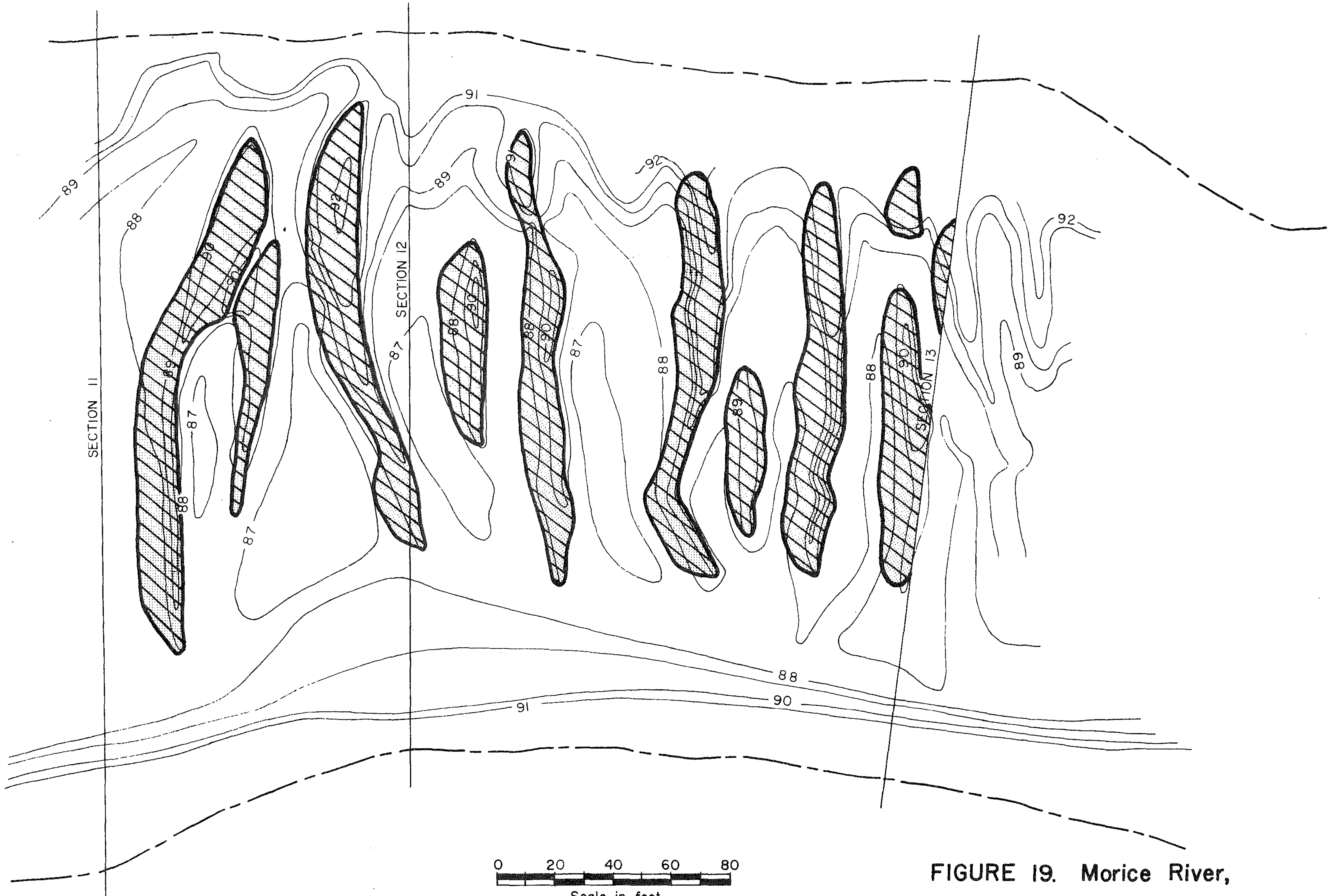


FIGURE 19. Morice River, Available Spawning Area at 2800 cfs. in Study Area C.

FIGURE 20. Morice River, Available Spawning Area at 1500 cfs. in Study Area C.

FIGURE 21. Morice River, Available Spawning Area at 460cfs. in Study Area C.

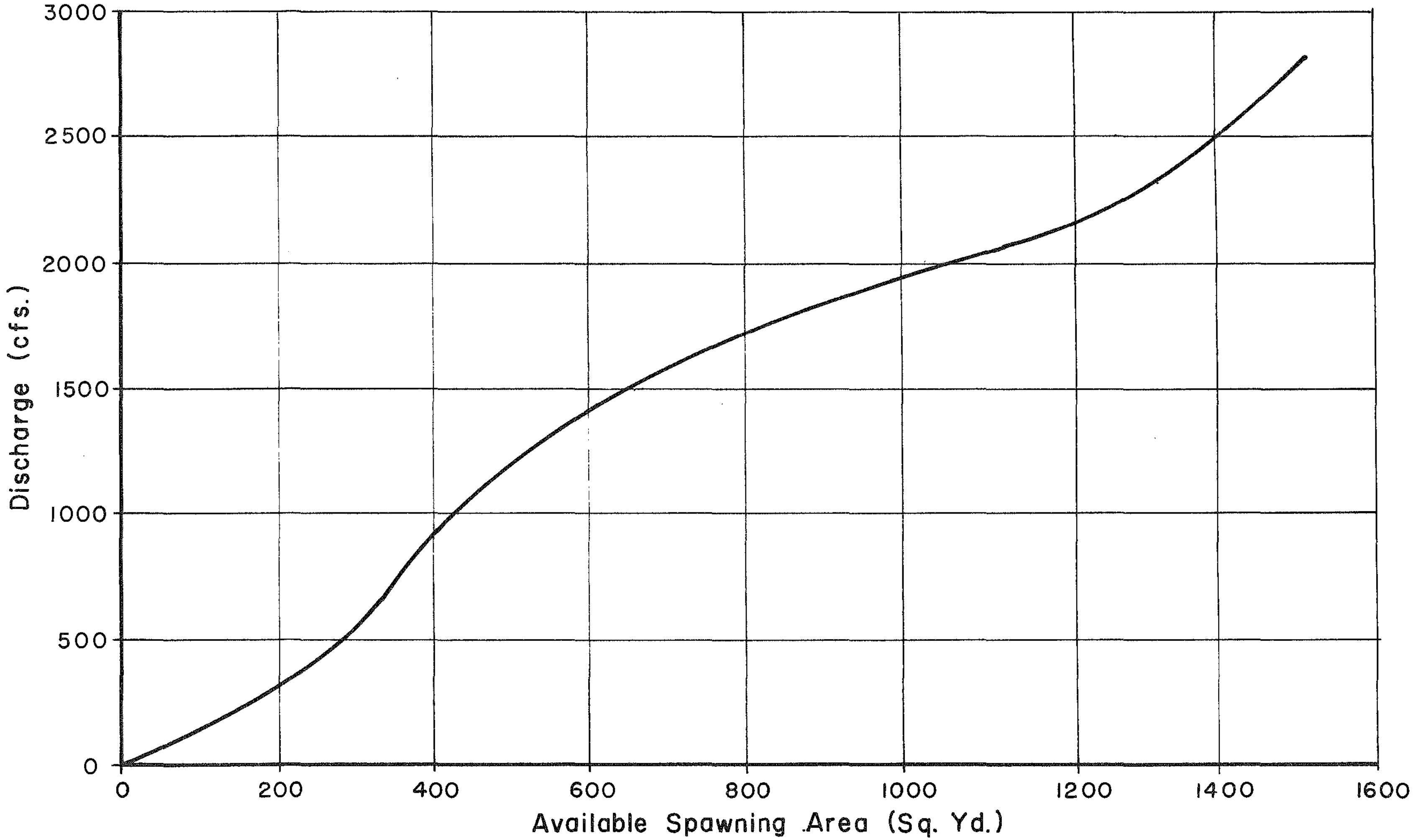


FIGURE 22. Morice River-Available Spawning Area in Study Area C.

FIGURE 22.

TABLE 6

AVAILABLE SPAWNING AREA IN MORICE RIVER, STUDY AREA C

DISCHARGE (CFS)	AVAILABLE SPAWNING AREA (SQ. YDS.)	PERCENT OF SUITABLE SPAWNING GRAVEL AVAILABLE FOR SPAWNING*
2800	1,520	100
2300	1,317	87
2000	1,033	68
1500	657	43
1000	424	28
460	295	19

* It is assumed that all spawning gravel within Study Area C could be utilized for spawning at a discharge of 2800 cfs.

Chinook spawning in the Morice River occurs between mid-July and October 31. During this period mean monthly flows vary between 6,300 and 2,800 cfs with an average of approximately 4,000 cfs. However, since most of the spawning occurs in late August to mid-October, natural spawning discharges would be in the lower part of this range. Although this study was conducted with a maximum discharge of 2,800 cfs, it was concluded that only marginally more gravel could be utilized in Study Area C with increased discharges. At 2,800 cfs all dunes are covered by more than 1 foot of water, nose velocities are reasonably high, and only slightly more area could be gained on the lower extremities of the dunes and along the margins of the shoreline with increased discharge.

The entire chinook spawning area in the Morice River was not measured as part of this study. However, most spawning occurs between the outlet of Morice Lake and Gosnell Creek, a distance of some 8 miles, with the greatest spawning density in the upper 3 miles, particularly in the vicinity of Study Area A. Chinook spawning records compiled by the Fisheries and Marine Service (see Volume 5) indicates that the maximum escapement was 12,000 excluding those years where approximate ranges were used. Similarly, the average escapement was 7,500 during the period 1949 to 75.

Without intensively surveying the total spawning area in Morice River, it is not possible to provide a direct relationship between discharge and available spawning area. Therefore, it has been assumed that all chinook spawning areas would be fully utilized by the maximum recorded natural escapements at a discharge of 2,800 cfs. If it is also assumed that Study Area C is representative of the remainder of the total spawning area, then the spawning potential for various discharges is as presented in Table 7.

The maximum escapement of 12,000 used in Table 7 is based on the highest firm count in the Morice River between 1949 and 1975. During the period 1956 to 1959 an escapement range of 10,000 - 20,000 was recorded, indicating that actual maximum escapements might possibly be higher than indicated in Table 7. Furthermore, present escapement levels in the Morice River are influenced to a large degree by both the present and past exploitation rates of the commercial and Indian food fisheries. It is therefore probable that the potential spawning populations indicated in Table 7 are lower than the levels that could occur on the basis of physical limitations alone.

TABLE 7

PROBABLE SPAWNING POTENTIAL AS RELATED TO DISCHARGE IN THE MORICE RIVER

DISCHARGE (CFS)	PERCENT OF SUITABLE SPAWNING GRAVEL AVAILABLE FOR SPAWNING IN STUDY AREA C (SEE TABLE 6)	SPAWNING POTENTIAL OF MORICE RIVER
2800	100	12,000
2300	87	10,400
2000	68	8,200
1500	43	5,200
1000	28	3,300
460	19	2,300

In considering diversion of water from the Morice River, emphasis should be placed on the maximum escapement levels since the Fisheries and Marine Service is currently intensifying chinook management efforts in the Skeena system. This may ultimately lead to increased average chinook escapements in the Morice River.

3. Incubation

Low flows can affect egg incubation in a variety of ways aside from direct dewatering of spawning gravel. Any reduction in discharge can be expected to result in reduced sub-gravel flow which will reduce the flow of oxygen-rich water into the redd and reduce the removal rate of toxic metabolic wastes such as carbon dioxide and ammonia (Phillips, 1971). In addition, fines will settle and accumulate more at lower flows, resulting in further reductions in intragravel water velocities and oxygen levels. This can increase embryo mortality, delay hatching by retarding development and physically bar fry from emerging. Lowered winter flows can increase the frost depth in the gravel, which can cause death.

Alevins, however, are not entirely at the mercy of environmental conditions, as they are able to move within the gravel immediately after hatching (Dill, 1969), and appear to be able to respond to lowered water levels by moving laterally or downward through the gravel (Bams, 1969). Aside from the need to maintain an adequate oxygen supply during the alevin stage, the most critical period with respect to reduced water levels is therefore in the egg stage prior to hatching.

The duration of time between egg fertilization and hatching is related to heat units of the water. It is generally accepted by hatchery personnel that chinook hatching requires 850 to 900 degree (fahrenheit) days, while sockeye hatching requires 950 degree days. Degree days are defined as the average number of degrees above 32^{o} F. occurring over a one day period. On the basis of water temperature records obtained in the Nanika and Morice Rivers during the 1966 hatchery operation (Palmer - unpublished data), egg hatching could be expected by the dates shown in Table 8.

TABLE 8

PROBABLE HATCHING DATES FOR NANIKA RIVER SOCKEYE EGGS AND MORICE RIVER CHINOOK EGGS

	Nanika River Sockeye	Morice River Chinook
Earliest Hatching Date	November 6	October 15
Average Hatching Date	April 10	December 15
Latest Hatching Date	June 25	January 1+*

* 740 heat units to January 1. If the river remains near 38° F. into January, hatching would occur during the first week of January. Hatching could be delayed until mid-April if winter temperatures are similar to the Nanika River temperatures.

Due to the difficulty in computing water levels with any degree of accuracy for discharges below those observed, and the uncertainty in defining spawning density at the various riverbed levels, it was not possible to determine incubation losses relative to reduced discharges. Accordingly, the assessment of incubation flows was limited to determining the minimum flows required to prevent any loss of incubating eggs.

Although surveys were not conducted in the Nanika and Morice Rivers specifically to assess incubation flow requirements, certain deductions can be made from the spawning ground surveys conducted at low discharges.

i) <u>Nanika River</u>

Incubation flow requirements are somewhat dependent upon the discharge at which spawning occurred. Since it was assumed that sockeye salmon need a minimum depth of 1 foot for spawning, the incubation flow necessary to inundate the total area spawned would be that discharge corresponding to a water level 1 foot lower than occurred during spawning.

Since Study Area A is much deeper than other spawning areas in the system, most of the spawning gravel remains inundated at very low discharges. At an incubation discharge of 100 cfs all spawning gravel was found to be inundated for any spawning discharge above 600 cfs.

Study Area B, however, is much more critical because it is located adjacent to the right bank and is shallower. In assessing incubation flows for this area three possible spawning discharges were chosen and their corresponding areas of spawning gravel were computed from the spawning ground surveys. The incubation discharges necessary to inundate the entire spawned area for each of these spawning discharges were then determined. The total inundated area was also determined for successively lower incubation discharges (Table 9). As indicated in this table, 1,600 square yards of gravel would be suitable for spawning at a discharge of 800 cfs. The incubation flow required to sustain all of the eggs deposited at this discharge would be 350 cfs. At an incubation flow of 100 cfs, only 600 square yards or 38% of the total area spawned at 800 cfs would be inundated.

The discharge at which eggs would begin to dewater is also presented in Table 9 for Study Area B. This is referred to as the dewatering discharge which is the discharge

TABLE 9 RELATIONSHIP BETWEEN INCUBATION DISCHARGE AND WETTED SPAWNING AREA, NANIKA RIVER, STUDY AREA B.

Spawning Discharge CFS	Spawned Area Sq.Yds.	Incubation Discharge CFS	Spawned Area Wetted Sq.Yds.	Percent of Spawned Area Wetted	Percent of Total Available Spawning Gravel Wetted	De-watering Discharge CFS
1,000	1,750	500	1,750	100	88	400
		400	1,600	94	80	
		300	1,520	87	76	
		200	1,250	71	63	
		150	1,000	57	50	
		100	600	34	30	
800	1,600	350	1,600	100	80	250
		300	1,520	95	76	
		200	1,250	78	63	
		150	1,000	63	50	
		100	600	38	30	
600	1,400	250	1,400	100	70	180
		200	1,250	89	63	
		150	1,000	71	50	
		100	600	43	30	

corresponding to a water level of 1.3 feet below the level that occurred during spawning. The depth of 1.3 feet is based on an egg burial depth of 0.3 feet, which is considered to be the minimum depth that sockeye eggs are buried below the surface of the gravel (Burner, 1951). However, it is possible that even though eggs remain inundated, reduced egg to fry survival rates may occur as a result of decreased inter-gravel velocities.

As indicated earlier, there are also numerous smaller but equally suitable spawning areas outside the boundaries of the two study reaches. In general, these areas are also located adjacent to the bank but are deeper than Area B and are therefore not as critical at lower discharges.

In view of the above, it is concluded that provision of an adequate incubation flow for Study Area B would more than satisy requirements for other spawning areas. Assuming a spawning discharge of 800 cfs, a minimum discharge of 250 cfs would be required to ensure egg survival. It is therefore recommended that a minimum incubation flow of 250 cfs be maintained in the Nanika River from the spawning period until such time that the discharge from Kidprice Lake would have naturally fallen below this level. Flow records for the period 1972 to 1975 indicate discharges generally drop to 250 cfs or lower during the month of January or February. Beyond this time on the falling stage of the hydrograph, outflow from Kidprice Lake should be regulated so as to closely simulate natural flows to a minimum of 100 cfs. This minimum discharge of 100 cfs should be provided during the spring freshet period until the end of June, except during such periods when increased flow may be required for flushing of spawning gravels.

ii) Morice River

At discharges of 460 and 675 cfs dune crests were exposed throughout some of the study area and the flow meandered between dunes in the area immediately below the island. Average velocities on the upstream face of wetted dunes were generally very low at these discharges. Redds located on the lower portion of the upstream face of dunes were normally in gravel containing some sand and silt. These fines would make this area less acceptable for incubation than the higher areas on the dune. Greatly reduced fry survival could be expected in the Morice River should water levels be reduced to cover only these redds. It is therefore imperative that the incubation flows be high enough so that eggs within the spawning redds on the upstream face of dunes are wetted throughout the pre-hatching period.

Burial depth of chinook eggs in the gravel is generally about 10 inches, but can vary from 2 to 48 inches (Burner, 1951). It is therefore apparent that flow should be maintained over the riverbed to a minimum of 2 inches below the dune crests for maximum survival. This condition does not prevail throughout the entire study area at natural low flows. As stated earlier in this report, even at 1500 cfs some crests are exposed in known spawning areas along the left bank within Study Area C. At 460 cfs further exposure of dune crests became evident in this area and dunes below the island in the vicinity of Study Area B became almost entirely exposed. However, most of the riverbed within the remainder of Study Area A remained wetted. No conclusive data could be obtained on wetted perimeters below the measured flow of 460 cfs, due to the complexities of computing water levels in the areas of extensive dune formations.

Morice River discharge records between 1961 and 1974 indicate that the lowerst recorded flow was 324 cfs on April 10, 1969. The minimum mean monthly flow was 392 cfs in April, 1969. These extremely low flows occurred near the end of fry emergence and would not necessarily be adequate for egg incubation. A graph of minimum mean monthly discharge between 1961 and 1974 at the outlet of Morice Lake is shown on Figure 23. This graph illustrates the natural low flow regime that prevails between spawning and fry emergence. Emergence would be almost completed by the end of May and in some years as early as the end of April.

In determining flow requirements during the incubation period, the pre-hatching and alevin stages should be considered separately. For Morice River chinook it is assumed that the pre-hatching stage would continue until December 31. Water temperatures should be obtained to confirm this. In the 15 years of stream flow records between 1961 and 1975 the average mean monthly flow for the period November 1 to December 31 ranged between 2320 and 1380 cfs. Mean monthly flows fell below 1000 cfs in only 3 cases throughout this 15 year period. Some of the spawning area along the shoreline and on the crests of dunes will be exposed within the study area at this discharge, although it is considered that very few eggs would be dewatered. Therefore, to ensure egg survival prior to hatching, it is concluded that the minimum incubation flow in the period of time between spawning and December 31 should be 1000 cfs.

Between January 1 and fry emergence, which could be as late as June, a lesser quanitty of water is required as alevins have some mobility within the spawning gravel. During the period 1962 to 1974, the average of the mean monthly flows between January 1 and April 30 ranged between 610 and 930 cfs. In this 13 year period the minimum mean

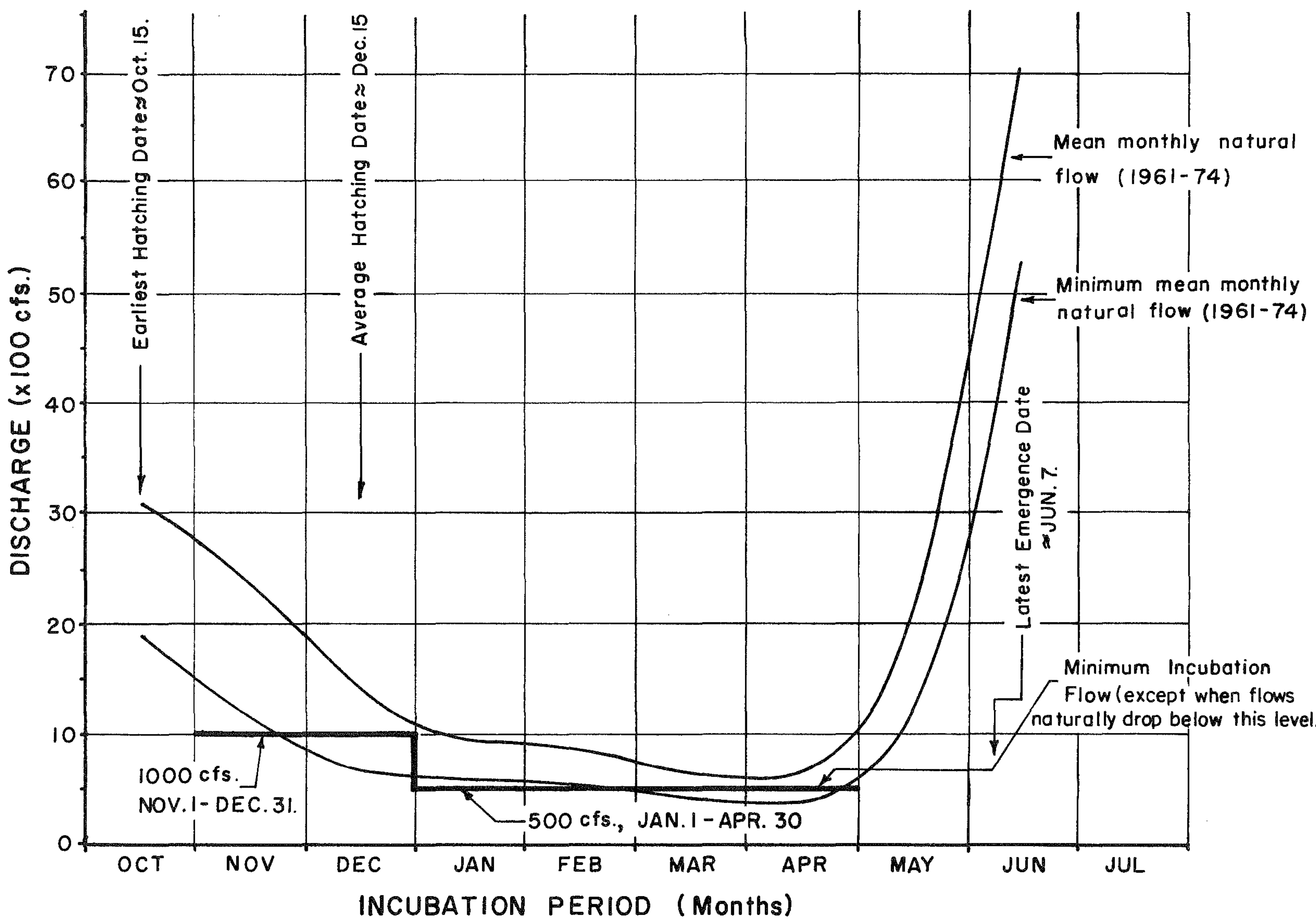


FIGURE 23. Morice River- Proposed Incubation Discharges relative to natural flows, 1961 to 1974.

FIGURE 23.

monthly flow varied between 600 cfs in January and 390 cfs in April. A mean of these latter discharges is considered to be adequate to ensure continued survival of alevin. It is therefore recommended that a minimum flow of 500 cfs be released between January 1 and April 30, except at such times when flows would naturally drop below this level. During this latter period of time, flow releases should be scheduled to coincide as closely as possible with the natural flows. After April 30, flow requirements will be governed by rearing needs as discussed in Volume 5 of this report.

iii) Flushing Requirements in Nanika and Morice Rivers

Studies on the Nanika and Morice Rivers did not include an assessment of flow requirements to induce bedload movement. It is considered that gravel should be occasionally disturbed to remove fine sediments so as to ensure that survival rates of incubating eggs are as high as possible. Observations on the Morice River indicated that gravel movement did not occur within the study area with discharges as high as 10,000 cfs. However, flows do exceed this level on occasion and it is possible that some bedload movement would occur at a somewhat higher discharge. Further studies should be undertaken on both the Nanika and Morice Rivers to determine whether a natural flushing action takes place during spring freshets and at what frequency.

4. Upstream Migration in Morice and Nanika Rivers

An aerial surveillance of potential low flow obstructions between Morice Lake and Nanika Falls was carried out in April, 1971 when the Nanika River discharge was 155 cfs. Although several falls and rapids were observed, no obstacles could be seen that would present any problem to migrating salmon. However, it was not established at what discharge below 155 cfs the river would become impassable.

The Morice River was inspected over its entire length when the discharge from Morice Lake was 1460 cfs. No obstructions to the upstream migration were observed. If flows were reduced to 500 cfs, certain rapids may present difficulties for the migrants or cause a delay in their migration. Further observations would be required to confirm this.

It is well known that in natural situations low flow conditions will inhibit upstream migration. Consequently, a reduction of flow in the Nanika and Morice Rivers during the migration period may result in blockage or delay of the run. While additional literature research should be undertaken to investigate flow requirements for migration, it is tentatively considered that discharges at least in the order of normal spawning discharges will be required in each river. This would represent approximately 1000 cfs from July 23 in the Nanika River and 3000 cfs from July 15 in the Morice River until spawning commences in each river.

5. Water Temperature Studies

(a) Description of Studies

Diversion of water from a river system will alter the natural water temperature regime downstream from the point of diversion. This is partly the result of decreased water velocities, which increases the travel time over the length of the river and hence the exposure time to the atmosphere. Furthermore, the heat gained from incoming solar radiation per unit area of water surface does not vary with changes in discharge. Therefore, under reduced discharge the heat received by the river is distributed to a lower volume of water and an increase in water temperature occurs. Similarly, when heat losses resulting from processes of evaporation, convection and back radiation exceed heat gains, the water temperature can be reduced by decreased discharges. The net effect of diversion is therefore to increase the maximum daily water temperature as well as the diurnal temperature range.

Given enough information on the physical and hydraulic features of a river and the prevailing meteorological conditions, water temperatures can be predicted with a reasonable degree of accuracy at any desired point in the river for any given discharge. A computer program was developed for this purpose by Mr. P. Saxvik of the International Pacific Salmon Fisheries Commission as part of the assessment of the Nechako River diversion. The program, as described in detail in Volume 2, was also applied to the Nanika and Morice Rivers. The program was specifically designed to perform an energy budget on one hour reaches of the river, starting at a given point with a given discharge and water temperature. The length of the one hour reach was determined by the average velocity within the reach. All factors contributing to heat transfer between the water and atmosphere were incorporated in the program. The net amount of heat gained or lost by the water was then converted to a temperature change over the length of the reach on the basis of the average volume of water in the reach. This determined the water temperature at the downstream end of the reach which was then used as the starting temperature for the next reach.

On the Nanika River a computer run would commence at Kidprice Lake with a given water temperature and discharge and would output the final water temperature at Morice Lake. Five physical reaches were selected over the length of the river to provide the physical and hydraulic information needed in the program. One representative cross-section was chosen from aerial photographs for each of the reaches and these were located in the field and surveyed over a range of discharges. The data obtained were used to compute the average velocity, depth and width of river for each reach over the desired range of discharges. These then represented the physical data over which weather conditions were subsequently superimposed. The computer printout is too large to be incorporated in this report, but is available at the Vancouver office of the Fisheries and Marine Service.

Since water temperatures in the Morice River are influenced to some extent by its tributary streams, the river was subdivided into three segments; Morice Lake to Gosnell Creek (Segment A), Gosnell Creek to Houston Tommy Creek (Segment B), and Houston Tommy Creek to the Bulkley River (Segment C). Gosnell and Houston Tommy Creeks are the largest of the tributary streams. Two smaller streams, Lamprey and Owen

Creeks, were assumed to enter with Gosnell and Houston Tommy Creeks, respectively. This assumption is not expected to have a marked influence on the results, since Lamprey and Owen Creeks are very small relative to the Morice River. As in the Nanika River study, physical reaches and their representative cross-sections were selected from aerial photographs for each river segment. Segment A was comprised of 4 reaches, Segment B of 10 reaches, and Segment C of 6 reaches.

(b) Verification of Computer Program

Trial runs were performed for each river to test the program. Weather and water temperature data were obtained over a two week period in September, 1975 for this purpose. A weather station was located at the Forest Service building near the north end of Morice Lake where continuous recorders were used to obtain solar radiation, air temperatures and relative humidity. Barometric pressure was obtained from the Ministry of Transport in Smithers. Water temperature recorders were installed and operated during this period at the following locations:

- Nanika River at the outlet of Kidprice Lake;
- Nanika River one half mile above Morice Lake;
- Morice River below Morice Lake;
- Morice River above Gosnell Creek;
- Gosnell Creek above Morice River;
- Morice River above Lamprey Creek;
- Lamprey Creek above Morice River;
- Morice River above Owen Creek;
- Owen Creek above Morice River;
- Morice River above Houston Tommy Creek;

- Houston Tommy Creek above Morice River; and
- Morice River above Bulkley River.

It was considered impractical to record the water temperatures of the Morice River below its tributaries since complete mixing would probably not occur for several miles beyond each of the confluences. Therefore, the initial water temperature for the lower two segments of the river was determined mathematically. For instance, if Gosnell Creek contained 200 cfs at a temperature of 50° F and Morice River above Gosnell contained 500 cfs at a temperature of 60° F, then the temperature of the Morice River below Gosnell would be computed as follows:

$$T_M = \frac{200 \times 50 + 500 \times 60}{200 + 500} = 57.1 \text{ F.}$$

i) Nanika River

The trial run on the Nanika River was performed for September 10 and 11, 1975, the warmest days which occurred during the two week study period. The discharge at the time was 715 cfs, resulting in a travel time of 7 hours between the two lakes. Individual runs were made at one hour increments between midnight (0 hour) on September 10, 1975 and 1 p.m. (1300 hour) on September 11, 1975. Using the recorded water temperature at the outlet of Kidprice Lake as the initial starting temperature for each of the hourly runs, a final water temperature was computed 7 hours later near Morice Lake.

The computed water temperatures are compared on Figure 24 with recorded water temperatures near Morice Lake. Although the computed curve is in the order of 2° F higher than the

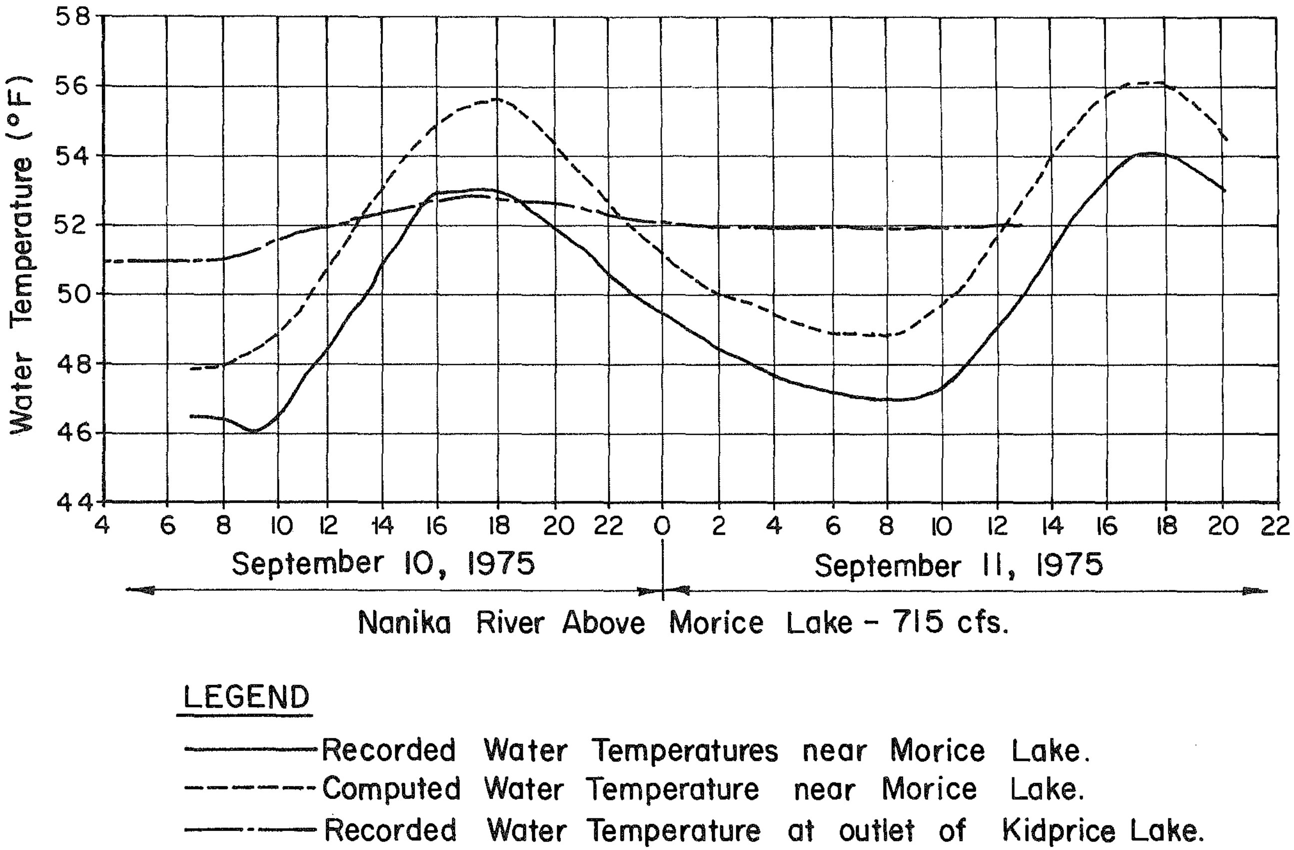


FIGURE 24. Nanika River - Recorded and Computed Water Temperatures above Morice Lake.

FIGURE 24.

recorded temperatures, the curves were found to be very parallel throughout the test period. The difference in the curves could perhaps be explained by the weather station being located at Morice Lake which is approximately 500 feet lower in elevation than Kidprice Lake. Air temperatures at this station are expected to be somewhat higher than those occurring at higher altitudes along the Nanika River. It is not considered that the discrepancy in the computed and recorded water temperatures will detract from the value of the program in providing comparative water temperatures for a range of discharges, since identical weather conditions were ultimately used for each discharge.

ii) Morice River

Water temperatures were computed for the lower end of each segment of the Morice River for September 10 and 11, 1975. Temperatures were also computed for September 8 and 9, 1975 over Segment B, since it is of somewhat greater length than the other segments. In Segment A, the actual temperature recorded in the river below Morice Lake was used as the initial water temperature for each hourly run. In Segments B and C, the initial temperatures were obtained by mathematically combining the temperatures recorded in the main river and the tributaries as discussed earlier.

The comparison between computed and recorded water temperatures is shown on Figures 25 and 26 for each of the segments. A similar comparison is also provided for the recording stations in the Morice River at Lamprey and Owen Creeks, both of which are located in Segment B.

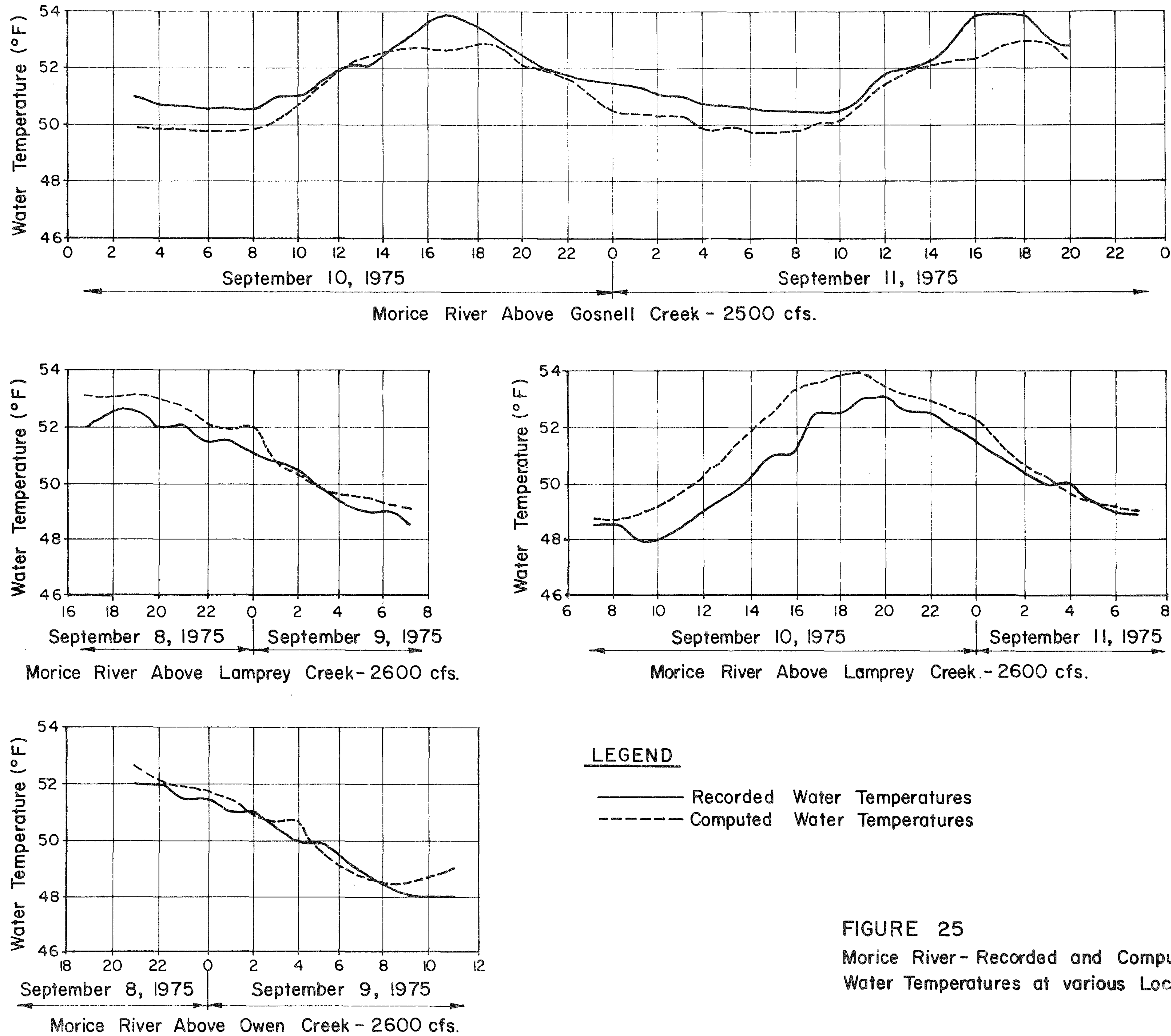


FIGURE 25

Morice River - Recorded and Computed Water Temperatures at various Locations.

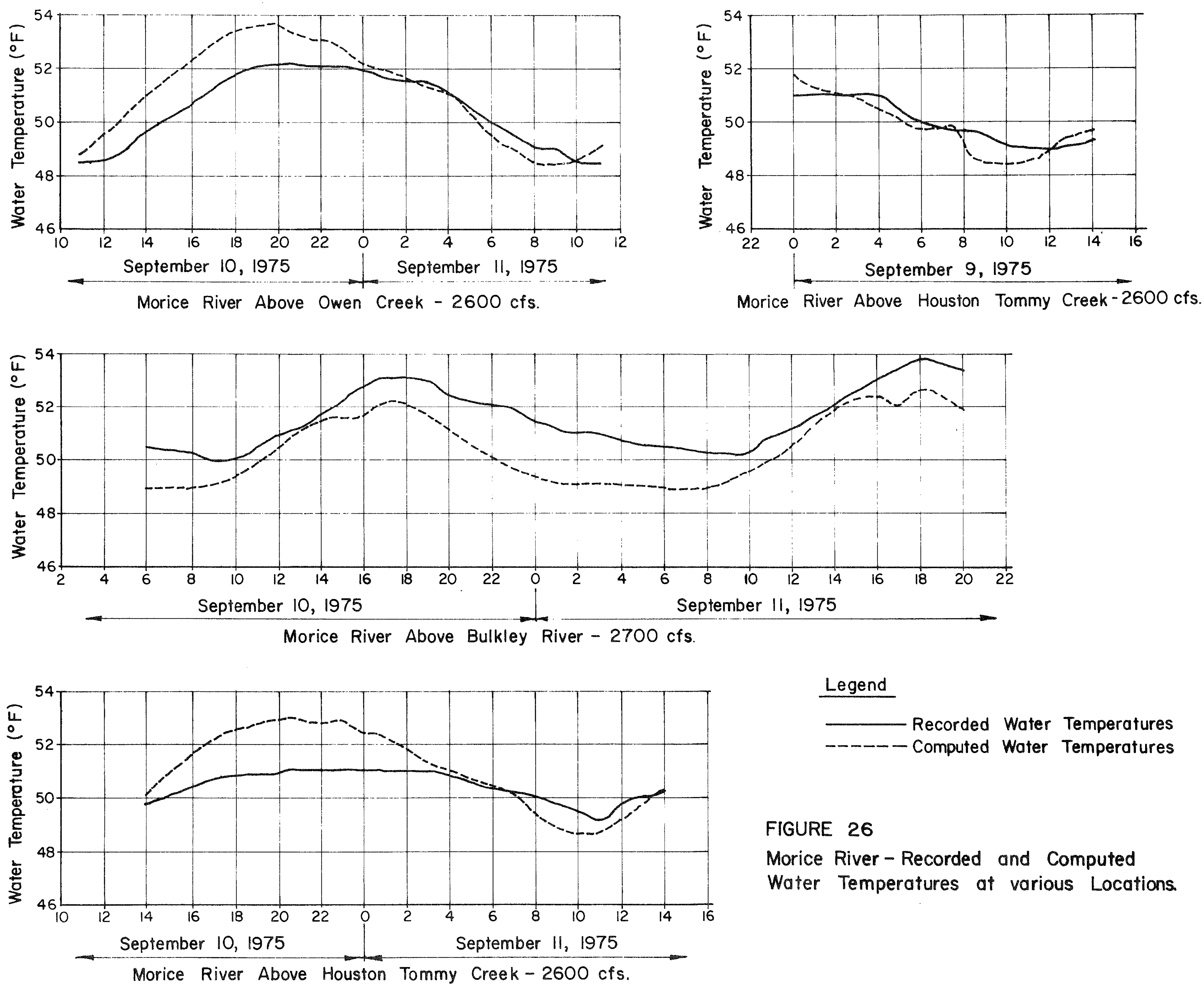


FIGURE 26

Morice River - Recorded and Computed Water Temperatures at various Locations.

The computed data were generally found to be very close to the recorded water temperatures and any discrepancy was never greater than 2° F. In Segments A and C, the computed temperatures were always lower than the recorded temperatures, but in Segment B the computed temperatures were generally higher. While the discrepancy might indicate the need for additional field data or modifications to the computer program, it is considered to be sufficiently accurate for a preliminary indication of the temperature changes resulting from reduced discharges.

(c) Effects of Flow Reduction on Water Temperature

To investigate the relationship between discharges and water temperature, computer runs were carried out on each river segment over a range of discharges and initial water temperatures. On the Nanika River, discharges of 184, 715 and 2040 cfs were simulated. On each segment of the Morice River the discharges ranged between 500 and 2000 cfs in 500 cfs increments. Individual runs were carried out for each discharge with initial water temperatures ranging from 40° F to 70° F in increments of 5° F.

The weather data used to predict maximum probable water temperatures in the Nechako River were also used for the Nanika and Morice Rivers. The data, which are described in detail in Volume 2, were selected on the following basis.

1. Hourly air temperatures were chosen to be representative of a series of hot days which have frequently occurred in August at Vanderhoof, although they do not represent the extremes on record.

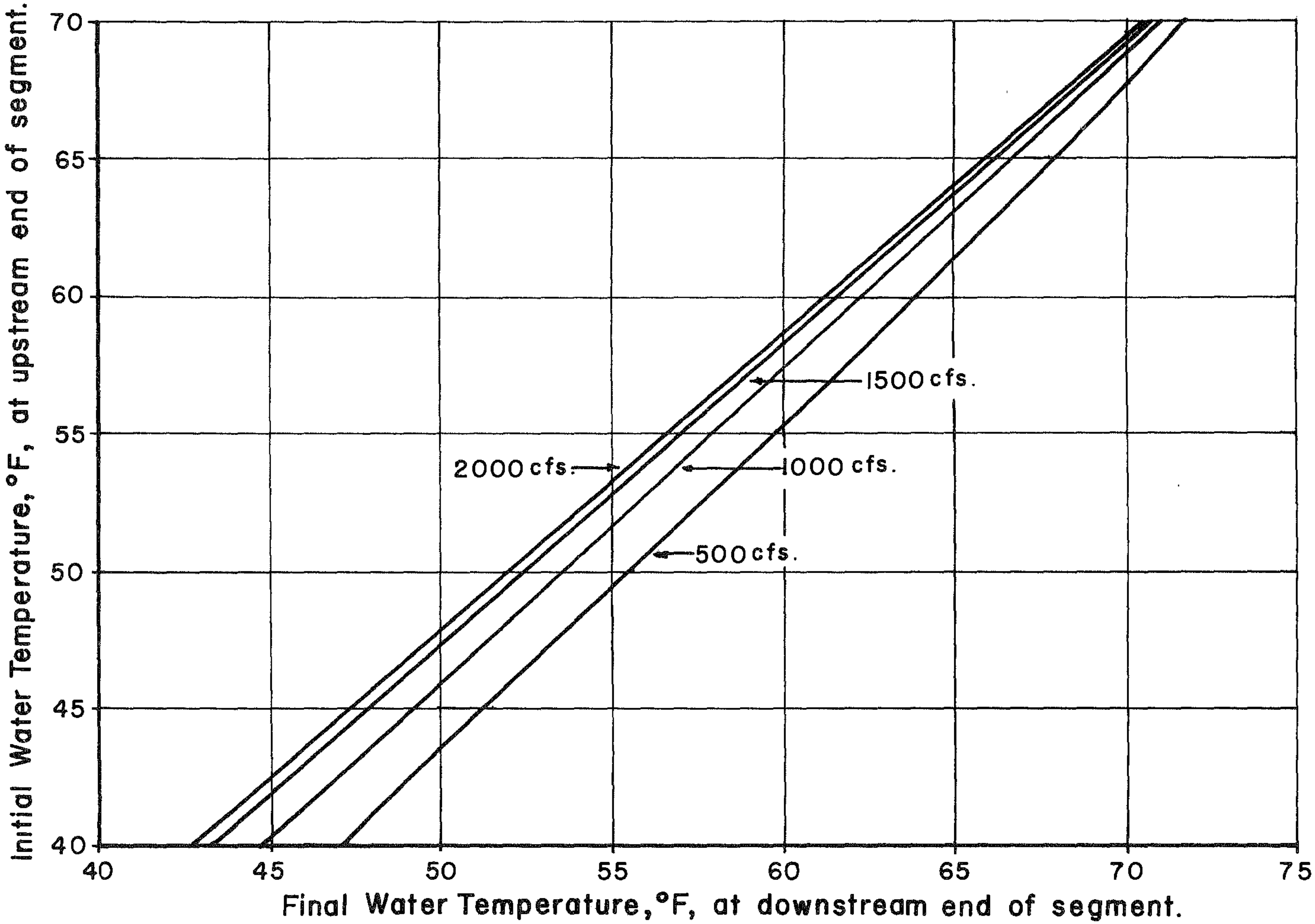


FIGURE 28. Morice River - Relationship between Initial and Final Water Temperatures - Morice Lake to Gosnell Creek (Segment A).

FIGURE 28.

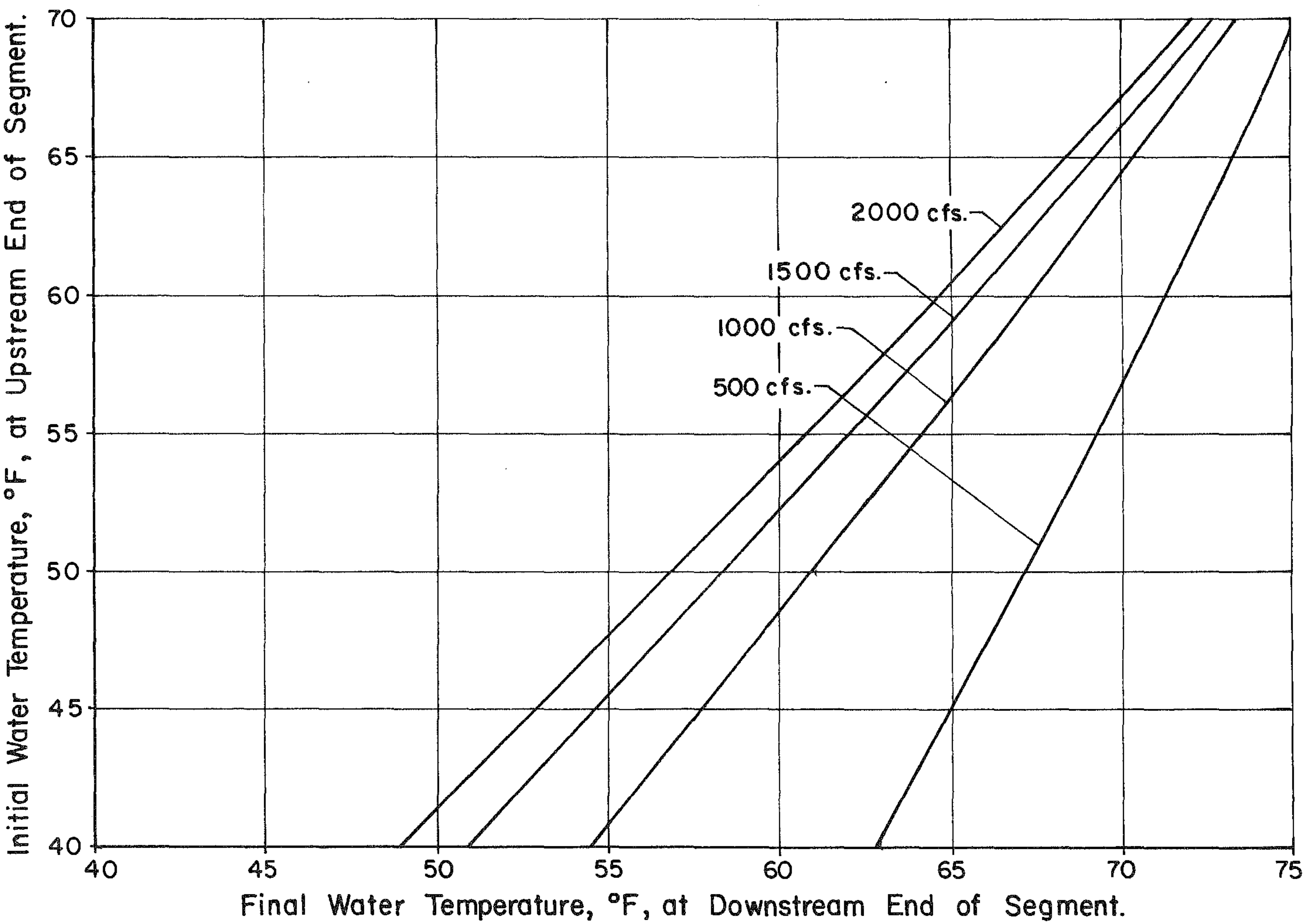


FIGURE 29. Morice River - Relationship between Initial and Final Water Temperatures Gosnell Creek to Houston Tommy Creek. (Segment B)

FIGURE 29.

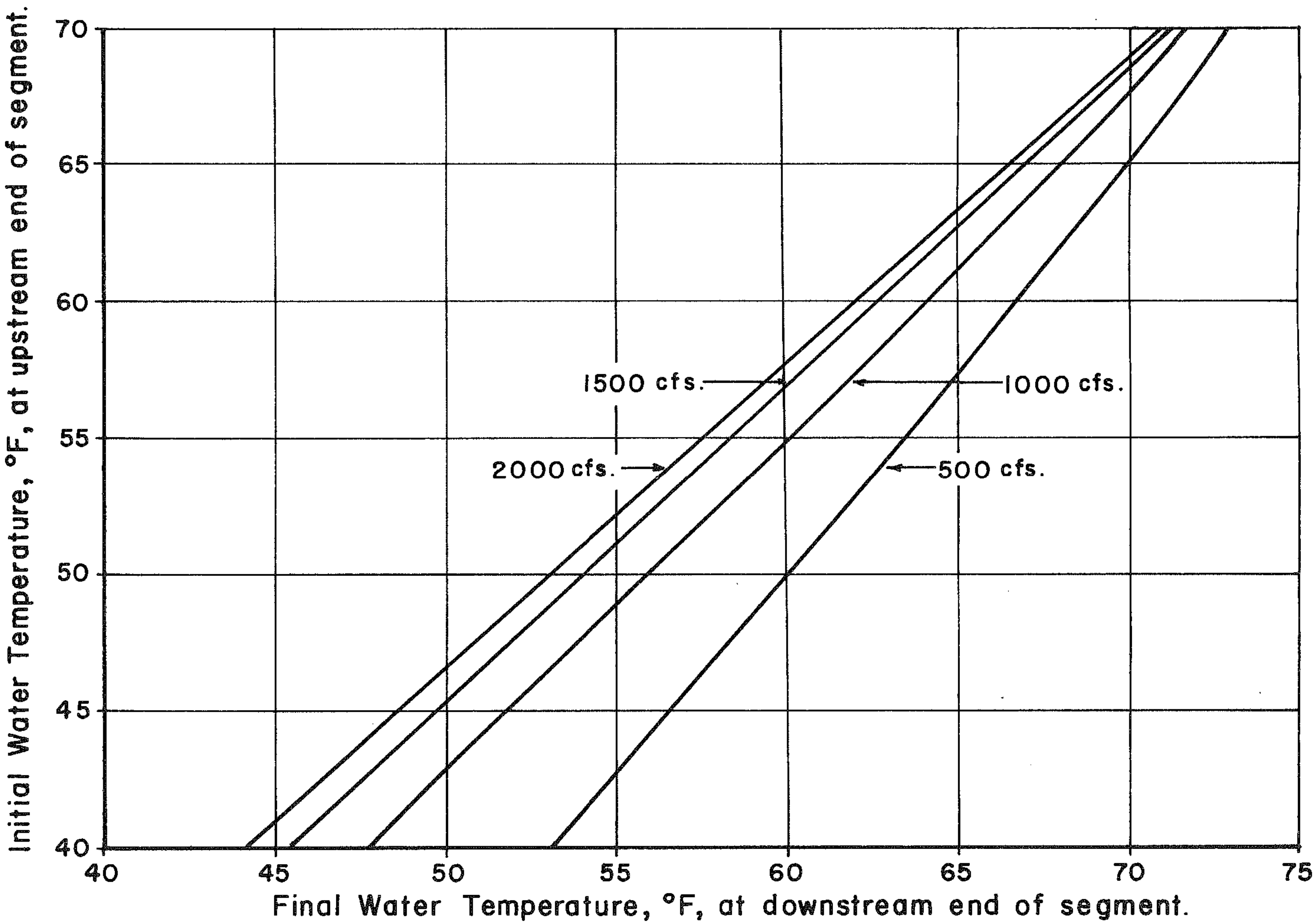


FIGURE 30. Morice River–Relationship between Initial and Final Water Temperatures–Houston Tommy Creek to Bulkley River (Segment C).

FIGURE 30.

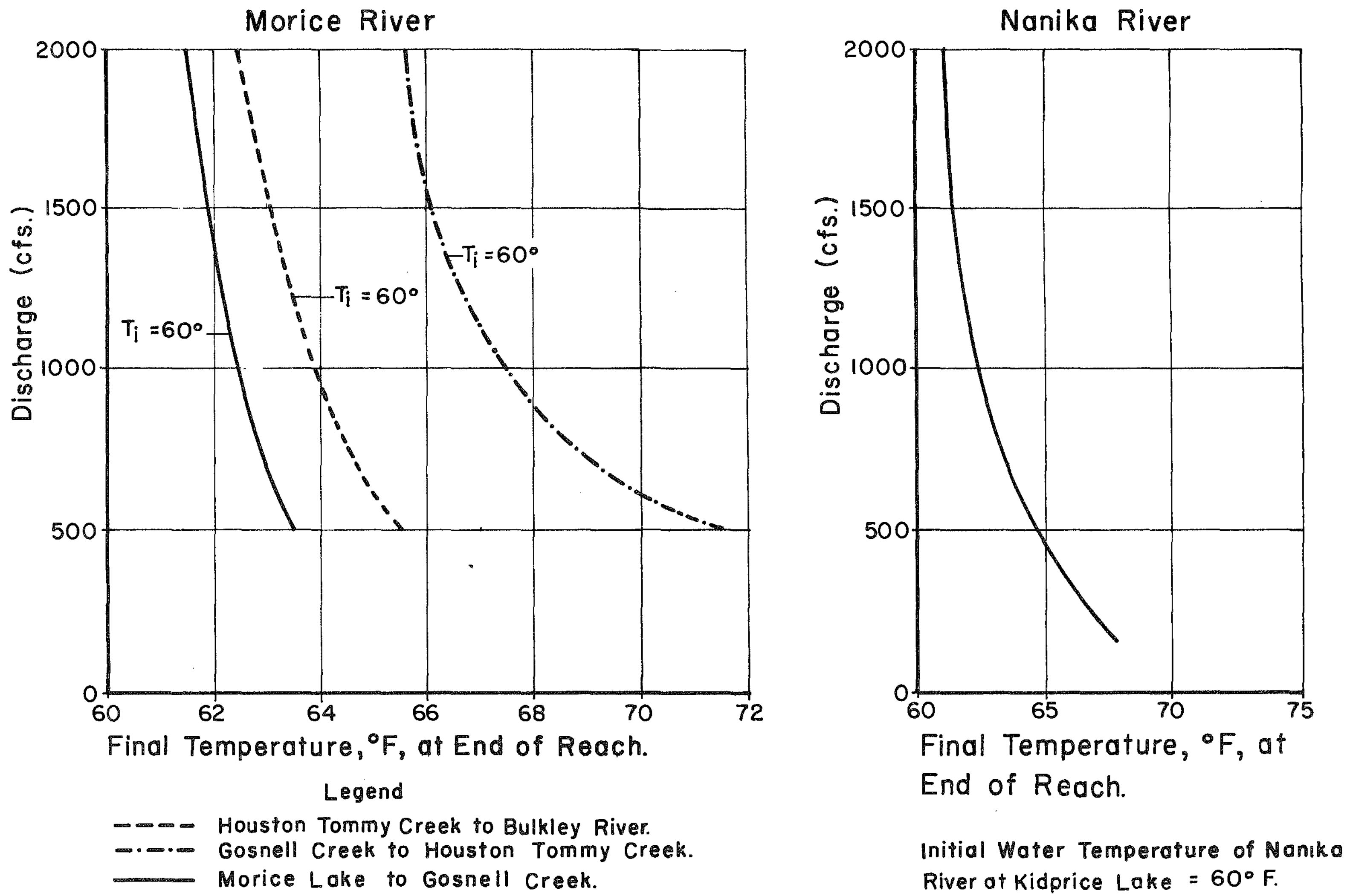


FIGURE 31. Relationship Between Discharge and Final Water Temperature for an Initial Water Temperature of 60°F for the Nanika and Morice Rivers.

FIGURE 31.

TABLE 10

MEAN DAILY WATER TEMPERATURE, °F
NANIKA RIVER BELOW KIDPRICE LAKE

AUGUST

DAY	1956*	1957*	1959*	1960*	1963*	1965*	1966*	1967	1974
1			54	54.5	53	50.5			51.5
2			54	54	53.5	52			52
3			54	55	54	52			52.5
4			53.5	55	54.5	52			52.5
5			52.5	55	55	52			51.5
6			52	54	55	51.5	49		51
7			52.5	55.5	55.5	52	49		51
8			52	56	55.5	51.5	49		52
9	58		53.5	57	56.5	51.5	50		53
10	58		54	57.5	56	52.5	49.5		54
11	57.5	52.5	53.5	58.5	56.5	53	48.5		53.5
12	56	51	53.5	57.5	57.5	54.5	47		53.5
13	59	50	53	56	55.5	54	46.5		53
14	58	51	53.5	54.5	56.5	51	47		53
15	59	51.5	53	54.5	57	51.5	47.5		53.5
16	58	52	53	54.5	57	49	48.5		54.5
17	57	52.5	52.5	54.5	56.5	51.5	47.5		54.5
18	57	51.5	53	54	57.5	53	47		54.5
19	57	52	53	53.5	56.5	52.5	47.5	57	53.5
20	58	52	53	53	57	53	48	56.5	52
21	57.5	52.5	53.5	53	55.5	54	48.5	56	52
22	57	53.5	53	52.5	55.5	55	48.5	56	53
23	58	53	53	52	57	55	49.5	55	
24	58	53	53.5	52.5	55.5	55	49.5	55	
25	58	53	53	53	55.5	54.5	50	55	
26	58	52.5	52.5	53	56	54.5	50.5	55	
27	57.5	51.5	52.5	52.5	56	53.5	51.5	55	
28	55.5	51.5	51.5	51.5	56.5	52.5	50	54.5	
29	55.5	52.5	51	51.5	56.5	50	49	54.5	
30	56.5	52.5	51	51	56.5	50	49	55	
31	56.5	53	50.5	50	56.5	49	48	55.5	

* ALUMINUM COMPANY OF CANADA

TABLE 11

MEAN DAILY WATER TEMPERATURE, °F
MORICE RIVER BELOW MORICE LAKE

AUGUST

DAY	1955*	1961	1962	1963	1964	1965	1974
1		61		50	48	57.5	53
2		62		51	48	58.5	53.5
3		62		51	48	58	54.5
4		63		51	48	58.5	54
5		63		52	48	58	54
6	48.5	61		52.5	48	58	53.5
7	51	62		53		57	53.5
8	51	62		63.5		58	54
9	52.5	62		54.5	49	59	54
10	51	61		55	49	59.5	54
11	51.5	62		54	50	59	53.5
12	52	62		55	49.5	59	53.5
13	51	63		54.5	49.5	58	53.5
14	51	62		54	49	58	54
15	51	63		55	49	57	55
16	51	63		55.5		57.5	56
17	51	63		56		58	56.5
18	51	63		56.5	50	58.5	57
19	51	63		56	49.5	59	57
20	51	62		55.5	50	59.5	57.5
21	51	61	51	55	50	60	57
22	52	61	51	55.5	50.5	60	55.5
23	52	61	51	55.5	51	60	55
24	51	62	51	54.5	50	59.5	55
25	52	61	51	54.5		59.5	54
26	51	60	51	55	49.5	59	54.5
27	51	60	51	55.5	49.5	58	55
28	52	60	51.5	55	49	57	56
29	52	60	51	55	49.5	56	56
30	54	59	51.5	55.5	49.5	54	56.5
31	53	58	51.5	55	50	53	57

* ALUMINUM COMPANY OF CANADA

TABLE 12

MEAN DAILY WATER TEMPERATURES, °F
GOSNELL AND HOUSTON TOMMY CREEKS

SEPTEMBER, 1975

DAY	GOSNELL CREEK	HOUSTON TOMMY CREEK
1	49	
2	49	
3	48.5	45
4	47.5	44.5
5	48	45.5
6	48.5	46.5
7	49	46.5
8	48	44
9	48	44.5
10	48.5	45
11	48.5	45
12	48.5	45

Miscellaneous Temperatures

August 17/75 @ 12:30 PM - 47.5° F at Gosnell Creek
August 20/75 @ 1:00 PM - 53.5° F at Houston Tommy Creek

From Table 10 it can be seen that the maximum mean daily temperature of the upper Nanika River is in the order of 60° F. Assuming no temperature change occurs as a result of impounding water in Kidprice Lake, the effect of diversion on water temperatures in the Nanika River above Morice Lake can be determined from the 60° F initial temperature curve on Figure 31. It can be seen that a reduction in discharge from 2040 cfs to 715 cfs would increase water temperatures in the lower Nanika River from 61° F to 62.5° F, while a further reduction in discharge to 184 cfs would increase the water temperature to 67.5° F.

The maximum mean daily temperature recorded in the upper Morice River was 63° F in August, 1961 (Table 11). While water temperatures were not recorded that year in the tributary streams, it is assumed that they would generally be cooler due to glacial runoff. Therefore, for purposes of analyzing temperature changes in the Morice River as a result of reduced discharges, the maximum mean daily water temperature of Gosnell and Houston Tommy Creeks were assumed to be 55° F and 60° F, respectively.

Discharges have never been recorded in the Morice River tributaries, except for a few miscellaneous measurements. Therefore, their probable minimum discharges have been determined from flow records for the Bulkley and Morice Rivers during the period 1962 to 1973. This was done by deducting the mean monthly flow of the upper Morice River from the mean monthly flow of the Bulkley River at Quick and assigning the balance to the various tributaries on the basis of their watershed areas. The minimum mean monthly discharge determined in this manner for Gosnell and Lamprey Creeks for the month of August was 140 cfs. Similarly, the August mean monthly discharge for Owen and Houston Tommy Creeks was 200 cfs.

Using the foregoing data the maximum mean daily water temperatures which can be expected to occur in the Morice River during August for discharges ranging between 500 cfs and 2000 cfs are as shown in Table 13.

TABLE 13

PROBABLE MAXIMUM MEAN DAILY WATER TEMPERATURES IN THE MORICE RIVER FOR VARIOUS MORICE LAKE OUTFLOWS

	500 cfs	1000 cfs	1500 cfs	2000 cfs
Morice River at Morice Lake	63° F	63° F	63° F	63° F
Morice River above Gosnell Cr.	66.2° F	65.1° F	64.5° F	64.2° F
Gosnell Creek above Morice River	55° F	55° F	55° F	55° F
Morice River below Gosnell Creek	63.8° F	63.9° F	63.7° F	63.6° F
Morice River above Houston Tommy Cr.	71.5° F	69.0° F	67.8° F	67.2° F
Houston Tommy Creek above Morice River	60° F	60° F	60° F	60° F
Morice River below Houston Tommy Cr.	68.8° F	67.7° F	67.0° F	66.6° F
Morice River above Bulkley River	71.3° F	69.6° F	68.5° F	68.0° F

(d) Water Temperature and Salmon

Computer analysis of Morice River water temperatures, with low discharges and weather condition which would promote maximum water temperatures, indicate that direct fish kills are unlikely. Brett (1952) found the one-week constant lethal temperature to be 77°F for juvenile chinook, and 75° F for juvenile coho. Mean daily temperatures in the Morice River would not approach these levels with the atmospheric conditions simulated in the computer program. However, sub-lethal increases in temperature can indirectly but significantly decrease salmon production in a variety of ways,[1.] for example:

i) Adults. Major and Mighell (1966) found adult sockeye to be blocked from entering the Okanagan River at temperatures above 70^{o} F. Such delays in migration can result in spawning losses even if temperatures return to tolerable levels. Thompson (1945) showed that most sockeye delayed longer than 12 days at the Hell's Gate rockslide did not reach their spawning grounds. However, if discharges from Morice Lake are maintained above 1000 cfs it is unlikely that such a thermal barrier would occur over the length of the Morice River. It is important to note that the analysis was not extended to the Bulkley River below its confluence with the Morice River.

Fish that have been exposed to high temperatures before reaching their spawning grounds often show reduced spawning success (Major and Mighell, 1966). This is due to energy losses incurred while holding below thermal blocks, higher metabolic rates, or higher incidence and more rapid progression of pathogens (Andrew and Geen, 1960).

ii) Juveniles. It has been commonly observed that increases in juvenile disease and parasites occur at higher temperatures. In natural systems, increases in temperatures have resulted in less desirable species, such as suckers, being

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1. A more complete discussion is contained in the report of the International Pacific Salmon Fisheries Commission, in Volume 2.

favoured over salmonids (Tarzwell, 1970). For coho salmon, Hartman (1966) has found aggression rates to increase with temperature, which may result in lowered rearing capacities (see Volume 5).

Coho, and to a lesser extent chinook, are likely to be most affected by temperature as they are year-round river residents during their juvenile stages. The complex and interactive nature of sub-lethal temperature effects does not allow quantitative prediction of fish losses at the present.

As previously indicated, the analysis of water temperatures in the Morice River was based exclusively on mean daily water temperatures. It is also important to consider the maximum hourly temperature which may occur in the river, as fish can be killed within a matter of hours when exposed to high water temperatures. In temperature tolerance studies on juvenile chinook and coho (Brett, 1952), it was found that 50 percent of the juveniles which had been acclimated to a water temperature of 68° F would die in as little as 1.5 hours when exposed to 82° F water. Similarly, they would die in 3 hours when exposed to 81° F, and 7 hours when exposed to 80° F. However, the computer data for the Morice River indicate that maximum hourly temperatures would not reach these levels with a discharge of 500 cfs or more from Morice Lake. Critical temperature levels may occur at lower discharges.

(e) Further Temperature Study Requirements

To fully assess the effects of diversion of water from the Nanika-Morice system on adult and juvenile salmon, water temperatures should be analyzed in the Bulkley River below its confluence with the Morice River. The study may not have to extend further downstream than the Telkwa River, since this river contributes a substantial proportion of the summer flows in the Bulkley River.

Studies have not been conducted to date on dissolved gases in the Morice and Bulkley Rivers. Nitrogen and oxygen supersaturation is a common occurrence in natural waterways and excessive levels could perhaps occur with spillway operation and increased water temperatures. Additional studies should therefore be undertaken to determine the natural levels of dissolved gases in the Morice and Bulkley Rivers and the possible changes that may result from increased water temperatures. The effects of the Nanika River dam on dissolved gases should also be investigated.

6. Potential Effects of Diversion on the Bulkley River

As mentioned earlier in this report, reduction of flow from the outlet of Morice Lake would entail a corresponding reduction throughout the Bulkley River. This presents various potential fishery problems which warrant further discussion. Of major concern is the possible adverse effects on the upstream migration of fish through Moricetown Falls as well as the potential problems which may be presented by increased concentrations of domestic and industrial effluent at Smithers.

6.1 Diversion of Nanika River

The reduction in discharges throughout the Bulkley River as a result of diversion of water from the Morice River can be determined simply by deducting the quantity of the diversion. However, the effect on discharges in the Morice and Bulkley Rivers as a result of diversion of the Nanika River alone is complicated by the storage potential of Morice Lake. The system was therefore analyzed by computer to illustrate the effect of diversion of the Nanika River on daily discharges at recording stations on the Morice River below Morice Lake and Bulkley River at Quick. The analysis was carried out for the period of July 1, 1972 to September 30, 1974. The results are shown on Figure 32 together with natural flows which occurred during the period. It was assumed, for illustrative purposes only, that annual residual flows in the Nanika River would be in accordance with the preliminary minimum flow requirements recommended in the Fisheries and Marine Service report of November, 1971, as follows:

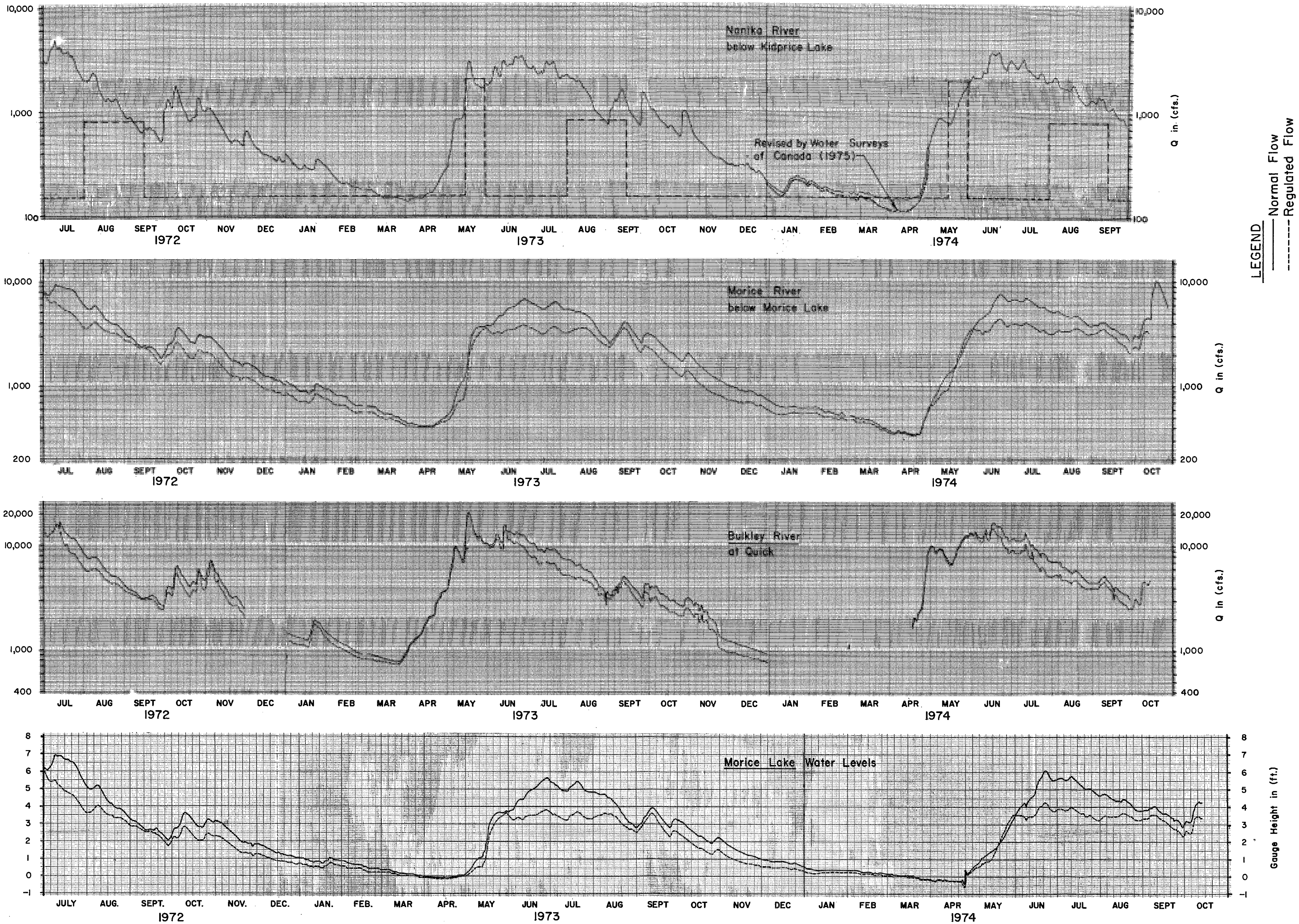

FIGURE 32. Hydrographs of natural and regulated discharges for Nanika, Morice, and Bulkley Rivers and water levels on Morice Lake, 1972 — 1974.

May 15 to May 30	-	2000 cfs
August 1 to Sept. 15	-	800 cfs
Remainder of year	-	150 cfs

The change in the water level regime of Morice Lake as a result of diversion of the Nanika River is also shown on Figure 32.

6.2 Moricetown Falls

Moricetown Falls has historically been a point of difficult passage for fish migrating up the Bulkley River. Studies conducted by the Fisheries and Marine Service prior to 1950 concluded that the migration of salmon and steelhead was being seriously delayed and in some cases blocked at certain water levels (Clay, 1949; Milne, 1950). The differential head across the falls increases with decreasing discharge and with less than 5,000 cfs at Moricetown, the falls were virtually impassable.

In 1951, vertical slot fishways were installed on each side of the falls to alleviate this problem. Each fishway is approximately 150 feet in length with 6' × 10' × 6' deep pools designed to pass 5 fish per minute at a river discharge of 5000 cfs. The fishways can function over a discharge range of 2000 to 10,000 cfs. However, in the lower part of this range it is unlikely that the fishways could handle the required numbers of fish during the peak of the migration since the depth and volume of water in the pools are considerably reduced.

The numbers of fish utilizing the fishways have been assessed on several occasions by the Fisheries and Marine Service similar over this length of river, it is assumed that the discharge at Moricetown can be interpolated between these two gauging stations on the basis of drainage area. The drainage area between Smithers and Hazelton is 1,290 square miles while the drainage area between Smithers and Moricetown Falls is 408 square miles. The mean monthly discharge at Quick can then be represented as follows:

$$Q_M = 0.12\, Q_Q^{1.15} + 0.85\, Q_Q + 182, \text{ where}$$

Q_M = mean monthly discharge at Moricetown

Each of the above discharge relationships are presented graphically on Figure 33.

The approximate timing of the salmon and steelhead trout migration through Moricetown Falls (Palmer, 1964) is shown in Table 14.

TABLE 14

APPROXIMATE TIMING OF SALMON AND STEELHEAD MIGRATION THROUGH MORICETOWN FALLS

SPECIES	MAIN MIGRATION PERIOD	PEAK OF RUN
Sockeye	July 1 - Aug. 31	Aug. 1
Chinook	June 1 - Sept. 30	Aug. 1
Coho	July 25 - Sept. 30	Aug. 15
Pink	July 25 - Sept. 10	Aug. 15
Chum	Aug. 15 - Sept. 15	Sept. 1
Steelhead	July 25 - Sept. 30	Aug. 15

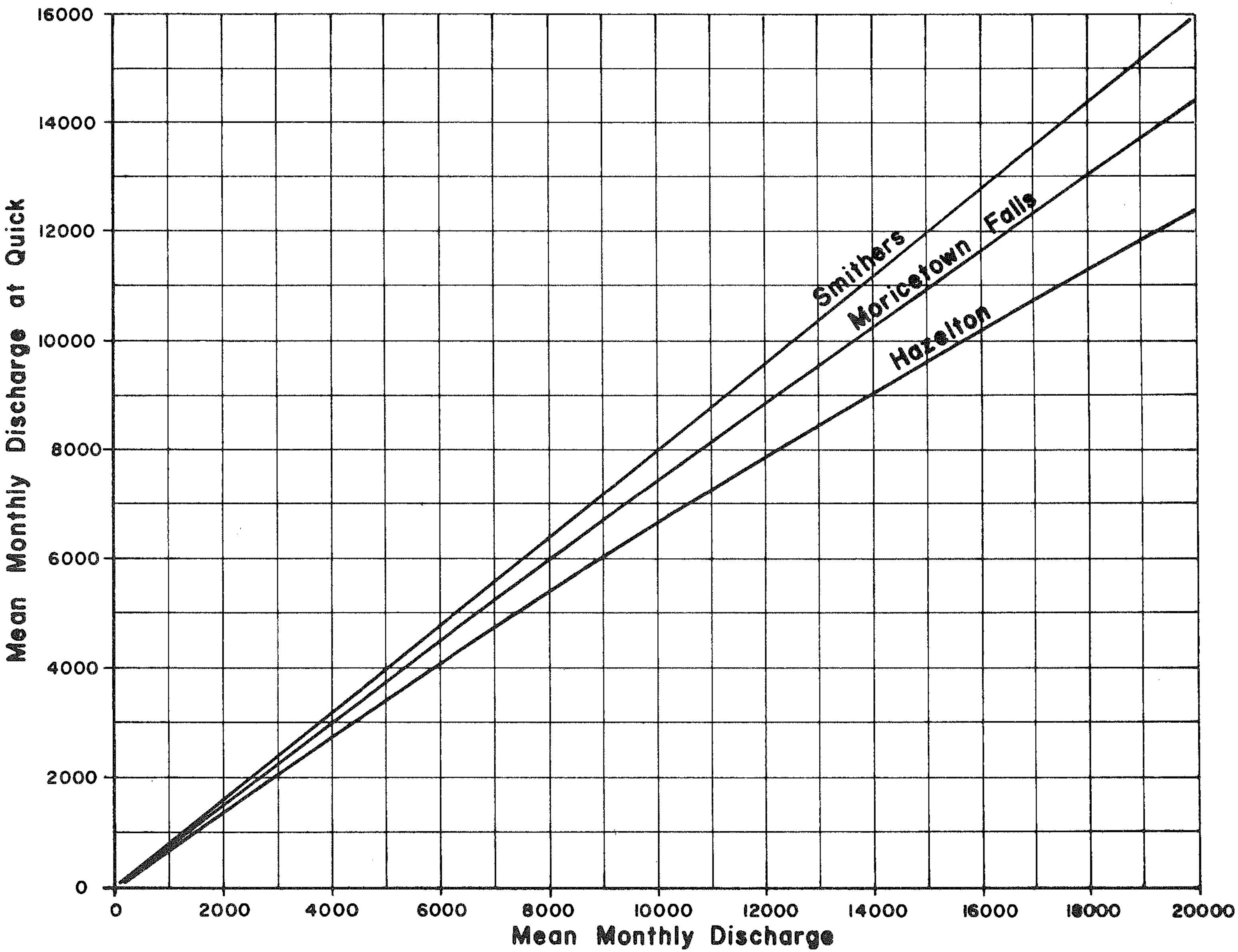

FIGURE 33. Estimated relationship between mean monthly discharges of the Bulkley River at Quick and various downstream locations.

FIGURE 33.

It can be seen that the upstream migration commences by June 1 and is essentially completed by September 30. Monthly discharge frequency curves for this period are shown on Figure 34. These curves are based on recorded mean monthly discharges at Quick between 1931 and 1974. The frequency curves for Moricetown Falls were derived from Figure 33.

Using these frequency curves in conjunction with the mean monthly discharges shown on Figure 2, it is possible to estimate the effect of diversion of water from Morice River on the operation of the Moricetown Falls fishway. For example, Figure 34 shows that the mean August flow at Moricetown has been less than 6000 cfs on a frequency of 20 percent over the past 43 years. From Figure 2, the mean flow from Morice Lake during August is 4500 cfs. If 2500 cfs were diverted from Morice River, it would therefore be expected that discharges at Moricetown Falls would be less than 3500 cfs during August on a frequency of 20 percent or 1 out of 5 years. Since this would coincide in timing with the peak of the salmon and steelhead runs, it is probable that the diversion would cause a much longer delay or total blockage of a large segment of the escapement. In this case, major modifications of the fishways would be required.

6.3 Domestic and Industrial Effluent Disposal at Smithers

An inventory of sources and quantities of effluent currently being discharged into the Bulkley River at Smithers has not been conducted as part of this study. It is possible that increased concentrations of effluent associated with reduced discharges could be detrimental to migratory and domestic fish stocks. Therefore, it is recommended that this be

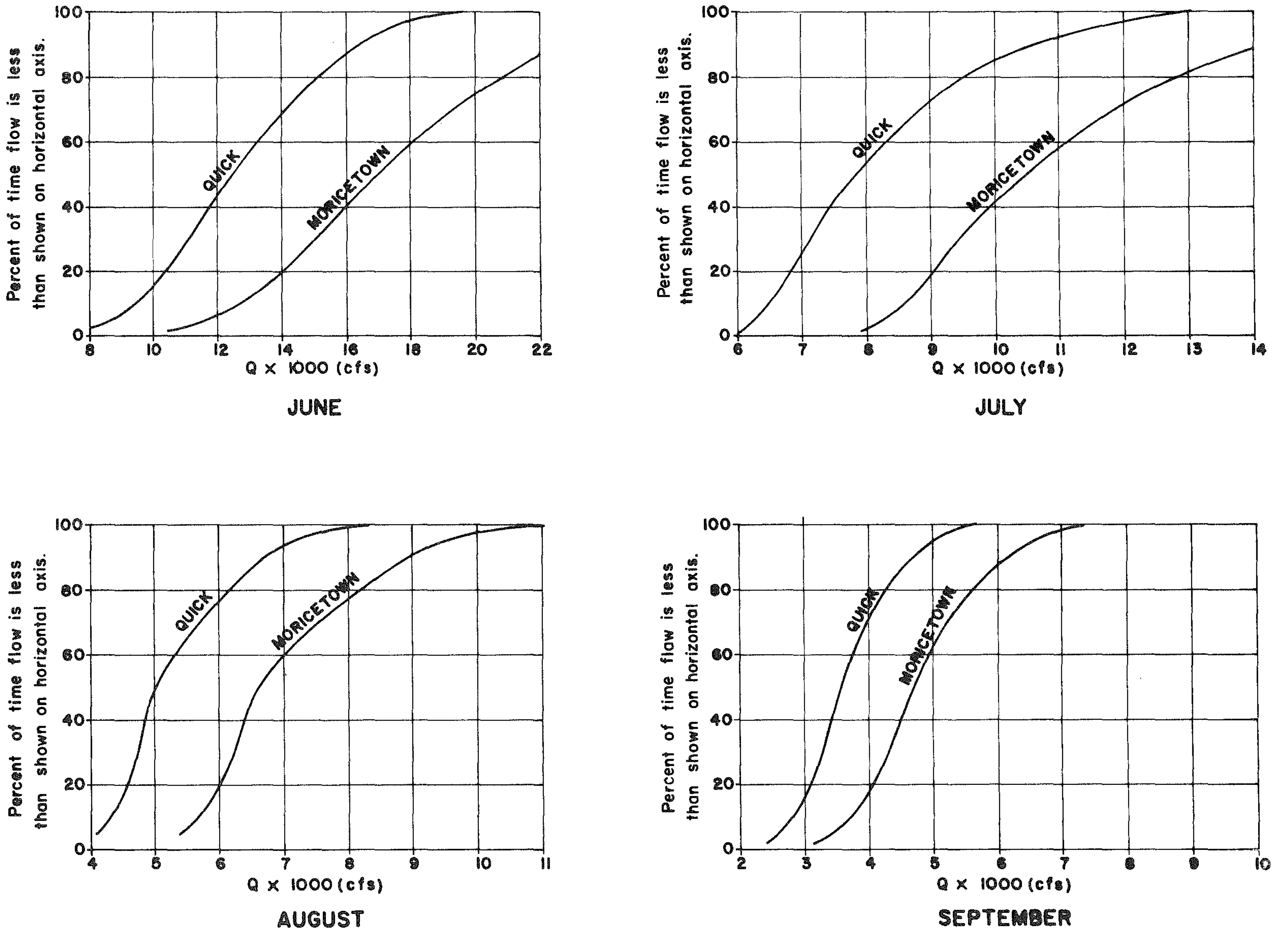

FIGURE 34. Mean monthly discharge frequency curves for the Bulkley River at Quick and Moricetown, 1931 to 1973.

FIGURE 34.

assessed by either the Provincial Pollution Control Board or the Environmental Protection Service of D. O. E. Due consideration should be given to the projected population and industrial growth rates in the area.

7. Conclusions and Recommendations

1. Nanika, Kidprice and Morice Lakes provide most of the lake storage in the Bulkley River system. As a result of the storage capacity of these lakes and the higher levels of precipitation in the surrounding areas, the discharge from Morice Lake can represent as much as 80 to 90 percent of the discharge in the Bulkley River at Quick during a large part of the year.

2. Most of the sockeye spawning in the Nanika River occurs in the upper two miles of river below Nanika Falls at the outlet of Kidprice Lake. Approximately 32,000 square yards of gravel occur in this area, representing a total potential spawning population of 32,000 sockeye salmon. The discharge required to allow this number to successfully migrate and spawn is estimated to be 1000 cfs during the period July 23 to October 31 (for timing of runs see Volume 5). The potential spawning populations corresponding to lower discharges would be 30,300 at 800 cfs; 10,800 at 600 cfs; 1,600 at 400 cfs; 400 at 200 cfs; and 0 at 150 cfs.

3. Hydrographical studies conducted on a portion of the major chinook spawning area a short distance below Morice Lake have indicated that all suitable spawning gravel would be available for spawning at a discharge of 2800 cfs. Assuming that the study area is representative of other chinook spawning areas in the river and that all suitable spawning gravel would be fully utilized by the maximum recorded escapement of 12,000 adults, the potential chinook spawning population relative to discharge would be 12,000 at 2800 cfs;

10,400 at 2,300 cfs; 8,200 at 2000 cfs; 5,200 at 1,500 cfs; 3,300 at 1,000 cfs; and 2,300 at 460 cfs. Migration and spawning would extend over the period July 15 to October 31.

4. For purposes of egg incubation a flow of 250 cfs should be provided in the Nanika River after spawning has been completed. This should be maintained until such time that flows would naturally drop below this level. Beyond this time on the following stage of the hydrograph, the minimum flow could be regulated so as to closely simulate the natural flow regime to a minimum of 100 cfs.

5. It is considered that an incubation flow of 1000 cfs would be required in the upper Morice River from the end of the spawning period to December 31. The flow could be reduced to 500 cfs between January 1 and April 30, except at such times when natural flows would drop below this level.

6. Physical barriers to upstream salmon migration should not occur in the Nanika and Morice Rivers with flows reduced to 155 cfs and 1,460 cfs, respectively. However, it is tentatively considered that flows will have to be at least in the range of the normal spawning discharge to encourage migration. This would represent about 1000 cfs in the Nanika River from July 23 and 3000 cfs in the Morice River from July 15 until spawning commences in each river.

7. With discharges in excess of 184 cfs in the Nanika River and 1000 cfs in the upper Morice River, water temperatures should not reach critical levels for

juvenile and adult salmon during hot summer periods (July 15 to September 15). Lower discharges in either of these rivers could result in lethal temperature conditions. Additional studies should be carried out to investigate the effects of reduced flow on water temperatures in the Bulkley River.

8. Flushing flows may be required every few years in the Nanika and Morice Rivers for cleaning spawning gravel. The discharge requirements for flushing could not be determined as part of this study and it is therefore recommended that this be further investigated.

9. Fishways installed at Moricetown Falls on the Bulkley River in 1951 by the Fisheries and Marine Service were designed to operate over a discharge range of 2000 to 10,000 cfs. However, in the lower part of this range the fishways may not provide enough capacity to handle the required numbers of upstream migrants during the peak of the run. Fishway modifications may therefore be necessary if water is diverted from the Nanika and Morice Rivers.

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