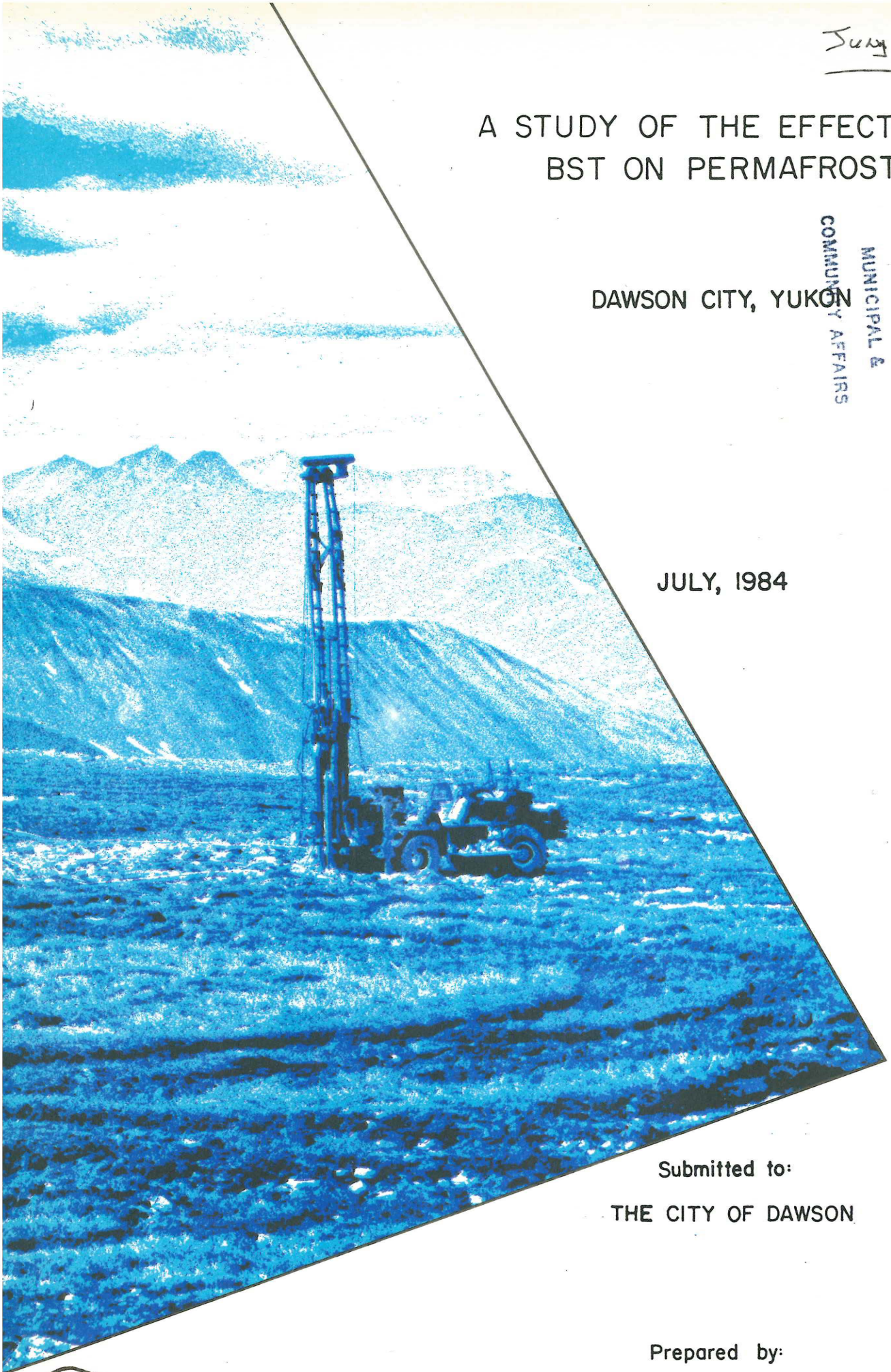
June/1984

A STUDY OF THE EFFECTS OF BST ON PERMAFROST

DAWSON CITY, YUKON



JULY, 1984

Submitted to:

THE CITY OF DAWSON

Prepared by:

EBA Engineering Consultants Ltd.

(19)

INA 5700 - D1

EBA Engineering Consultants ltd.

EARTH-SCIENCES ENGINEERING

E. W. Brooker, President
D. W. Hayley, Vice President
L. A. Balanko
C. B. Dawley
C. T. Hwang
A. B. MacDonald

1984 07 09

recd by hand 84.07.13

MM for info. a copy is on file.

City of Dawson
P.O. Box 308
Dawson City, Yukon
Y0B 1G0

ATTENTION: Mr. P. Dunbar
City Manager

Dear Sir:

Subject: Final Report --
Thermal Effects of BST on Permafrost
City of Dawson, Yukon
EBA Project No. 0201-3983

Subsequent to discussions with yourself and Mr. J. Cormie (YTG), please find enclosed two copies of the final report on the Dawson BST study. Also as discussed, we have recently acquired new research (still in draft form) from the State of Alaska (DOTPF) and CRREL concerning "The Effect of Colour and Texture on the Surface Temperature of Asphaltic Concrete Pavements". This paper indicates that we may have over-estimated the absorptivity of a BST surface, and hence used too low a value of albedo. This being the case, the permafrost thaw depth may not be increased to the total extent predicted by our analyses.

We are still; however, recommending that a modest test section be installed and monitored. The data could then be compared to the comprehensive Alaska study to determine if their conclusions can be realistically extrapolated to the Dawson City situation. A letter has already been sent to the National Research Council of Canada advising them of our proposed testing program, and requesting research funds for same. We hope to hear a reply before the BST crew arrives in the Dawson area in late July.

DWS3

3167-3rd AVENUE, WHITEHORSE, YUKON TERRITORY Y1A 1G4 TELEX 0368386 TELEPHONE (403) 668-3068

In the meantime, please contact the undersigned if you have any questions or require additional information.

Yours truly,

EBA Engineering Consultants Ltd.

J. Richard Trimble

J.R. Trimble, P.Eng.
Project Director, Whitehorse

JRT/nlm

Encl.

cc: Mr. J. Cormie, P.Eng., Government of Yukon
Mr. D.W. Hayley, P.Eng., EBA, Edmonton

A STUDY OF THE EFFECTS OF BST ON PERMAFROST

DAWSON CITY, YUKON

JULY, 1984

Submitted to:

THE CITY OF DAWSON

Prepared by:

EBA ENGINEERING CONSULTANTS LTD.

TABLE OF CONTENTS

1.0 INTRODUCTION

For the past several years, the Government of Yukon has undertaken a road resurfacing (chip seal) program for both highways and municipal streets throughout the Yukon Territory. Bituminous surface treatment (BST) is cost effective, can be quickly applied, and provides an all-weather surface. The City of Dawson, which is predominantly underlain by continuous permafrost, has applied to the Government of Yukon for BST application on City streets. In light of the recently installed sewer and water system in Dawson, and its design which relies on permafrost stability, additional studies were required to evaluate the effects of BST on the underlying permafrost.

EBA Engineering Consultants Ltd. (EBA) were retained by the City of Dawson to complete these studies, and to predict any changes in the position of the permafrost surface. The report was also to determine the engineering implications of BST application, and provide recommendations.

2.0 SCOPE OF WORK

With reference to EBA's proposal letter of 1983 12 07, the evaluation program was completed in 3 phases:

LIST OF TABLES

LIST OF FIGURES

2.1 Literature Search

This included a review of all pertinent data and previous studies concerning the effects of pavement and ground surface characteristics on permafrost thaw.

2.2 One-Dimensional Thermal Analysis

This computer-assisted analysis examined the effects of a change in surface albedo on permafrost thaw. It was completed for a general Dawson Street soil profile outside of the effects of subsurface utilities. Three different albedo values were examined -- two for natural conditions, and one for a black-topped surface.

2.3 Two-Dimensional Thermal Analysis

The computer was also used to examine the influence of varying surface conditions on permafrost underlying and adjacent to the existing sewer and water pipes. Finite element techniques were used to predict the seasonal thaw depth at a "worst-case" situation which included the effects of buried pipes and trench backfill.

3.0 LITERATURE SEARCH AND BACKGROUND DATA

The primary source of information used in the analyses was from previous EBA reports on the design, construction and monitoring of the Dawson sewer and water system. Although the University of Alberta Library and the Boreal Institute Library were visited, it was concluded that not much information has been published on this particular subject. Several papers from the Fourth Canadian Permafrost Conference were also reviewed, primarily to obtain case histories of similar applications, and relevant values of albedo for northern climates. A partial list of references is included at the back of this report.

4.0 THERMAL ANALYSES

Detailed information on soil conditions, locations of instrumentation suites and previous thermal analyses are all presented in previous EBA reports (see Reference) and will not be discussed in detail herein.

The cross-section used in all thermal analyses was adopted and slightly modified from the geometry of Instrumentation Suite No. 1 on Fifth Avenue. Figure 1 summarizes the general geometry of this site. The soil profile used in the analysis is comprised of 1.0 m of "common granular fill" (as it was referred to in the 1983 EBA report to NRC) overlying

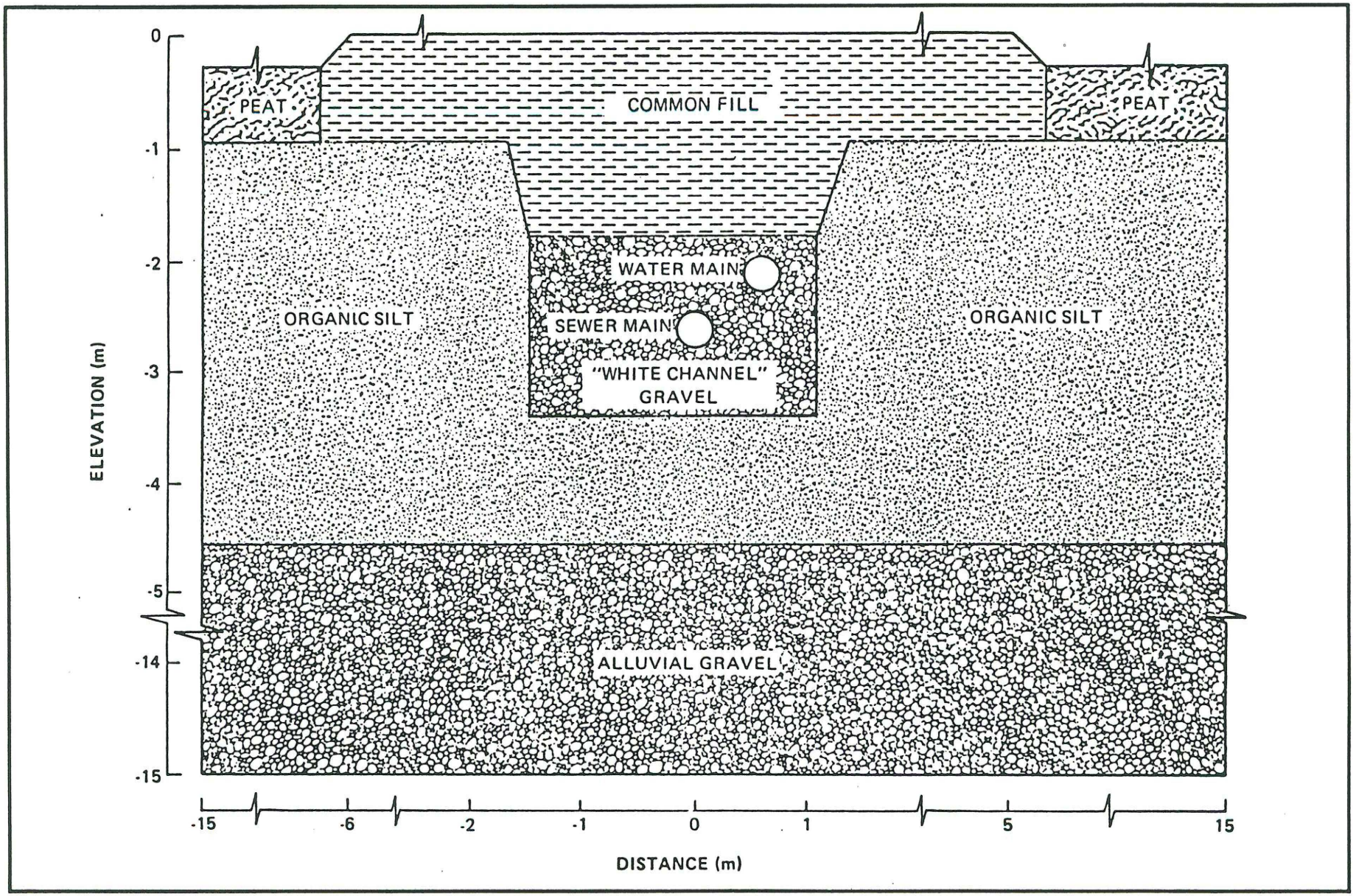


FIGURE 1

GEOMETRY USED FOR ANALYSIS OF FIFTH AVENUE INSTRUMENTATION SITE

ice-rich frozen organic silt. Frozen channel gravels underlie the silt, starting at a depth of 4.5 m. In the analyses, the material index and thermal properties changed automatically to reflect the effects of thaw consolidation. Therefore, once the seasonal depth of thaw reached undisturbed frozen silt the material and thermal properties automatically converted to those of a thaw consolidated material and remained that way for subsequent iterations. For the two-dimensional analyses, the trench and pipes were added. Material index and thermal properties for each of the soils are summarized in Table 1. General climatic data used in the analyses is summarized in Table 2.

4.1 One-Dimensional Analysis

The purpose of the one-dimensional analysis was to examine the effect of changing the albedo for a section through the roadway away from the influence of the utilities. The albedo is a measure of reflected solar radiation as a percent of the incident radiation and changes with the type of surface and the incident angle of the sun's rays. In the case of the Dawson streets, the study was to examine the contrast between sandy or granular soils and road surface treatments which alter the surface to a condition approaching that of asphaltic concrete or an oiled surface. Table 3 summarizes the albedo of various surfaces, and shows the values used in this analysis.

TABLE 1

REVISED SOIL THERMAL PROPERTIES
USED IN 1983 GEOTHERMAL ANALYSIS

MATERIAL	BULK DENSITY		MOISTURE CONTENT		THERMAL CONDUCTIVITY		SPECIFIC HEAT		LATENT HEAT
	FROZEN (Mg/m^3)	THAWED (Mg/m^3)	FROZEN (%)	THAWED (%)	FROZEN (W/(mK))	THAWED (W/(mK))	FROZEN (kJ/kgK))	THAWED (kJ/kgK))	(MJ/m^3)
Peat	1.23	1.23	200	200	1.35	0.50	2.01	3.44	276
Silt (Active Layer)	1.80	1.90	33	30	2.13	1.34	1.22	1.34	112
Silt (Permafrost)	1.70	1.90	45	30	2.19	1.34	1.12	1.34	153
Common Fill (Fifth Avenue)	2.11	2.11	14	14	1.45	1.47	0.98	1.15	47
White Channel Gravel	2.27	2.27	10	10	4.50	3.51	0.83	1.05	69
Alluvial Gravel	2.24	2.24	12	12	4.24	2.86	0.88	1.16	92
Insulation	0.48	0.48	0	0	0.023	0.023	1.21	1.21	0

TABLE 2

METEOROLOGICAL DATA USED FOR ANALYSES
(averages for Dawson City, Y.T.)

DATE (m-d)	TEMPERATURE (^oC)	WIND SPEED (km/h)	SNOW DEPTH (m)	INCIDENT SOLAR RADIATION (W/m^2)
1 -15	-28.6	5.0	0.53	11
2 -15	-23.0	6.9	0.61	32
3 -15	-14.1	7.4	0.57	97
4 -15	-1.8	8.6	0.25	160
5 -15	7.8	7.7	0	203
6 -15	13.9	6.6	0	232
7 -15	15.5	5.9	0	208
8 -15	12.7	5.6	0	151
9 -15	9.2	5.9	0	82
10-15	-3.2	8.0	0	37
11-15	-16.5	6.6	0.19	13
12-15	-25.3	5.9	0.38	5

TABLE 3

ALBEDO OF VARIOUS SURFACES

DESCRIPTION	PERCENT	
Fresh Snow Cover	75 - 95	
Dense Cloud Cover	60 - 90	
Old Snow Cover	40 - 70	
Clean Firm Snow	50 - 65	
Light Sand Dunes, Surf	30 - 60	
Clean Glacier Ice	30 - 46	
Dirty Firm Snow	20 - 50	
Dirty Glacier Ice	20 - 30	
Sandy Soil	15 - 40	*
Meadows and Fields	12 - 30	
Densely Built-up Areas	15 - 25	
Woods	5 - 20	
Dark Cultivated Soil	7 - 10	
Water Surfaces, Sea	3 - 10	
Asphaltic Concrete or BST	5	

* Values of 20% and 30% used to examine pre-BST conditions.

Initial ground temperatures were approximated using observed ground temperature data gathered at Instrumentation Suite No. 1. The combined effects of averaged monthly air temperatures, wind speed, snow depth and solar radiation information from Environment Canada were applied at the surface boundary. Snow depth was also modified to model the effect of some snow removal.

Each of the one-dimensional analyses simulated 10 years of seasonal climatic changes. This duration of analysis ensured that an equilibrium condition was established for a given albedo. Table 4 summarizes the results.

TABLE 4

MAXIMUM DEPTHS OF SEASONAL THAW
FROM ONE-DIMENSIONAL ANALYSES

MATERIAL	ALBEDO (%)	DEPTH OF THAW (metres)
SAND AND GRAVEL *	30	2.15
SAND AND GRAVEL	20	2.20
SAND AND GRAVEL with Bituminous Surface Treatement	5	2.35

* 1983 Re-analysis value of Albedo

4.2 Two-Dimensional Analysis

The two-dimensional analysis also focused on the roadway cross section at Instrumentation Suite No. 1 on Fifth Avenue. Available measured ground temperatures, utilities temperature data and a previously acquired knowledge of the sensitive geothermal conditions that exist at this

location make it a suitable "worst case" situation. The material index and thermal properties, the section geometry, and the surface properties were identical to our re-analysis reported to the National Research Council in 1983 (EBA, 1983). One modification to the analysis presented herein was that long term average meteorological data was substituted in place of the actual monthly averages from 1979 to 1981 used in the 1983 re-analysis. Utility pipe temperatures were assumed to be constant rather than vary seasonally to simplify the analysis without distorting the results. Table 5 summarizes the utility pipe temperatures used. The other input data is summarized in Tables 1 and 2, as previously noted.

TABLE 5

UTILITY PIPE TEMPERATURES USED FOR
TWO-DIMENSIONAL ANALYSIS

(degrees celsius)

SEWER-TOP	SEWER-BOTTOM	WATER LINE
9.5	9.75	9.5 *

* Note: Although the new stabilized water temperature is approximately 4.5°C, this is not believed to have a significant effect on temperatures outside the pipe insulation.

The analysis was conducted in two phases. The first phase allowed the geothermal regime to reach an equilibrium condition under the average climatic conditions. The second phase examined the influence of a bituminous surface treatment by altering the albedo at the surface granular (common) fill from 30% to 5%. Figure 2 illustrates the progression of the 0^{o} isotherm from year to year. Equilibrium is reached in the fourth year after BST application, as shown in Figure 3.

5.0 DISCUSSION OF RESULTS

Both the one-dimensional and two-dimensional analyses show that the depth of seasonal thaw beneath the roads is slightly increased by the application of BST. The two-dimensional analyses (Figures 2 and 3) further shows that the seasonal thaw beneath the sewer and water trench will be below the depth of the pipe's thermal bedding. The original design intent of the sewer and water system was to retain the permafrost as much as possible, and to allow seasonal freezing and thawing to occur only within this thermal bedding. Thus, the potential for detrimental pipe movements caused by seasonal frost action has been increased by the application of BST. In addition, lateral thaw of the trench walls has also been increased, in direct proportion to the vertical thaw increase. This might also have a detrimental effect on pipe stability.

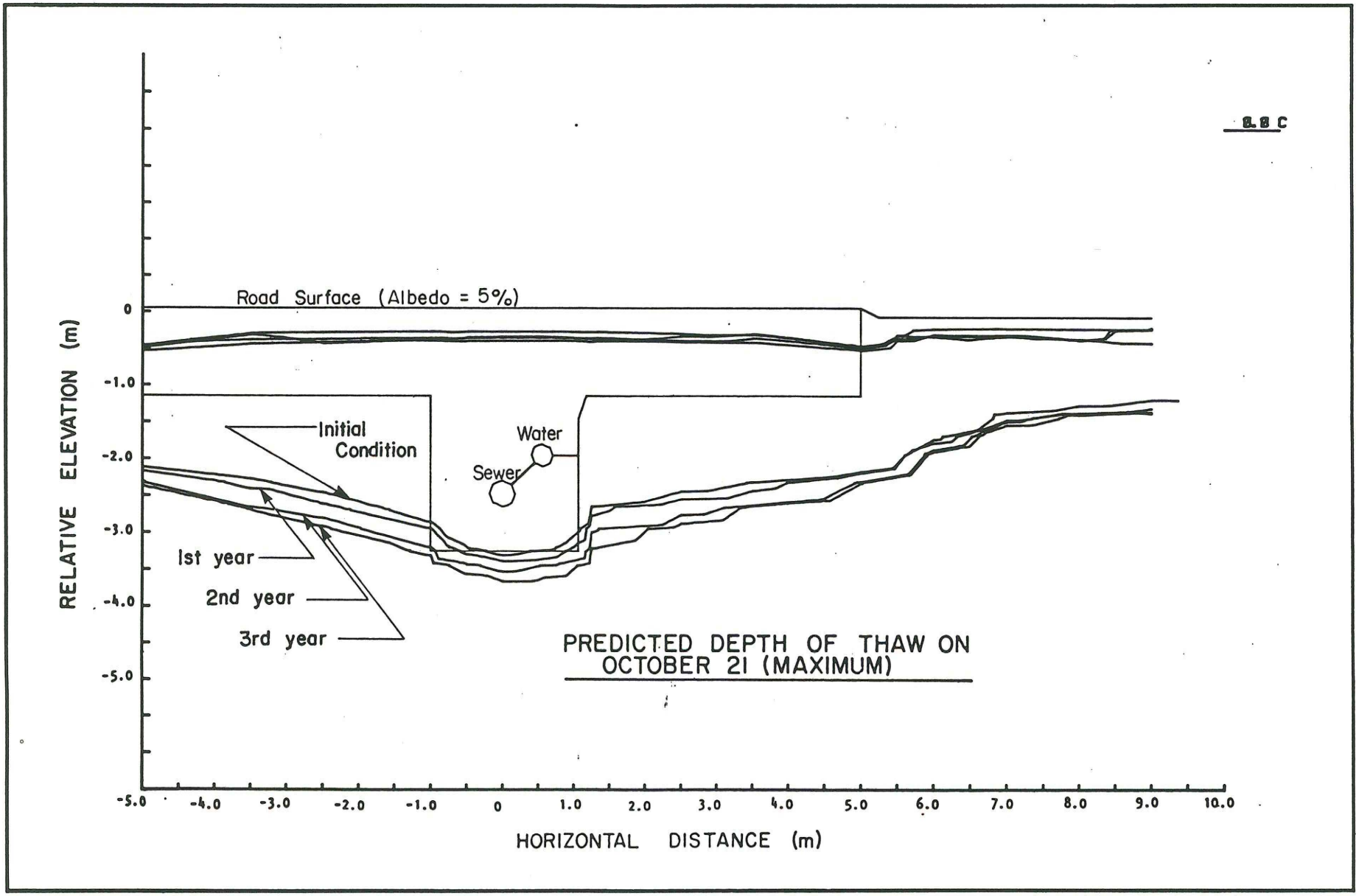


FIGURE 2

RESULTS OF TWO-DIMENSIONAL ANALYSIS
DAWSON CITY BST STUDY

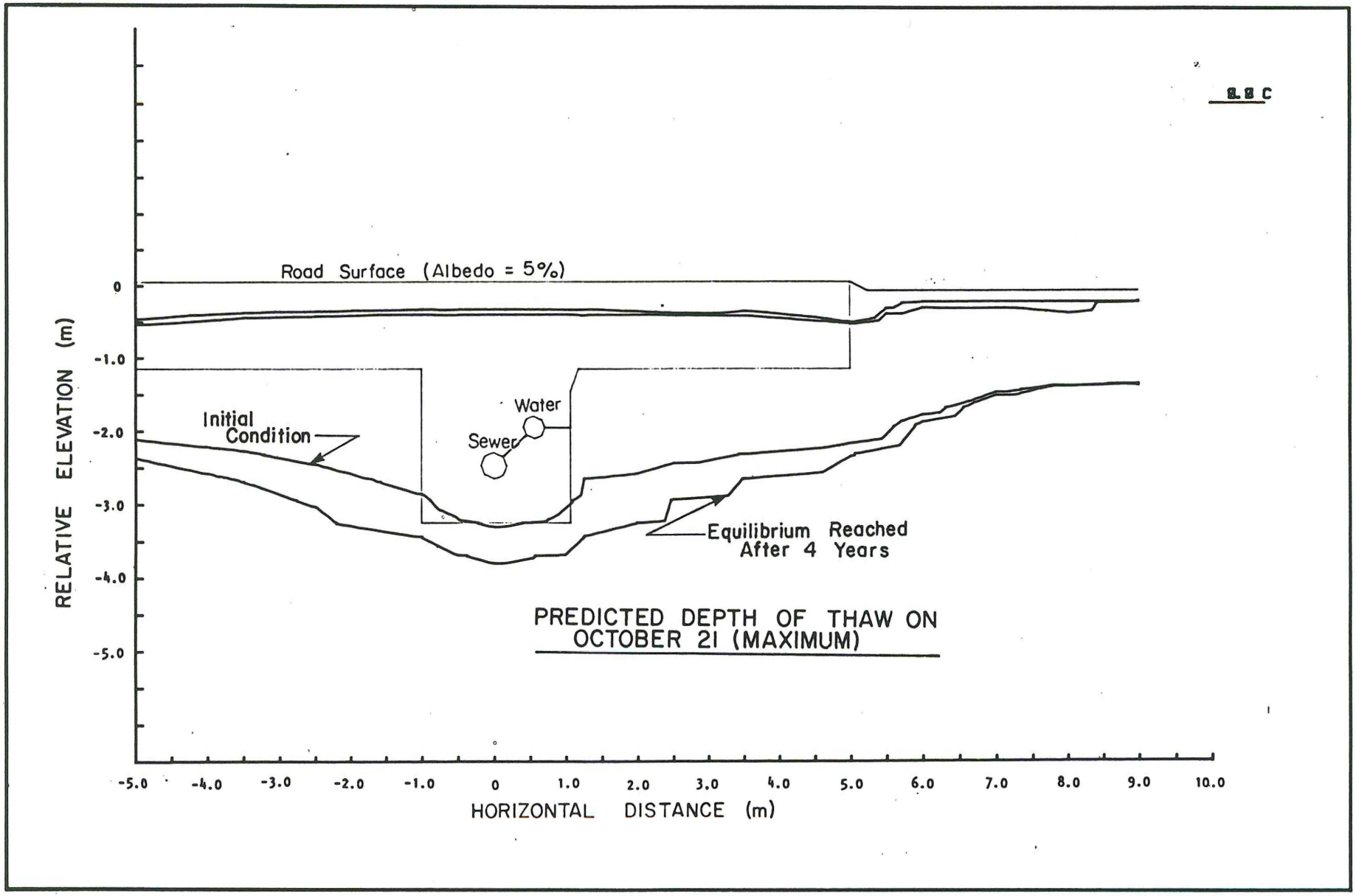


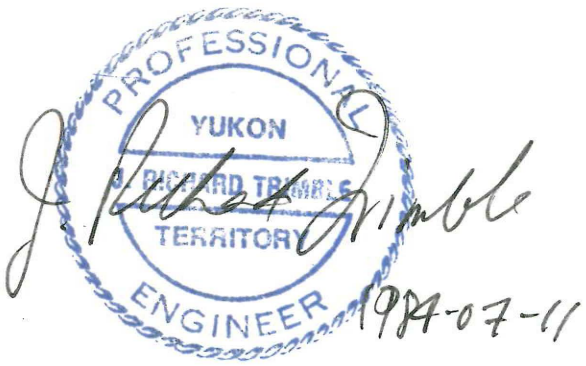
FIGURE 3

RESULTS OF TWO-DIMENSIONAL ANALYSIS
DAWSON CITY BST STUDY

6.0 RECOMMENDATIONS AND CONCLUSIONS

The data shows that the application of BST to the streets of Dawson may adversely impact on the sewer and water system. However, the results of these theoretical calculations should not necessarily conclude that BST should not be applied to the streets of Dawson. It is recommended that a small (one block) test section be constructed and monitored this summer. This would involve the installation of ground temperature cables in both the undisturbed street and in the BST section, followed by a suitable monitoring period. Although it is inferred that BST should not be applied on all streets in 1984, it is hoped that actual field data might show that BST application at some time in the future is a possibility.

Respectfully submitted,
EBA Engineering Consultants Ltd.



J.R. Trimble, P.Eng.
Project Director, Whitehorse

REFERENCES

1. Andersland, O.B., and Anderson, D.M. (1978). Geotechnical Engineering for Cold Regions. 566 p. McGraw-Hill, New York.

2. EBA Engineering Consultants Ltd. (1983). Geothermal Performance - Buried Utility System Dawson, Yukon. Prepared for NRC, DBR. (EBA File 101-2607).

3. Hwang, C.T. (1976). Predictions and Observations on the Behaviour of a Warm Gar Pipeline on Permafrost. Canadian Geotechnical Journal, V. 13(4) pp. 452-480.

4. Johnston, G.H. (ed) (1981). Permafrost Engineering Design and Construction. Associate Committee on Geotechnical Research, NRC. 540 p. J. Wiley and Sons, Toronto.