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APPLICATION OF FLOW MODEL FOR PREDICTING FLOWRATES IN AN ICE COVERED STREAM

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ABSTRACT

The application of a model for predicting flowrates in streams under ice cover is explored. The model can be applied to that period of solid ice cover, after freeze-up, until the initiation of breakup, or until open water sections appear.

Accuracy of the calculated flowrate is shown to be directly related to the number of discharge measurements used. The flowrate accuracies are given for a practical number of measurements for the period under ice.

The accumulation of degree days from the start of freezing appears to be an adequate forecast tool for timing the winter measurements.

Use of the model can be summed up as not only providing a consistant and less inaccurate method of flow computation but one that will save many man hours of work. It will also provide guidance for timing of measurement during the ice period.

1. INTRODUCTION

The need for a computerized method of calculating flowrate under ice prompted testing of a model outlined in a paper entitled "Predicting Flowrates In An Ice Covered Stream" by H.S. Santeford and G.R. Alger (1984).

The purpose of this report is to illustrate a procedure of flowrate derivation for a stream under ice. Numerous measurements are needed to calculate the parameters and to determine how they change throughout the ice period. A series of discharge measurements were taken on the Takhini River in a previous experiment. This provided a large quantity of data for the present study.

1.1 Takhini River Basin

The stream gauging station, Takhini River at Whitehorse (09AC001), is located in the lower reach approximately 35 miles downstream from the outlet of Kusawa Lake at the Alaska Highway Bridge. The location of the basin is shown in Figure 1.

1.2 Basic Data

Data are taken from measured discharges on the Takhini River during the winter periods 1964/65, 1965/66 and 1966/67.

80 measurements were taken during the ice period November 1, 1964 to May 17, 1965 (See Table 1).

In the ice period from November 5, 1965 to May 5, 1966, 32 measurements were taken (Table 2).

106 measurements were taken during the ice period November 13, 1966 to May 13, 1967. For all three years the measurements were taken approximately 1500 feet downstream from the gauge. See Table 3 for measurement listing.

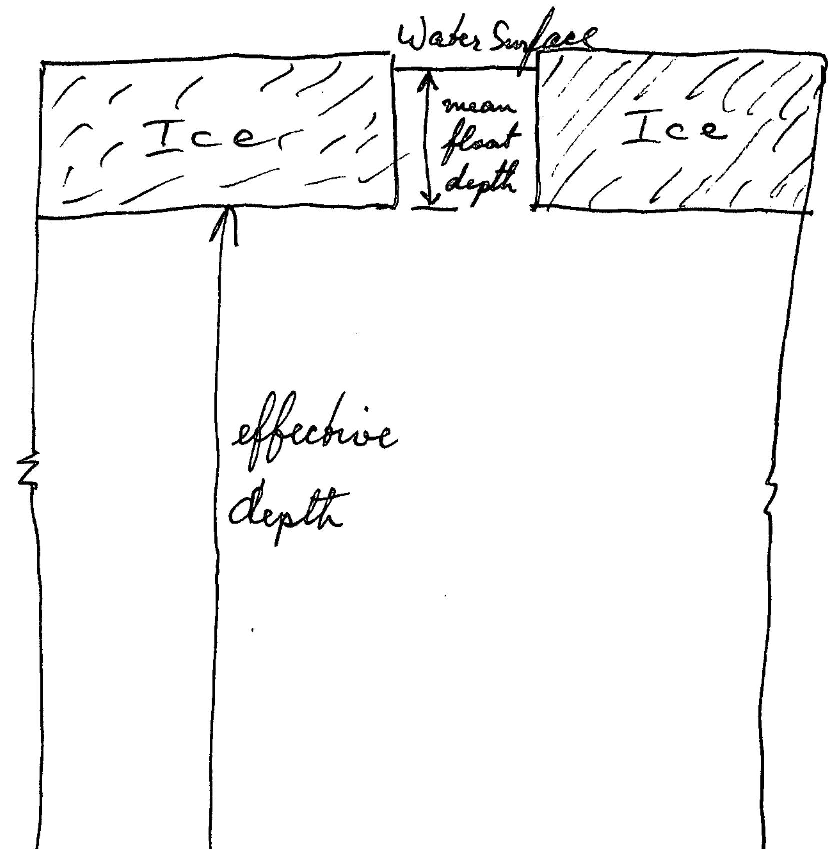
Open water measurements were made from the bridge just downstream from the gauge. Cross-sections for the open water section and the ice covered section are shown in Figure 2.

A nitrogen bubbler-type recorder was installed near the bridge in October of 1964 and continuous stage records have been collected for the three winter periods.

Since all basic data used in this study were in English units, it was deemed practical to carry out the analysis with the same units.

2. MODEL PARAMETERS

The model uses channel relationships developed between open water and ice covered conditions. Cross-sectional area, hydraulic radius, slope and coefficient of friction as in Mannings equation; are taken into account in the development of the model. The theory is



Water Surface
Ice
mean float depth
Ice
effective depth
Streambed

discussed in Appendix 1. Functional relationships are developed for the following:

a) mean hydraulic depth with stage for open water

b) mean hydraulic depth with stage for ice covered conditions

c) open water rating curve developed for the latest open water period

d) width of open water cross section with stage (not required for actual computations but used to determine how other parameters changed throughout the winter period). The relationships are shown in figure 3.

Other parameters required are the mean float depth (water surface to bottom of ice), and "hydraulic depth ratio". All of the above relationships and parameters can be calculated from field data, provided that all open water measurements are made at the open water section, and all under ice measurements are made at the winter section. It is not necessary that both sections be at the same location, but they should be in close proximity to each other and should have similar cross sections. This condition is discussed in Appendix 2.

3. ANALYSIS OF DATA

Development of functional relationships, for the mean hydraulic depth verses stage for both the open water section and the ice covered section, were carried out by using a selection of measurements.

These measurements provided data that represent the range of flow encountered for each of the winter periods under study. Only one stage vs cross-section width relationship covering the three year span was developed for the open water section. The change in section was not considered great enough to affect the accuracy of the calculated flowrate. An open water rating curve, dated 7 October, 1964, was used for the winter period of 1964/65 and 1965/66. The rating curve used for the winter period 1966/67 was dated January 3, 1968.

Sufficient measurements were analyzed to indicate how the right side of the equation:

$$f(GH_0)/f(GH_1) = (0.759)\ (X_1/X_0)^{0.6}\ \ (B_1/B_0)^{0.6}$$

evolved with time as the winter progressed. For explanation of this equation; refer to Appendix 1. From freeze-up until the end of December, the right side of the above equation changed gradually to a constant value, and remained constant until near the end of March, then changed gradually to breakup. It can also be seen from inspection of Table 4 that the float depth increases gradually from freeze-up, and reaches a maximum in March or April and then decreases slowly to breakup.

The daily flowrate is calculated using the stage-hydraulic depth relationships plus the float depth and the ratio $f(GH_0)/f(GH_1)$ called the section coefficient or hydraulic depth ratio. The float depth and section coefficient are interpolated between three selected measurements appropriately spaced throughout the winter ice period. The section coefficient is equivalent to the right hand side of the above equation.

The selection of the measurements was based on: practical considerations and obtaining the least discrepancy between measured and calculated flowrate. The measurement just after freeze-up gives the starting point; the second and the third measurements are chosen to catch the beginning and end of the period where the section coefficient is constant. Following this sequence, the parameters can be interpolated between measurements, thus obtaining good accuracy for the least number of measurements.

An example of the computations is shown in Appendix 1.

4. DISCUSSION OF RESULTS

The flowrate comparison shown in tables 5 to 7 are representative sample taken throughout the period of measurement for each year. There is a predominance of under estimation, but this could be reversed by using different measurements for calibration. The reason for the deviation is that the extrapolation of either the float depth or the section coefficient does not represent that particular period. To reduce the error, more measurement values could be used, but this procedure would be impractical, as the taking of measurements cannot be timed precisely. It has been shown earlier that the section coefficient changes in value gradually from freeze-up to a period where it becomes constant. Defining the beginning of this period would require a considerable number of measurements. Likewise defining the length of period that the section coefficient remains constant would also require many measurements.

The size of deviations are quite reasonable in light of the accuracy of some measurements, and in comparison with other methods of estimating flowrates.

The flowrate, as calculated by the model, and the actual measurements, are illustrated in figures 4 to 6 along with the mean temperature recorded at the Whitehorse Airport.

5. APPLICATION OF MODEL

In this part of the study, model parameters, as developed from three measurements, are tested for their ability to predict flowrate under ice conditions. Ice measurements are selected to achieve two objectives:

1) to provide adequate accuracy in calculating discharge data
2) to keep field costs, of obtaining data, to a minimum.

The use of three data points has its limitations for developing relationships. Generally there is not enough spread in the measurements to cover the entire range of stage. Developing the relation between stage and mean hydraulic depth for the winter period 1966/67 required an additional point to give direction to the lower portion of the curve. This has little effect on the accuracy (see figure 7) of the equation, as the point is placed so as to pass the line evenly between the two lower data points.

The timing of the measurements is selected with knowledge gained from the first part of the analysis in order to reflect the changes in the section coefficient. Flowrate comparisons are shown in tables 8, 9 and 10.

The flowrate deviations increased slightly during the 1964/65 winter period and changed from a predominance of under estimation to one of over estimation. In the 1965/66 winter period the deviations significantly increased and the predominance changed from under estimation to over estimation. There is a wide variation in the relationship of stage to mean hydraulic depth in the lower range of stage for this particular year. The use of three measurements to define this relationship was not too successful as the line of relation passed on the lower side of the data points. This wide spread in mean hydraulic depth may have either been due to the measurements being made at different sections; or there was an increase of frazil or slush ice. There was virtually no change in deviation values for the 1966/67 winter period.

For a practical application of the model, winter flowrate have been computed for the winter period of 1969/70 for the Takhini River near Whitehorse. Four ice measurements were taken throughout the winter period of November 12, 1969 to May 3, 1970 and all necessary relationships were developed from these measurements (See Figure 8.) The discharge, as calculated from the model, is compared to that estimated by normal methods, and is shown in Table 11 and illustrated in Figure 9. The greatest deviations occur during the early part of the ice period when the greatest recession is taking place.

There is very little to guide the estimation of flowrate using the present methods which consist of interpolating daily flow values between measurements based on temperature fluxuations. Once base flow has been attained, however the estimated data is very reasonable because there is very little daily variation.

This study is considered site specific because of the large amount of data required to adequately test the flowrate model. More experience and knowledge could have been gained had it been possible to test the model on other rivers. At present there is insufficient data available in the B.C. - Yukon Region. The trend in operation leans more to obtaining 2 ice measurements and taking the recorder out of operation during the winter period. This is not satisfactory for development of this flow model.

6. MEASUREMENT FORECAST

The correct timing of measurements is ~~quite~~ essential to the development of an optimum model in order to obtain the least inaccurate data. Degree-day temperature accumulations were used in an effort to forecast the timing of measurements that would fit in with the sequence of physical changes in ice conditions taking place at the rating section throughout the winter period.

The change in the thickness of an ice cover is governed by a heat exchange process at the top and bottom surfaces. The heat exchange between the ice surface and the ambient atmosphere is the dominating factor. The degree-day method has long been used in establishing ice thickness estimates. The ice thickness is related to the cumulative freezing degree-day of the air temperature S by $\theta = \alpha s \; S^{1/2}$. The constant αs has to be determined for each location based on historical data.

The true ice thickness is not available for this study; however, for demonstration purposes the float depth will be substituted. In most cases the float depth is synonymous with the ice thickness but is not noted as such on the measurement forms. Degree-day used in this study is the mean daily temperature accumulated below a base of 32° F.

Inspection of table 12, developed from temperature data at Whitehorse Airport 1964/67, indicates that:

degree-days in this study are the sum of the difference in mean daily temperatures below ~~from~~ 32° Fahrenheit.

~~and below~~

	Mean Temp.	diff.	Degree Day
e.g Day 1	28°F	32-28 = 4°	4
Day 2	20°F	12	16
Day 3	33°F	n/a	16

see bottom of previous page!

1) the ice thickness constant is different for every year but has a constant value within each ice period

2) float depth or ice thickness is not consistant each year with accumulated degree-days below the base of 32° F

3) the timing of measurements under ice could be based on accumulated degree-days, as they appear to correspond to calendar dates with acceptable limits for all three years.

The measurement sequence would be as follows:

a) first measurement made soon after freeze-up

b) second measurement could be made after the accumulation of 2,000 degree-days ± 10%

c) third measurement could be made after the accumulation of 4,000 degree-day ± 10%.

It must be noted that more testing of this method will be required to establish the proper measurement procedure.

7. OTHER CONSIDERATIONS

Individual measurements can have as much as a 10% error. Temporary storage or blockage may be caused either by a sudden spell of extremely cold weather, or by shifting frazil, or slush ice as illustrated on the recorder chart in Figure 10. This temporary storage can occur for short periods of time and may at times be reflected in the measurements but not in the average stage for the day. Since the duration of measurements is approximately one and a half hours, they can be considered as instantaneous.

Ice thickness and float depths can be affected by frazil and slush ice which is not always noted on the measurement form.

It is believed that some irregularities and deviations of the estimated to measured flowrate are the result of the above mentioned causes.

8. CONCLUSIONS AND RECOMMENDATIONS

1) The model can be used successfully to provide reliable data if
   a) similar and uniform cross-sections are used
   b) measurements are taken over a range of flow to develop good relationships - stage to hydraulic depth
   c) winter measurements must be made at the same location
   d) Sections are in the vicinity of the gauge, and are free from frazil or slush ice during the winter period
   e) Care is taken in assessing width of flow when measurements are taken.

2) The use of the degree-day system, to forecast the timing of winter flow measurements, will require an accumulation of temperature data at each specific site in order to establish a suitable procedure.

3) Measurements of ice thickness will be required before an ice thickness constant can be developed at each site.

4) Some experimental sites should be chosen and the model method pursued for use in calculating winter flows under ice.

5) More work could also be done in developing recession curves for estimating winter flowrates, as some sites may be very consistent from year to year.

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APPENDIX 1

1. Theory Behind Model
2. Description of Model
3. Example of Computations

1. THEORY BEHIND MODEL

The under-ice flow model for a wide rectangular section in an open channel is based on Manning's equation:

$$Q_o = 1/n_o \ B_o(D_o)^{5/3} \ (S_o)^{1/2} \tag{1}$$

The equivalent equation for under-ice flow is written:

$$Q_i = 1/n_i \ B_i(D_i)^{5/3}/(2)^{2/3} \ (S_i)^{1/2} \tag{2}$$

DEFINITION OF TERMS

B_i:	Water surface width of an ice covered channel section
B_o:	Water surface width of an open channel section
D_i:	Hydraulic depth of an ice covered channel section
D_o:	Hydraulic depth of an open channel section
n_i:	Manning's roughness coefficient for an ice covered channel section
n_o:	Manning's roughness coefficient for an open channel section
Q_i:	Discharge through an ice covered channel section
Q_o:	Discharge through an open channel section
S_i:	Energy slope at an ice covered channel section
S_o:	Energy slope at an open channel section

Notation for open water channel:

$$X_o = \frac{(S_o)^{1/2}}{n_o} \tag{3}$$

and for under ice conditions:

$$X_i = \frac{(S_i)^{1/2}}{n_i} \tag{4}$$

Replacing (3) in (1) and (4) in (2) and dividing Q_o by Q_1 gives:

$$Q_0/Q_1 = (2)^{2/3} B_0/B_1 (D_0/D_1)^{5/3} X_0/X_1 \qquad (5)$$

Since a relationship between parameters of under ice conditions and parameters of open channel conditions corresponding to the same flowrate $Q_o = Q_1$ is needed; equation (5) can be written with regards to D_o/D_1 as follows:

$$D_0/D_1 = 1/(2)^{2/3} (B_1/B_0)^{0.6} (X_1/X_0)^{0.6} \qquad (6)$$

The parameter X_1/X_o is termed the "winter regime coefficient". It is a site dependent factor and is constant as long as the section parameters do not change, the ratio B_1/B_o remains approximately constant, and when raised to the 0.6 power, it can also be considered as a constant. The ratio D_o/D_1 can be approximated by a constant.

$$D_0/D_1 \simeq \text{CONSTANT}$$

This ratio can vary slightly since the ice thickness, the roughness of the channel, and the area of the section, are changing during the winter.

2. DESCRIPTION OF THE MODEL

The computation of daily flowrate values from a corresponding continuous under ice stage record requires the following steps.

2.1 The first step is to establish relationships for the given section. To accomplish this, the least square method is commonly used (this study used Micro computer program "H/Q Curve" from Hydranaly):

- the stage-discharge relationship for open channel
- the stage-hydraulic depth relationship for open channel
- the stage-hydraulic depth relationship for under ice conditions determined from the available under-ice measurements.

2.2 The second step is to compute the values of the hydraulic depth ratio corresponding to each measurement. For this purpose, three different variables are needed:

- GH_w: gauge height for under ice conditions
- Q_1: flowrate estimated by the standard method of velocity measurements and gauge height
- F.D.: float depth, (distance from water surface to under ice) is averaged from measurements taken along the section.

To obtain the value of GH_o, the value of Q_1 is entered into the stage discharge relationship. The float depth F.D. is substracted from GH_w to obtain the gauge height GH_i:

- estimation of the value of D_i corresponding to GH_i using the stage-hydraulic depth relationship for under ice conditions
- estimation of the value of D_o corresponding to GH_o using the stage-hydraulic depth relationship for open channel conditions
- computation of the hydraulic depth ratio D_o/D_i.

2.3 The last step consists of the computation of flowrates and the following data and parameters are needed:

- continuous record of stage for under ice conditions (GH_w)
- successive measurements of float depth (F.D.)
- computed values of the hydraulic depth ratio for each measurement
- stage-discharge relationship for open channel conditions
- stage-hydraulic depth relationship for open channel conditions
- stage-hydraulic depth relationship for under-ice conditions.

a) Computation of flowrate:

- estimation of daily F.D. by interpolation between measurements or by extrapolation before and after measurement
- estimation of daily hydraulic depth ratio by interpolation between values corresponding to measurements and extrapolation before and after measurements

- GH_1, is obtained by subtracting the corresponding F.D. from GH_w
- estimation of daily hydraulic depth D_1 with GH_1 using stage-hydraulic depth relationships for under ice conditions
- computation of daily D_o: D_o = hydraulic depth ratio x D_1
- estimation of daily GH_o with D_o, using stage-hydraulic depth relationship for open channel
- estimation of daily Q from stage-discharge relationship for open channel.

3. EXAMPLE OF COMPUTATIONS

This example refers to the case corresponding to results of TABLE 9. Open water stage-discharge relationship and stage-hydraulic depth relationship were obtained from previous measurements, and under-ice stage-hydraulic depth relationship was calibrated from three measurements: Nov. 12, 1965; Jan. 5, 1966; and March 15, 1966. They are written as follows:

$$Q_o = 50.5472\ (GH_o - 5.11)^{2.1604} \qquad (2.1)$$

$$D_o = 0.29672\ (GH_o - 3.11)^{1.3761} \qquad (2.2)$$

$$D_1 = 3.16676\ (GH_1 - 7.61)^{0.1193} \qquad (2.3)$$

This leads to the second step: computation of the hydraulic depth ratio for each measurement.

1st MEASUREMENT: $Q_1 = 1280$ cfs

$GH_w = 11.78$ ft.

$FD = 0.77$ ft.

Reversing equation (2.1) for GH_o gives:

$$GH_o = (Q_o/50.5472)^{(1/2.1604)} + 5.11 \qquad (2.4)$$

$$= (1280/50.5472)^{(1/2.1604)} + 5.11 = 9.573$$

$$GH_1 = GH_w - F.D$$
$$= 11.78 - 0.77 = 11.01$$

$$D_1 = 3.16676\ (11.01 - 7.61)^{0.1193} = 3.665$$

$$D_o = 0.29672\ (9.573 - 3.11)^{1.3761} = 3.869$$

$$* \ D_o/D_1 = 3.869 / 3.665 = 1.056$$

2nd MEASUREMENT: $Q_1 = 429$ cfs

$GH_w = 9.80$ ft.

$FD = 1.50$ ft.

$$GH_o = (429/50.5472)^{(1/2.1604)} + 5.11 = 7.801$$

$$GH_1 = 9.80 - 1.50 = 8.30$$

$$D_1 = 3.16676\ (8.30 - 7.61)^{0.1193} = 3.030$$

$$D_o = 0.29672\ (7.801 - 3.11)^{1.3761} = 2.489$$

$$* \ D_o/D_1 = 2.489 / 3.030 = 0.821$$

3rd MEASUREMENT: $Q_1 = 303$ cfs

$GH_w = 9.63$ ft.

$FD = 1.94$ ft.

$GH_0 = (303/50.5472)^{(1/2.1604)} + 5.11 = 7.401$

$GH_1 = 9.63 - 1.94 = 7.69$

$D_1 = 3.16676\ (7.69 - 7.61)^{.1193} = 2.343$

$D_0 = 0.29672\ (7.401 - 3.11)^{1.3761} = 2.202$

* $D_0/D_1 = 2.202/2.343 = 0.940$

The last step is the computation of flowrates. Any daily flow between the first and the last measurement can be easily computed.

Example between first and second measurements:

Dec. 1st 1965 : $GH_W = 10.52$ ft.

The float depth "FD" is interpolated between the first two measurements:

Nov. 12 1965 - F.D. = 0.77 and $D_0/D_1 = 1.056$

Jan. 5 1966 - F.D. = 1.50 and $D_0/D_1 = 0.822$

$$FD = \frac{\text{No. Days (Dec. 1 - Nov. 12)}}{\text{No. Days (Jan. 5 - Nov. 12)}} \times (1.50 - 0.77) + 0.77$$

$$= \frac{19}{54} \times (1.5 - 0.77) + 0.77 = 1.027$$

The hydraulic depth ratio is interpolated similarly:

$$D_0/D_1 = 1.056 + \frac{19}{54} \times (0.822 - 1.056) = 0.973$$

$GH_1 = 10.52 - 1.027 = 9.493$

$D_1 = 3.16676\ (9.493 - 7.61)^{0.1193} = 3.415$

$D_0 = 3.415 \times 0.973 = 3.324$

The gauge height GH_0 is computed from equation (2.2) written for

GH_o as follows:

$$GH_o = (D_o/0.29672)^{(1/1.3761)} + 3.11 \qquad (2.5)$$

$$= (3.324/0.29672)^{(1/1.3761)} + 3.11 = 8.898$$

$$Q_o = 50.5472\ (GH_o - 5.11)^{2.1604}$$

$$= 50.5472\ (8.898 - 5.11)^{2.1604} = 898 \text{ cfs}$$

The second example is after the last measurement, on the 22nd of March.

The float depth "FD" is assumed constant for a short period after the last measurement although it may increase until the beginning of the melting period.

FD = 1.94 (Same as March 15 1966)

The Hydraulic Depth Ratio is fairly constant during a short period after the last measurement but its behaviour is unknown during the melting period. It is considered as constant from the 15th to the 22nd of March:

$$D_o/D_i = 0.940$$

$$GH_i = GH_w - FD = 9.71 - 1.94 = 7.77$$

$$D_i = 3.16676\ (7.77 - 7.61)^{0.1193} = 2.545$$

$$D_o = D_i \times (D_o/D_i) = 2.545 \times 0.940 = 2.392$$

$$GH_o = (2.392/0.29672)^{(1/1.3761)} + 3.11 = 7.667$$

$$Q_o = 50.5472\ (7.667 - 5.11)^{2.1604} = 384 \text{ cfs}$$

APPENDIX 2

GOVERNING CRITERIA FOR SECTIONS

GOVERNING CRITERIA FOR SECTIONS

Usually open water and winter measurements are not taken at the same section. However the model is developed for both open water and winter measurements to be taken at the same section in order to have the same stage-discharge and the same stage-hydraulic depth relationships. The first condition is satisfied if the parameters in Mannings equation have the same values and the second condition is satisfied, if the section geometries are identical.

Obviously these conditions cannot be entirely satisfied, however the choice of sections should be made according to the following criteria:

- a similar geometry: width vs. depth, bottom slope, type of bed
- inflow or outflow betwen the sections must be negligible
- no backwater effect
- away from control sections.

From a practical point of view, the simplest way to satisfy these criteria is to chose the winter measurement section as close as possible to the open water measurement section. Nevertheless, the application of the model made in this report shows how the estimate can be accurate when the measurement sections are located far apart, (up to 1,500 feet), if the flow regime is normal during open water, and the channel has a regular section for both sites.

TABLES 1 - 12

TABLE 1
MEASUREMENTS UNDER ICE

TAKHINI RIVER NEAR WHITEHORSE (09AC001)

WINTER PERIOD NOVEMBER 1, 1964 TO MAY 17,1965

DAY	NOVEMBER		DECEMBER		JANUARY		FEBRUARY		MARCH		APRIL		MAY	
	Gauge Height ft.	Discharge cfs	Gauge Height ft.	Discharge cfs	Gauge Height ft.	Discharge cfs	Gauge Height ft.	Discharge cfs	Gauge Height ft.	Discharge cfs	Gauge Height ft.	Discharge cfs	Gauge Height ft.	Discharge cfs
1	9.83		10.36		9.96		10.41	450	10.56	428	10.53		10.42	
2	9.95		10.18		9.87		10.40	469	10.58	439	10.50		10.32	
3	10.21		10.27		9.92		10.43	476	10.57	441	10.55		10.42	
4	10.47		10.39		9.91		10.45	495	10.60	468	10.54		10.19	
5	10.79		10.40		9.83	363	10.43	468	10.61	455	10.61		10.06	
6	10.57		10.47		9.88	353	10.45	468	10.60	452	10.58		10.04	
7	9.93		10.51		9.88	355	10.46	470	10.57	428	10.56			
8	11.70		10.50		9.83	319	10.45	461	10.58	455	10.60			
9	13.21		10.45		9.85	320	10.46	448	10.61	464	10.57			
10	13.03		10.28		9.83	328	10.50	442	10.64	465	10.58			
11	12.72		10.03		9.95	333	10.53	434	10.63	468	10.59			
12	12.59		10.06		9.99	348	10.53	454	10.62	459	10.60			
13	12.05	813	9.96		9.92	348	10.53	452	10.64		10.48			
14	11.98		10.06			345	10.52	443	10.64		10.47			
15	12.62		10.06		10.00	327	10.50	441	10.54		10.54			
16	12.43		10.03		10.02	351	10.49	434	10.53		10.68			
17	12.04		10.03		10.09	381	10.49	428	10.58		10.64			
18	11.94		9.99		10.17	398	10.46	420	10.58		10.49			
19	12.27		9.99		10.26	421	10.46	417	10.58		10.44			
20	12.02		9.98		10.36	442	10.44	413	10.58		10.43			
21	11.70		9.98		10.40	462	10.44	385	10.47		10.40			
22	10.92		9.99		10.42	471	10.41	403	10.57		10.33			
23	10.70		9.99		10.45	480	10.40	399	10.56		10.34			
24	10.50		9.98		10.48	490	10.40	391	10.51		10.37			
25	10.81		10.01		10.52	492	10.44	406	10.61		10.44			
26	10.82		10.02		10.53	501	10.49	417	10.62		10.57			
27	10.61		10.03		10.52	486	10.52	418	10.61		10.54			
28	10.54		10.04		10.48	475	10.53	421	10.60		10.44			
29	10.47		10.01		10.44	469			10.53		10.34			
30	10.39		9.98		10.45	472			10.57		10.37			
31			9.96		10.46	491			10.57					

TABLE 2
MEASUREMENTS UNDER ICE

TAKHINI RIVER NEAR WHITEHORSE (09AC001)

WINTER PERIOD NOVEMBER 5, 1965 TO MAY 5, 1966

DAY	NOVEMBER Gauge Height ft.	NOVEMBER Discharge cfs	DECEMBER Gauge Height ft.	DECEMBER Discharge cfs	JANUARY Gauge Height ft.	JANUARY Discharge cfs	FEBRUARY Gauge Height ft.	FEBRUARY Discharge cfs	MARCH Gauge Height ft.	MARCH Discharge cfs	APRIL Gauge Height ft.	APRIL Discharge cfs	MAY Gauge Height ft.	MAY Discharge cfs
1	10.06		10.52	971	9.96		9.72		9.78		9.80	320	8.67	
2	10.01		10.48		9.91		9.73	402	9.74	354	9.76		8.41	
3	9.99		10.40	839	9.89		9.75		9.74		9.80		8.36	
4	9.94		10.32		9.84		9.72	351	9.75		9.84		8.33	
5	10.10		10.27		9.80	429	9.77		9.72		9.86		8.30	
6	11.64		10.25		9.79		9.80		9.69		9.82	344		
7	11.85		10.28		9.78		9.79		9.68		9.82	351		
8	12.06		10.28	781	9.79		9.78		9.65		9.82			
9	12.08		10.22		9.80		9.78		9.65		9.78			
10	12.05		10.21		9.80		9.79		9.61	296	9.65			
11	11.90		10.23		9.82		9.81	421	9.60		9.70			
12	11.78	1280	10.18		9.86		9.78		9.60		9.74			
13	11.77		10.78		9.86	486	9.80		9.61		9.83	375		
14	11.70		10.21		9.85		9.80		9.61		9.90			
15	11.60		10.31	797	9.85		9.80	385	9.63	303	9.85			
16	11.54	1210	10.28		9.85		9.80		9.62		9.83			
17	11.40		10.19		9.85		9.81		9.62		9.82			
18	11.20		10.05		9.84		9.81		9.66		9.85			
19	10.99		10.04		9.84		9.83		9.68		10.00			
20	10.91		10.18	753	9.84		9.80		9.69		10.03			
21	10.92		10.15		9.85		9.78		9.70		9.96			
22	10.89		10.14		9.85		9.75	362	9.71	331	9.92			
23	10.80	956	9.93	595	9.86		9.76		9.71		9.81			
24	10.74		9.93		9.85		9.76		9.71		9.72			
25	10.61		9.97		9.85	415	9.79		9.73		9.64			
26	10.64		9.94		9.81		9.80		9.74		9.53			
27	10.66		9.95		9.79		9.79		9.75		9.40			
28	10.66		9.99	600	9.79		9.80		9.72		9.34			
29	10.60		10.00		9.77				9.72		9.25			
30	10.58		10.01	592	9.74				9.75		9.00			
31			10.00		9.71				9.78					

TABLE 3
MEASUREMENTS UNDER ICE

TAKHINI RIVER NEAR WHITEHORSE (09AC001)

WINTER PERIOD NOVEMBER 18, 1966 TO MAY 13, 1967

DAY	NOVEMBER		DECEMBER		JANUARY		FEBRUARY		MARCH		APRIL		MAY	
	Gauge Height ft.	Discharge cfs	Gauge Height ft.	Discharge cfs	Gauge Height ft.	Discharge cfs	Gauge Height ft.	Discharge cfs	Gauge Height ft.	Discharge cfs	Gauge Height ft.	Discharge cfs	Gauge Height ft.	Discharge cfs
1	10.13		10.84	820	9.76	570	9.30		9.55		9.46	292	9.98	423
2	10.17		10.80		9.75	540	9.30	319	9.56	346	9.50		10.10	482
3	10.11		10.72		9.72	544	9.30		9.57	361	9.54		10.20	537
4	9.99		10.67		9.67	515	9.31		9.59	361	9.54	292	10.21	
5	9.93		10.66	784	9.66	506	9.32	302	9.60	365	9.54		10.19	
6	10.03		10.59		9.67		9.33	332	9.62	373	9.57		10.10	
7	10.40		10.53		9.69		9.36	351	9.61	376	9.58	310	10.00	
8	11.03		10.50		9.67		9.40	341	9.65		9.53	289	9.76	
9	12.23		10.45	694	9.66	526	9.40	343	9.63	362	9.62	307	9.50	
10	12.80		10.39	704	9.62		9.41	342	9.60		9.62	313	9.22	
11	12.55		10.35	685	9.62		9.40		9.57		9.65	315	9.18	
12	12.73		10.31	681	9.63	478	9.40		9.57	333	9.70	317	9.47	
13	12.53		10.30	666	9.63	492	9.41		9.58		9.64		9.30	
14	12.28	1010	10.28		9.62	483	9.46	339	9.54		9.63	292		
15	12.16	953	10.26		9.56	459	9.46		9.52	324	9.69			
16	12.21	1060	10.22	683	9.22	313	9.46		9.54	332	9.66			
17	12.11	1040	10.21		9.43	432	9.49	354	9.52	329	9.63	304		
18	12.80	1110	10.15		9.49	403	9.50	339	9.50	335	9.73	323		
19	11.96	1060	10.11	663	9.50		9.52	341	9.50	337	9.73	317		
20	11.83		10.07	651	9.50		9.55	344	9.51	339	9.75	330		
21	11.70		10.05	631	9.48	388	9.53	352	9.50		9.77	337		
22	11.64	988	10.00	625	9.42		9.54	353	9.50		9.77	334		
23	11.61		9.96	575	9.40		9.56		9.51	349	9.71			
24	11.60	999	9.95	592	9.40		9.55	370	9.49		9.75			
25	11.51		9.91		9.39		9.54		9.45		9.75	338		
26	11.37	977	9.91		9.34	359	9.53		9.44		9.73			
27	11.18	894	9.86	581	9.32	346	9.54	383	9.44	299	9.76			
28	11.02	832	9.83		9.31	347	9.54		9.43	300	9.81	358		
29	10.92	858	9.80		9.30	337			9.43	291	9.82	370		
30	10.91	839	9.80		9.30				9.43	285	9.89	389		
31			9.79	571	9.30				9.44	271				

TABLE 4

STATISTICS FOR COMPUTATION OF FLOWRATE UNDER ICE 1964 - 1967

DATE OF MEASUREMENTS	WINTER COEFFICIENT	FLOAT DEPTH ft.	SECTION COEFFICIENT	MEASURED DISCHARGE cfs
Nov. 13/64	1.38	1.83	1.04	813
Jan. 5/65	1.39	2.26	0.91	360
Feb. 25/65	1.37	2.70	0.91	406
Mar. 1/65	1.39	2.82	0.91	428
Mar. 5/65	1.44	2.87	0.95	455
Mar. 12/65	1.40	2.83	0.94	459
Nov. 12/65	1.16	0.77	1.04	1280
Dec. 20/65	1.63	1.24	1.01	753
Dec. 23/65	1.54	1.28	0.98	595
Jan. 5/66	1.43	1.50	0.91	429
Jan. 25/66	1.47	1.91	0.97	415
Feb. 15/66	1.60	2.09	1.01	385
Mar. 22/66	1.60	2.05	0.98	331
Apr. 7/66	1.45	1.75	0.90	351
Nov. 17/66	1.09	0.71	1.00	1040
Nov. 30/66	1.28	0.88	1.15	839
Dec. 5/66	1.51	1.06	1.20	784
Dec. 16/66	1.79	1.11	1.27	683
Dec. 24/66	1.72	1.20	1.32	592
Jan. 14/67	1.85	1.31	1.38	483
Feb. 18/67	2.18	1.60	1.39	339
Mar. 16/67	2.23	1.64	1.37	332
Apr. 20/67	1.71	1.93	1.41	330
May. 3/67	1.29	1.22	1.20	537

TABLE 5

COMPARISON OF FLOWRATES FOR THE PERIOD 1964/65

DATE OF MEASUREMENT	MEASURED DISCHARGE cfs	CALCULATED DISCHARGE cfs	PERCENT DEVIATION	FLOAT DEPTH ft.	SECTION COEFFICIENT
Jan. 5	363	363	0	2.26	0.9114
Jan. 9	320	355	11		
Jan. 13	348	369	6		
Jan. 16	351	393	11		
Jan. 19	421	437	3		
Jan. 22	471	456	-3		
Jan. 25	492	465	-5		
Jan. 28	475	457	-3		
Jan. 31	491	451	-8		
Feb. 2	469	440	-6		
Feb. 5	468	440	-5		
Feb. 9	448	439	-1		
Feb. 13	452	445	-1		
Feb. 17	428	432	1		
Feb. 21	385	415	7		
Feb. 24	391	398	1		
Feb. 28	421	421	0	2.78	0.9167
Mar. 5	455	436	-4		
Mar. 8	455	431	-5		
Mar. 12	459	438	-4		

TABLE 6

COMPARISON OF FLOWRATES FOR THE PERIOD 1965/66

DATE OF MEASUREMENT	MEASURED DISCHARGE cfs	CALCULATED DISCHARGE cfs	PERCENT DEVIATION	FLOAT DEPTH ft.	SECTION COEFFICIENT
Nov. 12/65	1280	1280	0	0.77	1.0379
Nov. 16/65	1210	1191	-1		
Nov. 23/65	956	965	0		
Nov. 29/65	942	870	-7		
Dec. 1/65	791	836	5		
Dec. 3/65	839	793	-5		
Dec. 8/65	781	727	-6		
Dec. 15/65	797	683	-14		
Dec. 20/65	753	619	-17		
Dec. 23/65	595	541	-9		
Dec. 28/65	600	522	-12		
Dec. 30/65	592	514	-13		
Jan. 5/66	429	429	0	1.50	0.9128
Jan. 13/66	486	434	-10		
Jan. 25/66	415	419	1		
Feb. 2/66	402	302	-5		
Feb. 4/66	351	377	7		
Feb. 11/66	421	390	-7		
Feb. 15/66	385	383	0		
Feb. 22/66	362	362	0		
Mar. 2/66	354	349	-1		
Mar. 10/66	296	305	2		
Mar. 15/66	303	303	0	1.94	0.9347
Mar. 22/66	331	324	-1		

TABLE 7

COMPARISON OF FLOWRATES FOR THE PERIOD 1966/67

DATE OF MEASUREMENT	MEASURED DISCHARGE cfs	CALCULATED DISCHARGE cfs	PERCENT DEVIATION	FLOAT DEPTH ft.	SECTION COEFFICIENT
Nov. 14/66	1010	1010	0	0.69	0.9677
Nov. 17/66	1040	1013	-2		
Nov. 22/66	988	938	-5		
Nov. 26/66	977	903	-7		
Nov. 30/66	839	787	-6		
Dec. 5/66	784	747	-4		
Dec. 9/66	694	703	1		
Dec. 13/66	666	676	1		
Dec. 16/66	683	664	-2		
Dec. 19/66	663	637	-3		
Dec. 24/66	592	596	0		
Dec. 27/66	581	569	-2		
Dec. 31/66	571	552	-3		
Jan. 2/67	540	539	0		
Jan. 5/67	506	506	0	1.68	1.5522
Jan. 9.67	526	497	-5		
Jan. 14/67	483	470	-2		
Jan. 18/67	403	411	2		
Jan. 21/67	388	402	3		
Jan. 26/67	359	342	-4		
Jan. 29/67	337	323	-4		
Feb. 2/67	319	317	0		
Feb. 5/67	302	319	5		
Feb. 10/67	342	341	0		
Feb. 14/67	339	352	3		
Feb. 18/67	339	359	5		
Feb. 22/67	353	366	3		
Feb. 27/67	383	358	-6		
Mar. 2/67	346	359	3		
Mar. 6/67	373	373	0	1.77	1.4449
Mar. 9/67	362	376	3		
Mar. 12/67	333	356	6		
Mar. 16/67	332	346	4		
Mar. 20/67	339	336	0		
Mar. 23/67	349	336	-3		
Mar. 27/67	299	313	4		

TABLE 8

COMPARISON OF FLOWRATES FOR THE PERIOD 1964/65

For 3 Measurements

DATE OF MEASUREMENT	MEASURED DISCHARGE cfs	CALCULATED DISCHARGE cfs	PERCENT DEVIATION	FLOAT DEPTH ft.	SECTION COEFFICIENT
Jan. 5	363	363	0	2.26	0.9155
Jan. 9	320	354	10		
Jan. 13	348	369	6		
Jan. 16	351	401	14		
Jan. 19	421	470	11		
Jan. 22	471	504	6		
Jan. 25	492	520	5		
Jan. 28	475	506	6		
Jan. 31	491	495	0		
Feb. 2	469	475	1		
Feb. 5	468	476	1		
Feb. 9	448	475	5		
Feb. 13	452	485	7		
Feb. 17	428	463	8		
Feb. 21	385	434	12		
Feb. 24	391	407	3		
Feb. 28	421	443	5		
Mar. 5	455	455	0	2.87	0.9350
Mar. 8	455	445	-2		
Mar. 12	459	458	0		

TABLE 9

COMPARISON OF FLOWRATES FOR THE PERIOD 1965/66

For 3 Measurements

DATE OF MEASUREMENT	MEASURED DISCHARGE cfs	CALCULATED DISCHARGE cfs	PERCENT DEVIATION	FLOAT DEPTH ft.	SECTION COEFFICIENT
Nov. 12/65	1280	1280	0	0.77	1.0559
Nov. 16	1210	1202	0		
Nov. 23	956	1029	7		
Nov. 29	942	932	-1		
Dec. 1	791	898	13		
Dec. 3	839	859	2		
Dec. 8	781	786	0		
Dec. 15	797	716	-10		
Dec. 20	753	646	-14		
Dec. 23	595	575	-3		
Dec. 28	600	537	-10		
Dec. 30/65	592	522	-11		
Jan. 5/66	429	429	0	1.50	0.8216
Jan. 13	486	451	-7		
Jan. 25	415	461	11		
Feb. 2	402	433	7		
Feb. 4	351	430	22		
Feb. 11	421	462	9		
Feb. 15	385	459	19		
Feb. 22	362	439	21		
Mar. 2	354	429	21		
Mar. 10	296	310	4		
Mar. 15	303	303	0	1.94	0.9398
Mar. 22	331	384	16		

TABLE 10

COMPARISON OF FLOWRATES FOR THE PERIOD 1966/67

For 3 Measurements

DATE OF MEASUREMENT	MEASURED DISCHARGE cfs	CALCULATED DISCHARGE cfs	PERCENT DEVIATION	FLOAT DEPTH ft.	SECTION COEFFICIENT
Nov. 14/66	1010	1010	0	0.69	0.9155
Nov. 17	1040	1009	-3		
Nov. 22	988	948	-4		
Nov. 26	977	916	-6		
Nov. 30	839	819	-2		
Dec. 5	784	780	-1		
Dec. 9	694	737	6		
Dec. 13	666	707	6		
Dec. 16	683	692	1		
Dec. 19	663	663	0		
Dec. 24	592	616	4		
Dec. 27	581	586	1		
Dec. 31	571	561	-2		
Jan. 2/67	540	545	1		
Jan. 5	506	506	0	1.68	1.2908
Jan. 9	526	498	-5		
Jan. 14	483	470	-3		
Jan. 18	403	409	1		
Jan. 21	388	400	3		
Jan. 26	359	336	-6		
Jan. 29	337	316	-6		
Feb. 2	319	310	-3		
Feb. 5	302	312	3		
Feb. 10	342	338	-1		
Feb. 14	339	349	3		
Feb. 18	339	357	5		
Feb. 22	353	365	3		
Feb. 27	383	356	-7		
Mar. 2	346	358	3		
Mar. 6	373	373	0	1.77	1.2024
Mar. 9	362	377	4		
Mar. 12	333	355	7		
Mar. 16	332	344	4		
Mar. 20	339	334	-1		
Mar. 23	349	334	-4		
Mar. 27	299	309	3		

TABLE 11

COMPARISON OF FLOWRATES FOR PERIOD 1969/70

TAKHINI RIVER NEAR WHITEHORSE (09AC001)

Day	NOVEMBER				DECEMBER				JANUARY			
	Gauge Height ft.	Q Est cfs	Q Cal cfs	Deviation %	Gauge Height ft.	Q Est cfs	Q Cal cfs	Deviation %	Gauge Height ft.	Q Est cfs	Q Cal cfs	Deviation %
1					11.30	1140	979	-14	10.34	810	806	0
2					11.24	1130	962	-15	10.29	770	788	2
3					11.11	1100	907	-18	10.17	730	739	1
4					10.05	1080			10.12	690	721	4
5					10.98	1060	867	-18		660		
6					10.91	1050	844	-20		650		
7					10.88	1040	841	-19		630		
8					10.81	1030	819	-20		620		
9					10.70	960	776	-19		620		
10					10.56	905	721	-20		620		
11					10.47	880	691	-21		615		
12					10.43	830	682	-18		602		
13					10.37	800	665	-17		590		
14					10.39	807	683	-15		575		
15					10.42	840	706	-16		560		
16					10.46	862	734	-15		548		
17					10.39	810	710	-12		536		
18					10.31	750	682	-9		524		
19					10.32	760	696	-8		512		
20	12.08	1230	1230*	0	10.32	763	704	-8		500		
21	12.06	1230	1238	1	10.29	725	699	-4		496		
22	11.99	1240	1216	-2	10.31	745	717	-4		492		
23	11.88	1230	1171	-5	10.31	752	725	-4		488		
24	11.83	1230	1160	-6	10.29	725	724	0		484		
25	11.74	1220	1127	-8	10.28	725	728	0		480		
26	11.82	1200	1191	-1	10.30	740	745	1		480		
27	11.69	1180	1133	-4	10.28	725	744	3		480		
28	11.58	1180	1087	-8	10.31	745	767	3		480		
29	11.46	1170	1036	-11	10.39	795	816	3		472		
30	11.36	1160	997	-14	10.41	835*	835	0		464		
31						825		0		455		

*Measured discharge used to develop model
Calculated discharge: from model
Estimated discharge: normal methods

TABLE 11 (Continued)

COMPARISON OF FLOWRATES FOR PERIOD 1969/70

TAKHINI RIVER NEAR WHITEHORSE (09AC001)

Day	FEBRUARY				MARCH				APRIL			
	Gauge Height ft.	Q Est cfs	Q Cal cfs	Deviation %	Gauge Height ft.	Q Est cfs	Q Cal cfs	Deviation %	Gauge Height ft.	Q Est cfs	Q Cal cfs	Deviation %
1		460			10.03	436	426	-2	10.12	438	432	-1
2		470			10.04	432	429	-1	10.07	420	413	-1
3		480			10.04	428	428	0	10.06	400	409	2
4		480			9.99	424	410	-3	10.05	395	404	2
5		470			10.00	420	413	-2	10.07	393	410	4
6		460			10.04	427	426	0	10.02	392*	392	0
7	10.18	460	460	0	10.04	433	426	-2				
8	10.16	470	477	1	10.05	440	428	-3				
9	10.11	470	457	-3	10.05	440	428	-3				
10	10.07	460	442	-4	10.05	435	427	-2				
11	10.09	450	450	0	10.05	428	426	0				
12	10.10	460	454	-1	10.02	421	415	-1				
13	10.09	460	450	-2	10.00	414	407	-2				
14	10.08	460	446	-3	10.02	407	413	1				
15	10.09	450	450	0	10.02	400	412	3				
16	10.10	460	454	-1	10.02	400	411	3				
17	10.11	460	457	-1	10.02	400	411	3				
18	10.05	460	435	-5	10.06	420	424	1				
19	10.06	450	439	-2	10.11	420	441	5				
20	10.11	460	457	-1	10.06	420	422	0				
21	10.16	460	477	4	10.02	400	407	2				
22	10.13	460	465	1	10.04	390	413	6				
23	10.11	446	457	2	10.05	390	416	7				
24	10.11	446	457	2	10.01	400	401	0				
25	10.13	446	465	4	10.00	410	397	3				
26	10.13	446	465	4	10.03	390	406	4				
27	10.08	446*	446	0	10.15	385	448	16				
28	10.05	440	434	-1	10.16	395	451	14				
29					10.14	410	442	8				
30					10.12	425	434	2				
31					10.13	435	436	0				

*Measured discharge used to develop model
Calculated discharge: from model
Estimated discharge: normal methods

TABLE 12

ICE THICKNESS CONSTANT

DATE OF MEASUREMENT	FLOAT DEPTH (ft.)	ACCUMULATED DEGREE DAYS (F°)	CONSTANT αs
Nov. 13/64	1.83	200	0.129
Jan. 5/6	2.26	2270	0.047
Feb. 25/65	2.70	3890	0.043
Feb. 28/65	2.78	3980	0.044
Mar. 1/65	2.82	3980	0.045
Mar. 5/65	2.87	3980	0.045
Mar. 12/65	2.83	3980	0.045
Nov. 12/65	0.77	420	0.037
Dec. 20/65	1.24	1110	0.037
Dec. 23/65	1.28	1190	0.037
Jan. 5/66	1.50	1960	0.034
Jan. 25/66	1.91	3040	0.035
Feb. 15/66	2.09	3760	0.034
Mar. 15/66	1.94	4410	0.029
Mar. 22/66	2.05	4490	0.031
Apr. 7/66	1.75	4500	0.026
Nov. 14/66	0.69	440	0.033
Nov. 16/66	0.71	560	0.030
Nov. 30/66	0.88	950	0.029
Dec. 5/66	1.06	1160	0.031
Dec. 16/66	1.11	1600	0.028
Dec. 24/66	1.20	1740	0.029
Jan. 5/76	1.68	1960	0.038
Jan. 14/67	1.31	2120	0.028
Feb. 18/67	1.60	3400	0.027
Mar. 6/67	1.77	3640	0.029
Mar. 16/67	1.64	3900	0.026
Apr. 20/67	1.93	4450	0.029
May. 3/67	1.22	4480	0.018

FIGURES 1 - 10

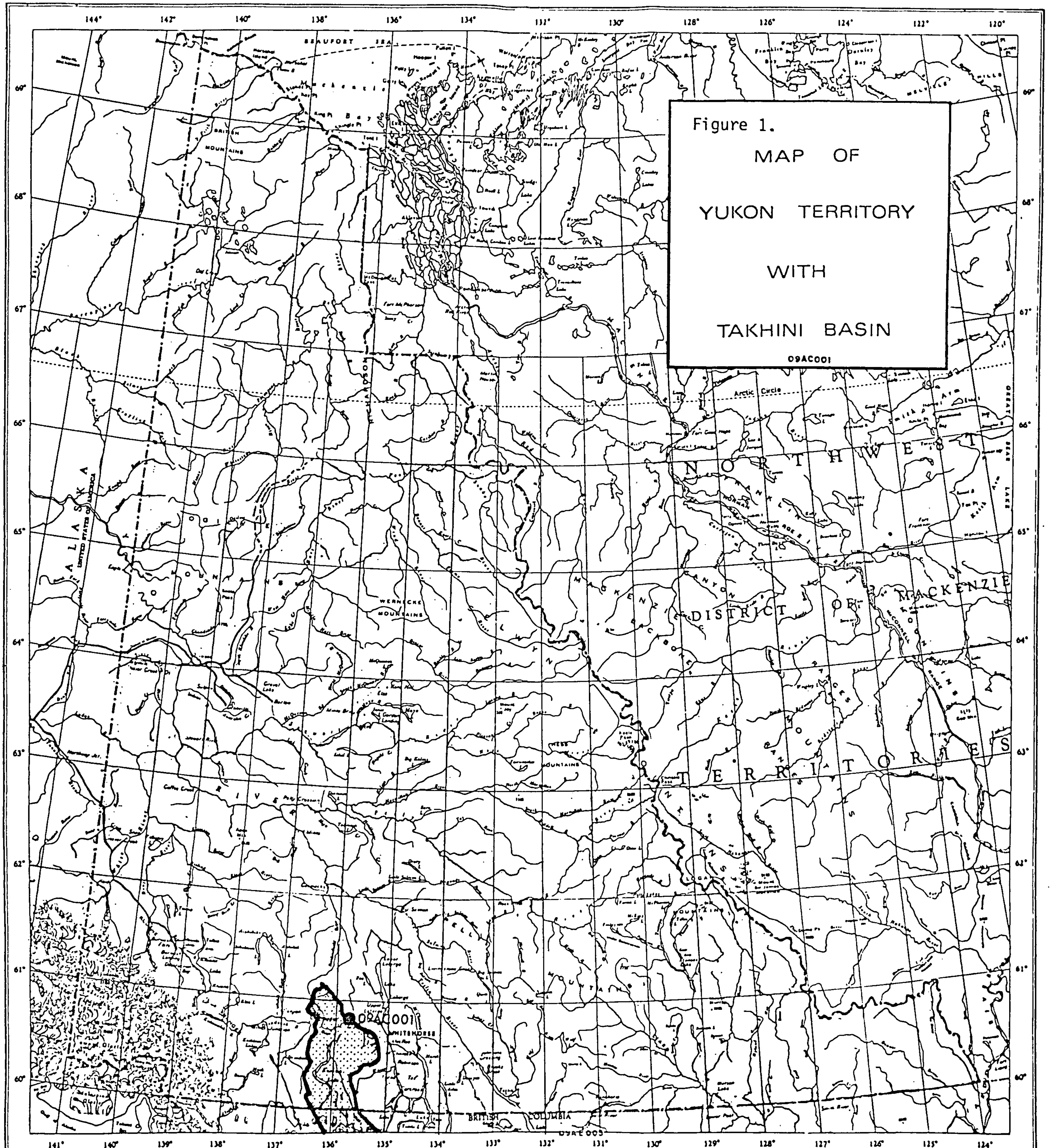

Figure 1.
MAP OF
YUKON TERRITORY
WITH
TAKHINI BASIN
09AC001

TAKHINI RIVER NEAR WHITEHORSE 09AC001

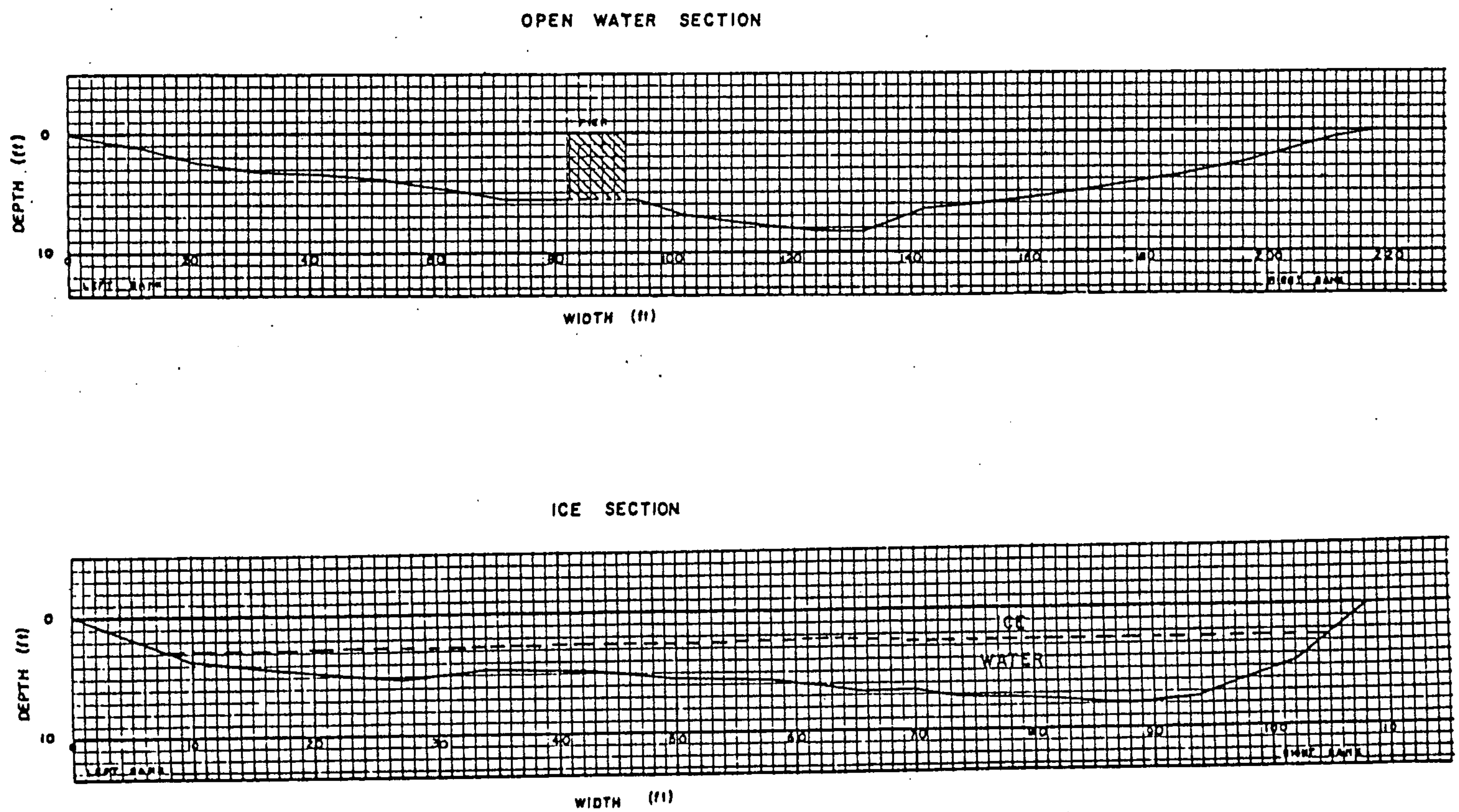

Figure 2. Cross - Section of Measurement Sites for Open Water and Ice Conditions, 1964 - 1967.

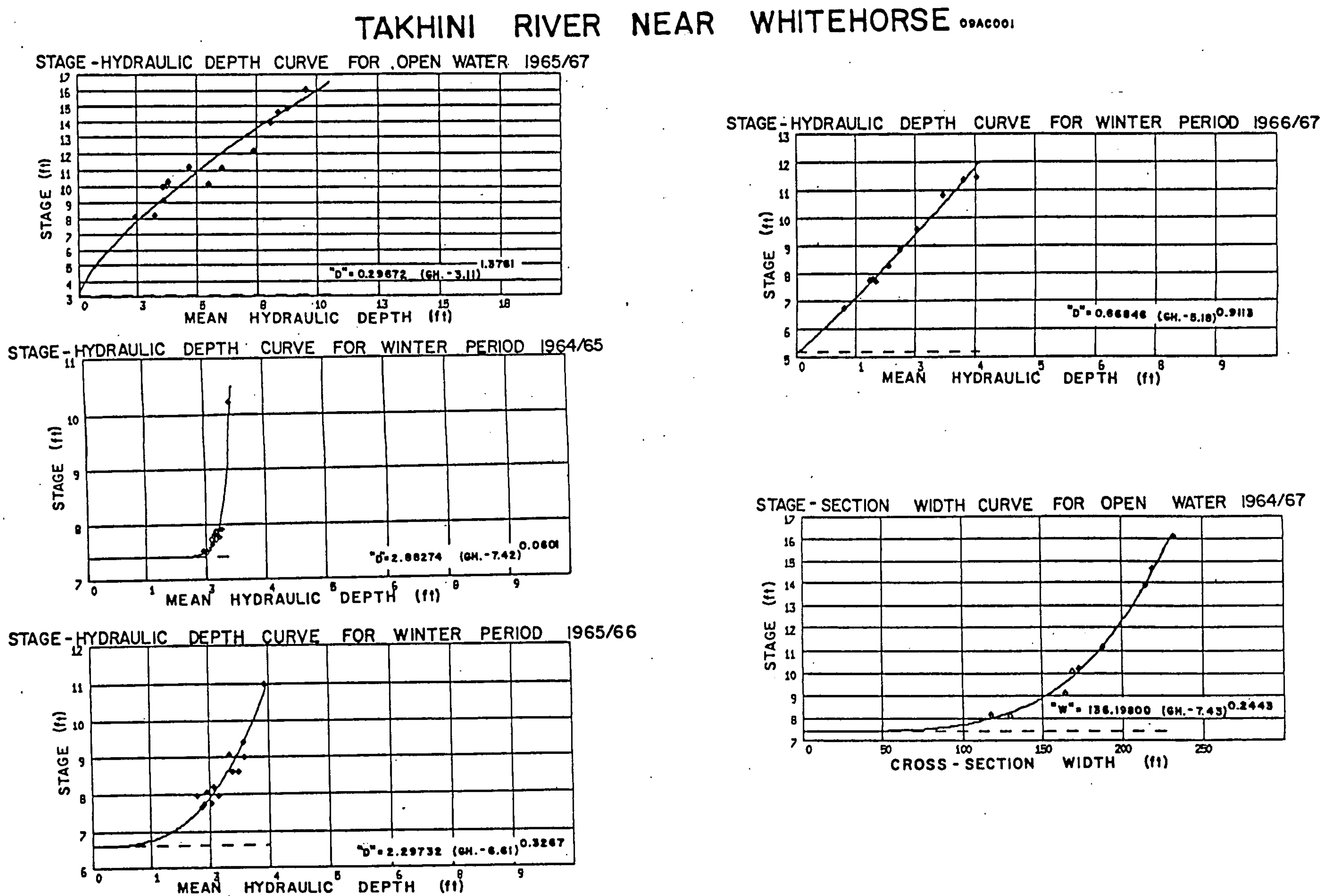

Figure 3. Stage vs Mean Hydraulic Depth and Cross Section Width, 1964 - 1967.

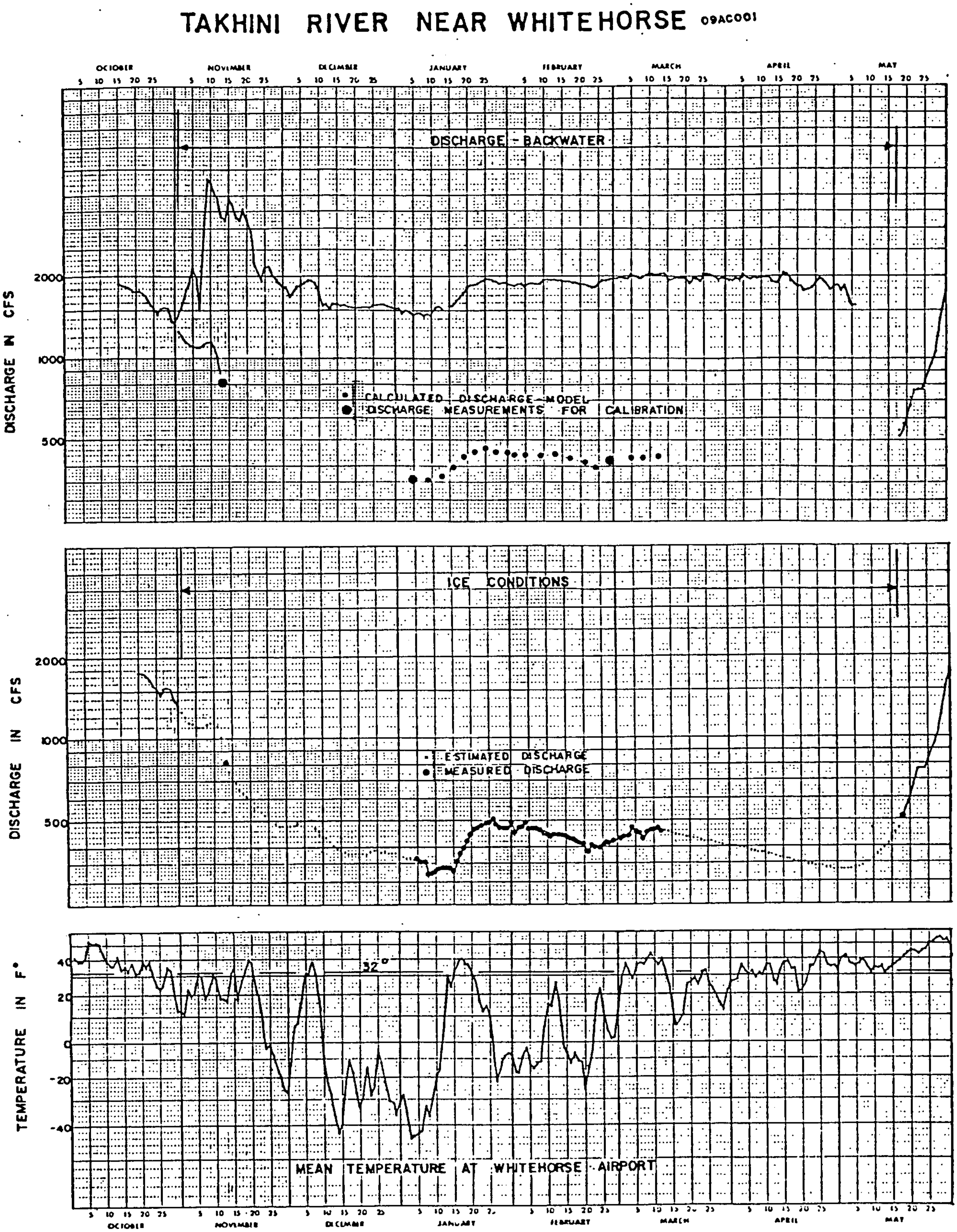

Figure 4. Hydrographs and Mean Temperature for Winter Period, 1964/65.

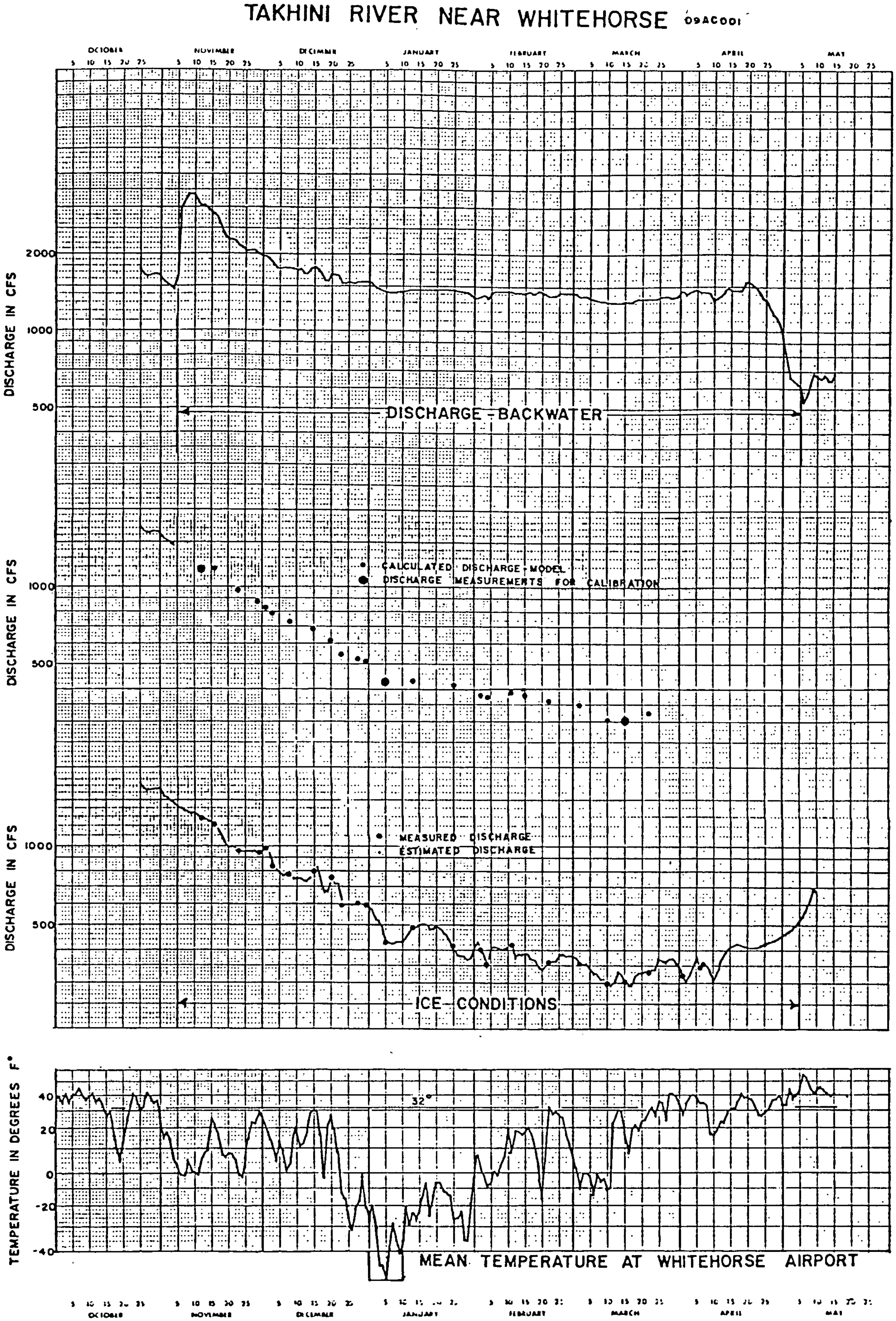

Figure 5. Hydrographs and Mean Temperature for Winter Period, 1965/66.

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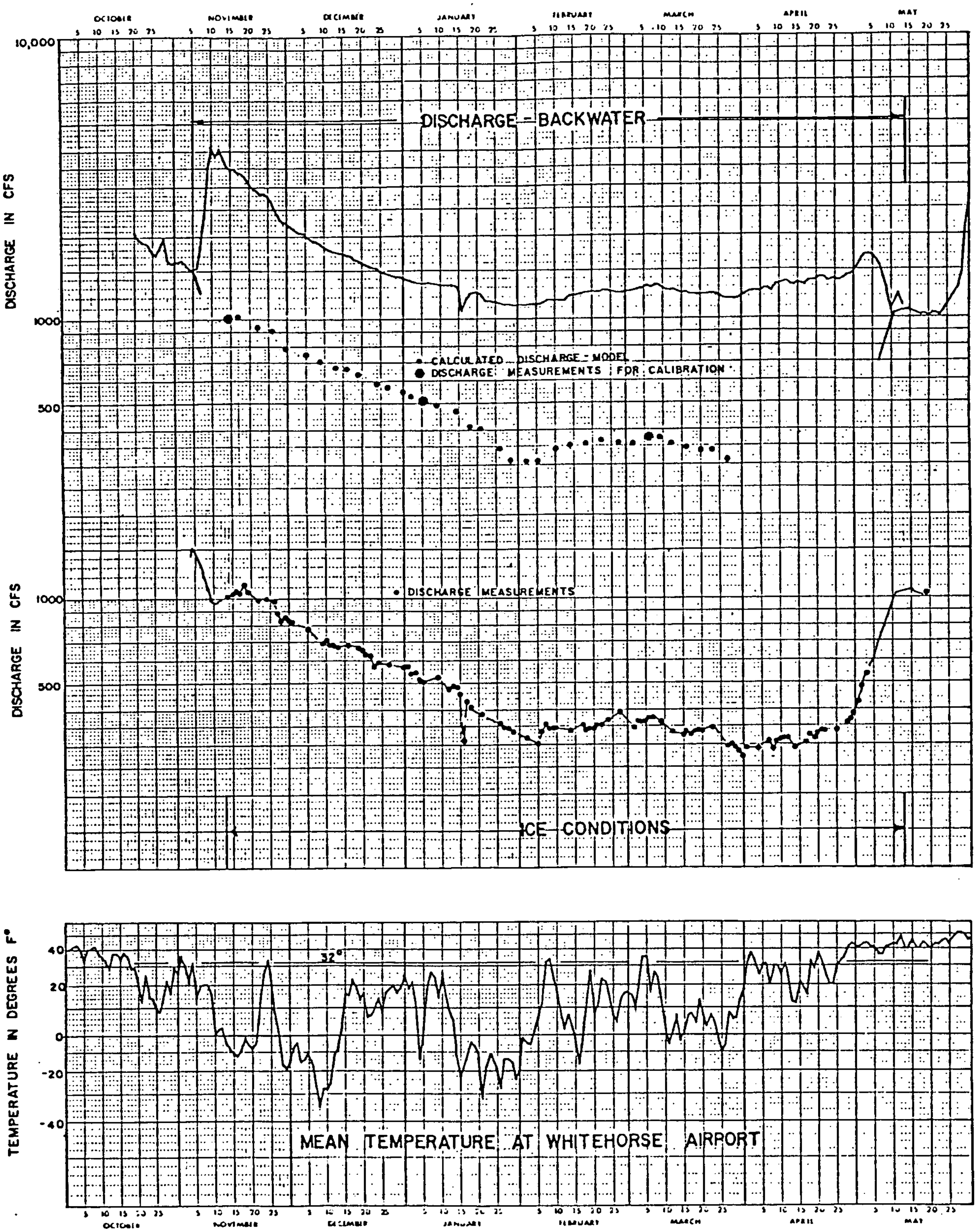


Figure 6. Hydrographs and Mean Temperature for Winter Period, 1966/67.

TAKHINI RIVER NEAR WHITEHORSE 09AC001

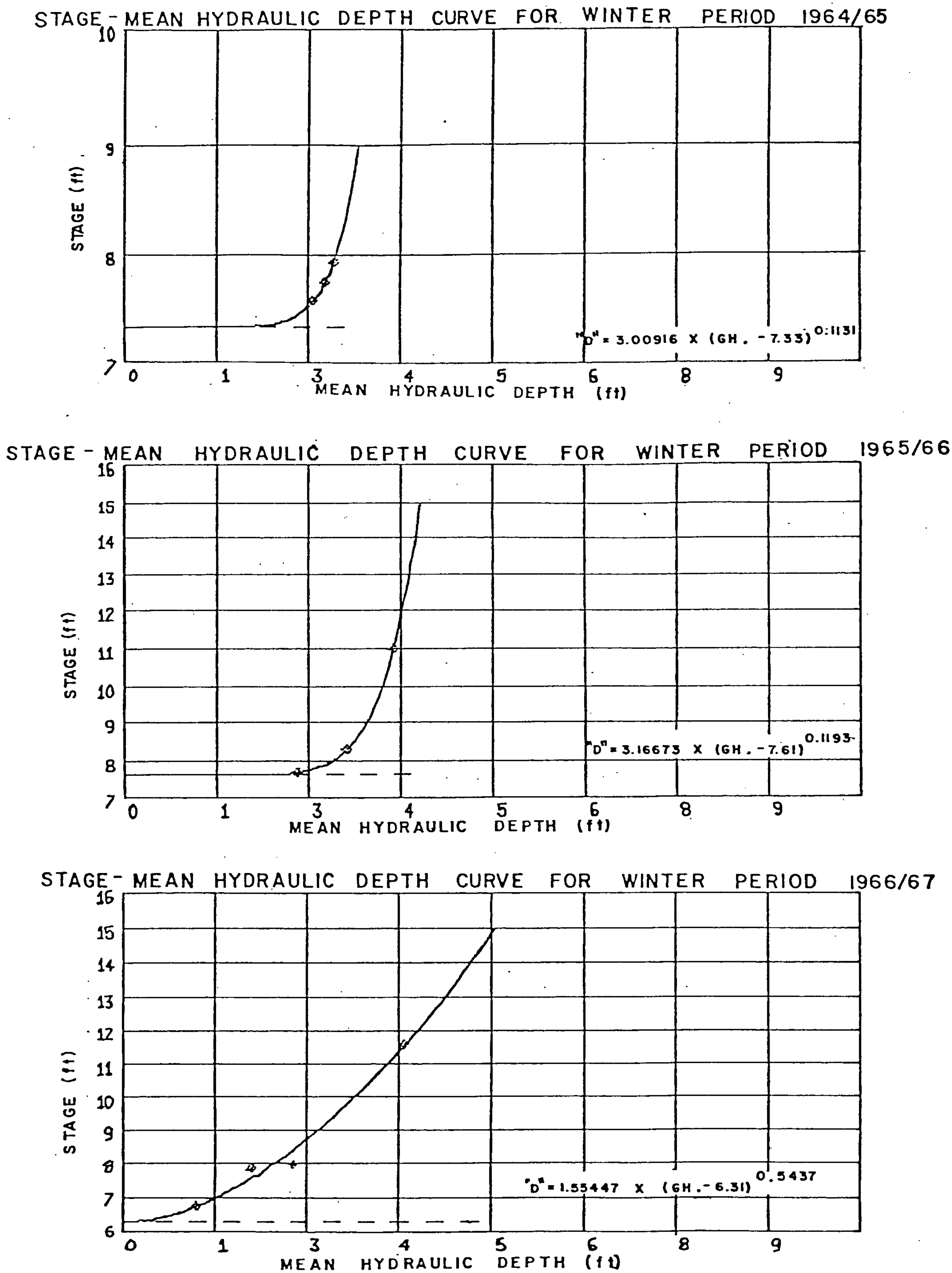
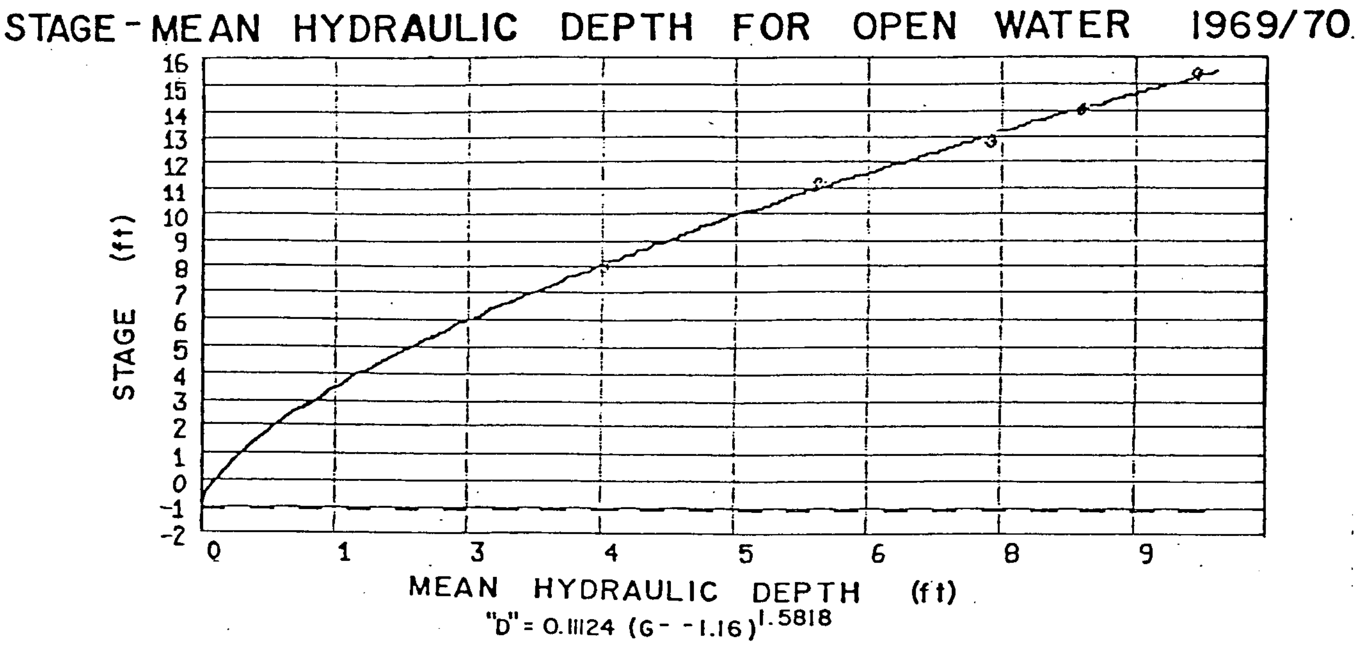


Figure 7. Stage vs. Mean Hydraulic Depth, Developed with Three Measurements, 1964 - 1967.

TAKHINI RIVER NEAR WHITEHORSE 09AC001



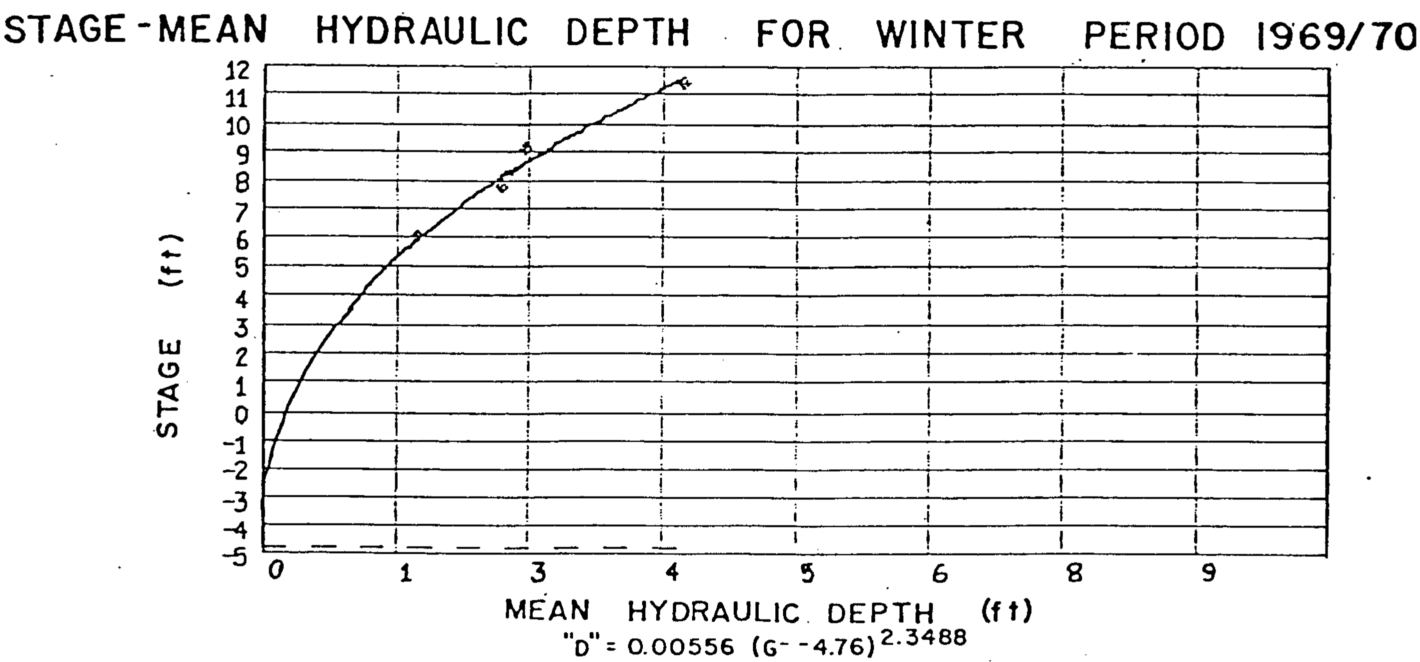


Figure 8. Stage vs Mean Hydraulic Depth and Cross-Section Width, 1969/70

TAKHINI RIVER NEAR WHITEHORSE 09AC001

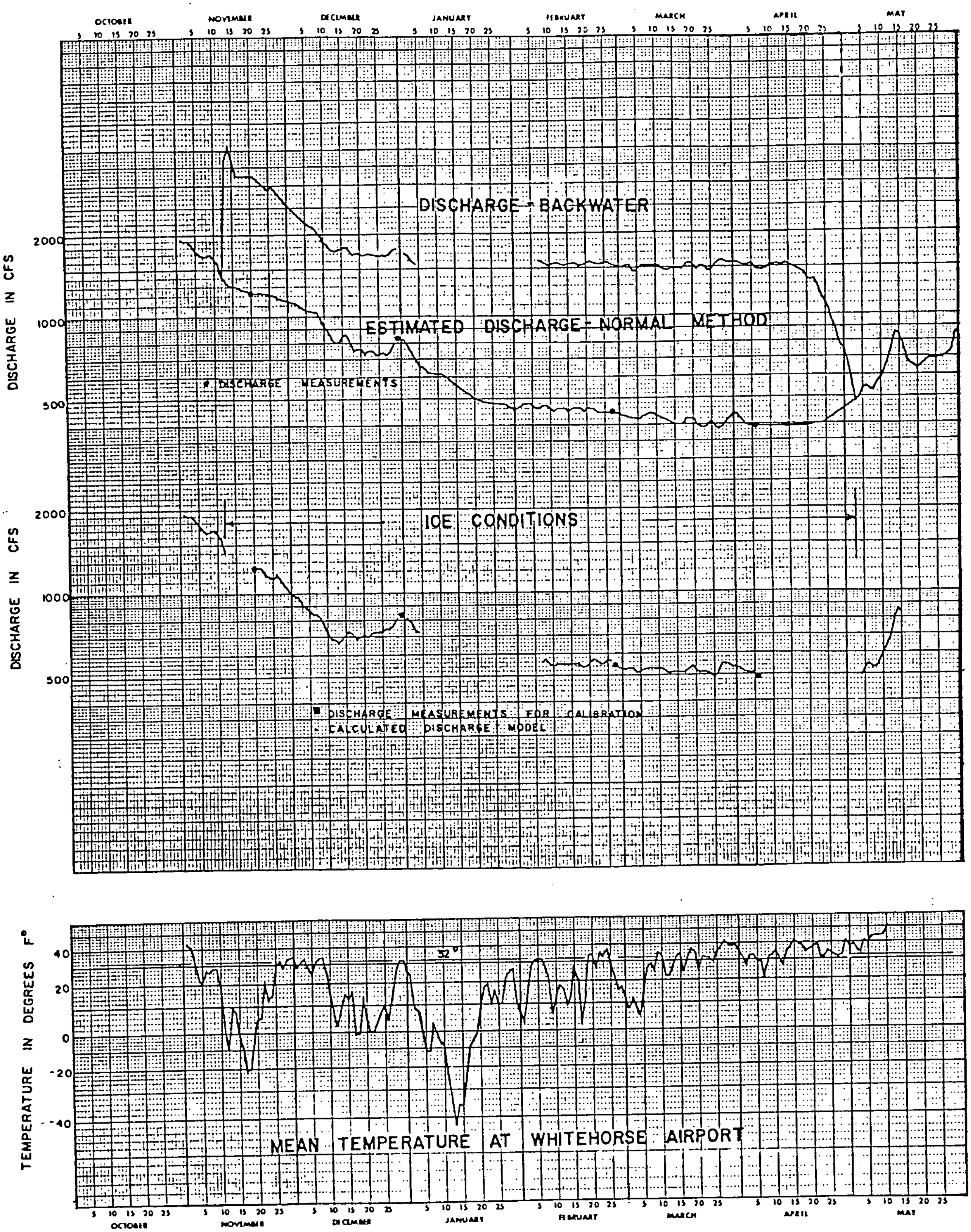


Figure 9. Hydrographs and Mean Temperature for Winter Period, 1969/70.

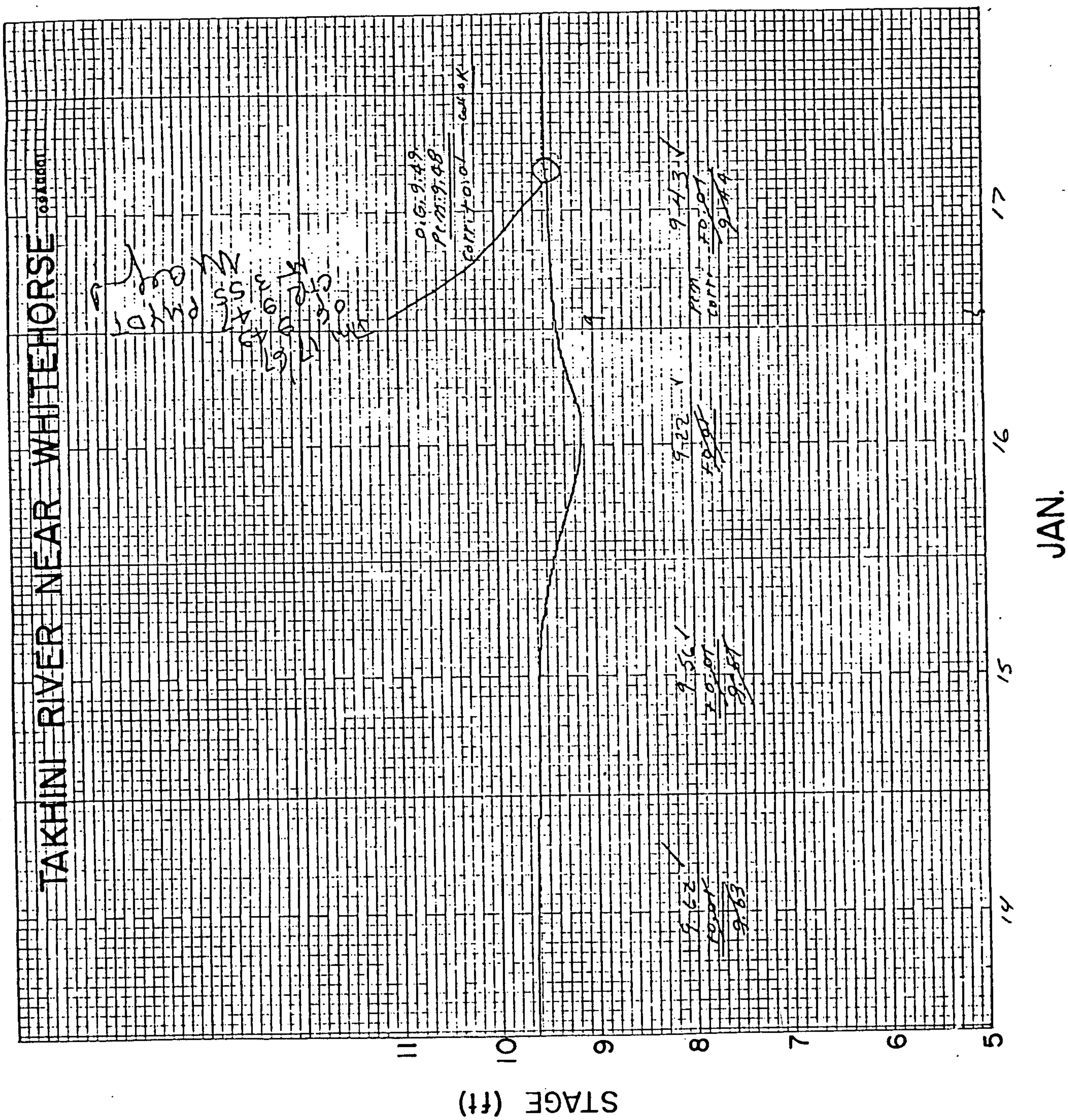


Figure 10. Chart Trace of Stage, January 14 to 17, 1967.