SOIL TEMPERATURE AND STABILITY EVALUATION
FIFTH AVENUE REPLACEMENT SEWER SYSTEM
DAWSON CITY, YUKON

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FIFTH AVENUE REPLACEMENT SEWER SYSTEM
DAWSON CITY, YUKON

SUBMITTED TO:

The City of Dawson
Dawson City, Yukon

PREPARED BY:

EBA Engineering Consultants Ltd.
14535 - 118 Avenue
Edmonton, Alberta
T5L 2M7

0201-10471

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1.0 INTRODUCTION

The City of Dawson has had an underground sewer and water system since 1903. The original system, constructed from wood stave pipes, was replaced during 1979 and 1980 with insulated high density polyethylene (HDPE) pipes. Since installation, this system has required annual maintenance and repairs. Information collected from ground temperature instrumentation, annual pig testing and pipe condition observations recorded during repair incidence has been reviewed by several earlier studies to determine the cause(s) of pipe failure and distress. These studies were conducted with a view to developing design alternatives that would result in improved performance for new extensions to the buried utilities in Dawson City.

The HDPE sewer system along Fifth Avenue had been particularly troublesome with several segments requiring major repair. As it was proposed to surface the streets of Dawson in 1987, it was decided to replace the system along Fifth Avenue between Harper and King Streets to reduce the possibility of further sewer repairs after the street had been paved. It was decided to use this replacement length as an opportunity to install a test section of the new sewer system design that had evolved from recommendations based on the earlier studies.

The test sewer system comprises a thicker walled HDPE pipe (Series 100 rather than Series 45) with insulation coating and a corrugated steel pipe sheath. The pipe is underlain by rigid board insulation having a thickness of 50 mm.

EBA Engineering Consultants Ltd. (EBA) was retained by the Government of Yukon, Department of Community of Transportation Services (YTG) to design, procure and install an instrumentation system for the replacement pipeline. The instrumentation was to provide data that would allow comparison of the performance of the modified trench design utilizing rigid board insulation with the original design that included thick granular bedding below the pipe. This work was carried out in conjunction with the sewer system replacement in October 1986 and was summarized in a subsequent installation report (EBA, 1987).

EBA was retained by YTG for the present study in September 1990 to summarize the ground temperature and inclinometer data that has been collected on the new test section, to compare the geothermal and settlement performance of the new section with the original installation, and to provide recommendations for the thermal design aspects of future installations. The present study was authorized by Mr. Mark Malinsky, P.Eng. of YTG.

2.0 INSTRUMENTATION PROGRAM

Several contributing causes have been suggested by previous review studies for sewer pipe distress. Many of the potential causes have been addressed by the changes made to the pipe design, including the use of thicker walled HDPE pipe (Series 100) and the use of a corrugated metal pipe sheath. The success of the changes in preventing pipe ovalling distress would need to be determined by pig testing. The present instrumentation program focused on monitoring ground temperatures within the trench backfill and differential settlements along a segment of the new pipe.

The modified pipe system would still be susceptible to longitudinal distortion caused by differential settlement or heave that could ultimately affect gravity drainage performance of the system if not properly addressed by the thermal design characteristics of the trench. The instrumentation program included suites of thermistor cables at two locations and a horizontal inclinometer casing strapped to the top of a segment of the new sewer line. Details of the instrumentation equipment, installation procedures and monitoring locations are described in the installation report (EBA, 1987). Figure 1 presents a general location plan for the Fifth Avenue instrument locations. Figures 2 and 3 present further location plan information on larger scale drawings.

3.0 OVERVIEW OF SOIL CONDITIONS

Relatively consistent soil conditions were encountered within the length of sewer trench that was observed by EBA personnel. Surface material consisted of approximately 1 m of fill, overlying organic silt. In some places, a layer of peat up to 0.3 m in thickness was noted. The organic silt continued to the base of the trench at most locations. Between Harper and Princess Streets (the location of thermistor Suite 1 and of the horizontal inclinometer casing), the base of the trench was situated in an orangey-brown, silty gravel. The soil conditions are summarized in Table 1.

TABLE 1
SUMMARY OF SOIL CONDITIONS ENCOUNTERED

MATERIAL	DESCRIPTION	AVERAGE DEPTH (m)	RANGE IN THICKNESS (m)
Fill	mixtures of White Channel and 5th Avenue Pit Run	0	0.6 - 1.5
Peat	amorphous, well-decomposed	1.0	0.0 - 0.3
Organic Silt	nonplastic; firm to stiff dark grey to black Nbn to Vs 30%	1.2	1.0 - 4.0
Silt	some gravel, grading to silty gravel below trench, some cobbles, orangey-brown	3.5	0.0 - 0.5

Considerable variation in the depth to permafrost was observed, from a maximum of 2.8 m to a minimum of 1.8 m (October, 1986). Local depressions in the permafrost table were often located at utility services, but occasional anomalies had no explanation. These may be related to subsurface water flow.

Conditions encountered in the trench at the locations of the instrumentation are illustrated on Figures 4 and 5. At thermistor Suite 1 the active layer was approximately 2 m thick on the west side of the trench, whereas on the east side of the trench, the presence of the old sewer system allowed thaw to penetrate to a total depth of about 3 m, approximately 100 mm below the base of the pipe.

Silty gravel was encountered at levels between 50 mm and 250 mm above the maximum depth of excavation along most of the length where the inclinometer casing was installed. Approximately 150 mm of the trench was excavated into this material at the location of thermistor Suite 1.

Very similar conditions were observed at the Suite 2 location. The silty gravel layer was encountered approximately 50 mm below the base of the trench. Frozen soil was encountered at a depth of 2 m in the trench but appeared to be deeper when a hole was augered 4 m from the trench centreline in the centre of the street.

Extensive ground ice was not observed near either thermistor location. However, borehole data (EBA, 1972; 1974; 1977) indicate that excess ice in the organic silt is typically stratified and occupies 10% to 25% of total soil volume. Visible ice contents of 40 percent are not uncommon in recovered samples and at a number of locations the volume of ice in soils exceeded 50 percent. Also, massive ice deposits were observed by the Stanley Associates Engineering Ltd. (SAEL) field inspectors in relative abundance during construction (SAEL, 1982). At one location on Fifth Avenue, ice was reported in the trench walls from a depth of 1.5 m to the bottom of the trench for a distance in excess of 150 m. wow!

4.0 MONITORING RESULTS

4.1 Thermistor Data

Ground temperature information was collected from both suites of thermistor cables by an automatic data logger. The data was recorded hourly, but stored as daily maximums and minimums on cassette tapes. The raw data has been downloaded and converted into spreadsheet format, from which representative weekly mean temperatures have been computed. These temperatures are plotted against time for selected thermistor positions on a vertical orientation through the trench at each suite location in Figures 6 and 7. These plots illustrate the transient annual temperature cycle experience within the trench backfill and show how the amplitudes of the cycle diminish with depth.

The temperature data has also been used to produce temperature contour maps through the instrumented cross section at various times, including dates corresponding to inclinometer readings and periods of peak seasonal freezing and thawing. These contours are presented in Figures 8 through 14 for Suite 1 and Figures 15 through 21 for Suite 2.

The contour plots show that during peak thaw in September of 1987 (Figures 9 and 16), the maximum thaw depth is maintained within the rigid board insulation at the Suite 2 location and fairly well maintained within the trench backfill at the trench bottom (except near the east wall) at the Suite 1 location. The slightly poorer performance at the Suite 1 location may be partly due to both the wider trench dimension and the lack of insulation extension across the full width of the trench floor. Both trench locations are shown to have frozen back entirely by the time of peak freeze in March of 1988 (Figures 11 and 18).

Greater thaw depths and backfill warming were experienced at both suite locations during the second summer (1988), as shown by the temperature contours presented in Figures 13 and 20. Thaw had penetrated into the underlying native soil by the time of peak thaw in September. It is uncertain as to the reason for this condition. It may be a result of slight differences in corresponding freezing and thawing indices for the years of 1987 and 1988. The mean monthly air temperature information collected at the Dawson City airport indicates slightly colder winter temperatures and marginally cooler summer temperatures over the year preceding the 1987 maximum thaw depth in comparison to 1988. Another possible cause might be the change in the pavement surface characteristics following application of a bituminous surfaced treatment (BST) in 1987, although a test section study conducted by EBA (1987b) suggested the BST application would have minimal effect.

4.2 Inclinometer Data

Four sets of readings were taken on the horizontal inclinometer casing. An initial set of readings was recorded on June 13, 1987. Subsequent readings were recorded on November 4, 1987 and on July 29 and November 24 of 1988.

These dates were selected to allow computation of the incremental pipe movements attributed to the respective intervening periods of thaw settlement and frost heave below the pipe. The incremental pipe deflections between manholes MH D2-51 and MH D2-41 are presented in Figure 22.

The incremental deflection profiles indicate that the pipe settled about 10 mm over most of its length during the first post-installation thaw season (when thaw was contained above the trench floor). During the following freeze-back season, the settlement was more or less recovered by heave approaching 10 mm over most of the pipe length. These observations are consistent with expected behaviour in closed system freezing and thawing, where movements result from the volumetric phase change associated with conversion of water to ice. It should be noted that the plotted deflections have been computed relative to a zero reading at manhole MH D2-51 and assume the manhole itself is not subject to seasonal movement. If there has been manhole movement (unknown), the magnitude would be additive to the plotted deflections in determining absolute pipe deflections.

The 1988 thaw season again reproduced about the same settlement over the northern half of the instrumented pipe segment, but showed additional settlement over the southern half. This seems to be consistent with the greater thaw depth (into the underlying native soils) experienced during 1988. Since the trench floor was mostly founded within the top of a silty gravel deposit, the different settlement response between the northern and southern halves of the pipe segment might reflect a difference in the inherent thaw stability of the gravel deposit along these intervals. It is noted that the presence of three large 1.5 m thick ice wedges were indicated on the trench wall logs (EBA, 1987) at distance positions of -28 m, -22 m and -12 m between manholes. As seen by the coordinates on the distance axis in Figure 22, these positions are located through the interval where greater thaw settlements were observed.

Figure 23 presents the cumulative pipe deflections relative to the initial reading on June 13, 1987. These profiles show the vertical position of the new sewer line has mostly remained with ±25 mm of its installed position, assuming negligible manhole movement.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The thermal design aspects of the test section adequately maintained the maximum thaw depth above the trench floor during the 1987 thaw season but not during 1988. The pipe movements of both years appear tolerable, although the 1988 settlements may have been larger had the trench not been keyed into the top of the silty gravel deposit, as was the case for the original sewer system.

There is potential for additional movements in areas where dips in the gravel surface may leave the trench floor positioned within the organic silt layer. At these locations, it would appear prudent to increase the thickness of rigid board insulation to 100 mm, and extend it across the full width of the trench floor. Also, it may be more effective to position some of the insulation above the sewer pipe rather than below, since the heat flux from seasonal surface thaw is more significant than that from the insulated sewer pipe.

A suggested priority system for use of trench insulation on future installations is shown in Figure 24. The most effective insulation is the horizontal sheet that spans the entire trench width above the pipe (Sheet A, Figure 24). This should be supplemented with an additional layer below the pipe where the silt is expected to extend below the maximum excavation depth. Use of vertical insulation between the two horizontal sheets (Sheets C, Figure 24) would be beneficial in undisturbed areas where the organic silt is anticipated to be particularly ice rich.

Construction activities should be planned to minimize thermal disturbance to the permafrost. This can be achieved by giving due consideration to a desireable construction schedule that would provide favourable ambient weather conditions, and maintaining a minimum trench width.

Respectfully submitted
EBA Engineering Consultants Ltd.

PROFESSIONAL ENGINEER
YUKON
J. RICHARD TRIMBLE
TERRITORY
1991-09-18

J.R. Trimble, P.Eng.
Project Engineer

Reviewed by,

PROFESSIONAL ENGINEER
YUKON
D.W. HAYLEY
TERRITORY
17-09-91

D.W. Hayley, P.Eng.
Senior Project Director

DCC/tr

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FIGURES

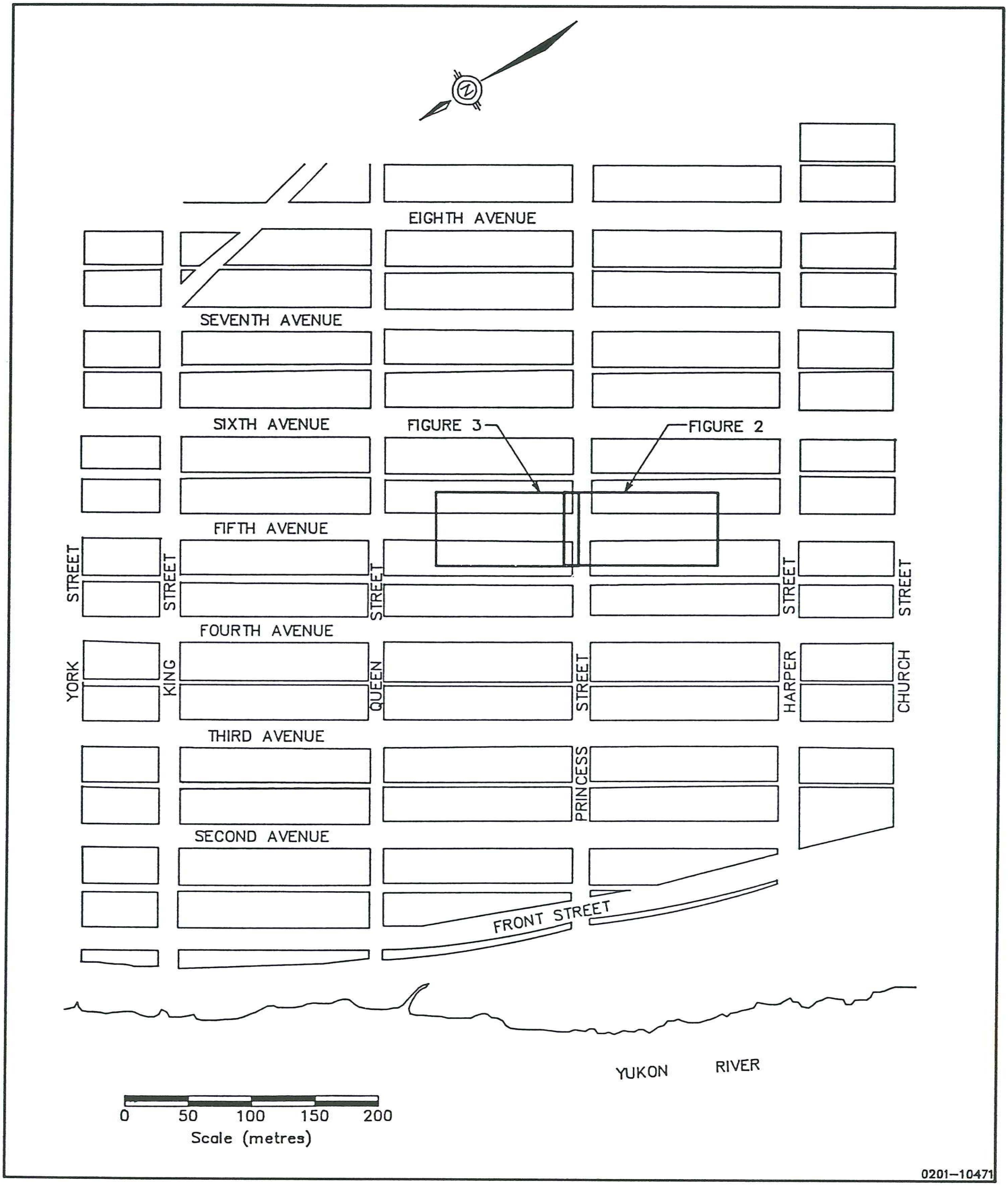

**FIGURE 1 LOCATION PLAN
INSTRUMENTATION INSTALLATIONS
DAWSON CITY, YUKON**

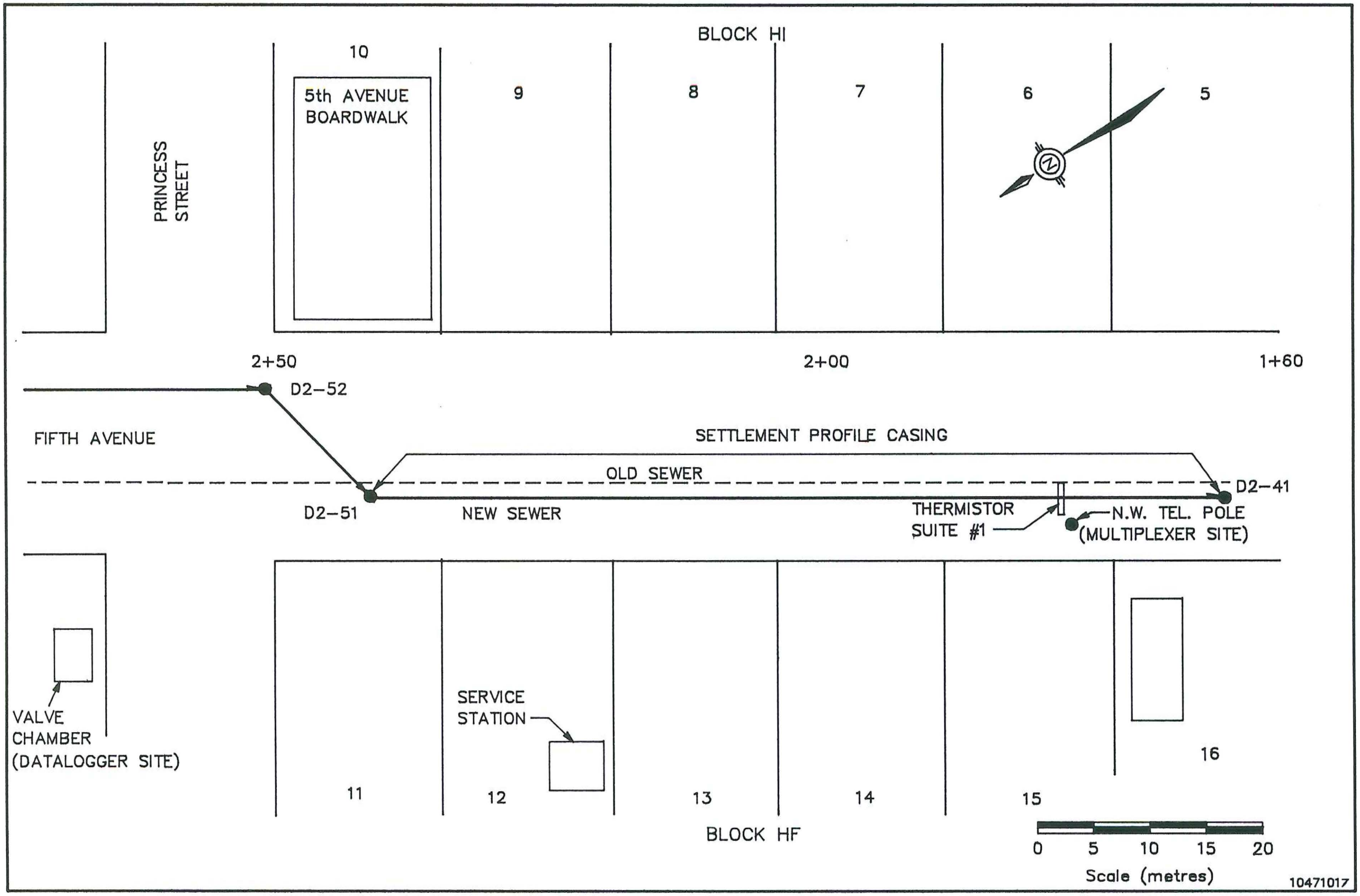

FIGURE 2 LOCATION PLAN
THERMISTOR SUITE #1 AND SETTLEMENT PROFILE CASING
FIFTH AVENUE AT BLOCK HF

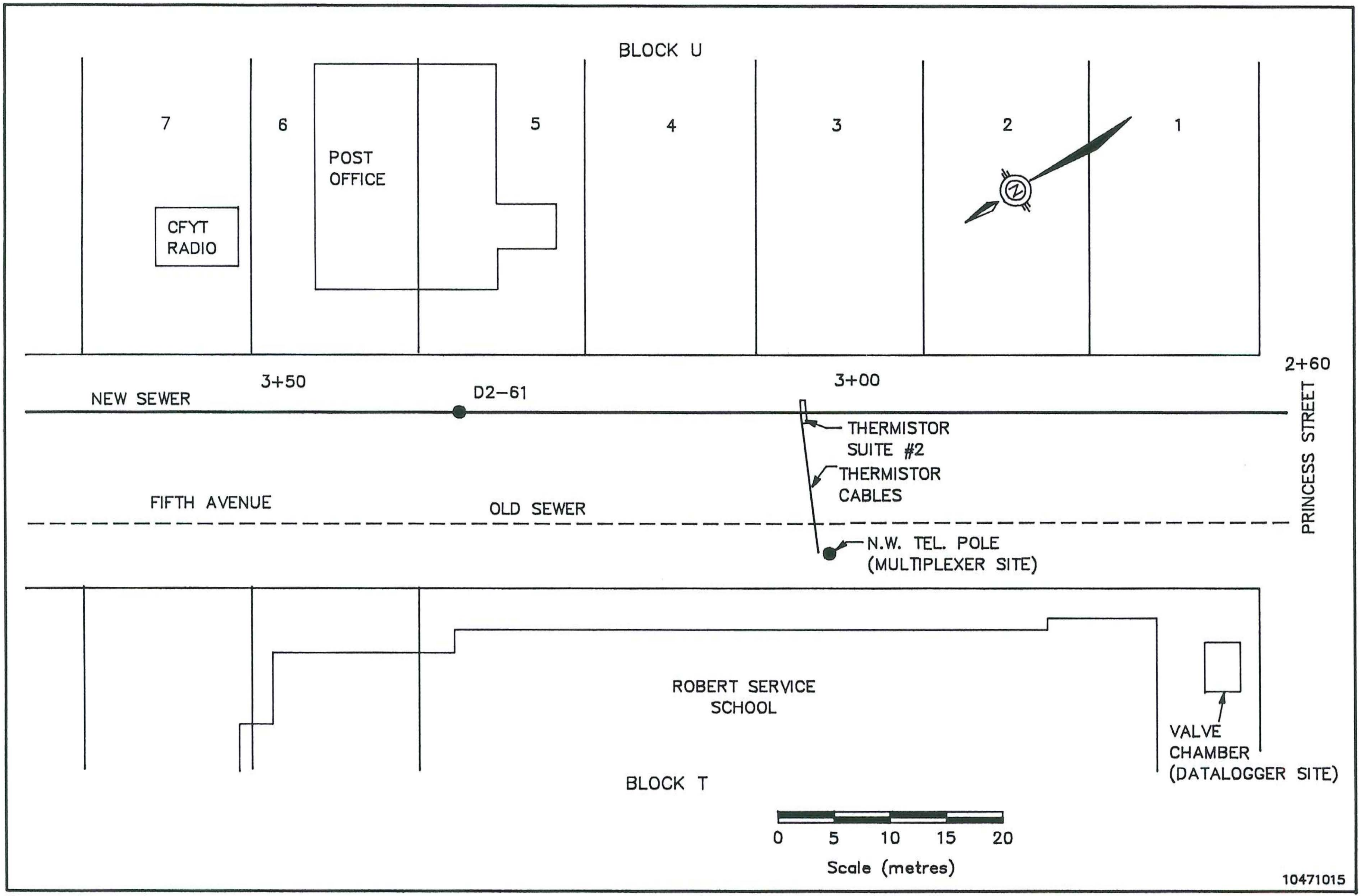

FIGURE 3 LOCATION PLAN – THERMISTOR SUITE #2
FIFTH AVENUE AT ROBERT SERVICE SCHOOL

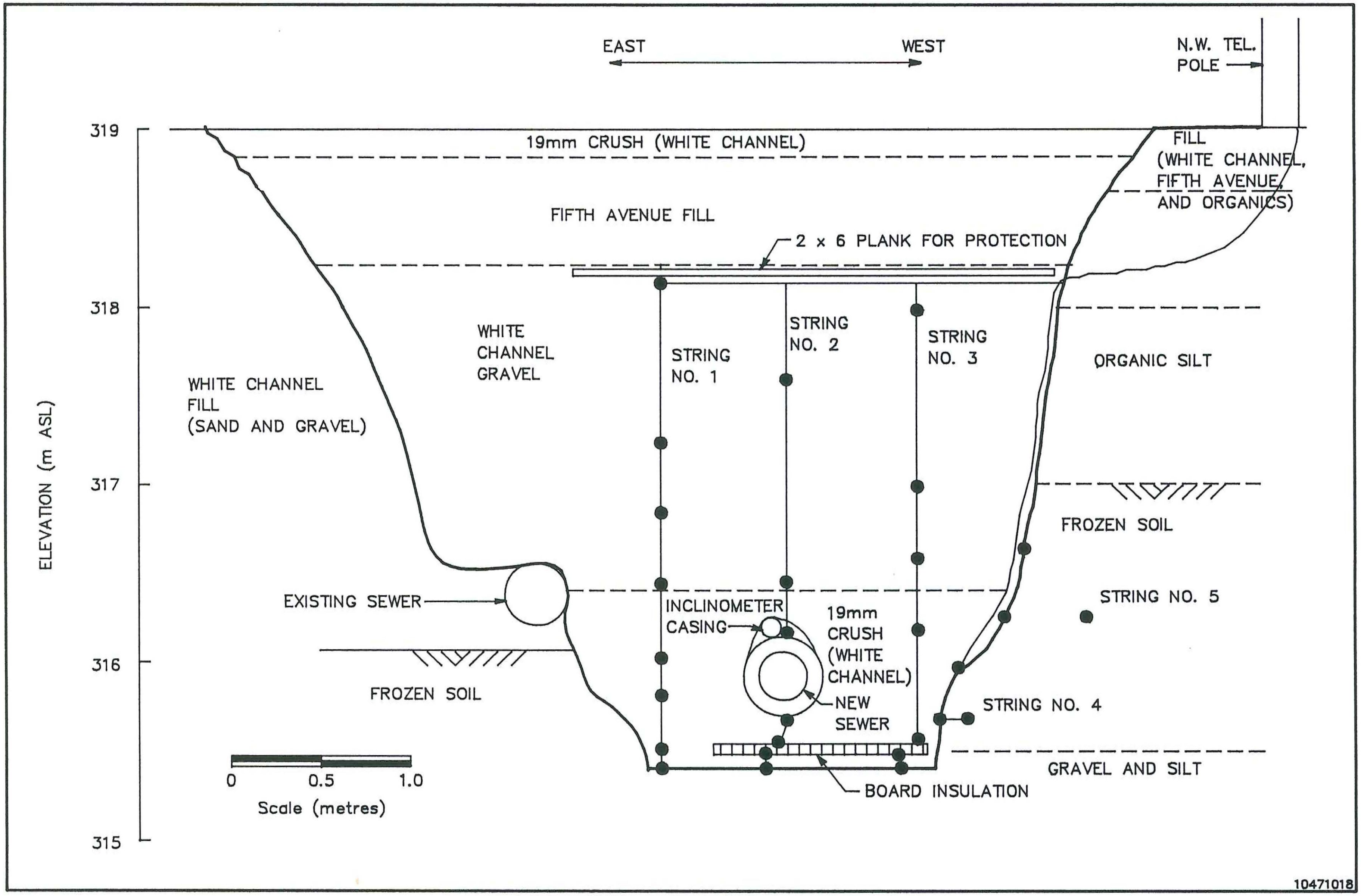

FIGURE 4 THERMISTOR SUITE #1
BLOCK HF – LOT 15, FIFTH AVENUE
INSTALLED CONFIGURATION
CROSS–SECTION FACING SOUTH

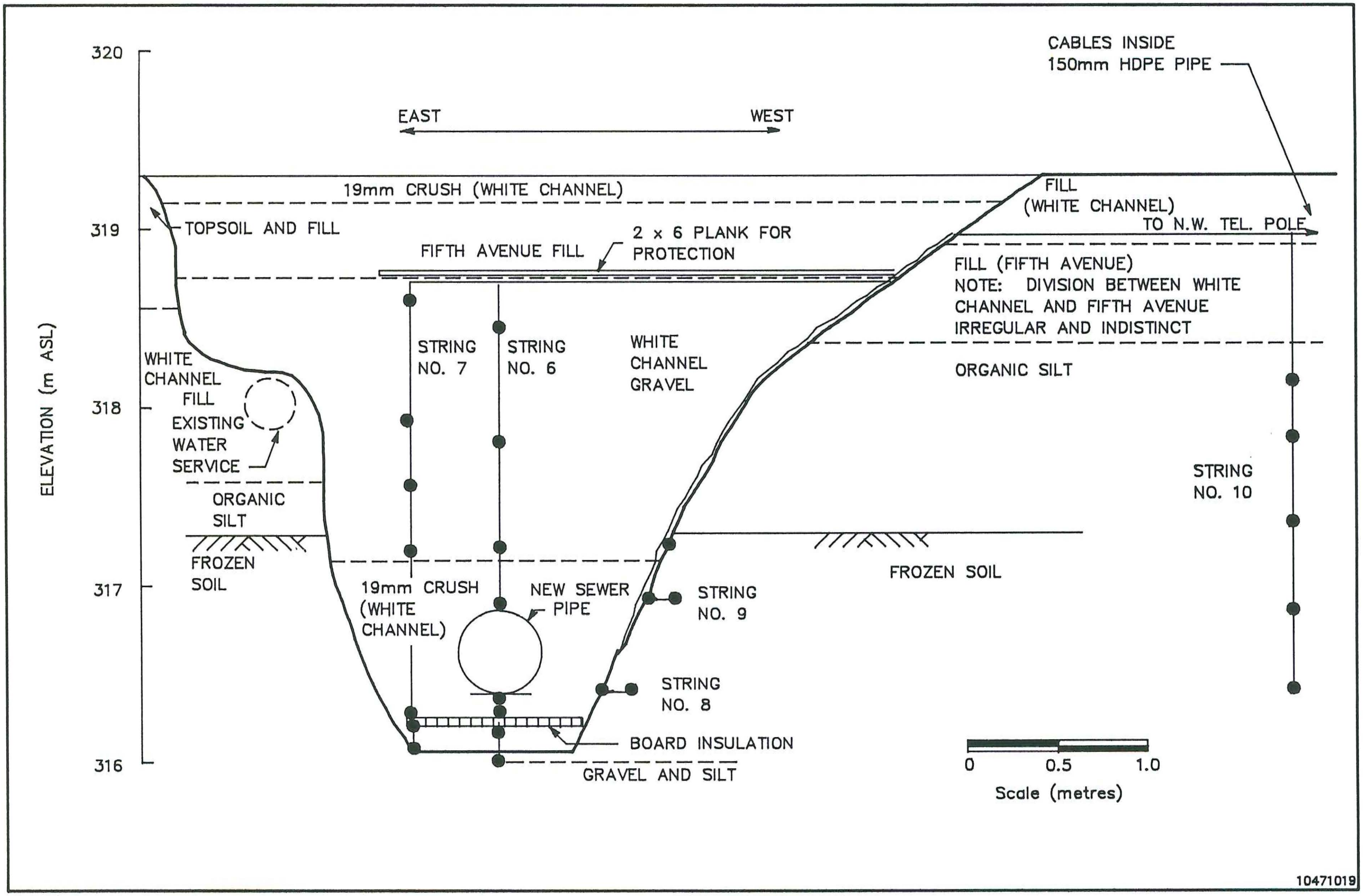

FIGURE 5 THERMISTOR SUITE #2
FIFTH AVENUE AT ROBERT SERVICE SCHOOL
INSTALLED CONFIGURATION
CROSS-SECTION FACING SOUTH

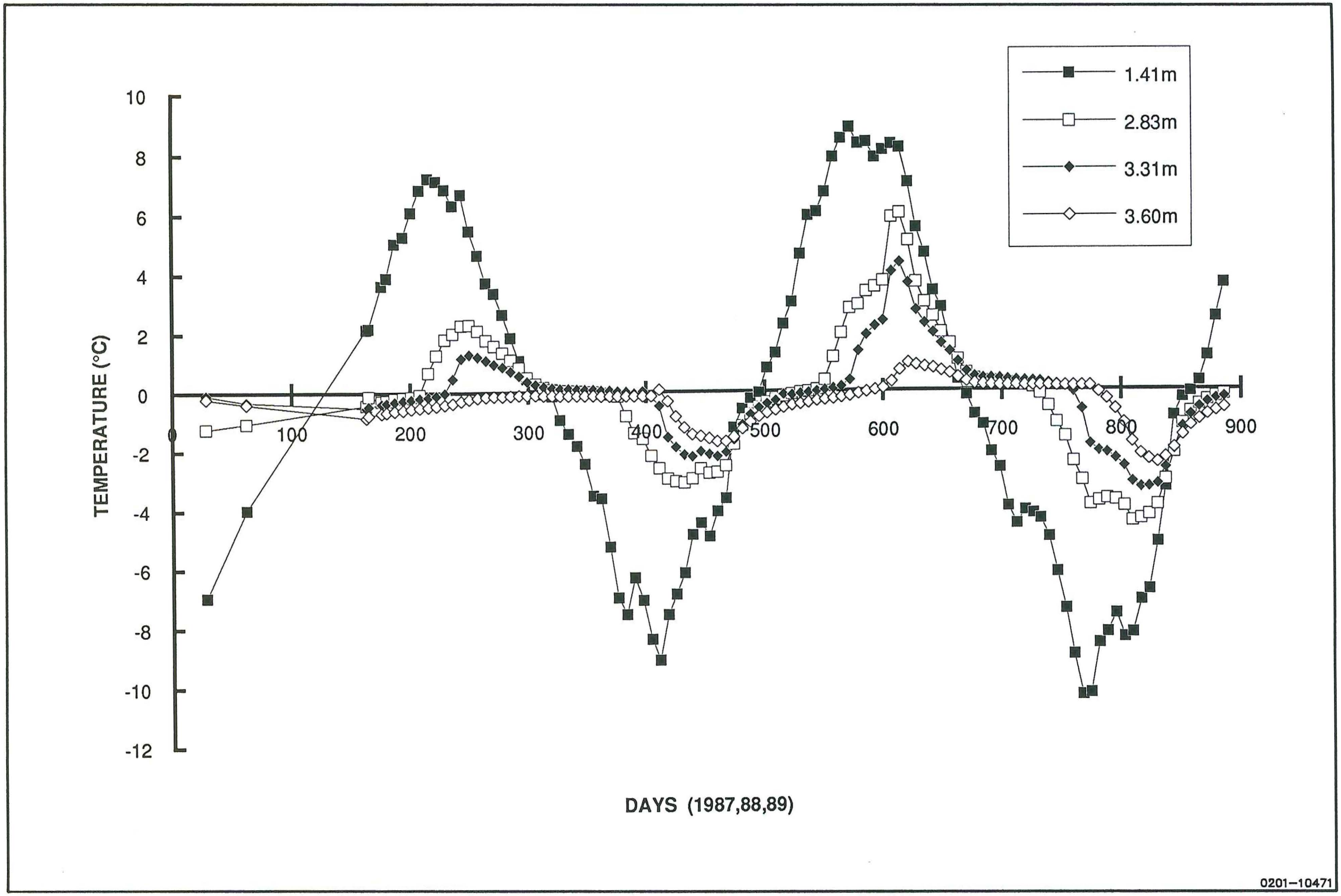

FIGURE 6 TEMPERATURE HISTORY
SUITE #1, CABLE 651

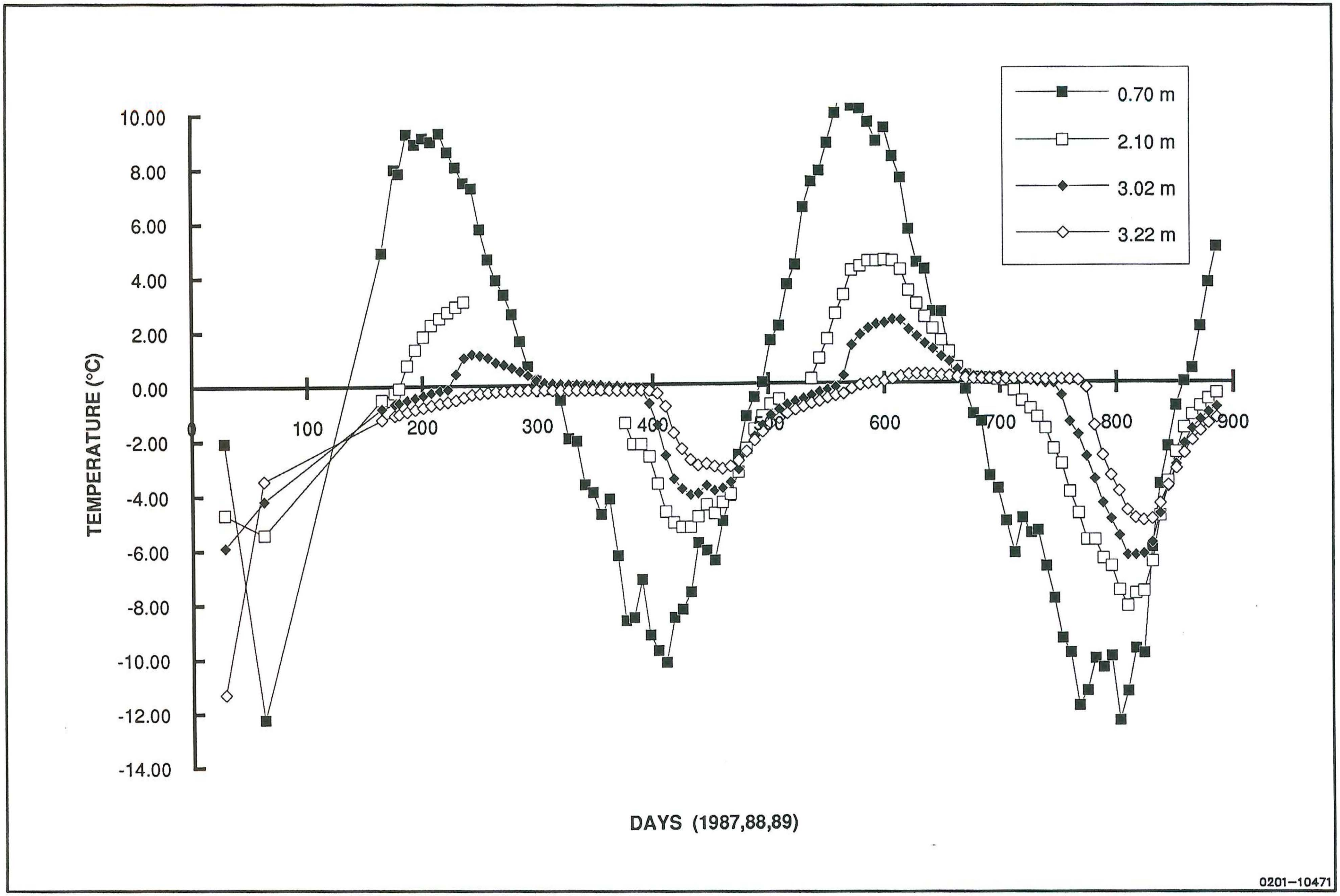

FIGURE 7 TEMPERATURE HISTORY
SUITE #2, CABLE 656

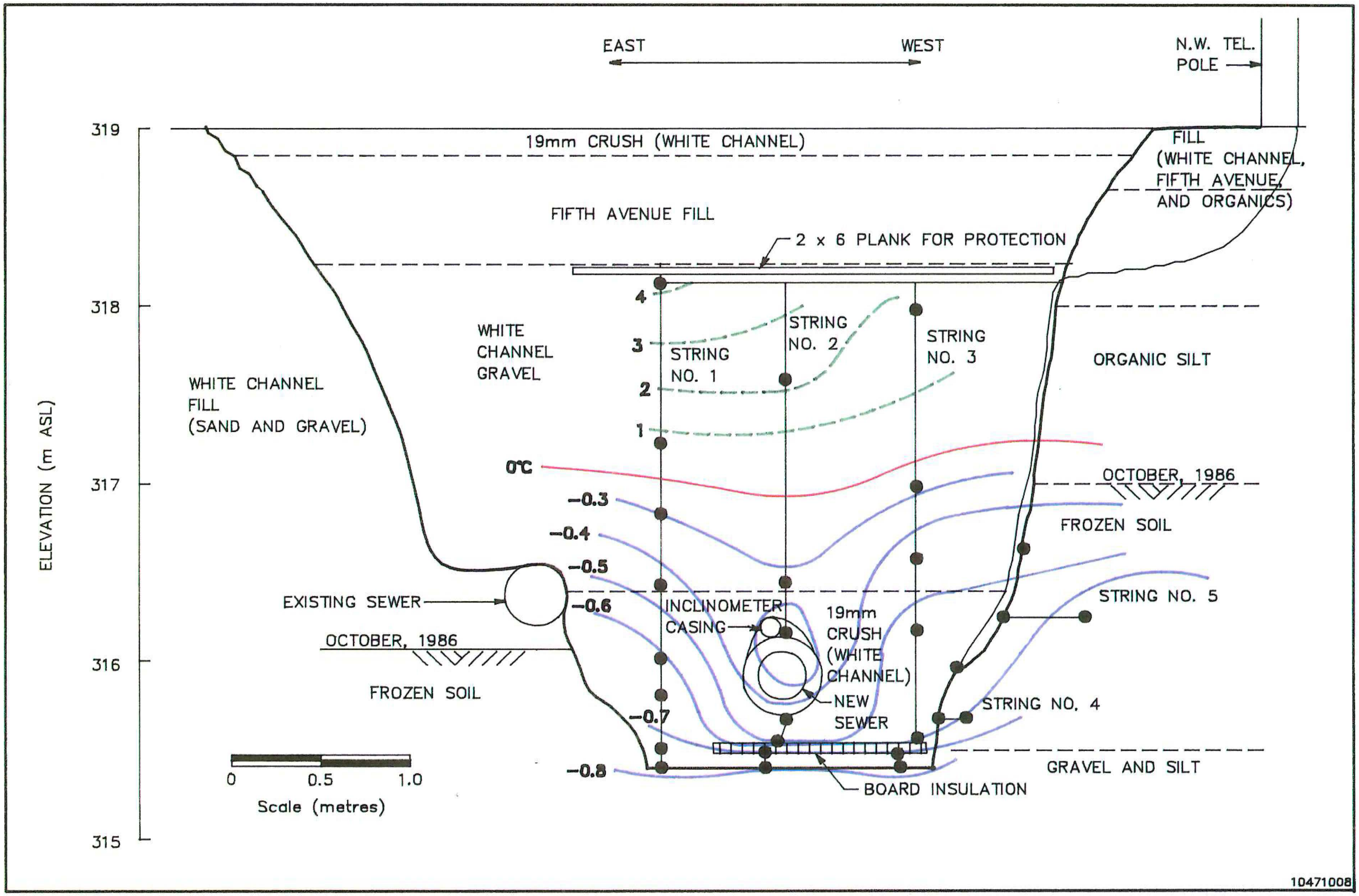

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FIGURE 8 THERMISTOR SUITE #1
TEMPERATURE ISOTHERMS
JUNE 13, 1987

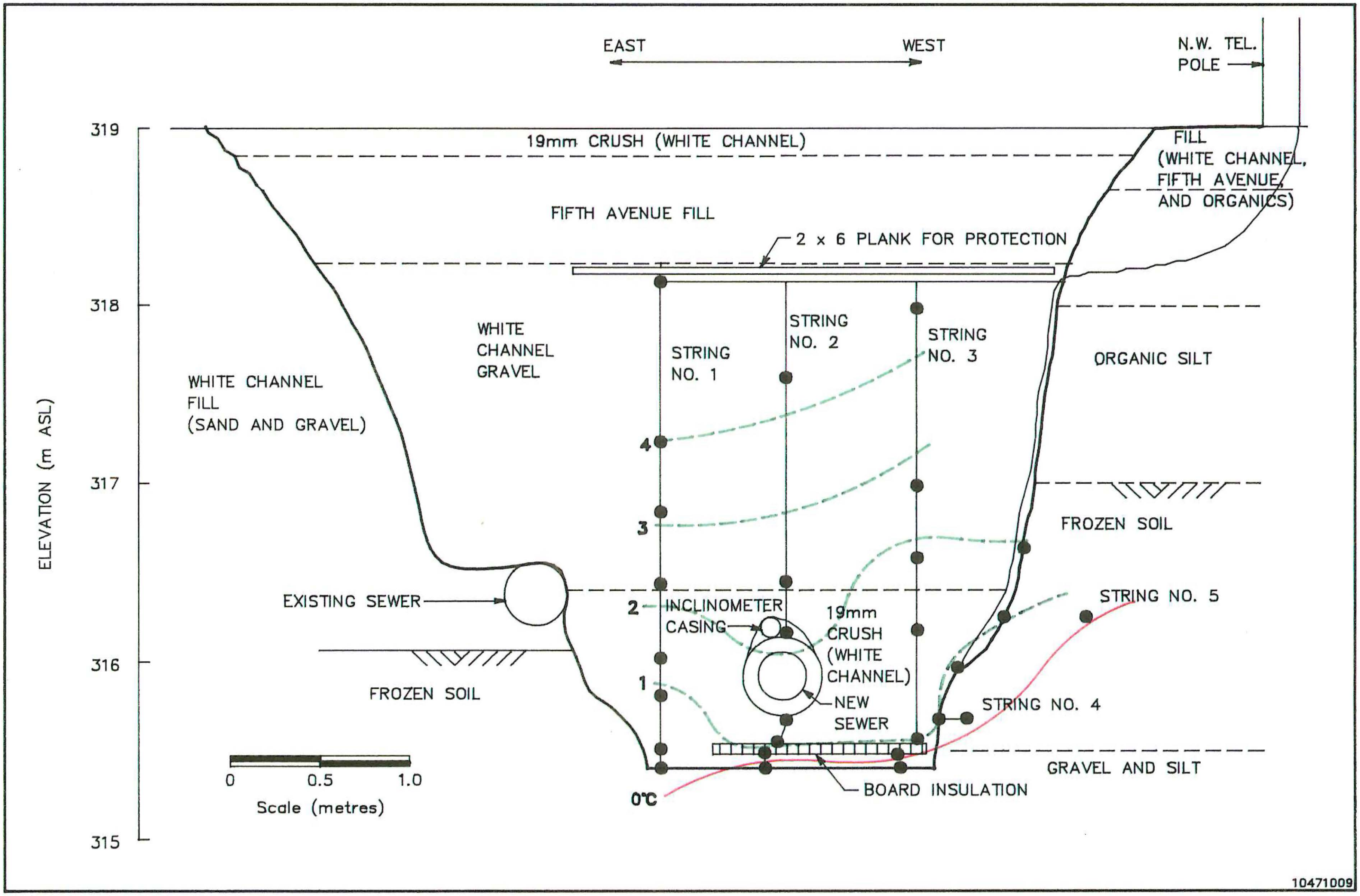


**FIGURE 9 THERMISTOR SUITE #1
TEMPERATURE ISOTHERMS
SEPTEMBER 14, 1987 (PEAK THAW)**

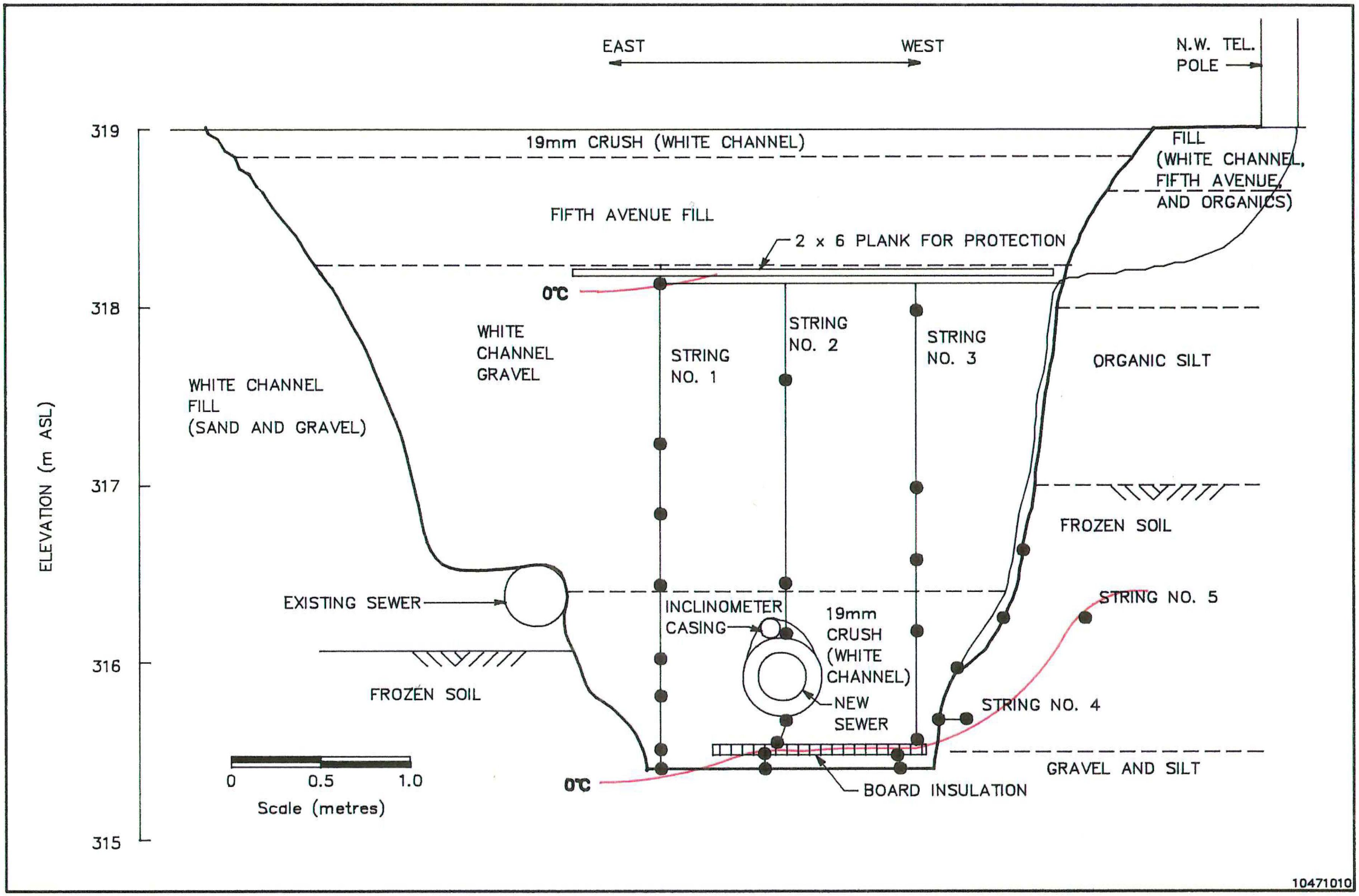


FIGURE 10 THERMISTOR SUITE #1
TEMPERATURE ISOTHERMS
NOVEMBER 4, 1987

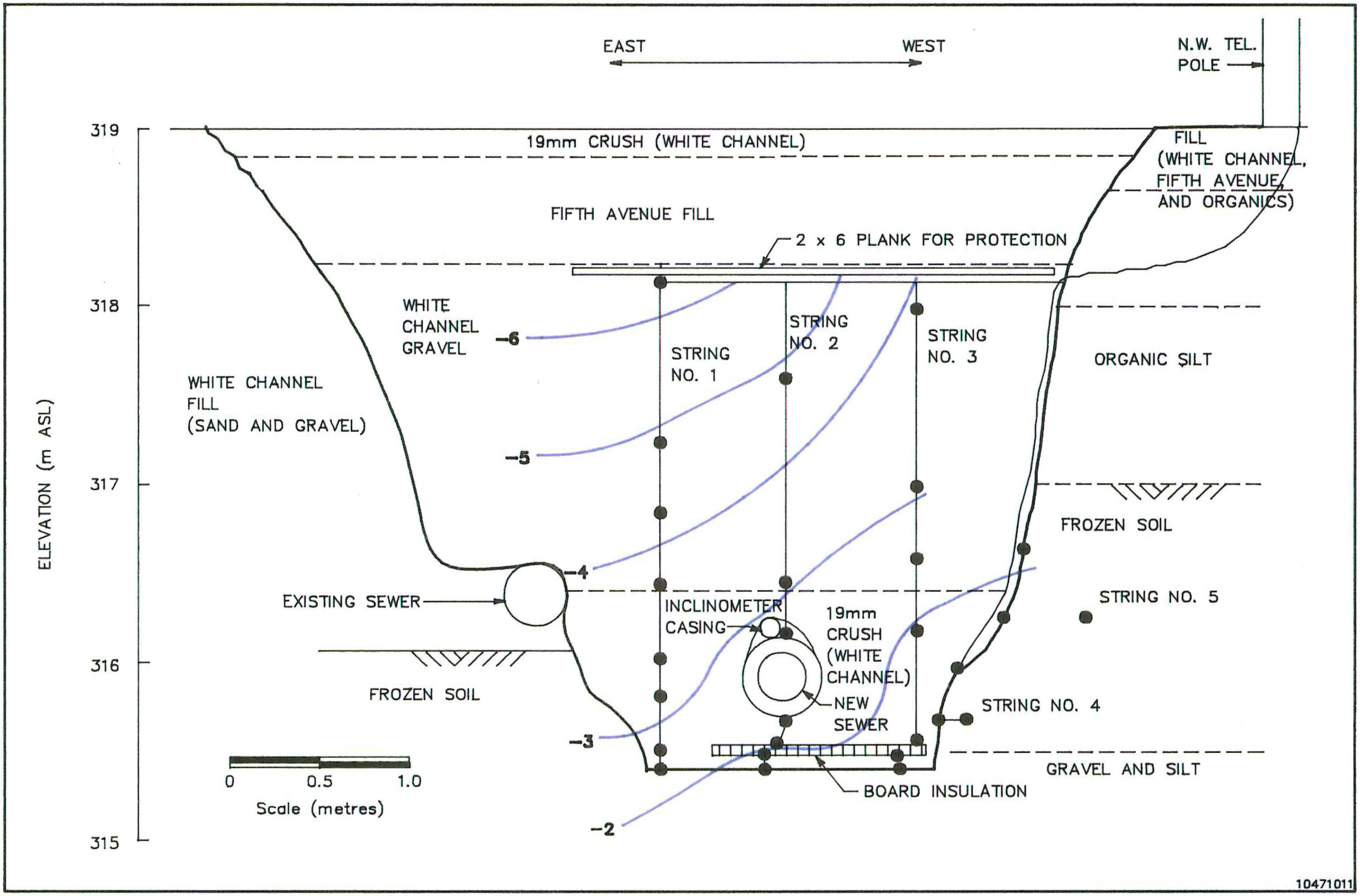


FIGURE 11 THERMISTOR SUITE #1
TEMPERATURE ISOTHERMS
MARCH 28, 1988 (PEAK FREEZE)

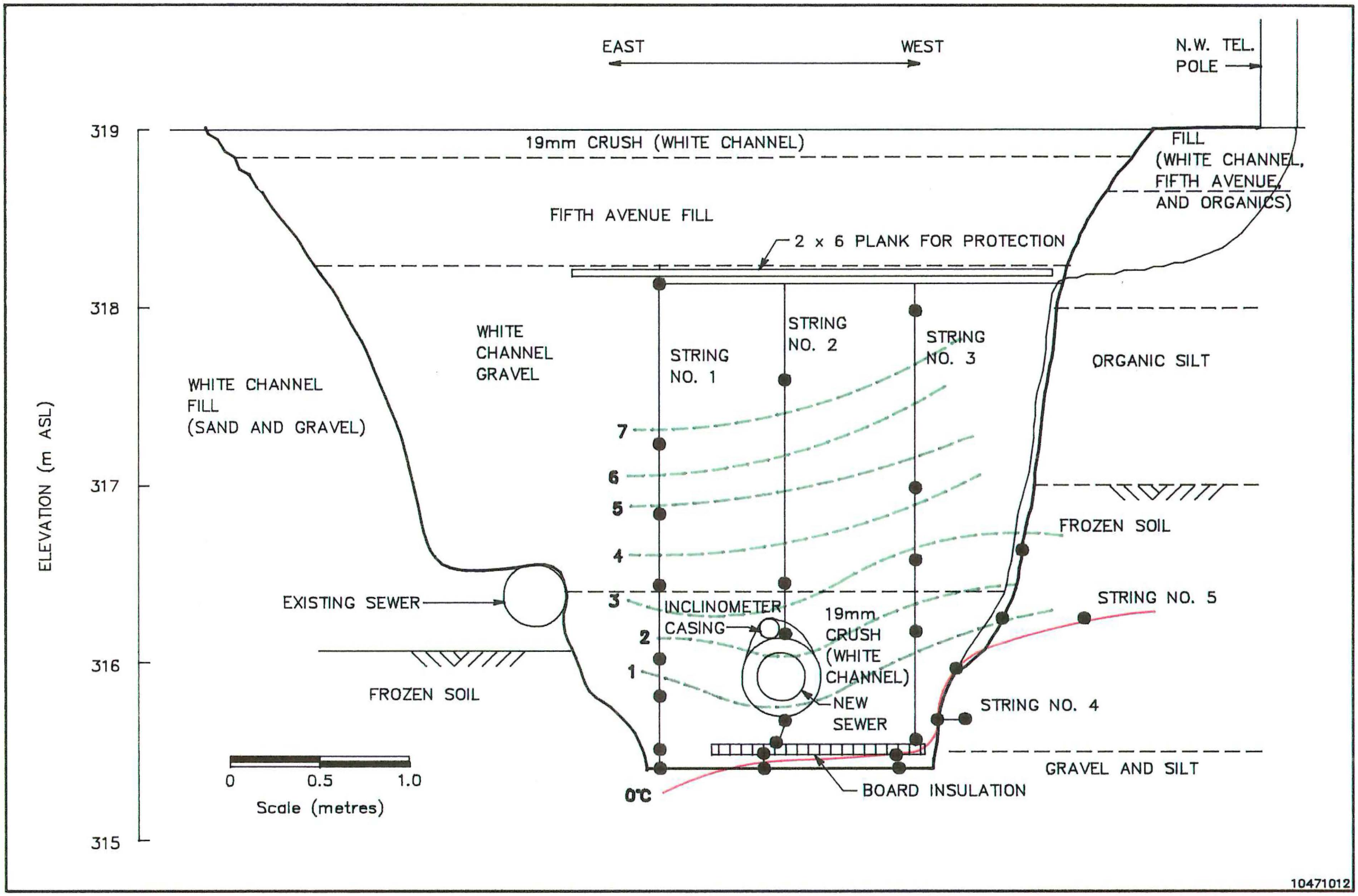


FIGURE 12 THERMISTOR SUITE #1
TEMPERATURE ISOTHERMS
JULY 29, 1988

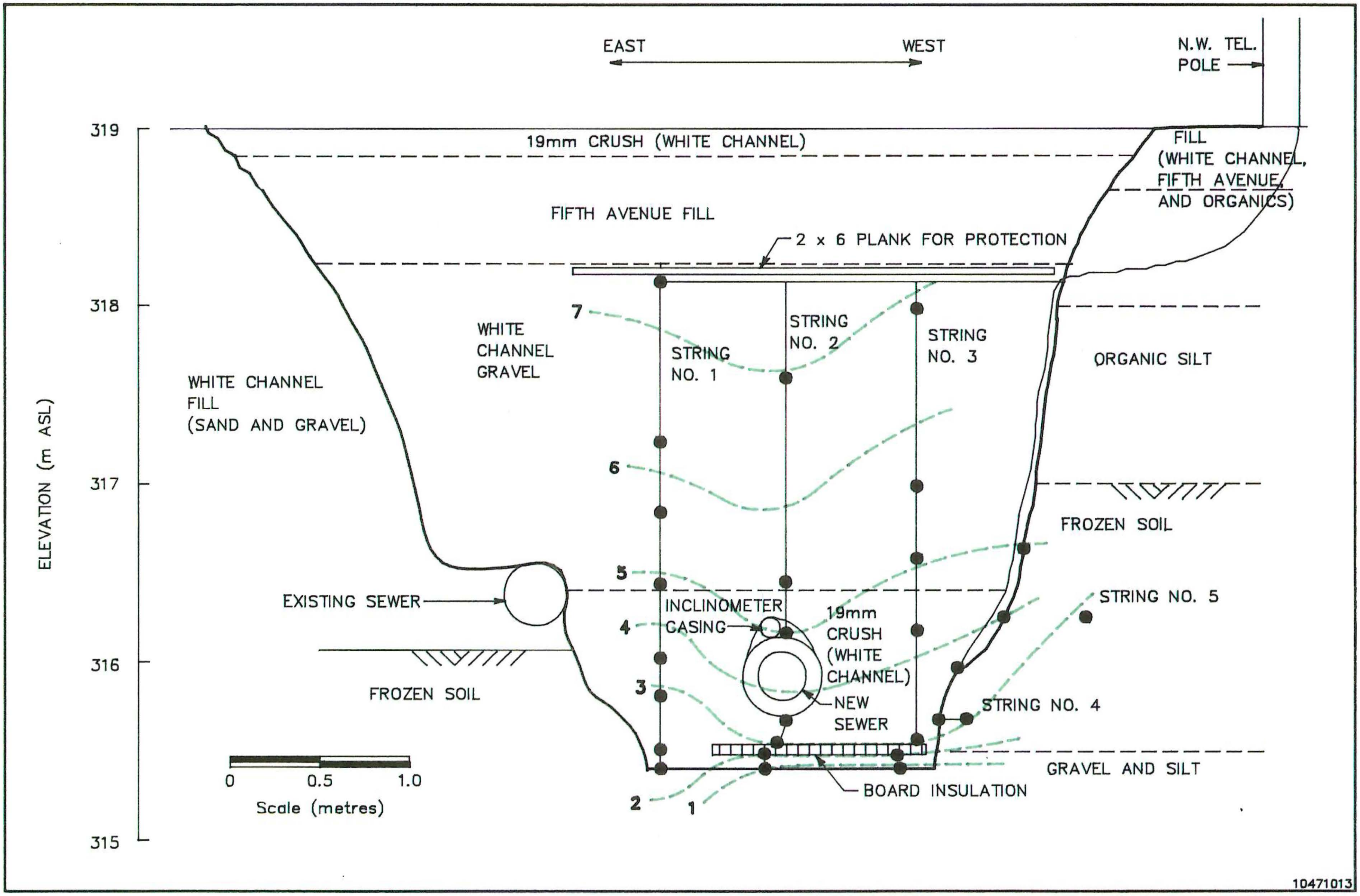


**FIGURE 13 THERMISTOR SUITE #1
TEMPERATURE ISOTHERMS
SEPTEMBER 12, 1988 (PEAK THAW)**

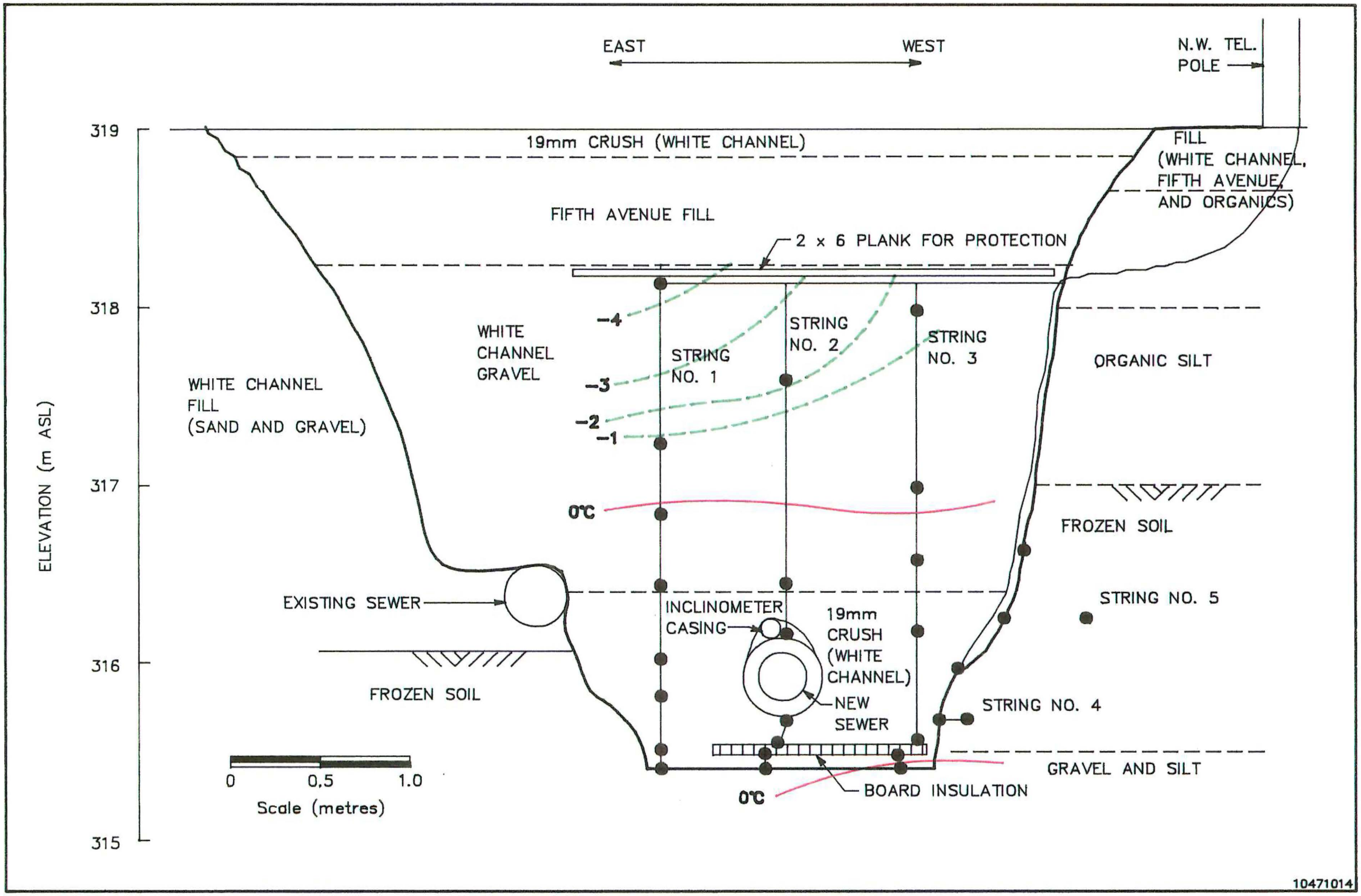


FIGURE 14 THERMISTOR SUITE #1
TEMPERATURE ISOTHERMS
NOVEMBER 24, 1988

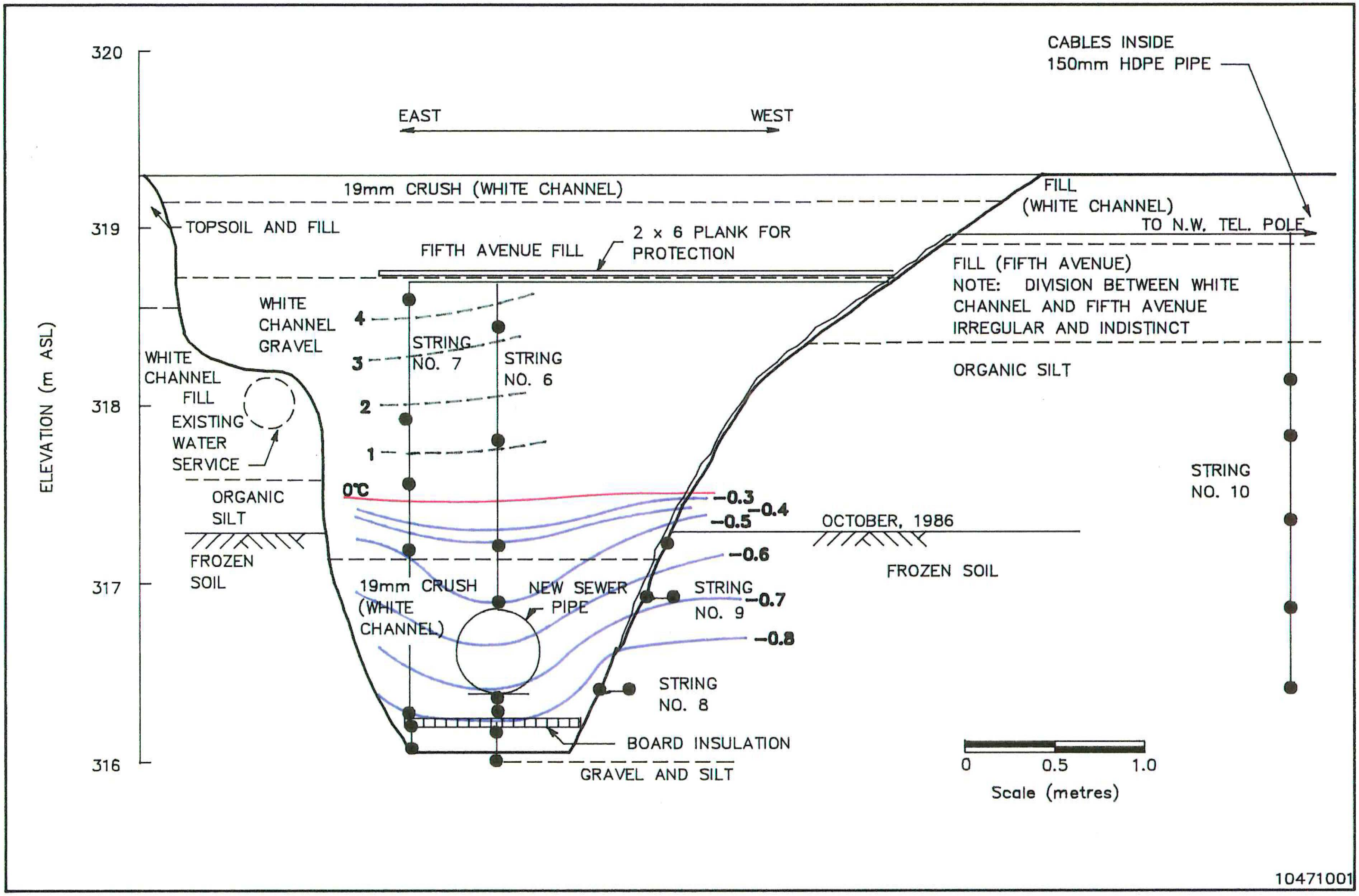


FIGURE 15 THERMISTOR SUITE #2
TEMPERATURE ISOTHERMS
JUNE 13, 1987

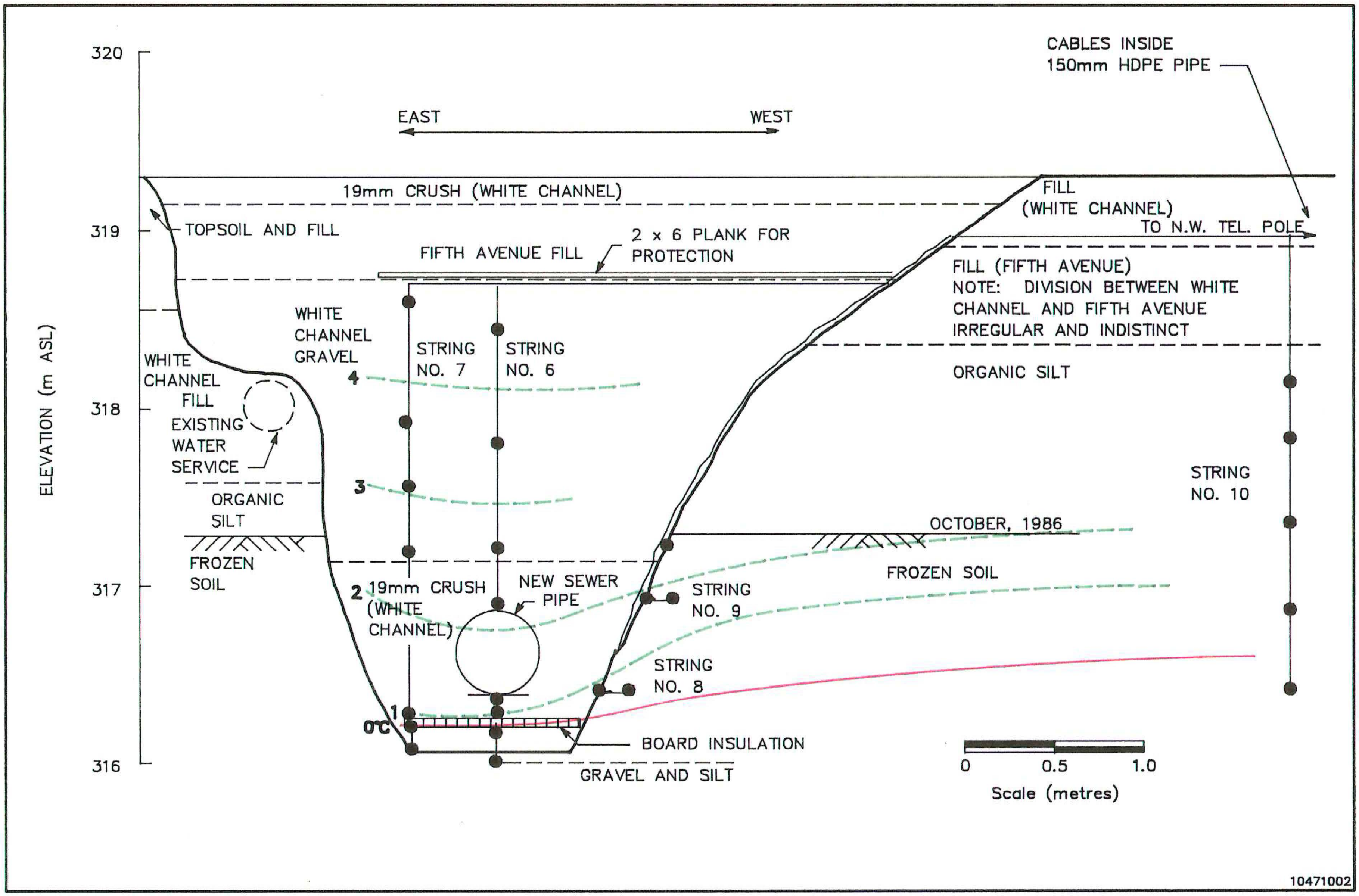


FIGURE 16 THERMISTOR SUITE #2
TEMPERATURE ISOTHERMS
SEPTEMBER 14, 1987 (PEAK THAW)

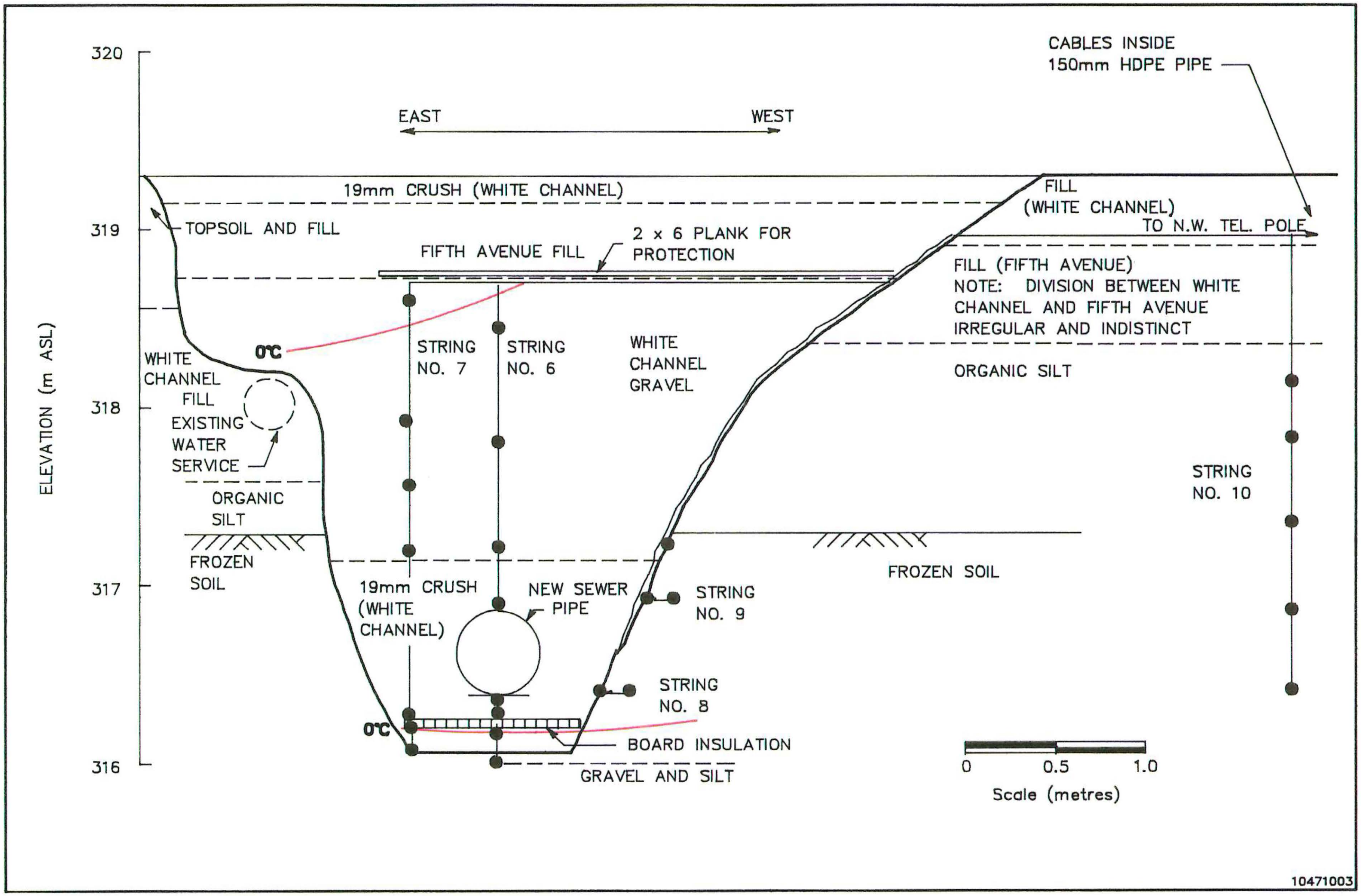


FIGURE 17 THERMISTOR SUITE #2
TEMPERATURE ISOTHERMS
NOVEMBER 4, 1987

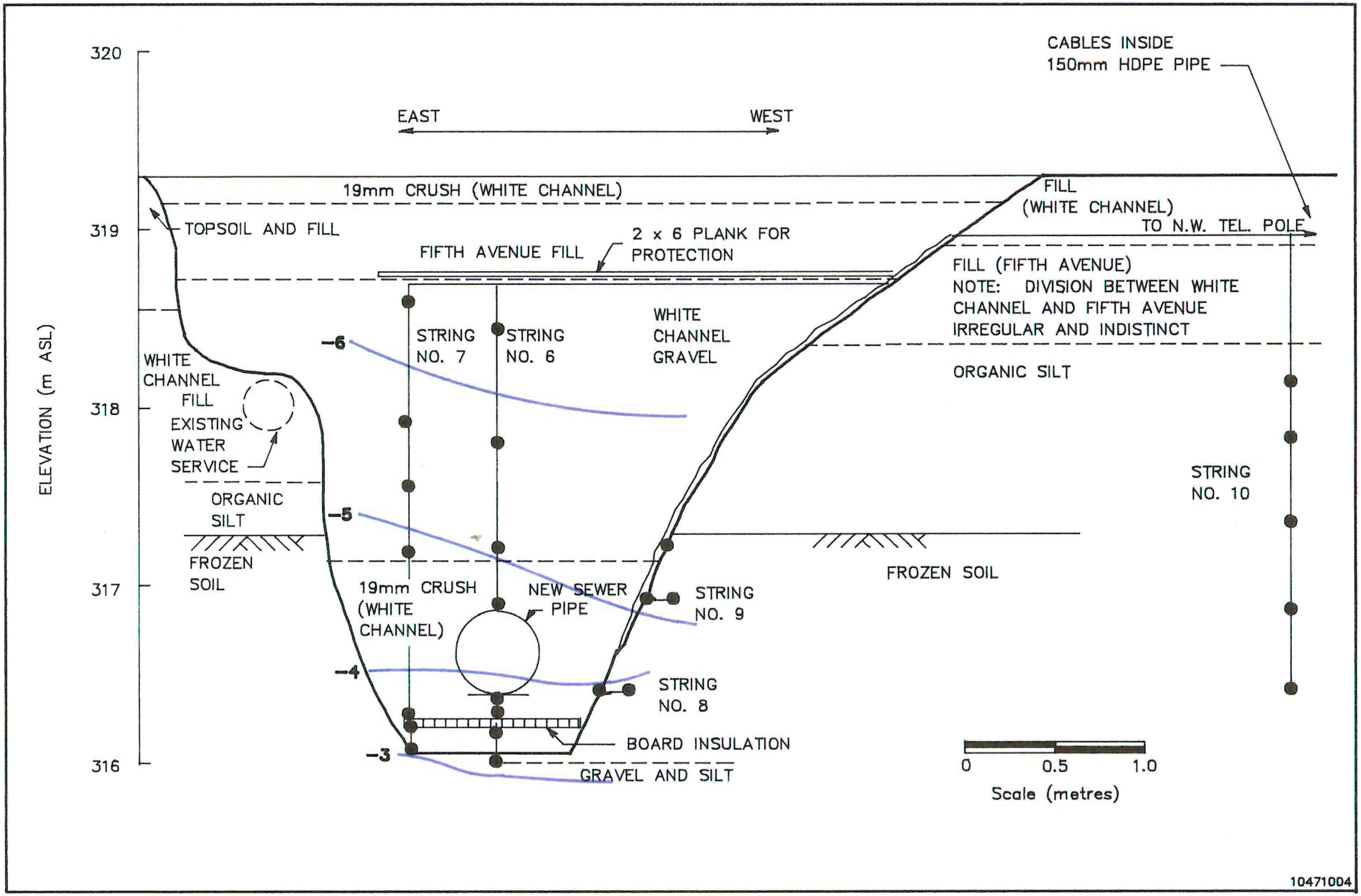


FIGURE 18 THERMISTOR SUITE #2
TEMPERATURE ISOTHERMS
MARCH 28, 1988 (PEAK FREEZE)

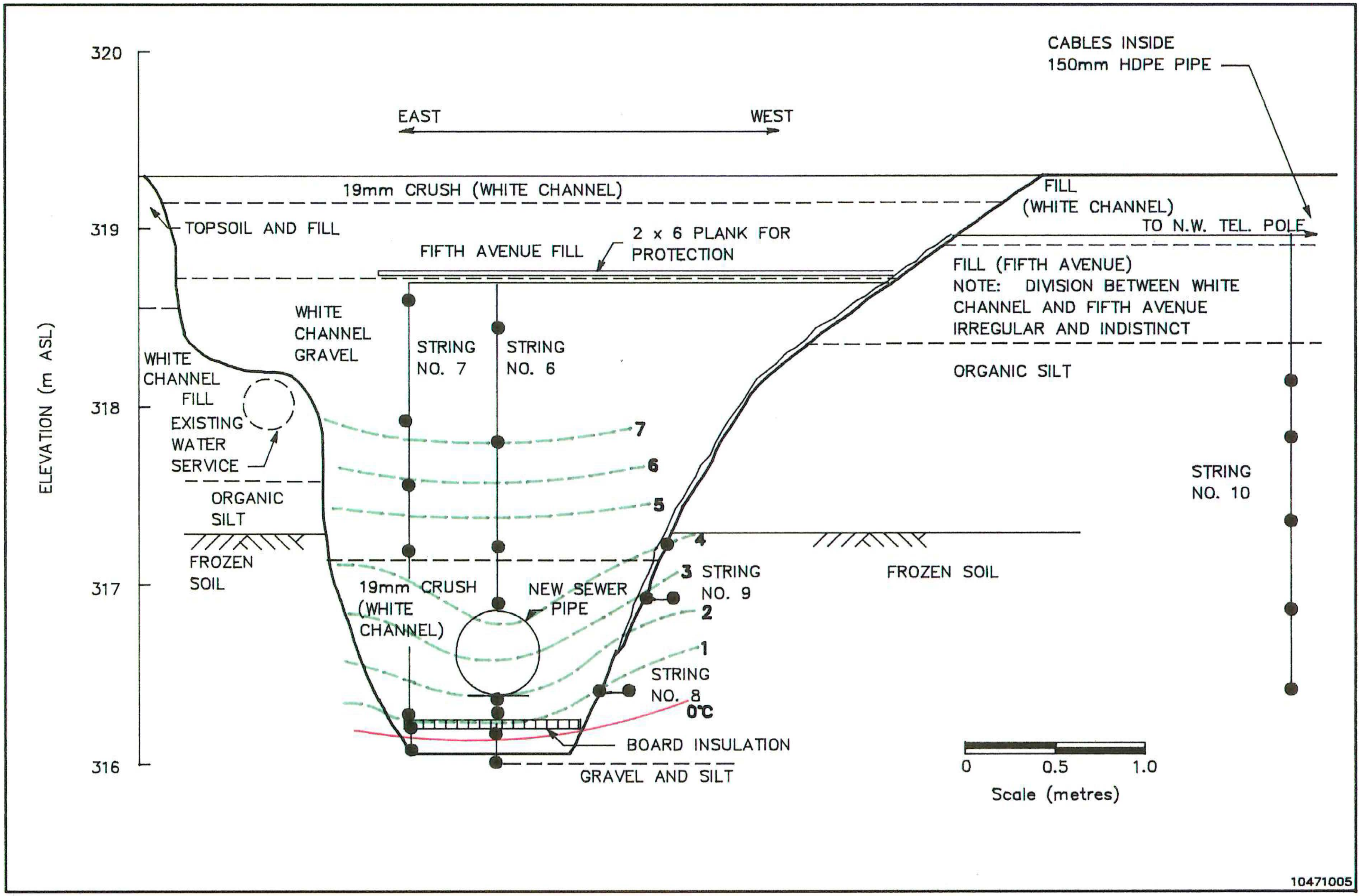


**FIGURE 19 THERMISTOR SUITE #2
TEMPERATURE ISOTHERMS
JULY 29, 1988**

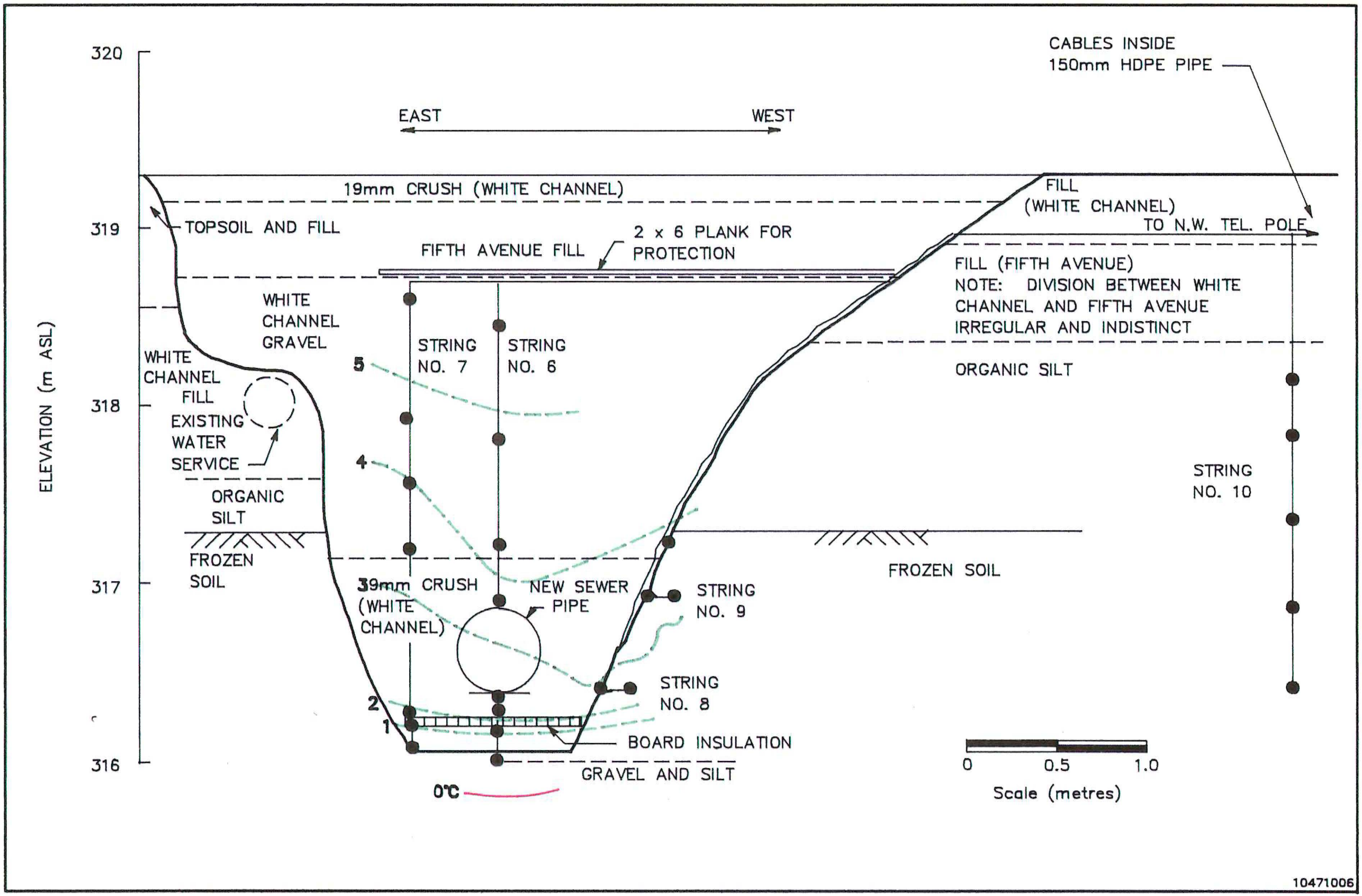


FIGURE 20 THERMISTOR SUITE #2
TEMPERATURE ISOTHERMS
SEPTEMBER 12, 1988 (PEAK THAW)

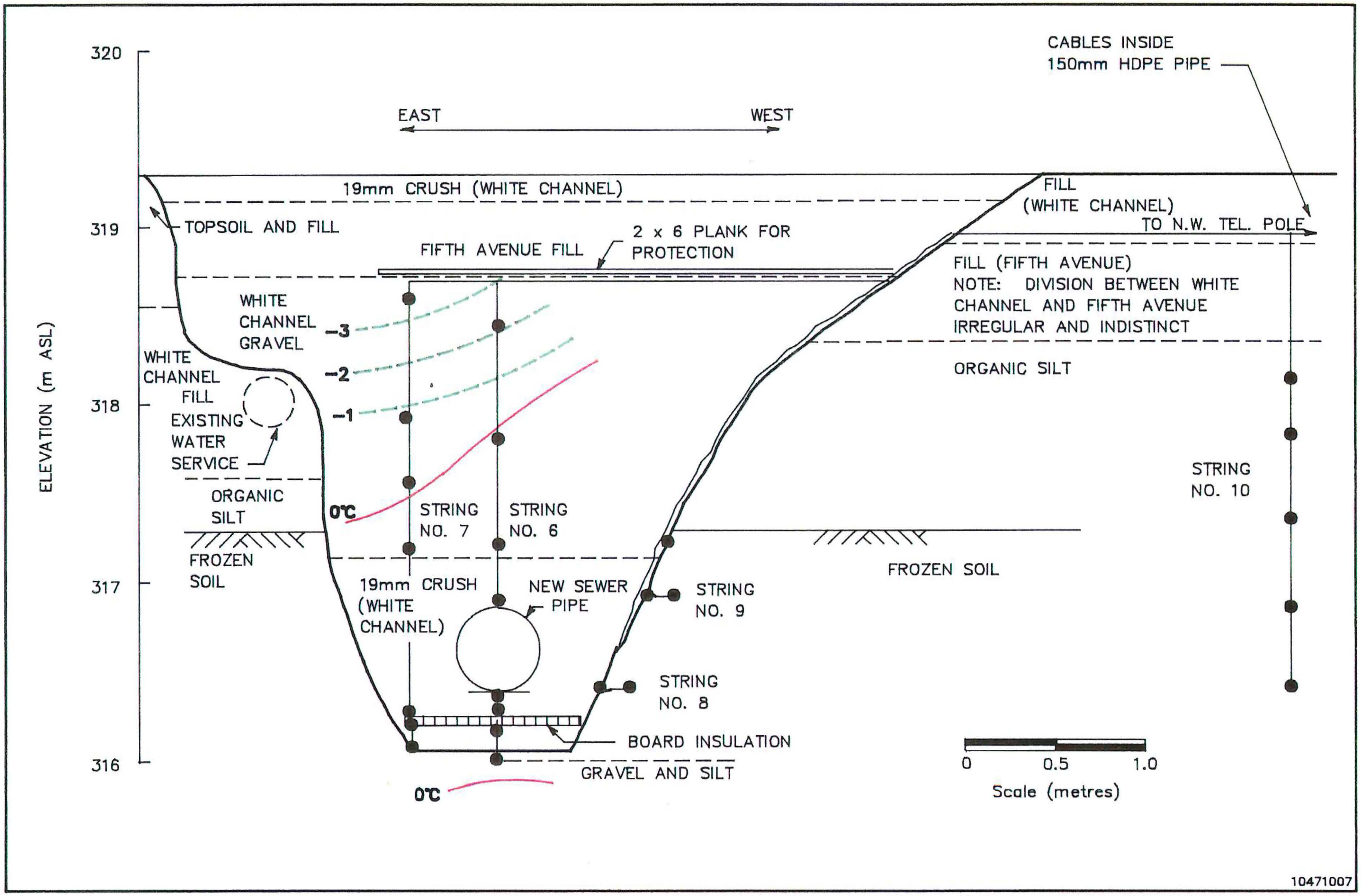


FIGURE 21 THERMISTOR SUITE #2
TEMPERATURE ISOTHERMS
NOVEMBER 24, 1988

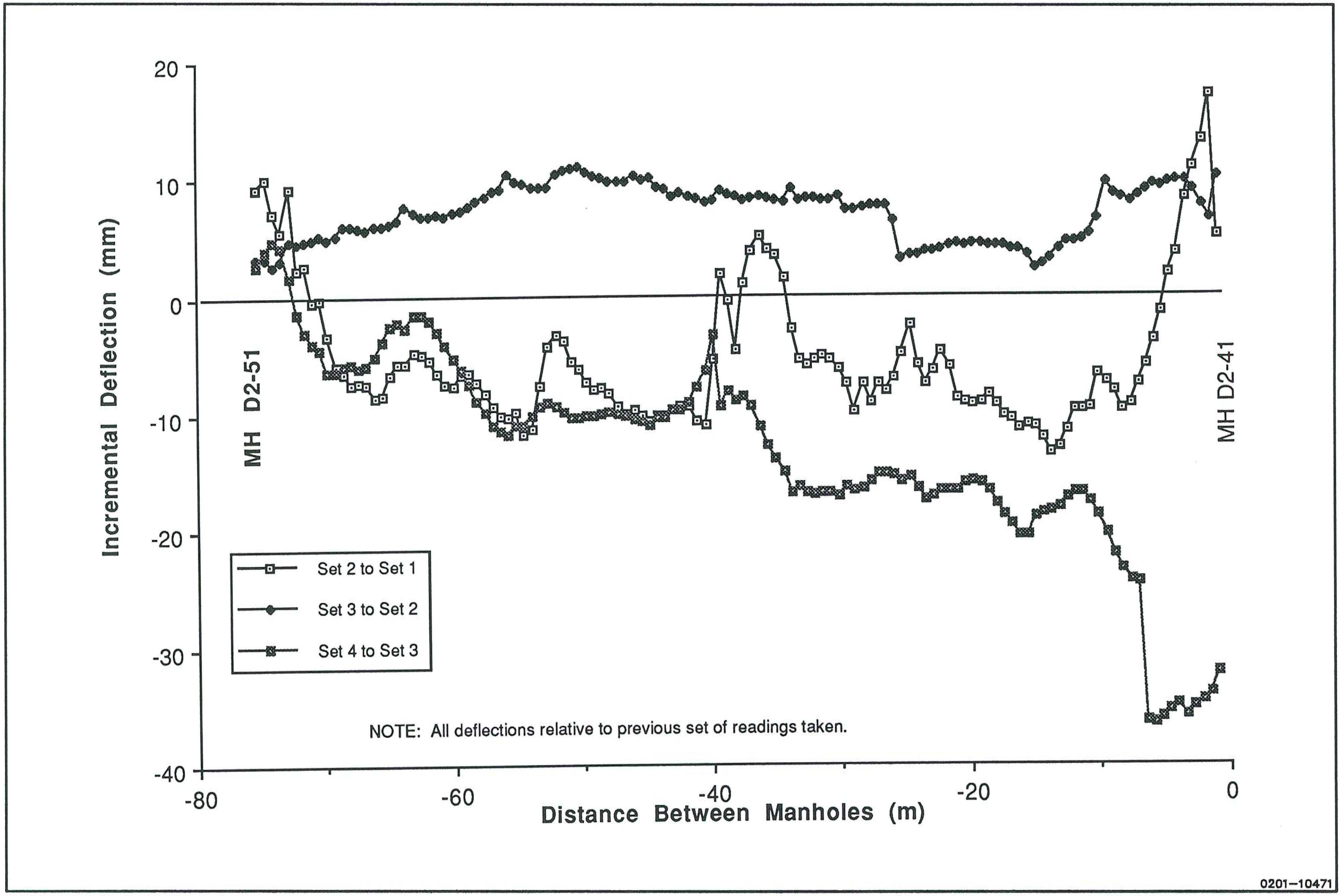


FIGURE 22 5TH AVENUE SANITARY SEWER INCREMENTAL DEFLECTIONS

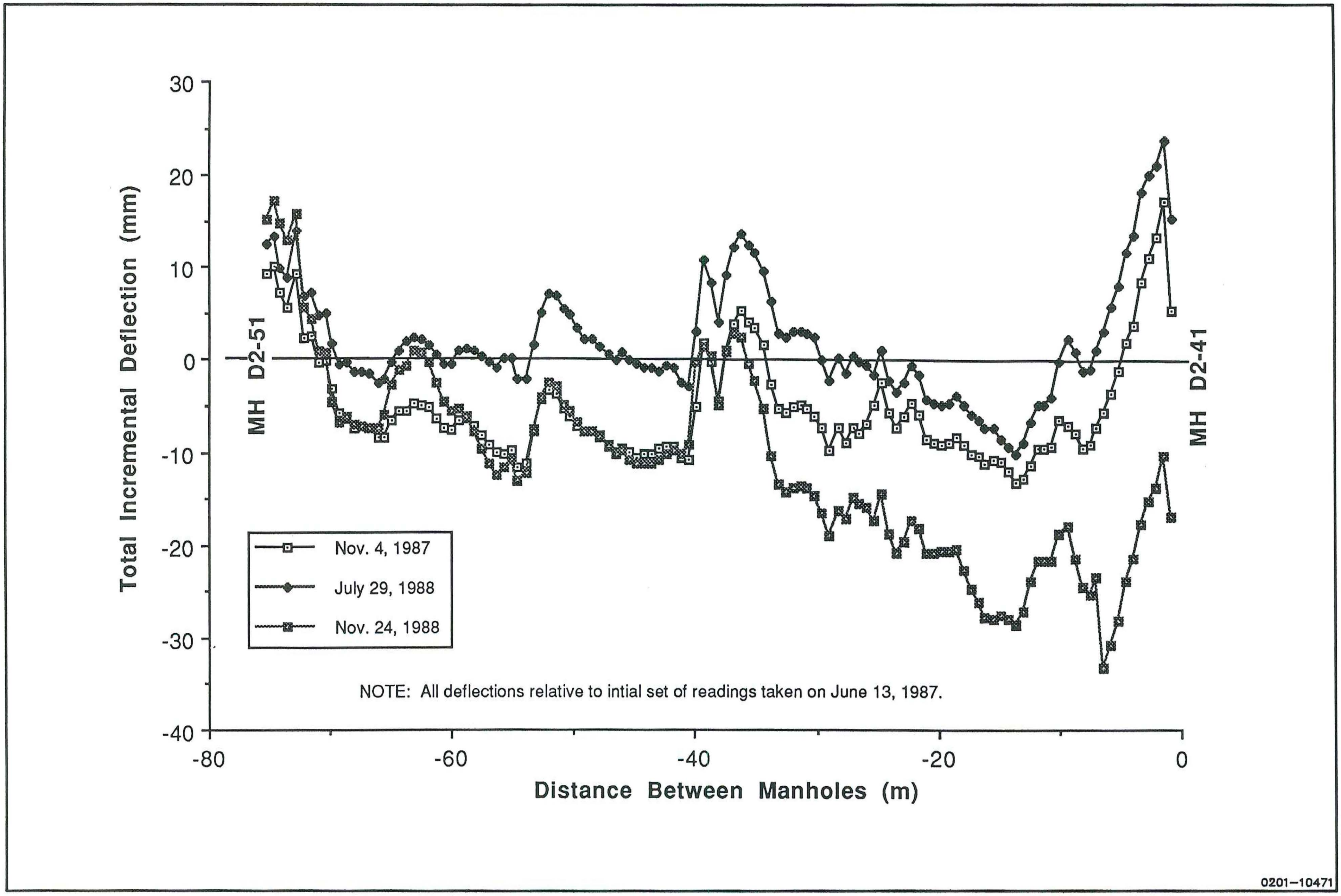
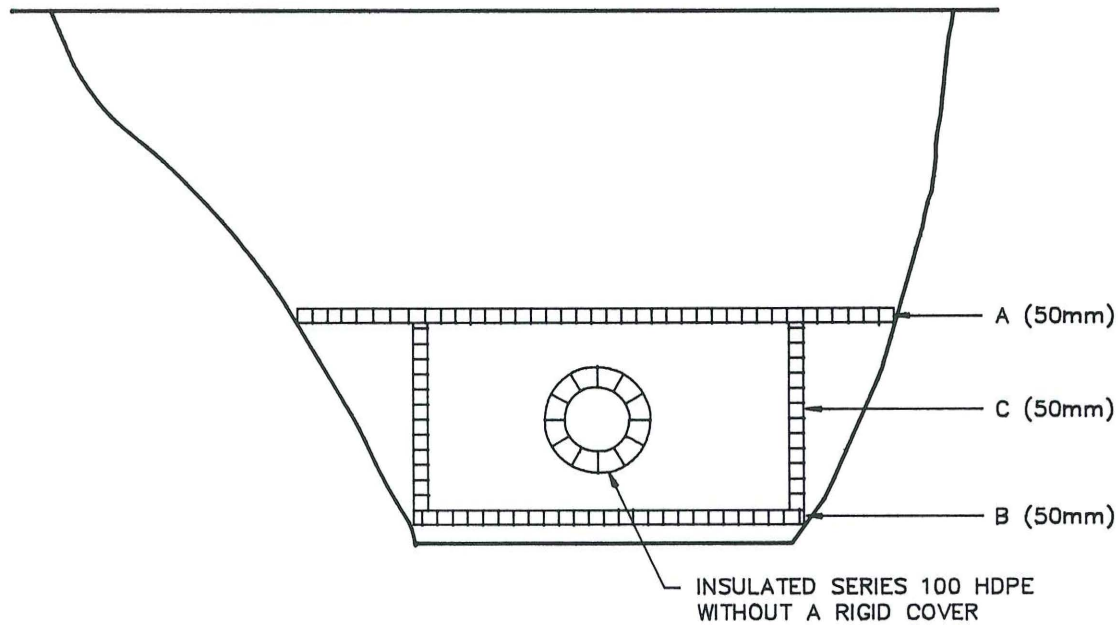


FIGURE 23 5TH AVENUE SANITARY SEWER DEFLECTION BETWEEN MANHOLES



PRIORITY	
A	ALL PERMAFROST AREAS
A+B	ALL PERMAFROST AREAS WHERE SILT REMAINS BELOW
A+B+C	THE MAXIMUM DEPTH OF EXCAVATION. ALL PERMAFROST AREAS WHERE SILT REMAINS BELOW THE MAXIMUM DEPTH OF EXCAVATION AND THE WALLS ARE IDENTIFIED AS ICE RICH.

NOTE: DRAWING NOT TO SCALE

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FIGURE 24 PROPOSED INSULATION PRIORITY