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TEMPERATURE, CONDUCTIVITY AND WIND OBSERVATIONS IN THE ARROW LAKES, B.C.: A DATA REPORT

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Temperature, conductivity and wind observations in the Arrow Lakes, B.C.: A Data Report

by

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MANAGEMENT PERSPECTIVE

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EC Priority/Issue: *At the request of DFO and DOE, Pacific and Yukon Region this baseline study of the limnology of the Arrow Lakes was undertaken in September, 1996 to assist in the assessment of the environmental impact of proposed hydroelectric power generation of the thermal regime of the Arrow Lakes*

Current Status: *This document reports on the temperature and total dissolved solids distributions and instrumentation performance on a lakewide survey undertaken during the stratified season. These results will form the basis for future work.*

Next Steps: *These results will be disseminated to the appropriate persons making the environmental assessment and discussed in detail at the Arrow Lakes thermal workshop.*

Résumé

L'intérêt récent pour la limnologie du réservoir des lacs Arrow a été suscité par une proposition visant à altérer le régime de décharge de ce réseau. Pour l'instant, on ne dispose que de peu de connaissances sur la limnologie des lacs Arrow. Dans ce rapport, nous décrivons un programme d'échantillonnage entrepris en septembre 1996 afin d'obtenir un relevé du champ de vent, du régime thermique et de la distribution des matières solides dissoutes pendant la saison de stratification. À cette fin, on utilise des équipements de mesure des profils récents, qui permettent de couvrir rapidement une grande étendue d'eau comme le réservoir des lacs Arrow. En plus de présenter les données collectées dans leur forme finale corrigée, nous examinons certains des résultats mis en évidence grâce à cet ensemble de données et nous évaluons la performance d'un nouveau profileur et de son instrumentation auxiliaire (un système de navigation électronique et un profondimètre).

Abstract

Recent interest in the limnology of the Arrow Lakes Reservoir stems from a proposal to alter the outflow regime of the system. Little prior knowledge of the limnology of the Arrow Lakes exists at present. In the report we describe a sampling programme undertaken in September 1996 to survey the wind field, the thermal regime and the distribution of dissolved solids during the stratified season. Our observations take advantage of recently developed profiling instrumentation which makes the rapid coverage of a large water body such as the Arrow Lakes Reservoir feasible. Besides presenting the data collected in final corrected form we discuss some of the findings in the data set and evaluate the performance of a new profiler and ancilliary instrumentation, namely the electronic navigation system and a depth sounder.

Introduction

The Arrow Lakes are ultra-eutrophic fjordic lakes situated in the Columbia River system between Revelstoke and Castlegar, British Columbia. As a result of the construction of the Hugh Keenleyside Dam at their outflow in 1968 the water level was raised about 20m to form the present pair of interconnected lakes. Despite attention to the fishery and contaminant loading of the Columbia River downstream of the dam, to the authors' knowledge there has been no study of the limnology of the post-development Arrow Lakes. The only limnological investigation is that of Davison and Thuesen(1963) who observed the summer distributions of temperature, conductivity and dissolved oxygen in the predevelopment lakes.

Present interest in the limnology of the Arrow Lakes stems from a proposal by the Columbia Power Corporation to change the operation of the Keenleyside dam from storage and flood control to include at-site generation of hydroelectric power. The alteration of the outflow structure and the effective withdrawal depth of the outflow at the dam could have potential impacts on the limnology of the lakes especially the thermal regime. Secondly, on a longer term there is concern that the upstream impoundments on the Columbia River may trap incoming nutrients needed to sustain a productive ecosystem as is the case with Kootenay Lake (Ashley, 1994). Understanding of the limnology of the Arrow Lakes would be required in order to assess the effectiveness of such remediation strategies as lake fertilization.

This report provides an analysis and presentation of observations taken of the baseline limnology of the Arrow Lakes during a one week period in September, 1996. The goal was to obtain whole lake coverage as rapidly as possible without sacrificing the possibility of looking at such details as transverse gradients in properties along the thalweg of the lake.

Field and Data Processing Methods

A 7-m long motor launch capable of steady speeds of 50km/hr and equipped with a depth sounder was trailered to various launching sites along the lake. From this survey platform about 30 profiles of temperature and conductivity per day were collected with an Ocean Sensors probe, model OS-200. With this sampling strategy both the Upper and Lower Lakes were covered in three days which is considered sufficiently short that conditions do not change significantly. A repeat of the first day for reasons of data reproducibility was limited to four transects due to equipment failure.

A small lead weight was attached to the case of the profiler in order to increase its rate of descent in a free fall. Despite this, it only fell at approximately 0.8m/s which meant that the time taken per cast was much larger than necessary. A 0.25 inch polypropylene line was stored on a rapid take-up reel but unfortunately it could not be used to haul the profiler in. The most difficult task in the survey was the hand-over-hand retrieval of the instrument particularly for deeper stations and during windy conditions.

The sampling interval on the instrument is variable up to 100hz but instead of recording individual samples at this rapid rate averages of three channels of data (depth, temperature and conductivity) were recorded at about 4hz. Depending on the rate of fall at least four samples per metre were measured. Sampling time was recorded as an auxiliary data channel. Since there was no AC power on board the data residing on the internal memory of the OS-200 was uploaded to a battery-operated laptop computer (IBM ThinkPad) after in most instances the three profiles comprising a cross lake traverse were logged and while proceeding to the next transect along the lake. When the internal batteries in the laptop failed an inverter was purchased which was powered from the boat's 12V system. When the inverter blew the transformer on the laptop computer the survey had to be abandoned. Fortunately, this did not occur until September 16, the final day planned for the field experiment.

Station times and positions were noted manually from a hand-held GPS as well as wind speed and direction at a height of approximately 3m above the water surface. The profiler was programmed to start recording data as soon as the pressure sensor detected immersion. This greatly simplified subsequent data processing as all data started at the same location in the file. Unfortunately, for some unknown reason part way through the survey the instrument failed to start recording upon submersion. Subsequently, the data collection program was re-written to start recording the instant the instrument was turned on. Periodically, the internal battery aboard the OS-200 was checked for voltage. One battery sufficed for the four days of field operation.

When uploading the data in binary format from the OS-200 internal memory each cast generated two files which first had to be converted to ASCII. Next, the ASCII files containing the instrument counts in each channel were converted to physical units according to the calibrations established in the National Water Research Institute's (NWRI) Calibration Laboratory just prior to field deployment. As the manufacturer's software ignored the sample date and time these had to be merged from another file to form a file containing all the data in a calibrated state. For convenience all data files originating from a single transect were stored in a separate directory on the laptop computer.

The depth channel was calibrated at NWRI near sea level while the lake surface is 437m. One of the files recorded on each cast contained the apparent pressure before immersion. These pressure values were used to correct the depth channel on a profile-by-profile basis for the elevation, barometric changes and instrument drift using spread sheet software. The depth correction was typically about 1.3m. Temperature (T) effects on conductivity are routinely compensated for by correcting conductivity (Cond) to 25°C ($Cond_{25}$) or specific conductance according the formula,

$$Cond_{25}=1.827803125\ Cond/(1.+0.0297175.T-1.5551x10^{-4}T^{2}-7.89x10^{-7}T^{3}).$$

As well, these corrections were performed by the spread sheet software. Finally, the temperature of maximum density as a function of depth was calculated according to the expression of Farmer and Carmack (1981) as a reference curve for the very deep stations. Corrected temperature and specific conductivity profiles are plotted for each cast based on the spread sheet software in Appendices I-IV.

GPS position uncorrected for errors due to selective availability were used to plot station location charts shown in the appendices. The relatively large errors in the GPS positions are evident from a close inspection of these maps.

As the manufacture did not supply a conductivity sensor designed for the freshwater conductivity range there was a question about the performance of the OS-200 in the very low conductivity waters of the Arrow Lakes. The lack of reproducibility between both the upwards and downwards conductivity casts in Figure 1 suggests that fluctuations in conductivity of about 5% of the signal level are due to sensor noise and not fine structure in the conductivity profile. In a few profiles the down-cast conductivity appeared to be about 50µS/cm higher than the up-cast trace. Whatever the cause of this anomalous behaviour was the more consistent of the two curves was used in the subsequent analysis and data presentations in those cases where the complete up-cast was available.

The manufacturer's specification of the range of the pressure sensor is from zero to 300m which would be sufficient for all locations in the Arrow Lakes. During the prefield calibration it was found that the instrument ceased to record at pressures in excess of 250m depth. This was borne out in the field with no data recorded below 247m. Thus, in some cases 40m of the water column were not sampled.

Some preliminary data processing in the evenings between daily surveys revealed that temperatures at depth were significantly lower than the temperature of maximum density at the surface (3.98°C). Consequently, a spare OS-200 profiler was lashed to the standard instrument and lowered at several deep stations. The horizontal separation between the two temperature sensors was estimated to be several centimetres. Difference between the two instruments demonstrate in Figure 2 that the deep temperature must be correct to within 0.01°C, the accuracy of the temperature calibration performed at the National Water Research Institute's calibration laboratory prior to field deployment.

The OS-200 profiler was programmed to collect 1215 samples before shutting down automatically. This number was considered to be sufficient to capture all levels at the deepest locations in the lakes of 290m on the down-cast and in most cases the up-cast as well.

A distributor of digital bathymetric data for the Canadian Hydrographic Service was contacted for the availability of digital information on the Arrow Lakes. When it was determined that these data were unavailable the feasibility of in-house digitization of the bathymetric charts was investigated at NWRI. Unfortunately this proved to be too costly. Alternately, for the purposes of displaying the station positions the bathymetric charts were reduced by several photocopying stages. Then, the positions reference points and of the field stations according to their GPS co-ordinates were plotted to the same scale as the reduced charts. Next, the shoreline contour was traced on the station position map and the result digitally scanned following further photoreduction. The digital file was then input to a graphic routine, SHOWCASE, where the reference points and station locations were labelled. Unfortunately, this laborious procedure provides only an approximate location and not the additional bathymetric information required to establish the hypsometric information needed for mathematical modelling.

To examine the question of representativeness of a stationary wind station for the Arrow Lakes Reservoir hourly wind speed and direction were obtained from the Castlegar Airport for the daytime hours. Unfortunately similar data were not available for the Keenleyside Dam where a monitoring station was formerly located.

Results

Charts showing transect and station locations for each of the four days sampled are provided on the first page of Appendices I-IV. Corrected profiles of temperature and conductivity are given for each cast. In Appendix V archival information is presented for the corrected data set and the computer programs used in the analysis.

Evaluation of the performance of field equipment

With respect to the launch one difficulty was the depth sounder which performed poorly at depths greater than 80m. It would have been most useful to have had full coverage of depth over the 290m depth range. Reliable AC power is desirable. The use of inverters with computers is not recommended. Improvements in the OS-200 profiler could occur in a number of areas. The pressure and conductivity ranges should be closely examined. We recommend the use of additional weight and a tail fin for more rapid decent and an electrically operated capstan for recovery. The electronic navigation system based on GPS should be used in conjunction with a ground reference station or some other form of post processing of the navigation data.

Conversion of specific conductance to dissolved salts

No water samples were collected during the field experiment for analysis of major ionic constituents. However, Davison and Tinesen(1963) measured conductivity, ash remaining after ignition and total solids concentration for eight water samples. Based on their results the best fit factor for salt concentration in mg/l is 0.52 times the conductivity in µS/cm at 25°C.

Wind comparisons

It is of interest whether the Castlegar Airport wind station measures representative winds for the Arrow Lakes. If there is correspondence, then these data could be useful in thermal modelling studies. While hourly wind is recorded only during daylight hours at Castlegar concurrent wind speed and directions were obtained for the measurement period. Winds at Castlegar were resolved into components along a north-south axis with northerly components taken as positive. Similarly, winds observed on the lake during the survey were considered positive if the wind blew from a northern or northwesterly direction. Winds at Castlegar were linearly interpolated to the times of the lake stations. The most likely agreement would occur for the Lower Lake as it is closest to the airport station. Thus, components are compared in the Lower Lake for September 13 and 16, 1996 in Figures 5 and 6. Both days indicate that the winds on the lake surface are more variable than at the Castlegar airport station. Due to the absence of any agreement evident in these scatter plots neither correlation coefficients nor further attempts to examine possible correspondence in the Upper Lake was attempted.

Discussion

Although greater emphasis is being placed upon analysis of impacts associated with the change to the discharge structure associated with the proposed Keenleyside Powerplant Project (KPP), some patterns are fairly apparent in the depth profiles. Profiles from the two sources feeding into the upper basin show in Appendix III that both the Columbia River mainstem and the Beaton Arm have distinct temperatures and conductivities. Mainstem Columbia River water, with temperatures and conductivities of 11.2 °C and 151 µS/cm respectively, is apparent in river stations 2 and 4 (S15R2 and S15R4). By station S15R6 the effect of Beaton Arm surface water can be seen at the surface where temperatures exceed 14 °C and conductivity is 130 µS/cm.

The greater flow down the Columbia River mainstem would suggest that the contribution from the Columbia River fraction is greater. The influence of these two water sources can be traced much of the way down the upper basin as far as station S15tr6, as a pattern of a 11 °C interflow underlying 13.5 °C surface waters. The downstream decrease in the conductivity of the 11 °C intrusion of Columbia River water suggests mixing with the above lower conductivity water. Lateral differences in the thermal structure across the reservoir indicate that the 11 °C inflow moves as a discrete unit. It is found primarily along the western shoreline at stations S15tr3 to S15tr5, then, as the thalweg shifts to the west, it is present along the eastern coastline from stations S15tr6 and S15tr7. Remnants of this feature may be present in profiles such as S14tr9 mid and east, but the warmer temperature of this layer and its predominance compared to upstream sites (e.g. S15tr8) make this uncertain.

At the downstream end of the upper basin limited deep cooler water discharges through the narrows and into the lower basin due to the restricted depth of the Narrows region. Water temperatures at stations S14tr8 through S14tr4 are generally greater than 10 °C. This influx of warmer water may be related to the generally warmer surface water in the lower basin, however, some of the coldest (S14tr4) and warmest (S13tr5) surface water were located within the lower basin which indicates the likely importance of other factors such as wind driven fluctuations. Temperatures below 9°C were not observed until deeper stations beginning at station S14tr3, and more so downstream of station S14tr1.

From station S13tr6 downstream to S13tr2 there is a general pattern of temperatures at 30 m depth of about 9 °C. Below this depth water shows a gradual cooling trend approaching the temperature of maximum density. Above this depth thermal structure is not strong and temperatures decrease at a rate of about 0.23°C/m from a surface temperature of about 16 °C. Depths and temperatures at the dam suggest that very little of the deeper water is passed downstream, and therefore most of the outflow through the lower basin is drawn from the upper 30 m of the water column.

An increase in the temperature difference across the thermocline was evident at transect S13tr1 where water above 15 m was about 16 °C, and below this there was an abrupt 3°C drop. This feature is likely due to the selective withdrawal of water through the subsurface ports at the dam.

Comparison of sites sampled on September 13 and 16 shows a general cooling of the thermal structure seen on September 13th. The rate of stratification present at S13tr1 was diminished at transect S16tr4, although it was still evident. The water column was still somewhat isothermal (near 13.5 °C) for the top 10 m at transect S16tr1 (at the floating guide wall of the dam). Such changes are likely related to changes in the discharge regime from sluice and ports to ports only, and to seasonal decreases in the maximum air temperature between September 13 and 16 (R.L&L 1997).

Downstream temperature changes

The question of whether the KPP will result in changes to the thermal structure of the reservoir or downstream of the dam is addressed in other reports. However, Klohn Crippen Integ (1996) identified the fact that the present thermal regime below the dam is somewhat different that it was prior to river regulation. No clear explanation has been forwarded for this observed shift, and therefore a number of ideas generated by this survey deserve mention.

The survey confirmed that both reservoir basins have a surface inflow-surface outflow type of structure, which would be similar to the original Arrow Lakes prior to impoundment. Although temperature data for the Columbia River upstream of the reservoir are scanty for the period prior to impoundment they indicate that summer temperatures were warmer prior construction of the Mica and Revelstoke Dams, both of which have deep water outlets which would result in lower inflow temperatures to the Arrow Lakes. Since the relation between reservoir inflow and outflow temperatures is likely to be generally positive, it is therefore difficult to conceive how cooling of inflow water would lead to warming of outflow water. Furthermore, the size of the reservoir is sufficient for temperature changes to occur within the reservoir due to meteorological effects, as shown by the above-mentioned cooling between September 13 and 16, and observations in R.L&L (1997).

Changes in the discharge structure from the natural lake to the discharge structures of the Keenleyside Dam also seem an unlikely cause of warming of such magnitude. The natural lake outflow can be described as an overflow whereas the present dam has either surface overflow or subsurface outflow. In comparison to natural outflow the subsurface ports would seem most likely to lead to a decrease in downstream temperature.

A possible explanation could be the loss of the spring flood pulse. The natural flood flows into Arrow Lakes would have contributed a large volume of fairly cool water at the beginning of the heating cycle. It would also likely have decreased epilimnetic residence time, and thereby decreasing the time for heating due to meteorological contributions. Under a regulated scenario the lower summer flow leading to greater residence time, combined with an increased reservoir surface area due to impoundment might therefore be responsible for the observed increase in outflow temperatures in summer, and probably surface water temperatures as well. Unfortunately the lack of pre-impoundment data make it difficult to thoroughly examine this hypothesis. However, such hypotheses could be evaluated by a calibrated numerical model of the reservoir dynamics and thermodynamics. Further examination is warranted as it may shed light upon potential methods for mitigating this impact

Conclusions and Recommendations

The development of new electronic instrumentation has greatly facilitated the field measurement of physical characteristics in lakes. However, while potentially useful on account of its rapid sampling rate the OS-200 profiler should be improved for use in the Arrow Lakes Reservoir The noise in the conductivity sensor should be eliminated and its dependability and reproducibility increased by narrowing the range specifically for freshwater. An attempt should be made to adjust the pressure sensor to exploit its full range. Finally, a tail fin and more weight should be added to the body to increase the profiling speed. An electric capstan would greatly facilitate the field operation.

A hand-held GPS is not sufficiently accurate with errors of hundreds of metres perhaps due to interferences from the towering shorelines of the lake. GPS data should be recorded continuously along with the necessary auxiliary data to post process positions to about 10m accuracy. Reliable depth sounding beyond 80m depths would be most useful. Clean AC power aboard the motor launch would be helpful.

In further studies of the Arrow Lakes meteorological stations should be established on the lake surface in well exposed locations with at least one on each lake. Meteorological data extrapolated from distant sites would appear to have limited usefulness.

Acknowledgements

Berni Claus, Environment Canada, Pacific and Yukon Region and Herb Klassen, DFO are thanked for their arrangement of financial support to this project. J. Bull and C. He are thanked for their assistance in the operation of the CTD profiler. In addition, C.He greatly assisited in the presentation of the field data.

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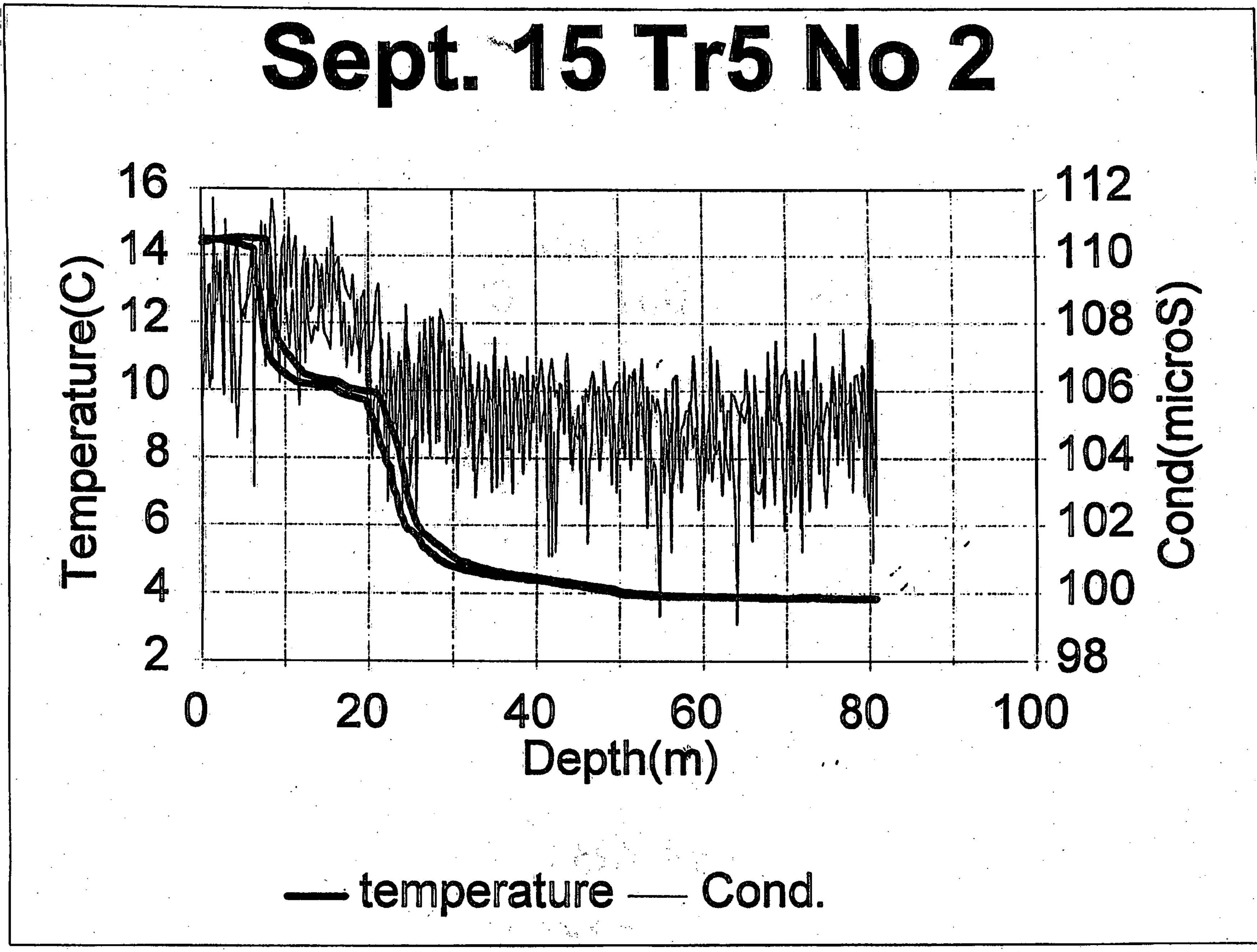
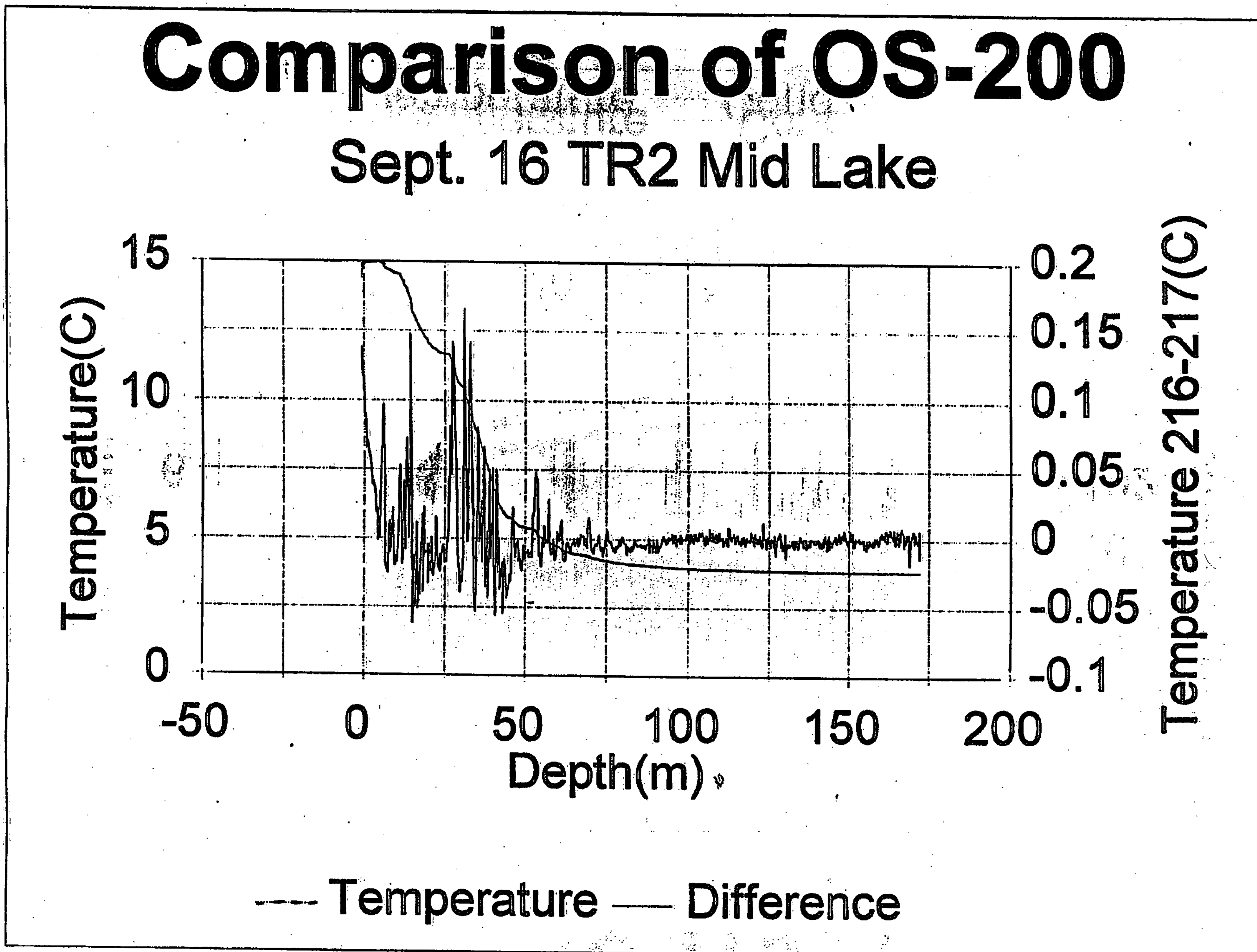
R,L&L. Environmental Services Ltd. 1977. Hugh L. Keenleyside Dam water temperature monitoring - 1996. Data report prepared for Columbia Power
Corporation. R.L. & L. Report No. 517F: 17pp. + 3 app.

List of Figure captions

1)Comparison of up-cast and down-cast temperature and conductivity traces for station S15tr5_2.
2)Comparison of temperature between two OS-200 profilers at the same location.
3) Comparison of the north-south component of wind at Castlegar with the along axis component of wind on Lower Arrow Lake, September 13, 1996.
4) Same as Figure 3 but for September 16, 1996.


Sept. 15 Tr5 No 2
Temperature(C)
16
14
12
10
8
6
4
2
112
110
108
106
104
102
100
98
Cond(microS)
0
20
40
60
80
100
Depth(m)
temperature
Cond.



Comparison of OS-200
Sept. 16 TR2 Mid Lake
15
10
5
0
Temperature(C)
0.2
0.15
0.1
0.05
0
-0.05
-0.1
Temperature 216-217(C)
-50
0
50
100
150
200
Depth(m)
Temperature
Difference

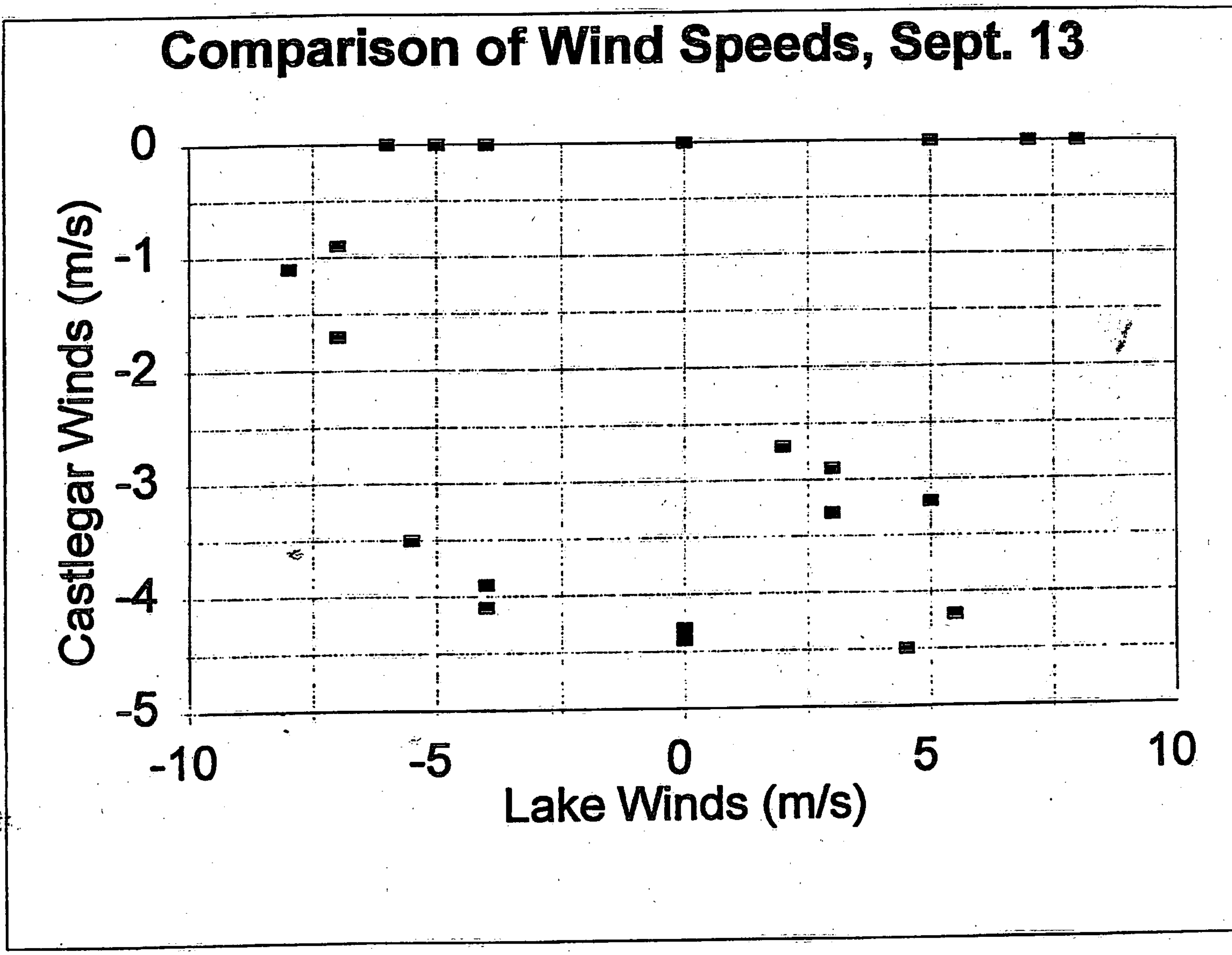

Comparison of Wind Speeds, Sept. 13
Castlegar Winds (m/s)
0
-1
-2
-3
-4
-5
-10
-5
0
5
10
Lake Winds (m/s)

FIGURE 3

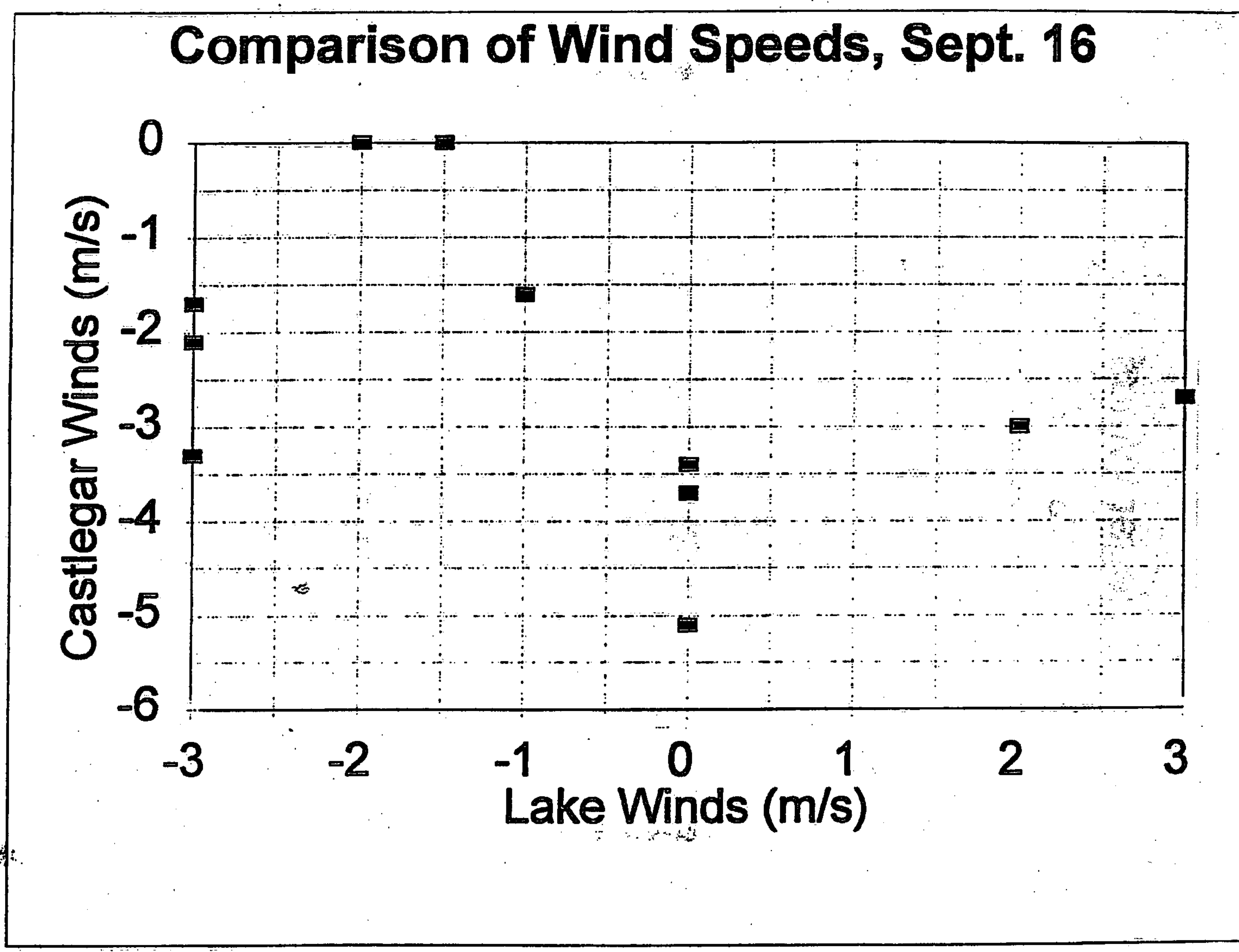
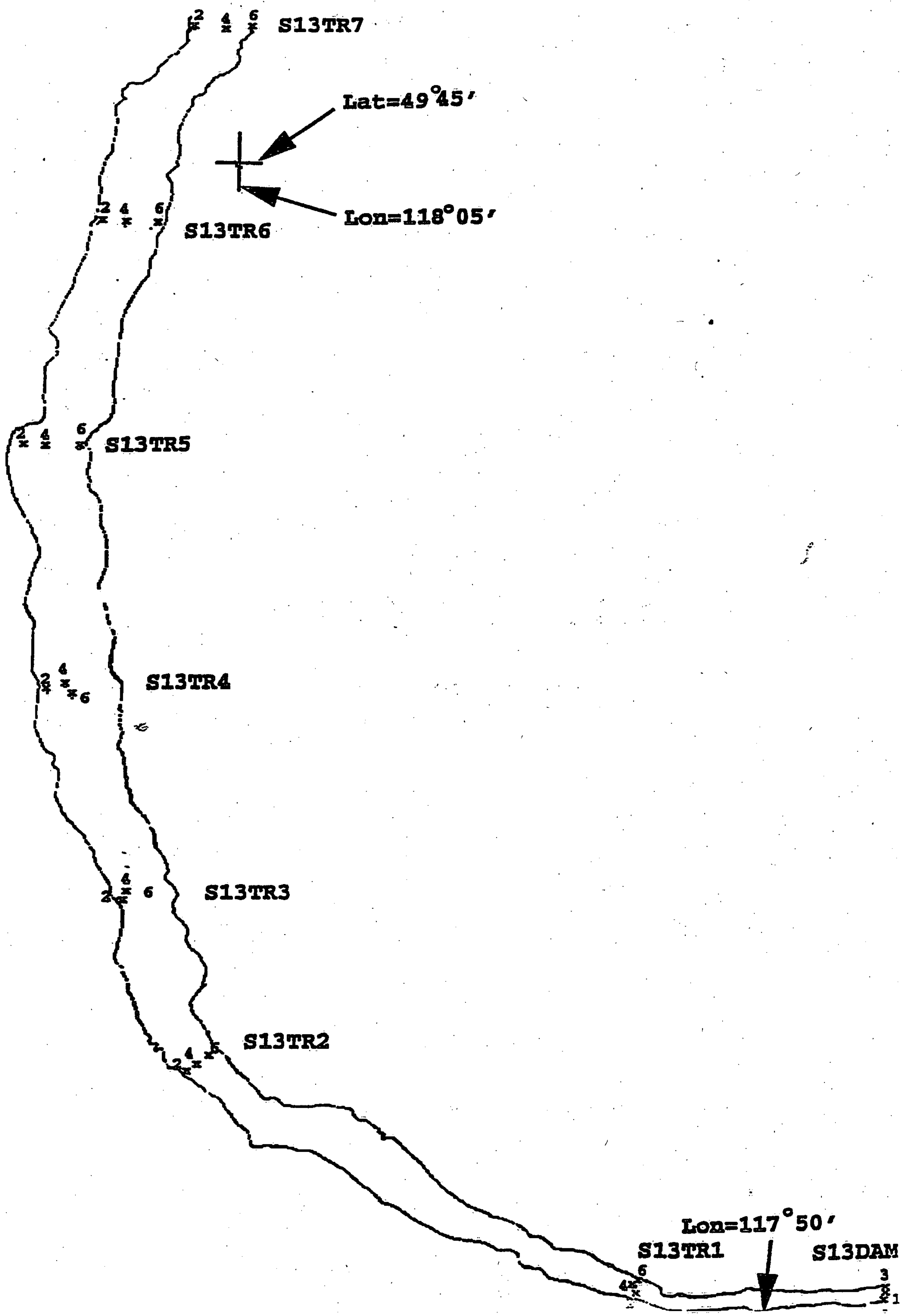
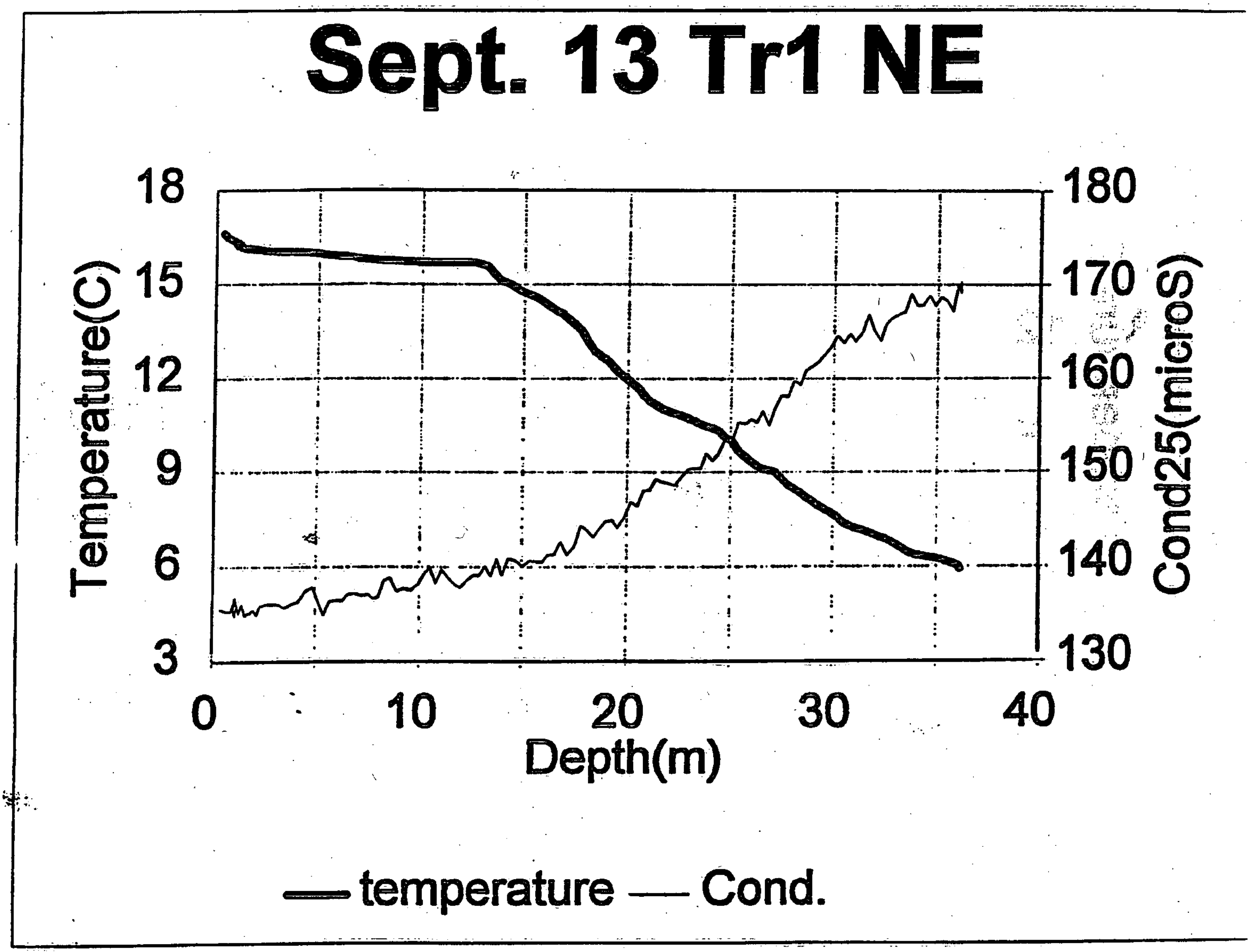

Comparison of Wind Speeds, Sept. 16
Castlegar Winds (m/s)
0
-1
-2
-3
-4
-5
-6
-3
-2
-1
0
1
2
3
Lake Winds (m/s)

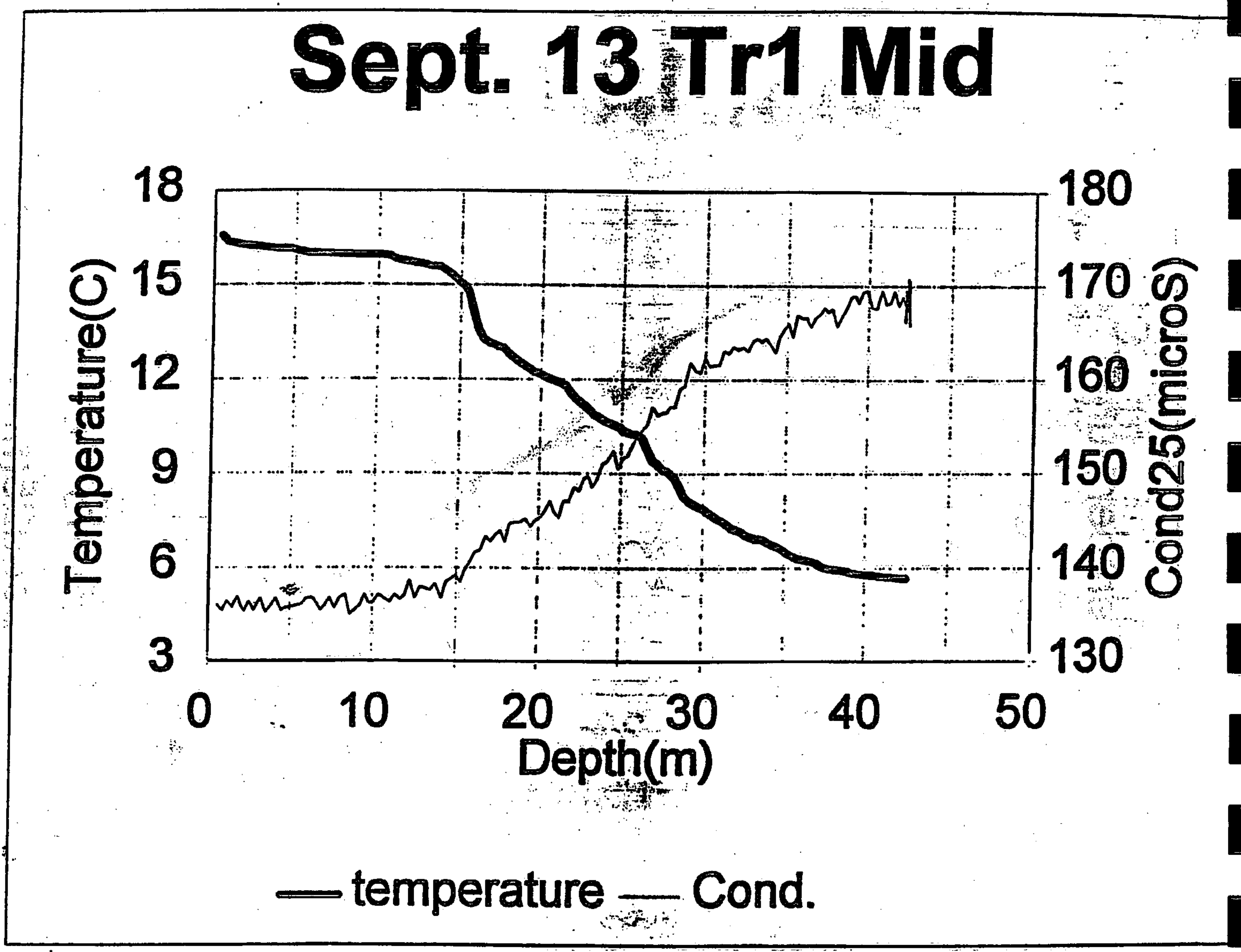
FIGURE 4

Appendix I Data collected on September 13, 1996
Lower Arrow Lake

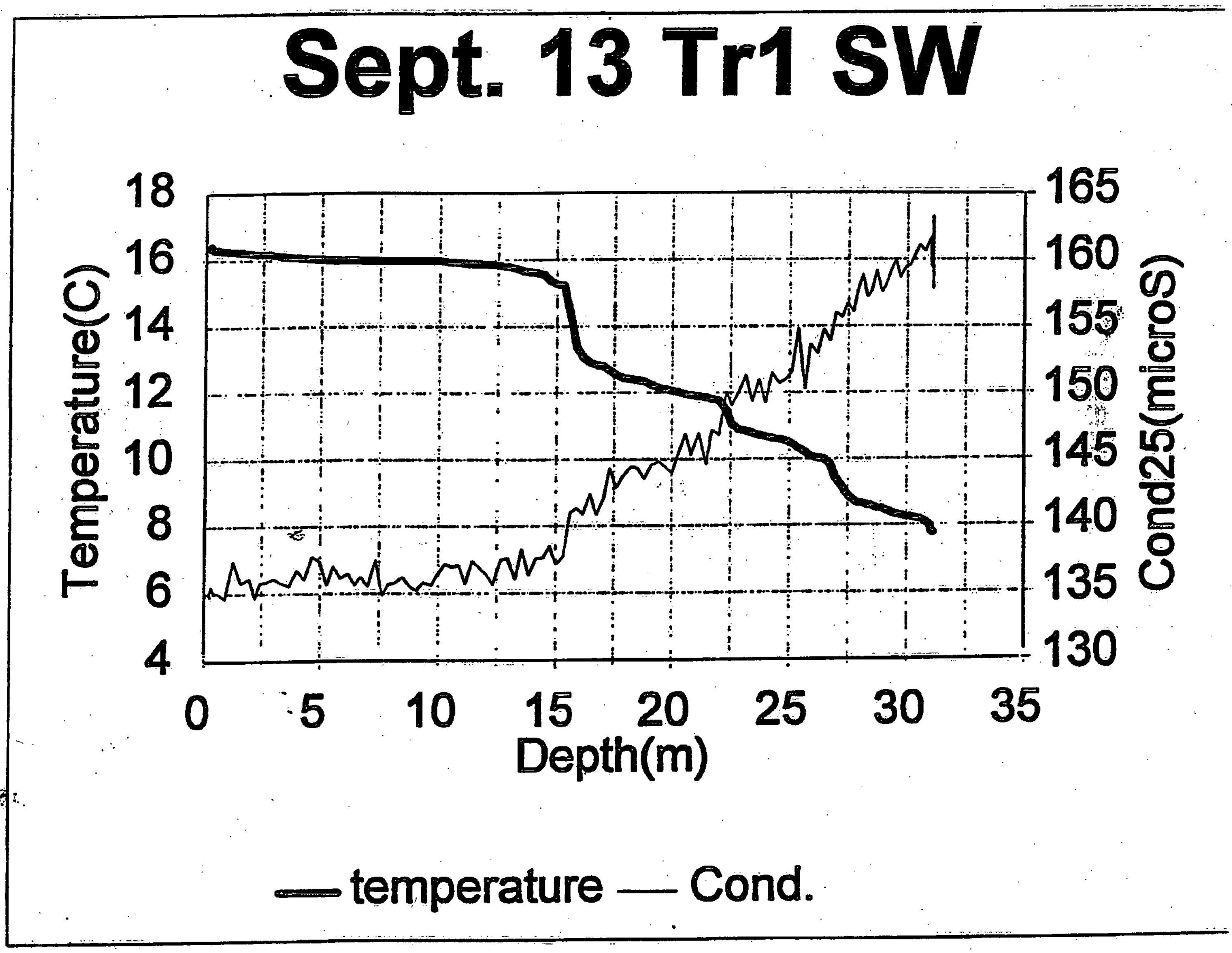

S13TR7
Lat=49°45′
Lon=118°05′
S13TR6
S13TR5
S13TR4
S13TR3
S13TR2
Lon=117°50′
S13TR1
S13DAM

Station Latitude(N) Longitude(W), TimeUCT, Wind m/s, Direction along thalweg
s10tr1_1 49 20 34.0 117 49 49. 17:40 8. West
s10tr1_2 49 20 18.0 117 49 49.
s13dam_1 49 20 24.23 117 46 26.53 19:17 Calm
s13dam_2 49 20 16.06 117 46 38. 19:49 4.0 Southeast
s13dam_3 49 20 28.51 117 39 27. 20:02 4.0 "
s13tr1_2 49 20 29.35 117 53 19.34 20:20 5.0 West
s13tr1_4 49 20 38.3 117 53 19.94 20:27 7.0 West
s13tr2_6 49 23 5.42 117 59 9.14 8.0 West
s13tr2_2 49 25 20.84 118 5 9.21 21:52 5.0 southeast
s13tr2_4 49 25 28.19 118 4 54.99 21:55 5.0 "
s13tr2_6 49 25 39.81 118 4 36.39 21:59 6.0 "
s13tr3_2 49 29 5.51 118 7 2.11 22:20 7.0 Southeast
s13tr3_4 49 29 14.11 118 6 47.26 22:35 8.0 Southeast
s13tr3_6 49 29 14.45 118 6 46.77 22:40 7.0 "
s13tr4_2 49 33 31.33 118 9 8.11 23:00 4.0 Southeasr
s13tr4_4 49 33 24.1 118 8 29.12 23:10 4.0 "
s13tr4_6 49 33 38.93 118 8 39.54 23:24 5.5 "
s13tr5_2 49 38 42.38 118 10 12.47 23:47 3.0 Northwest
s13tr5_4 49 38 40.46 118 9 31.35 23:55 2.0 "
s13tr5_6 49 38 40.86 118 8 35.49 00:03 4.5 "
s13tr6_2 49 43 37.47 118 8 36.39 00:20 calm
s13tr6_4 49 43 35.41 118 7 51.86 00:30 "
s13tr6_6 49 43 32.91 118 7 10.86 00:37 "
s13tr7_2 49 48 00.00 118 6 30.00 00:55 5.5 North
s13tr7_4 49 48 00.00 118 5 42.00 01:05 5.0 North
s13tr7_6 49 48 00.00 118 5 00.00 01: 10 3.0 North

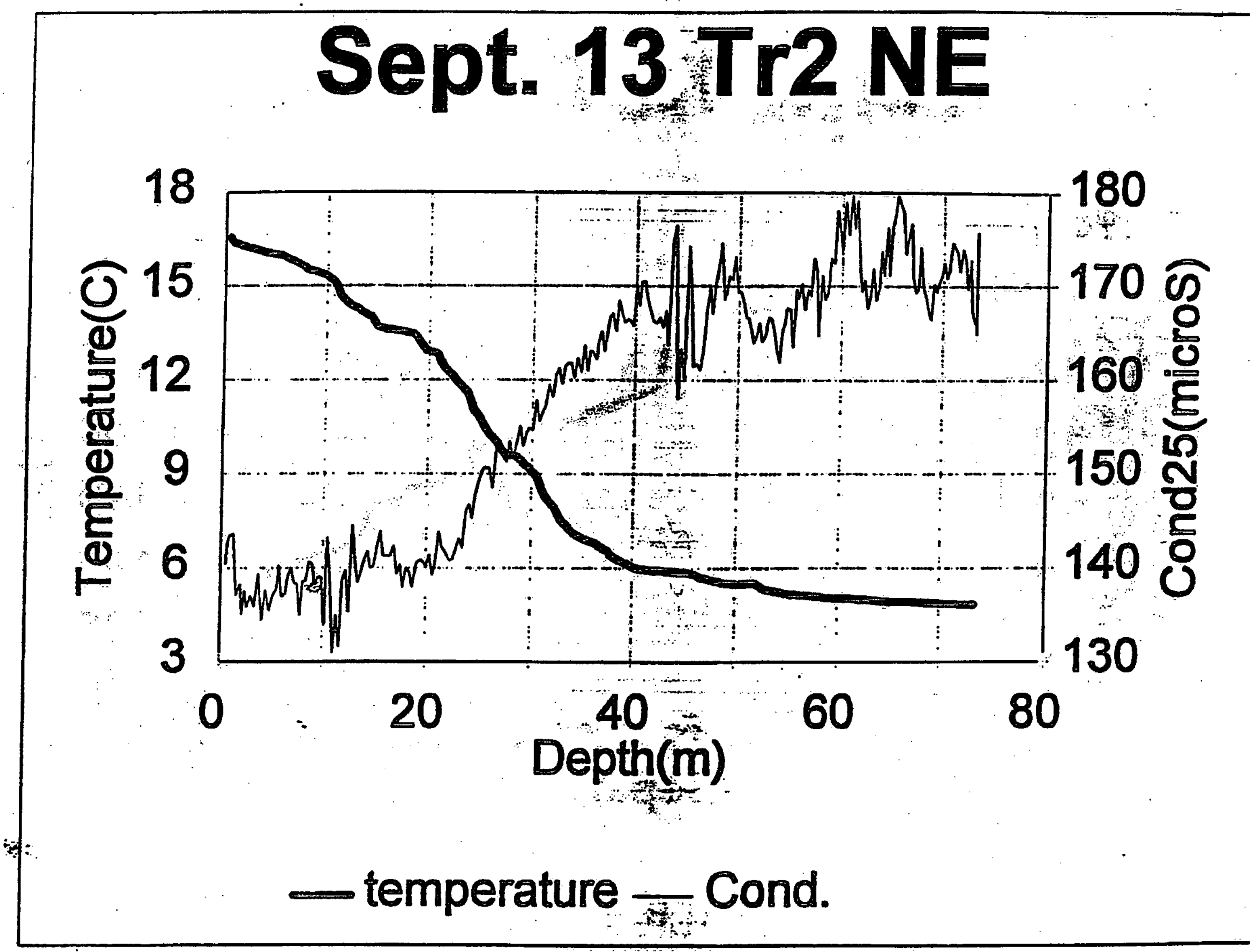

Sept. 13 Tr1 NE
Temperature(C)
Cond25(microS)
18
15
12
9
6
3
180
170
160
150
140
130
0
10
20
30
40
Depth(m)
temperature
Cond.



Sept. 13 Tr1 Mid
Temperature(C)
Cond25(microS)
18
15
12
9
6
3
180
170
160
150
140
130
0
10
20
30
40
50
Depth(m)
temperature
Cond.

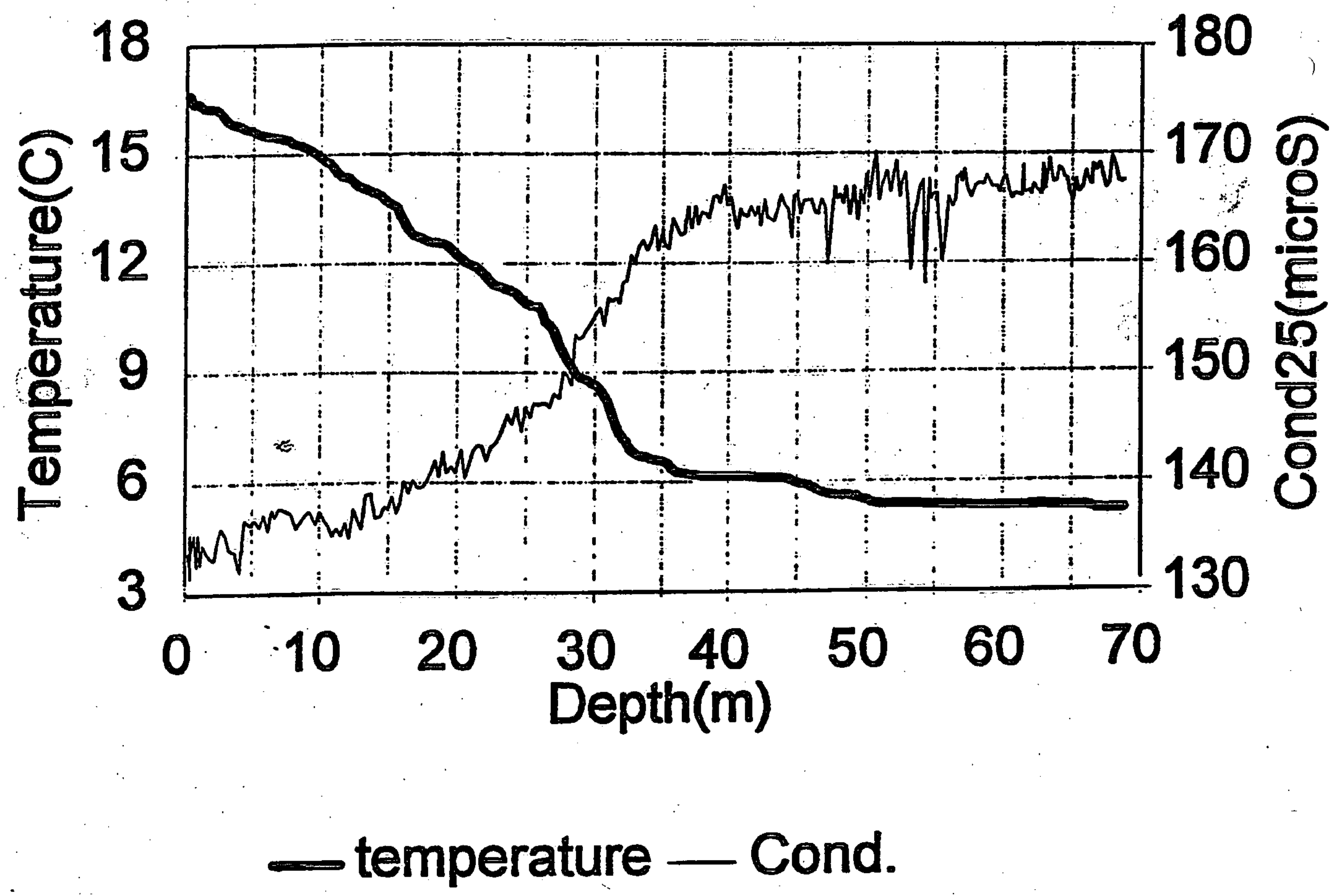


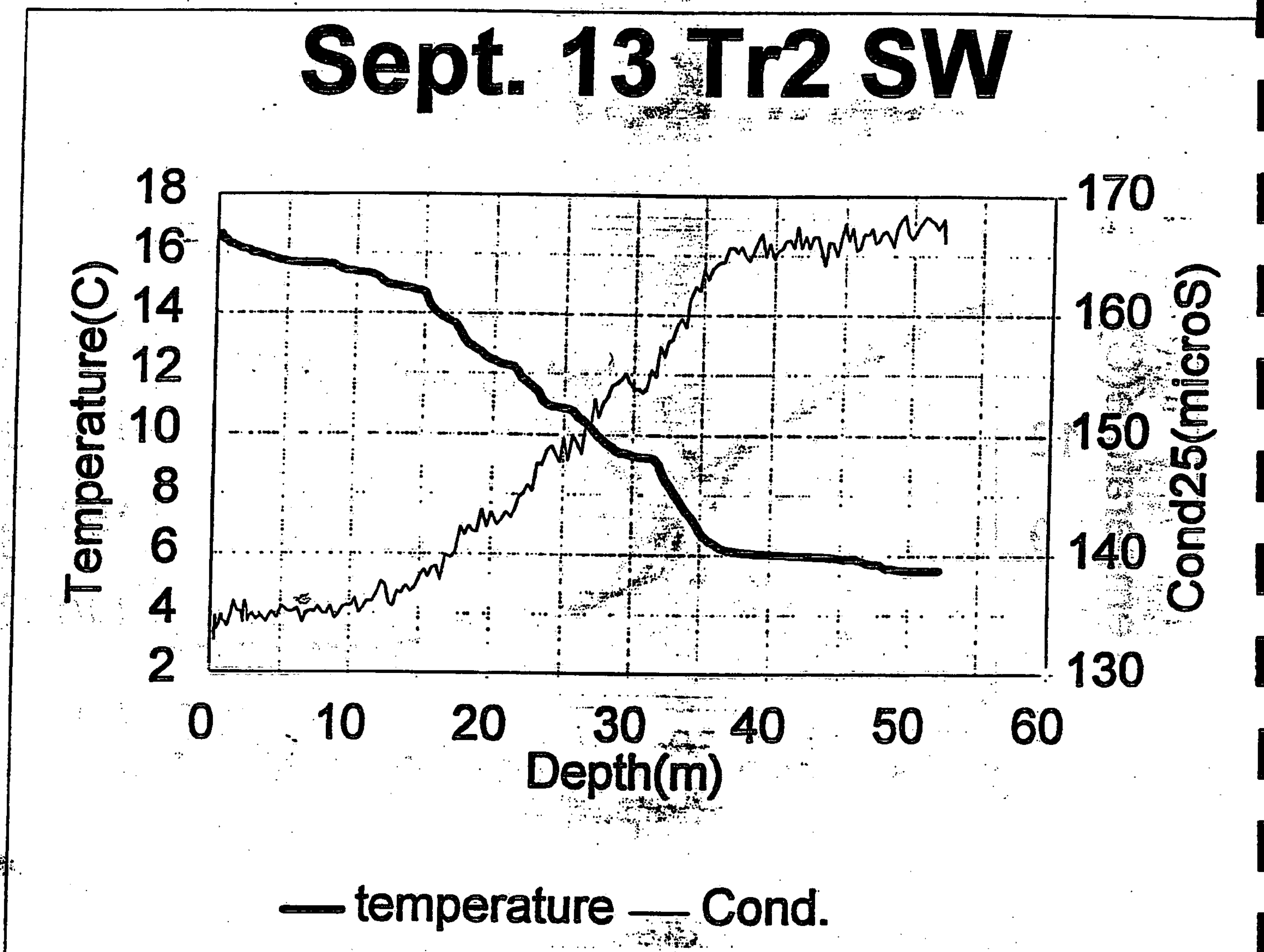
Sept. 13 Tr1 SW
18
16
14
12
10
8
6
4
Temperature(C)
165
160
155
150
145
140
135
130
Cond25(microS)
0
5
10
15
20
25
30
35
Depth(m)
temperature
Cond.

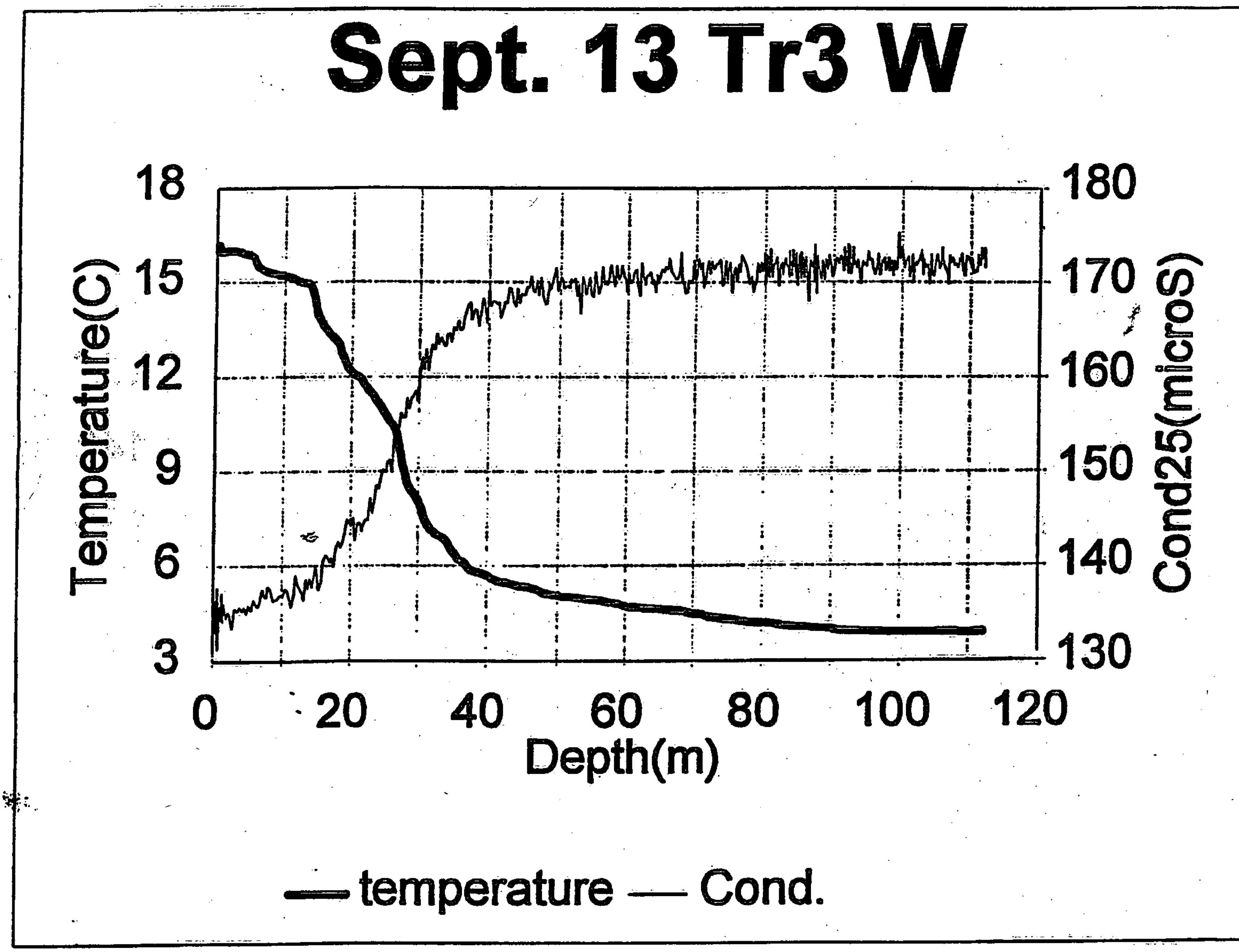


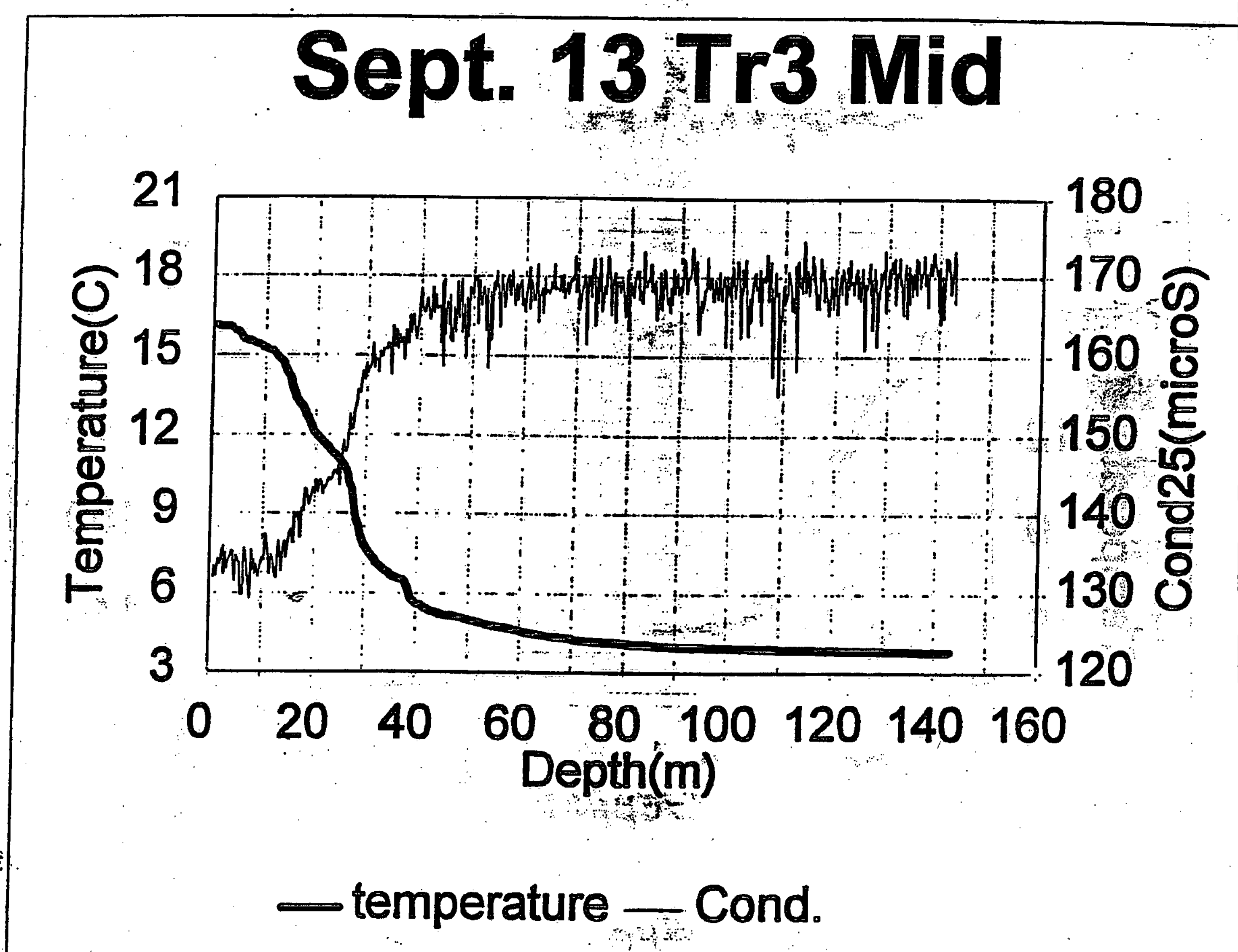
Sept. 13 Tr2 NE
18
15
12
9
6
3
Temperature(C)
180
170
160
150
140
130
Cond25(microS)
0
20
40
60
80
Depth(m)
temperature
Cond.

Sept. 13 Tr2 Mid

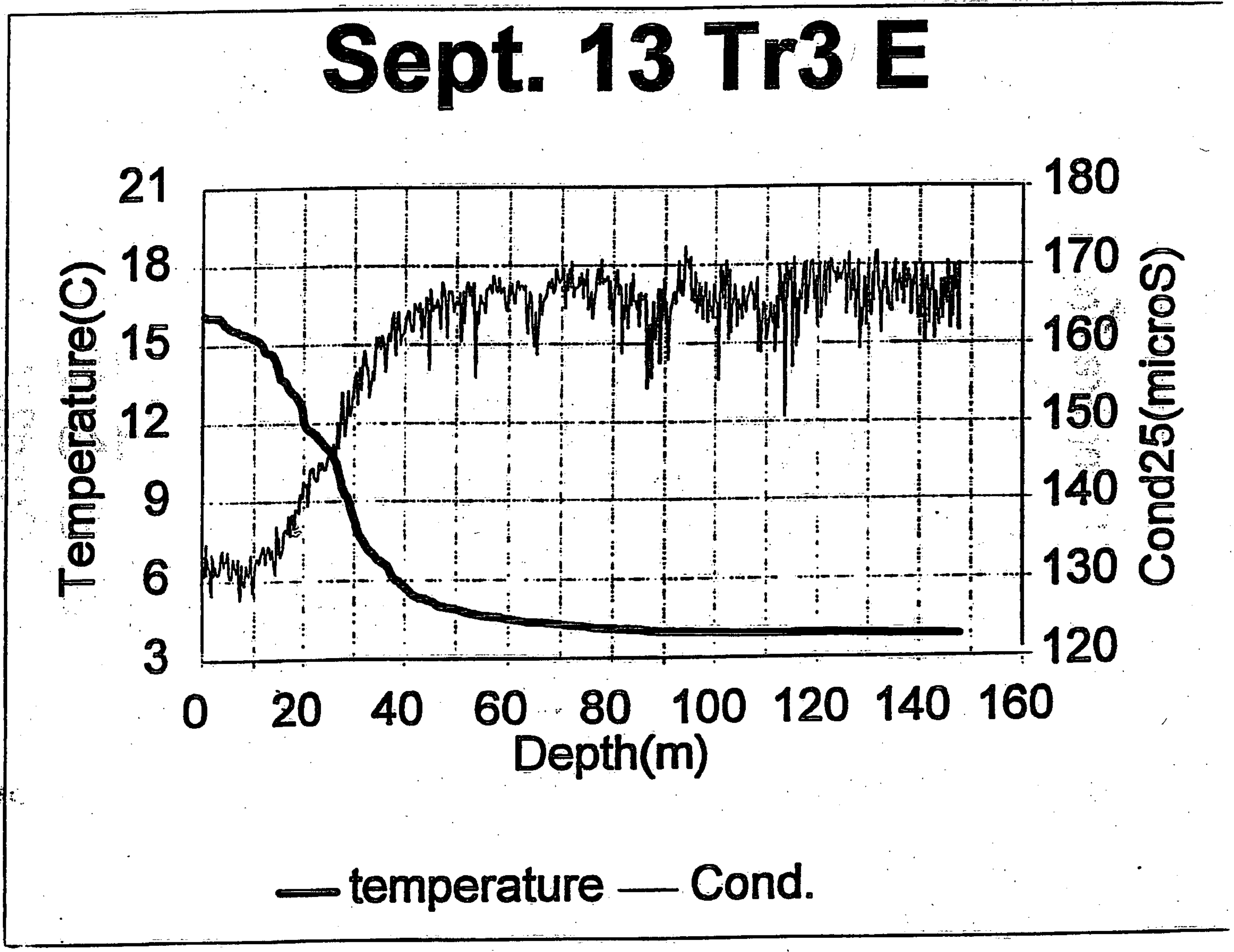



Sept. 13 Tr2 SW
Temperature(C)
18
16
14
12
10
8
6
4
2
Cond25(microS)
170
160
150
140
130
0
10
20
30
40
50
60
Depth(m)
temperature
Cond.

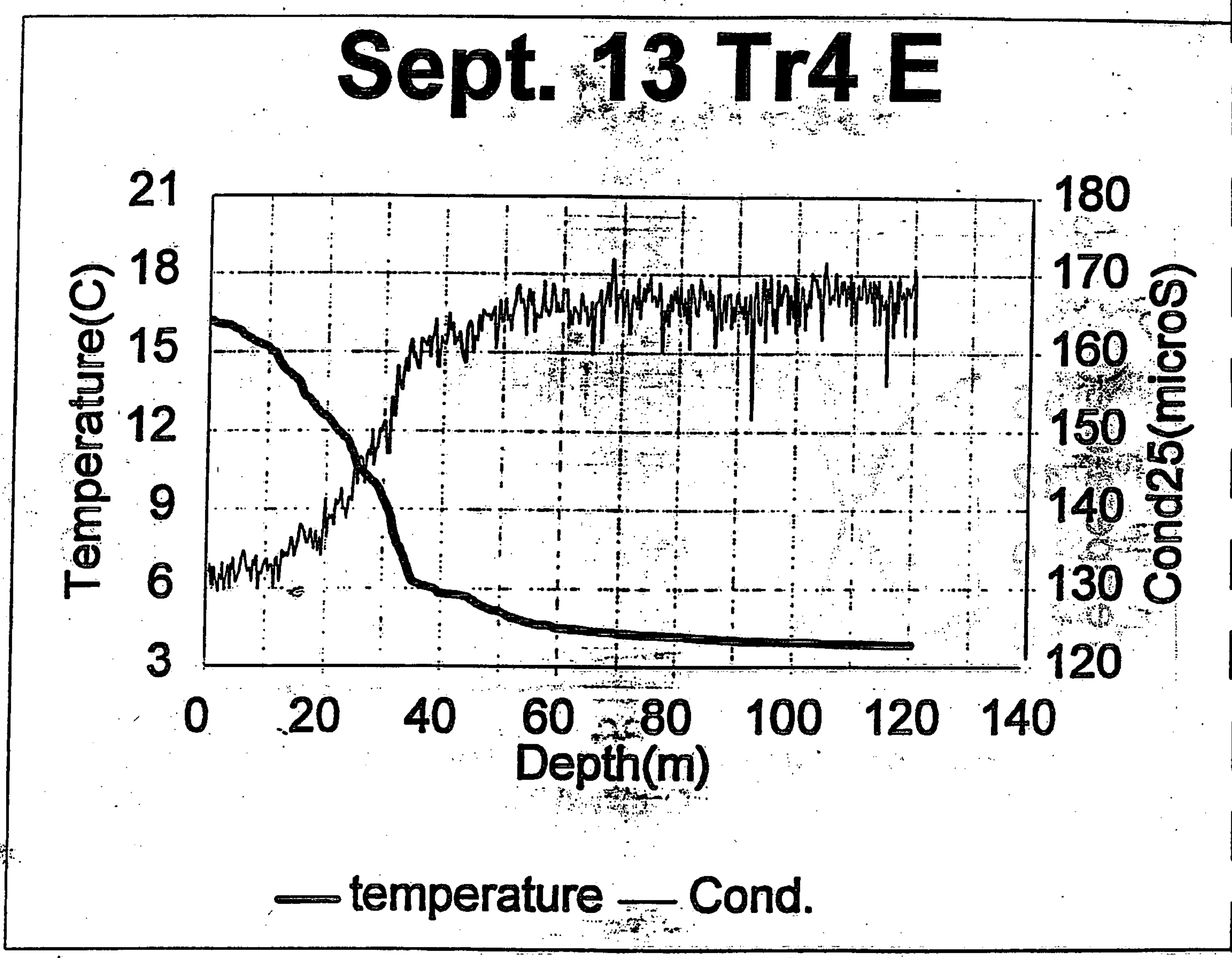

Sept. 13 Tr3 W
Temperature(C)
Cond25(microS)
Depth(m)
18
15
12
9
6
3
180
170
160
150
140
130
0
20
40
60
80
100
120
temperature
Cond.



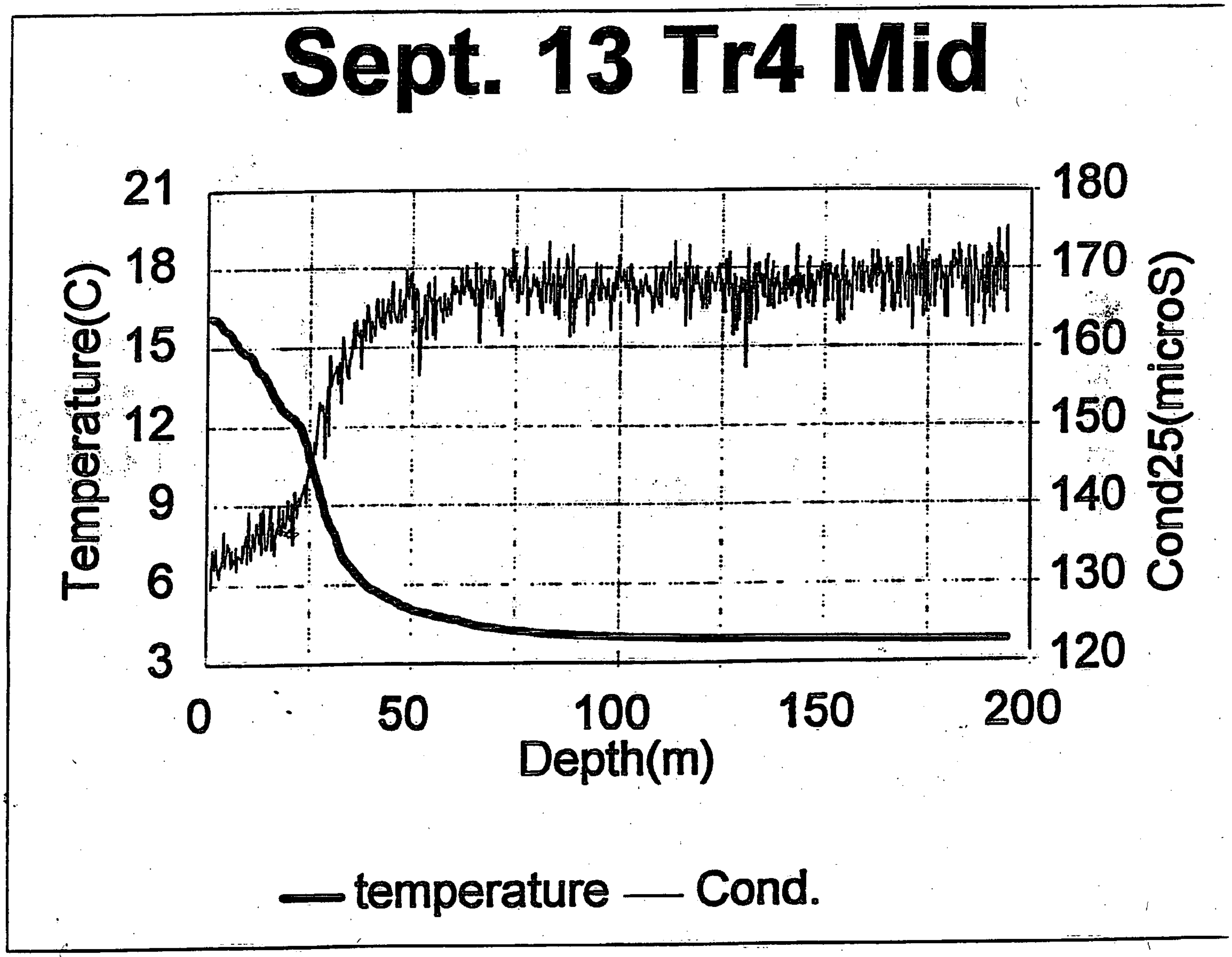
Sept. 13 Tr3 Mid
21
18
15
12
9
6
3
Temperature(C)
180
170
160
150
140
130
120
Cond25(microS)
0
20
40
60
80
100
120
140
160
Depth(m)
temperature
Cond.

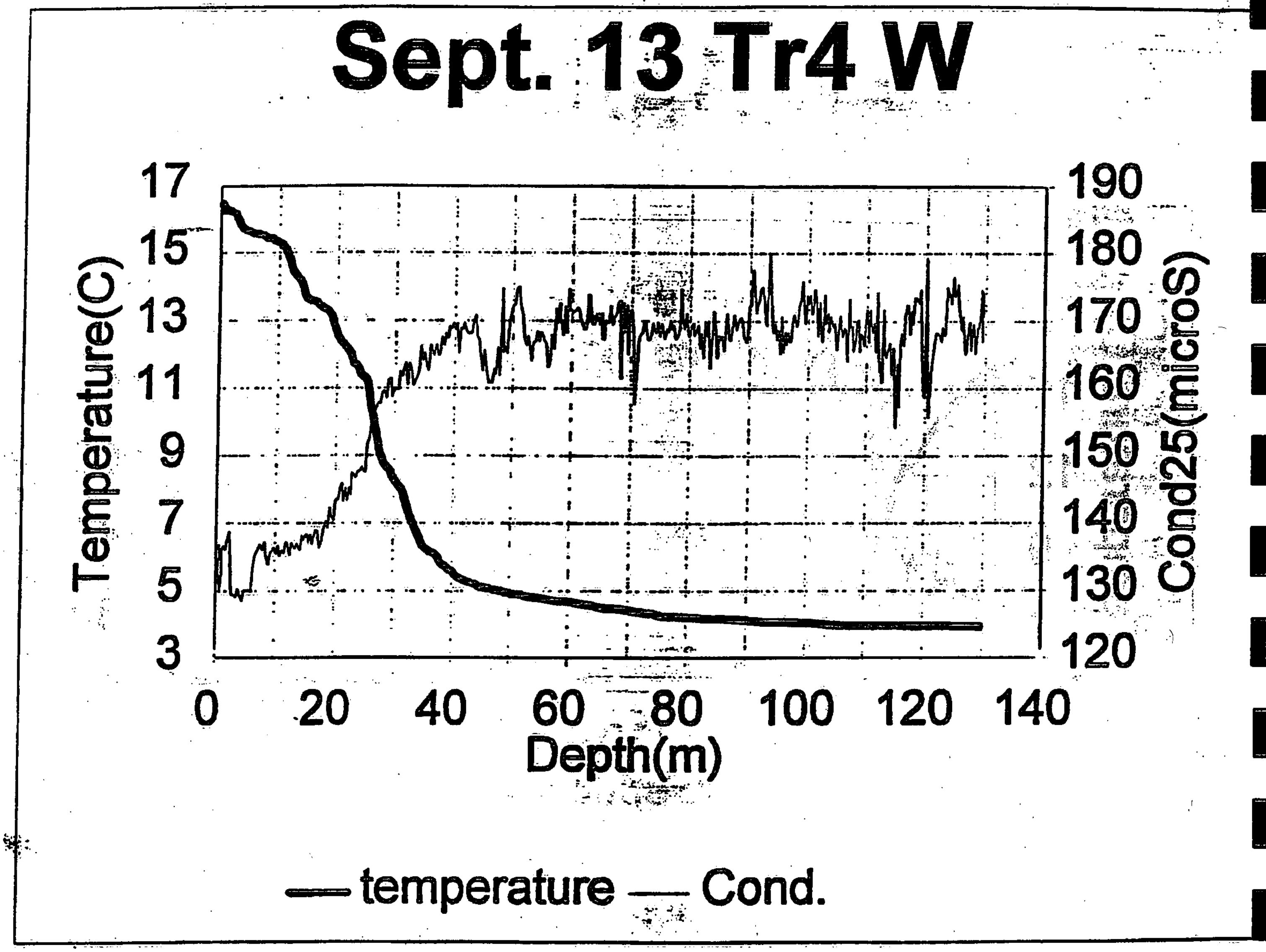


Sept. 13 Tr3 E
21
18
15
12
9
6
3
Temperature(C)
180
170
160
150
140
130
120
Cond25(microS)
0
20
40
60
80
100
120
140
160
Depth(m)
temperature
Cond.

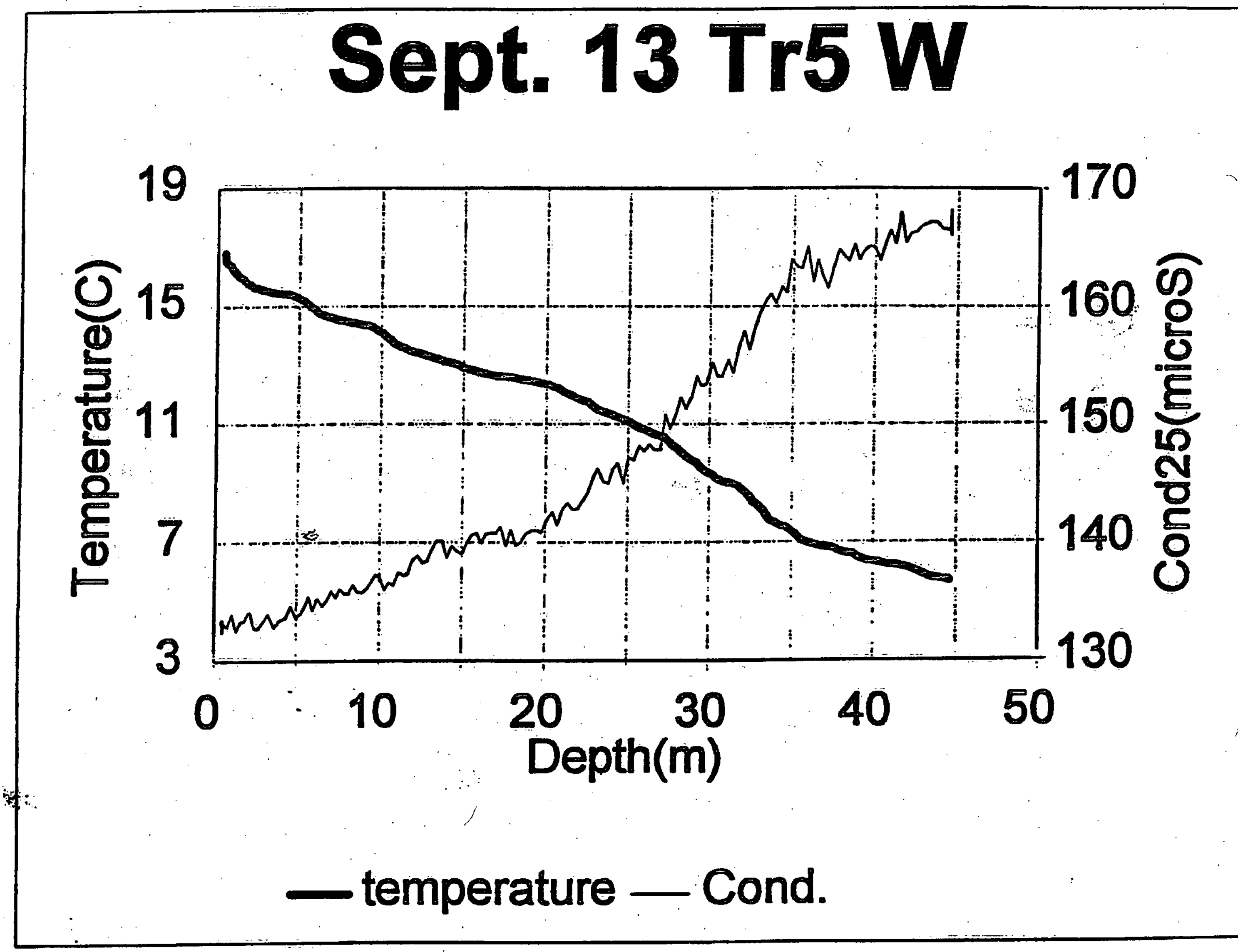


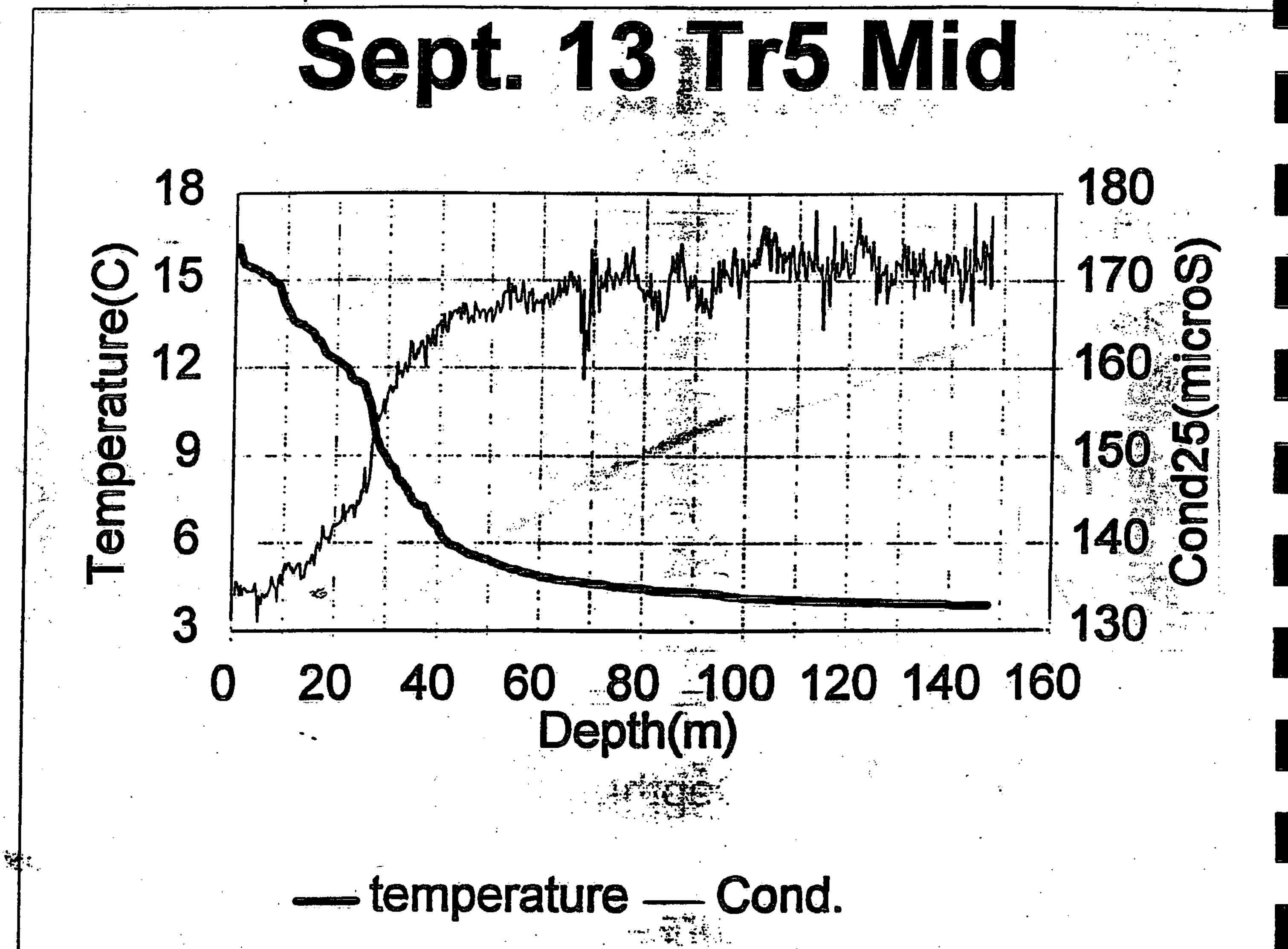
Sept. 13 Tr4 E
Temperature(C)
21
18
15
12
9
6
3
Cond25(microS)
180
170
160
150
140
130
120
0
20
40
60
80
100
120
140
Depth(m)
temperature
Cond.

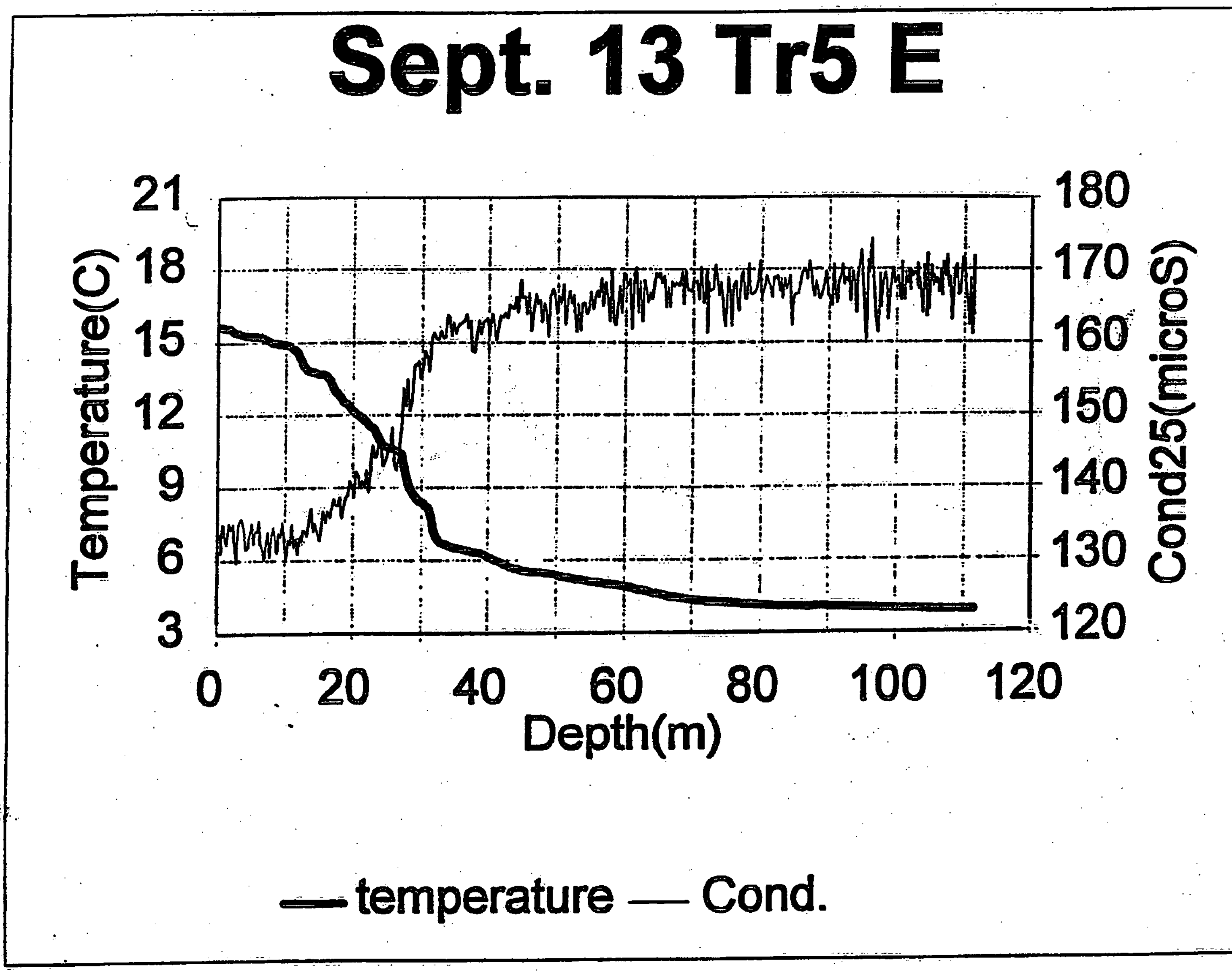

Sept. 13 Tr4 Mid
21
18
15
12
9
6
3
Temperature(C)
180
170
160
150
140
130
120
Cond25(microS)
0
50
100
150
200
Depth(m)
temperature
Cond.

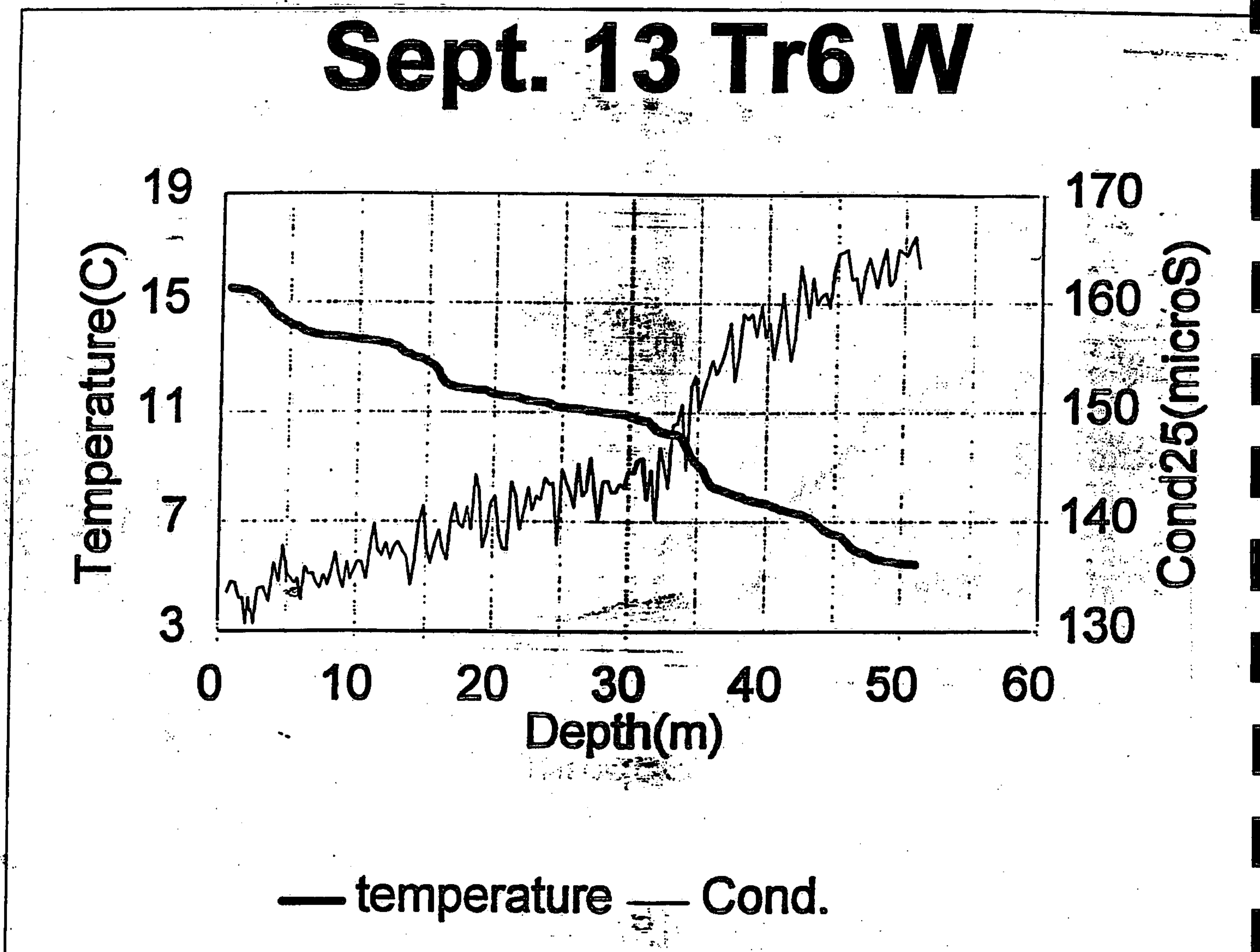


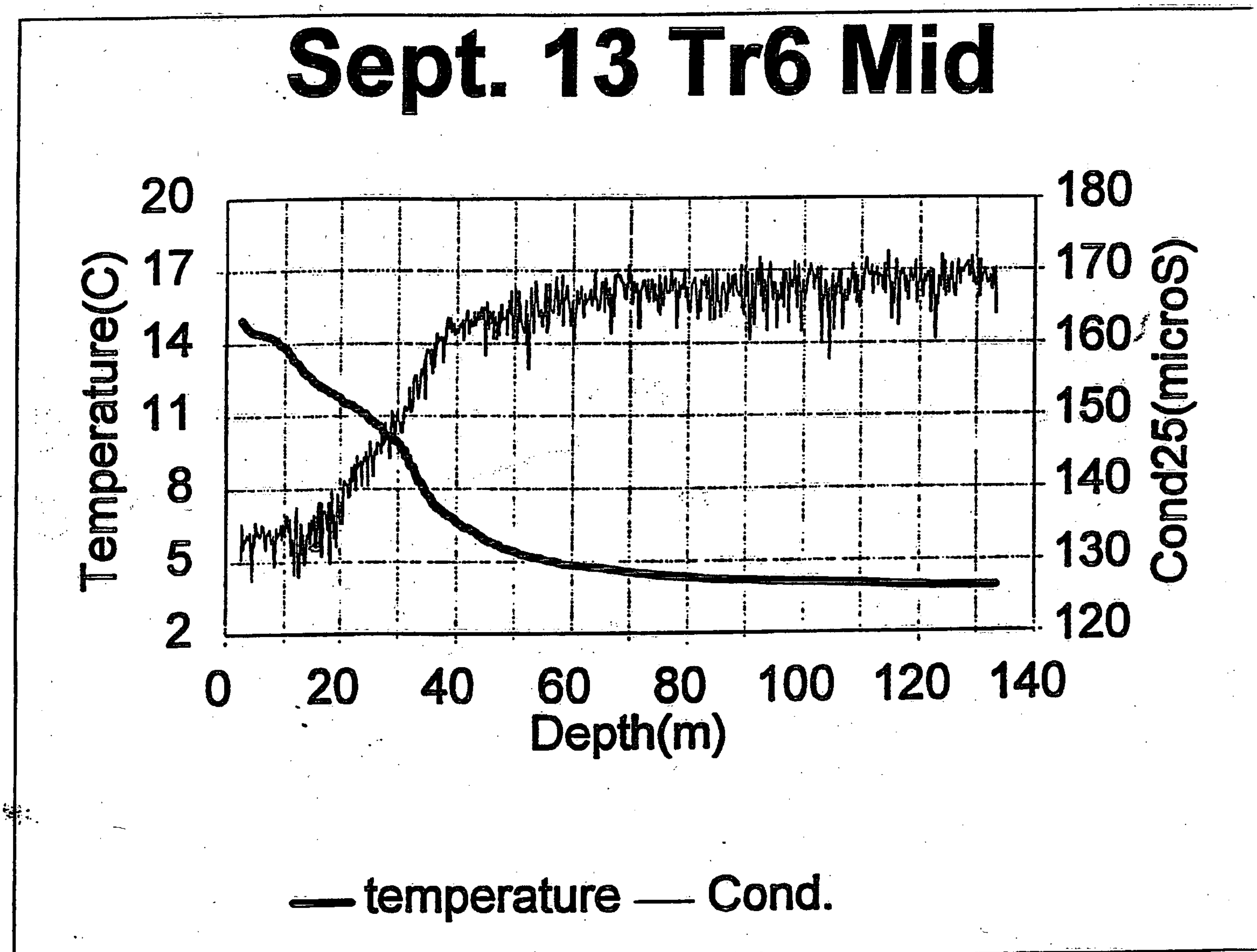
Sept. 13 Tr4 W
17
15
13
11
9
7
5
3
190
180
170
160
150
140
130
120
0
20
40
60
80
100
120
140
Depth(m)
Temperature(C)
Cond25(microS)
temperature
Cond.


Sept. 13 Tr5 W
19
15
11
7
3
Temperature(C)
170
160
150
140
130
Cond25(microS)
0
10
20
30
40
50
Depth(m)
temperature
Cond.

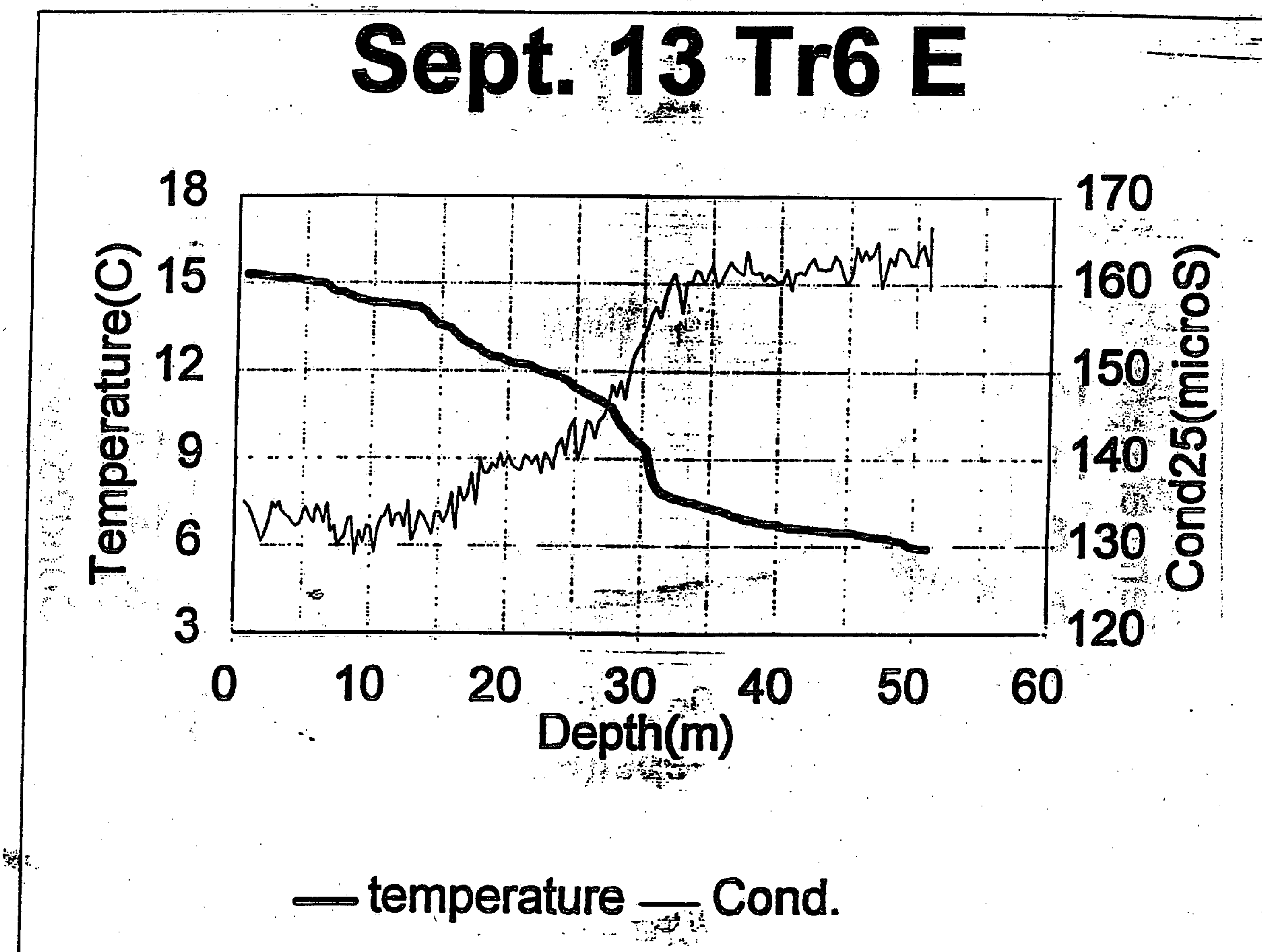

Sept. 13 Tr5 Mid
Temperature(C)
Cond25(microS)
Depth(m)
18
15
12
9
6
3
180
170
160
150
140
130
0
20
40
60
80
100
120
140
160
temperature
Cond.


Sept. 13 Tr5 E
Temperature(C)
Cond25(microS)
Depth(m)
21
18
15
12
9
6
3
180
170
160
150
140
130
120
0
20
40
60
80
100
120
temperature
Cond.

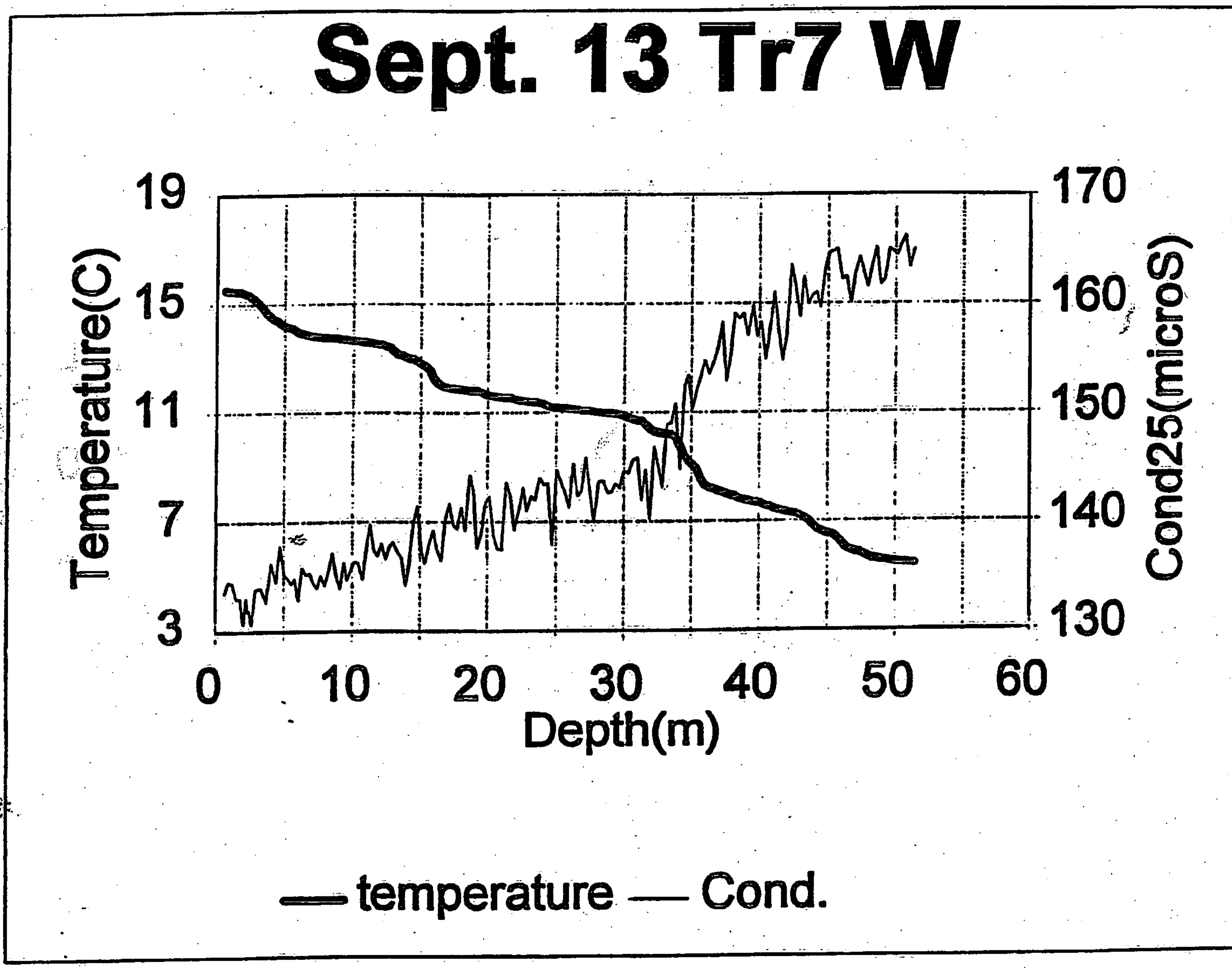

Sept. 13 Tr6 W
Temperature(C)
19
15
11
7
3
Cond25(microS)
170
160
150
140
130
0
10
20
30
40
50
60
Depth(m)
temperature
Cond.



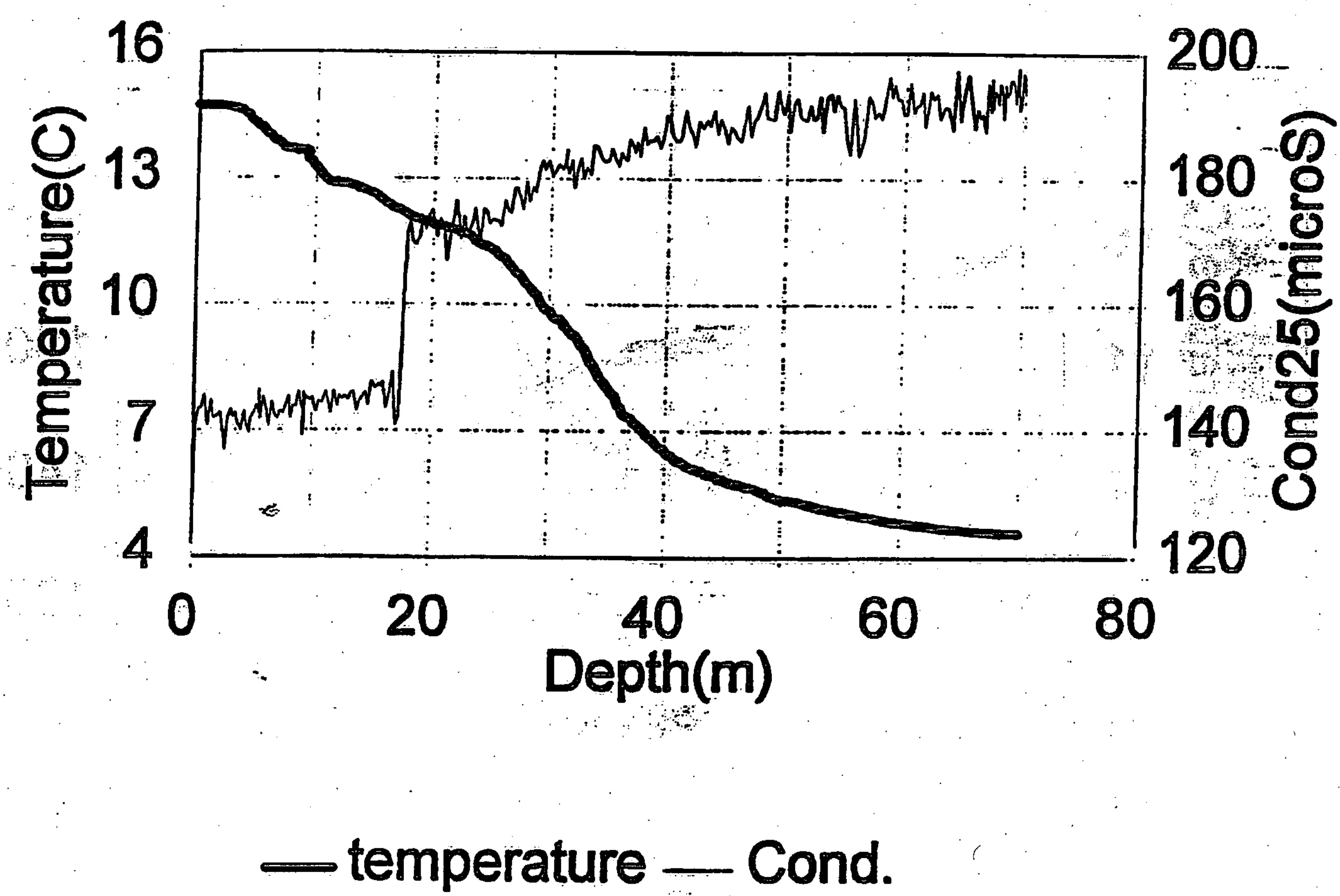
Sept. 13 Tr6 Mid
20
17
14
11
8
5
2
Temperature(C)
180
170
160
150
140
130
120
Cond25(microS)
0
20
40
60
80
100
120
140
Depth(m)
temperature
Cond.

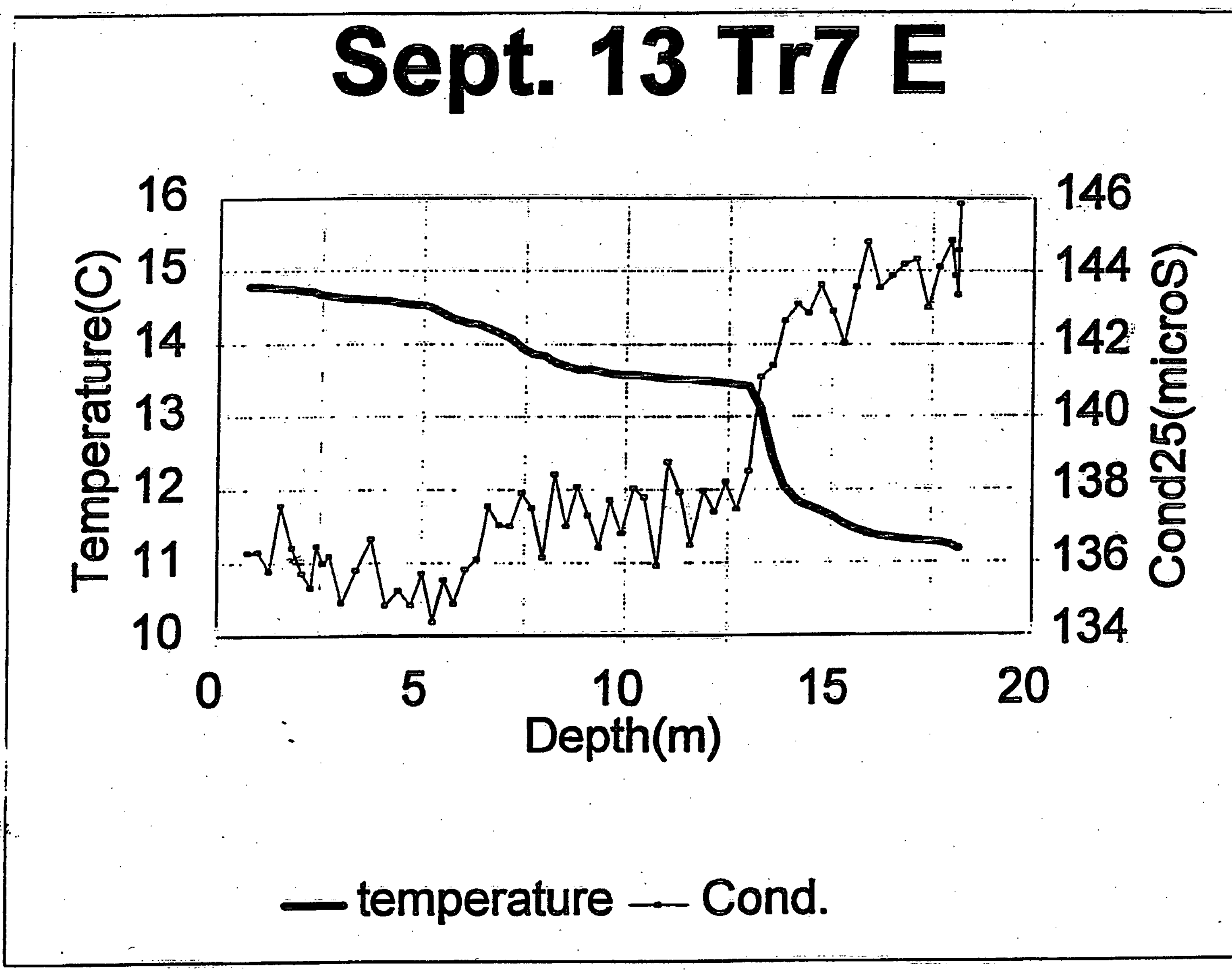


Sept. 13 Tr6 E
Temperature(C)
Cond25(microS)
18
15
12
9
6
3
170
160
150
140
130
120
0
10
20
30
40
50
60
Depth(m)
temperature
Cond.


Sept. 13 Tr7 W
19
15
11
7
3
170
160
150
140
130
Temperature(C)
Cond25(microS)
0
10
20
30
40
50
60
Depth(m)
temperature
Cond.

Sept. 13 Tr7 Mid

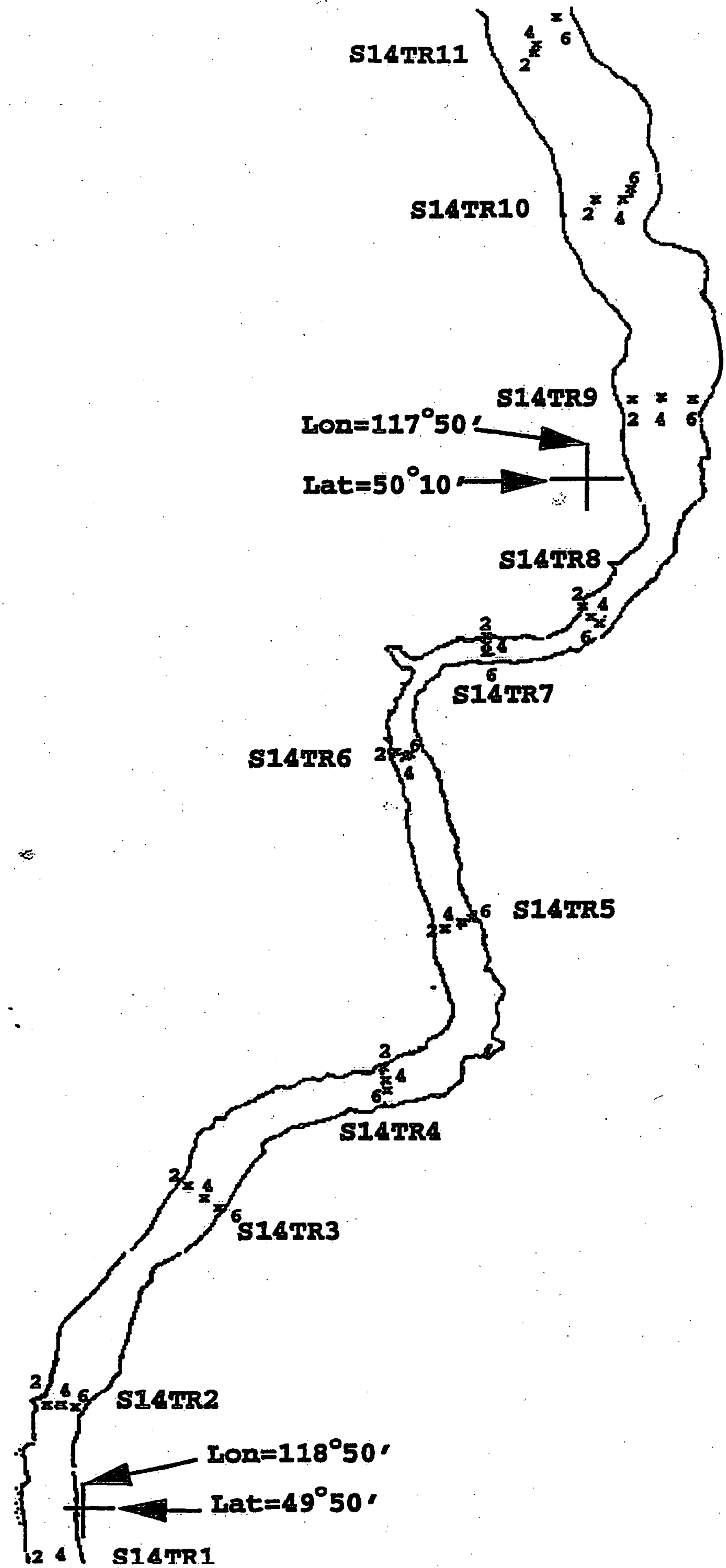




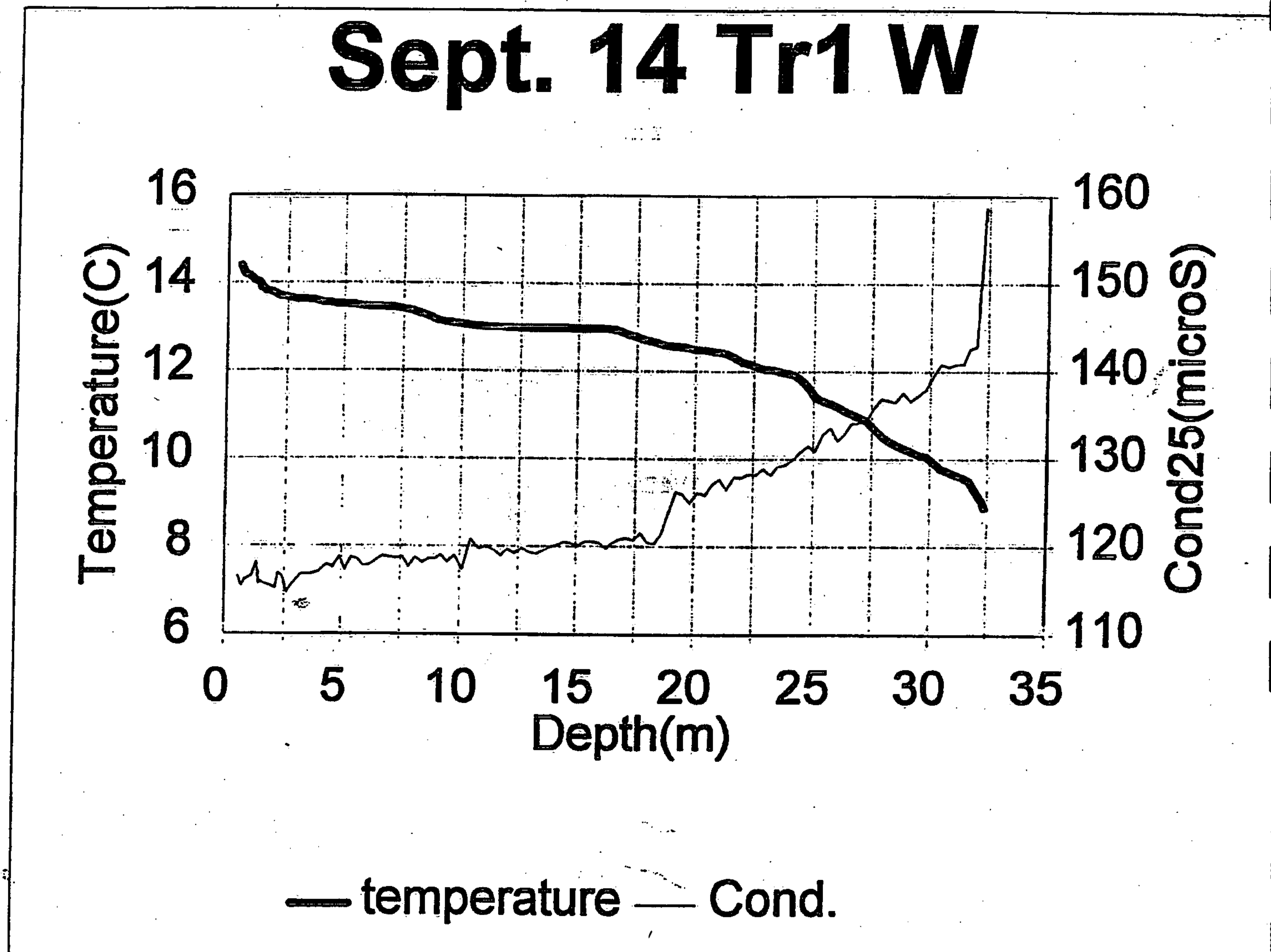
Sept. 13 Tr7 E
16
15
14
13
12
11
10
Temperature(C)
146
144
142
140
138
136
134
Cond25(microS)
0
5
10
15
20
Depth(m)
temperature
Cond.

Appendix II Data collected on September 14, 1996
Lower Arrow Lake, The Narrows Region and Upper Arrow Lake

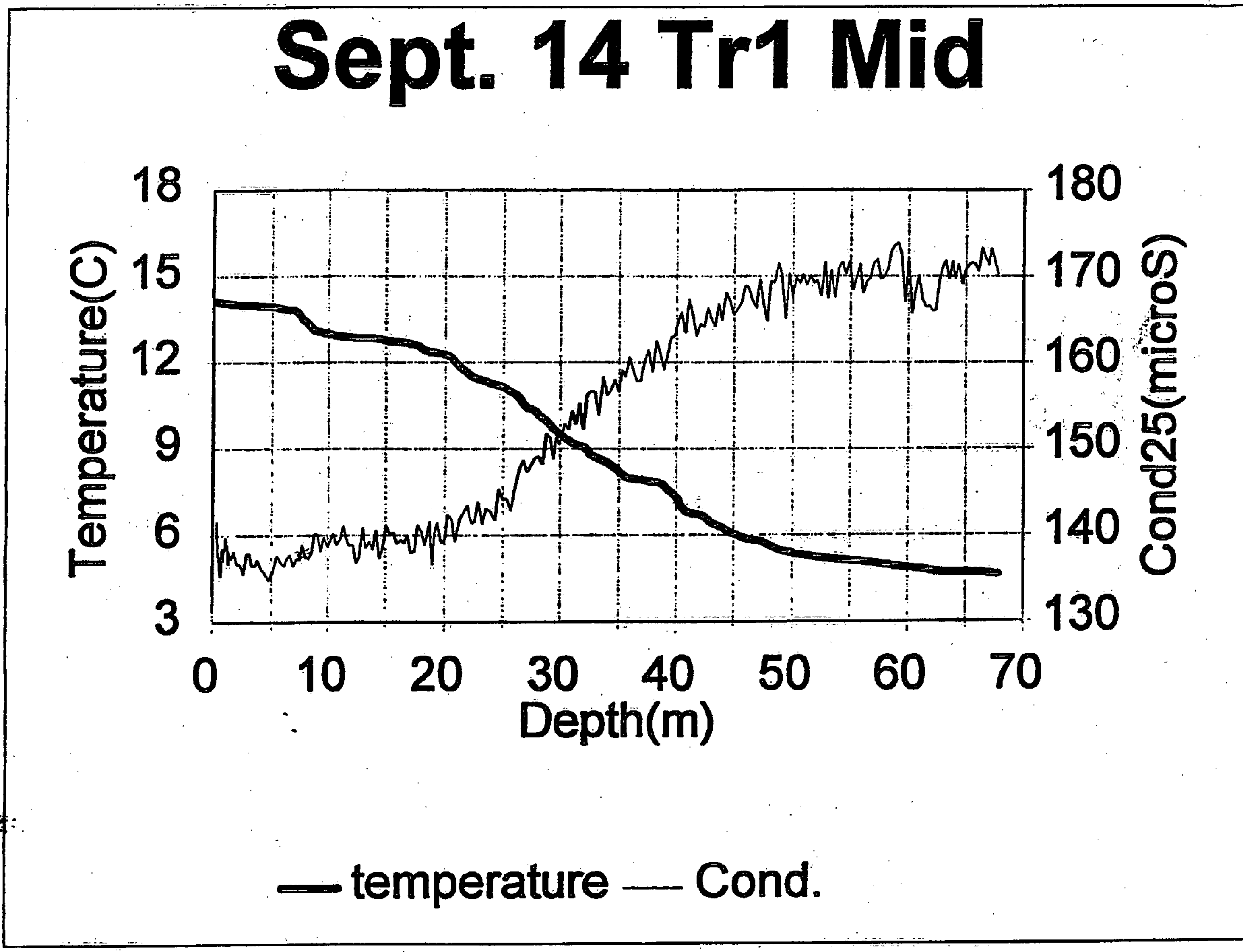
Station Latitude(N) Longitude(W), TimeUCT, Wind m/s, Direction along thalweg
s14tr1_2 49 48 25.72 118 6 22.05 19:28 9.0 Southeast
s14tr1_4 49 48 23.18 118 6 2.13 19:35 7.0 Southeast
s14tr1_6 49 48 14.3 118 5 26.77 19:38 7.5 "
s14tr2_2 49 52 5.28 118 5 37.36 19:55 10. South
s14tr2_4 49 52 3.39 118 5 32.14 20:00 10.5 "
s14tr2_6 49 52 3.3 118 5 25.5 20:05 11. "
s14tr3_2 49 56 15.06 118 1 56.65 20:20 8.5 South
s14tr3_4 49 56 1.58 118 1 26.41 20:28 8.0 "
s14tr3_6 49 55 45.85 118 1 2.02 20:34 7.5 South
s14tr4_2 49 58 23.62 117 56 27.00 20:50 13.0 South
s14tr4_4 49 58 10.82 117 56 26.82 20:53 11.0 "
s14tr4_6 49 57 50.62 117 56 22.32 21:02 9.5 South
s14tr5_2 50 1 59.49 117 54 37.91 21:18 3.0 South
s14tr5_4 50 1 8.45 117 54 15.63 21:22 4.5 "
s14tr5_6 50 1 15.00 117 54 5.19 21:27 7.0 "
s14tr6_2 50 4 29.00 117 56 9.67 21:40 1.5 North
s14tr6_4 50 4 24.75 117 55 54.15 21:47 2.0 North
s14tr6_6 50 4 25.90 117 55 46.52 21:50 2.0 North
s14tr7_2 50 6 39.54 117 53 30.41 22:01 5.0 North
s14tr7_4 50 6 30.34 117 53 25.37 22:05 6.0 "
s14tr7_6 50 6 22.76 117 53 17.4 22:10 5.0 "
s14tr8_2 50 7 15.36 117 50 38.14 22:35 6.0 North
s14tr8_4 50 7 9.75 117 50 26.02 22:42 5.0 "
s14tr8_6 50 7 6.12 117 50 4.34 22:45 4.5 West
s14tr9_2 50 11 13.68 117 49 32.47 23:00 5.5 North
s14tr9_4 50 11 14.67 117 48 39.5 23:10 7.0 North
s14tr9_6 50 11 12.97 117 47 31.6 23:15 6.5 "
s14tr10_2 50 14 48.3 117 51 30.82 23:40 5.5 North
s14tr10_4 50 15 00.96 117 50 42.29 23:50 7.0 North
s14tr10_6 50 15 9.06 117 49 39.36 23:58 7.0 North
s14tr11_2 50 17 35.26 117 53 31.27 01:10 4.0 North
s14tr11_4 50 18 00.03 117 52 41.93 01:20 3.0 "
s14tr11_6 50 17 59.86 117 52 37.8 01:30 2.0 "
s14tr11_8 50 18 37.11 117 51 58.58 01:38 2.0 "

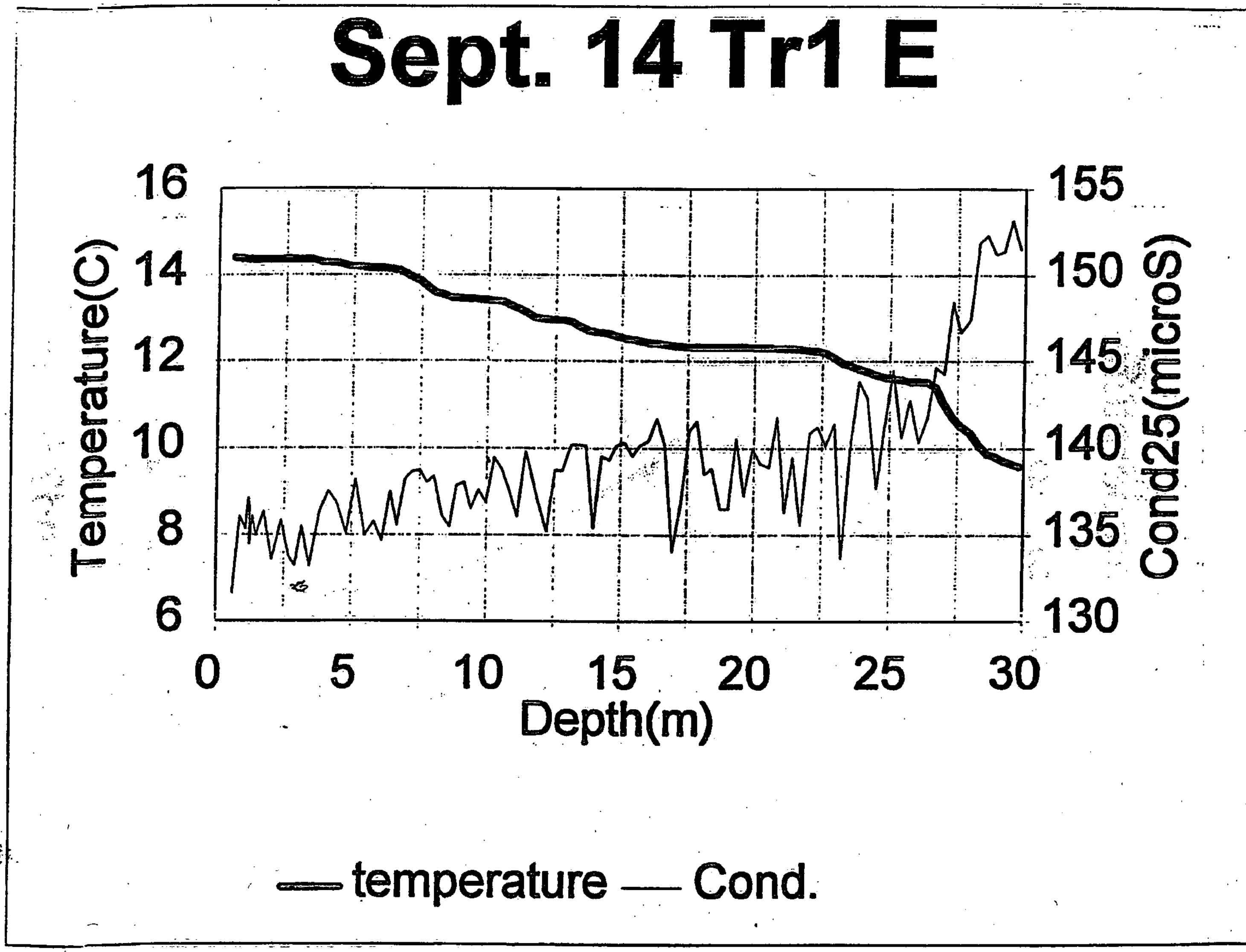


S14TR11
S14TR10
S14TR9
Lon=117°50′
Lat=50°10′
S14TR8
S14TR7
S14TR6
S14TR5
S14TR4
S14TR3
S14TR2
Lon=118°50′
Lat=49°50′
S14TR1



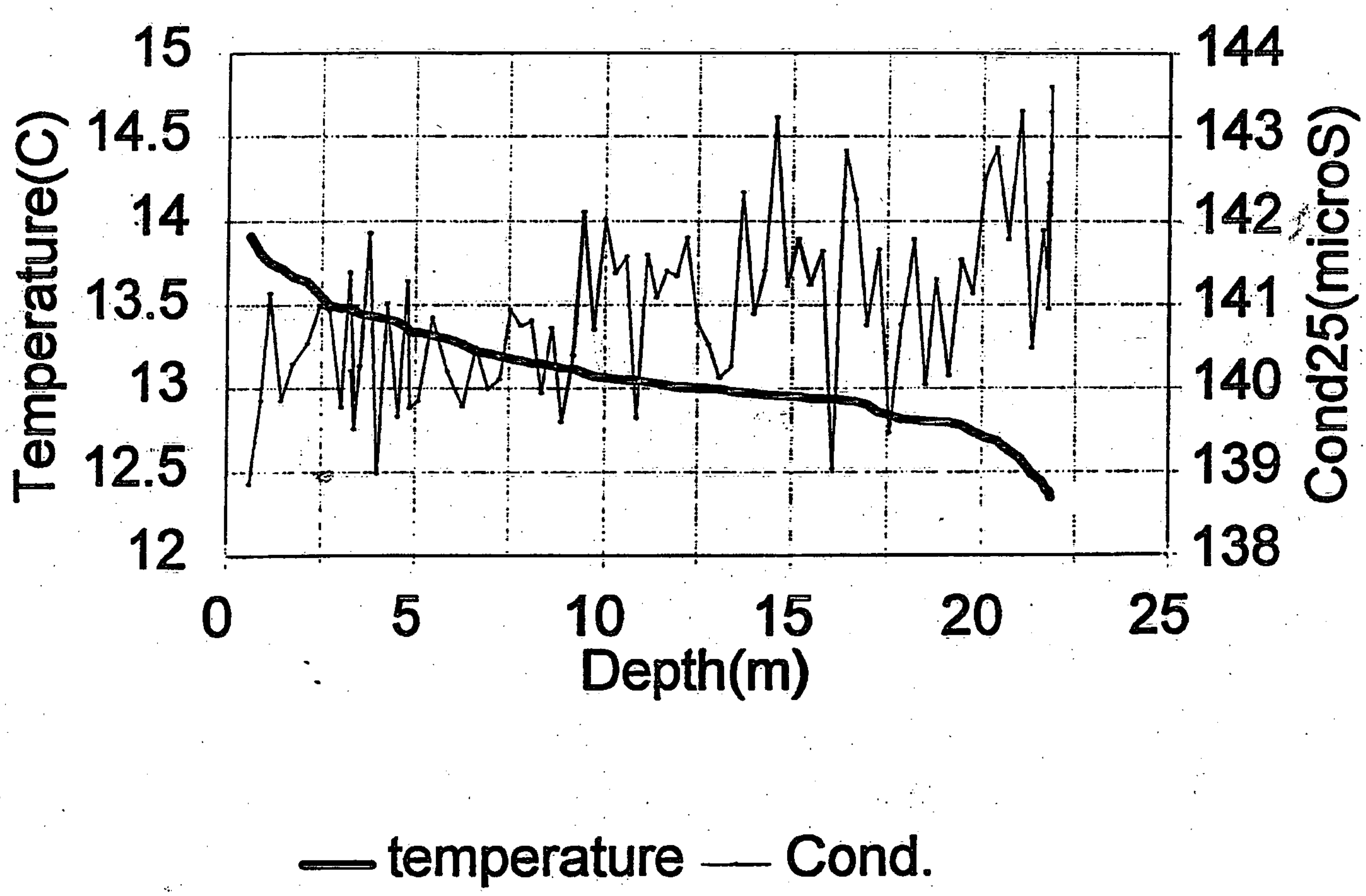
Sept. 14 Tr1 W
Temperature(C)
16
14
12
10
8
6
160
150
140
130
120
110
Cond25(microS)
0
5
10
15
20
25
30
35
Depth(m)
temperature
Cond.


Sept. 14 Tr1 Mid
Temperature(C)
18
15
12
9
6
3
Cond25(microS)
180
170
160
150
140
130
0
10
20
30
40
50
60
70
Depth(m)
temperature
Cond.

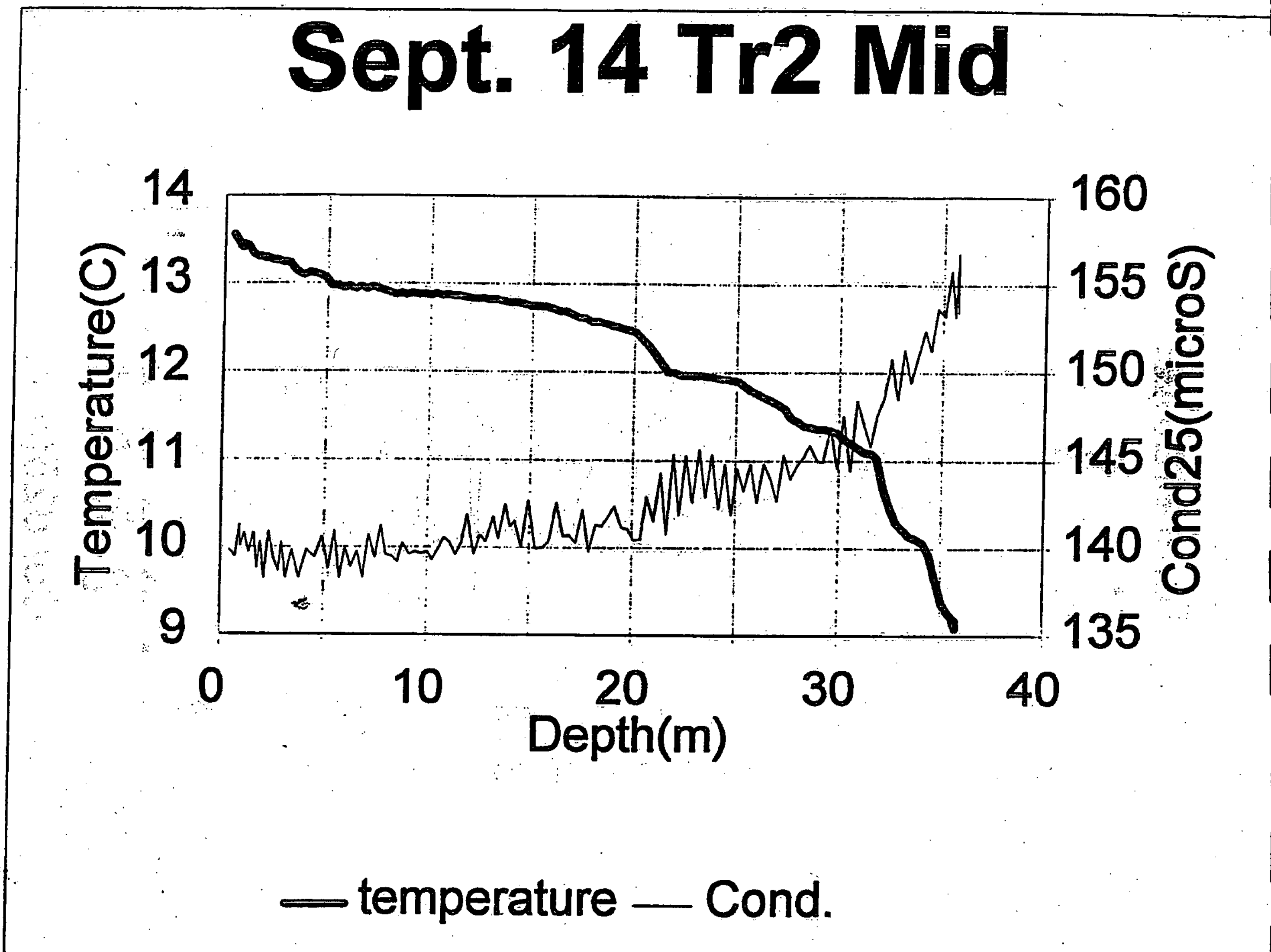


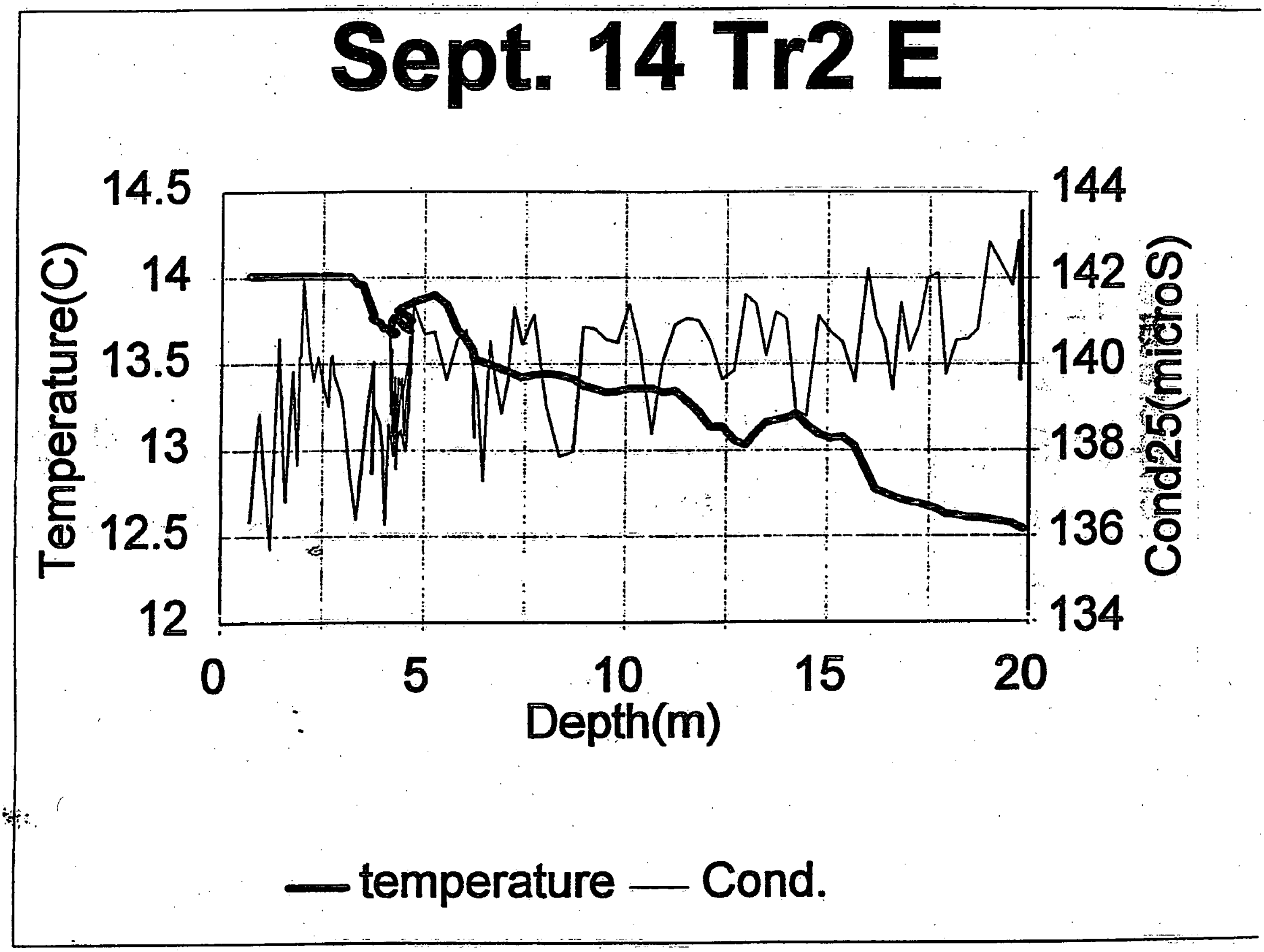
Sept. 14 Tr1 E
Temperature(C)
16
14
12
10
8
6
Cond25(microS)
155
150
145
140
135
130
0
5
10
15
20
25
30
Depth(m)
temperature
Cond.

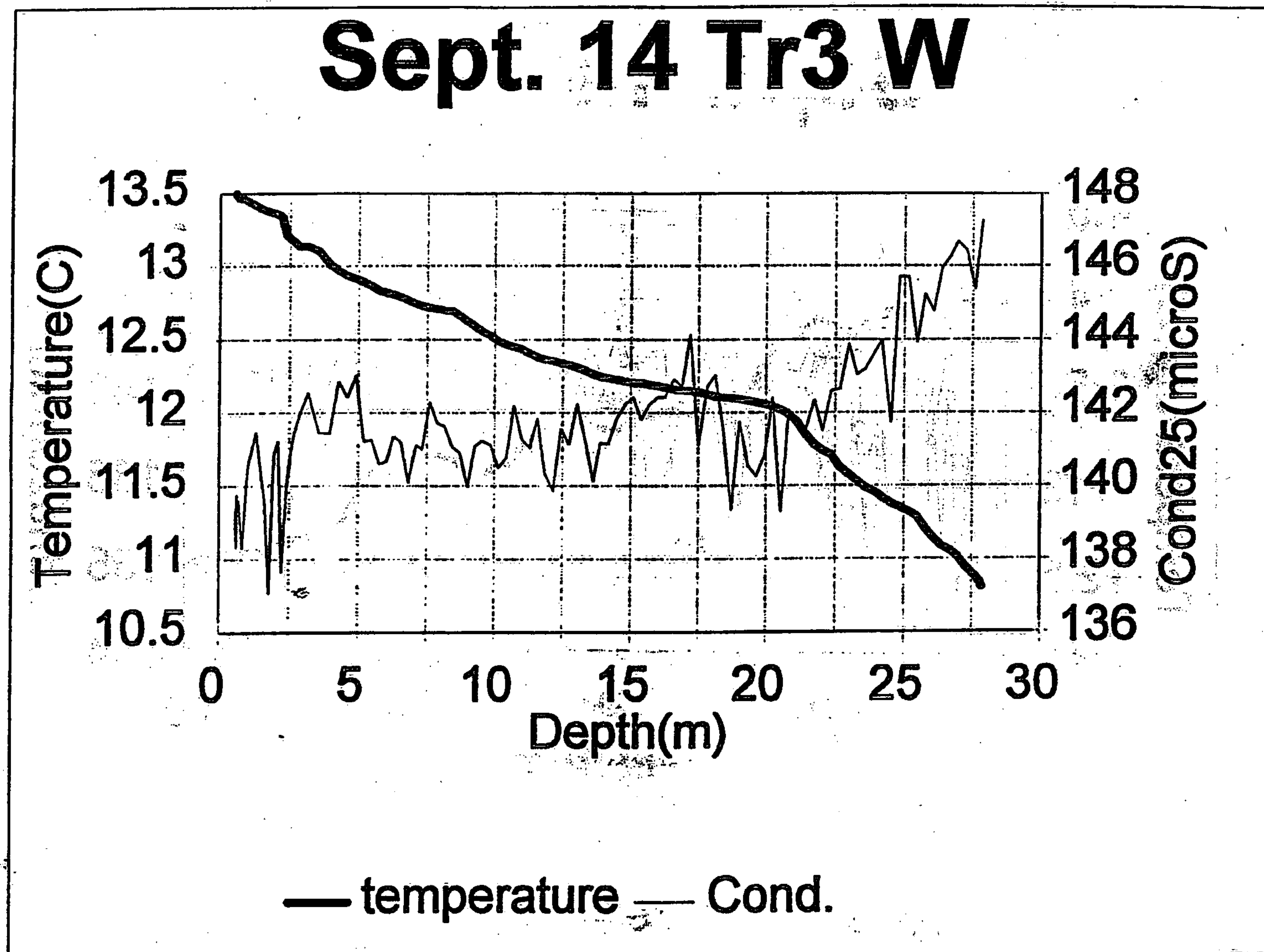
Sept. 14 Tr2 W



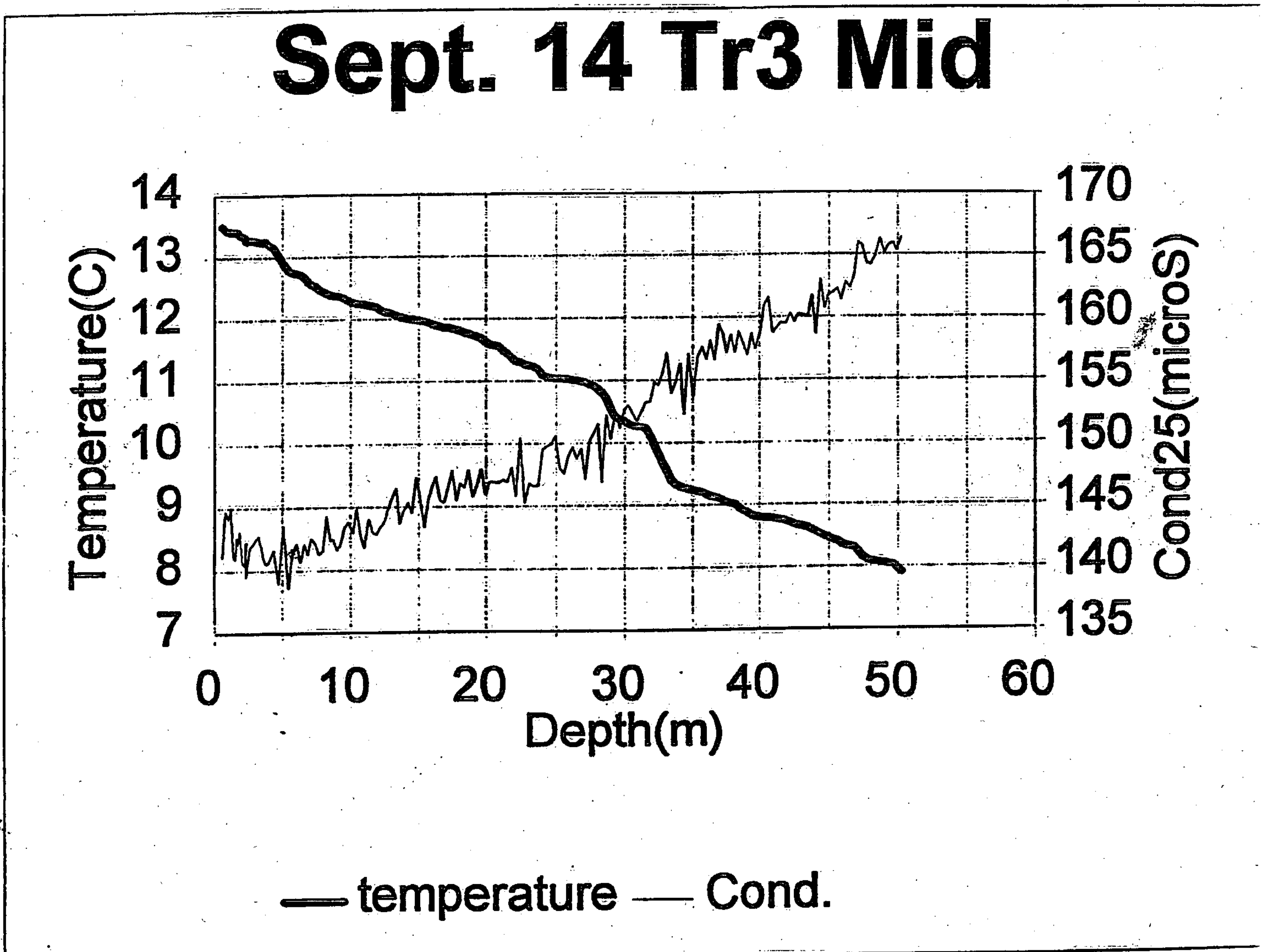
15
14.5
14
13.5
13
12.5
12
Temperature(C)
144
143
142
141
140
139
138
Cond25(microS)
0
5
10
15
20
25
Depth(m)
temperature
Cond.

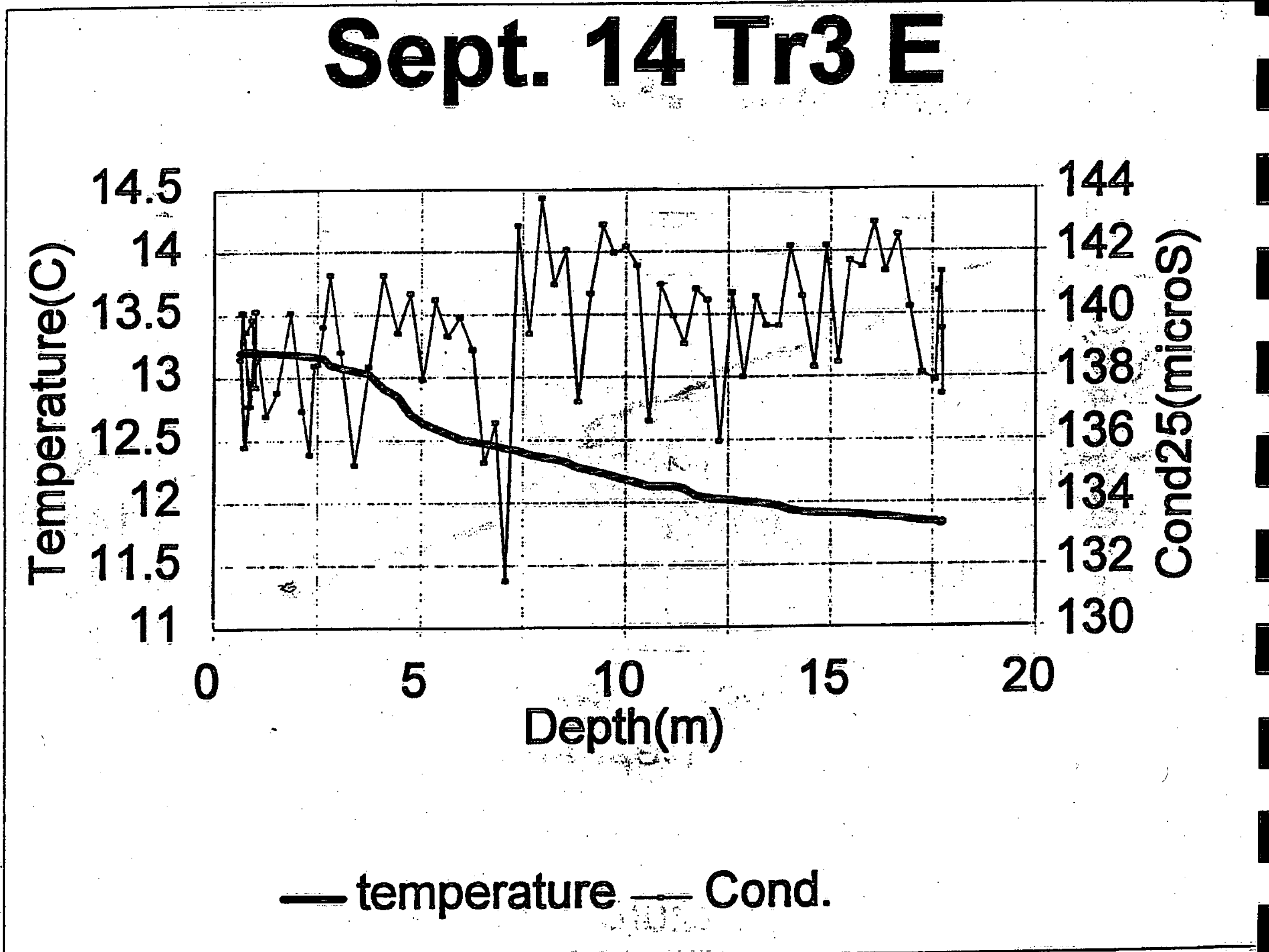

Sept. 14 Tr2 Mid
14
13
12
11
10
9
Temperature(C)
160
155
150
145
140
135
Cond25(microS)
0
10
20
30
40
Depth(m)
temperature
Cond.


Sept. 14 Tr2 E
14.5
14
13.5
13
12.5
12
Temperature(C)
144
142
140
138
136
134
Cond25 (microS)
0
5
10
15
20
Depth(m)
temperature
Cond.

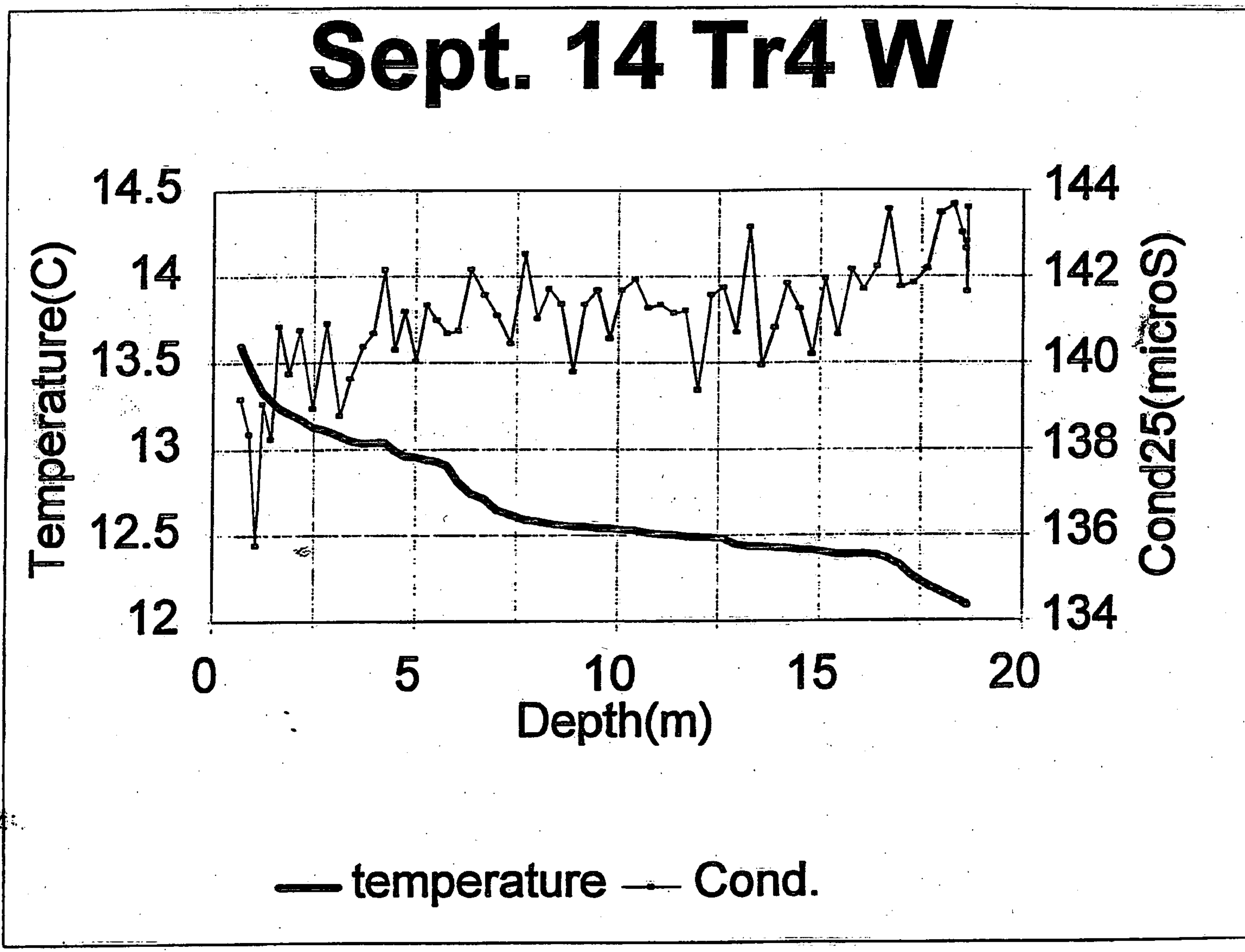


Sept. 14 Tr3 W
13.5
13
12.5
12
11.5
11
10.5
Temperature(C)
148
146
144
142
140
138
136
Cond25(microS)
0
5
10
15
20
25
30
Depth(m)
temperature
Cond.

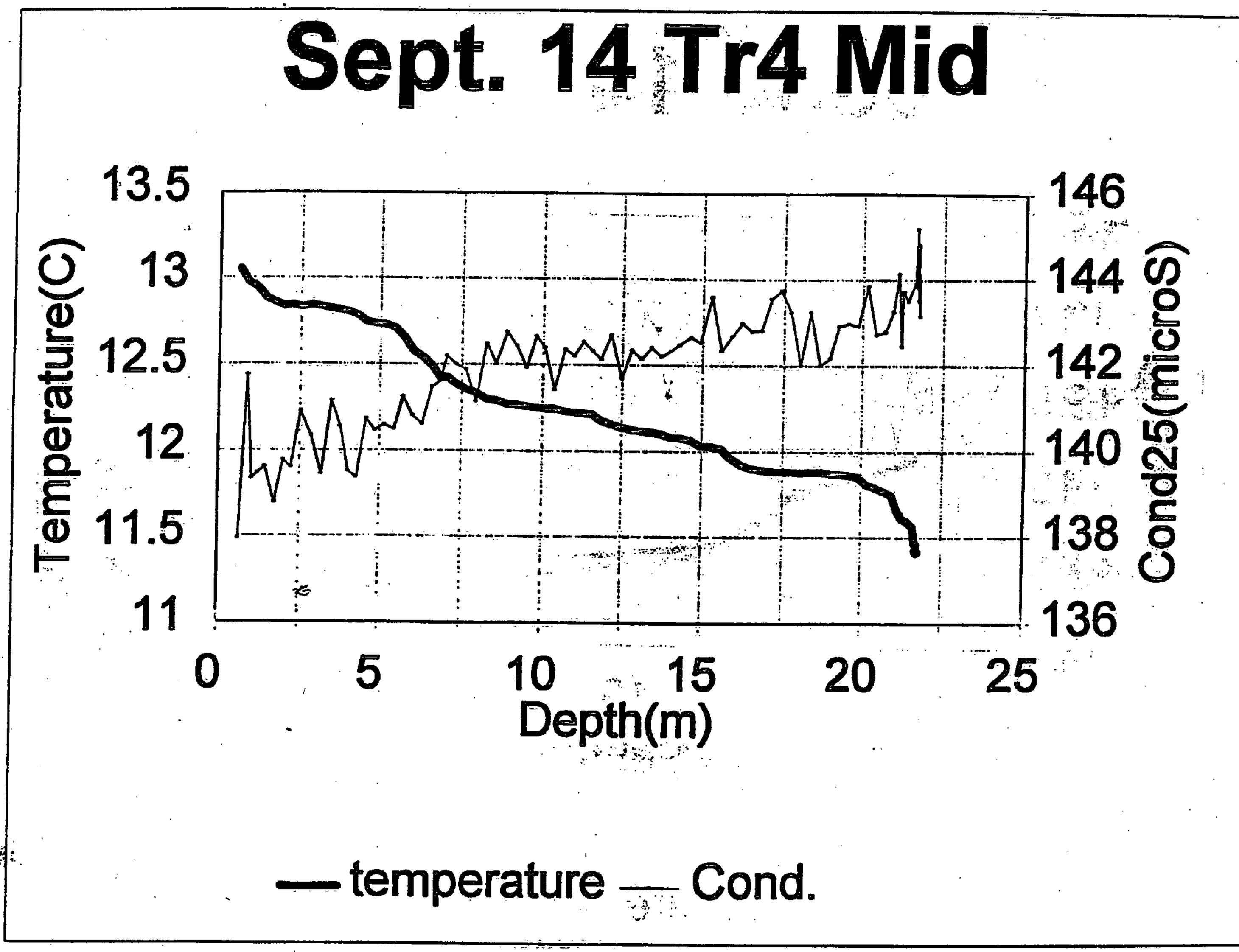

Sept. 14 Tr3 Mid
Temperature(C)
14
13
12
11
10
9
8
7
Cond25(microS)
170
165
160
155
150
145
140
135
0
10
20
30
40
50
60
Depth(m)
temperature
Cond.

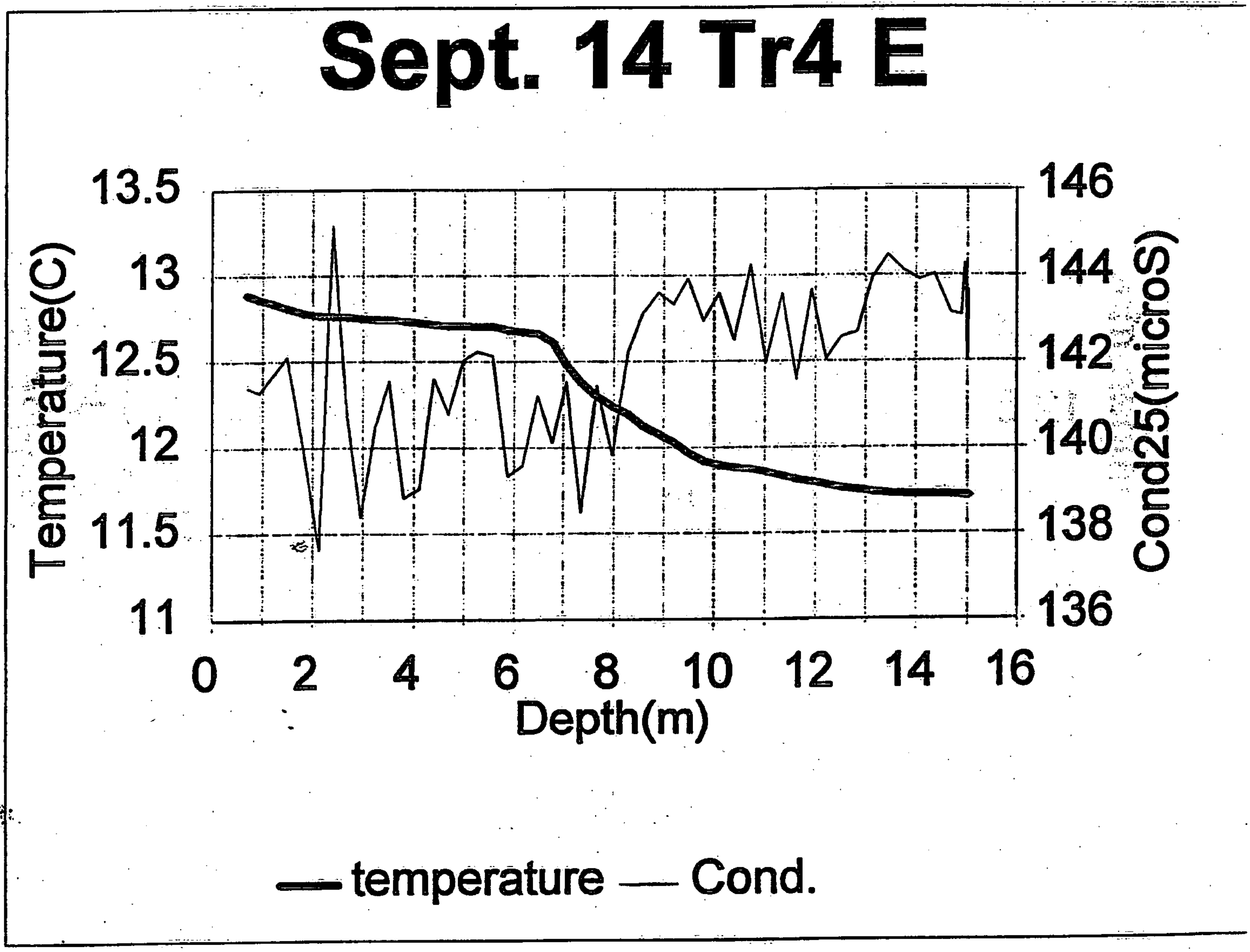


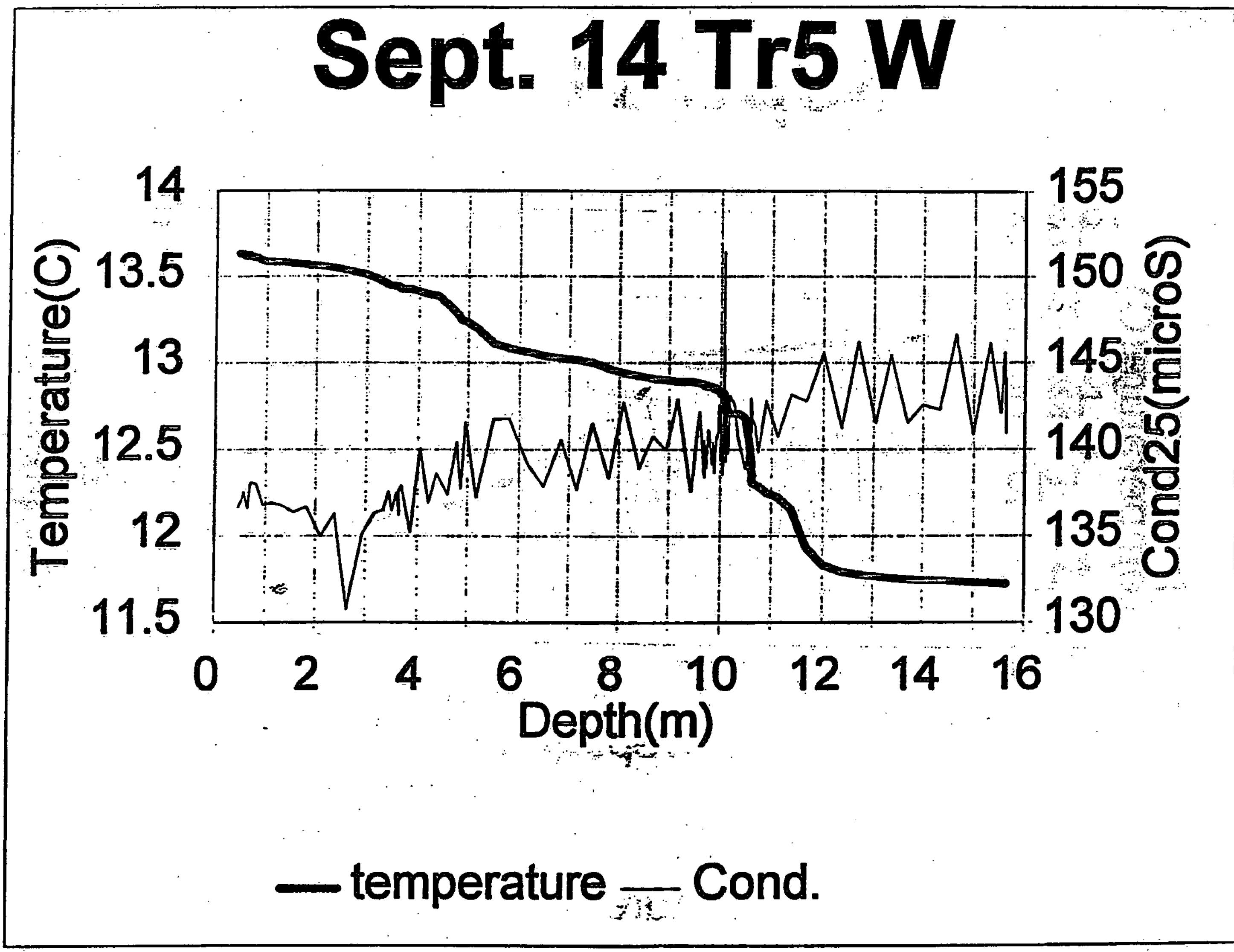
Sept. 14 Tr3 E
Temperature(C)
14.5
14
13.5
13
12.5
12
11.5
11
Cond25(microS)
144
142
140
138
136
134
132
130
0
5
10
15
20
Depth(m)
temperature
Cond.

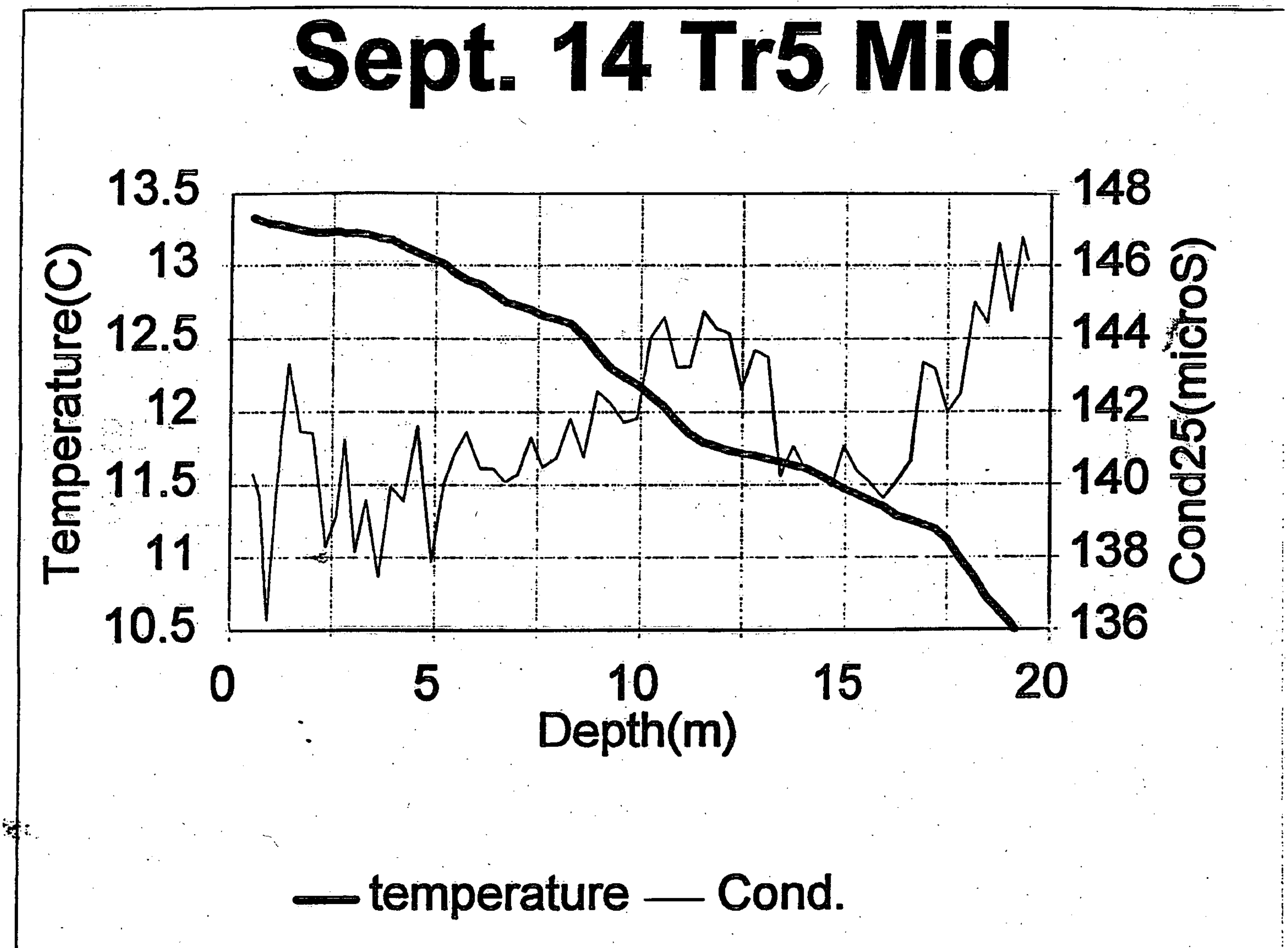


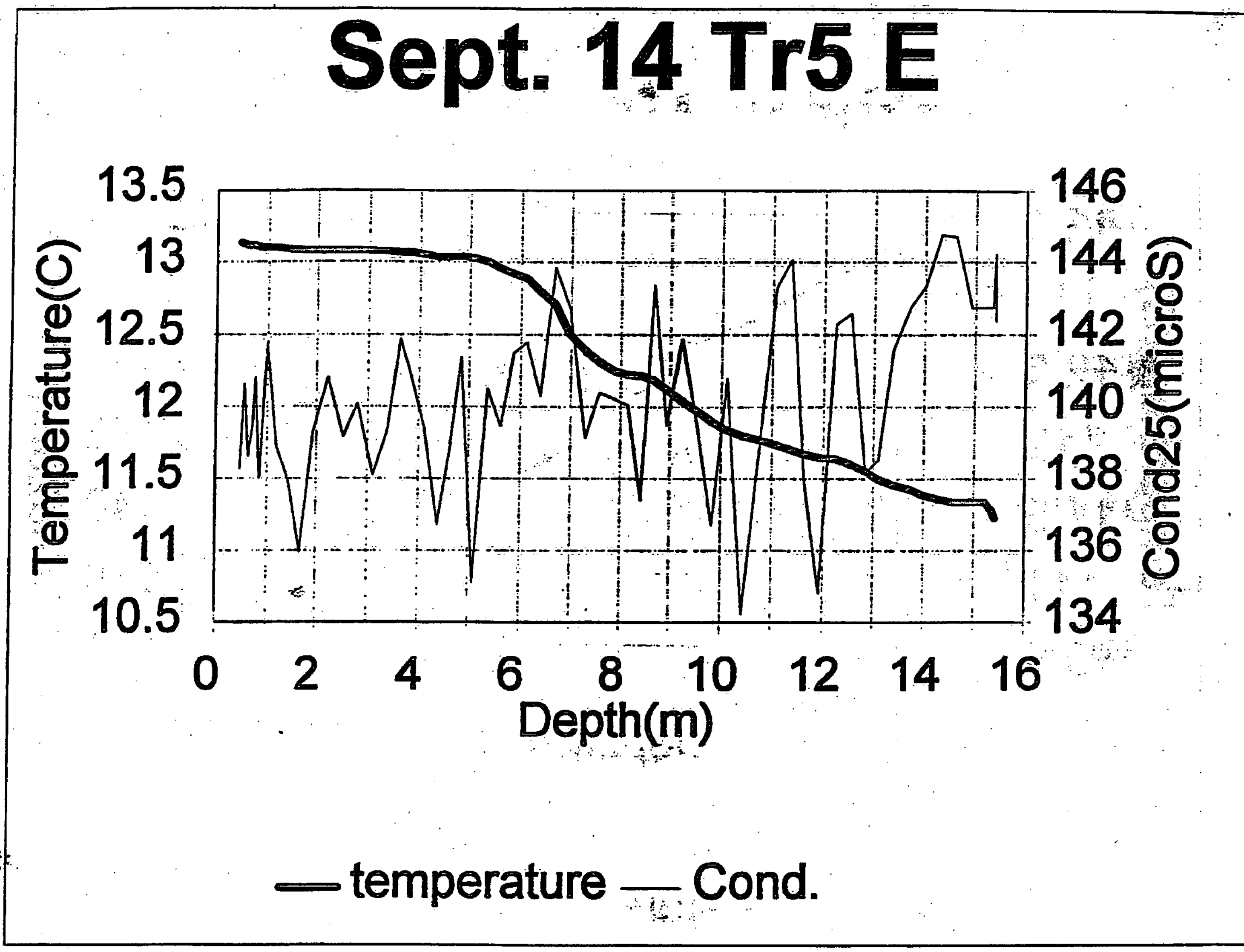
Sept. 14 Tr4 W
14.5
14
13.5
13
12.5
12
Temperature(C)
144
142
140
138
136
134
Cond25(microS)
0
5
10
15
20
Depth(m)
temperature
Cond.

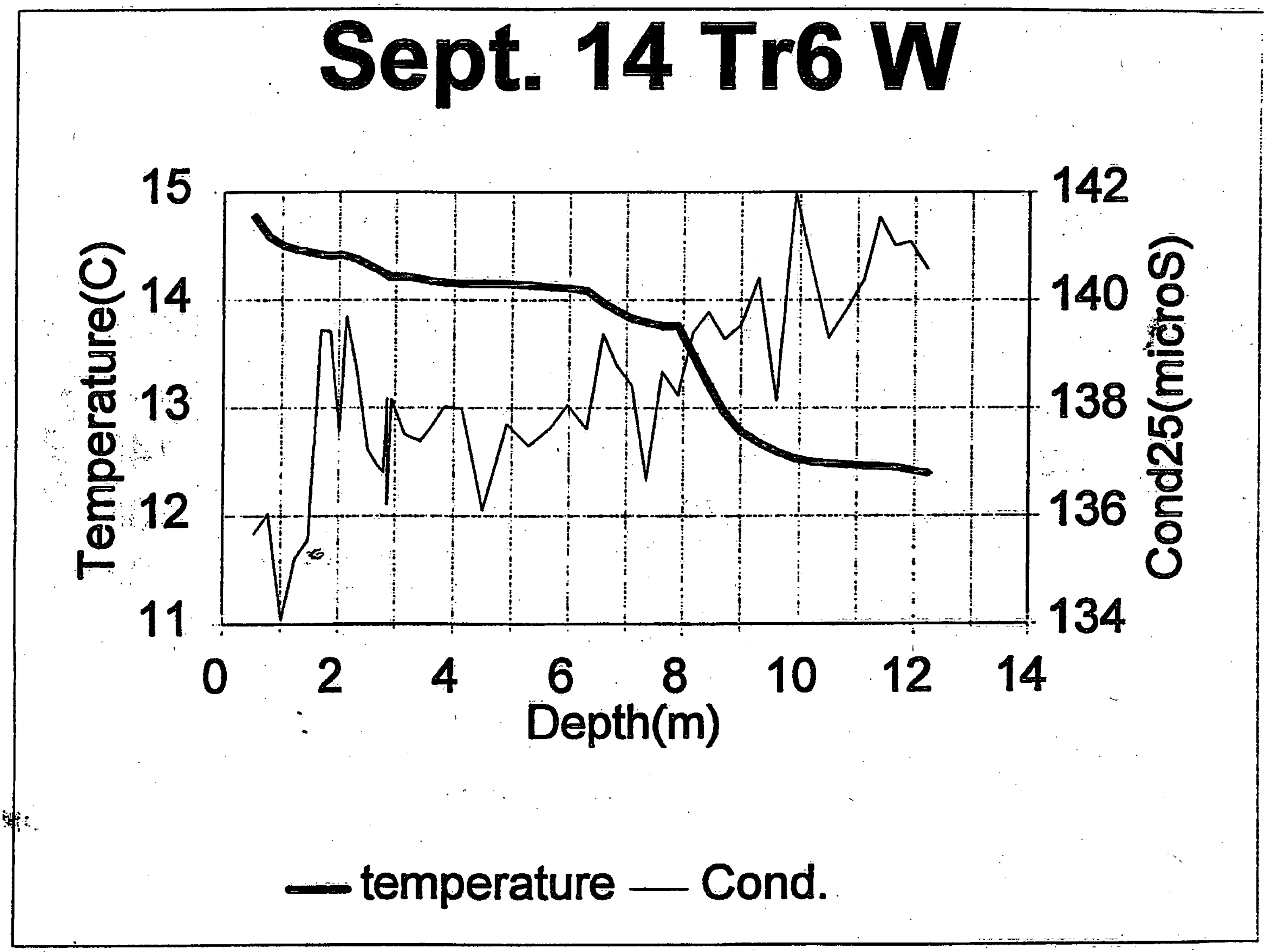

Sept. 14 Tr4 Mid
Temperature(C)
13.5
13
12.5
12
11.5
11
Cond25(microS)
146
144
142
140
138
136
0
5
10
15
20
25
Depth(m)
temperature
Cond.

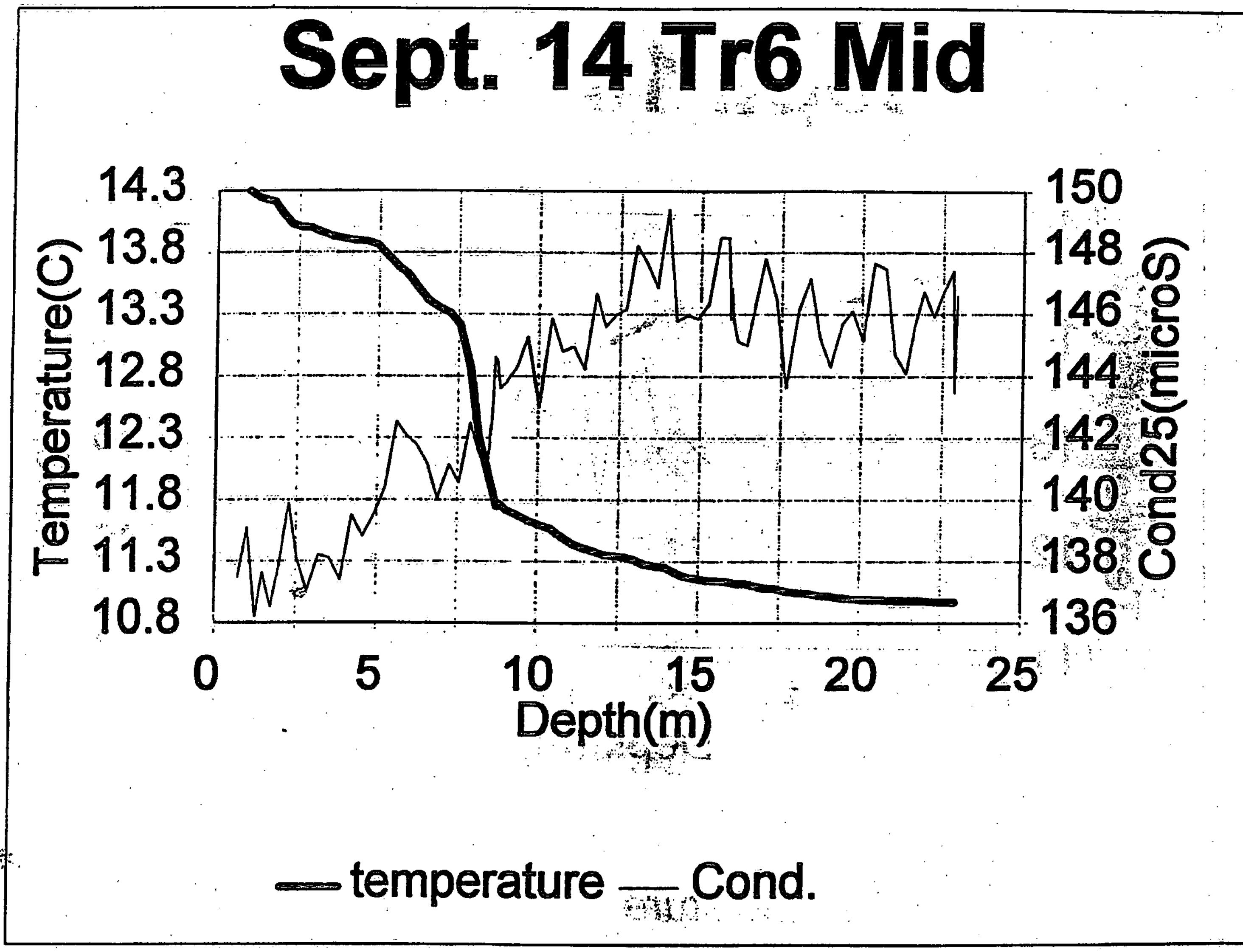

Sept. 14 Tr4 E
Temperature(C)
Cond25(microS)
Depth(m)
13.5
13
12.5
12
11.5
11
146
144
142
140
138
136
0
2
4
6
8
10
12
14
16
temperature
Cond.


Sept. 14 Tr5 W
Temperature(C)
14
13.5
13
12.5
12
11.5
Cond25(microS)
155
150
145
140
135
130
0
2
4
6
8
10
12
14
16
Depth(m)
temperature
Cond.

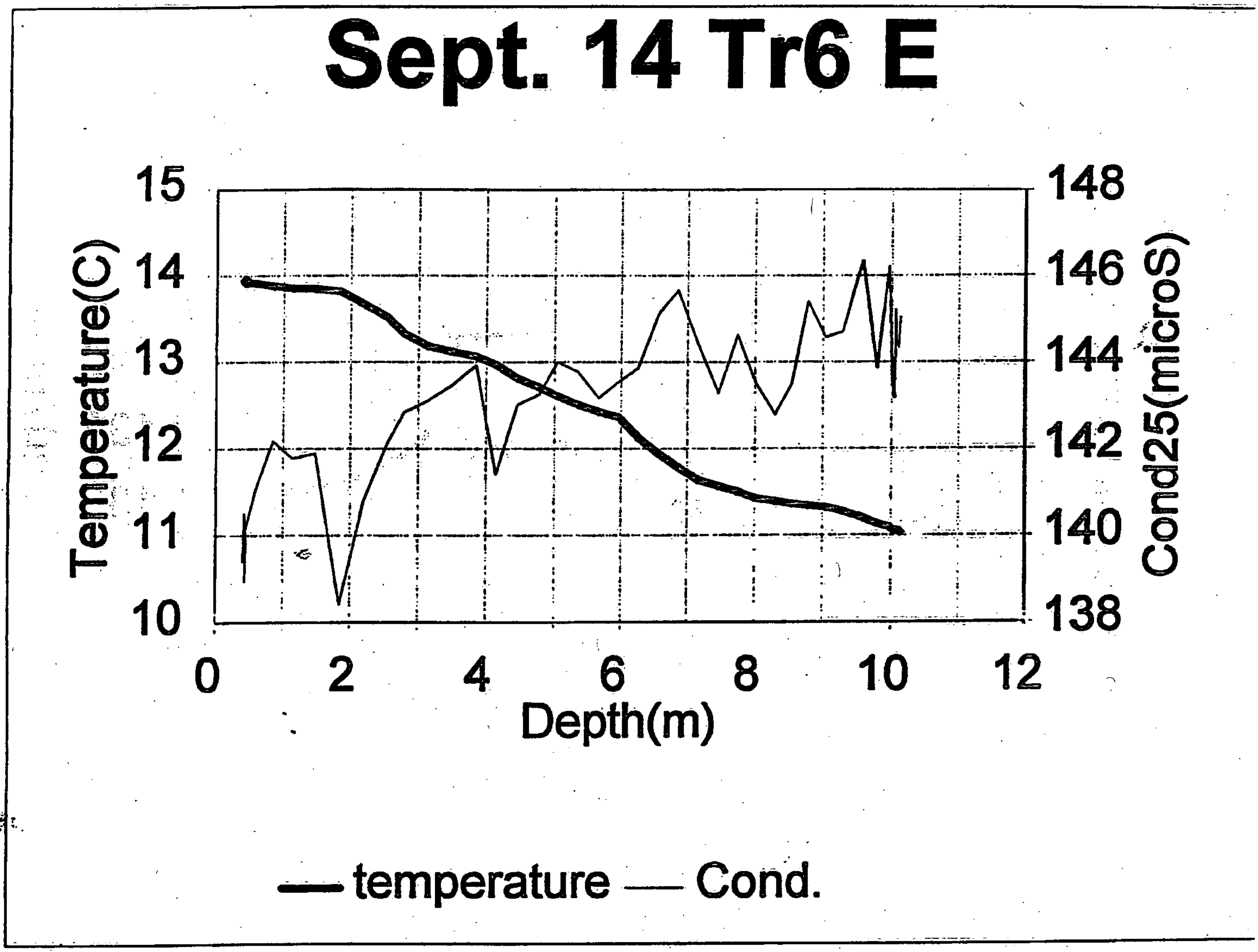

Sept. 14 Tr5 Mid
Temperature(C)
13.5
13
12.5
12
11.5
11
10.5
Cond25(microS)
148
146
144
142
140
138
136
0
5
10
15
20
Depth(m)
temperature
Cond.

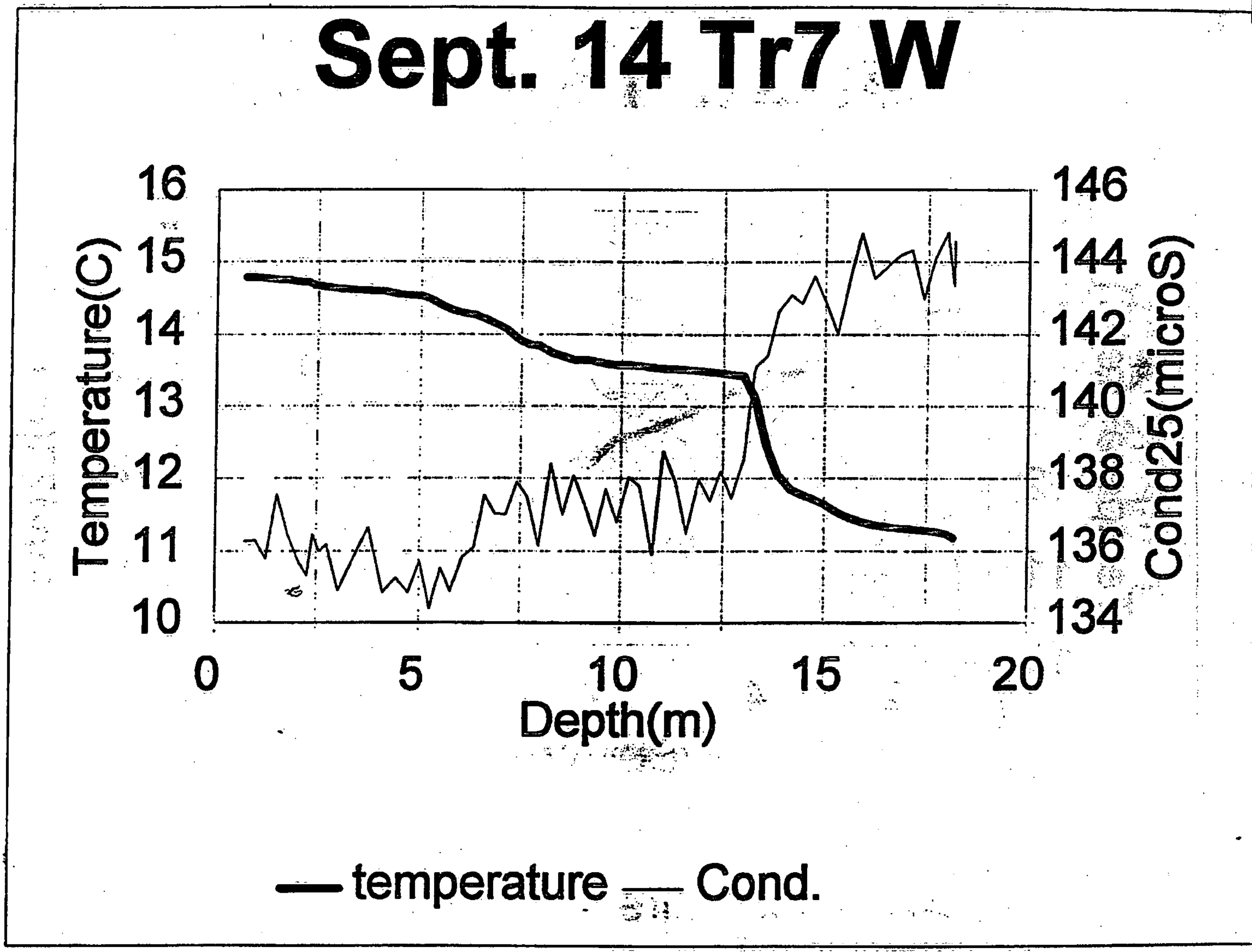

Sept. 14 Tr5 E
Temperature(C)
13.5
13
12.5
12
11.5
11
10.5
Cond25(microS)
146
144
142
140
138
136
134
0
2
4
6
8
10
12
14
16
Depth(m)
temperature
Cond.


Sept. 14 Tr6 W
Temperature(C)
Cond25(microS)
Depth(m)
15
14
13
12
11
142
140
138
136
134
0
2
4
6
8
10
12
14
temperature
Cond.

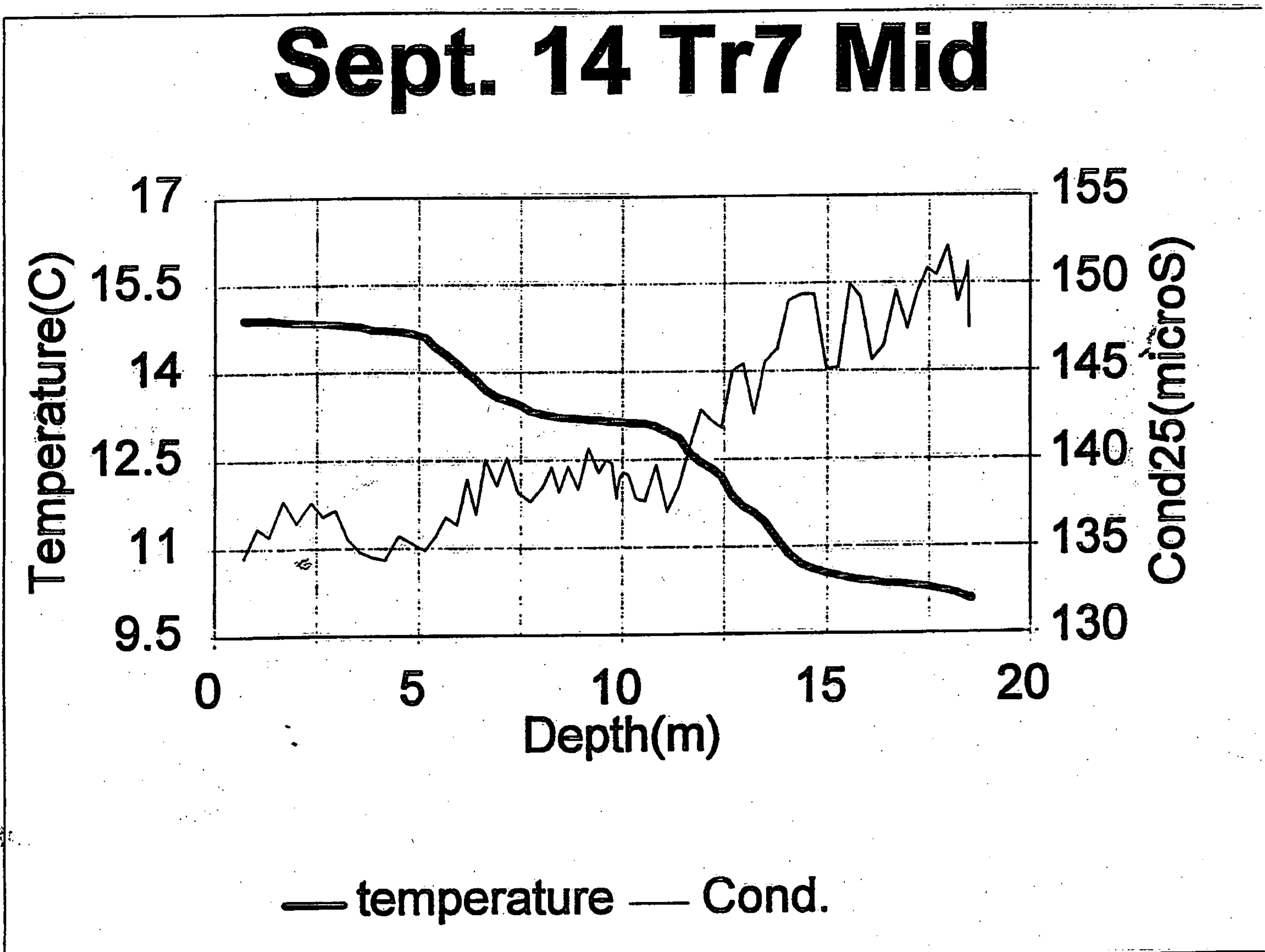


Sept. 14 Tr6 Mid
Temperature(C)
14.3
13.8
13.3
12.8
12.3
11.8
11.3
10.8
Cond25(microS)
150
148
146
144
142
140
138
136
0
5
10
15
20
25
Depth(m)
temperature
Cond.

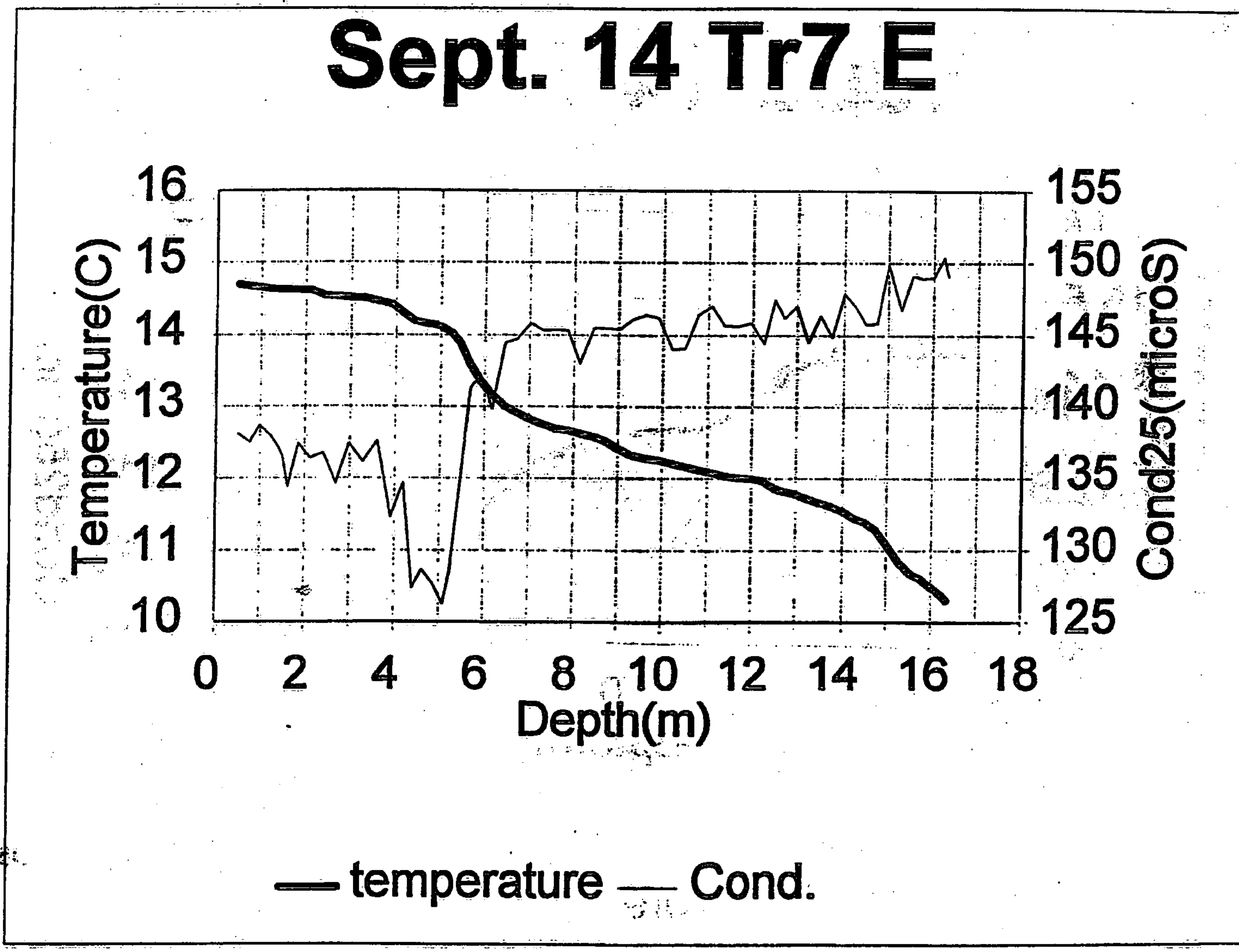

Sept. 14 Tr6 E
Temperature(C)
Cond25(microS)
Depth(m)
15
14
13
12
11
10
148
146
144
142
140
138
0
2
4
6
8
10
12
temperature
Cond.



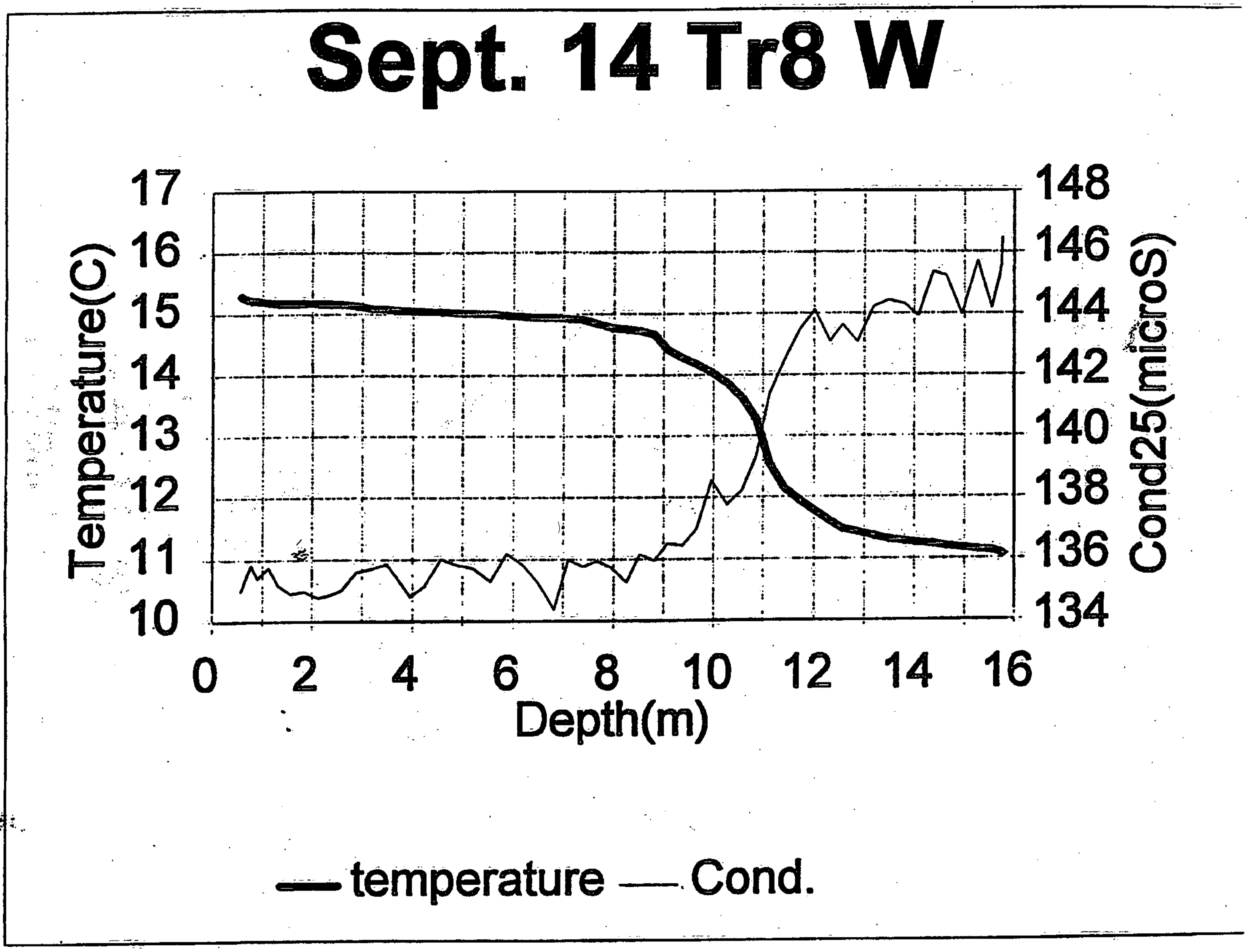
Sept. 14 Tr7 W
Temperature(C)
Cond25(microS)
Depth(m)
16
15
14
13
12
11
10
146
144
142
140
138
136
134
0
5
10
15
20
temperature
Cond.



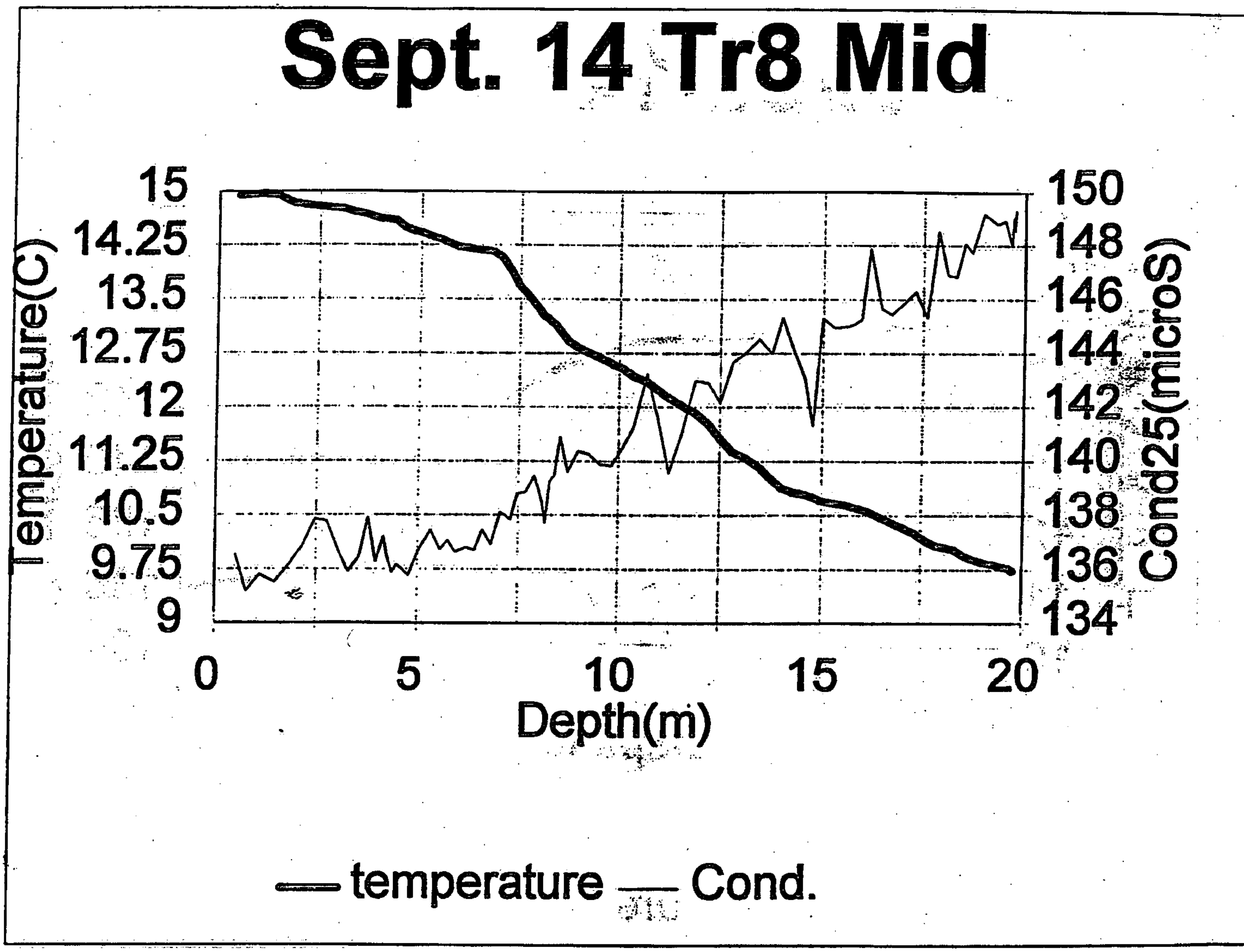
Sept. 14 Tr7 Mid
17
15.5
14
12.5
11
9.5
Temperature(C)
155
150
145
140
135
130
Cond25(microS)
0
5
10
15
20
Depth(m)
temperature
Cond.

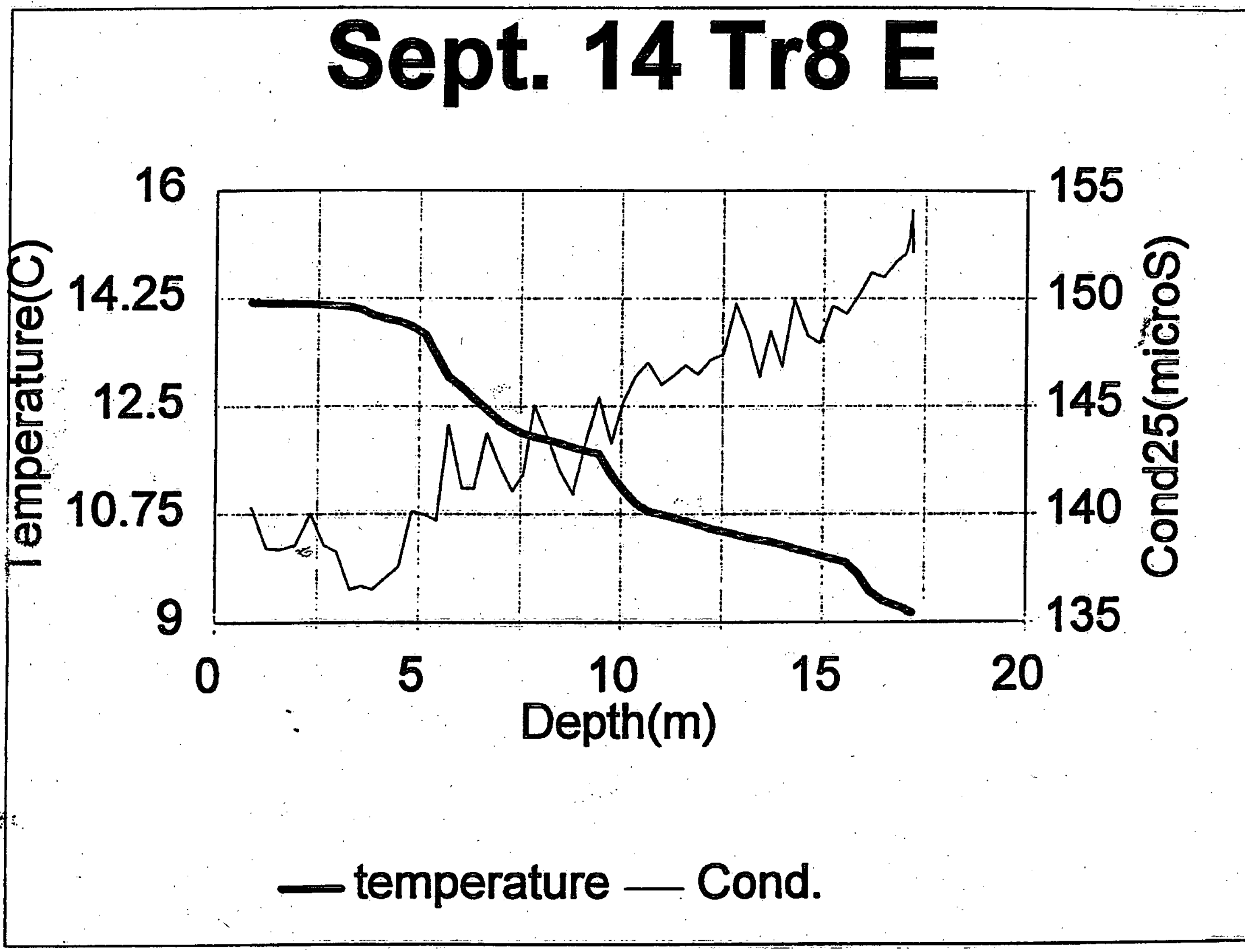


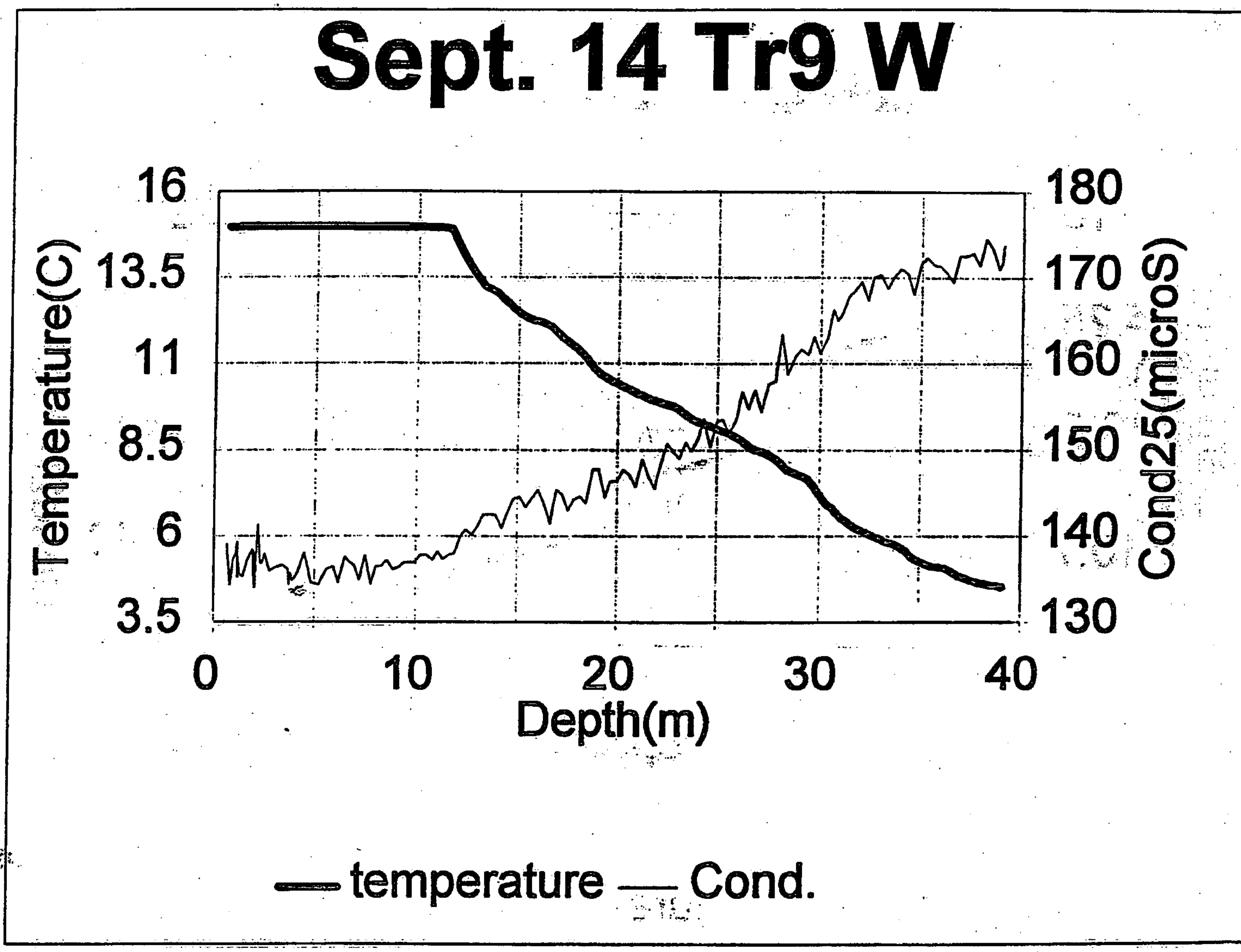
Sept. 14 Tr7 E
16
15
14
13
12
11
10
Temperature(C)
155
150
145
140
135
130
125
Cond25(microS)
0
2
4
6
8
10
12
14
16
18
Depth(m)
temperature
Cond.



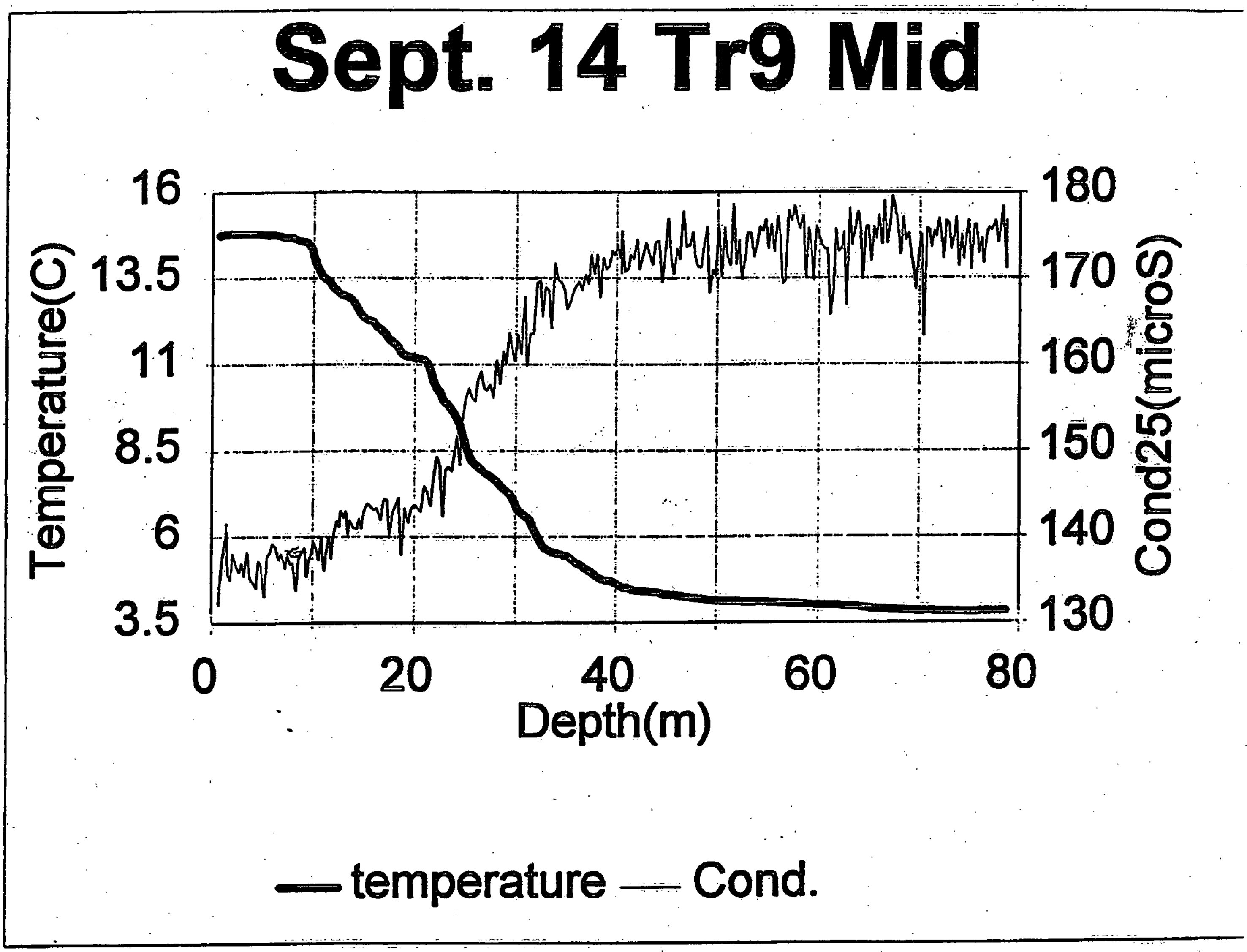
Sept. 14 Tr8 W
17
16
15
14
13
12
11
10
148
146
144
142
140
138
136
134
0
2
4
6
8
10
12
14
16
Depth(m)
Temperature(C)
Cond25(microS)
temperature
Cond.


Sept. 14 Tr8 Mid
15
14.25
13.5
12.75
12
11.25
10.5
9.75
9
Temperature(C)
150
148
146
144
142
140
138
136
134
Cond25(microS)
0
5
10
15
20
Depth(m)
temperature
Cond.

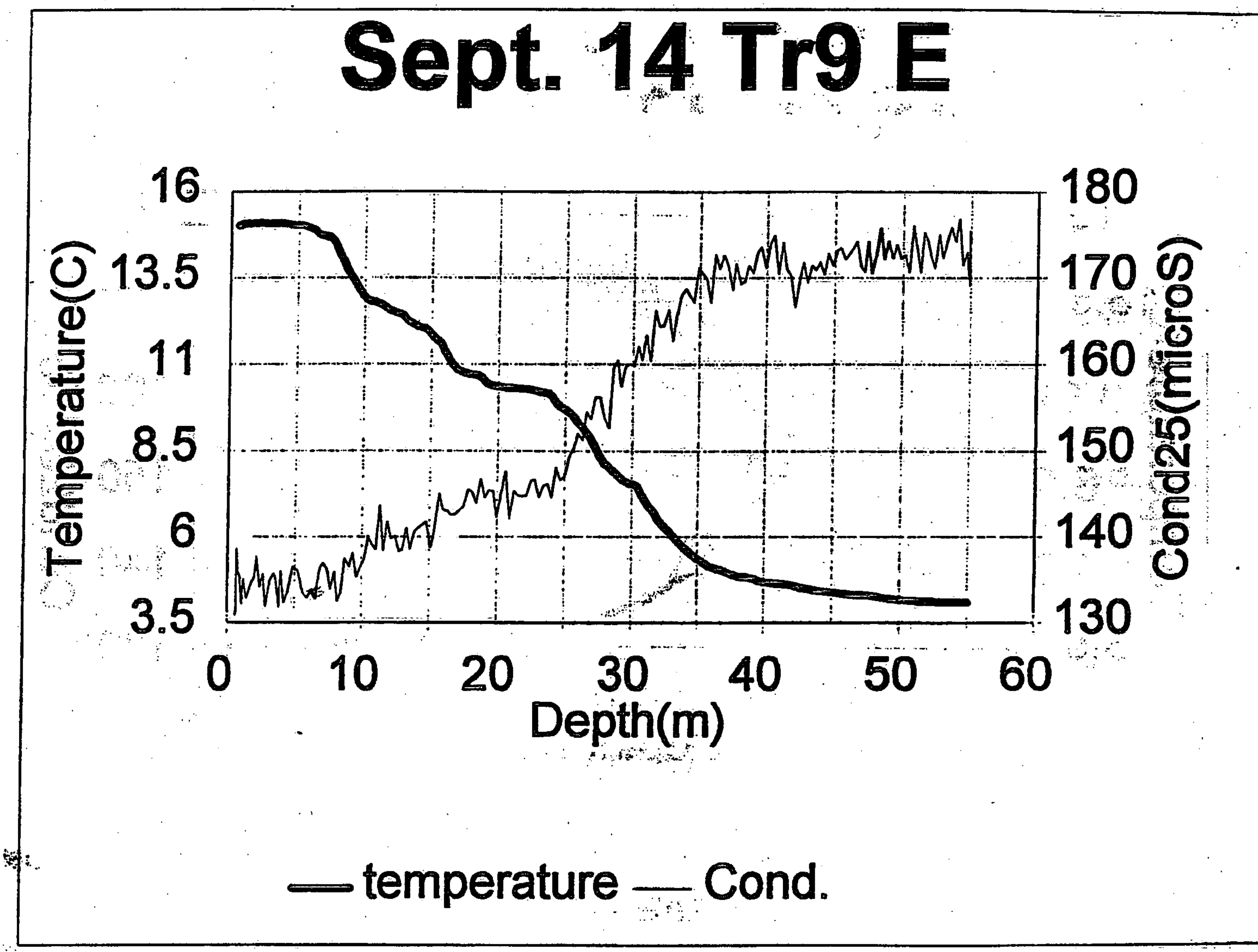

Sept. 14 Tr8 E
16
14.25
12.5
10.75
9
Temperature(C)
155
150
145
140
135
Cond25(microS)
0
5
10
15
20
Depth(m)
temperature
Cond.

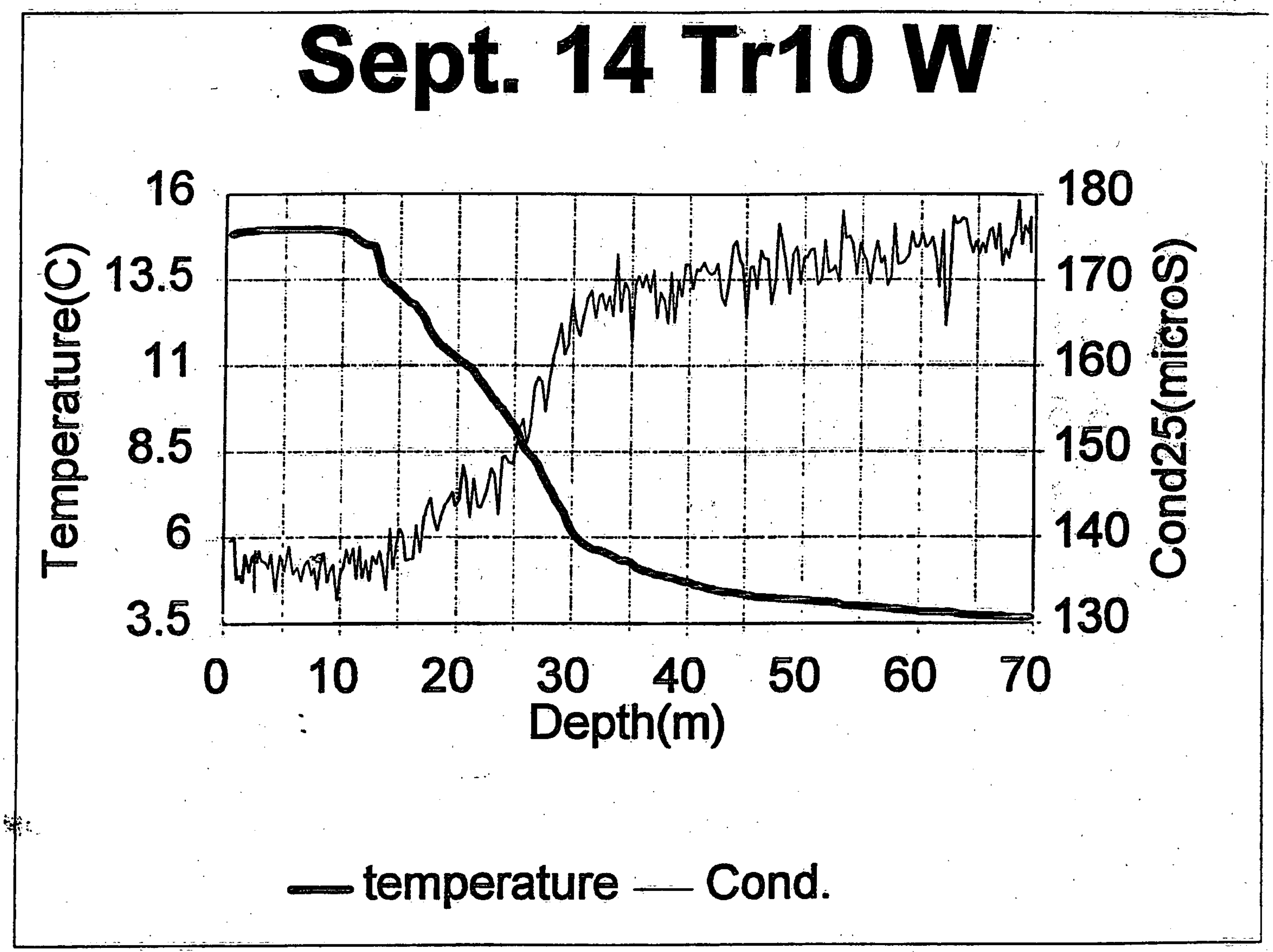


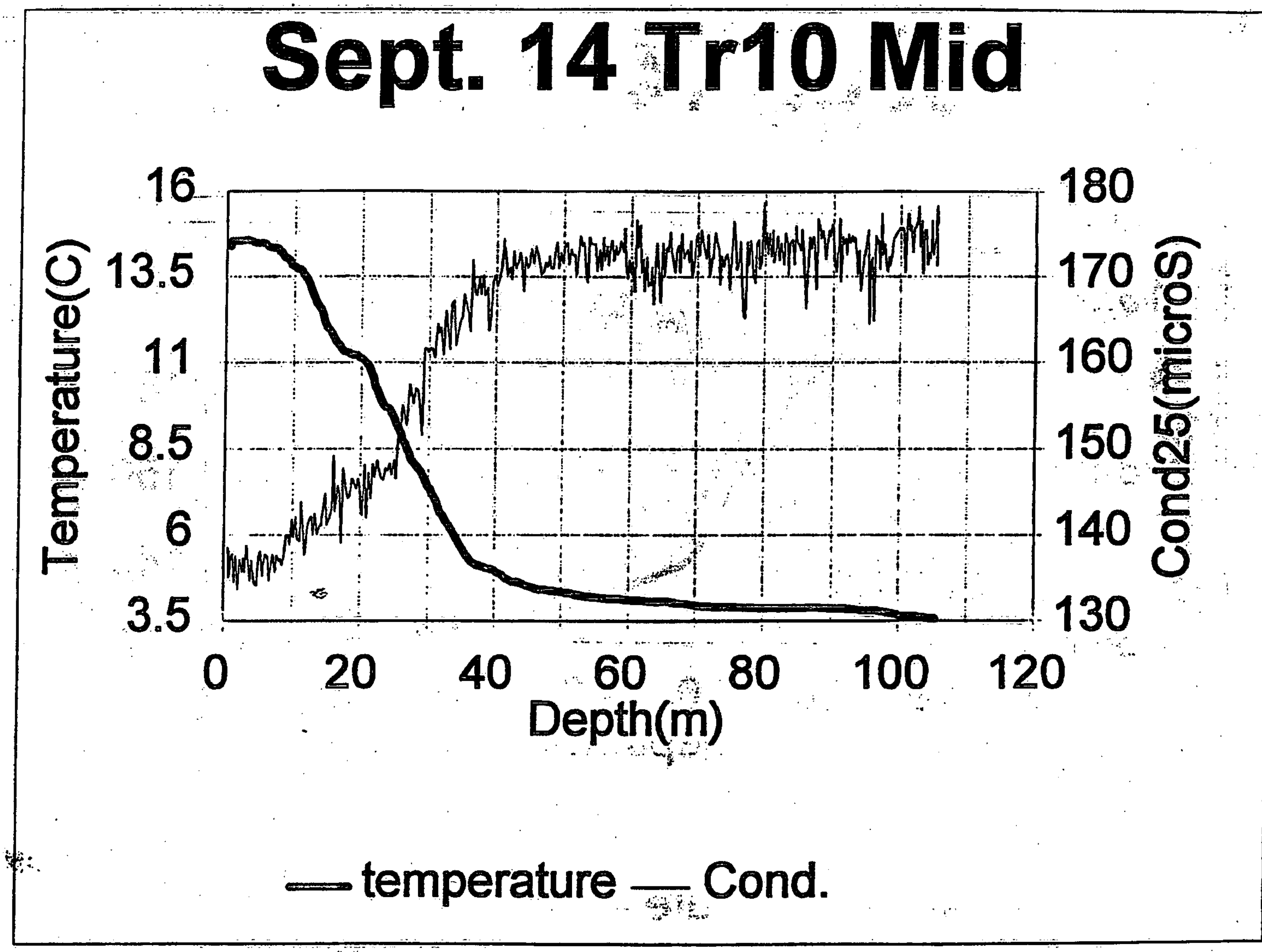
Sept. 14 Tr9 W
16
13.5
11
8.5
6
3.5
Temperature(C)
180
170
160
150
140
130
Cond25(microS)
0
10
20
30
40
Depth(m)
temperature
Cond.



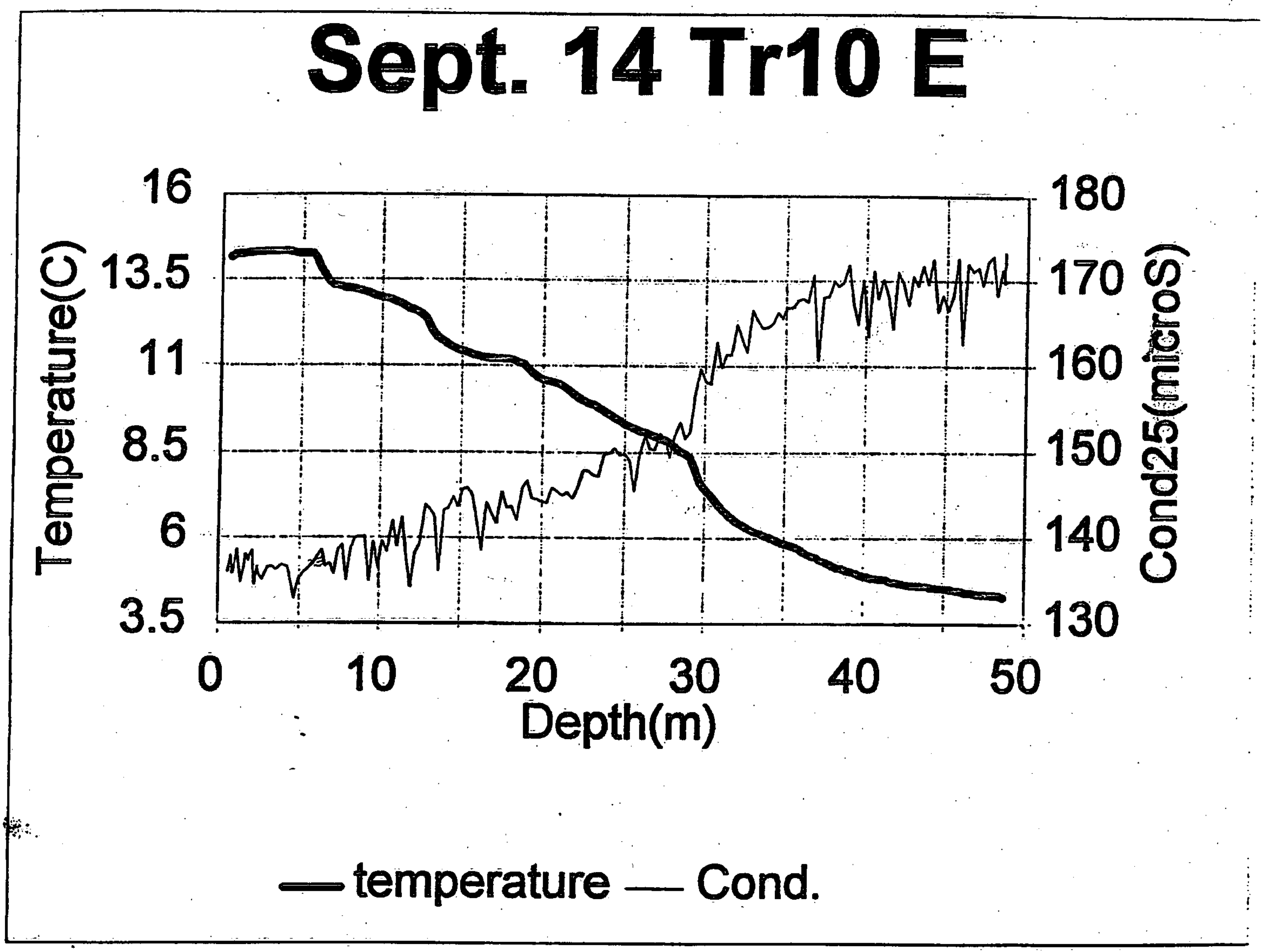
Sept. 14 Tr9 Mid
16
13.5
11
8.5
6
3.5
Temperature(C)
180
170
160
150
140
130
Cond25(microS)
0
20
40
60
80
Depth(m)
temperature
Cond.


Sept. 14 Tr9 E
16
13.5
11
8.5
6
3.5
Temperature(C)
180
170
160
150
140
130
Cond25(microS)
0
10
20
30
40
50
60
Depth(m)
temperature
Cond.

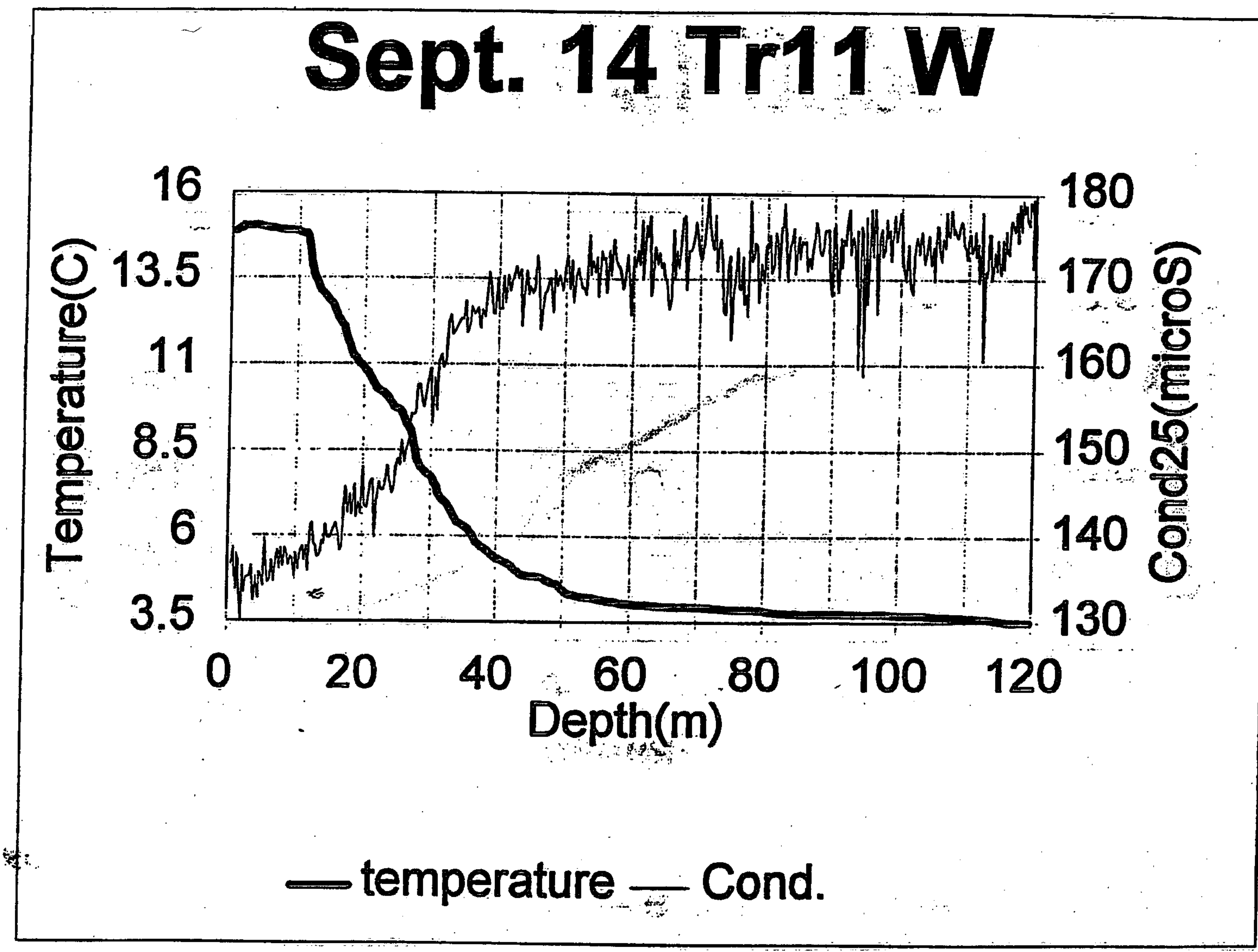

Sept. 14 Tr10 W
Temperature(C)
16
13.5
11
8.5
6
3.5
Cond25(microS)
180
170
160
150
140
130
0
10
20
30
40
50
60
70
Depth(m)
temperature
Cond.



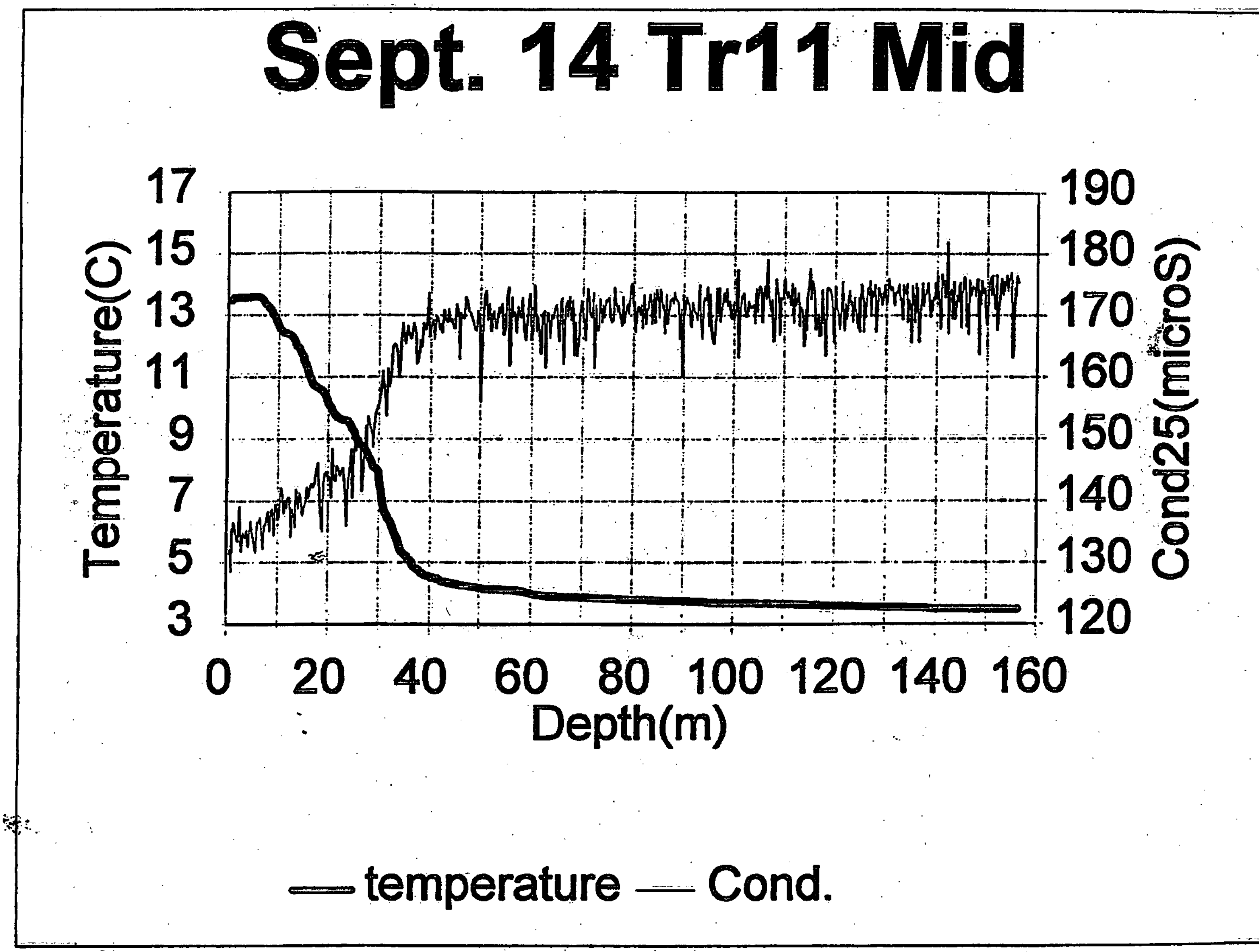
Sept. 14 Tr10 Mid
Temperature(C)
16
13.5
11
8.5
6
3.5
Cond25(microS)
180
170
160
150
140
130
0
20
40
60
80
100
120
Depth(m)
temperature
Cond.

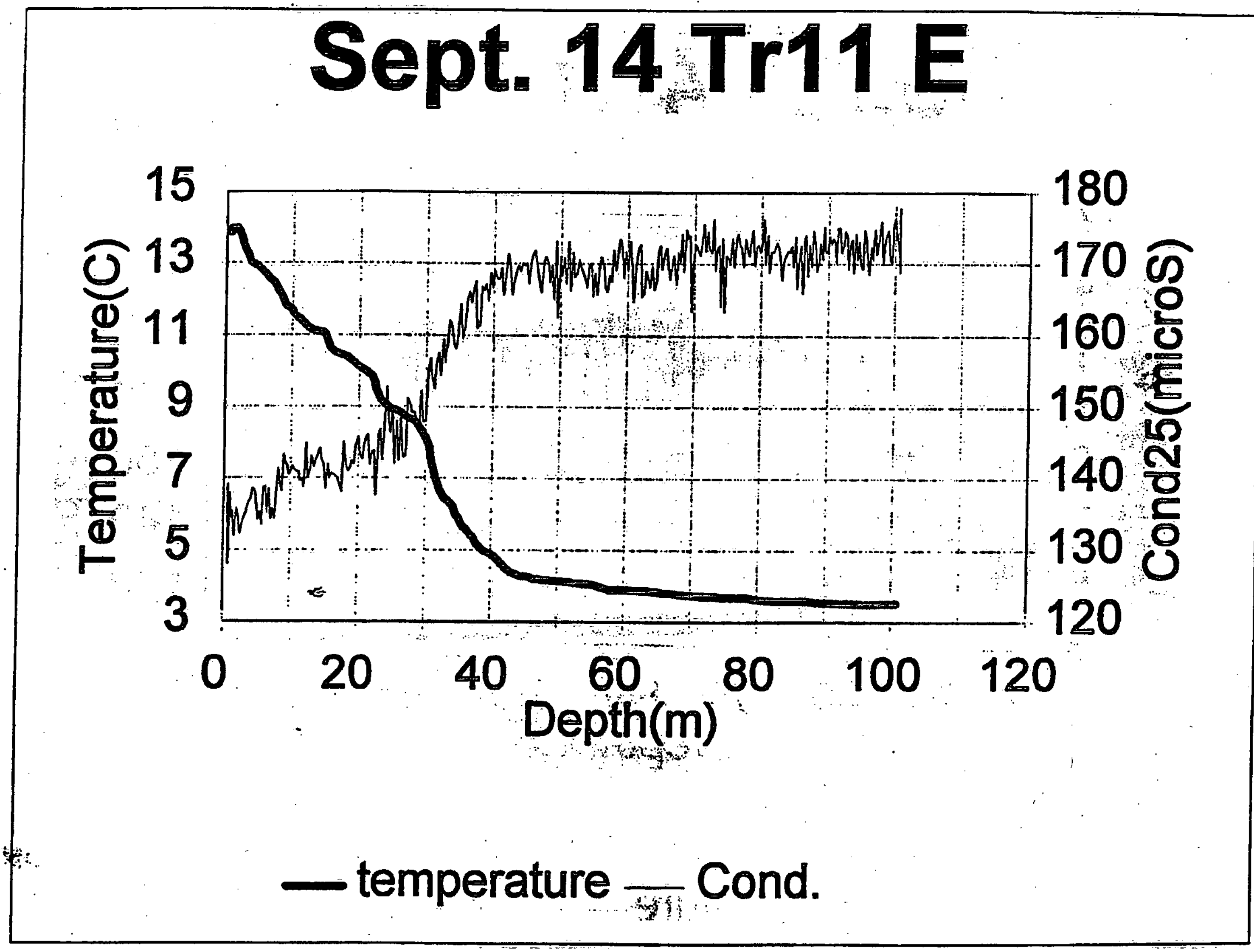


Sept. 14 Tr10 E
Temperature(C)
16
13.5
11
8.5
6
3.5
180
170
160
150
140
130
Cond25(micros)
0
10
20
30
40
50
Depth(m)
temperature
Cond.



Sept. 14 Tr11 W
16
13.5
11
8.5
6
3.5
Temperature(C)
180
170
160
150
140
130
Cond25(microS)
0
20
40
60
80
100
120
Depth(m)
temperature
Cond.


Sept. 14 Tr11 Mid
17
15
13
11
9
7
5
3
Temperature(C)
190
180
170
160
150
140
130
120
Cond25(microS)
0 20 40 60 80 100 120 140 160
Depth(m)
temperature
Cond.


Sept. 14 Tr11 E
Temperature(C)
15
13
11
9
7
5
3
Cond25(microS)
180
170
160
150
140
130
120
0
20
40
60
80
100
120
Depth(m)
temperature
Cond.

Appendix III Data collected on September 15, 1996
Upper Arrow Lake, Beaton Arm and Columbia River

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