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INDIAN AND NORTHERN AFFAIRS CANADA
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Open File 1996-1(T)

# WILLIAMS CREEK PROJECT
# THERMAL LEACH PROJECT
# TEST HEAP LEACH AT CARMACKS
# YUKON TERRITORY, CANADA

By

BROWN AND ROOT INC.

FOR

WESTERN COPPER HOLDINGS LIMITED

Canada

Yukon
Government

This report is available from:
Exploration and Geological Services Division,
Indian and Northern Affairs Canada,
300 Main Street, Whitehorse, Yukon  Y1A 2B5

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# EXECUTIVE SUMMARY

An extensive heap leach field test was conducted during the 1993-1994 winter season at Carmacks, Yukon Territory. The test was performed to demonstrate the viability of heap leaching Williams Creek Copper ores in an Arctic setting. Williams Creek is proposing to process ore on a year-round basis. This test was modeled after the successful winter leaching operation of Pegasus Gold at their Zortman, Montana mine. In the latter operation, the leachate distribution system is overlain with approximately one meter of crushed ore. The over layer, plus a variable snow cover, adequately insulate the heap and permit year-round operation.

The test itself utilized an approximately 5 m. diameter crib loaded with a composite of ore from the northern (higher grade) end of the Williams Creek deposit. The ore was stacked to a total height of 7 m., including one meter of ore atop the emitter system. This matched the commercial heap height planned for Williams Creek at the time the test was started. By insulating the side walls of the crib, lateral heat flux was minimized. Thus, the crib replicated an interior segment of the commercial heap.

Leaching was done at a flow rate that matched those commonly used in industry. Leachate temperature was about 21°C, a level achieved with no external heat input other than normal process heat transferred from electrowinning to the leachate via solvent extraction.

An analysis of the test results showed that the winter conditions at Carmacks were quite typical of those expected at the mine site. Conditions included ambient temperatures below minus 40°C and an average temperature of minus 13°C.

In terms of leachate flow to and from the crib, the test ran continuously from late September through mid-February. In spite of some flow system problems, leaching continued unabated. There was no freezing in the interior of the crib or in the solution reservoir at the bottom. Freezing was limited to the insulating ore over layer and a few isolated points high in the crib near the outer walls.

The test clearly demonstrates that year-round heap leaching of Williams Creek ore is practical. The heap appears to be adequately insulated by a 1 m. ore layer on top of the emitter system. Normal process heat should be sufficient to maintain a leachate return temperature of approximately 20°C at the heap. However, provisions for some supplemental heating in the commercial operation may be desirable. This would permit recycle of the heated solution if electrowinning goes off-line or if there a long run of exposed leachate pipeline back to the heaps.

# INTRODUCTION

Brown & Root, Inc. was retained by Western Copper Holdings, Ltd. to assist in planning a pilot scale study of copper heap leaching under Arctic conditions, then interpreting the results from these tests. The site selected for this study was Carmacks, Yukon Territory, Canada. Carmacks is located in the same region as Williams Creek mine site at an altitude of approximately 760 m. Thus, the location is believed to experience Arctic conditions similar to those expected at the mine.

There is little operative knowledge or published information available for leaching at extreme latitudes where sub-freezing conditions occur continuously for several months. Therefore, the benefits of the Arctic study are two fold. First, an accurate study will quantify the heat losses from the heap, consequently the heat input necessary to maintain continuous year round operation. Second, the study will help correlate laboratory bench work and large scale testing. Thus, results will permit accurate thermal modeling of a commercial operation. Therefore, the overall objective of the proposed test work was to demonstrate that leaching during the winter season is practical.

The proposed operational plan for the mine has been patterned after one used by Pegasus Gold at the Zortman mine in Montana. At the mine, winter operations are maintained by installing drip emitters and then burying them under approximately 1 m. if ore. The Zortman mine has been successfully operated for several years under extreme winter conditions approaching those at Carmacks.

The field program at Carmacks involved the construction of a highly instrumented, full height segment of a commercial ore heap. Also included were leach solution distribution and collection systems and a small solvent extraction - electrowinning (SX-EW) facility to decopperize and recycle leach solution. Both thermal and metallurgical (leaching) aspects of heap leaching were studied in detail. However, only the thermal aspects are presented and discussed in this report. Metallurgical performance can not be fully assessed until the ore heap is subjected to a detailed post mortem examination. This is scheduled for the summer of 1994, at which time a metallurgical report will be prepared and issued.

Partial funding for the project was provided by the Canadian/Yukon Geoscience Office as part of the Mineral Development Agreement.

# DESCRIPTION OF FACILITIES

The ore was leached in a plywood test crib. The crib is octagonal in shape with a center wall to center wall diameter of approximately 5 m. and a height of 7.6 m. The crib was constructed using 2.45 m. long, 7.6 cm. thick X 20 cm. wide planks reinforced with steel beams ( 0.64 cm thick X 7.6 cm. wide). The beams over lapped at the ends and were locked together with 19 mm. redi-rods inserted through holes in the end of each beam. These rods were joined with connector nuts so that they ran to the top of the crib. Spacers made from 10 cm. diameter ABS pipe sections were used to reduce the number of planks needed. Spacers were 15 cm. high over the bottom half of the crib and 23 cm. high over the top half. The interior of the crib wall was lined with plywood sheeting, 19 cm. thick.

Due to the large areal extent of a commercial heap, horizontal heat flux will be minimal except around the sloping ore faces at the outer edge of the heap. This condition was simulated in the crib by placing fiberglass insulation (R32) between the beams and covering the entire crib with plastic sheeting. An additional 2-in. layer of Styrofoam insulation (R20) was placed over the sheeting and a second layer of sheeting was placed over the Styrofoam. The total insulating value of the insulation layers and sheeting was estimated to be approximately R60.

Prior to construction of the crib, the area was covered with 30-mil. thick HDPE sheeting. This was supported on both sides with geotextile fabric. About 15 cm. of crushed rock was placed on top of the liner and sloped to a lined event pond. The liner provided secondary solution containment. After erecting the crib, the edge of the liner were raised and dirt was packed underneath to provide a diversion/containment berm around the crib.

In order to simulate in-pile impoundment of leach solution, a 2 m. high 30-mil thick cup shaped PVC liner was installed in the bottom of the crib. A 0.6 m. deep flooded zone was maintained by installing a slotted standpipe through the liner. In an emergency, the PVC cup could provide storage for all leach solution in the crib. The upper crib walls were lined with HDPE sheeting to direct solution flow to the PVC cup.

An array of temperature probes (sensors) was located in the crib, underlying soil, and other ambient locations to determine: heat loss (gain) into the air and ground, lateral heat loss through the crib walls, solar flux on the side of the crib, and ambient conditions. In total, 48 sensors were installed and connected to six 8-channel data loggers. Details on the sensor locations are given in Appendices A.1 and A.2. The data loggers were set to record every five minutes and report an hourly average.

PVC lines were used to pipe solution in and out of the pile. Loading of the crib was stopped to allow installation of an irrigation header along the west wall of the crib after ore reached the 6m. level. Drip emitter piping was connected to the header every 50 cm. There was an 45 cm. spacing between emitters. Variable flow emitters were installed to allow flexibility in the solution application rates. A duplicate header and irrigation lines were installed in the event of a failure of the primary line. All exterior piping was heat traced and insulated. A plan view of the irrigation system is included on the drawing in Appendix A.2. The bottom drain was also located along the west wall.

In the commercial operation material mined from several benches will be under irrigation simultaneously. Therefore, the bulk ore sample was excavated from three trenches, representative of the ore at the north end of the deposit. This is the higher grade portion of the deposit and accounts for the bulk of recoverable copper. The number of trenches sampled was decreased in favor of increased sample depth to obtain unweathered ore. A minimum of 4 m. of weathered bedrock was blasted and removed before mining the samples. The samples were excavated from a 1.5 m. wide cut blasted across the full width of the ore zone exposed in the bottom of each trench.

Three methods of sample preparation were used to establish the ore grade in each trench: compositing the blast hole cuttings, chip sampling the trench walls, and size analysis of crushed sample splits (see table below). Assays were then performed on appropriate samples.

Ore from each trench was segregated and transported to the test site in Carmacks. The ore was reduced to minus 2.5 cm. with a portable two stage closed circuit crusher. A representative metallurgical sample was cut from each trench and shipped to Vancouver where it was sieved into five fractions, weighed and analyzed. The results are as follows:

| | TRENCH T91-20 | | TRENCH T91-21 | | TRENCH T91-02 | |
|---|---|---|---|---|---|---|
| SIEVE FRAC. | WEIGHT % | % Cu | WEIGHT % | % Cu | WEIGHT % | % Cu |
| -3/4 + 1/2 | 17.97 | 0.68 | 23.00 | 0.80 | 22.7 | 0.92 |
| -1/2 + 3/8 | 12.3 | 0.78 | 15.7 | 0.86 | 14.8 | 0.96 |
| -3/8 + 1/4 | 13.4 | 0.86 | 13.9 | 0.93 | 14.4 | 1.02 |
| -1/4 + 6 MESH | 14.4 | 1.06 | 14.1 | 1.05 | 14.4 | 1.12 |
| -6 MESH | 41.9 | 1.42 | 33.3 | 1.91 | 33.7 | 2.06 |
| AVERAGE | | 1.08 | | 1.23 | | 1.35 |

These values are somewhat lower than those obtained from blast hole cuttings and chip samples. Therefore, confirmation of the ore grade must await final sampling of the leached material in the crib. However, the grade is expected to be near 1.3% copper.

Metallurgical testing had previously demonstrated that acid preconditioning improves leaching efficiencies. Therefore, at Carmacks, batches of ore were blended in a cement truck proportionate to the sample weights. Concentrated acid and water in a 1:1 ratio, were added to the ore as it was being loaded into the truck. A total of 13.6 kg. of acid was added per ton of ore. The agglomerate was mixed for 3-5 minutes and dumped onto an inclined conveyor which lifted the ore to the top rim of the crib.

In order to reduce compaction or breakup of the agglomerated material, drop off from the end of the conveyor was held to less than 3 m. The walls of the crib and conveyor were raised in 1.2 m. lifts as the crib was being filled. Ore was dropped against the east wall of the crib. The surface of the pile was allowed to build up at the natural angle of repose. This is similar to an actual operation where the ore is dumped on the top edge of a new lift and allowed to cascade down the open face. After the leachate distribution system was installed, an additional meter of ore was added as insulation. Eventually, a layer of snow also accumulated on top of the ore.

A SX-EW pilot plant was used to de-copperize the leach solution and reduce the amount of make-up acid needed for the study. The solvent extraction portion employed a 2 X 2 circuit of extraction and strip mixer - settlers. The electrowinning cells comprised three tanks, each containing four stainless steel cathodes and five lead anodes. The cathodes were one quarter full size and weighed approximately 15 kg each. Copper was harvested manually by lifting the cathodes from each cell and peeling the copper off the sides. PLS was pumped into a 2000 l. storage tank. A solution inventory was maintained between 375 and 750 l. Raffinate flowed by gravity from the extraction cells into the first of three 200 l. leachate tanks. Tank #1 had a bottom drain which allowed entrained organic to collect at the top of the tank. Tank #2 was fitted with instrumentation to control acid additions. Leachate was pumped from the third tank back to the top of the ore pile. Lean organic recycled to the extraction stage contained considerable entrained electrolyte. This was sufficient to keep the pH of the raffinate at less than 1.5 when combined with acid pickup from transfer reactions in the extraction stages. Hence, no additional acid was required.

A flow sheet for the SX-EW circuit is provided in Appendix A.3. The circuit and its operation will be discussed in more detail in the metallurgical report to be issued later.

# OPERATION OF FACILITIES

As described above, the ore was acidulated before being loaded into the crib. Heat from acid hydration and reaction with the ore raised the temperature of the agglomerated material to about 35°C. This temperature later stabilized at around 30°C in the crib.

Irrigation started on September 27, 1993 (DAY 0). Solution breakthrough at the bottom of the crib occurred 20 hours later. The SX-EW pilot plant was started as soon as sufficient PLS became available. The SX-EW plant was shut down on December 17, 1993 (DAY 81). However, heated leach solution was circulated through the pile until February 8, 1994 (DAY 134). Thermal conditions were monitored throughout the 137-day test by recording the temperature data using the array of sensors. Other than the limited solar flux, the only heat input to the crib was in the leach solution recirculated back to the emitter system. This heat input can be calculated from the temperature and flow rate of the leach solution going back to the crib.

During the first 80 days of the test, there was no direct heating of the leachate. Only the electrolyte was heated to maintain a solution temperature of 35°C. Heat was transferred from the electrolyte, through the organic, and finally into the leachate. This process heat transfer was sufficient to maintain average leachate temperature at 21°C.

When the SX plant was shut down, after Day 80, a heater in the leachate tank was used to maintain the solution temperature at 21°C. Recirculation of the heated solution continued until February 8, 1994 when the test was terminated. Temperature data were collected through February 11, 1994 to follow the cool down of the system.

Every effort was made to minimize the lateral heat flux as this will approach zero in a commercial operation, except around the extreme edges of the heap. For all practical conditions this was achieved after the additional Styrofoam layer was added. Therefore, the only significant heat losses from the crib were the solution flowing from the crib and vertical fluxes into the material below the crib and upward through the ore and snow layers above the emitters.

# PRESENTATION AND ANALYSIS OF DATA

Chart 7.0 illustrates the ambient temperatures from temperature sensor **B4** mounted above the top of the crib. This sensor is the highest and is affected more by wind than any other sensor. However, all ambient sensors tracked within about a degree of each other. See Chart 16.0. Chart 7.0 shows the daily high, low, and average temperatures over the course of the field test. Of equal importance is the fourth line, the delta temperature. This is the difference between the daily high and low temperatures. The average delta was 7.4°C, which stayed fairly constant throughout the study. After the last week in November the temperatures (high, low, average) dropped below freezing and averaged minus 13°C for the remainder of the test.

Chart 8.0, normalized in time to the experiment, tracks temperature data from the Faro area 200 km east of Carmacks. This plot represents the average conditions for the 6-year period 1985-1990. The Yukon Weather Centre (YWC) of Canadian Weather does not track conditions in Carmacks. According to YWC, Faro and Carmacks are very similar environments. Indeed, at minus 13.3°C, the daily average temperature for Faro during the 1985-1990 period is virtually identical to the minus 13.0°C seen at Carmacks during the 1993-1994 field test.

Chart 9.0 is a comparison of the test period temperatures recorded in Carmacks (from sensor **B4)** and the 6-year average in Faro. (Faro temperatures are normalized to days of leaching.) There is a close correlation between Carmacks and Faro. Taking in to account a warm spell in December and a cold snap in January at Carmacks, the temperatures at the two locations track within a few degrees of each other. The delta temperatures at Faro and Carmacks are particularly close.

Chart 10.0 is a profile of centerline temperatures within the heap, with the readings from ambient temperature sensor **B4** included for reference. Of note is that the center of the heap does not freeze. On December 17, 1993 the SX-EW plant was shut down. Even with the loss of the this process heat input, the temperature does not significantly decline due to auxiliary heating of the recycle leachate.

Leach solution was detected at the base of the crib in late December. The leak was traced to the point where the raffinate return header penetrated the crib. Here the pipe was melted by heat tracing which had shorted due to acid attack. Consequently, only the west side of the crib was being irrigated. During repair it was found that the heap had subsided about 45 cm. or 7.5%. This behavior is quite normal during the initial leach cycle. The irrigation lines were re-attached to the header and normal flow was established on approximately Day 113. This resulted in a sudden temperature rise as can be seen on the chart.

In relation to the highly variable ambient temperature (sensor **B4)**, the heap shows much greater thermal stability. Note that the heap has sufficient heat capacity so that it only responds to seasonal and not daily fluctuations in ambient conditions. Even during December's warm weather the heap temperature decline was only nominally affected.

Chart 11.0 illustrates a lateral profile of temperature in the solution reservoir of the crib at +0.15 m. elevation. Again, the ambient temperature sensor **B4** is included for reference to the environment. The peripheral probes, **B5**, **C3**, **D1**, and **D7** track within three to four degrees of each other, with **C3** being slightly higher. This is possibly due to its southern expose with more incidental solar radiation.

The disruptions in the temperature profiles of sensors **D1**and **D7** are probably due to the failure at the leachate header. Theses temperatures start to recover on Day 113 when the leachate header was repaired. They return to almost the same equilibrium temperature as before the failure. It is of interest that sensors **C3** and **B5** were not critically affected by this failure. This suggests that the reservoir has a high degree of lateral heat conduction due to inundation. This permits rapid equilibration.

Charts 12.0 shows another lateral temperature profile at +3.05 m. elevation. This should have been an area of unsaturated flow. Again effect of the header failure can be seen; with the disruption starting at approximately Day 80, and culminating at Day 113, when repairs were affected. At Day 113 the temperatures begin to recover and approach their original trend. Note that the north side sensor **B7,** went sub-zero when the break was repaired. However, the area apparently did not freeze completely and was warming up as the test ended.

With the failure of the irrigation lines, either some short circuiting of leachate solution occurred or there was increased flow in the remaining lines. This created a higher flow rate on the terminal side of the irrigation lines.

Chart 13.0 is a lateral temperature profile at +5.5 m. elevation. When the header failure occurred, the temperature disruptions at this level were not as pronounced as at the lower elevations. Of particular interest on this group of charts is the East side sensor **D4**. It indicates that freezing occurred on approximately Day 113. This is evident because sensor **D4** tracks almost identically with the ambient conditions registered by sensor **B4**. Apparently, once an area has been sufficiently saturated and the flow drops below some minimum level then that area is likely to freeze faster than other sections of the heap that are not as saturated.

Chart 14.0 shows the lateral temperature profile at +5.8 m. elevation. Note that as the elevation increases, the difference between the lateral sensors becomes more pronounced and the average lateral sensor temperature is cooler than the centerline temperature. Again on Day 78, when it is thought that the main header began to separate from the irrigation lines, the North side, sensor **D5** froze and tracked the ambient conditions. The data also shows that once the repairs were affected on Day 113, the heap temperatures begin to recover. Sensors **C1** and **C7** (North and South sides) also dropped below zero, but recovered when the header was repaired and the flow pattern improved.

Chart 15.0 illustrates the lateral temperature profile at +6.6 m. elevation This is the layer of ore that acts as an insulating layer just above the emitters. On approximately Day 80 the East sensor, **D6**, froze. This coincided with the freezing at sensor **D5**, in the heap just below the emitters at elevation +5.8 m. Once the irrigation lines were repaired, the centerline, north, and south sides started to recover. The east and west emitters froze during the disruption and never thawed after normal flow to the heap was restored. However, due to the repairs, the West sensor was exposed to ambient air from Day 90 on. Thus, it appears that once a wet or saturated section of the heap freezes, it will thaw slowly even with elevated flow. However, unsaturated areas that freeze will thaw relatively quickly when irrigation is resumed. The freezing effects are also pronounced in a vertical manner and affect conditions both above and below the frozen region.

Chart 16.0 provides a comparison of the ambient temperatures from sensors at various locations. Sensor **E5** (north side of the heap) was the coldest, with sensor **E7** (the east side of the heap) the warmest. The ambient sensors all tracked within one to two degrees of each other, however.

Chart 17.0 shows a temperature comparison of the top four layers and the ambient and are as follows: sensor **A8**( emitter level) , **B1** (ore level), **B2** (top of pile), **B3** (in snow) and **B4** (ambient). As seen in the chart, the air, the snow, and the top of the pile all tracked approximately together. It is the second (lower) layer of ore just above the emitters that was not readily affected by the fluctuations in ambient temperature, but more by the temperatures at the emitter level. These results show the attenuating effects of burying the emitters under an insulating ore layer.

Chart 18.0 is a profile of the centerline temperatures below grade. As expected, these temperatures were stratified with the deeper probes being slightly warmer. As the experiment progressed these temperature values tended to equilibrate and the stratification was much less pronounced. This is probably because the heap served as a large heat reservoir for the area below it.

Chart 19.0 is a profile of the north side temperature below grade. Like the centerline temperatures in Chart 18.0, the North side profile was stratified at the beginning of the experiment. However, the outer profile remained stratified throughout the experiment while cooling off with the onset of winter. As expected, the coldest layers were the closest to the surface. At 0.3 m. below grade elevation the ground eventually froze. This illustrates the fact that there was very little heat flow from just above and almost no lateral heat flow from underneath the heap.

# CONCLUSIONS

The winter weather conditions in Faro and Carmacks were demonstrated to be similar. The daily average temperature during the test at Carmacks tracked closely with the average daily temperature over a six year period from Faro. This shows that the winter experienced in Carmacks was typical of the area in terms of severity.

The heap appeared to be a well behaved thermal system that responded normally to perturbations in heat flux. With the insulated sides, the heat flow was predominately a vertical flux. Areas that were not frozen and that were in the mid to lower levels of the crib exhibited slight concentric temperature stratification, with the exception of the reservoir level. These zones responded slowly and tracked only seasonal trends. The top levels were more responsive to the ambient temperature and tended to converge. Similarly, since the reservoir level was inundated with leachate, it exhibited a higher degree of heat conduction. The temperatures here also tended to equilibrate. The test results demonstrate that the reservoir will not approach freezing temperatures. Also, if leachate is continuously applied at a reasonable rate during the freezing months, the pile does not freeze. The temperature of the return flow need not be excessive. A level of 20°C was maintained in the leachate due to the transfer of process heat from electrowinning. This was sufficient to balance heat losses, even though the ambient temperature dropped to minus 40°C.

In all charts there is downward trend in temperature. However, this trend can not continue with the advent of spring. Chart 8.0 shows that by the end of March, the average daily low temperature will be above freezing. Hence, a gradual warming trend will occur.

The temperature response to the leak demonstrated that there are two consequences once a moist to saturated area freezes. First, the insulating value decreases so the frozen zone will be more susceptible to the ambient conditions. Hence, the frozen zone will tend to grow. Second, the frozen section will not thaw rapidly even with a resumption of flow or an increase in heat input. In this regard, unsaturated areas
will thaw more quickly than saturated ones.

Freezing seems to creep vertically and not laterally in ore that has a high moisture content or that is being short circuited. As the depth below emitters increased the lateral temperature variation became less pronounced.

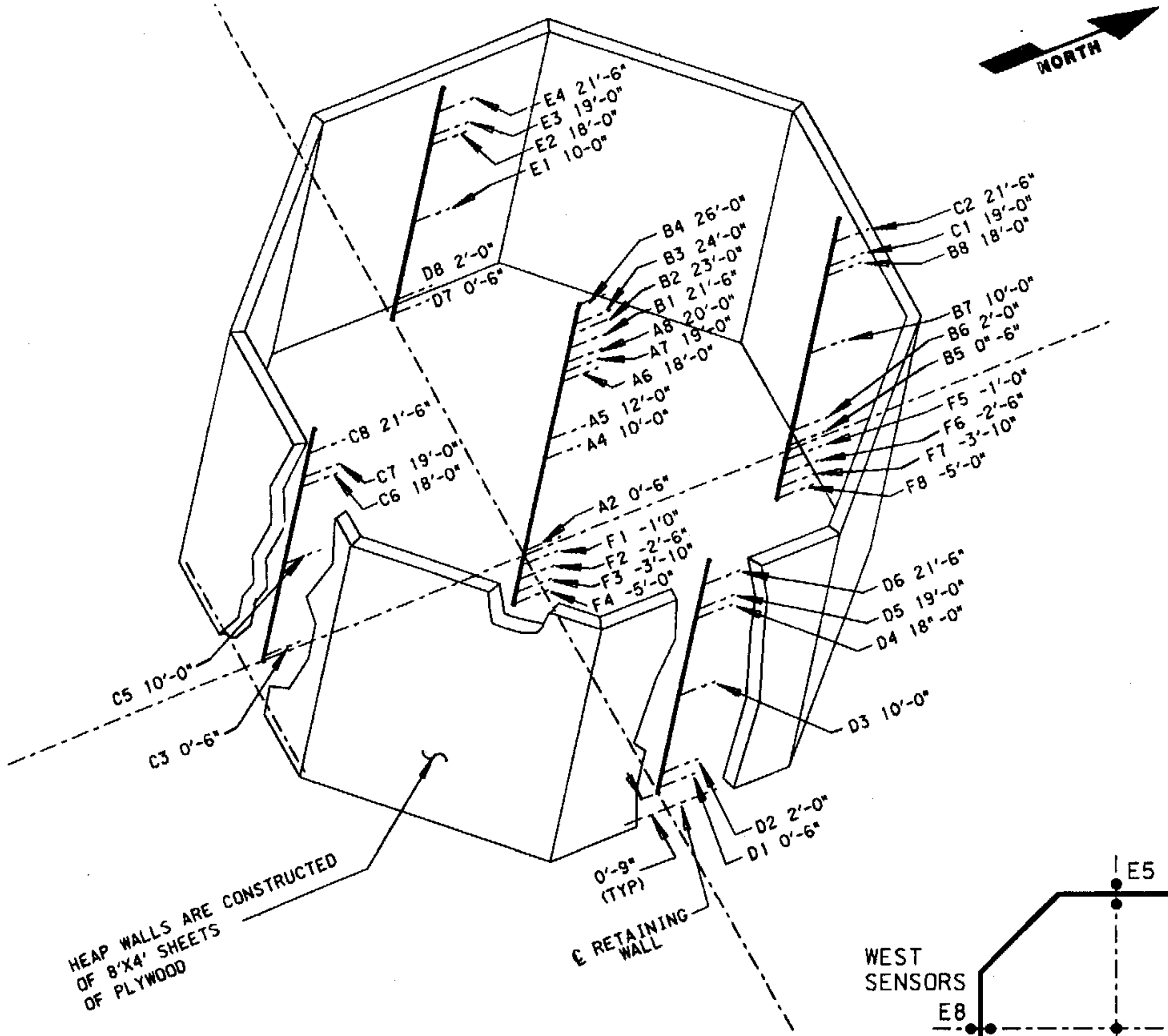
One of the most important conclusions that can be drawn is that the deeper the emitters are buried, the lower the heat loss to the surroundings. Chart 17.0 illustrates the dramatic difference that 2.5 feet of dry overburden can make in temperature distribution. Also, any copper in this insulating layer above the emitters is not lost. It will be recovered when the next lift is added and leached.

The only solid freezing that occurred within the crib was limited to some isolated points. These were either in the insulating layer above the emitters or around the outside in the upper half of the ore. Freezing around the periphery of the heap is to be expected even in commercial operation. However, the field test at Carmacks clearly demonstrated that leaching can be conducted throughout the winter. All ore below the emitters, except for that at the extreme edges remained well above the freezing point. In this regard it is worth noting that the high acid content of the leach solution depresses the freezing point below 0°C. Thus the temperature must drop below zero before the zone freezes completely. For the leach solution used at Carmacks the expect freezing point is -1 to -2 °C

A final consequence of the observed test performance is the need to maintain emitter flow. If flow stops or is somewhat reduced, the affected zone is likely to freeze completely. The frozen zone may then continue to grow as the flow to surrounding areas is restricted. However, due to the heat content of the heap, brief interruptions in flow are unlikely to cause freezing.

# TABLE 1.0 TEMPERATURE SENSOR LOCATIONS

| LEVEL | | C-LINE | NORTH | SOUTH | EAST | WEST |
|---|---|---|---|---|---|---|
| **HEAP TEMPERATURE SENSORS** | | | | | | |
| +24'-0" | IN SNOW | B3 | | | | |
| +23'-0" | IN ORE | B2 | | | | |
| +21'-6" | IN ORE | B1 | C2 | C8 | D6 | E4 |
| +20'-0" | EMITTER | A8 | | | | |
| +19'-0" | IN HEAP | A7 | C1 | C7 | D5 | E3 |
| +18'-0" | IN HEAP | A6 | B8 | C6 | D4 | E2 |
| +12'-0" | IN HEAP | A5 | | | | |
| +10-0" | IN HEAP | A4 | B7 | C5 | D3 | E1 |
| +2-0" | IN HEAP | | B6 | | D2 | D8 |
| +0'-6" | IN RESERVOIR | A2 | B5 | C3 | D1 | D7 |
| 0'-0" | GROUND LEVEL | | | | | |
| -1'-0" | BELOW HEAP | F1 | F5 | | | |
| -2'-6" | BELOW HEAP | F2 | F6 | | | |
| -3'-10" | BELOW HEAP | F3 | F7 | | | |
| -5-0" | BELOW HEAP | F4 | F8 | | | |
| **EXTERNAL TEMPERATURE SENSORS** | | | | | | |
| +26-0" | IN AIR | B4 | | | | |
| +12-0" | IN AIR | | | A1 (SOUTH FENCE) | | |
| +10'-0" | IN AIR | | E5 | E6 | E7 | E8 |
| -1'-0' | BELOW GROUND | | | A3 (SOUTH FENCE) | | |
| -3'-10" | BELOW GROUND | | | C4 (SOUTH FENCE) | | |

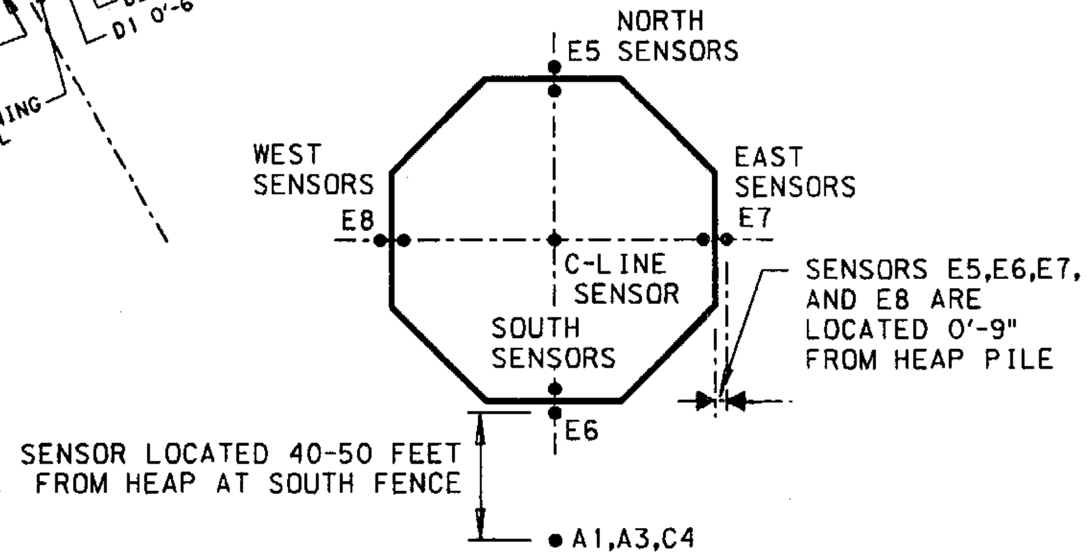


HEAP TEMPERATURE SENSORS

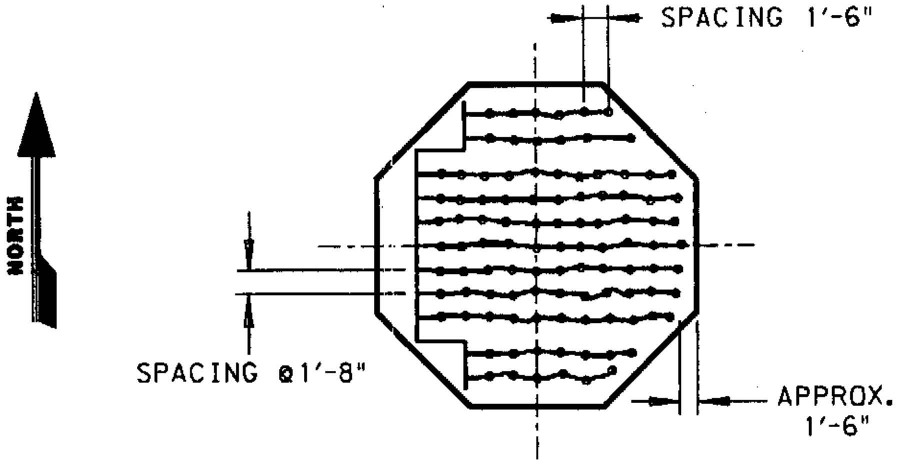
| LEVEL | LOCATION | SENSOR ARRAY LOCATION | | | | |
|---|---|---|---|---|---|---|
| | | C-LINE | NORTH | SOUTH | EAST | WEST |
| +24.0' | IN SNOW | B3 | | | | |
| +23.0' | IN ORE | B2 | | | | |
| +21.5' | IN ORE | B1 | C2 | C8 | D6 | E4 |
| +20.0' | EMITTER | A8 | | | | |
| +19.0' | IN HEAP | A7 | C1 | C7 | D5 | E3 |
| +18.0' | IN HEAP | A6 | B8 | C6 | D4 | E2 |
| +12.0' | IN HEAP | A5 | | | | |
| +10.0' | IN HEAP | A4 | B7 | C5 | D3 | E1 |
| +2.0' | IN HEAP | | B6 | | D2 | D8 |
| +0.5' | IN RESERVIOR | A2 | B5 | C3 | D1 | D7 |
| 0.0' | GROUND LEVEL | | | | | |
| -1.0' | BELOW HEAP | F1 | F5 | | | |
| -2.5' | BELOW HEAP | F2 | F6 | | | |
| -3'-10" | BELOW HEAP | F3 | F7 | | | |
| -5.0' | BELOW HEAP | F4 | F8 | | | |

AMBIENT TEMPERATURE SENSORS

| LEVEL | LOCATION | SENSOR ARRAY LOCATION | | | | |
|---|---|---|---|---|---|---|
| | | C-LINE | NORTH | SOUTH | EAST | WEST |
| +26.0' | IN AIR | B4 | | | | |
| +12.0' | IN AIR | | | A1 | | |
| +10.0' | IN AIR | | E5 | E6 | E7 | E8 |
| -1.0' | BELOW GROUND | | | A3(SOUTH FENCE) | | |
| -3'-10" | BELOW GROUND | | | C4(SOUTH FENCE) | | |



**PLAN VIEW**
SENSOR LOCATIONS



**PLAN VIEW**
EMITTER LOCATIONS

| NO. | DATE | REVISIONS | BY | CHKD | APPD | REFERENCES |
|---|---|---|---|---|---|---|

DRAWN BY KMP DATE 03-31-94
CHECKED BY HJW DATE 04-04-94
COST/SCHED-AREA
SCALE NONE

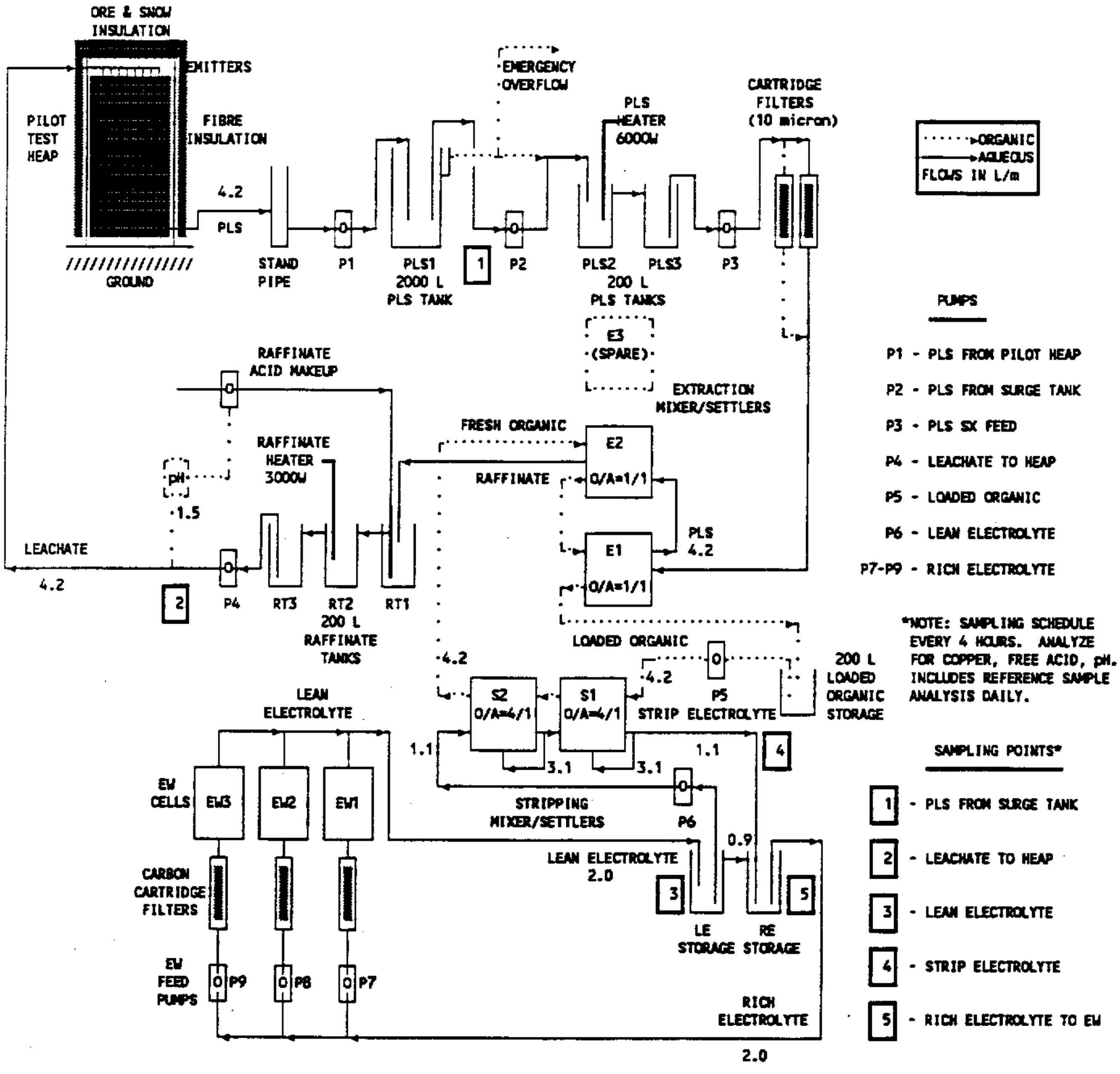
**Brown&Root, Inc.**

WESTERN COPPER HOLDINGS, LTD.
WILLIAMS CREEK PROJECT
WILLIAMS CREEK FIELD TEST

CONTRACT NO. KR-0346
OWNER NO.
APPROVED BY
DATE 04/26/94
APPROVED BY
DATE
DRAWING NO. TEST CRIB
REV. A

FORM NO. EF-000-52.41-0-8A
FORM CADD NO. 62418BRI.DGN - REV 0 - 05/28/92

## WILLIAMS CREEK PILOT PLANT CIRCUIT
## 2-2 SX CIRCUIT DESIGN



PUMPS

P1 - PLS FROM PILOT HEAP
P2 - PLS FROM SURGE TANK
P3 - PLS SX FEED
P4 - LEACHATE TO HEAP
P5 - LOADED ORGANIC
P6 - LEAN ELECTROLYTE
P7-P9 - RICH ELECTROLYTE

*NOTE: SAMPLING SCHEDULE EVERY 4 HOURS. ANALYZE FOR COPPER, FREE ACID, pH. INCLUDES REFERENCE SAMPLE ANALYSIS DAILY.

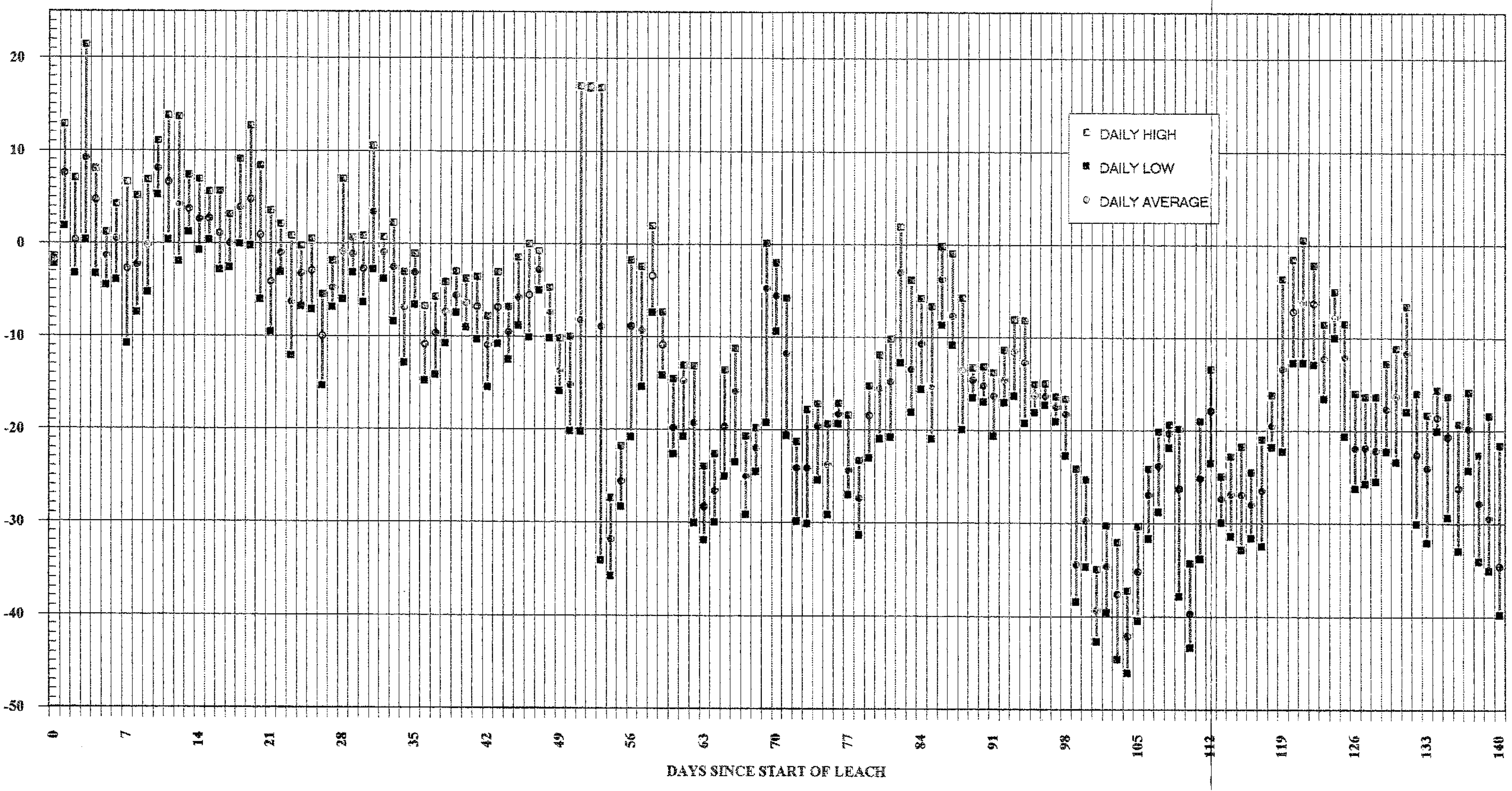
SAMPLING POINTS*

1 - PLS FROM SURGE TANK
2 - LEACHATE TO HEAP
3 - LEAN ELECTROLYTE
4 - STRIP ELECTROLYTE
5 - RICH ELECTROLYTE TO EW

Refer to
Colour CD

## AMBIENT DAILY HIGH , LOW, AND AVERAGE TEMPERATURES

TEMPERATURES ARE FROM SENSOR B4 @26' CENTERLINE OF HEAP



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Colour CD

AMBIENT DAILY HIGH , LOW, AND AVERAGE TEMPERATURES FOR 1985-1990

NOTE: ABSCISSA BEGINS IN THE NINETH MONTH

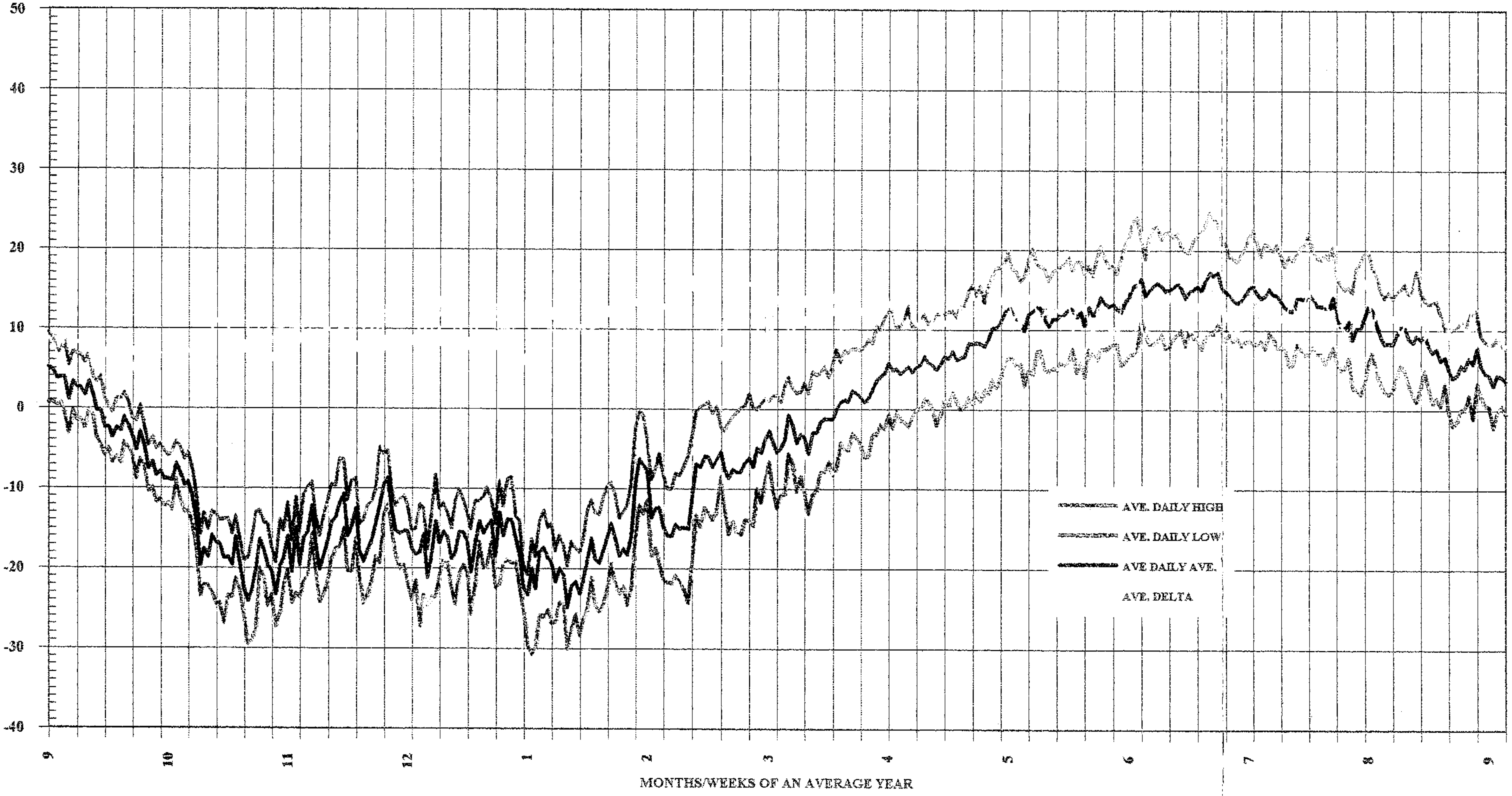
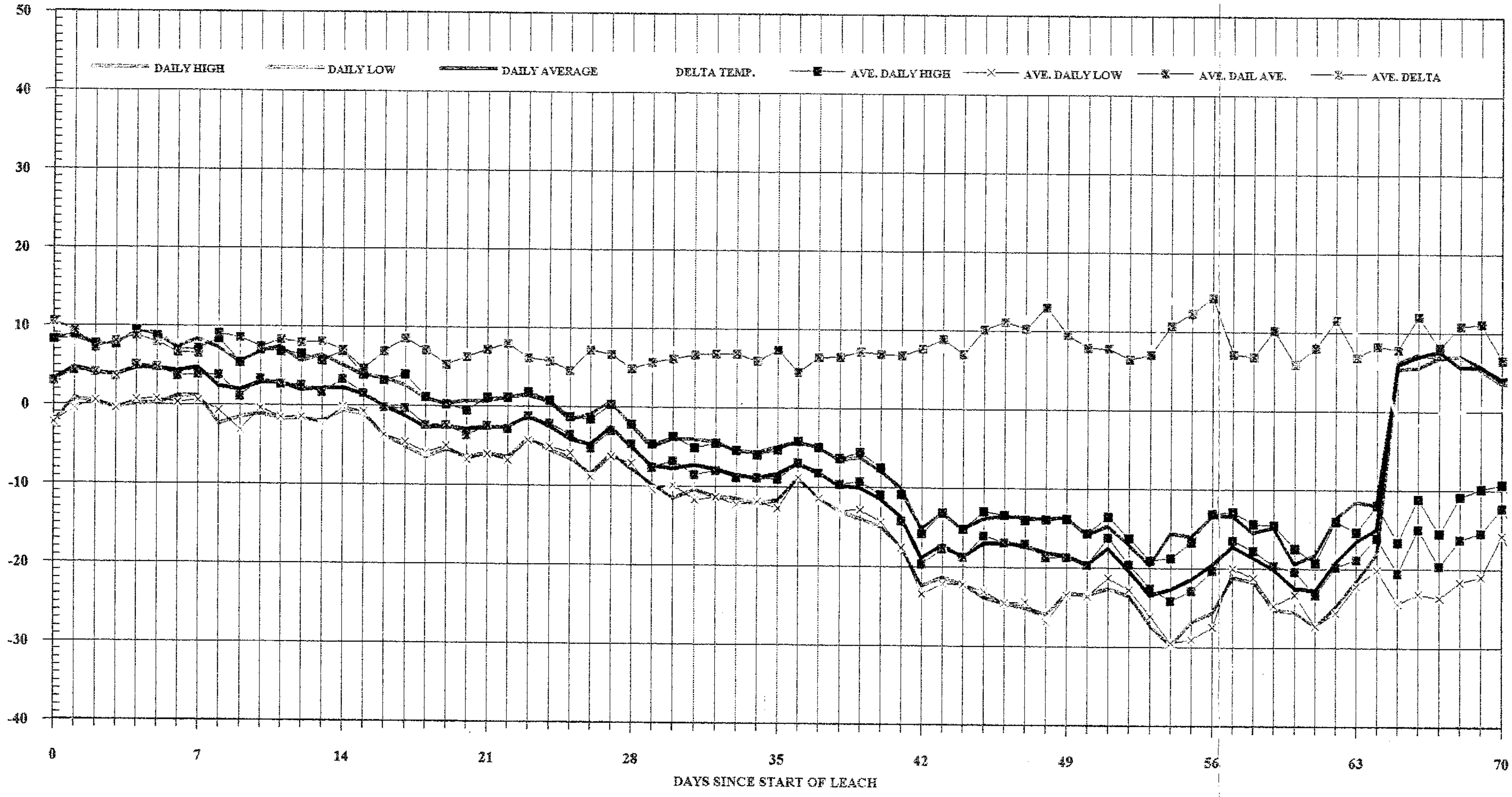


CHART 8.0

# CARMACKS FIELD TEST

Refer to
Colour CD

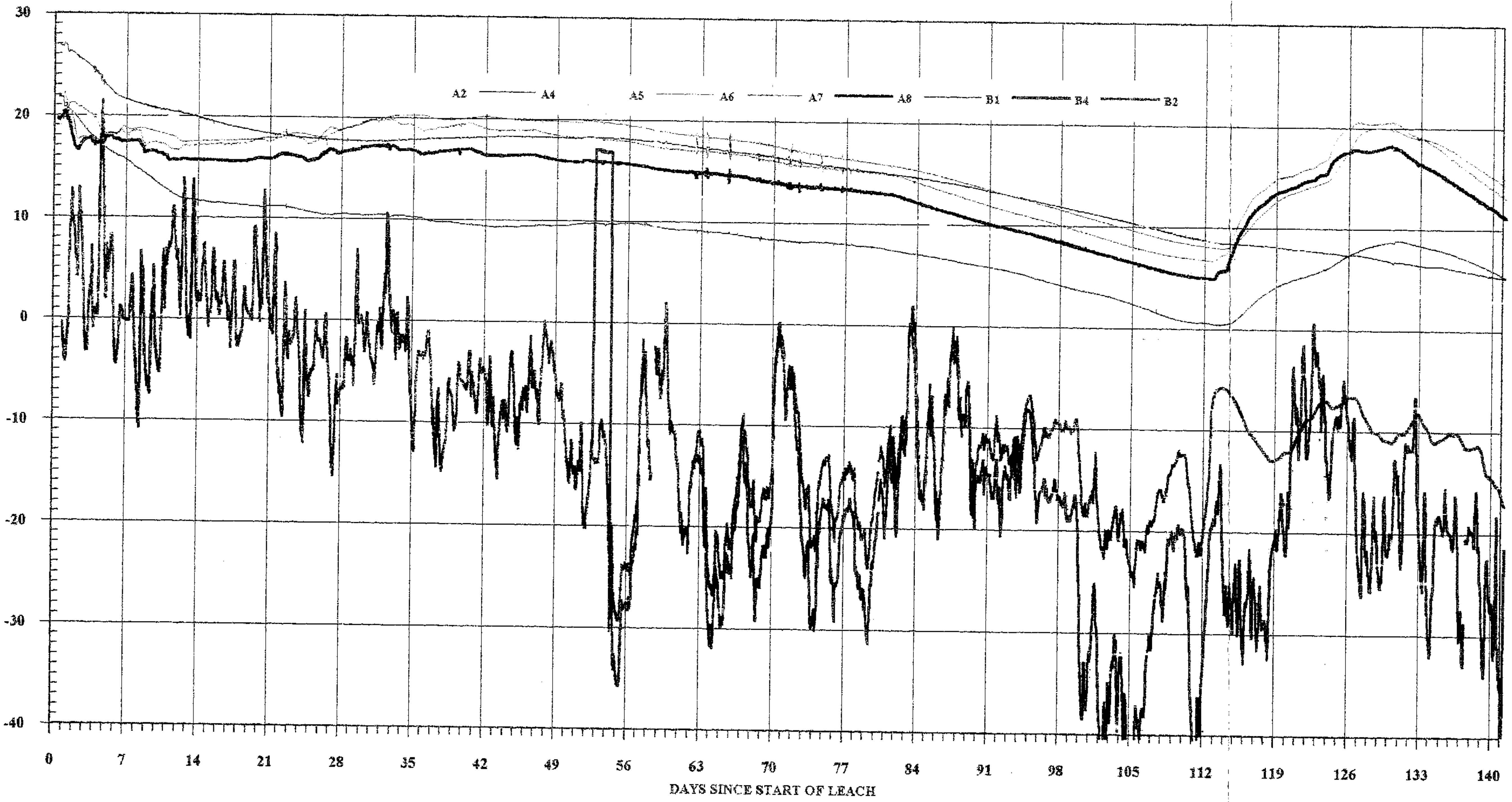
## COMPARISION OF TEST AMBIENT TEMPERATURES TO AVERAGE AMBIENT TEMPERATURES FOR 1985 - 1990



# CARMACKS FIELD TEST

Refer to
Colour CD

## CENTERLINE TEMPERATURE PROFILE



## CARMACKS FIELD TEST

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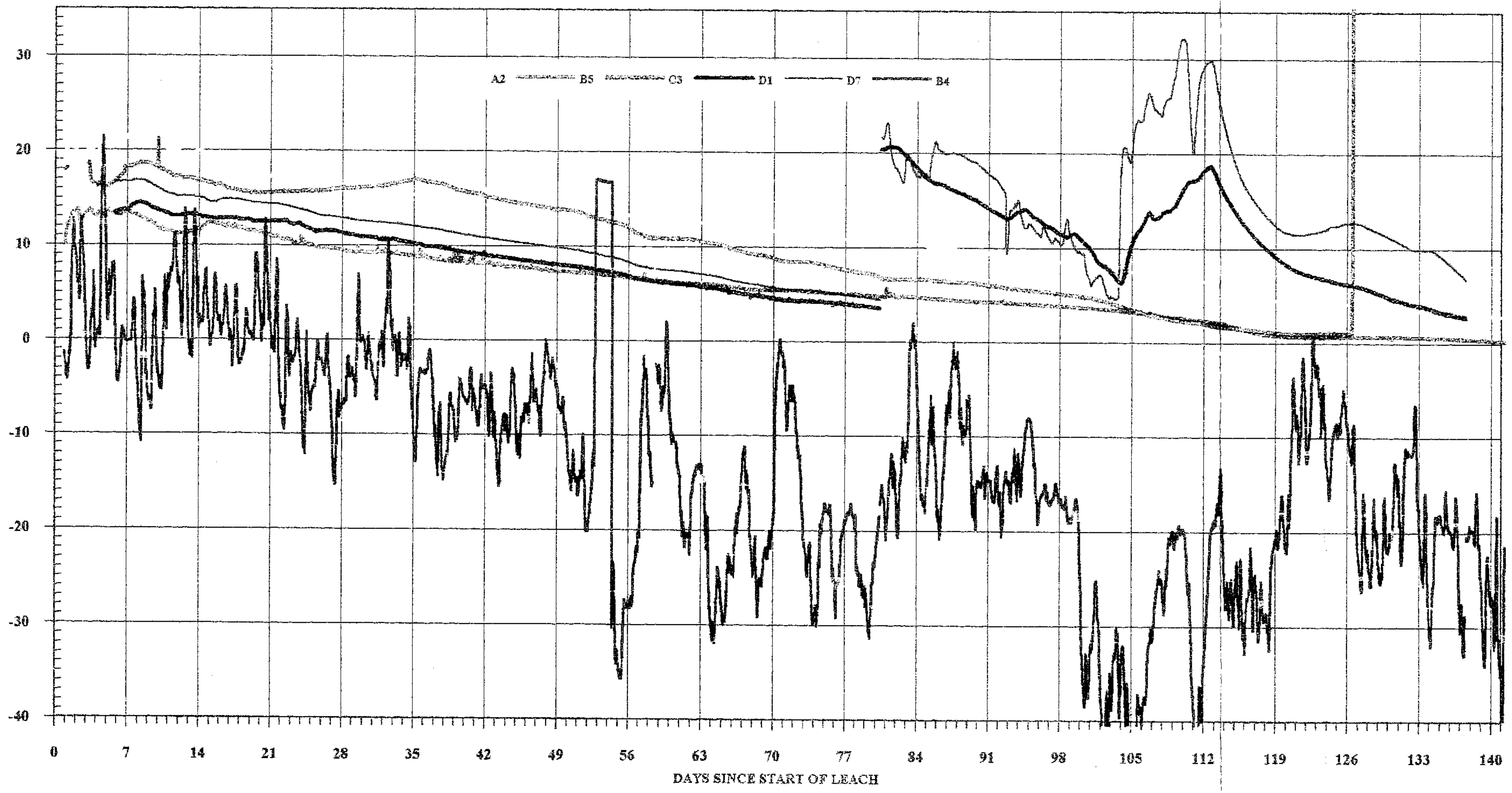
### LATERAL TEMPERATURE PROFILE @+0.5FT



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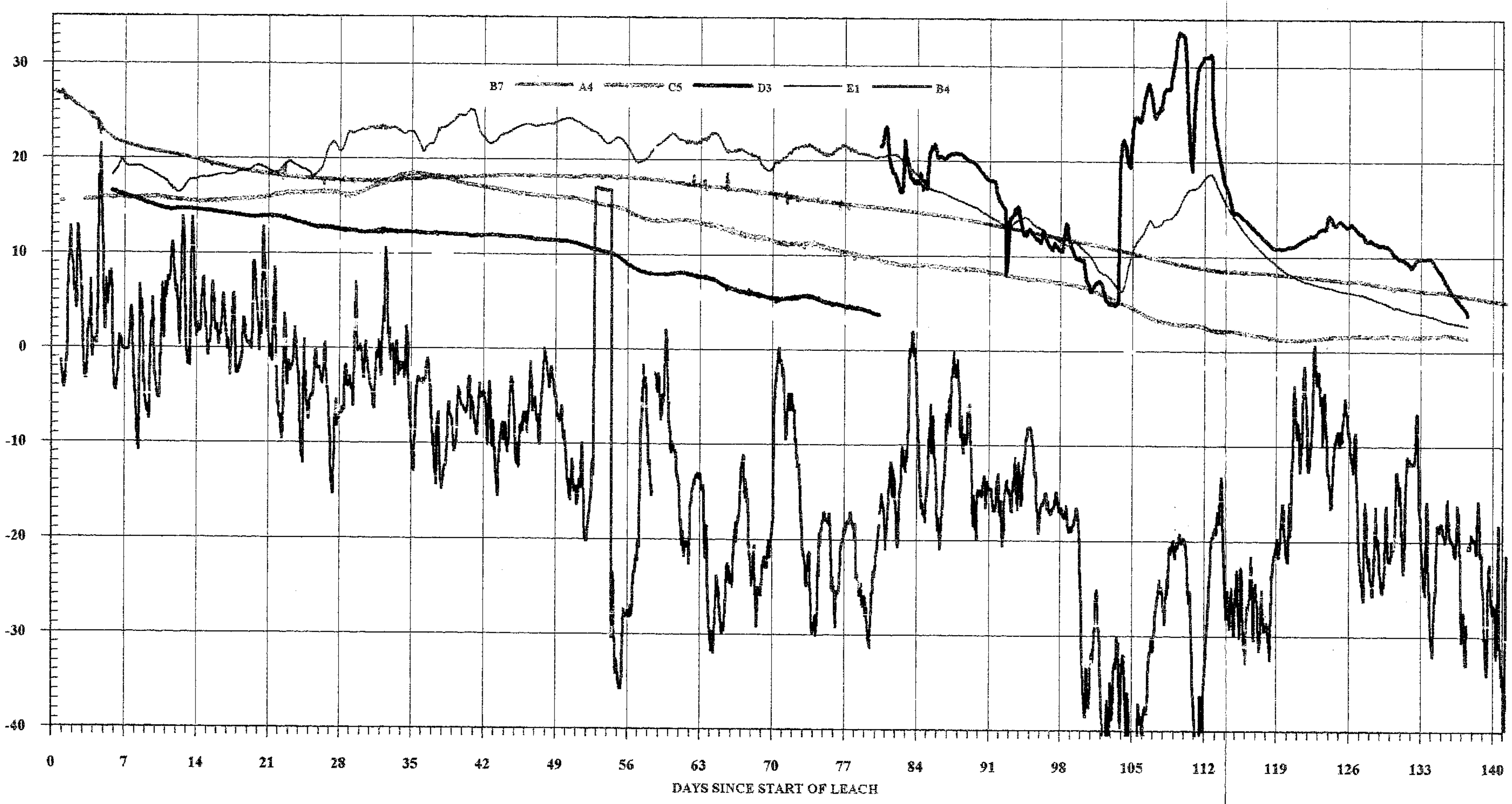
## LATERAL TEMPERATURE PROFILE @+10.0FT



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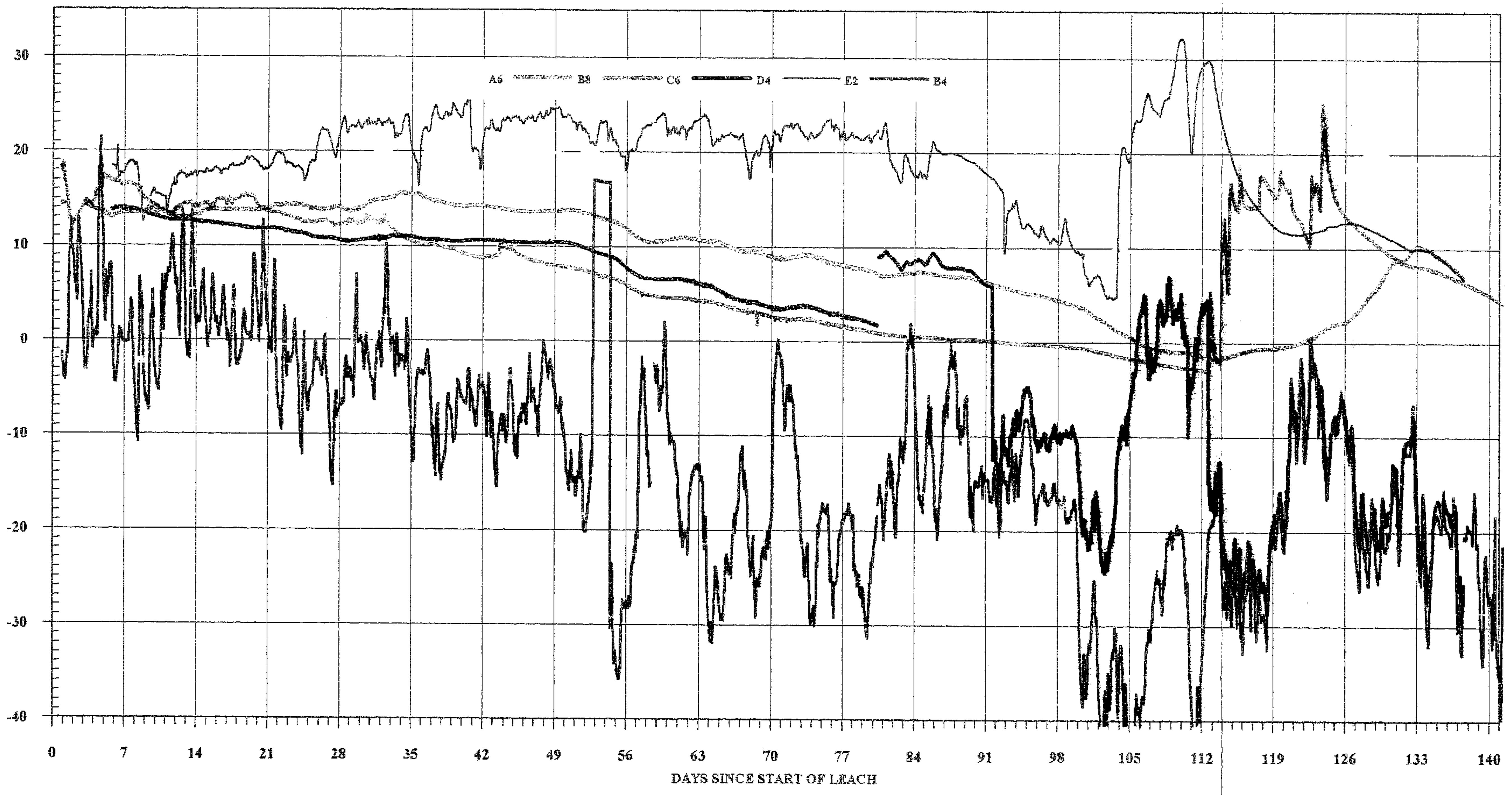
## LATERAL TEMPERATURE PROFILE @+18.0FT



**WESTERN COPPER HOLDINGS, LTD.**
WILLIAMS CREEK PROJECT

CARMACKS FIELD TEST

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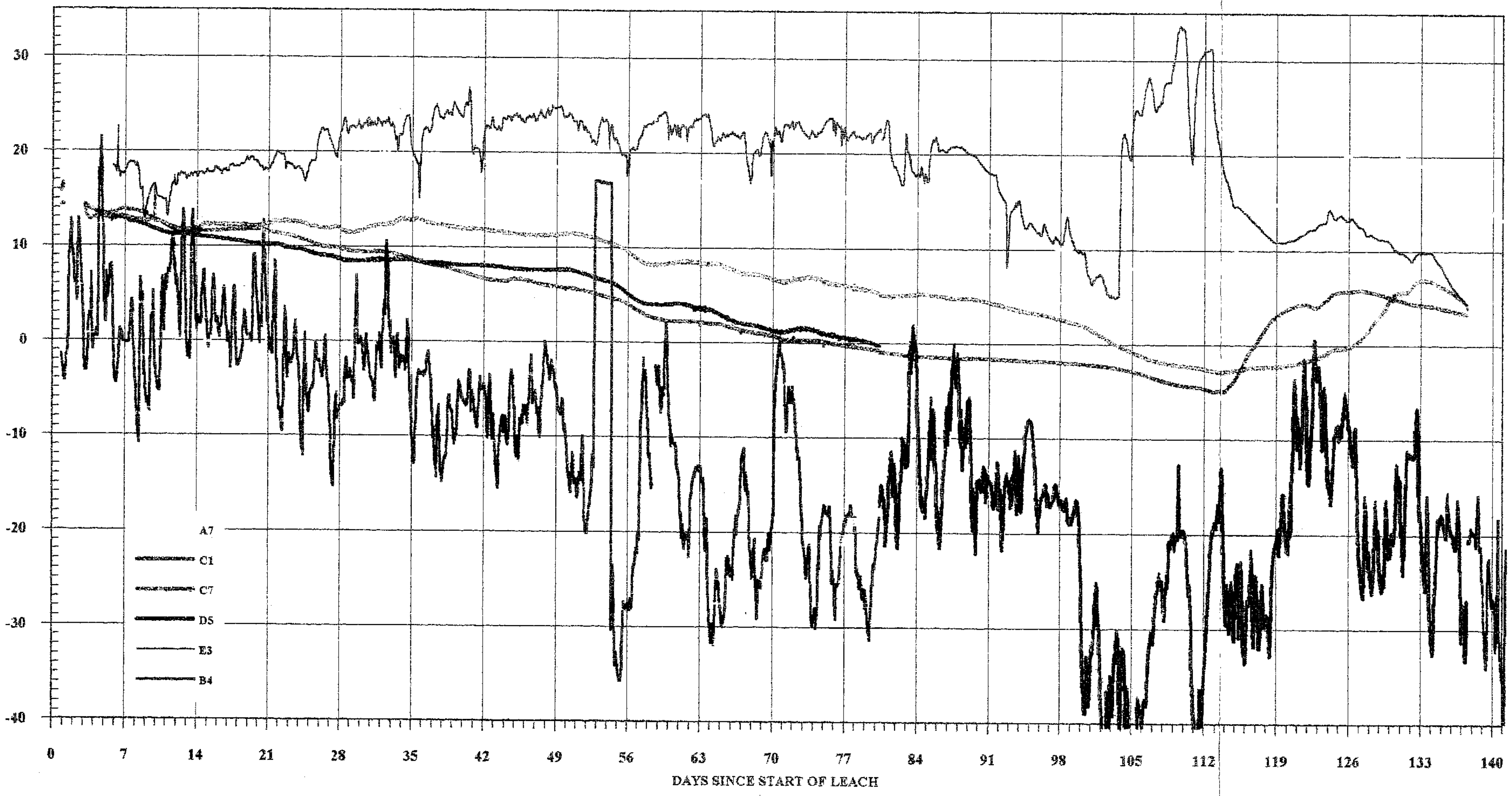
**BROWN & ROOT, INC**
JOB NO. KR-Q346

LATERAL TEMPERATURE PROFILE @+19.0FT



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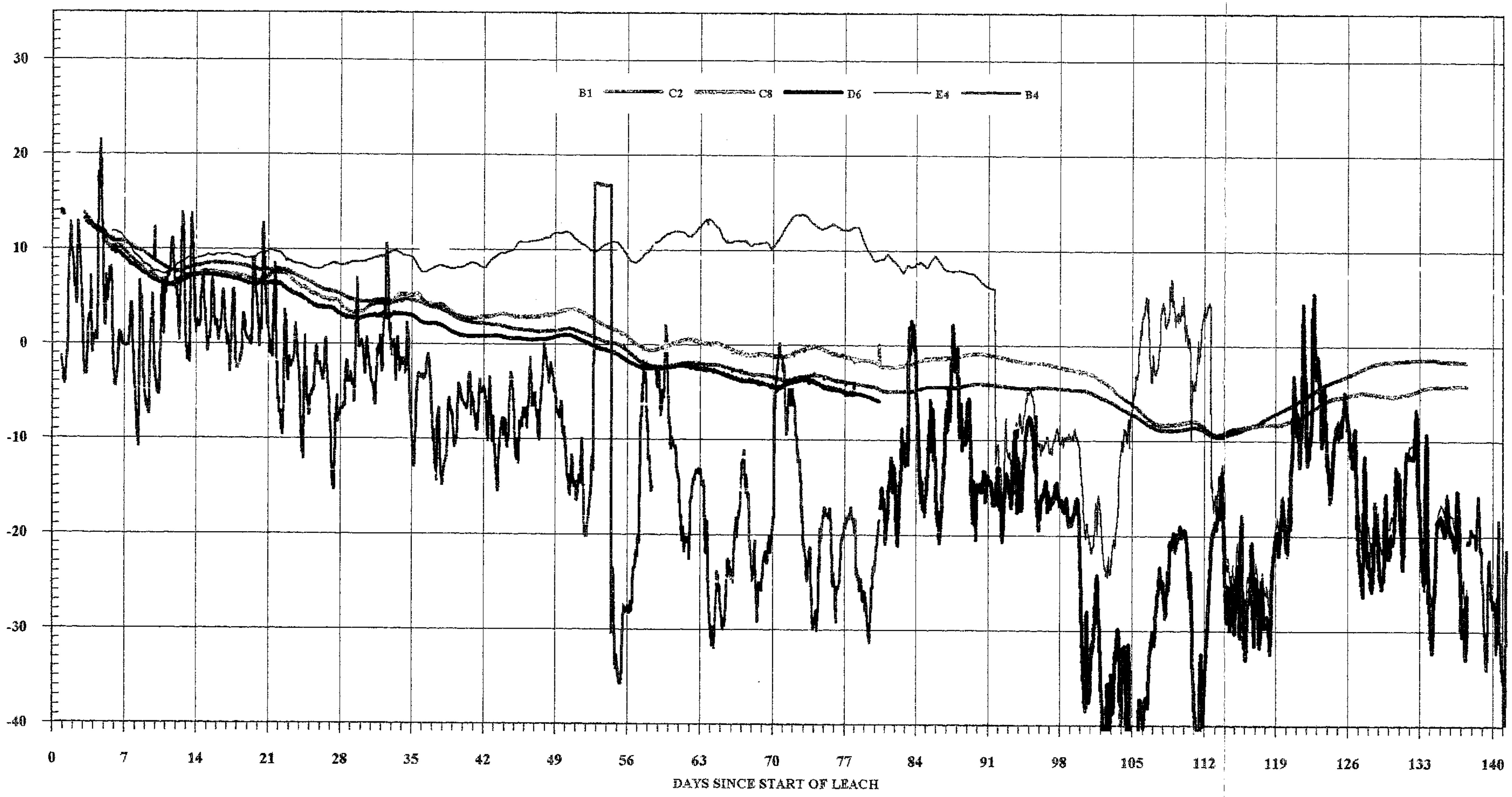
LATERAL TEMPERATURE PROFILE @+21.5FT



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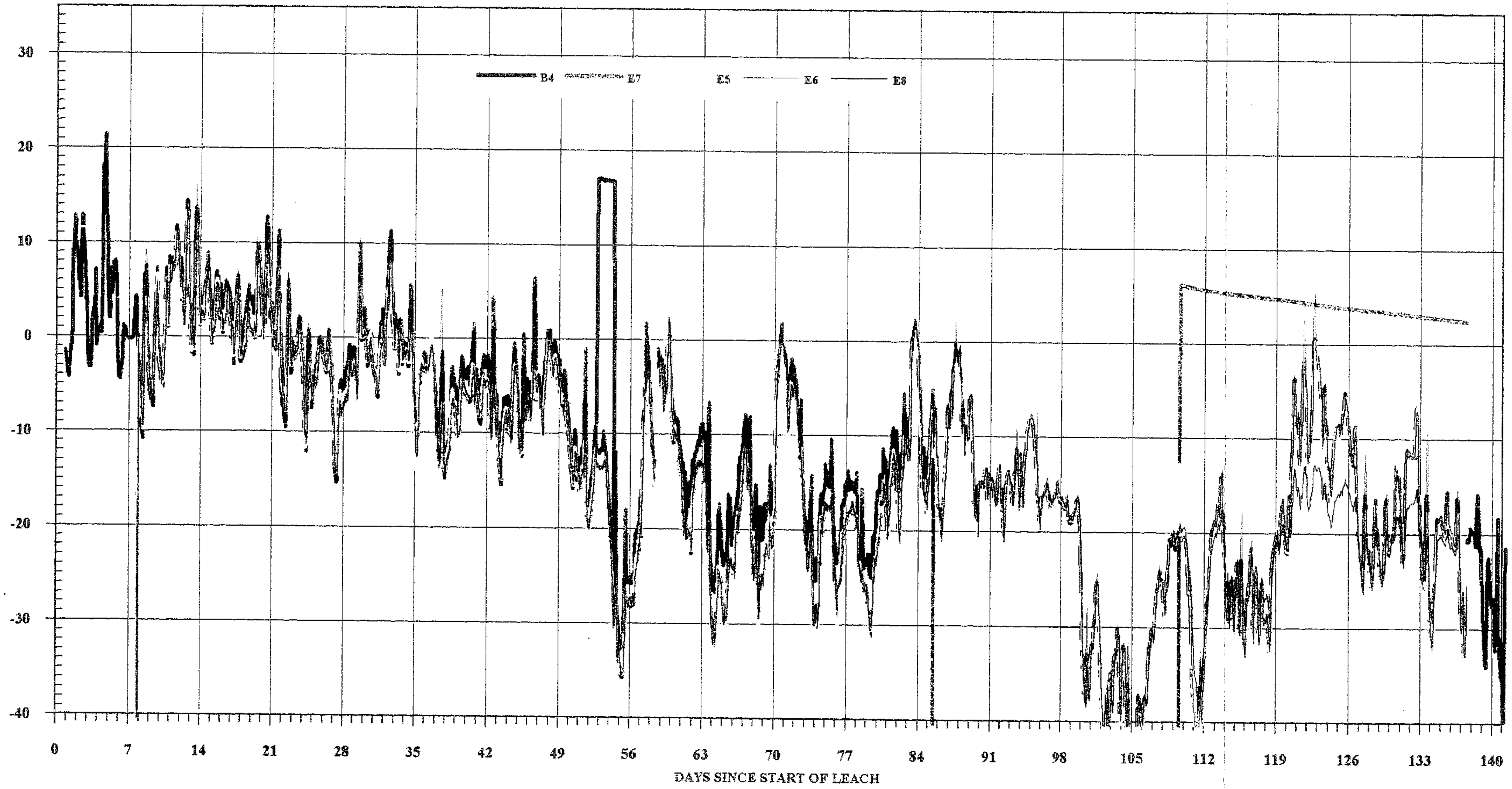
## COMPARISION OF AMBIENT TEMPERATURE SENSORS



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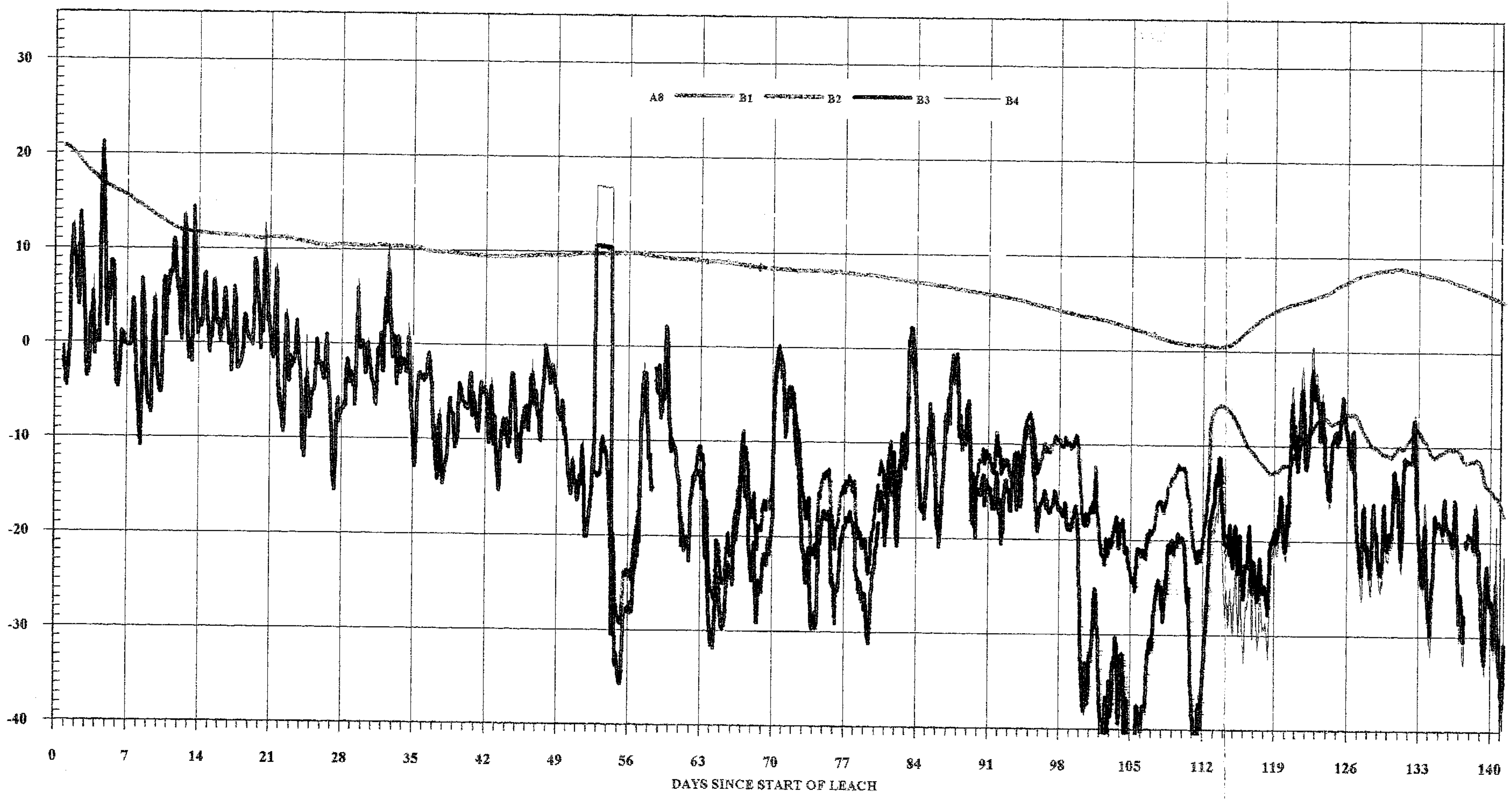
## COMPARISION OF TEMPERATURES OF THE TOP FOUR LAYERS



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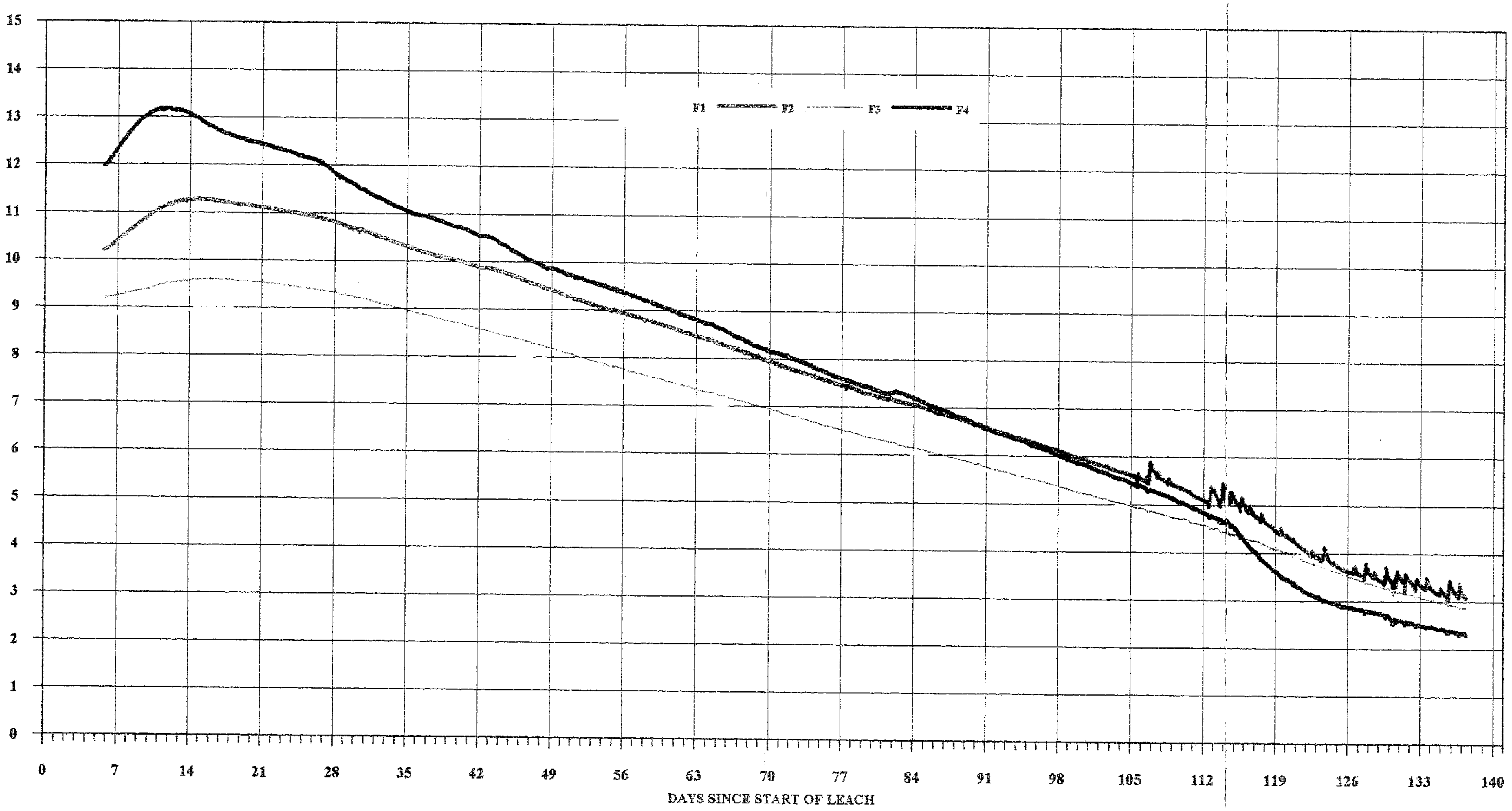
## CENTERLINE BELOW GROUND TEMPERATURE PROFILE



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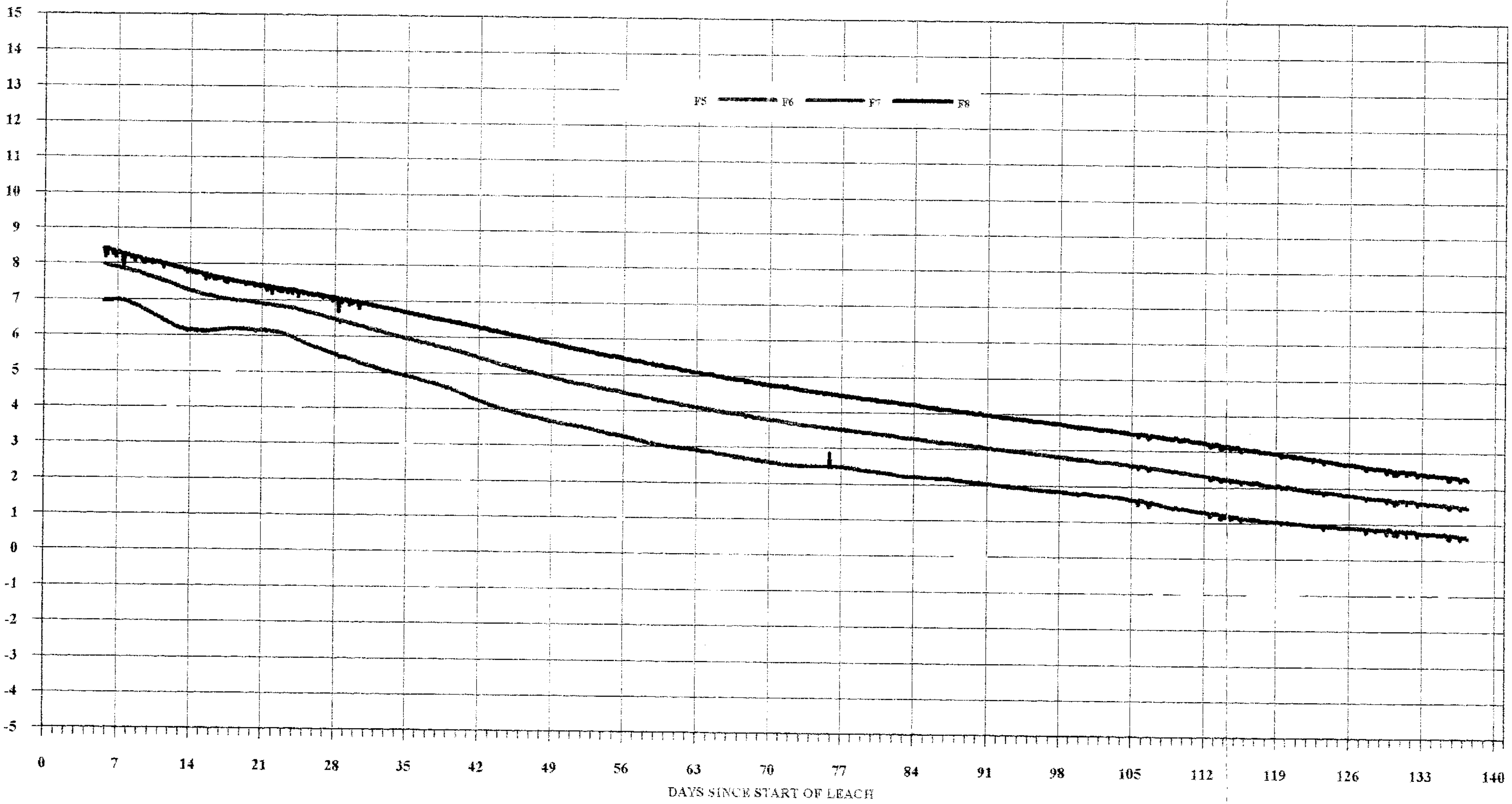
## NORTH BELOW GROUND TEMPERATURE PROFILE



# WINTER OPERATION TEMPERATURE PROFILES OF A PILOT TEST LEACH
# CARMACKS COPPER OXIDE PROJECT
# YUKON, CANADA

BY: WESTERN COPPER HOLDINGS LIMITED
VANCOUVER, B.C.
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- ROBERT QUARTERMAIN

AND

: BROWN AND ROOT, INC.
HOUSTON, TX
- W. JOSEPH SCHLITT
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AUGUST 1994

# ABSTRACT

A heap leach field test was conducted during the 1993-1994 winter season at Carmacks, Yukon Territory. The test was performed to demonstrate the viability of heap leaching Carmacks Copper ores in a sub-Arctic setting. Western Copper is proposing to process ore on a year-round basis. This test was modeled after the successful winter leaching operation of Pegasus Gold at their Zortman, Montana mine. In the latter operation, the leachate distribution system is overlain with approximately one meter of crushed ore. The over layer, plus a variable snow cover, adequately insulate the heap and permit year-round operation.

The test itself utilized an approximately 5 meter diameter crib loaded with a composite of ore from the northern (higher grade) end of the Carmacks Copper deposit. The 250 tonne bulk sample was stacked in the crib to a total height of 7 meters, including one meter of ore on top of the emitter system. This matched the commercial heap height planned for Carmacks Copper at the time the test was started. By insulating the side walls of the crib, lateral heat flux was minimized. Thus, the crib replicated an interior segment of the commercial heap.

Leaching was done at a flow rate that matched those commonly used in industry. Leachate temperature was approximately 21°C, a level achieved with no external heat input other than normal process heat transferred from electrowinning to the leachate via solvent extraction.

An analysis of the test results showed that the winter conditions at Carmacks were quite typical of those expected at the mine site. Conditions included ambient temperatures below minus 45°C and an average temperature of minus 13°C.

In terms of leachate flow to and from the crib, the test ran continuously from late September through mid-February. In spite of some flow system problems, leaching continued unabated. There was no freezing in the interior of the crib. Freezing was limited to the insulating ore over layer and a few isolated points high in the crib near the outer walls.

The test clearly demonstrates that year-round heap leaching of Carmacks Copper ore is practical. The heap appears to be adequately insulated by a 1 meter ore layer on top of the emitter system. Normal process heat should be sufficient to maintain a leachate return temperature of approximately 20°C at the heap. However, provisions should be made for supplemental heating in the commercial operation. This would permit recycle of the heated solution if electrowinning goes off-line or if there is a long run of exposed leachate pipeline back to the heaps.

## INTRODUCTION

A comprehensive heap leach field test was conducted during the 1993-1994 winter season at Carmacks, Yukon Territory. The test was performed to demonstrate the viability of heap leaching Carmacks Copper ores in a sub-Arctic setting. Western Copper Holdings Limited is proposing to process ore on a year-round basis. The site selected for this study was Carmacks, Yukon Territory, Canada. Carmacks is located 40 kilometers from the Carmacks Copper project site. Thus, the location is anticipated to have sub-Arctic conditions similar to those expected at the proposed mine site.

There is little operative knowledge or published information available for leaching at extreme latitudes where sub-freezing conditions occur continuously for several months. Therefore, the benefits of the sub-Arctic study are obvious. A detailed study will quantify the heat losses from the heap, consequently defining the heat input necessary to maintain a continuous year round operation. Results then permit accurate thermal modelling of a commercial operation. The overall objective of the proposed test work was to demonstrate that leaching during the winter season is practical.

The proposed operational plan for the mine has been patterned after one used by Pegasus Gold at the Zortman heap leach gold mine in Montana. At Zortman, winter operations are maintained by installing drip emitters and burying them under approximately 1 meter of ore. The Zortman mine has successfully operated for several years under extreme winter conditions occasionally approaching those normally experienced at Carmacks.

The field program at Carmacks involved the construction of a highly instrumented, full height segment of a commercial ore heap. Also included were leach solution distribution and collection systems and a small solvent extraction - electrowinning (SX-EW) facility to decopperize and recycle leach solution. Both thermal and metallurgical (leaching) aspects of heap leaching were studied in detail. However, only the thermal aspects are presented and discussed in this report. Metallurgical performance can not be fully assessed until the ore heap is subjected to a detailed post mortem examination. This is scheduled for the summer of 1994, after which time a metallurgical report will be prepared and issued.

Partial funding for the project was provided by the Canadian/Yukon Geoscience Office as part of the Mineral Development Agreement.

## DESCRIPTION OF FACILITIES

The ore was leached in a plywood test crib. The crib was octagonal in shape with a centre wall to centre wall diameter of approximately 5 meters and a height of 7.6 meters (Figures 1, 2, 3). The crib was constructed using 2.45 meter long, 7.6 centimeter thick X 20 centimeter wide planks reinforced with steel beams (0.64 centimeter thick X 7.6 centimeter wide). The beams over lapped at the ends and were locked together with 19 millimeter redi-rods inserted through holes in the end of each beam. These rods were joined with connector nuts so that they ran the

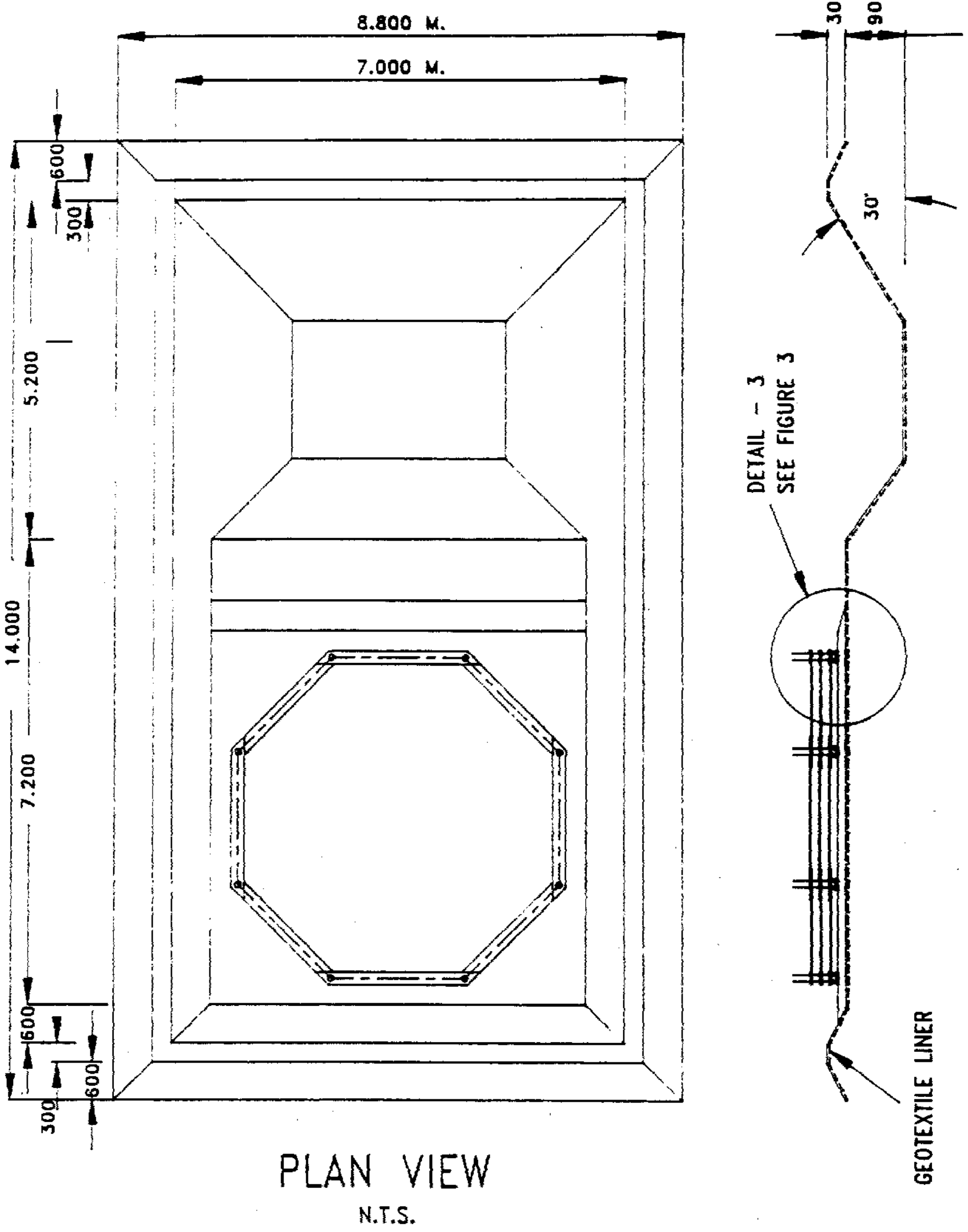


Figure 1: TEST LEACH PAD LAYOUT

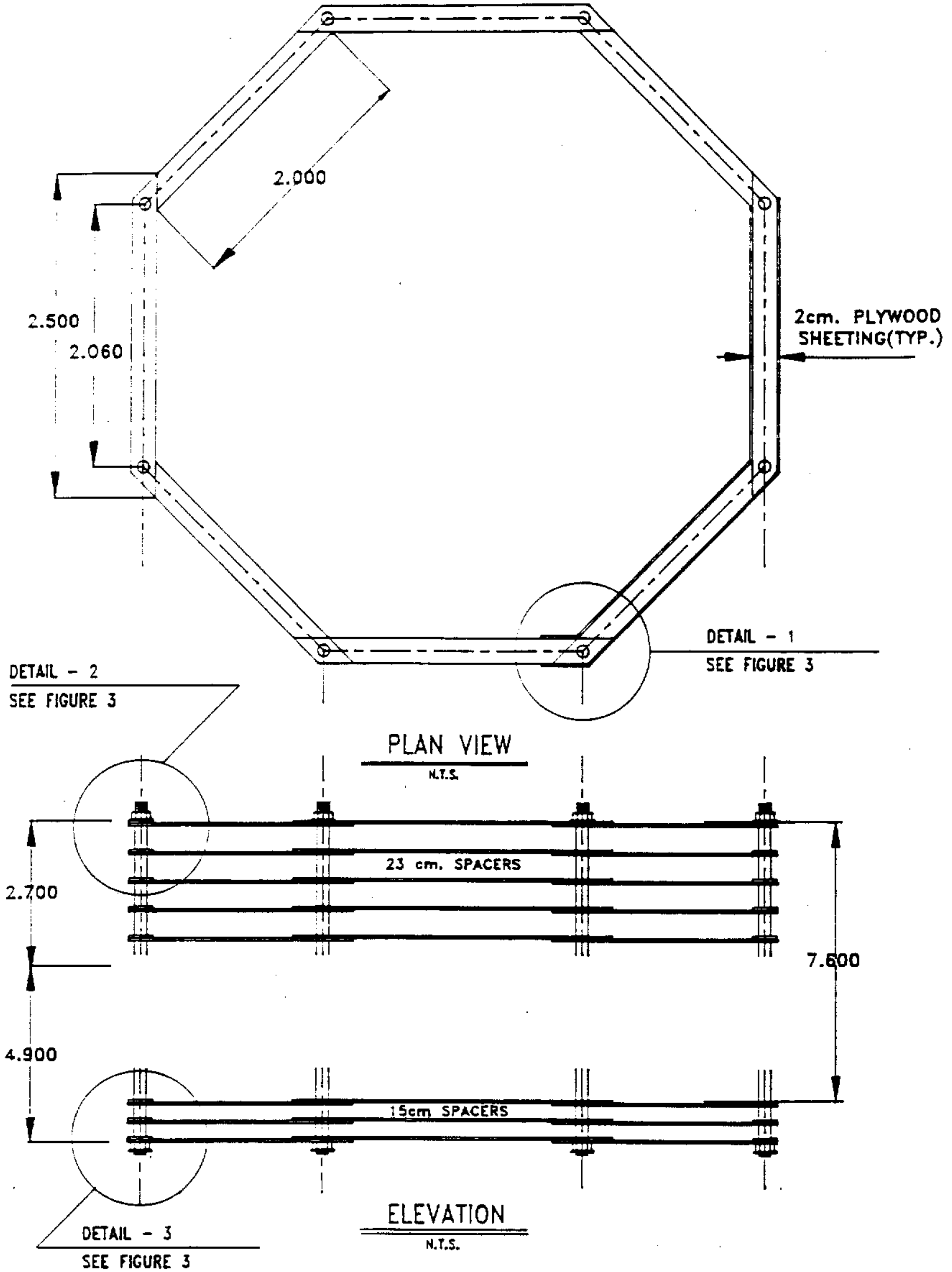
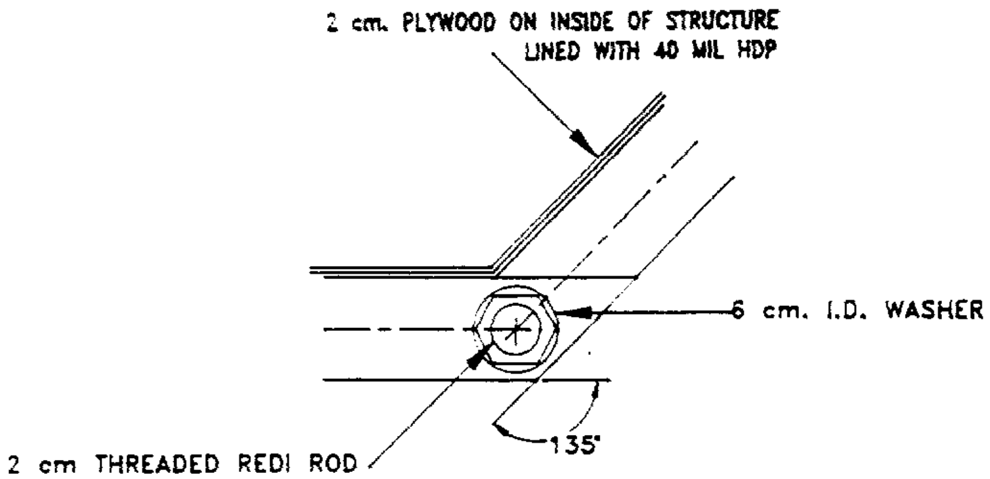
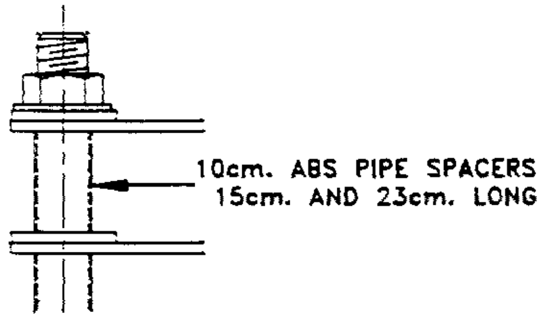


Figure 2: TEST LEACH CRIB DESIGN



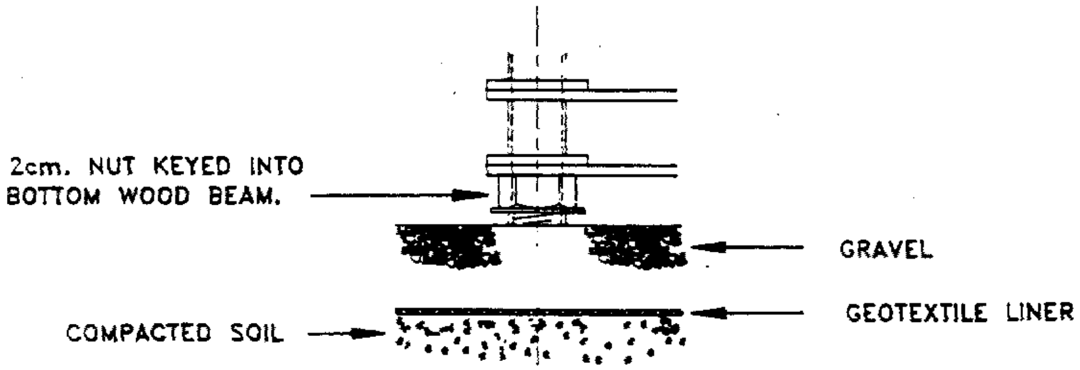
DETAIL - 1

N.T.S.



DETAIL - 2

N.T.S.



DETAIL - 3

N.T.S.

Figure 3: DESIGN DETAILS

full height of the crib. Spacers made from 10 centimeter diameter ABS pipe sections were used to reduce the number of planks needed. Spacers were 15 centimeters high over the bottom half of the crib and 23 centimeters high over the top half. The interior of the crib wall was lined with plywood sheeting, 19 centimeters thick.

Due to the large extent of a commercial heap, horizontal heat flux will be minimal except around the outer edge of the heap. This condition was simulated in the crib by placing fibreglass insulation (R32) between the beams and covering the entire crib with plastic sheeting. An additional 5 centimeters layer of Styrofoam insulation (R20) was placed over the sheeting and a second layer of sheeting was placed over the Styrofoam. The total insulating value of the insulation layers and sheeting was estimated to be approximately R60.

Prior to construction of the crib, the area was covered with 30-mill thick HDPE sheeting. This was supported on both sides with geotextile fabric. About 15 centimeters of crushed rock was placed on top of the liner and sloped to a lined event pond. The liner provided secondary solution containment. After erecting the crib, the edge of the liner was raised and dirt was packed underneath to provide a diversion/containment berm around the crib.

In order to simulate in-pile impoundment of leach solution, a 2 meter high cup shaped PVC liner was installed in the bottom of the crib. A 0.6 meter deep flooded zone was maintained by installing a slotted standpipe through the liner. In an emergency, the PVC cup could provide storage for all leach solution in the crib. The upper crib walls were lined with HDPE sheeting to direct solution flow to the PVC cup.

In the latter stages of the test, make-up water was drawn from the flooded zone. By November 20 (DAY 54) the reservoir had been completely drawn down and was maintained at this level for the rest of the test.

A array of temperature probes (sensors) was located in the crib, in the underlying soil, and other ambient locations to determine: heat/loss (gain) into the air and ground, lateral heat loss through the crib walls, solar flux on the side of the crib, and ambient conditions. In total, 48 sensors were installed and connected to six 8-channel data loggers. Details on the sensor locations are given in Table 1 and Figure 4. The data loggers were set to record temperatures every five minutes and report an hourly average.

PVC piping was used to move solution in and out of the pile. Loading of the crib was stopped to allow installation of an irrigation header along the west wall of the crib after ore reached the 6 meter level. Drip emitter piping was connected to the header every 50 centimeters. There was a 45 centimeter spacing between emitters. Variable flow emitters were installed to allow flexibility in the solution application rates. A duplicate header and irrigation lines were installed in the event of a failure of the primary line. All exterior piping was heat traced and insulated. A plan view of the irrigation system is included in Figure 4. The bottom drain was also located along the west wall.

## DESCRIPTION OF LEACH MATERIAL

A 250 tonne bulk ore sample was excavated from three trenches, representative of the ore at the north end of the deposit. This is the higher grade portion of the deposit and accounts for the bulk of recoverable copper. The number of trenches sampled was minimized in favour of increased sample depth to obtain unweathered ore. A minimum of 4 meters of bedrock was blasted and removed before mining the samples. The samples were excavated from a 1.5 meter wide cut blasted across the full width of the ore zone exposed in the bottom of each trench.

Ore from each trench was segregated and transported to the test site in Carmacks. The ore was reduced to minus 2.5 centimeters with a portable two stage closed circuit crusher. A representative metallurgical sample was cut from each trench and shipped to Vancouver where it was sieved into five fractions, weighed and analyzed. The results are as follows:

| | TRENCH T91-20 | | TRENCH T910-21 | | TRENCH T91-02 | |
|---|---|---|---|---|---|---|
| SIEVE FRAC. | WEIGHT % | Cu % | WEIGHT % | Cu % | WEIGHT % | Cu % |
| -3/4 + 1/2 | 17.97 | 0.68 | 23.00 | 0.80 | 22.7 | 0.92 |
| -1/2 + 3/8 | 12.3 | 0.78 | 15.7 | 0.86 | 14.8 | 0.96 |
| -3/8 + 1/4 | 13.4 | 0.86 | 13.9 | 0.93 | 14.4 | 1.02 |
| -1/4 + 6 MESH | 14.4 | 1.06 | 14.1 | 1.05 | 14.4. | 1.12 |
| -6 MESH | 41.9 | 1.42 | 33.3 | 1.91 | 33.7 | 2.06 |
| AVERAGE | | 1.08 | | 1.23 | | 1.35 |

Three methods of sampling were used to establish the ore grade in each trench: compositing the blast hole cuttings, chip sampling the trench walls, and size analysis of crushed sample splits (see table above). Assays were then performed on appropriate samples.

| TRENCH # | DRILL CUTTINGS | CHIP SAMPLE | METALLURGICAL SAMPLE |
|---|---|---|---|
| T91-20 (800N) | 1.20 | 1.50 | 1.08 |
| T91-21 (1200N) | 1.48 | 1.64 | 1.23 |
| T91-02 (1700N) | 1.25 | 1.53 | 1.35 |

These values are somewhat lower than those obtained from blast hole cuttings and chip samples. Therefore, confirmation of the ore grade must await final sampling of the leached material in the crib. However, the grade is expected to be near 1.3% copper.

Metallurgical testing had previously demonstrated that acid preconditioning improves leaching efficiencies. Therefore, batches of ore were blended in a cement truck proportionate to the sample weights mined from each trench. Concentrated acid and water in a 1:1 ratio, were added to the ore as it was being loaded into the truck. A total of 15 kilograms of acid was added per

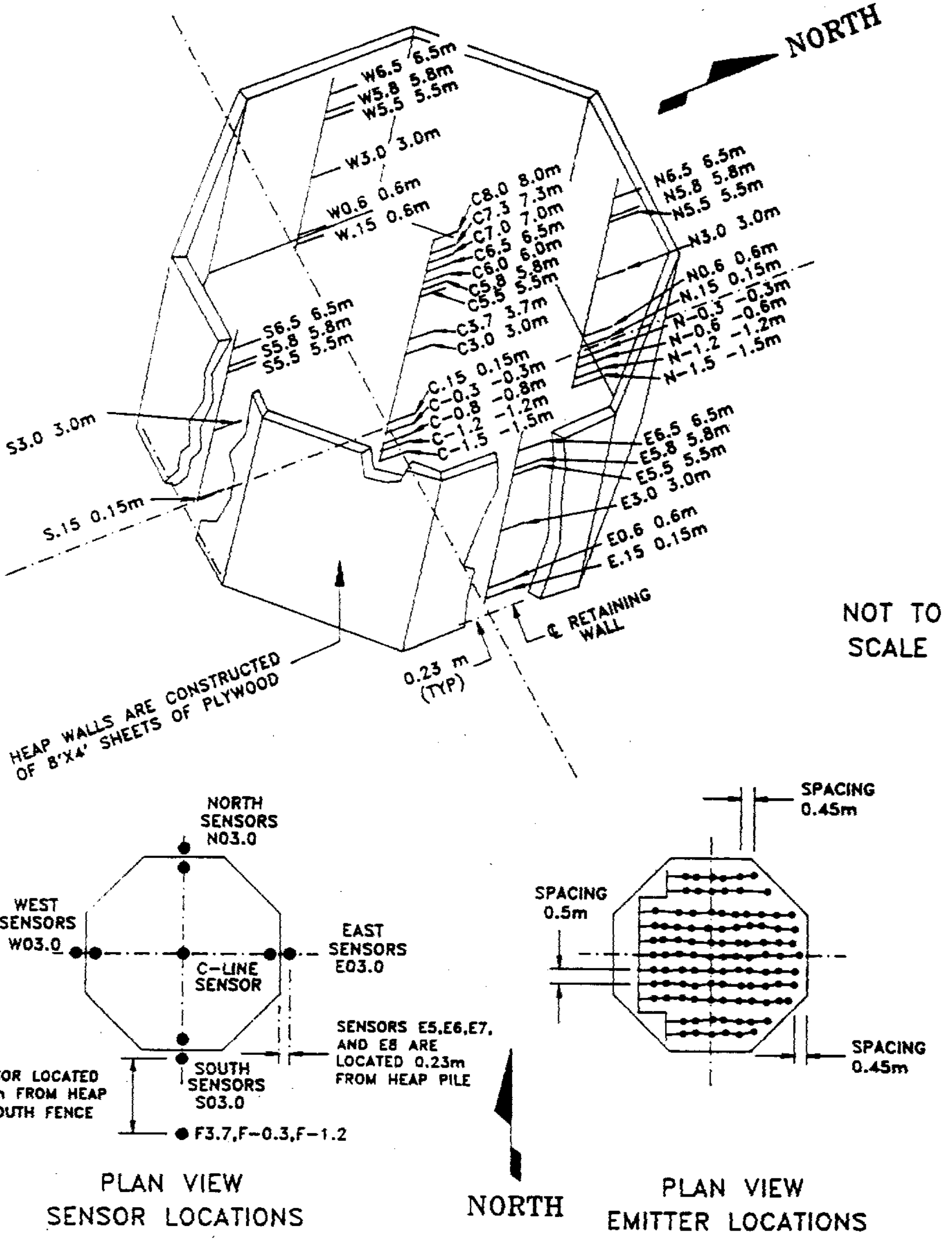
**HEAP TEMPERATURE SENSORS**

| LEVEL meters | LOCATION | SENSOR ARRAY LOCATION | | | | |
|---|---|---|---|---|---|---|
| | | C-LINE | NORTH | SOUTH | EAST | WEST |
| +7.3 | IN SNOW | C7.3 | | | | |
| +7.0 | IN ORE | C7.0 | | | | |
| +6.5 | IN ORE | C6.5 | N6.5 | S6.5 | E6.5 | W6.5 |
| +6.0 | EMITTER | C6.0 | | | | |
| +5.8 | IN HEAP | C5.8 | N5.8 | S5.8 | E5.8 | W5.8 |
| +5.5 | IN HEAP | C5.5 | N5.5 | S5.5 | E5.5 | W5.5 |
| +3.7 | IN HEAP | C3.7 | | | | |
| +3.0 | IN HEAP | C3.0 | N3.0 | S3.0 | E3.0 | W3.0 |
| +0.6 | IN HEAP | | N0.6 | | E0.6 | W0.6 |
| +0.15 | IN RESERVOIR | C.15 | N.15 | S-.15 | E.15 | W.15 |
| 0 | GROUND LEVEL | | | | | |
| -0.3 | BELOW HEAP | C-0.3 | N-0.3 | | | |
| -0.8 | BELOW HEAP | C-0.8 | N-0.6 | | | |
| -1.2 | BELOW HEAP | C-1.2 | N-1.2 | | | |
| -1.5 | BELOW HEAP | C-1.5 | N-1.5 | | | |

**AMBIENT TEMPERATURE SENSORS**

| LEVEL meters | LOCATION | SENSOR ARRAY LOCATION | | | | |
|---|---|---|---|---|---|---|
| | | C-LINE | NORTH | SOUTH | EAST | WEST |
| +8.0 | IN AIR | C-8.0 | | | | |
| +3.7 | IN AIR | | | F3.7 (SOUTH FENCE) | | |
| +3.0 | IN AIR | | N03.0 | S03.0 | E03.0 | W03.0 |
| -0.3 | BELOW GROUND | | | F-0.3 (SOUTH FENCE) | | |
| -1.2 | BELOW GROUND | | | F-1.2 (SOUTH FENCE) | | |

TABLE 1



PLAN VIEW
SENSOR LOCATIONS

PLAN VIEW
EMITTER LOCATIONS

Figure 4

tonne of ore. The ore was mixed for three to five minutes and dumped onto an inclined conveyor which lifted the ore to the top rim of the crib.

In order to reduce compaction or breakup of the preconditioned material, drop off from the end of the conveyor was held to less than 3 meters. The walls of the crib and conveyor were raised in 1.2 meter lifts as the crib was being filled. Ore was dropped against the east wall of the crib. The surface of the pile was allowed to build up at the natural angle of repose. This is similar to an actual operation where the ore is dumped on the top edge of a new lift and allowed to cascade down the open face. After the leachate distribution system was installed, an additional 1 meter of ore was added to the top of the pile. Eventually, a layer of snow also accumulated on top of the ore.

Lakefield Research supplied a SX-EW pilot plant which was used to decopperize the pregnant leach solution (PLS) prior to recirculation back into the pile. The solvent extraction portion employed a 2 X 2 circuit of extraction and strip mixer-settlers. The electrowinning cells comprised three tanks, each containing four stainless steel cathodes and five lead anodes. The electrodes were one quarter commercial size and weighed approximately 15 kilograms each. Copper was harvested manually by lifting the cathodes from each cell and peeling the copper off the sides. PLS was pumped into a 2000 litre storage tank. A solution inventory was maintained between 375 litres and 750 litres. Raffinate flowed by gravity from the extraction cells into the first of three 200 litre leachate tanks. Tank #1 had a bottom drain which allowed entrained organic to collect at the top of the tank. Tank #2 was fitted with instrumentation to control acid additions. Leachate was pumped from the third tank back to the top of the ore pile. Lean organic recycled to the extraction stage contained considerable entrained electrolyte. This was sufficient to keep the pH of the raffinate at less than 1.5 when combined with acid pickup from transfer reactions in the extraction stages. Hence, no additional acid was required.

A flow sheet for the SX-EW circuit is provided in Figure 5. The circuit and its operation will be discussed in more detail in the metallurgical report to be issued later.

## OPERATION OF FACILITIES

As described above, the ore was pre-acidified before being loaded into the crib. Heat from acid hydration and reaction with the ore raised the temperature of the preconditioned material to about 35°C. The crib took four days to load during which time the top of each lift was exposed to freezing conditions through the evenings. The core temperature of the pile was still equilibrating between 27°C and 30°C at the time the irrigation was initiated.

Irrigation started on September 27, 1993 (DAY 0). Solution breakthrough at the bottom of the crib occurred 20 hours later. The SX-EW pilot plant was started as soon as sufficient PLS became available. The SX-EW plant was shut down on December 16, 1993 (DAY 80). However, heated leach solution was circulated through the pile until February 8, 1994 (DAY 134) and temperatures monitored until February 15, 1994 (DAY 141). Thermal conditions were monitored throughout the 141-day test by recording the temperature data using

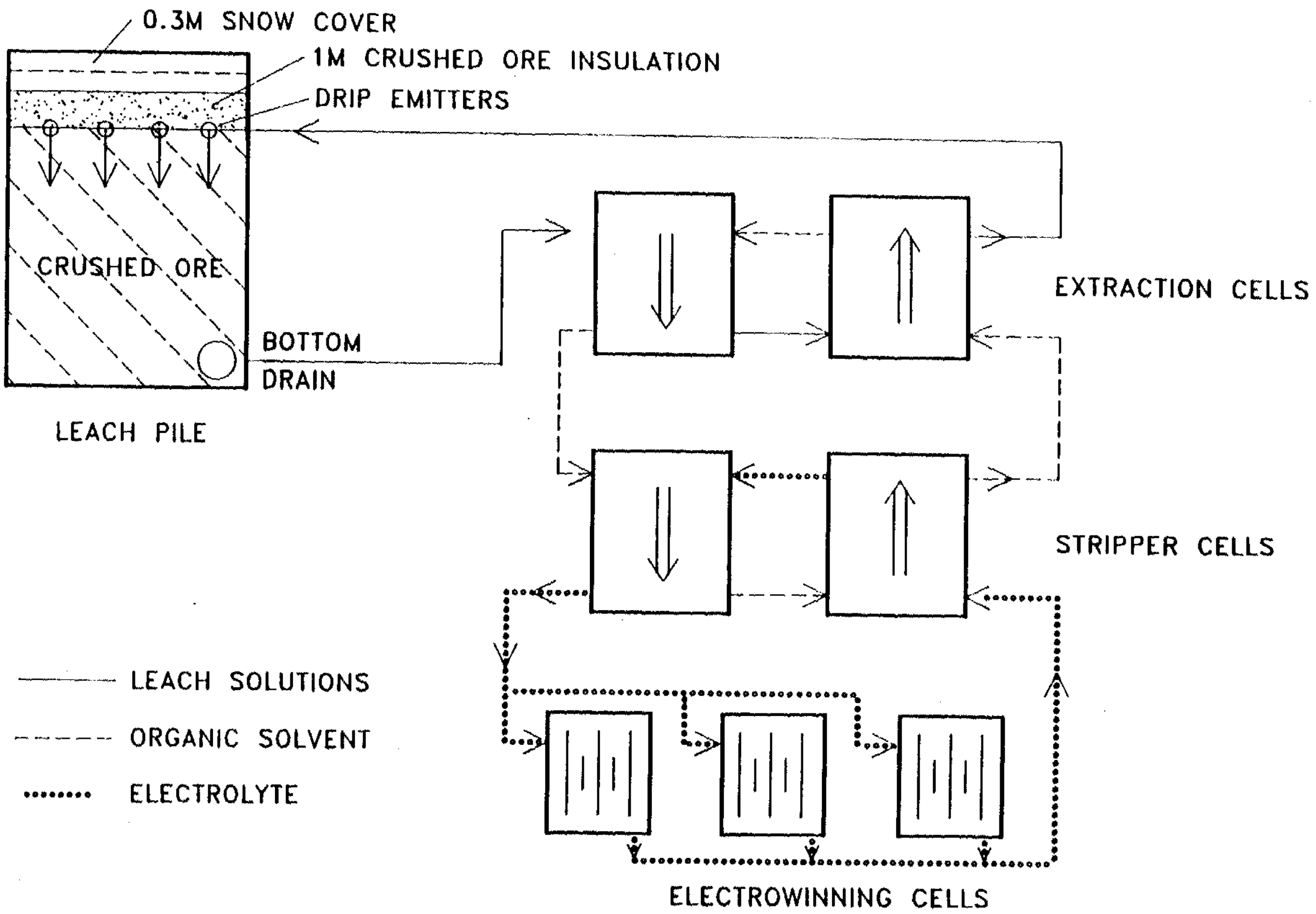


Figure 5: PILOT PLANT FLOW SCHEMATIC

the array of sensors. Other than the limited solar flux, the only heat input to the crib was in the leach solution recirculated back to the emitter system. Over the duration of the test this heat input averaged 720 to 1,000 Kcal per hour.

During the first 80 days of the test, there was no direct heating of the leachate. Only the electrolyte was heated to maintain an electrolyte solution temperature of 35°C. Electrolyte heating in commercial electrowinning plants is done to achieve optimum current densities and cathode quality. Heat was transferred from the electrolyte, through the organic into the leachate. This process heat transfer was sufficient to raise the average leachate temperature to 21°C from the average PLS temperature of 18°C.

When the SX plant was shut down, after December 16 (DAY 80), a heater in the leachate tank was used to maintain the solution temperature, simulating continued operation of the SX plant. Recirculation of the heated solution continued until February 8, 1994 (DAY 123) when the test was terminated. Temperature data was collected through February 15, 1994 (DAY 141) to follow the cool down of the system.

Every effort was made to minimize the lateral heat flux as this will approach zero in a commercial operation, except around the extreme edges of the heap. The lateral heat loss in the test was greatly reduced, however, there was some limited effect on the sides of the crib. Significant heat losses were attributed to solutions flowing from the crib and vertical fluxes into the soil below the crib and upward through the ore and snow layers above the emitters.

## PRESENTATION OF DATA

Figures 6 through 9 include the ambient temperatures from temperature sensor C8.0 mounted above the top of the crib. This sensor is the highest and is affected more by wind than any other sensor. However, all seven ambient sensors tracked within a degree of each other. After the last week in November the temperatures (high, low, average) dropped below freezing and averaged minus 13°C for the remainder of the test.

Temperature data from the Faro area, 200 km east of Carmacks, was analyzed to determine the average conditions of the 6-year period 1985-1990. The Yukon Weather Centre (YWC) of Canadian Weather does not track conditions in Carmacks. According to YWC, Faro and Carmacks are very similar environments. Indeed, at minus 13.3°C, the daily average temperature for Faro during the 1985-1990 period is virtually identical to the minus 13.0°C seen at Carmacks during the 1993-1994 field test.

During the test period there was a close correlation between Carmacks and an average winter at Faro. Taking into account a warm spell in December and a cold snap in January at Carmacks, the temperatures at the two locations tracked within a few degrees of each other. The variance between daily high and low temperatures at Faro and Carmacks was particularly close.

Leach solution was detected outside the base of the crib in late December. The leak was traced to the point where the feed line for the header penetrated the crib. Here the pipe was melted by heat tracing which had shorted due to acid attack. Consequently, only the west side of the crib was being irrigated. During repair it was found that the heap had subsided about 45 centimeters or 7.5% and several irrigation lines had pulled away from the header. Leach pile settlement is quite normal during the initial leach cycle. The irrigation lines were re-attached to the header and normal flow was established on January 18 (DAY 113) which resulted in a sudden temperature rise detected by most thermistor probes.

In relation to the highly variable ambient temperature, the heap showed much greater thermal stability. Note that the heap had sufficient heat capacity so that it only responded to seasonal and not daily fluctuations in ambient conditions. Periods of extreme cold lasting 7 to 10 days had limited or no effect on most probes.

Temperatures within the crib had a much greater sensitivity to the temperature of the irrigating solution than to external conditions. Leachate temperatures were consistently between 20°C and 22°C up to January 10 (DAY 100) at which time the temperature was increased to 30°C. This was done to reduce the amount of time required to return the pile to the approximate temperature when the header severed. Leachate temperatures were maintained at these levels until January 27 (DAY 122) when they were returned to 21°C. PLS temperatures were consistent throughout the test, varying between 14°C to 20°C. The warming trend in the pile continued even after the temperature of the leachate was reduced.

Temperature probes located 0.15 meters above the crib bottom showed a consistent decline in temperature. The probes 45 centimeters in from the walls were all approaching or slightly below freezing. These temperatures reflect frost penetrating through the soil under the sides of the crib. The central probe was the same temperature as the underlying soil.

At 3.0 meters above the crib bottom, probes against the north, south and east walls measured the chilling affect around the sides. By the end of the test, temperatures in these areas slowly decayed to slightly above or below freezing. Variations in the slopes of the curves correspond to both high and low ambient temperature spikes. After January 13 (DAY 108) the temperatures were consistently within 3°C of freezing.

On the west sides of the crib, up to December 17 (DAY 81), probe W 3.0 was consistent, varying up to 2°C above or below 20°C. This corresponds with the temperature of the leachate being pumped back on top of the pile. On Day 81, the measured temperature began to drop to an eventual low of 6.3°C on January 8 (DAY 104) at which time the temperature began to recover. This dip in the temperature profile reflects the time between the leaking of solutions outside of the crib and repair of the header.

Probe C 3.0 measured a steady drop in the core temperature from a high of 28°C at the start of the test to 18°C some 21 days later. From October 18 (DAY 21) until December 1 (DAY 65) the temperature at the core of the pile varied within 1°C of 18°C. After December 1, the temperature began to slowly drop as a result of the lack of irrigation. Ambient temperature spikes appeared to have little or no effect on the slope of the curve. Re-establishing the irrigation also had no effect on the temperature profile.

At 5.5 meters above the crib floor, 0.5 meters below the emitter lines, temperatures generally had similar trends as at 3.0 meters. Inflection in the curves caused by ambient air temperature swings were more dramatic. As with the deeper sections of the pile, the north, south and east sides slowly dropped to below freezing until the header was repaired.

Within five days after irrigation was re-established both the north and south probes began warming and eventually reached temperatures around 6°C. The east side of the crib did not show any sign of warming, indicating a lack of irrigation.

Temperatures measured at the centre of the pile closely reflected those of at the 3.0 meter level up until January 18 (DAY 113), after which time they steadily rose. The measured temperatures reached a low of 6.7°C before climbing back to a high of 20.5°C where they remained until the irrigation was shut off.

The probe against the western wall, W 5.5, had a similar profile to the one described for the 3.0 meter level. Daily temperature swings were more dramatic, corresponding mainly to daily temperature variations of the incoming leachate.

At 6.5 meters above the crib floor, 0.5 meters above the emitters, temperature profiles closely reflected those of the underlying material. The difference being that minimum temperatures observed were 7°C cooler than at 5.5 meters and the edges of the pile were frozen by November 23 (DAY 57). As before, when irrigation was re-established this layer began to warm, although the edges of the pile remained slightly below freezing.

At the centre of the pile, temperatures cooled to just above freezing before warming to 8.9°C. The slope of the warming portion of the profiles are shallower than those at 5.5 meters. The area around the western probe was excavated on December 28 (DAY 92). The bottom of the pit was covered with insulation, however, this probe was exposed to ambient air for the duration of the test.

Comparison of the above data indicates that the outside edges of the pile were subjected to lateral cooling even though the crib walls were well insulated. It is assumed that this lateral heat loss had minimal effect at the centre of the pile. As a result, only temperature profiles for the central string of thermistors are presented in Figures 6 through 8.

Temperature profiles for probes C.15, C 3.0, C 5.5 and ambient are shown in Figure 6 and for C 5.5, C 6.0, C 6.5 and ambient in Figure 7. These are expected to be typical of a commercial heap where irrigation is interrupted and then re-started. Note that between October 1 and December 1 the profiles are fairly flat reflecting the long term seasonal temperature variations.

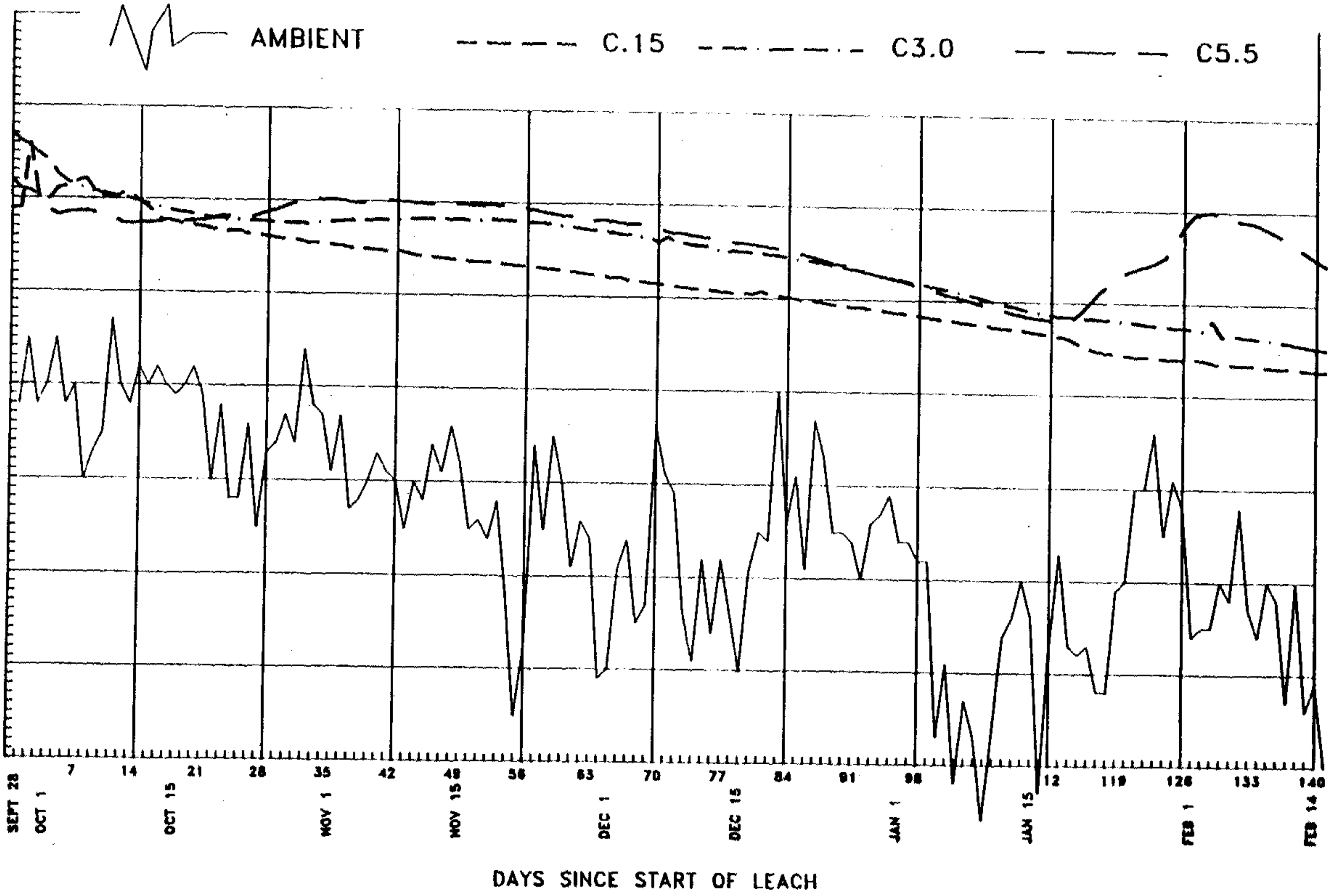


Figure 6: LEACH PILE TEMPERATURE PROFILES BELOW THE DRIP EMITTERS

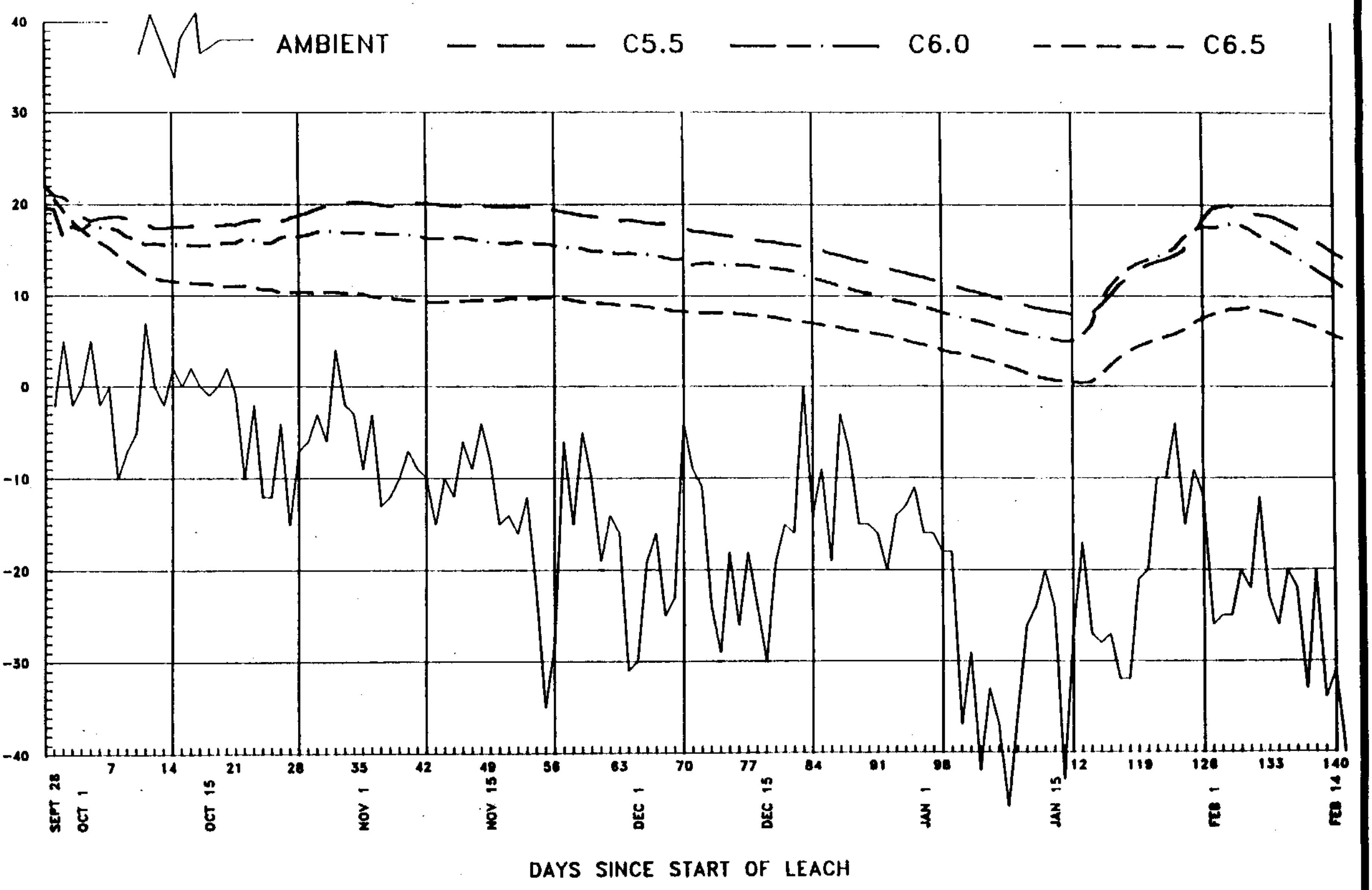


Figure 7: LEACH PILE TEMPERATURE PROFILES WITHIN 0.5M OF THE DRIP EMITTERS

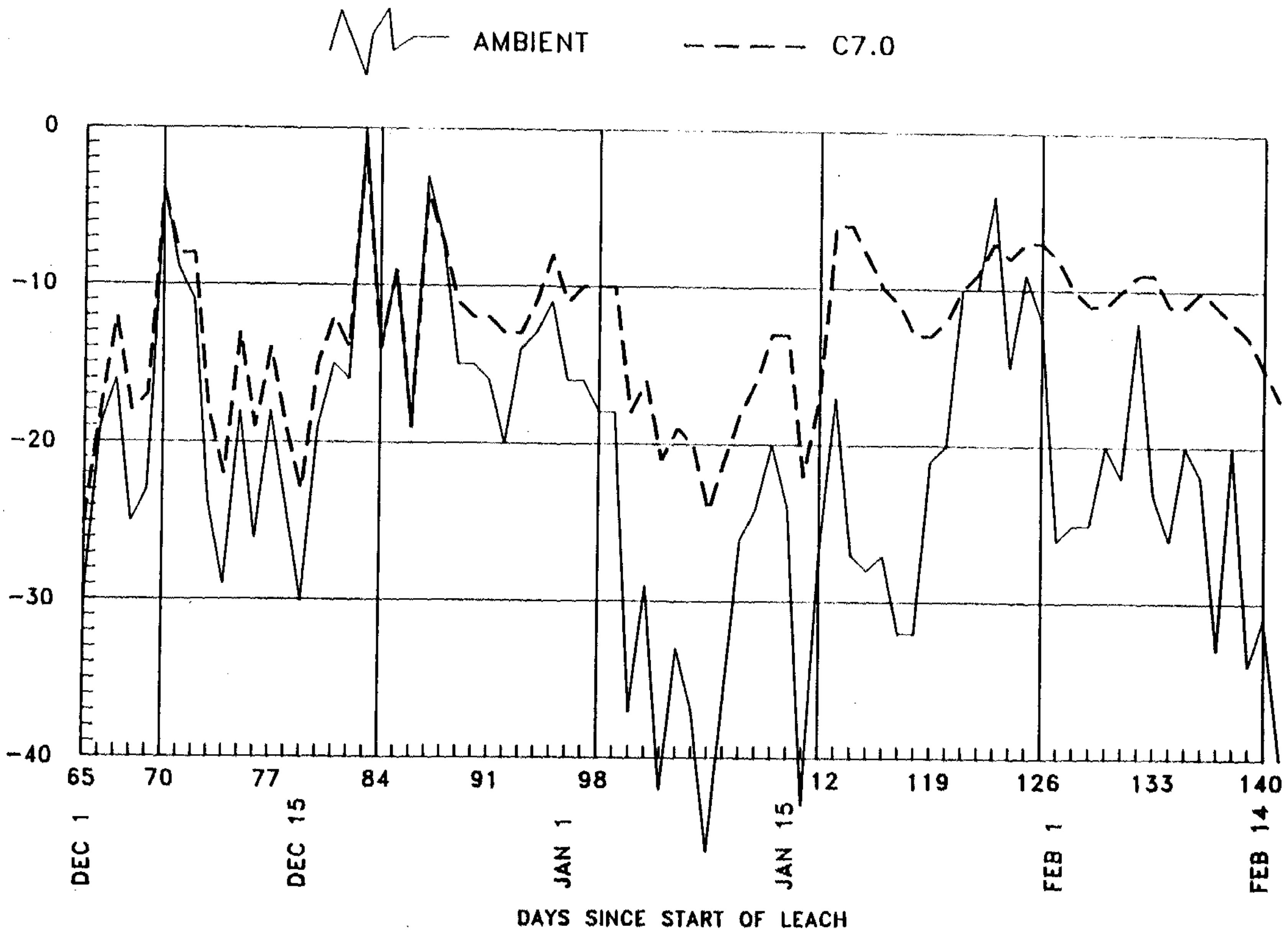


Figure 8: COMPARISON OF TEMPERATURES ABOVE AND AT BOTTOM OF SNOW COVER

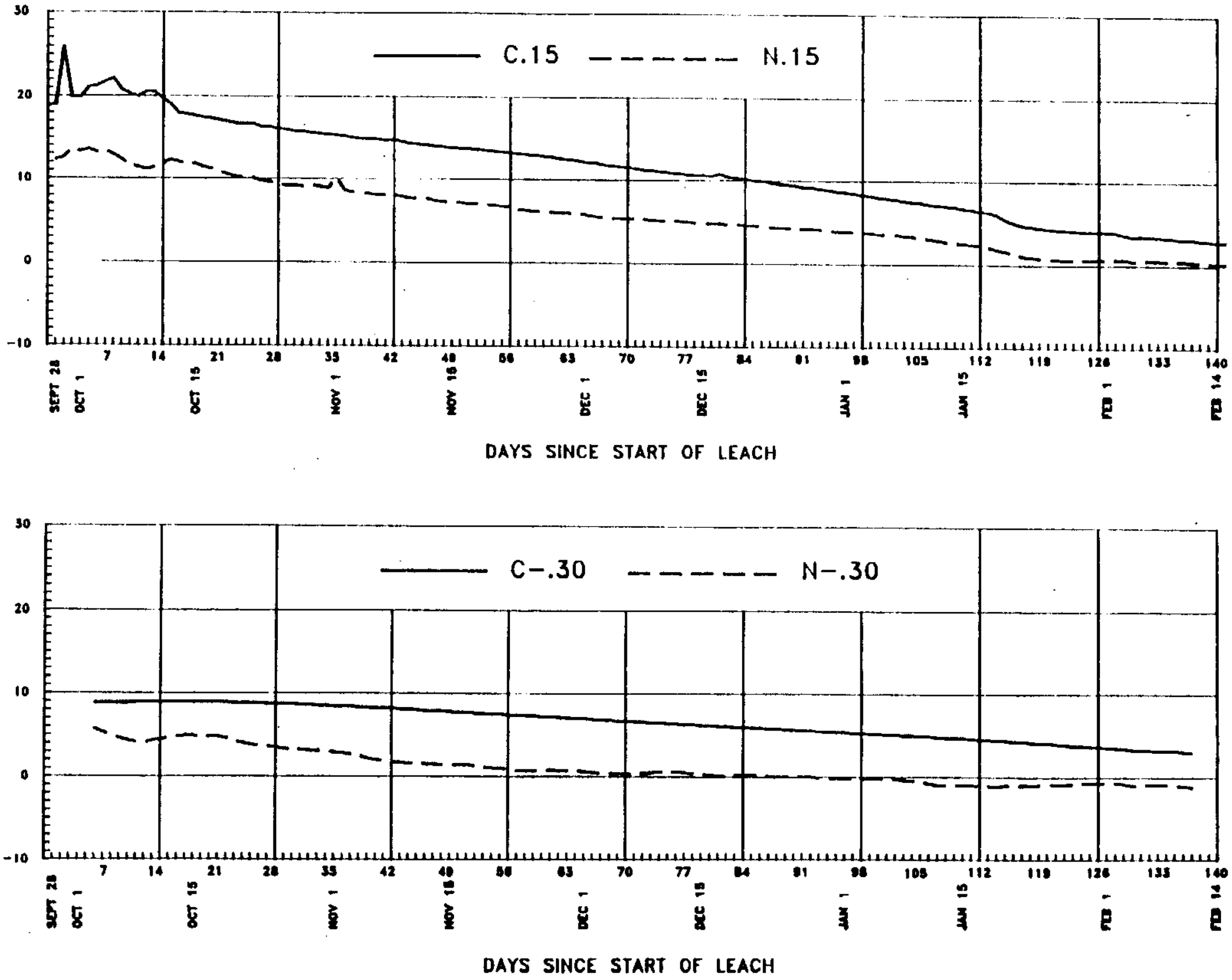


Figure 9: COMPARISON OF TEMPERATURES AT THE BASE OF THE LEACH PILE AND IN THE UNDERLYING SOIL

A permanent layer of snow did not accumulate on top of the pile until December 7 (DAY 71). The snow smoothed out the daily temperature variations as well as providing insulation. When the snow reached a thickness of 30 centimeters, the difference in temperatures between ambient air and the bottom of the snow averaged 8°C to 10°C. During periods of extreme temperature lows, this difference was as much as 20°C (-25.4°C vs - 45.2°C). Conversely, during an unseasonably warm period, the bottom of the snow layer was 3°C to 5°C cooler than ambient air. These profiles are shown in Figure 8.

Ground temperatures below the centre and north edge of the crib are shown in Figure 9. Temperatures at the base of the crib were equilibrating with those of the underlying soil. Presumably, as additional heat transferred into the soil these basal temperatures would slowly begin to rise.

## CONCLUSIONS

The winter weather conditions in Faro and Carmacks were demonstrated to be similar. The daily average temperature during the test at Carmacks tracked closely with the average daily temperature over a six year period from Faro. This shows that the winter experienced in Carmacks was typical of the area in terms of severity.

The heap appeared to be a well behaved thermal system that responded normally to variations in heat flux. With the insulated sides, the heat flow was predominantly vertical into the air above and the underlying soils below. Lateral heat loss was monitored in the form of chilling along the sides of the crib. In a commercial operation, freezing would be restricted to the outside edges of the leach pile. Consequently, the conclusions of this study are drawn from the centre thermistor string which was relatively unaffected by lateral heat loss.

In the first half of the test, temperatures inside the pile varied only 2°C or 4°C. In fact between October 11 (DAY 14) and November 8 (DAY 42) core temperatures were on a steady increase. Continued drop in the ambient temperature reversed this trend. The pile did not begin to cool rapidly until irrigation was stopped by the break of the header. When irrigation was restored, temperatures quickly rose to their original levels. The rate of increase in the temperature was in part a reflection of an increase in the leachate temperature. When the leachate temperature was lowered, the warming trend continued until temperatures in the pile equilibrated with those of the leachate. Rates of cooling, similar to those during the time of no irrigation, were measured during the last seven days of the test when irrigation was stopped in preparation for plant decommissioning.

The exception to this trend were the temperature profiles at the base and 3 meters above the base of the crib. As seen on Figure 8, temperatures at the base of the leach pile equilibrated with those of the underlying soil. Emplacement of the leach pile prevented those soils from freezing except along the perimeter of the pile where frost crept in from the sides. The lack of warming at probe C 3.0 was presumably a result of restricted solution flow. Analysis of the post mortem pile inspection will be required to confirm this.

Figures 5 and 6 show that in the areas of active irrigation frost penetration into the top of the pile will be less than 0.5 meters if the drip emitters are 1 meter below surface. If irrigation is interrupted the surface of the pile will cool. Once irrigation is re-established, temperatures will return to levels experienced before the break in irrigation.

Freezing on the sides of the pile is not expected to exceed 4 to 5 meters. This is inferred from probe C 3.0 which is 4 meters below the top of the pile. At this point the temperature appears to be unaffected by ambient conditions. Even during periods of no irrigation, the slope of the curve was unchanged. Areas under active irrigation will experience less frost penetration into the sides than areas which are not.

Thawing of frozen areas in the pile may be achieved by irrigation. Areas on the sides of the crib froze due to lateral heat loss. The zone immediately below the header thawed once irrigation was re-established. Temperatures at the 3 meter level were slowly warming at the end of the test and presumably would have thawed.

This test demonstrated that the leaching procedures used by Pegasus Gold at the Zortman mine are applicable to sub-Arctic conditions. Burying drip emitters is an effective leach solution delivery system. Frost will not penetrate below the level of the emitters. A 30 centimeter layer of snow adds additional insulation which can create temperature differentials of up to 20°C between the top and bottom of the snow cover. The base of the heap will thaw and remain unfrozen except for a very limited area around the perimeter of the leach pile.

The test clearly demonstrates that year round leaching of Carmack Copper ore is practical. The heap appears to be adequately insulated by a 1 meter ore layer on top of the emitter system. Normal process heat should be sufficient to maintain a leachate return temperature of approximately 20°C. However, provisions should be made for supplemental heating in a commercial operation. This would permit recycling of the heated solution if electrowinning goes off-line or if there is a long run of exposed pipeline back to the heaps.