DRAFT

SUSITNA HYDROELECTRIC PROJECT

SLOUGH HYDROGEOLOGY REPORT

March 1983

SUS 165

DRAFT

SUSITNA HYDROELECTRIC PROJECT

SLOUGH HYDROGEOLOGY REPORT

MARCH 1983

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SUSITNA HYDROELECTRIC PROJECT
SLOUGH HYDROGEOLOGY STUDIES REPORT

1 - OBJECTIVES AND APPROACH

The objective of this study task is to understand slough hydrogeology under existing, natural conditions and thus provide a methodology by which post-project conditions can be predicted.

The study is comprised of four stages

- data collection
- data interpretation
- modeling of existing conditions to understand processes
- prediction of post-project conditions.

2 - FIELD DATA

2.1 - Collection

Field data collection has included:

(a) walk-overs and fly-cvers of the various sloughs between Talkeetna and Devil Canyon to appreciate their morphology

(b) excavation of test pits and installation of shallow wells in Sloughs 8A and 9 (spring 1982)

(c) measurement of slough profiles, cross sections and discharges

(d) deep drill holes and installation of water level and water temnerature measuring devices

(e) monitoring of groundwater levels, temperatures, river stages and discharge.

On-going work includes completion of recent deep drilling instrumentation and continuing monitoring of observation wells and upwelling temperatures.

Complete details of all field data are continued in the Slough Hydrology Interim Report (R&M Consultants 1982b).

2.2 - Interpretation

The sloughs are formed as side channel spillways during ice jam conditions at breakup or during ice front progression in early winter. Apart from these occasions and open water high flow conditions, there is no direct connection between the head end of the slough and the Susitna mainstem.

The groundwater provides two important functions with regard to the fisheries habitat. Firstly, during the spawning season it provides flow within the slough to allow the salmon to reach spawning areas in the upstream sections of the sloughs; secondly, the groundwater upwelling provides a nearly constant temperature for incubation of the salmon eggs and prevents freezing during the winter period.

The soil stratigraphy, determined by the drilling and test pit excavation, consists of a thin layer of topsoil overlying 2 to 6 ft of sandy silt. Below this is a heterogeneous alluvium comprising sand, silt, gravel, cobbles and boulders. It is probable that this alluvium has variable hydraulic conductivities both vertically and laterally, reflecting the moving stream bed location during deposition.

Observation well and piezometer installation indicate a general groundwater flow in a downstream direction and locally laterally toward the sloughs (Figures 1 and 2).

Temperature measurements in the mainstem show a constant temperature of approximately 0°C for the period of mid-October to mid-April. The temperature rises to a daily maximum of approximately 13°C in mid-July and then decreases to 0°C by mid-October. The slough temperatures show a similar pattern. The shallow groundwater temperatures vary between near 0°C in spring, up to 8°C by late summer. In general, those closest to the river show a faster response to river temperature than do those more distant (Figures 3 and 4). Upwelling temperatures measured by intergravel probes show a near constant annual temperature of 2 to 4°C.

The upwellings are visible as small "sand boils" at some discrete locations. However, sufficient measurements have not yet been made to determine if upwelling is actually occurring at a reduced rate in other areas where there is no evident surface expression. Localized upwelling is not unexpected due to the spatial variability of the alluvium. Visible upwelling probably occurs in areas where there is thin cover to a layer or lens with particularly high hydraulic conductivity.

2.3 - Determination of Material Properties

2.3.1 - Hydraulic Conductivity

Hydraulic conductivity has been estimated by the following methods.

(a) Grain Size - Based on grain size analyses from a bulk sample taken from the riverbank in slough 9 (Figure 5), the hydraulic conductivity is estimated at 170 ft/d from application of the Hazen formula (Terzaghi and Peck 1948).

(b) Similar Deposits - Measurements of the hydraulic conductivity of alluvial gravels in the city of Fairbanks give a value of 1,000 ft/d (Nelson 1978).

Based on these data a value of 200 ft/d has been used in analyses.

2.3.2 - Transmissivity

Transmissivity is defined as hydraulic conductivity multiplied by saturated thickness. In some techniques, the transmissivity is determined initially, and the hydraulic conductivity is calculated using an assumed saturated thickness. Transmissivity has been calculated based on the following methods.

(a) Flow Net - From a flow net sketch (Figure 6) and measurement of discharge into the upper reaches of slough 9 of 1 cfs, the transmissivity is estimated at 9,000 ft^2/d.

(b) Well Response - From the response of shallow wells to rapid changes in storage in the mainstem (Figure 7), the method described by Pinder, Bredehoeft and Cooper (1969), results in estimates of transmissivity in the range of 1200 to 306,000 ft^2/d. It appears that this method is not suitable for the particular site conditions. These results have therefore not been used.

2.3.3 - Thermal Properties

The thermal conductivity, specific heat and latent heat of the soils is required for the thermal analysis. No measurements were made in the field or laboratory. However, published data (Kersten 1942) allows the thermal conductivity and specific heat to be estimated with adequate accuracy from the natural moisture content and dry density of the soi . The values used in these analyses are summarized below.

	Thermal Conductivity (W/mK)		Specific Heat (Wyr/m^3K)	
	Unfrozen	Frozen	Unfrozen	Frozen
Silt	1.42	1.42	0.068	0.056
Sand gravel, cobbles, boulders	2.70	3.70	0.083	0.064

Latent heat of the soil is determined from natural moisture content (Lunardini 1981). For the soils in the slough areas the following values have been used.

	Latent Heat (Wyr/m^3)
Silt	1.525
Sand, gravel, cobbles, boulders	3.002

3 - ANALYSES

3.1 - Groundwater Flow

3.1.1 - Introduction

The objective of the groundwater flow modeling is to determine the flow patterns around the sloughs. Predicted head distributions are compared with actual water levels measured in the wells. Values of the transmissivity are altered until a reasonable agreement is reached and the model is then considered to be calibrated. It should be noted however that a particular head distribution can be obtained by a variety of boundary conditions and material properties. That is, a unique solution is not necessarily available.

3.1.2 - Method

The groundwater flow analyses have been undertaken using a 2-D plan finite element method with the flow integrated over depth, i.e., equipotentials are vertical. The transmissivity at any point depends on the depth of the bedrock (assumed impermeable) and the groundwater surface elevation. Analyses are therefore nonlinear and require iterations to define the steady state groundwater surface. Constant potentials and/or defined fluxes can be applied as boundary conditions.

3.1.3 - Geometry

Slough 9 was selected for modeling since it was the location of site investigation and drilling. The area modeled is shown in Figure 8 and the finite element mesh in Figure 9.

3.1.4 - Boundary Conditions

Four boundary conditions are required

- valley wall
- river boundary
- bedrock elevation
- streams and sloughs.

(a) Valley Wall

This is assumed as an impermeable barrier with zero fluxes. Initial analyses assumed the valley side to be vertical. This was subsequently changed to follow the approximate slope of the exposed valley wall.

(b) River Boundary

Water elevations at cross sections LRX-31 through LRX-36 have been computed using HEC-2 program for 13,400cfs (R&M 1982a). River water elevations were taken as the fixed boundary potentials based on interpolation between the calculated values at the cross sections.

(c) Bedrock Elevations

Bedrock elevation was assumed to be 100 ft below river water elevation and constant in a direction perpendicular to the river flow. As noted above, the valley wall was included along the lower margin of the model. In addition, some analyses included a postulated bedrock high in an attempt to achieve model calibration.

(d) Streams and Sloughs

Three-noded film elements were located along all streams and sloughs to allow the fluxes into or out of these surface waters to be computed. Measured elevations of the slough surface water were applied as boundary conditions.

3.1.5 - Material Properties

Based on the analyses described in Section 2.3, a value of 9,000 ft^2/d was used for the transmissivity, with a value of 0.18 for the storage coefficient.

3.1.6 - Results

The anlayses undertaken are discussed below.

- Run 1 applied only river water level boundary conditions and an impermeable valley wall with a fixed saturated thickness. Flow paths were all in a downstream direction with a gradient approximating the river gradient.

- For Run 2 the elements below the sloughs were given a transmissivity higher by a factor of 100. The objective of this was to simulate the high conveyance of the surface water in these areas.

- Run 3 used the same geometry as Run 2 with the incorporation of the valley wall slope. This was an attempt to better match the elevations in the area of wells 9-11 and 9-15.

- In Run 4 the sloping valley wall geometry is included, with the water elevations in the sloughs applied as fixed boundary conditions through 3-noded film elements. The contours are shown in Figure 10 and again indicate relatively poor agreement in the area of piezometers 9-11.

- Runs 5 and 6 represent modifications to the bedrock elevations in the vicinity of those piezometers. The bedrock high in this area was hypothesized based on the shape of the visible valley wall in this area. However, neither of these runs were able to exactly reproduce the actual water well elevations in this area (Figures 11, 12).

3.1.7 - Discussion and Conclusions

In general, the groundwater flow pattern as deduced from the model compares reasonably well with that measured in the field. It indicates that flow is primarily along the valley with local lateral flow toward the sloughs. Typical flow path lengths between entry and exit are of the order of 2,000 to 4,000 ft. However, the model was not able to reproduce the groundwater conditions in the area of well 9-11. This may be due to a number of reasons.

- A surface stream exists in that area, probably due to runoff from the upland areas. This could locally recharge the alluvial aquifer.

- Ponding of surface water behind the railway embankment has also been observed, and would lead to elevated groundwater levels.

- Soil stratigraphy adjacent to the valley wall may be much more variable than in the center of the valley. It may contain silty layers which would result in perched water table conditions. The wells in this area may therefore not be measuring the main alluvial water surface.

3.2 - Thermal Analyses

3.2.1 - General

Seasonal fluctuations in air temperature cause fluctuations in the soil temperature. The depth and magnitude of these changes will indicate the relative importance of air temperature compared with seasonal changes in river water temperature on the upwelling groundwater slough temperatures.

3.2.2 - Method

Analyses were made of a one-dimensional vertical idealization of the soil stratigraphy using a finite element transient heat transfer program which incorporates the latent heat of freezing of the soil.

3.2.3 - Geometry

Since the finite element code uses 2-D elements, the 1-D geometry was idealized as a 3.2-ft wide by 30-ft deep (1-m by 9.1-m) vertical strip. Six-noded triangular isoparametric elements were used with material properties for silt to a depth of 6.9 ft. Below this properties for sand and gravel were used to the base of the model.

3.2.4 - Boundary Conditions and Loads

The boundary at 30 ft is adiabatic, i.e., no heat flows across it, since the geothermal flow is considered negligible relative to surface temperature driven heat flows. The temperature applied to the ground surface was determined from the monthly average air temperature measured at Talkeetna multiplied by the "n" factor. The "n" factor for freezing is defined as the ratio of surface freezing index to air freezing index and for thawing is defined as a ratio of surface thawing index to air thawing index. Based on Lunardini (1981), "n freezing" was taken as 0.29 representing a snow-covered surface and "n thawing" was taken as 0.37 representing a surface covered by trees, brush, etc. The monthly average surface temperature was therefore determined by multiplying the monthly average air temperature by the appropriate "n" factor depending on the season. This ensures reasonable surface freezing and thawing indexes although it does not necessarily accurately reflect the variation of surface temperature versus time nor the variations which may occur due to different depths of snow cover through the winter or from year to year.

3.2.5 - Properties

Thermal conductivity and specific heat were determined from published data for similar materials, and are detailed in Section 2.3.3. Research has indicated that unfrozen moisture exists in soils below 0°C and thus the latent heat is released over a range of temperatures as indicated in Table 1.

3.2.6 - Results and Conclusions

The results of the thermal analyses are shown in Figures 13 and 14. The surface temperature follows an approximate sinusoidal shape reflecting the seasonal temperature variations. The maximum depth of freezing is approximately 6 ft and at a depth of 10 ft the annual temperature range is less than 2°C.

An approximate analytical solution (Stefans equation) gives results which are in agreement with the finite element modeling in predicting a maximum freezing depth of approximately 6 ft.

Since the depth of the groundwater table is typically greater than 6 ft, the impact of seasonal air temperature variations does not appear to be significant in determining the groundwater temperatures.

* But g.w. inflow [illegible] through river doesn't come from below

3.3 - Coupled Thermal and Groundwater Flow

3.3.1 - Method

Coupled thermal and groundwater flow has been analyzed by considering conditions along a flow path, i.e. 1-D solutions. Two processes are significant

- heat exchange between the flowing pore water and the soil mineral skeleton

- longitudinal dispersion.

(a) Heat Exchange

The absorption of heat by the mineral skeleton from the water is analagous to the sorption process whereby chemical species in solution are sorbed onto soil particles. Therefore the equations used for the former can be modified to handle thermal considerations. The relative volumetric heat capacities of the soil and water are

$$V_w = C_w n$$
$$V_s = C_s(1-n)$$

where

V_w, V_s = volumetric heat capacities of water and soil skeleton respectively

C_w, C_s = volumetric specific heats of water and soil respectively

n = porosity

The ratio of heat capacities is therefore

$$V_s/V_w = \frac{Cs\ (1-n)}{C_w n}$$

The similarity between the retardation factor or contaminant and for thermal transport is illustrated by the following.

For contaminant transport

$$Rd = 1 + \frac{\rho b}{n} Kd \qquad \text{(Freeze and Cherry 1979)}$$

Rd = retardation factor

ρ_b = bulk mass density

n = porosity

Kd = distribution coefficient

For thermal transport

$Rd = 1 + V_s/V_w$

Also, for both

$$\frac{v}{v_r} = Rd$$

where

v = average linear velocity of groundwater

v_r = average retarded velocity of the mean concentration or temperature.

(b) Longitudinal Dispersion

The concentration of a dissolved species transported by groundwater is described by the following

$$D \frac{\partial^2 c}{\partial x^2} - v \frac{\partial c}{\partial x} = \frac{\partial c}{\partial t}$$

where

D = coefficient of hydrodynamic dispersion

v = average linear groundwater velocity

c = concentration

x = coordinate direction

t = time

For transport in permeable media, the molecular diffusion component in the coefficient of

hydrodynamic dispersion can be neglected.
Therefore

$$D = \alpha v$$

where α = dispersivity

For heat transport, the temperature is equivalent to concentration, and therefore the governing equation may be written

$$D \frac{\partial^2 T}{\partial x^2} - v \frac{\partial T}{\partial x} = \frac{\partial T}{\partial t}$$

where T = temperature.

For a step function input boundary condition, at large x or t, the solution is (Freeze and Cherry 1979)

$$T/T_0 = 1/2 \ \operatorname{erfc}\left(\frac{x - vt}{2\sqrt{Dt}}\right)$$

where

T = temperature at x, t
T_0 = step temperature at $x = 0$, $t>0$
erfc = complementary error function.

(c) Combined Heat Exchange and Dispersion

The combined effects of heat exchange and dispersion can be approximated by replacing v by v_r, and therefore

$$T/T_0 = 1/2 \quad \mathrm{erfc}\left(\frac{x - v_r t}{2\sqrt{Dt}}\right)$$

where v_r = average retarded velocity.

3.3.2 - Geometry

Analyses have employed 1-D methods, i.e. consideration of longitudinal dispersion along a flow line. Typical flow path lengths are in the order of 1,000 to 4,000 ft in plan.

3.3.3 - Boundary Conditions

The boundary conditions requiring definition are temperature and average groundwater velocity.

(a) Temperature

The river temperature is 0°C between mid-October and mid-April, and rises to a daily maximum of approximately 13°C in July. The mean annual temperature is approximately 3°C. For the purpose of preliminary analysis, the annual temperature variation has been approximated by a square wave with 6 months at 0°C and 6 months at 6°C.

(b) Average Groundwater Velocity

The average groundwater velocity is defined by

$$v = Ki/n$$

where

v = average groundwater velocity
K = hydraulic conductivity
i = hydraulic gradient
n = porosity.

The ranges of these parameters result in a best estimate average groundwater velocity of 22.2 ft/d (K = 200 ft/d, i = 2 x 10^{-3}, n = 0.18).

(c) Retarded Groundwater Velocity

Using the relationships in Section 3.3.1(c) and a porosity of 18 percent, the retardation factor has been calculated to be 3. The average retarded groundwater velocity is therefore 0.74 ft/d (270 ft/yr).

(d) Square Wave Solution

The annual variation in river temperature can be coarsely approximated by a square wave with 50 percent duty cycle, representing average summer and winter temperatures of 6°C and 0°C respectively. This results in a mean annual river temperature of 3°C. The solution for the propagation of a square wave along a flow line can be developed by superposition of a series of pulses of 6°C for 6 months at intervals of 6 months. Each pulse comprises two step inputs as shown in Figure 15.

3.3.4 - Results and Conclusions

Groundwater temperatures along a flow line from the mainstem have been calculated using the equation given in 3.3.1(c) above. Average retarded velocities of 270 ft/yr 1000 ft/yr and 2700 ft/yr have been used. The first value (270 ft/yr) is based on the best estimate of properties: the other two values are included to examine the sensitivity of the temperature range to the retarded velocity. They represent for example, an increase in the hydraulic conductivity by factors 3.7 and 10.

Figures 16, 17, and 18 show the groundwater temperatures along the flow line for summer and winter. The annual temperature fluctuation at various distances is summarized in Table 2. This shows that the temperature is 3 $\pm$ 1.5°C at distances greater than 400 feet from the mainstem, for average retarded velocities of 1000 ft/yr or less. For a retarded velocity of 2700 ft/yr the temperature fluctuation is 3 $\pm$ 1.5°C for distances greater than 2400 ft. Since the flow line from mainstem to slough is generally greater than 500 feet and typically 1000 to 4000 ft dispersion along the flow line and heat exchange between the water and soil particles appears to be a reasonable mechanism to account for the nearly constant slough upwelling temperatures.

3.4 - Discussion

The 2-D groundwater flow analyses show that the flow direction is principally downstream and this accords well with field observations. Local details of the groundwater elevation are not reproduced by the model and this may be due to a variety of factors as discussed in Section 3.1. The thermal modeling indicates that the atmospheric conditions do not penetrate deeper than a few feet into the subsoil. They are therefore not considered to be a dominant factor in determining groundwater temperature conditions. The coupled thermal and groundwater flow analyses show that the temperatures in the mainstem Susitna can be transferred into the groundwater. However, dispersion and interchange of thermal energy between the water and soil skeleton along the long flow paths dampens the seasonal fluctuations. As a result, the exit temperatures measured in slough upwellings are close to the mean annual average temperature of the mainstem Susitna.

4 - POST-PROJECT IMPACTS

4.1 - Types of Changes

Operation of the power plants will result in modification of the seasonal discharge pattern compared to the existing natural flow regime. In particular, winter flows will be higher (approximately 10,000 cfs, compared with 1,000 - 2,000 cfs at present), and the spring snowmelt flood peak will be substantially reduced in order to store water in the Watana reservoir. Summer and fall variations in discharge due to rainfall events will also be reduced in magnitude due to the routing of the flow through the reservoir. Because of the large storage volume of the Watana reservoir, outlet temperatures will be cooler in the early summer and warmer in the fall and winter. However, the mean annual river temperature post-project will be close to the natural mean annual river temperature (Acres 1983).

Scour and deposition will take place downstream from the project as the river attains a new equilibrium under post-project flow conditions. However, the principal material properties of the alluvium are not anticipated to be modified.

4.2 - Description of Impact

4.2.1 - Watana Construction

Since there will be no change in mainstem discharge and hence no change in water level, there will be no change in groundwater conditions in the vicinity of the sloughs downstream from Watana. Additionally, water temperatures will also be unchanged.

4.2.2 - Watana Impoundment

(a) Mainstem

As a result of the decreased summer flows during filling, water levels in the main stem of the river will be reduced between Watana and Talkeetna. This will in turn cause a reduction in adjacent groundwater levels. However, the groundwater level changes will be confined to the river floodplain area. The groundwater level will be reduced by about 2 to 4 feet (0.6 to 1.2 m) during the summer near the streambank with less change occurring with distance away from the river.

(b) Sloughs

The reduced mainstem flows and associated lower Susitna River water levels will slightly modify the groundwater relationship between the mainstem and the sloughs. The mainstem water levels upstream and downstream of a slough control the groundwater gradient in the slough and since both levels change by approximately the same amount for different flows, the gradient will remain the same.

Because the sloughs are adjacent to the mainstem of the river, the groundwater level in the sloughs will be lowered by the same amount as the stage change within the mainstem. This will have the effect of dewatering the areas in the sloughs between where the groundwater table currently intersects the slough and where the lowered groundwater table will intersect the slough.

Data to confirm the areal extent of upwelling at various flows are unavailable at this time. However, it is believed that slough upwelling extends from the slough mouths well upstream to the steeper reaches of the sloughs near the upstream berms. Therefore, the areas that will be dewatered will generally be the steep upstream ends of the sloughs. If both mainstem stage and groundwater level change by approximately 2 feet (0.6 m), the potential loss in groundwater upwelling length will be the stage change (2 feet, or 0.6 m) multiplied by the slough gradient. Using the 18.6 foot per mile (3.5 m per km) gradient measured in Slough 9, the dewatered length would be approximately 570 feet (171 m). This is 10 percent of the slough length and, if a uniform upwelling rate is assumed over the entire length of the slough, the decrease in slough discharge at the mouth will also be 10 percent.

4.2.3 - Watana Operation

(a) Mainstem

Groundwater impacts between Devil Canyon and Talkeetna during summer will be similar to those described in Section 4.2.2 and will be confined to the river area. Since powerhouse flows will generally be greater than filling flows during summer, the groundwater level change from natural conditions will be slightly less than during filling. During winter, increased ice staging will occur during freeze-up and hence groundwater level will be increased along ice-covered sections of the mainstem.

(b) Sloughs

During winter in the Devil Canyon to Talkeetna reach, some of the sloughs (i.e., those nearer Talkeetna) will be adjacent to an ice-covered section of the Susitna River. In ice-covered sections, the Susitna River will have staged to form an ice cover at project operation flows of about 10,000 cfs. The associated water level will be a few feet above normal winter water levels and will cause an increase in the groundwater table. This will in turn cause an increase in groundwater flow in the sloughs adjacent to an ice covered reach of the river.

Sloughs upstream of Gold Creek, in the vicinity of Portage Creek, may be adjacent to open water sections of the Susitna River. Because flows will average approximately 10,000 cfs in winter, the associated water level will be less than water levels occurring under the natural freeze-up process. Hence, the groundwater table will be lower. Sloughs in this area may experience a decrease in groundwater flow in the winter. ?

During the summer, the mainstem-slough groundwater interaction will be similar to that discussed in Section 4.2.2, with the exception that operational flows will be greater than the downstream flows during filling, and thus, the groundwater table will be closer to the natural elevation than during filling.

Preliminary investigations indicate that groundwater upwelling temperatures in sloughs reflect the long-term average water temperature of the Susitna River which is approximately 3° (37.4°) (Section 3.4). In the Devil Canyon to Talkeetna reach, the long term average temperature will not change significantly from pre-project conditions (Acres 1983). Hence, groundwater upwelling temperatures will also not change significantly.

4.2.4 - Devil Canyon Construction

Since the construction at Devil Canyon will not modify the discharge, the groundwater impacts discussed under Watana operation (Section 4.2.3) will remain relevant during this period.

4.2.5 - Devil Canyon Impoundment

No major groundwater impacts are anticipated during the filling of the Devil Canyon reservoir. There may be a slight decrease in the groundwater table caused by the reduced filling flows. A decrease in the groundwater level in the same proportion as the decrease in mainstem stage would be expected.

4.2.6 - Devil Canyon Operation

Downstream flows and hence groundwater impacts will be similar to those occurring with Watana operating alone.

The average annual temperature at Sherman is calculated to be approximately 4°C (Acres 1983). This is an increase of about 1°C above the natural long-term average temperature. Therefore, based on the groundwater studies described in Section 3.3 and the above preliminary analysis, the slough upwelling temperature in the vicinity of Sherman may increase approximately 1°C.

References

Acres American Incorporated. 1983. Susitna Hydroelectric Project, Application for License for Major Project.

Freeze, R.A. and J.A. Cherry. 1979. Groundwater. Prentice Hall.

Kersten, M.S. 1949. Thermal Properties of Soils. University of Minnesota, Engineering Experiment Station Bulletin 28.

Lunardini, J.F. 1981. Heat Transfer In Cold Climates. Van Nostrand Reinhold.

Nelson, G.L. 1978. Hydrologic Information for Land-use Planning, Fairbanks Vicinity, Alaska. U.S. Geological Survey, Open File Report 78-959, Anchorage, Alaska.

Pinder, G. F., J.D. Bredehoeft and H.H. Cooper. 1969. Determination of Aquifer Diffusivity From Aquifer Response to Fluctuations in River Stage. Water Resources Research, Volume 5, No. 4.

R&M Consultants, Inc. 1982a. Susitna Hydroelectric Project, Hydraulic and Ice Studies. Prepared for Acres American Incorporated.

______, 1982b. Susitna Hydroelectric Project, Slough Hydrology Interim Report. Prepared for Acres American Incorporated.

Terzaghi, R. and R.B. Peck. 1948 Soil Mechanics In Engineering Practice. Wiley.

TABLE 1

LATENT HEAT DISTRIBUTION FOR SILT

T (°C)	Latent Heat (Wyr/m^3)
- 0.11	0.184
- 0.2	0.388
- 0.5	0.320
- 1.0	0.209
- 2.0	0.140
- 3.0	0.076
- 4.0	0.066
- 6.0	0.060
- 8.0	0.041
-10.	0.029
-12.	0.012
Total	1.525

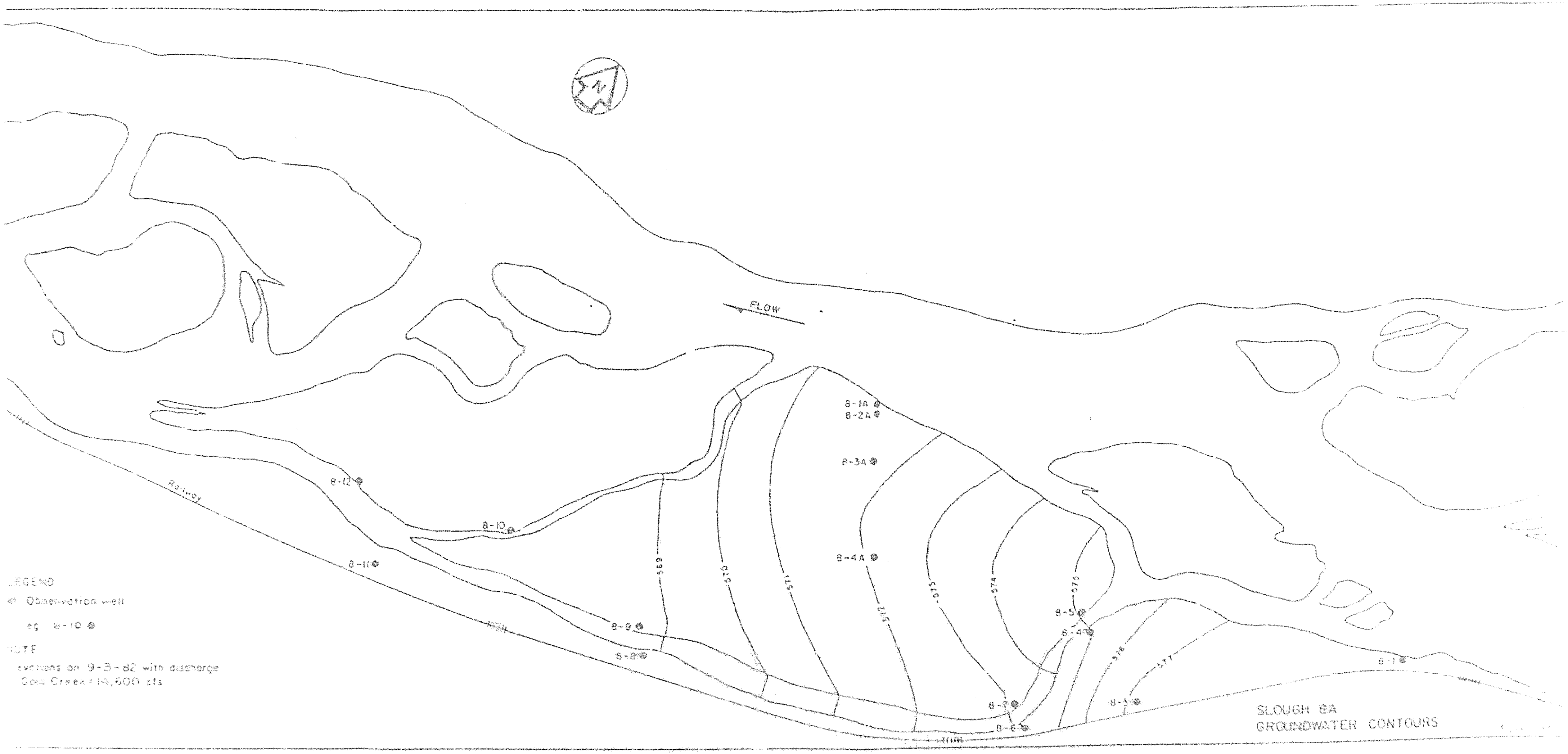
LATENT HEAT DISTRIBUTION FOR SAND AND GRAVEL

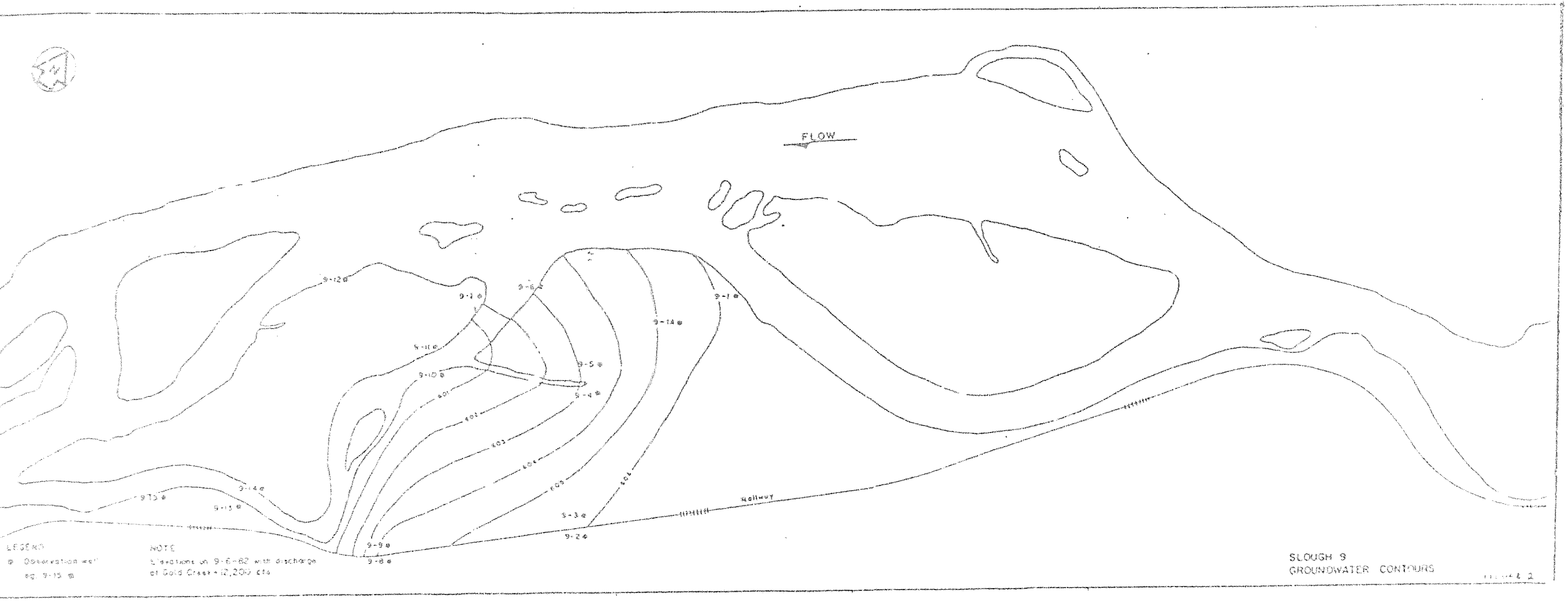
T (°C)	Latent Heat (Wyr/m^3)
- 0	1.734
- 0.1	0.951
- 0.2	0.317

TABLE 2

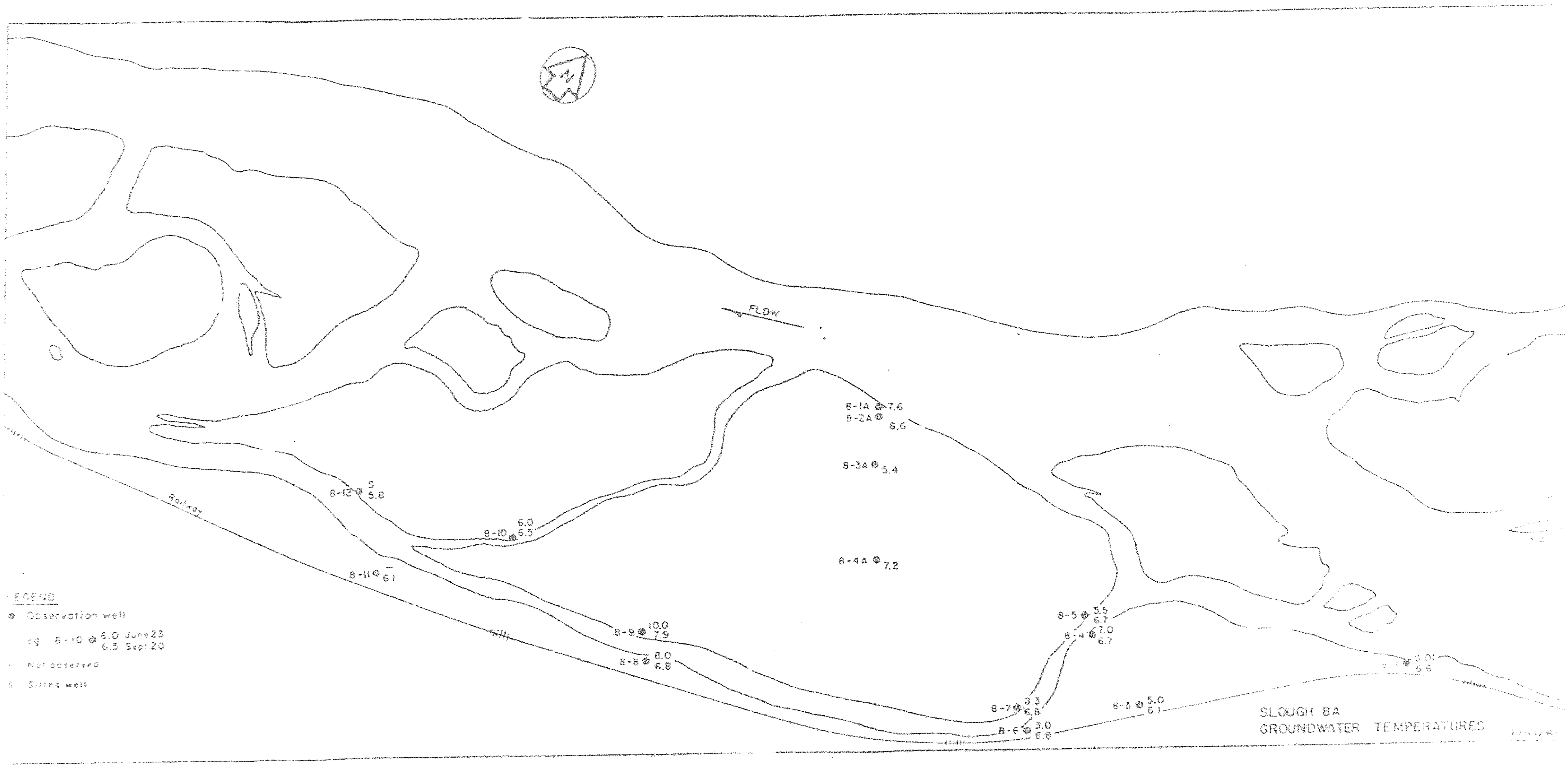
COMPUTED SEASONAL GROUNDWATER TEMPERATURE FLUCTUATIONS

Distance	Temperature Fluctuation (°C)					
(ft)	V_r=270 ft/yr		V_r=1000 ft/yr		V_r=2700 ft/yr	
	min	max	min	max	min	max
0	0	6	0	6	0	6
200	2.24	3.76	0.65	5.35	0.02	5.98
500	2.80	3.20	1.62	4.38	0.15	5.85
1000	2.94	3.06	2.48	3.52	0.53	5.47
2000	2.99	3.01	2.88	3.12	1.20	4.80

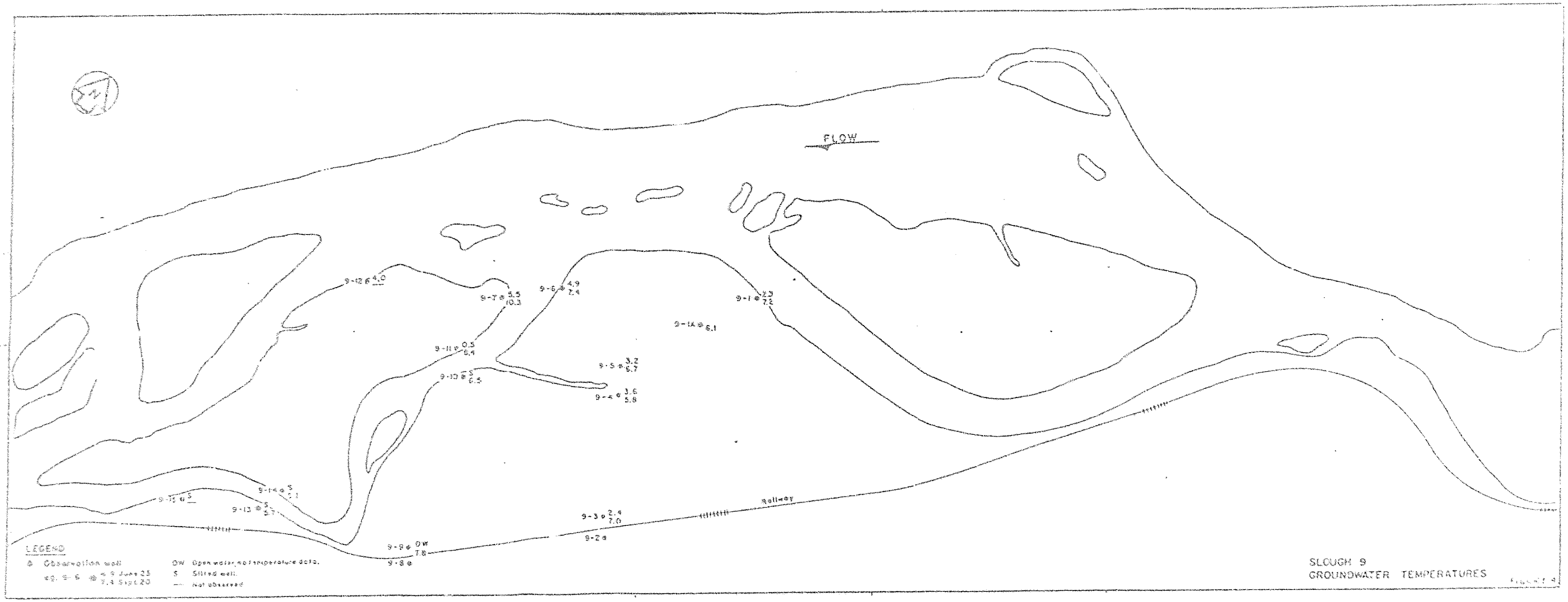

N
FLOW
Railway
8-1A
8-2A
8-3A
8-4A
8-1
8-3
8-4
8-5
8-6
8-7
8-8
8-9
8-10
8-11
8-12
569
570
571
572
573
574
575
576
577
LEGEND
Observation well
eg 8-10
on 9-3-82 with discharge
Gold Creek = 14,600 cfs
SLOUGH 8A
GROUNDWATER CONTOURS



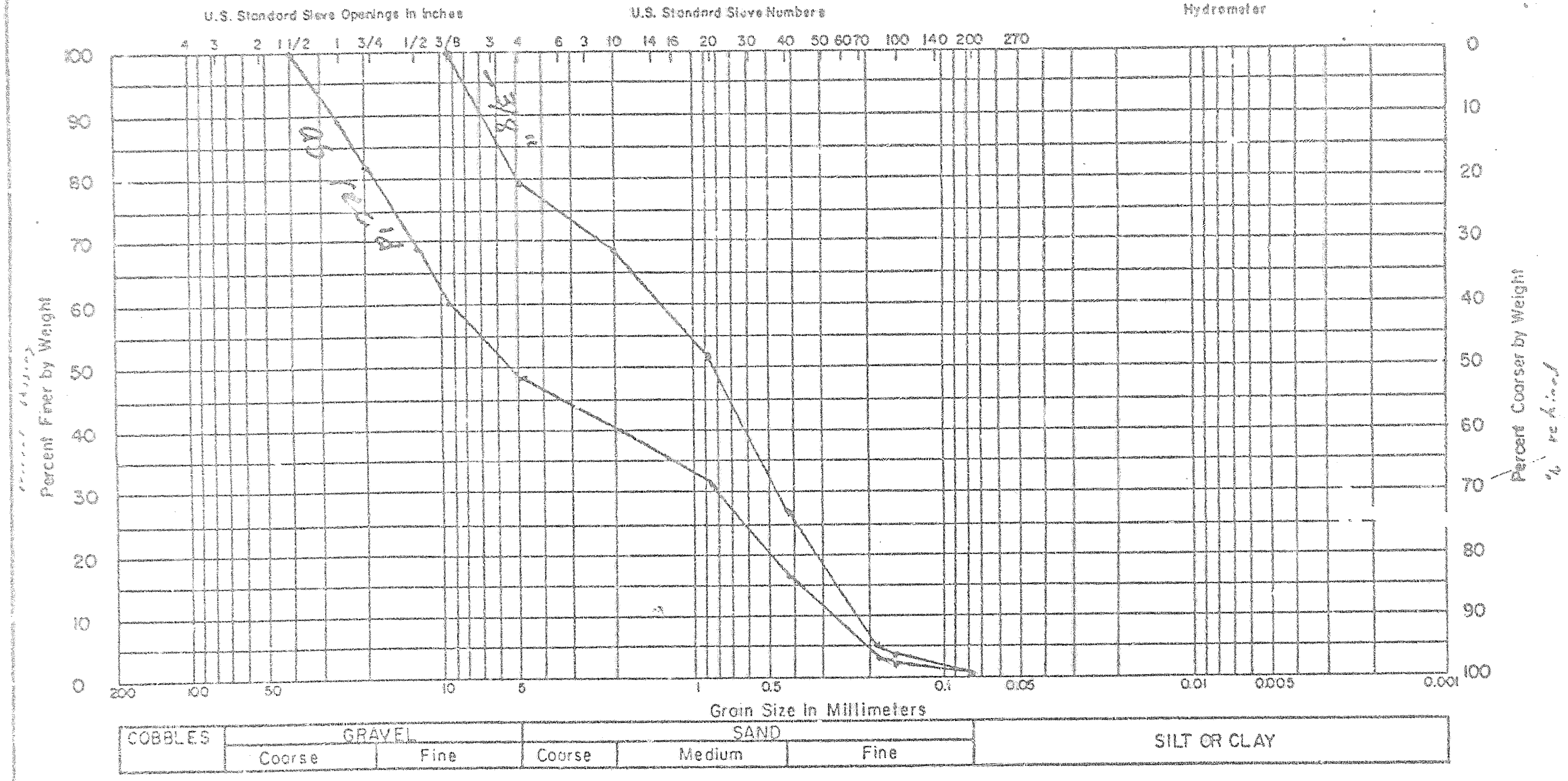
SLOUGH 9
GROUNDWATER CONTOURS



SLOUGH 8A
GROUNDWATER TEMPERATURES



SLOUGH 9
GROUNDWATER TEMPERATURES

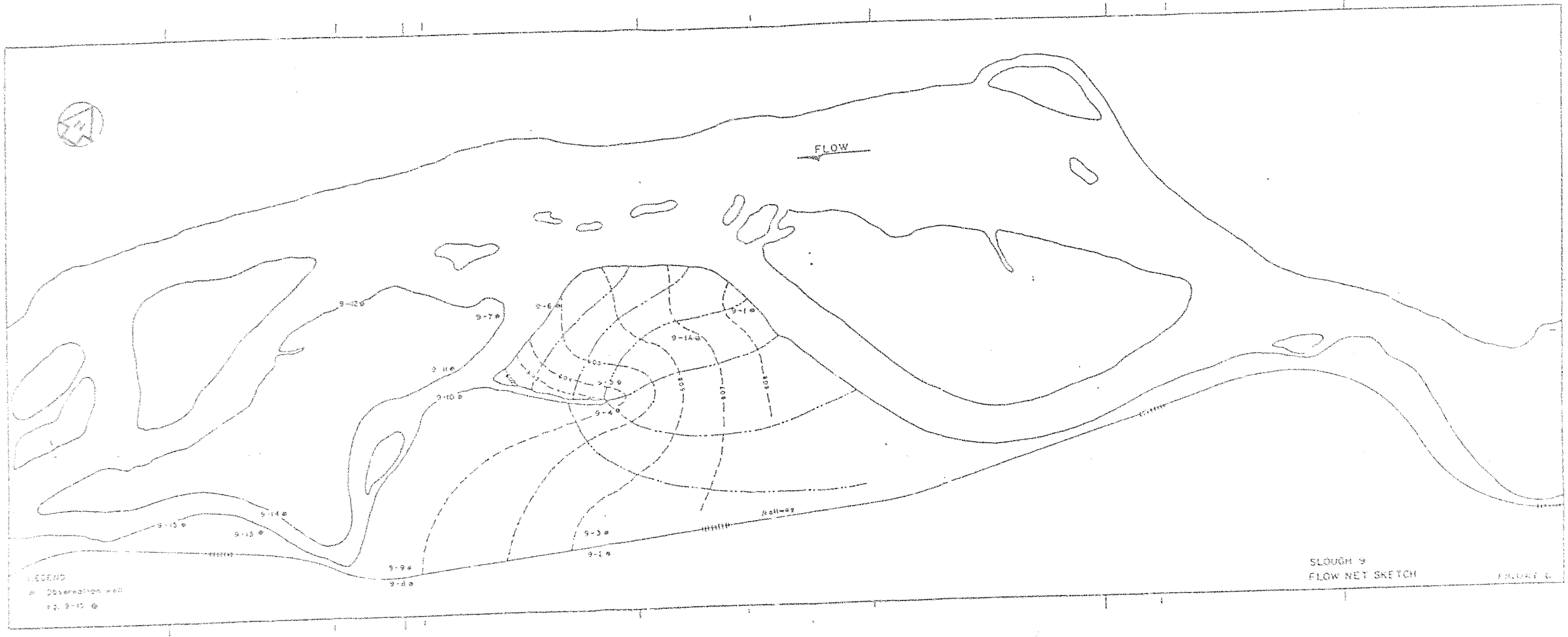


SAMPLE NO.	MOISTURE CONTENT	DRY DENSITY	LL	PI	CLASSIFICATION & DESCRIPTION
252314					
					Average Particle size = D_{50} = 0.85 mm
					uniformity coeff = D_{60}/D_{10} = $1.4/0.23$ ≈ 6 well graded
					Sample was tested without gravel component

R&M CONSULTANTS, INC.

DRAWN BY
APPROVED BY
DATE 9-23
PROJECT NO.

FIGURE 5


FLOW
Railway
SLOUGH 9
FLOW NET SKETCH

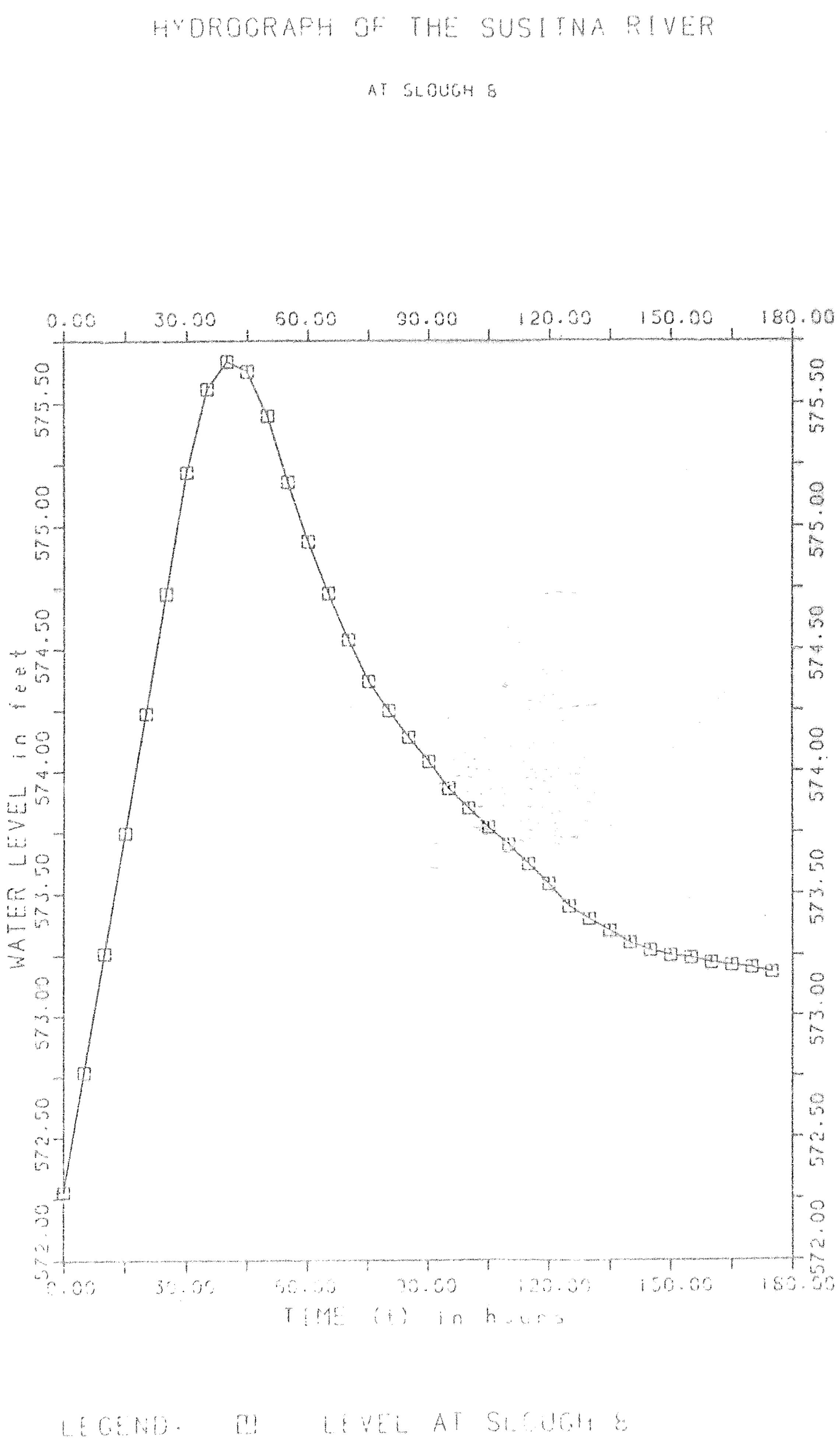
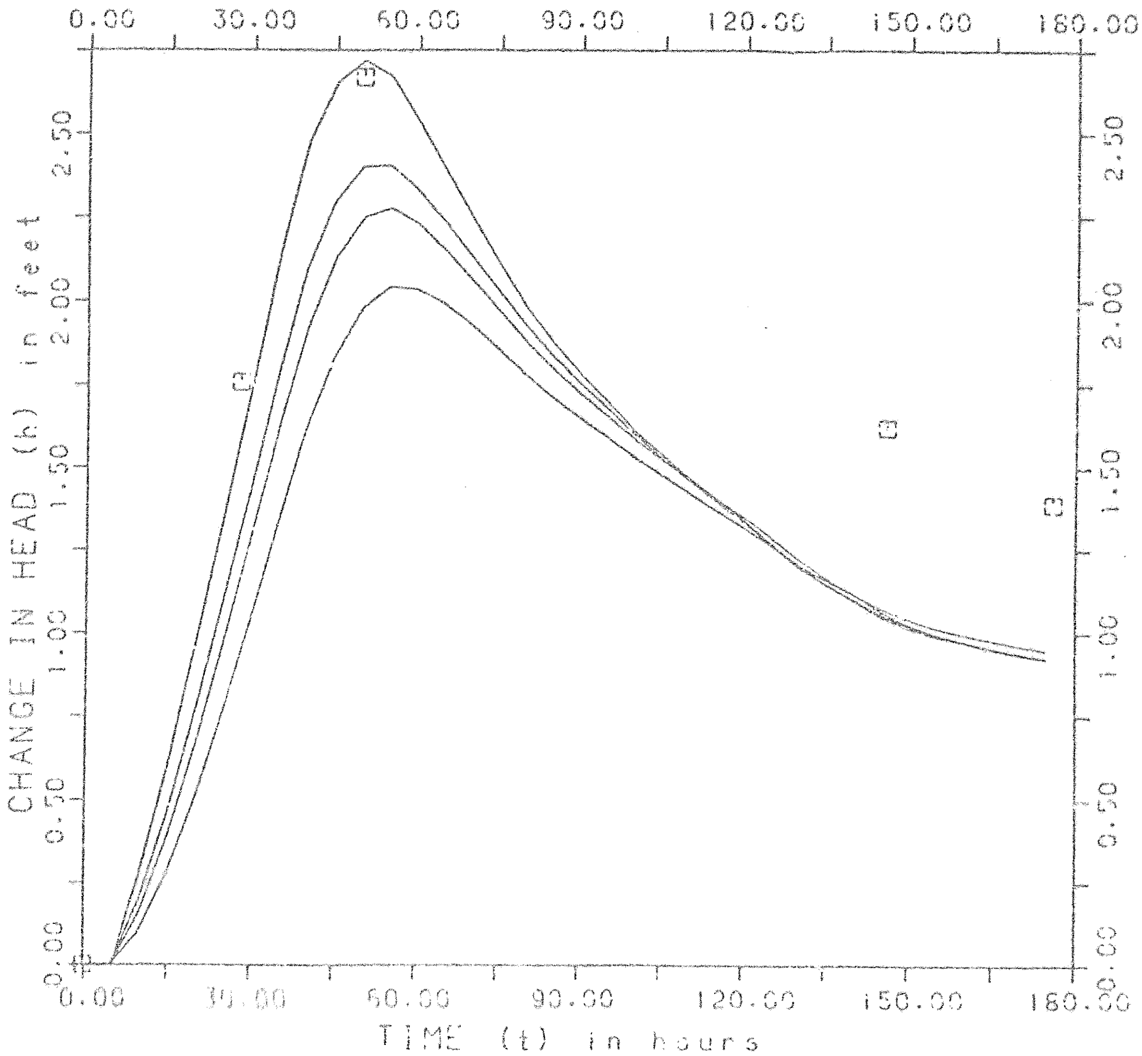

HYDROGRAPH OF THE SUSITNA RIVER
AT SLOUGH 8
WATER LEVEL in feet
TIME (t) in hours
LEGEND: ⊡ LEVEL AT SLOUGH 8

FIGURE 7a

AQUIFER DIFFUSIVITY FROM AQUIFER RESPONSE TO

FLUCTUATIONS IN SUSITNA RIVER AT SLOUGH 8

WELL 8-1A



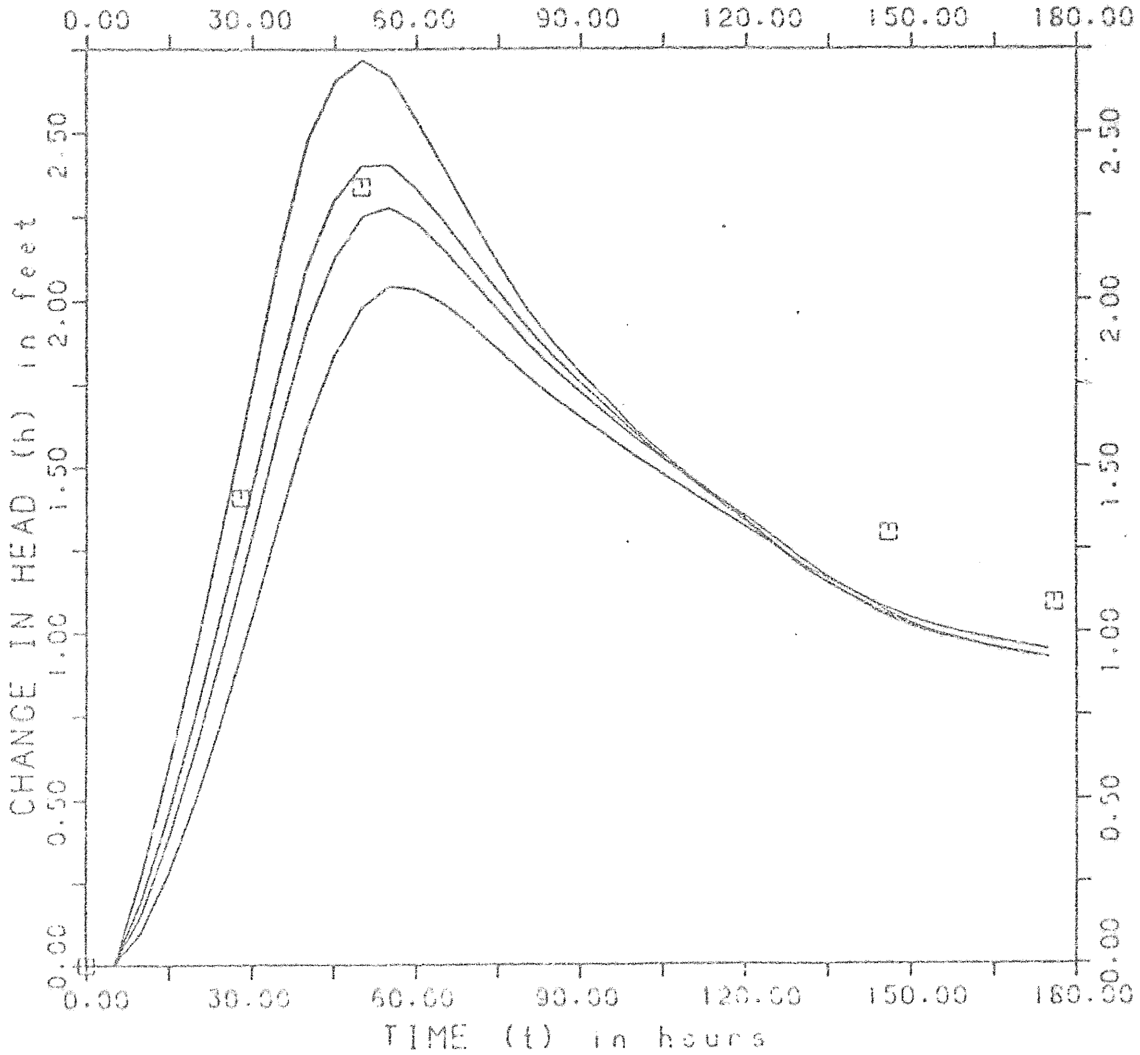
LEGEND: ⊡ WELL 8-1A (x=30 ft)
- RESPONSE IF U=0.600
- RESPONSE IF U=1.200
- RESPONSE IF U=1.400
- RESPONSE IF U=1.800

FIGURE 7b

AQUIFER DIFFUSIVITY FROM AQUIFER RESPONSE TO

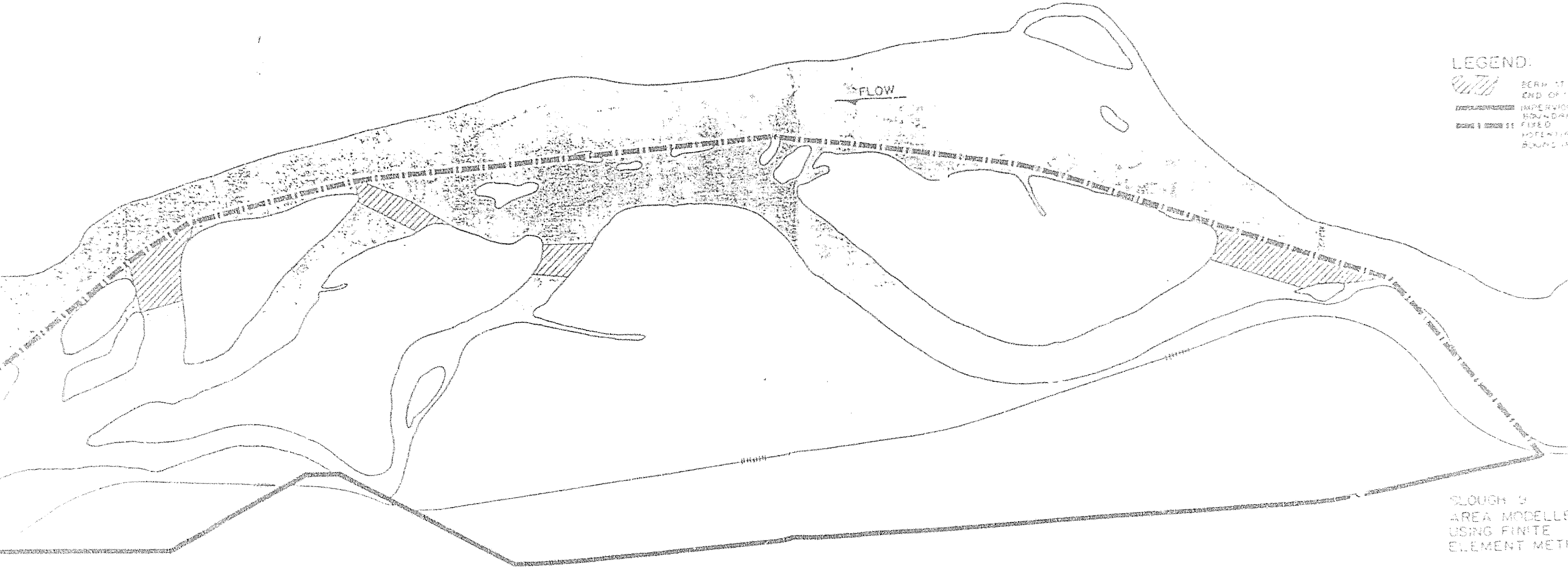
FLUCTUATIONS IN SUSITNA RIVER AT SLOUGH 8

WELL 8-2A



LEGEND: ⊡ WELL 8-2A (x=200 ft)
- RESPONSE IF U=0.800
- RESPONSE IF U=1.200
- RESPONSE IF U=1.400
- RESPONSE IF U=1.800

FIGURE 7c



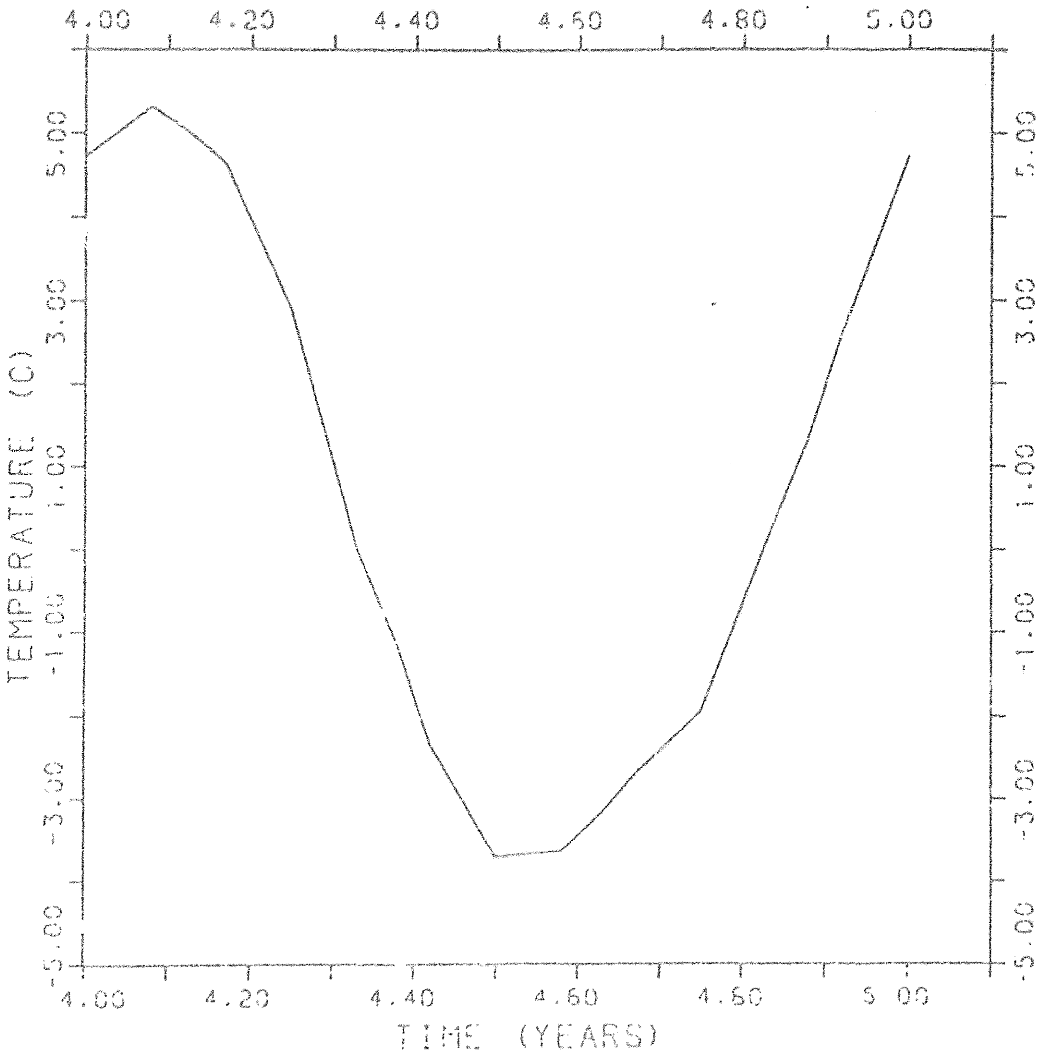
SLOUGH 9
AREA MODELLED
USING FINITE
ELEMENT METHOD

FIGURE 3

GROUND SURFACE TEMPERATURE

SUSITNA RIVER VALLEY

N-FREEZE = 0.29, N-THAW = 0.37



LEGEND: - SURFACE TEMPERATURE

FIGURE 13

TEMPERATURE VARIATION WITH DEPTH

SUSITNA RIVER VALLEY

N-FREEZE = 0.29, N-THAW = 0.37, (10 YEARS)

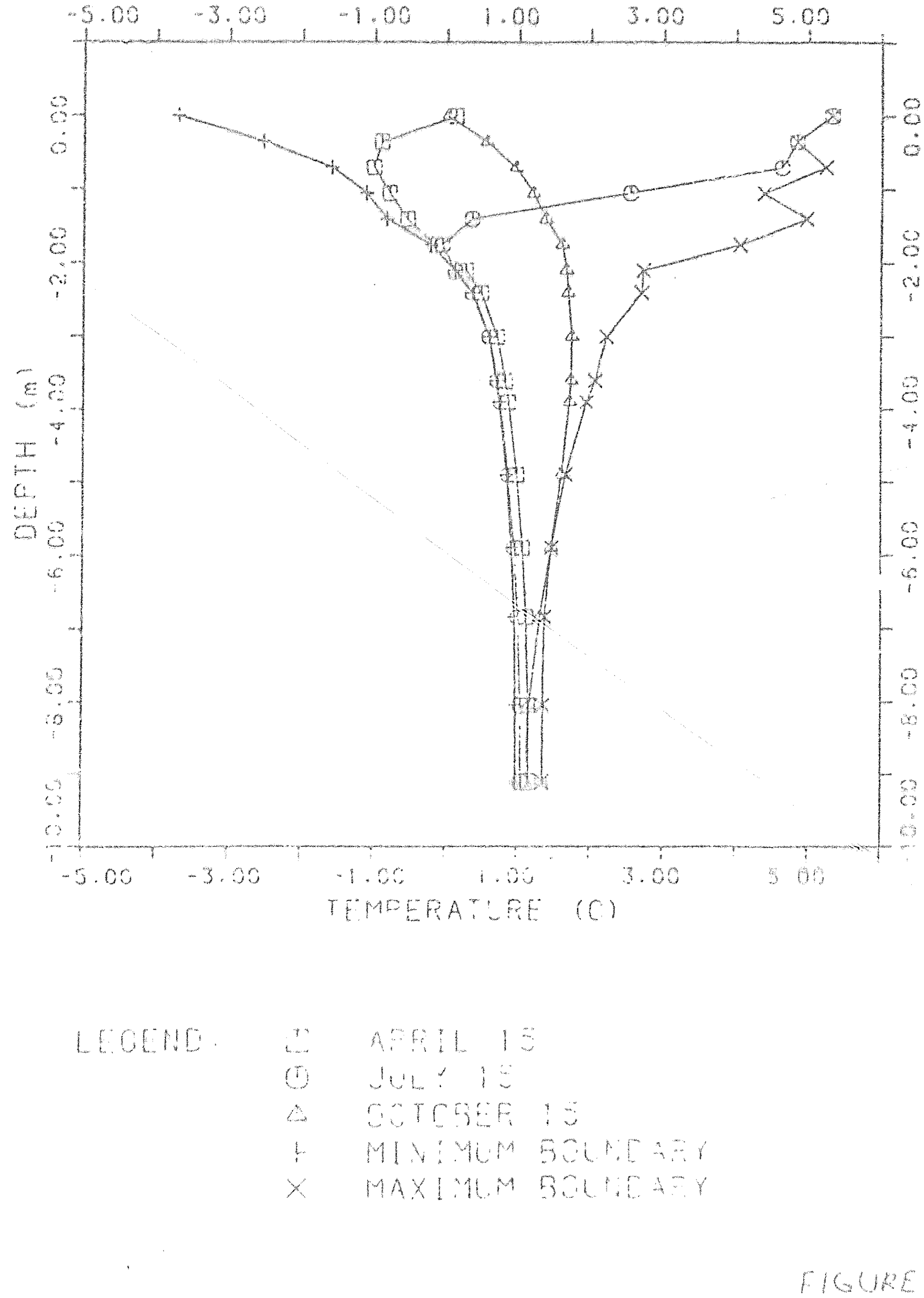
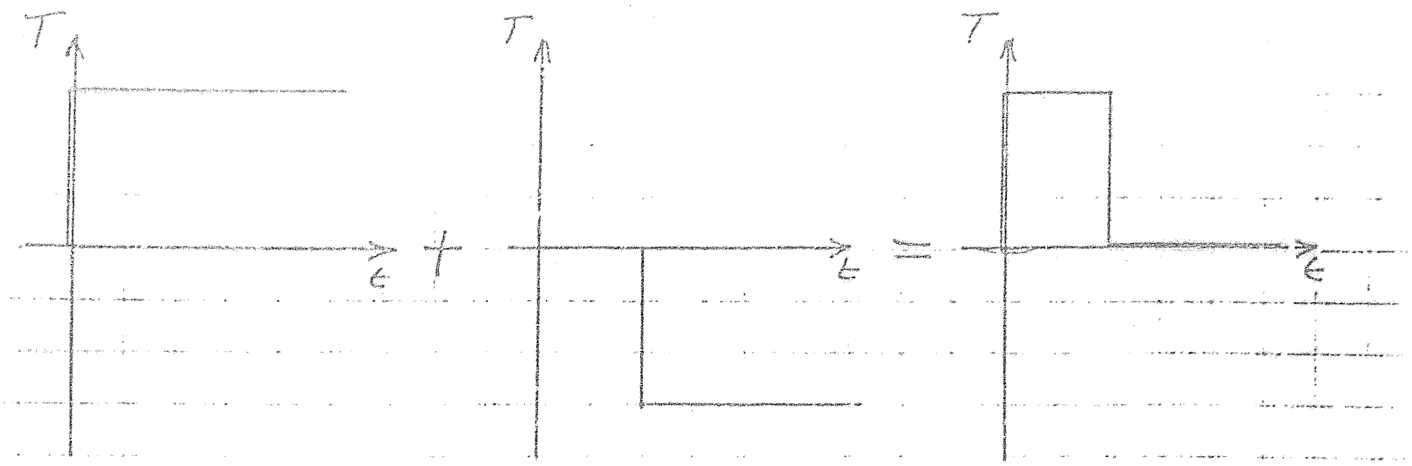


FIGURE 14

SUM OF TWO STEP INPUTS = PULSE



SUM OF EQUALLY SPACED PULSES = SQUARE WAVE

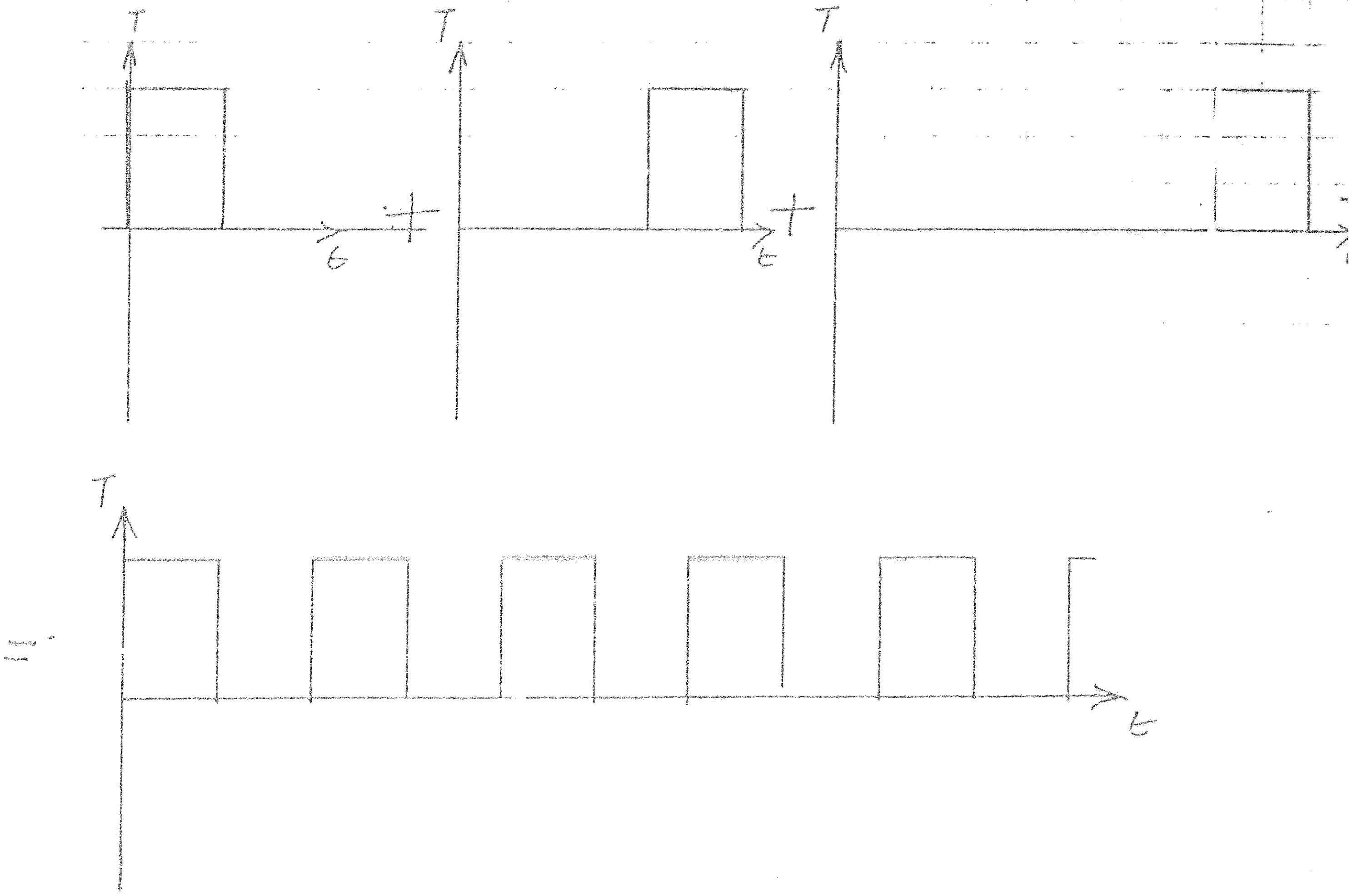


FIGURE 15

DEVELOPMENT OF SQUARE WAVE

SUSITNA RIVER VALLEY

TEMPERATURE VERSUS DISTANCE

VELOCITY = 270 ft/yr

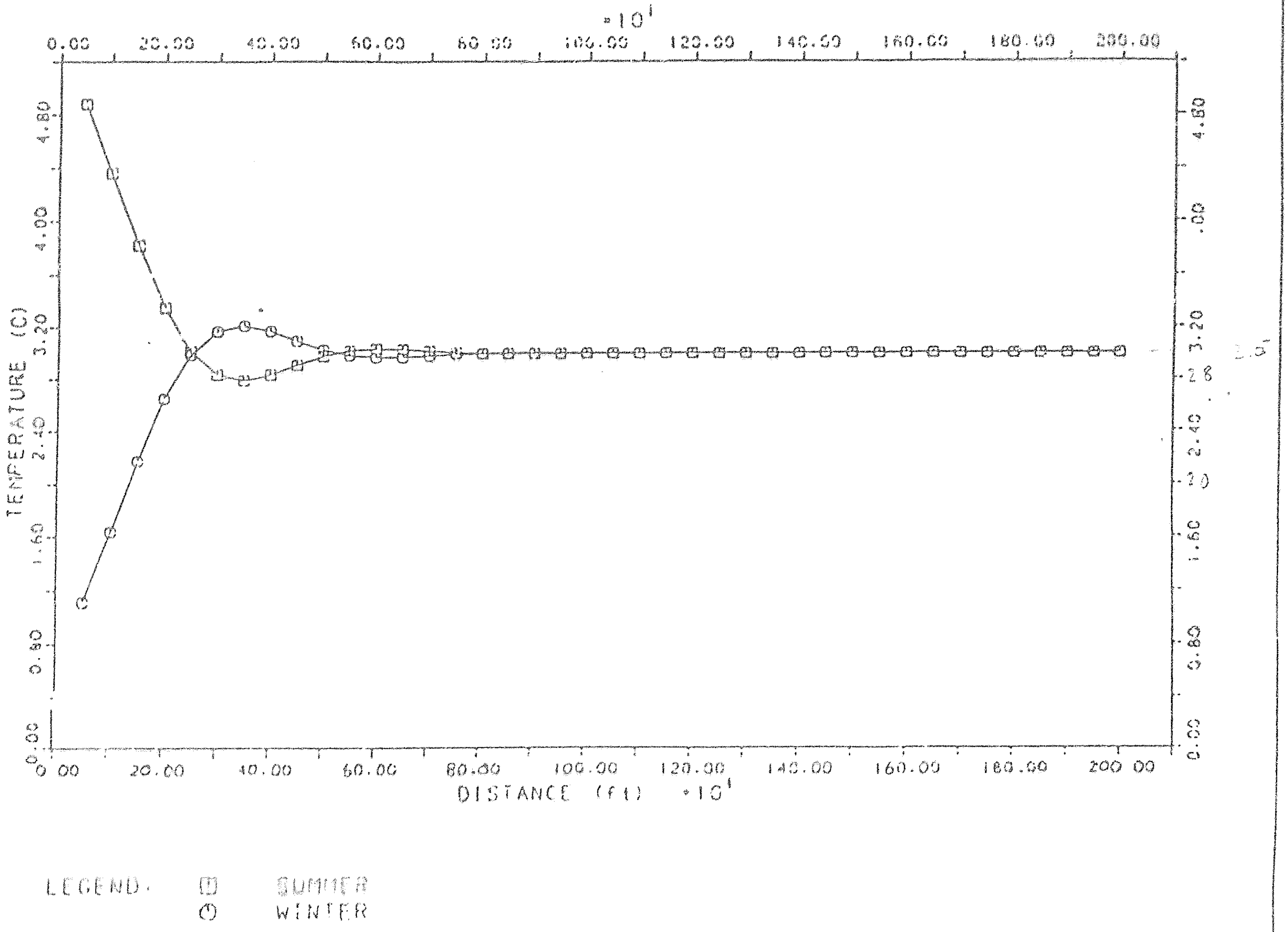
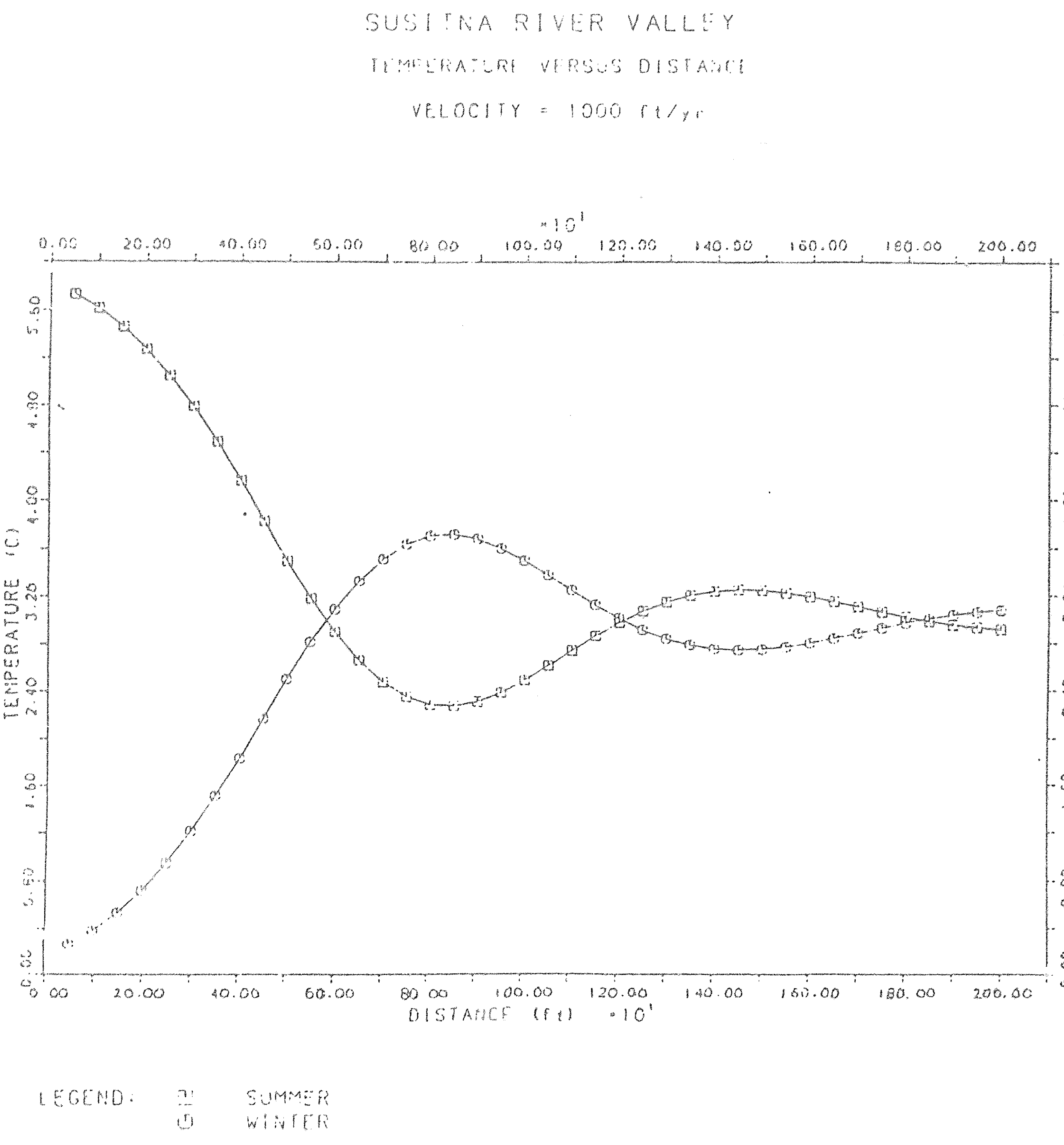


FIGURE 16



SUSITNA RIVER VALLEY
TEMPERATURE VERSUS DISTANCE
VELOCITY = 1000 ft/yr
TEMPERATURE (C)
DISTANCE (ft) *10¹
LEGEND: SUMMER
WINTER

FIGURE 17

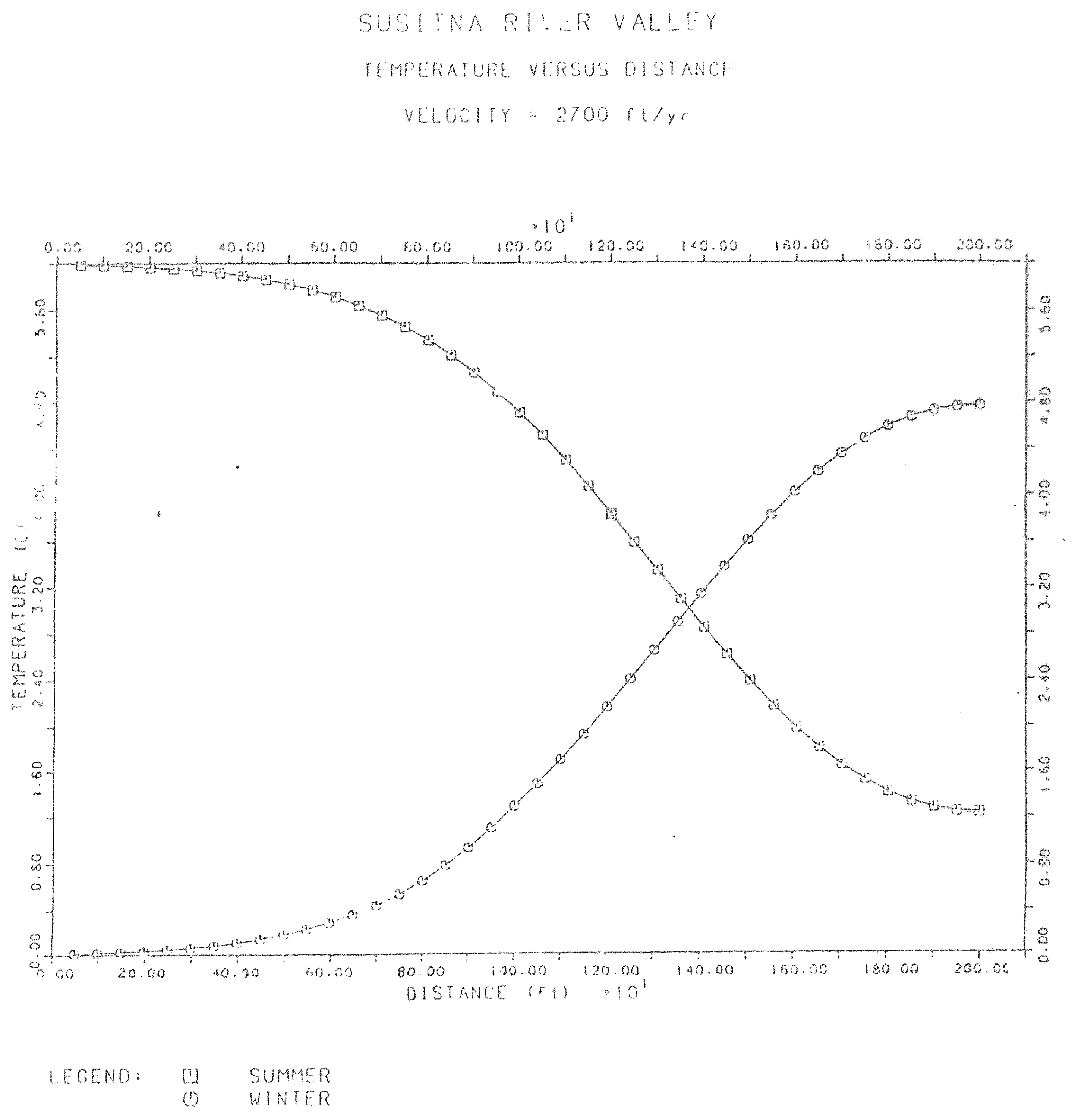

SUSITNA RIVER VALLEY
TEMPERATURE VERSUS DISTANCE
VELOCITY = 2700 ft/yr
*10¹
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
160.00
180.00
200.00
TEMPERATURE (C)
0.00
0.80
1.60
2.40
3.20
4.00
4.80
5.60
DISTANCE (ft) *10¹
LEGEND: SUMMER
WINTER

FIGURE 18