EFFECTS OF HYDRAULIC DREDGING ON THE AESTHETICS AND WATER QUALITY OF ADA CITY LAKE

PHASE II
CLEAN LAKES RESTORATION PROJECT

FINAL REPORT

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Effects of Hydraulic Dredging on the Aesthetics and Water Quality of Ada City Lake

Phase II
Clean Lakes Restoration Project

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September 1987 Herbert J. Grimshaw

This report has been reviewed by the Oklahoma Water Resources Board and the Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the OWRB and the EPA, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

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LIST OF ACRONYMS AND SYMBOLS

$mg.L^{-1}$	milligram per liter
$ug.L^{-1}$	microgram per liter
$ng.L^{-1}$	nanogram per liter
$g.L^{-1}$	gram per liter

SECTION I

GENERAL INTRODUCTION

This report was prepared in response to Section 314-a of the Clean Water Act (P.L. 92-500) of 1977 which, upon election to participate, requires each state to trophically classify, diagnose, and restore selected publicly-owned freshwater lakes. The initial step in this process, the classification study, culminated in the publication, in December 1980, of the "Classification of Oklahoma Reservoirs Using LANDSAT Multispectrial Scanner Data." This document, a Phase II Clean Lakes restoration project report, constitutes one result of compliance with this process.

SECTION II

GENERAL SUMMARY

A phase II Clean Lakes Reservoir Restoration Project was conducted on Ada City Lake. This project involved the hydraulic dredging of the reservoir, storage of the spoil in earthen pits and water quality monitoring prior to, during and after completion of the project. As a result of these actions, the aesthetic and recreational uses of the reservoir have been improved. The detrimental effects of dredging on water quality are diminishing rapidly and appear to be only temporary conditions.

SECTION III

CONCLUSIONS

1. The hydraulic dredging of Ada City Lake has greatly improved the recreational uses and aesthetic qualities of this water body.

2. Dredging has transformed a hypereutrophic reservoir into a eutrophic water body and this process of water quality improvement appears to be continuing.

3. The volume of Ada City Lake has been increased by approximately 40,000 cubic meters and is now 1.04×10^5 M^3 at spillway elevation.

4. The sediment storage pits appear to be operating effectively.

5. Elevated levels of nutrients, suspended sediment, chlordane and mercury were detected during stormwater monitoring of tributaries to Ada City Lake.

SECTION IV

RECOMMENDATIONS

1. Efforts should be made to eliminate the sources of chlordane and mercury pollution detected at sampling stations two and four (Figs. 147 and 152).

2. Efforts should also be made to eliminate the sources of nutrient pollution detected at stations one, two and three (Figs. 141, 143 and 145) through the improvement of existing sewer lines or the installation of new sewer lines in the watershed above these stations.

3. Efforts should be made to reduce the elevated amounts of suspended solids detected at sampling stations one, two and four (Fig. 136).

SECTION V

INTRODUCTION

Ada City Lake is a shallow, warm, temperate, polymictic (wind and stormwater mixed) reservoir, seven hectares (17.3 acres) in surface area located in Pontotoc County, in south central Oklahoma (Fig. 1). A preliminary inspection in 1982 indicated that the reservoir had been seriously impacted by various pollutants for an extended period of time. Cultural eutrophication in the forms of excessive nutrient and inorganic sediment loading had dramatically reduced the depth in a major portion of the main body of the reservoir. Many areas of the lake were less than 0.2 meters deep and there were extensive stands of both submerged and emergent aquatic macrophytes. Such conditions precluded swimming and boating, impaired fishing and seriously detracted from the aesthetic qualities of the water body. Consequently, it became apparent that hydraulic dredging would be required to restore the aesthetic and recreational uses of this reservoir.

This report describes the dredging operation and the results of a water quality monitoring program that was conducted prior to, during and after this Phase II Clean Lakes Reservoir Restoration Project.

SECTION VI

METHODS

Dredging

The hydraulic dredge used on this project was an auger-type, with a horizontal cutting bar that could be lowered approximately 3 meters below the water's surface. Since this barge-mounted dredge was maneuvered via a cable anchored to opposite shores, dredging was conducted along west to east transects. During dredging the lowered cutting bar would dig into and redistribute bottom sediments into the water column. A suction hose, positioned near the cutting bar, collected the majority of these resuspended sediments which were pumped through a plastic, pipeline to one of four dewatering and sediment storage pits (Fig. 2). Each pit was constructed to accommodate 10,000 cubic meters of sediment. In addition, a large track-mounted backhoe was used at the northern and northeastern headwaters of the reservoir to remove sediment since *Typha sp.* (cattails), which were concentrated in these areas, tended to wrap around the cutting bar of the hydraulic dredge, eventually making it inoperable (Fig. 3).

Water Quality Monitoring

Reservoir. Pre and post-dredging water quality monitoring was conducted from 11 August 1982 through 25 June 1986. Pre-dredging sampling was conducted orginally at sampling stations one through eight (Fig. 1). These samples were analyzed for total suspended solids and total phosphorous, nitrate, nitrite, ammonia and Kjeldahl nitrogens, pH, temperature, specific conductance, dissolved oxygen, alkalinity, hardness, chlorophyll *a* content, nephelometric turbidity and total dissolved and settleable solids. It soon became apparent that sampling stations six and eight adequately reflected the water quality of Ada City Lake. Consequently, the sampling program was redesigned and the parameters--total phosphorous, total nitrogen, pH, dissolved oxygen, temperature and specific conductance--were monitored during the majority of the study.

Stormwater Monitoring. Fixed stage samplers were used to obtain stormwater samplesfrom the five tributaries to and the outlet from Ada City Lake. Samples were collected using flint glass sample bottles positioned 0.3 meters above each stream's base-flow stage. Parameters analyzed included nitrate, nitrite, ammonia and Kjeldahl nitrogens and total sample phosphorous, mercury, chlordane, 2,4-dichlorophenoxyacetic acid and suspended solids.

Quality Control. Water temperature, pH, dissolved oxygen and specific conductance were monitored *in situ* with a Hydrolab Digital Model 4041. The accuracy and precision of the hydrolab's thermister were ± 0.2°C and ± 0.1°C, respectively, while the

Wheatstone bridge specific conductance meter exhibited an accuracy of $\pm$ 20 umhos cm^{-1} and a precision of $\pm$ 5 umhos cm^{-1}. The accuracy and precision of the hydrolab's pH meter were both $\pm$ 0.1 standard units, while dissolved oxygen exhibited accuracy and precision ranges of $\pm$ 0.2 mg L^{-1} and $\pm$ 0.1 mg L^{-1}, respectively. All analytical methods used during this study were those recommended in <u>Standard Methods</u> (APHA, 1985) or by the U. S. Environmental Protection Agency (1979).

SECTION VII

RESULTS

Areas dredged within Ada City Lake are illustrated in Figure 3. Dredging was not conducted in the immediate vicinity of the dam to eliminate the possibility of inadvertently increasing seepage through or below it. Hydraulic dredging was, therefore, largely confined to the central portion of the main body of the reservoir. Forty thousand cubic meters of sediment was removed from this water body, dewatered and stored in earthen pits. Since these storage pits were located at a higher elevation than the lake (Fig. 2) and due to the 400 meters of 20 cm pipeline required, an auxiliary pump was necessary to move the sediment-water slurry. The presence of *Typha sp*. in the headwaters of the reservoir and its northeastern arm (Fig. 3) made hydraulic dredging in those areas impractical. Consequently, it was necessary to mechanically dredge these areas using a large track-mounted backhoe.

With this equipment, the reservoir was dredged within a period of 17 months. Twenty-eight sonar transects were made during May of 1987 to document the ffectiveness of the dredging effort (Fig. 4). From these data it was determined that the water volume of Ada City Lake is now 1.04×10^5 M^3 at spillway elevation.

Water Quality Monitoring

Predredging. Ada City Lake thermally stratified on several occasions prior to dredging (Figs. 5-8). Water temperature ranged from 10°C in December 1982 to 33°C on August 11, 1982 (Figs. 5 and 9). Specific conductance (Figs. 10-14) varied from 400 to 520 umhos $cm^{-1}m$, pH ranged from 7.2 standard units on September 30, 1982 to 9.1 standard units on March 16, 1983 (Figs. 15-19) and chlorophyll *a* content was 140 $ug.L^{-1}$ on December 8, 1982. (Fig. 20). Dissolved oxygen ranged from 12 $mg.L^{-1}$ to less than 2 mg L^{-1} (Figs 21-24), and oxygen saturation varied from 20 to 160 percent (Figs. 25-30).

During Dredging. Ada City Lake also thermally stratified on several occasions while hydraulic dredging was in progress. Water temperature (Figs. 31-36) ranged from 1.8°C on January 23 to 26.2°C on June 19, 1985. Specific conductance (Figs. 37-42) varied from 400 to 465 $umhos.cm^{-1}$ in the immediate vicinity of the dredge, and pH (Figs. 43-48) ranged from 8.1 standard units on May 8, 1984 to a low of 5.9 standard units on June 19, 1985. Dissolved oxygen (Figs. 49-54) ranged from 12.7 $mg.L^{-1}$ to less than 0.2 and mg L^{-1} and oxygen saturation (Figs. 55-60) varied from 2 to 148 percent.

Post-dredging. Thermal stratification was also evident in Ada City Lake during post-dredging monitoring (Figs. 61-75). Water temperature ranged from 2.3°C on December 17 to 30.4°C on July 17, 1985. Specific conductance (Figs. 76-90) varied from 205 to 689 $umhos.cm^{-1}$; pH (Figs. 91-105) ranged from 8.7 standard units on August 1, 1985 to a low of 5.2 standard units on April 23, 1986 and chlorophyll a content (Fig. 20) was 174 $ug.L^{-1}$ on September 9, 1985. Dissolved oxygen (Figs. 106-120) ranged from 18.4 to less than 0.2 $mg.L^{-1}$ and oxygen saturation (Figs. 121-135) varied from 10 to 250 percent on August 1, 1985.

Stormwater Monitoring

The highest suspended sediment concentration of 6.37 $g.L^{-1}$ was obtained at station one (Fig. 136). Station 2, with a suspended sediment concentration of 2.31 $g.L^{-1}$, was followed by Station 4 with a mean and maximum concentration of 0.85 and 1.564 $g.L^{-1}$, respectively. Station 3 had a mean suspended sediment concentration of 0.59 $g.L^{-1}$ followed by Station 5 with a mean concentration of 0.06 $g.L^{-1}$.

As was the case with suspended sediment, total phosphorous was highest at Station 1, with a mean concentration of 2.2 $ug.L^{-1}$ (Figs. 137-138). Stations two, three and four followed sequentially with mean concentrations of 1.31, 0.72 and 0.41 $ug.L^{-1}$, respectively. Station five, with a total phosphorous concentration of 0.09 $ug.L^{-1}$, was the lowest mean concentration obtained for any tributary.

Nitrate-nitrogen (Figs. 139 and 140) was found at maximum concentration at Station 3, which exhibited a mean and maximum concentration of 1.58 and 2.91 $mg.L^{-1}$, respectively. Stations two, one, five and four followed in decreasing order with means of 1.04, 0.66, 0.62 and 0.61 $mg.L^{-1}$, respectively. Nitrite-nitrogen (Figs. 141 and 142) was 20 $ug.L^{-1}$ at Stations 1, 2 and 3 and was 10 $ug.L^{-1}$ at Stations 4, 5 and 6. The mean concentration of ammonia-nitrogen (Figs. 143 and 144) at Station 1 was 230 $ug.L^{-1}$, 210 $ug.L^{-1}$ at Stations 2 and 3 and 100 $ug.L^{-1}$ at Stations 4 and 5. Kjeldahl-nitrogen (Figs. 145 and 146) exhibited the highest mean value, 7.7 $mg.L^{-1}$, at Station one, followed closely by Station 2 which had a mean value of 7.52 $mg.L^{-1}$. Stations 3, 4 and 5 followed with kjeldahl nitrogen means of 3.86, 3.07 and 1.09 $mg.L^{-1}$, respectively.

Chlordane (Figs. 147 and 148) exhibited identical maximum mean concentrations of 220 $ug.L^{-1}$ at Stations 2 and 4, while Stations one, three and five exhibited mean concentrations of 1.0 $ug.L^{-1}$. Mercury was found at Stations two and three (Fig. 149) while 2,4-dichlorophenoxyacetic acid never exceeded the detection level of 1.0 $ng.L^{-1}$ at any tributary (Figs. 150 and 151).

SECTION VIII

DISCUSSION

Dredging

Effects on the water quality of Ada City Lake, due to the nature of the dredging operation, were expected and did occur. Hydraulic dredging increased the amount of total phosphorous (Fig. 152) and other nutrients in the water column and tended to lower pH (Fig. 95 and 96). It also decreased the amount of dissolved oxygen in the lake due to the oxygen demand of resuspended sediments. This was particularly apparent in the hypolimnion under conditions of thermal stratification (Figs. 35 and 53). Specific conductance did not increase during dredging, indicating that this parameter is largely controlled by a factor or factors in the watershed.

Water quality data acquired subsequent to the completion of dredging indicates that the water quality of Ada City Lake is steadily improving. Notable in this regard is the chlorophyll content (Fig. 20), which, after peaking in September of 1985, generally indicated a decreasing trend. Post dredging chlorophyll a values have decreased to about one half of the chlorophyll standing crop present prior to dredging (Fig. 20). A decrease in the magnitude of the oscillations in other parameters such as dissolved oxygen (Figs. 49-60), is also apparent in these data, and suggests that, over time, a further dampening and reduction of other parameter concentrations may occur.

Stormwater Monitoring

The hydraulic dredging of Ada City Lake has resulted in the transformation of a shallow hypereutrophic macrophyte-dominated reservoir into an aesthetically pleasing water body of appreciably greater depth (Figs. 3 and 4). Initial concern regarding the ability of earthen sediment storage pits to adequately handle and retain pesticides and herbicides, found in the reservoir's sediment, appears to be groundless, based upon samples obtained during stormwater monitoring (Figs. 147, and 150). Since these storage pits were located above Stations one and five, the data presented in Figures 147 and 150 clearly illustrates that sample means for chlordane total and 2,4-dichlorophenoxyacetic acid at these sites were generally equal to or less then the detection limits.

Higher than expected levels of chlordane (Fig. 147) and total mercury (Fig. 149) were found at Stations 2, 4, 2 and 3, respectively. Since Station 2 was located below a golf course (Fig. 1), it is reasonable to assume that these chemicals are associated with the maintenance of "greens". This assumption is supported by the fact that drains have been installed below these greens which lead and discharge directly to the tributary upstream from station two. The source or sources of chlorodane have not been confirmed to date. Chlordane is often used on golf course greens to eliminate insect pests while mercury is present in compounds used on greens for the control of grass fungi. Since Station three is located on a tributary which also receives drainage from the golf course, golf greens are possibly the source of its elevated mercury levels. The chlordane found at Station 4 cannot, however, be attributed to the golf course. Although the source or sources of this chlordane are presently unknown, it is likely that it is a non-point source manifestation of chlordane which was intentionally applied to the soil as a persistent pesticide prior to the pouring of footings and slabs for buildings. The fact that the watershed upstream from Station 4 is composed of rather densely-spaced residential dwellings supports this supposition.

Initially, questions were also raised regarding the storage pits' ability to handle and retain suspended solids, total phosphorous and ammonia and kjeldahl nitrogens. Data for these parameters, obtained as a result of stormwater monitoring activities, are present in figures 136, 137, 143 and 145. Inspection of these data reveals that a least squares regression line, connecting the means of parameter concentrations obtained at Stations 1 through 5, would have a negative slope. That is to say that as one progresses from Stations 1 through 5, the mean concentration of these parameters generally decreased. That Stations 1 and 5, which were both located downslope from sediment storage pits, were at opposite ends of this trend, or regression line, indicates that some factor other than the storage pits was responsible for the greatly elevated suspended solids, total phosphorus, ammonia and Kjeldahl nitrogen mean concentrations found at station one and elsewhere. Subsequent inspection of the watershed revealed that urban runoff is probably responsible for the elevated suspended solids and total phosphorus concentrations found in samples collected at this Station and also at Stations 2, 3 and 4. In contrast, elevated concentrations of kjeldahl, nitrite and ammonia nitrogens strongly suggest the occurrence of sewage contamination above Stations 1 through three. Inspection of the watershed upslope from Station 2 revealed several locations where sewage was or had obviously percolated through or displaced the sewer lines' manhole covers and had flowed out and over the ground. Presumably, this is due to the infiltration of rainwater into sewer lines which exceeds their design capacities.

SECTION IX

CONCLUSIONS

Hydraulic dredging of Ada City Lake has increased its volume by 40,000 M^3 and has greatly improved the recreational and aesthetic qualities of this water body. It has transformed a hypereutrophic reservoir into a eutrophic water body and this process of water quality improvement appears to be continuing. Sediment storage pits that were built to hold and dewater dredged material were found to be operating effectively.

During stormwater monitoring activities, several tributaries to Ada City Lake were found to contain higher than expected levels of nutrients, suspended sediment, chlordane and mercury. The sources of chlordane and mercury should be investigated and eliminated. Elevated nutrient levels, which appear to be due to infiltrating sewer lines, should be corrected by the installation of new or rehabilitated sewer lines in the watershed. Failure to improve these sewer lines will eventually result in Ada City Lake again becoming hypereutrophic.

The increase in impervious watershed area resulting from urban development is responsible for both the increased discharge and higher suspended solids load of tributaries to Ada City Lake. Efforts should be made to reduce the sharp peaking of the hydrographs of these tributaries through temporary storage of runoff.

SECTION X

GENERAL REFERENCES

APHA. 1985. Standard methods for the examination of water and and wastewater. 16th ed. American Public Health Association, Washington, D. C.

EPA. 1979. Methods for chemical analysis of water and wastes. Environmental Monitoring and Support Laboratory, U. S. Environmental Protection Agency, Cincinnati, Ohio.

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APPENDIX A

TASK 1

DREDGING AND STORAGE OF SEDIMENT

Ada City Lake has been dredged both hydraulically and mechanically. Forty thousand cubic meters of sediment was transported through a pipeline, dewatered and deposited in four earthen pits. Two of these pits have been landscaped and are now functioning as a golf green. The remaining two have been allowed to revegetate naturally. Sediment that was mechanically dredged, using a track-mounted backhoe, was transported by truck to the sediment disposal pits.

APPENDIX B

TASK 2

POLLUTION ABATEMENT MEASURES

Prior to the onset of this project, it was hypothesized in the workplan that "generous fertilizer application on the golf course grounds results in runoff with a high nutrient content." Subsequently, however, stormwater runoff data have been acquired which indicates that overloaded and overflowing sewer lines, and not fertilizer application, are responsible for the elevated nutrient content of stormwater which enters Ada City Lake.

The elevated suspended solids concentration found at Station one is due to reduced infiltration of rainwater into the soil which is caused by urban paving of the land surface. Major watershed modification, beyond the scope of this study, would be required to reduce the amount of runoff water which reaches Station 1. Although a reduction in peak discharge at Station 1 cannot be effected immediately, subsequent planning and construction activities in this watershed should incorporate measures, such as stormwater detention ponds, to reduce the amount of surface runoff water.

APPENDIX C

TASK 3

ENVIRONMENTAL MONITORING PROGRAM

Prior to the implementation of dredging operations, baseline water quality and sediment analyses were conducted as described in the main report (see page 10). Chlordane and 2, 4-D were found at 490 $ug.kg^{-1}$ and 5,080 $ug.kg^{-1}$ levels, respectively, at Station 8. USGS alert levels for 2,4-D and chlordane in sediments are both 20 $ug.Kg.^{-1}$. Subsequent sediment analysis using the E.P. Toxicity Methods indicated 2,4-D was present in concentrations of less than 0.10 $ug.L^{-1}$ and that chlordane was present at less than 0.70 $ug.L^{-1}$. However, total mercury concentrations of 3.61 and 2.96 $ug.L^{-1}$ were found. Fish that were examined--largemouth bass, channel catfish and bullhead catfish--were found to have chlordane residues of 88, 435 and 358 $ug.Kg^{-1}$, respectively. The FDA action level for chlordane in fish flesh is 300 $ug.Kg^{-1}$. Reexamination of largemouth bass and crappie composite fish flesh residues from samples collected June 28, 1985 indicated, that at the detection limit of 50 $ug.Kg^{-1}$, no mercury, 2,4-D, silvex, 2,4,5-T, dicamba or chlordane were recovered.

Although catfish were not included in our last sampling effort, the latest fish flesh residue data obtained indicates that the FDA action level was not exceeded.

Stormwater monitoring of the tributaries to and outflow from Ada City Lake indicates that problems still exist regarding suspended solids, total phosphorous, ammonia, nitrite and kjeldahl nitrogens as well as with chlordane and mercury pollution. The installation of new sewer lines and careful management of the golf course should help eliminate these problems. City planners should be aware of the urban runoff problem and should incorporate stormwater detention or slow release methods where possible. Further investigation would be necessary to determine the source or sources of chlordane above Station 4.

Prior to dredging, emergent and subemergent aquatic macrophytes occupied approximately 50 percent of the surface area of the reservoir. After dredging was completed, they occupied less than one percent of the reservoir's surface area. It is anticipated that there will be regrowth and redevelopment of macrophytes in Ada City Lake, particularly in its headwaters. This is normal and should not be cause for concern. Ada City Lake is presently eutrophic and its water quality appears to be improving over time. Consequently, improvement in its aesthetic quality should also continue.

APPENDIX D

TASK 4

UPGRADING WATER QUALITY STANDARDS

INTRODUCTION

Task 4 of the Ada City Lake Clean Lake Phase II Workplan, requires a review of the designated beneficial uses for Ada City Lake and Lake Creek as listed in the Oklahoma Water Quality Standards, 1985. The designated beneficial uses for Lake Creek, including Ada City Lake,are: Secondary Warmwater Fishery, Agriculture, Industrial and Municipal Process and Cooling Water, Secondary Body Contact Recreation and Aesthetics. These uses were automatically designated according to Section 7 of the Standards since the stream segment is not listed in Appendix A of the Standards. The review of the beneficial uses consisted of a series of one day site-specific surveys to determine if the stream, lake and its tributaries can support higher beneficial uses.

Methods

Methods used for data collection and quality control are listed and described in the justification for the 1985 revisions to the Oklahoma Water Quality Standards. The survey consisted of two parts: Lake Creek; and Ada City Lake and its tributaries.

Watershed and Land Use

Lake Creek (including Ada City Lake) is a tributary of Clear Boggy Creek in the cross timber ecotone in east-central Oklahoma. Lake Creek flows due south from Ada City Lake for approximately one mile to its confluence with Clear Boggy Creek in Section 3, Township 3N, Range 6EIM (Fig. 1).

Climate

Elevation of the Ada City Lake Spillway is 885 feet MSL NGUD, which is typical for the hilly cross timber ecotone. The climate is moist, subhumid with a mean annual precipitation of 39 inches and combined evaporation and transpiration rates of 34 inches. Temperature varies from 112° to 0.6°F with an annual mean temperature of 62.4°F. July and August usually are the hottest months while May is usually the wettest month. The large amounts of precipitation and runoff in this region foster frequent damaging floods but, because of the impoundment, Lake Creek is not usually subject to highly variable flows. The high rate of precipitation, the naturally rough, steep terrain and the urbanization of the watershed result in substantial flow to the tributaries of Ada City Lake within the comparatively small drainage area.

Soils

Soils vary from loamy underlain by limestone and chert to well-drained soils underlain by sandstone and clay to claying soils underlain by calcareous clay and shale as the creek approaches Clear Boggy Creek. The loamy, well-drained soils absorb and transmit water rapidly so that the ephemeral flows in the tributaries persist only for a few days after a rain. The claying soils absorb less water but transmit it slower so that first permanent pools and then permanent flow occur in downstream segments of the creek below the dam. Thus, the flow characteristics of Lake Creek and tributaries of Ada City Lake conform predictably to patterns of climate and soils in the watershed.

Stream Orders

Tributaries above Ada City Lake are first order streams while Lake Creek, below Ada City Lake to Clear Boggy Creek, is a second order stream (Fig. 1) Classical stream orders are described by Horton (1945).

RESULTS AND DISCUSSION

The beneficial use survey was divided into two parts with Ada City Lake dam being the boundary line. Therefore, the survey results are presented in two parts.

Ada City Lake Tributaries

Four tributaries flowing into Ada City Lake from the north (1-4) and one from the east (5) were examined (Fig. 1). Since none of these tributaries are large enough to merit consideration as primary warmwater fisheries or primary body contact recreation, the usual field sheets were not filled out. Instead, a summary of observations of each creek is presented, and photographs are available.

The westernmost creek (Cr. #1 in the Figure) headwaters north of the football stadium on East Central University property. Several university buildings are in the vicinity. The remaining area is primarily lawn, paved street and parking area. Nutrient enrichment was evident from the algal growth in the stream but little erosion was observed.

The stream flows south under Norris field stadium and then through a university housing area. Seeps into the creek near the north end of the housing area did not appear to be natural springs. Again, high nutrient levels were evidenced by the stream algae, and erosion was seen in the vicinity of a road repair. The stream ran clear and most of the area was occupied by lawns in the housing area. A good riparian zone exists near the creek with trees in abundance. The banks appear stable and habitat is abundant but the stream is too small to support much in the way of a fish population. The stream has considerable freestone and bedrock areas, with the rest gravel.

Further downstream, the stream flows through an area being made into a golf course and past one of the sludge pits used for dredging the lake. The pit has been covered over and is no longer noticeable.

As tributary #1 enters the lake, it is clear at low water levels. High nutrient levels are evidenced by the algae, but minnows, small bass and green sunfish were observed.

Tributary #2 (See Figure) has more flow than the others. Most of its drainage basin is the golf course which is being modified and expanded. The golf course modification has a large impact on this creek. The headwaters of the stream are in the northernmost portion of the golf course. The water was turbid, perhaps due to the cement washing or dumping that was in evidence. The golf course expansion continued to affect the creek further downstream. Vegetation was not thick enough to completely hold the soil so the water remained turbid. Some areas of completely bare soil and obvious erosion existed. Since the golf course lies on both sides of the creek, there are no trees in the riparian zone in the northern portion of the watershed. Wooden riprap confines the stream to a narrow, deep channel in one section. Several low water crossings exist within the golf course. These contribute to the turbidity. Some crossings have concrete low water bridges in the creek bottom with gravel roads leading down steep banks to them. This poor design invites erosion and causes turbidity.

A drainage system for the greens is being developed. Drains were noticed being laid directly from the greens to the stream. Intensive watering and fertilization required to grow and maintain the greens will result in nutrients entering the stream. Since little algae or aquatic macrophytes exist in the stream, nutrient uptake will be slow and most of these nutrients will end up in the lake.

Trees appear in the riparian zone in the southern half of Creek #2's watershed. Parts of the riparian zone are densely forested and very little bare soil was observed there, except at low water crossings.

No aquatic animals and little algae were observed in the golf course tributary. Besides turbidity, toxicity may contribute to this conditions. Many golf courses use pesticides and herbicides which, when washed into the creek by irrigation or rainwater, can inhibit growth and reproduction of aquatic life.

Steps have been taken by golf course management to control erosion and reduce turbidity in the creek. After the golf course expansion is completed, erosion should be minimized. Areas of concern which will remain are the low water crossings, which will contribute sediment directly to the stream, and the drains from the greens, which will contribute nutrients, herbicides and pesticides and overloaded infiltrating sewer lines. The sewer lines are not the golf course's problem, and they will require the attention of the City of Ada. These sources may cause the golf course tributary to contribute more pollution to Ada City Lake than other tributaries will in the future.

Tributary #3 (see Fig. 1) has an undisturbed riparian zone with dense vegetation through much of its length although the watershed lies largely in a residential area. It does receive some golf course runoff. The headwaters actually run down the center median of a residential road. The substrate in this tributary contains much more clay material than the freestone areas of tributary #1. The water was clear as it entered the lake and minnows and small sunfish were seen near the mouth of the creek.

The next tributary east, #4 (see figure), probably has the best water quality. The headwaters are very clear with only a little algae. The substrate is primarily sand and bedrock. Further downstream, minnows were observed in abundance. Increasing algae downstream indicates some nutrient loading from nearby residential areas, even through this tributary flows through more undisturbed area than the others do.

The tributary joining the lake on the southeast side was dry at the time of observation. The sludge pits, into which dredge material was pumped, have been covered over, although not reclaimed. There is no evidence that they erode into the stream and they do not appear to affect water quality in the lake.

There are no current point sources of pollution in the watershed of Ada Lake, except for the green drains on the golf course. However, a considerable nutrient load is delivered from the watershed to the lake. No additional loading can be tolerated. Therefore, the lake and watershed should have the "a" beneficial use limitation applied in the Oklahoma Water Quality Standards. This will protect the lake by prohibition of any new point source discharge which would increase pollutant loading or increased load from an existing point source. The "a" also encourages best management practices for control of nonpoint source discharges.

LAKE CREEK

Physical Characteristics

Volume of flow. The volume of flow was .3 cfs at Lake Creek park during low flow conditions and 2.5 cfs during Spring conditions. The volume of flow below the park before entering Clear Boggy Creek increases only slightly due to groundwater discharge.

Temperature. Temperature of the water was 18.6°C above the riffle and 19.0°C below the riffle at Station 1 (See Figure 153) and 19.4°C at 6" water depth and 18.5°C at 4' water depth at Station 2. These mild temperatures reflect the warm weather that occurs during the month of May. Also, the difference in the temperatures may be accounted for by the smaller volume of water at Station 1 warming more quickly than the larger volume at Station 2.

Chemical Characteristics

Dissolved oxygen. The water at Station 1 contained 8.0 mg/l of dissolved oxygen while the computed saturation value was 9.3 mg/l. Thus, the existing concentration is 86 percent of saturation. At Station 2, the existing concentration was 7.3 mg/l and the saturation value was 9.25 mg/l. Therefore, dissolved oxygen there was 78.9 percent of saturation.

Aeration through the surface is slow unless the surface film is broken by turbulence caused by water falls or the railed surface of riffles. Falls and riffles exist immediately above Station 1 and is typical of the creek below the dam. At Station 2 no riffles or falls were in the immediate area upstream of the station, which is typical of the creek below the park. Therefore, at Station 1, the higher dissolved oxygen concentration in the water was probably due to riffles. There is no reason to believe that dissolved oxygen concentrations would be low enough in summer to preclude colonization by intolerant benthos and fishes which are indigenous to the region. The pH indicates mildly akaline conditions at both stations (7.4 at Station 1 and 7.2 at Station 2), probably because of relatively high concentrations of biocarbonates. The specific conductance (704 umhos.cm^{-1} at Station 1 and 717 umhos.cm^{-1} at Station 2) tends to substantiate the presence of bicarbonates. Both parameters are suitable for the intolerant warmwater fishes of this region.

Land Use

Station 1. Wintersmith Park surrounds Lake Creek at Station 1. The park has an amphitheater, jogging and nature trails, picnic tables and park benches. The bank and riparian zone are maintained by the park service. The bank is 5 percent devoid of cover with 70 percent vines and shrubs, 10 percent grass, and 20 percent trees. The vegetative cover is dense. The bank slope consists of 5 percent flat, 25 percent moderate and 60 percent vertical. The riparian cover consists of 5 percent grass, 60 percent shrubs/vines and 35 percent trees with dense vegetative cover. The stream canopy is heavy with partial to total shading of the stream.

Station 2. Lake Creek at station 2 is surrounded by 95 percent natural undisturbed cover and 5 percent residential use. The bank is 15 percent devoid of cover due to rocks with the dense vegetative cover primariliy consisting of 10 percent grass, 70 percent shrubs and vines and 20 percent trees. The bank slope is 25 percent moderate, 60 percent steep and 15 percent vertical. The dense riparian vegetative cover consists mainly of 10 percent grass, 70 percent shrubs and 20 percent trees. The stream canopy is heavy with partial to total shading of the stream.

Habitat

Station 1. Riffles comprise only 5 percent of the surface area of the creek. The mean dimensions of riffles are 30 Ft. long, 2.5 Ft. wide, and 0.33 Ft. deep. Velocity of flow was 2.0 feet/second (ft/sec). Bottom material was comprised of 30 percent sand, 50 percent gravel and 20 percent large rocks. Some man-made falls were observed in the creek in the vicinity of Station 1. Rocks and artificial substrate (cement and rocks) are adequate for small quantities of benthos or for any riffle-dwelling fishes.

Areas of flat run comprised 5 percent of the creek at Station 1. Typical stream dimensions at the time of the survey were 30 ft. long, 3 ft. wide and 1 ft. deep. Velocity of flow was approximately 1 ft./sec. Bottom material at the site is approximately 50 percent sand, 45 percent gravel and 5 percent large rocks. Gravel and man-made substrate were present in some flat runs.

Production of benthos is relatively sparse in sand but approximately 20 linear feet of gravel and large rocks per run provide substrate for relatively high rates of production. Therefore, overall production of benthos is moderate. This habitat also is adequate for small, intolerant, shallow stream fishes which do not specifically require riffles.

The remaining 90 percent of the surface area at Station 1 consisted of pools. In general, the pools were 100 yards long, 20 ft. wide and 3 ft. deep. Velocity of flow was too slow to measure. Composition of bottom materials varied but typical pools contained 5 percent organic detritus, 15 percent clay, 5 percent silt, 30 percent sand, 25 percent gravel and 20 percent rock and rubble. Sparse logjams and brush piles, occasionally found large root systems and boulders, combined with the size and depth of pools, constituted excellent habitat for many warmwater fishes.

Station 2. Riffles comprised 30 percent of the surface area at this site. The mean dimensions of riffles were 20 ft. long, 3 ft. wide and 0.5 ft. deep. Velocity of flow was 2.5 ft./sec. Bottom material was comprised of 10 percent sand, 30 percent gravel, 40 percent large rocks and 20 percent bedrock. Rocks, gravel and undercut bedrock enhance the habitat for benthos and fishes and provide cover and concealment for riffle-dwelling fishes. Moderate reproduction probably occurs in both benthos and fishes.

Flat runs, which had mean dimensions of 15 ft. long, 4 ft. wide and 1 ft. deep, made up 20 percent of the site's surface area. Velocity of flow was 2 ft./sec. Composition of bottom materials within the areas of flat run consisted of 45 percent sand, 20 percent gravel, 30 percent bedrock and 5 percent large rocks. Approximately 40 percent of the bank was undercut, including occasional large tree-root systems and abundant, but small, vines. Brush piles, logjams, and large rocks occurred in the channel. Undercut banks and tree/vine roots provide habitat for sunfishes and small catfishes.

Pools comprised about 50 percent of the surface area of the creek at Station 2. Mean dimensions were approximately 40 ft. long, 15 ft. wide and 2.5 deep. Velocity of flow was approximately 0.5 feet/sec. Composition of bottom materials was typical with other habitats at 5 percent clay, 55 percent sand, 30 percent gravel and 10 percent large rocks. Undercut banks, tree roots, brush, logs and large rocks provide habitat for warmwater fishes.

CONCLUSIONS AND RECOMMENDATIONS

The tributaries of Ada City Lake receive sources of pollutants from the golf course and watershed urbanization (pesticides and nutrients). No additional loading can be tolerated by the lake. Therefore, the watershed should have the "a" beneficial use limitation placed upon it in the Oklahoma Water Quality Standards. This designation is needed to restrict additional pollutant loading from point sources. Since the lake currently supports a sport fishery, the primary warmwater fishery beneficial use should be applied to it. Even though the tributaries do not generally contain sufficient flow to support the primary warmwater fishery use, this use should be applied to protect other current uses of the lake.

The lake's limited watershed cannot supply enough water for a reliable municipal supply. Therefore, only the emergency water supply use should be designated. In summary, Ada City Lake and its watershed should be designated "a", primary warm water fishery, primary body contact recreation, and emergency water supply.

Lake Creek is an intermittent stream but man-made impoundments contain enough refuge pools, along with natural habitat, to minimally support a primary fishery. This use should be realized when water quality becomes adequate. Pools in the creek also occasionally support primary body contact recreation. Since the flow in the creek is intermittent under critical conditions, the public and private water supply use cannot be achieved.

In summary, beneficial uses which should be designated for Lake Creek include primary warmwater fishery, primary body contact recreation and emergency water supply. These uses are the highest that this creek can support and they are only achievable when water quality improves.

Literature Cited

Horton, R. E. 1945. Erosional development of streams and their drainage basins; hydro-physical approach to quantitative morphology. Bulletin of the Geological Society of America 56: 275 - 370.

OWRB. 1985. Oklahoma's water quality standards, 1985. Oklahoma Water Resources Board Publication No. 127. Oklahoma City.

Bogard V. A. 1973. Soil Survey of Pontotoc County, Oklahoma United States Department of Agriculture Soil Conservation Service, Washington, D. C.

APPENDIX E

TASK 5

STATE MANAGEMENT AND MAINTENANCE OF PROJECT

The City of Ada is responsible for protecting the water quality and quantity of Ada City Lake. It is their responsibility to protect the lake so that the beneficial effects of dredging on the aesthetic and recreational use of Ada City Lake are not allowed to be reversed. As a result of several conversations with Mr. Randy McFarlin, Ada City Parks Superintendent, I am quite confident that the City of Ada intends to protect their newly renovated reservoir. The installation of new sewer lines within portions of the watershed and careful maintenance of the park area surrounding the reservoir attests to these facts.

APPENDIX F

TASK 6

MAINTENANCE OF EQUIPMENT

No equipment was purchased with the Clean Lakes funds that were used for lake restoration.

APPENDIX G

TASK 7

MITIGATING MEASURES TO MINIMIZE ADVERSE ENVIRONMENTAL IMPACT DURING RESTORATION ACTIVITIES

Four sediment dewatering and storage pits were used on this project, each of which was designed to handle 10,000 cubic meters of sediment. These pits were built in series at two locations. Building them in series, so that water from the pipelines' sediment-water slurry flowed first through one pond and then through the second, permitted the majority of the sediment to settle prior to the slurry water's return to Ada City Lake. Inspections of these pits were made routinely during the course of the project and, as a result of careful management by Mr. Randy McFarlin, they continued to function effectively during the dredging process.

APPENDIX H

TASK 8

PUBLIC PARTICIPATION

Public hearings have been conducted as required during the course of this project. A final public hearing has been scheduled in Ada to complete the project. During the course of our field work on Ada City Lake we have been informed on several occasions of how people greatly appreciate the dredging project. To date, no adverse responses have been received from any individual, public agency or the private sector regarding the restoration of Ada City Lake.

APPENDIX I

TASK 9

PRINTING FINAL REPORT

The final report was prepared in a manner which facilitates easy comprehension of the results of the project. An effort has been made to simplify and clarify the text to the greatest extent possible.

APPENDIX J

TASK 10

PROJECT LEADER ADMINISTRATION

The Oklahoma Water Resources Board acted as project leader on this Phase II Clean Lakes Restoration Project. The City of Ada contracted with and provided the dredger, while the OWRB conducted water quality monitoring, administered the project and authored the final report.

APPENDIX K

TASK 11

COORDINATOR ADMINISTRATION

The Oklahoma Department of Pollution Control provided interagency coordination, transmitted reports, reviewed the progress of the project and submitted all required financial reports to EPA.

APPENDIX L

TASK 12

QUALITY ASSURRANCE REPORT

PARAMETER		
O-PO4 (Accuracy)	n = 24 X = 96.4 SD = 6.8	Current UCL = 112.3 UWL = 107.0 X = 96.4 LWL = 85.5 LCL = 80.2 SD = 5.3
O-PO4 (Precision)	n = 25 X = 0.014 SD = 0.026	Current CL = 0.21 WL = 0.15 X = 0.03 SD = 0.06
Nitrate-N (Accuracy)		Current UCL = 163.8 UWL = 145.5 X = 108.9 LWL = 72.3 LCL = 54 SD = 18.3
Nitrate (Precision)		Current LL = 0359 WL = 0259 X = .0059 SD = .01
Ammonia (Accuracy)	n = 36 X = 101.3 SD = 8.1	Current UCL = 121.1 UWL = 114.7 X = 101.9 LWL = 89.1 LCL = 82.7 SD = 6.4
Ammonia (Precision)	n = 16 X = .091 SD = .095	Current CL = .47 WL = .35 X = .011 SD = .12

PARAMETER		
Solids (Precision)	n = 63 X = 4.9 SD = 5.8	CL = 17.2 WL = 12.9 X = 96.4 SD = 4.3
Chlorophyll (Precision)	n = 16	CL = 23.8 WL = 18.3 X = 7.3 SD = 5.5
Pheophytin (Precision)	n = 16	CL = 26.3 WL = 20.0 X = 7.4 SD = 6.3
Total Phosphorous (accuracy)	n = 33 X = 98.2	UCL = 127.6 UWL = 118.2 X = 99.4 LWL = 80.6 LCL = 71.2 SD = 9.4
Total Phosphorous (precision)	n = 28 X = .014 SD = .025	LL = .020 WL = .015 X = .005 SD = .005
Kjeldahl (Accuracy)	7/85 to 5/87 n = 47 X = 99.4 SD = 7.2	UCL = 120.0 UWL = 113.1 X = 99.3 LWL = 85.5 LCL = 78.6 SD = 6.9
Kjeldahl (Precision)	n = 48 X = 0.12 SD = 0.18	CL = 0.80 WL = 0.58 X = 0.14 SD = .22

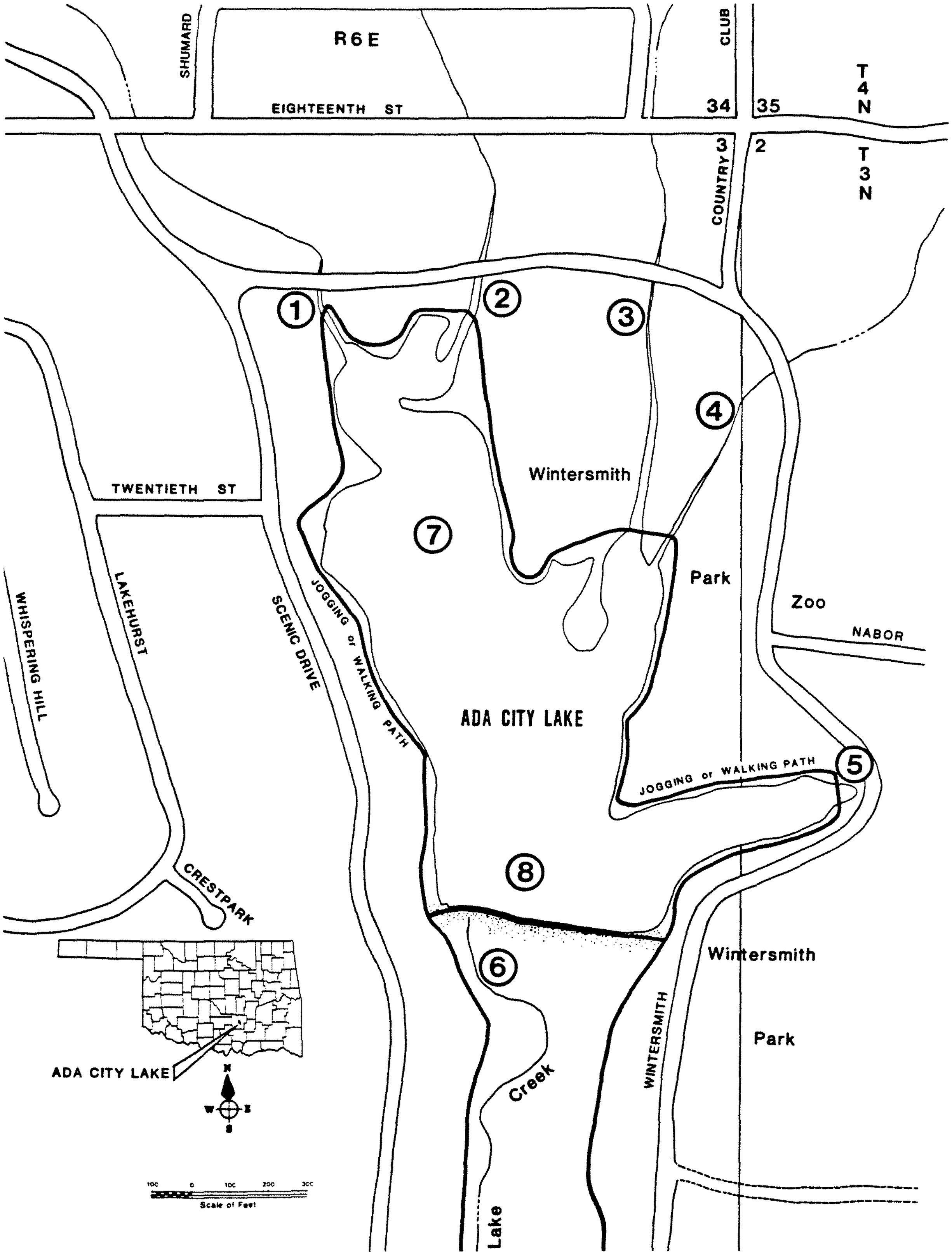

Figure 1. The locations of Ada City Lake and of sampling stations used in this study.

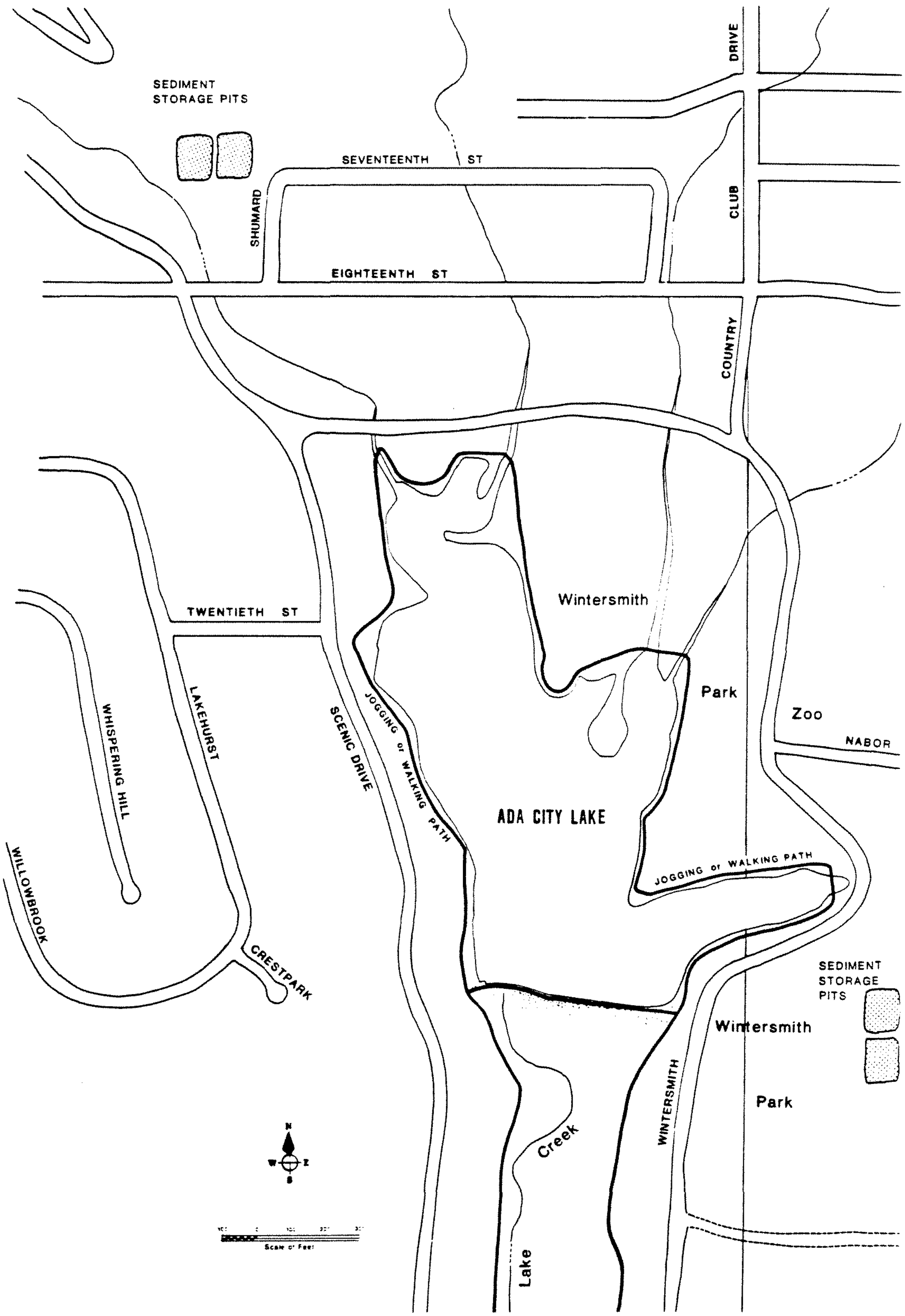

Figure 2. Locations of sediment storage and dewatering pits used in this project.

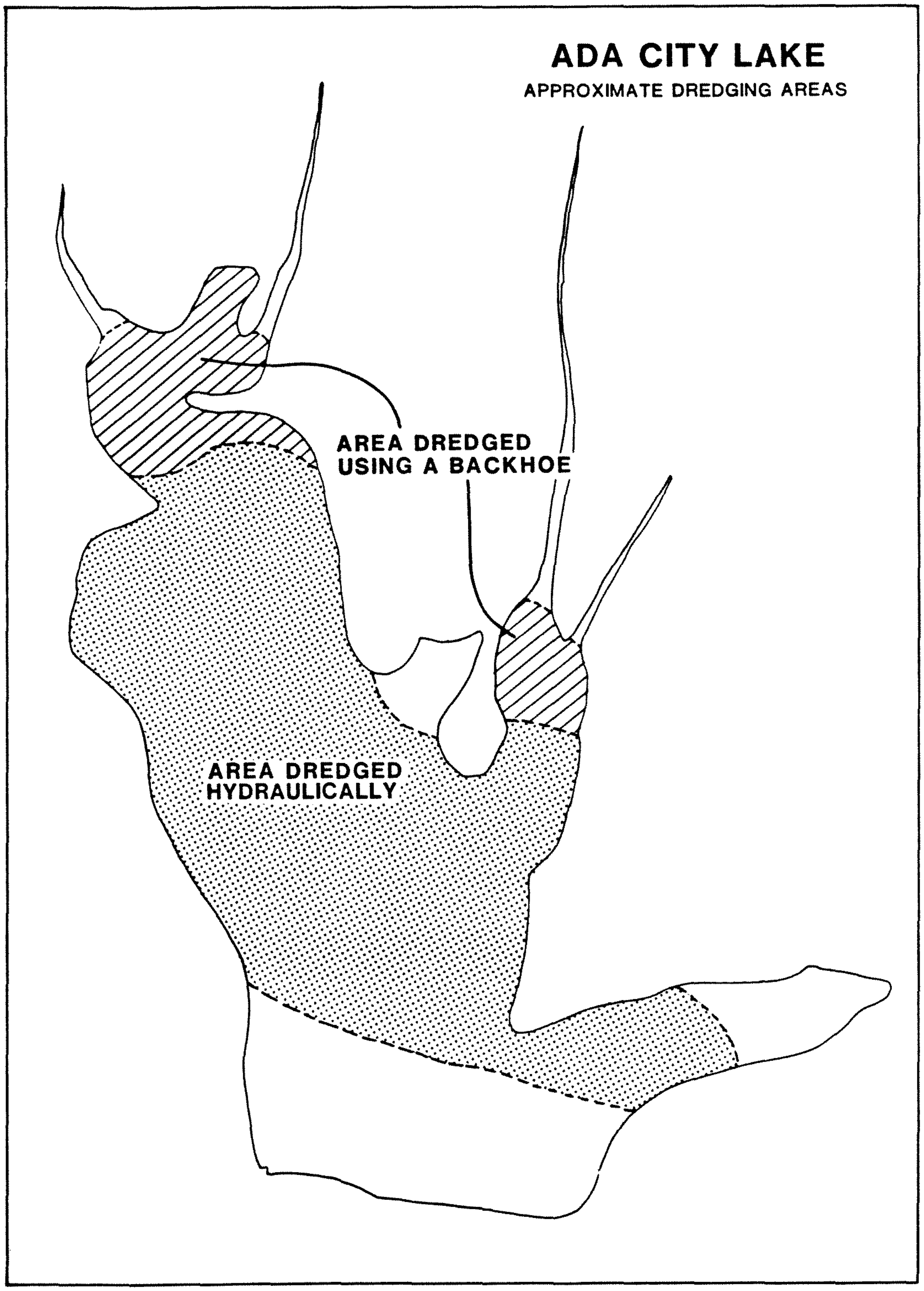

Figure 3. Areas within Ada City Lake that were dredged hydraulically and mechanically.

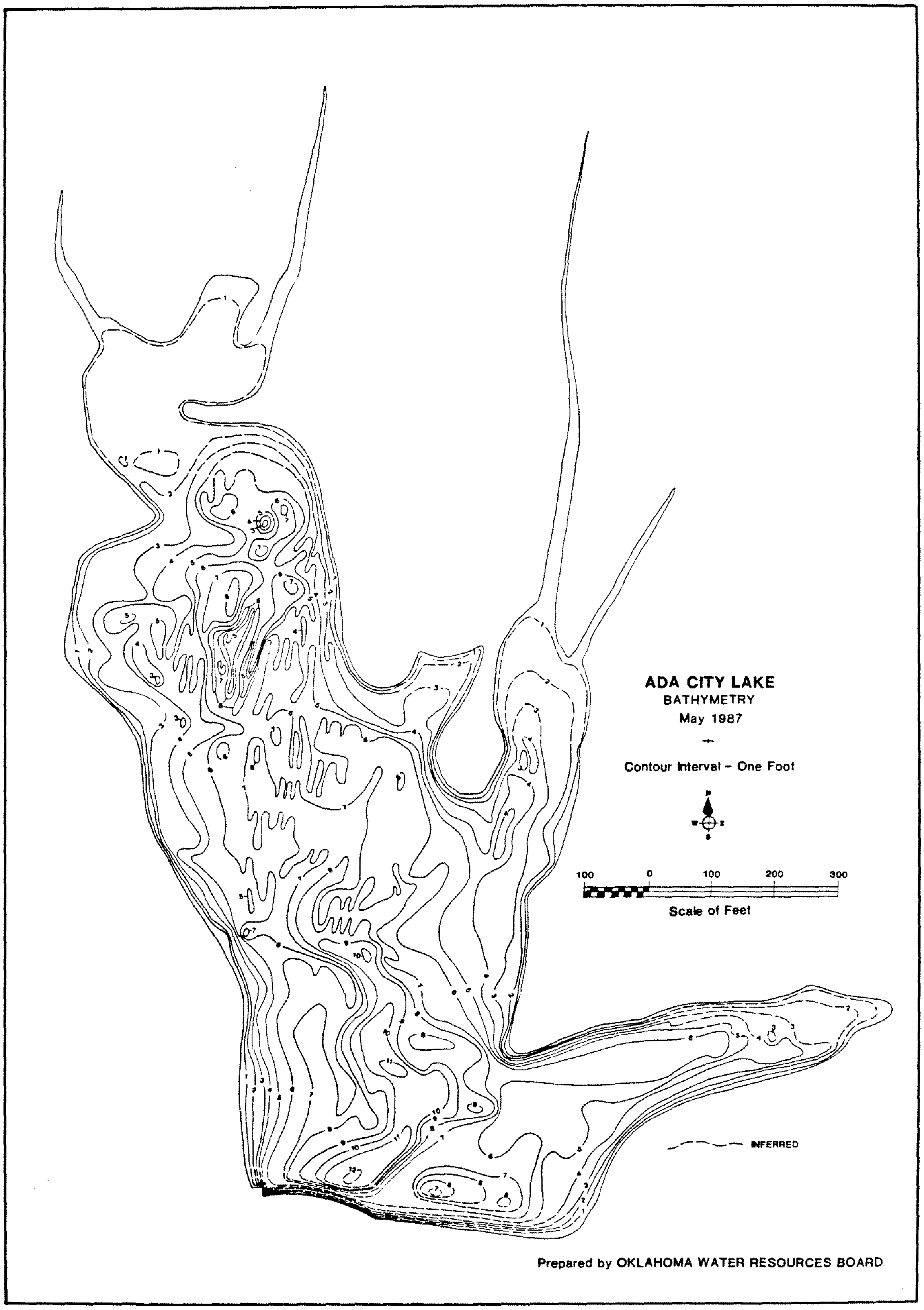

Figure 4. Bathymetric map of Ada City Lake based upon sonar data collected in May of 1987.

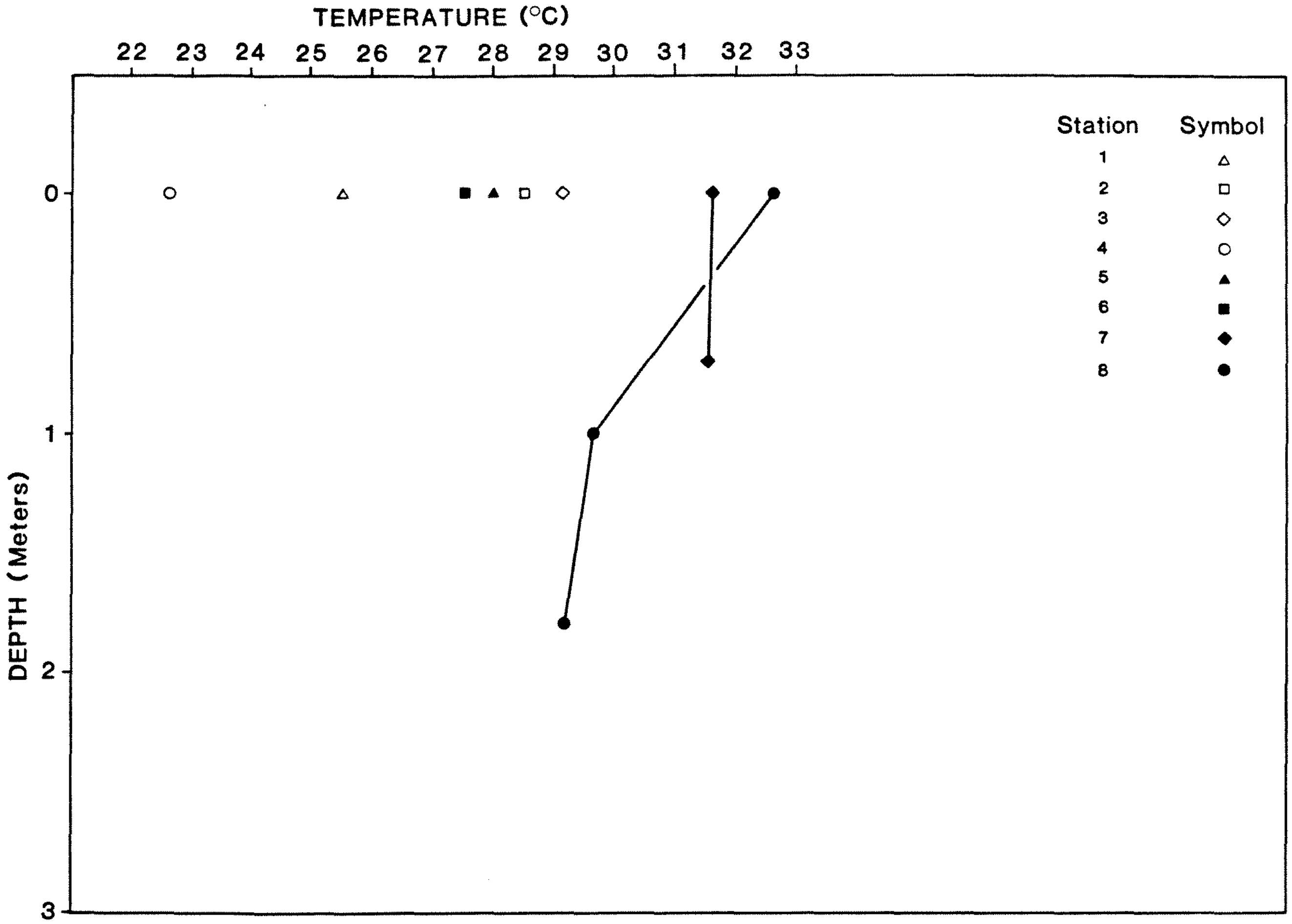

Figure 5. Vertical thermal profile and ancillary thermal data collected 11 August 1982 on Ada City Lake.

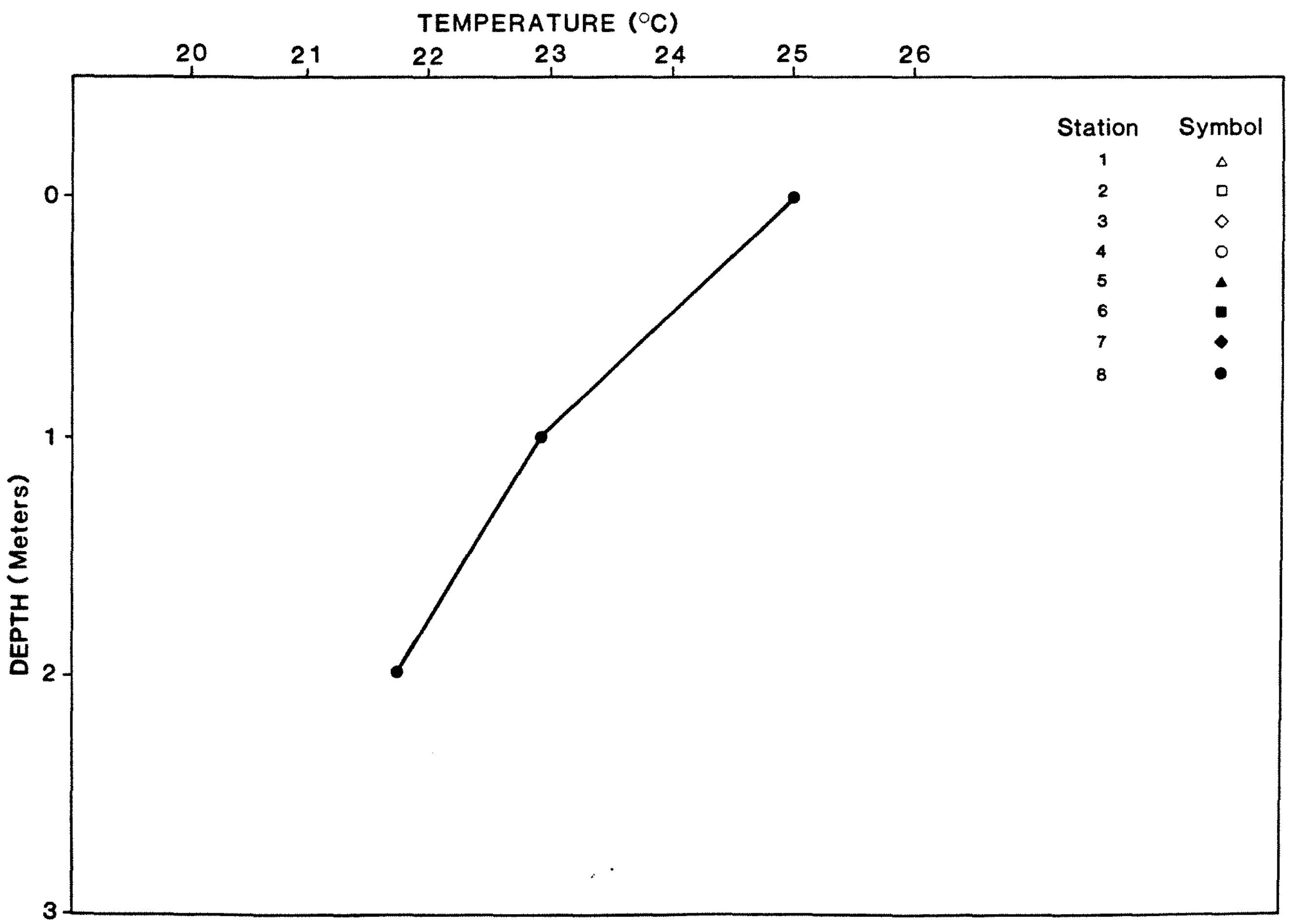

Figure 6. Vertical thermal profile and ancillary thermal data collected 30 September 1982 on Ada City Lake.

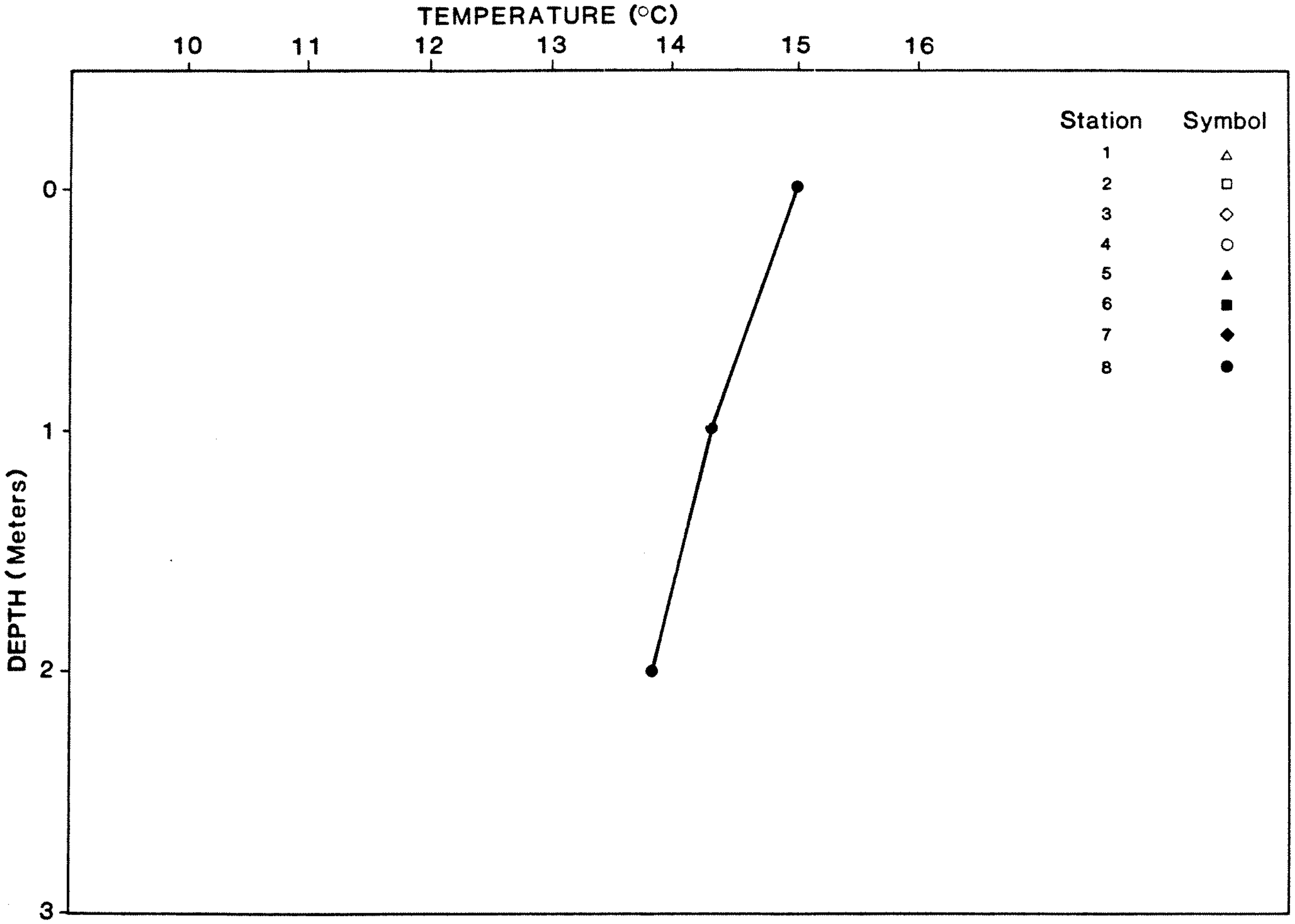

Figure 7. Vertical thermal profile and ancillary data collected 9 November 1982 on Ada City Lake.

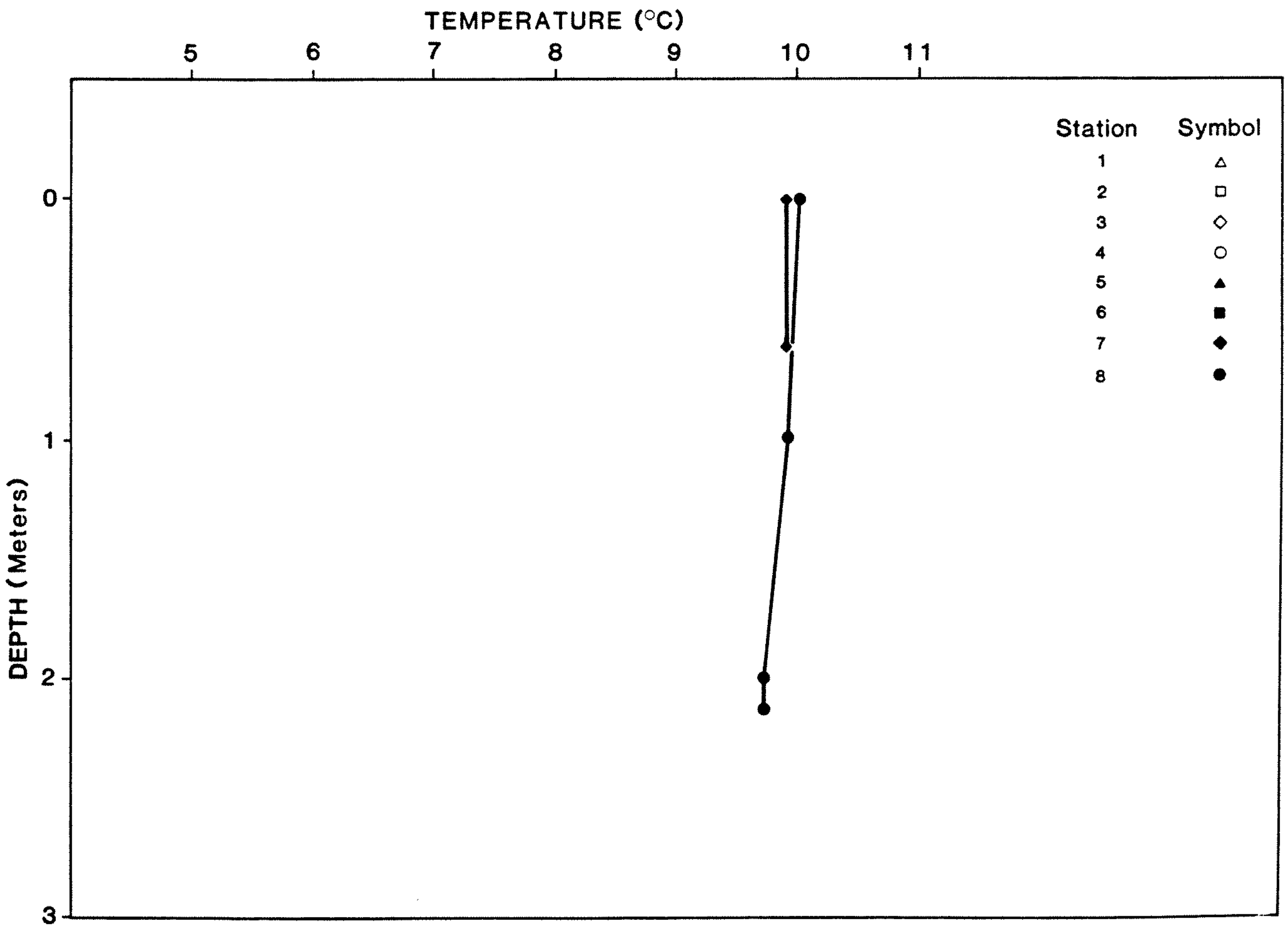

Figure 8. Vertical thermal profile and ancillary thermal data collected 7 December 1982 on Ada City Lake.

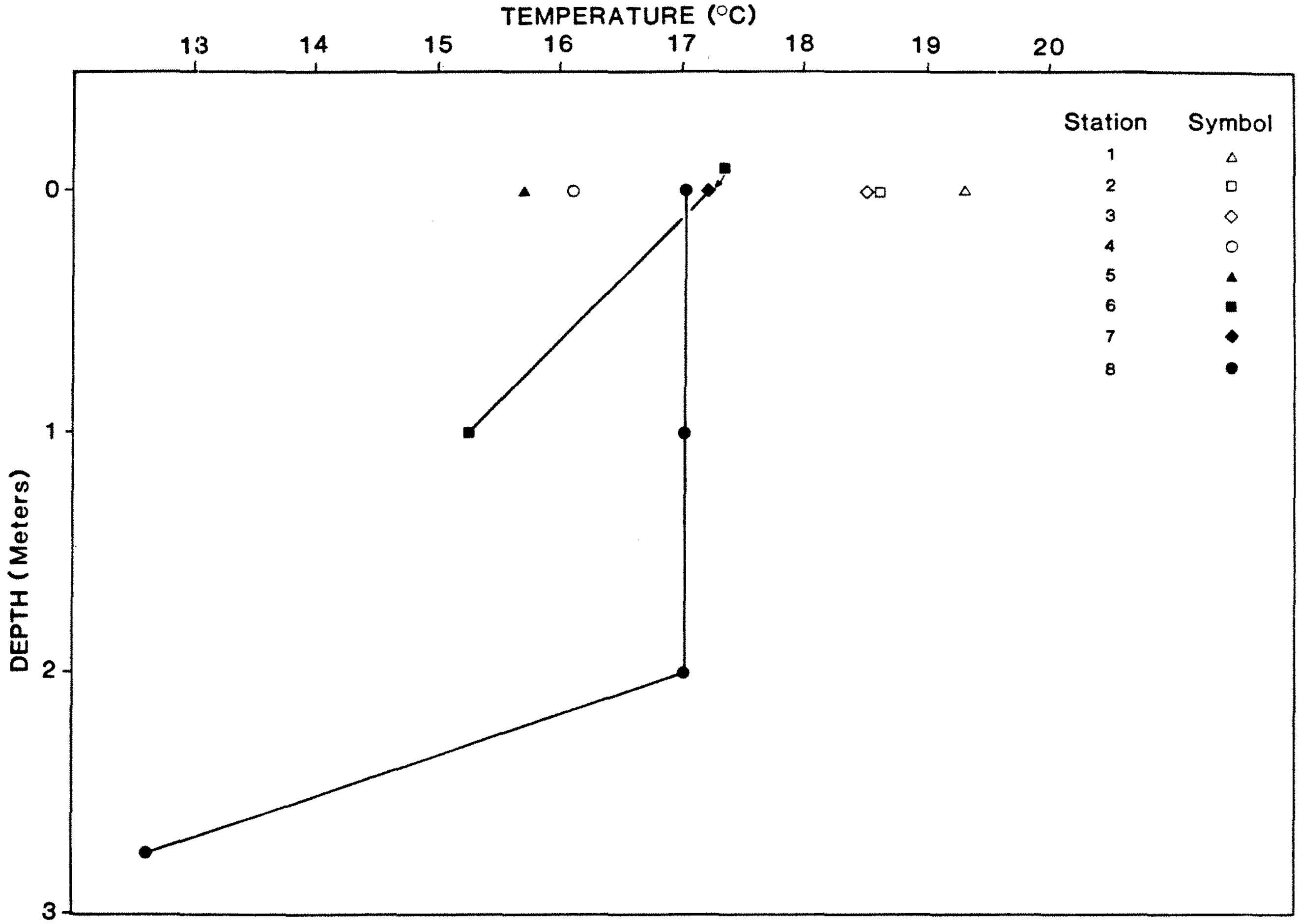

Figure 9. Vertical thermal profile and ancillary thermal data collected 16 March 1983 on Ada City Lake.

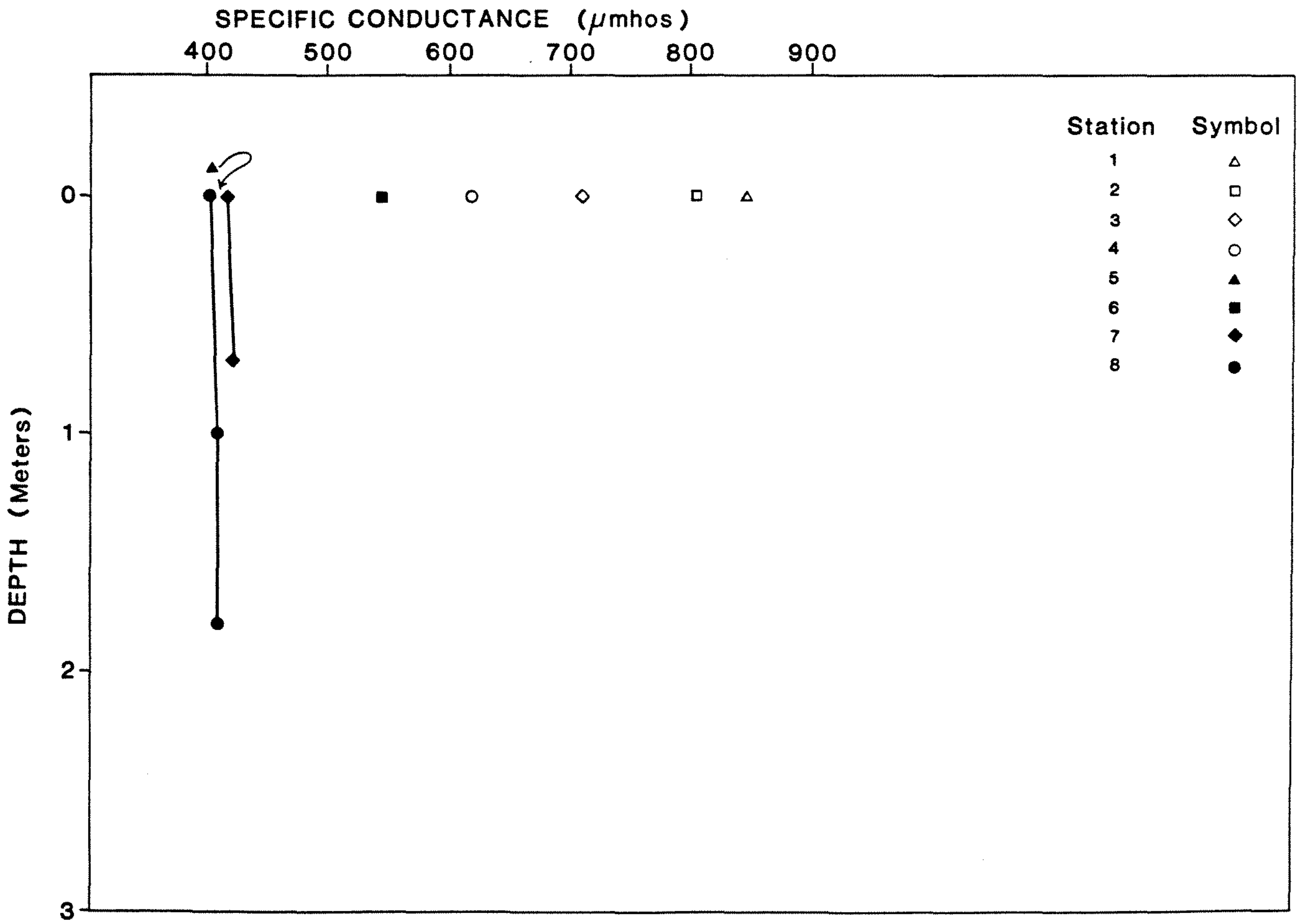

Figure 10. Vertical conductivity profile and ancillary specific conductance data collected 11 August 1982 on Ada City Lake.

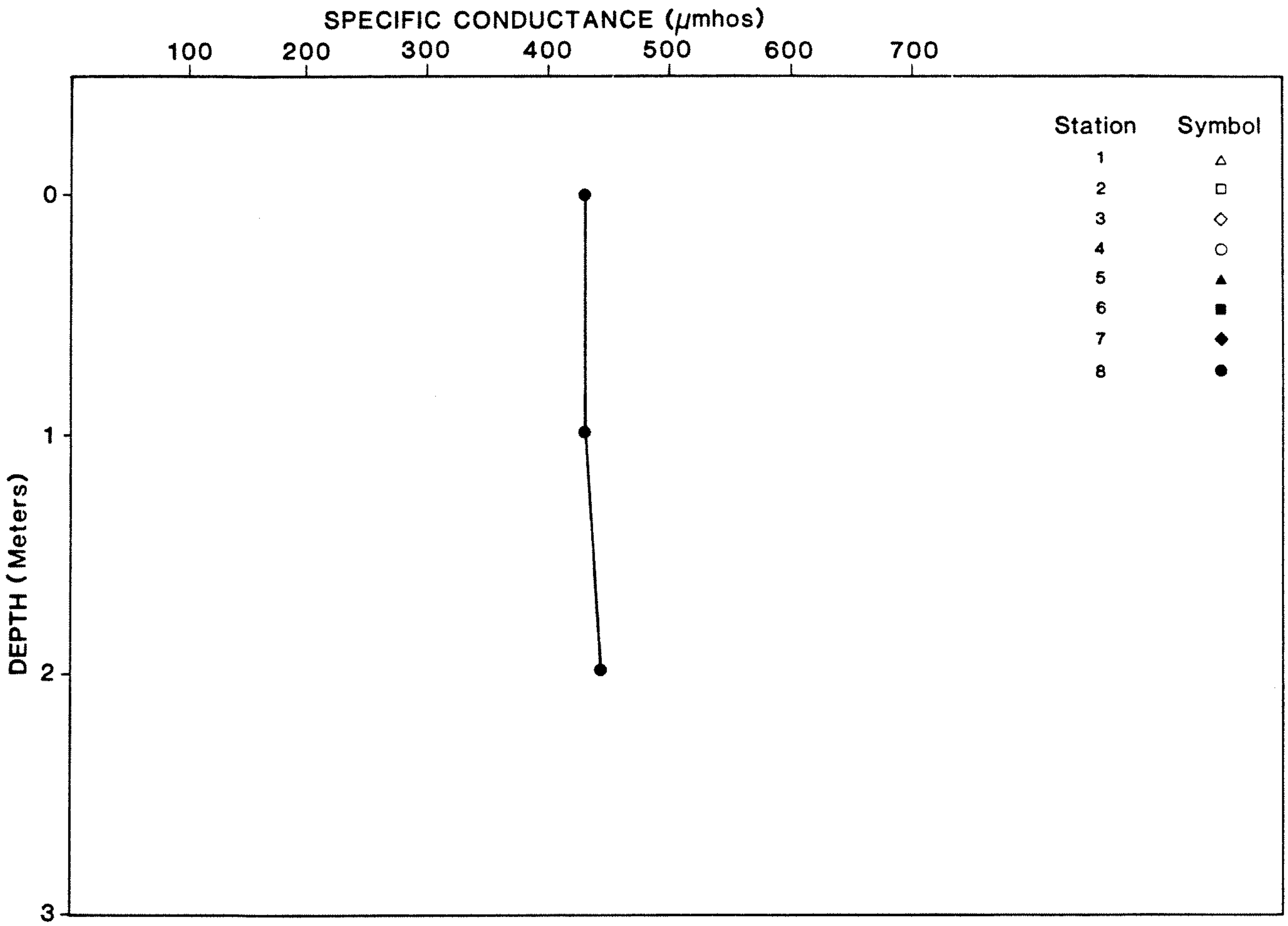

Figure 11. Vertical profile of specific conductance made 30 September 1982 on Ada City Lake.

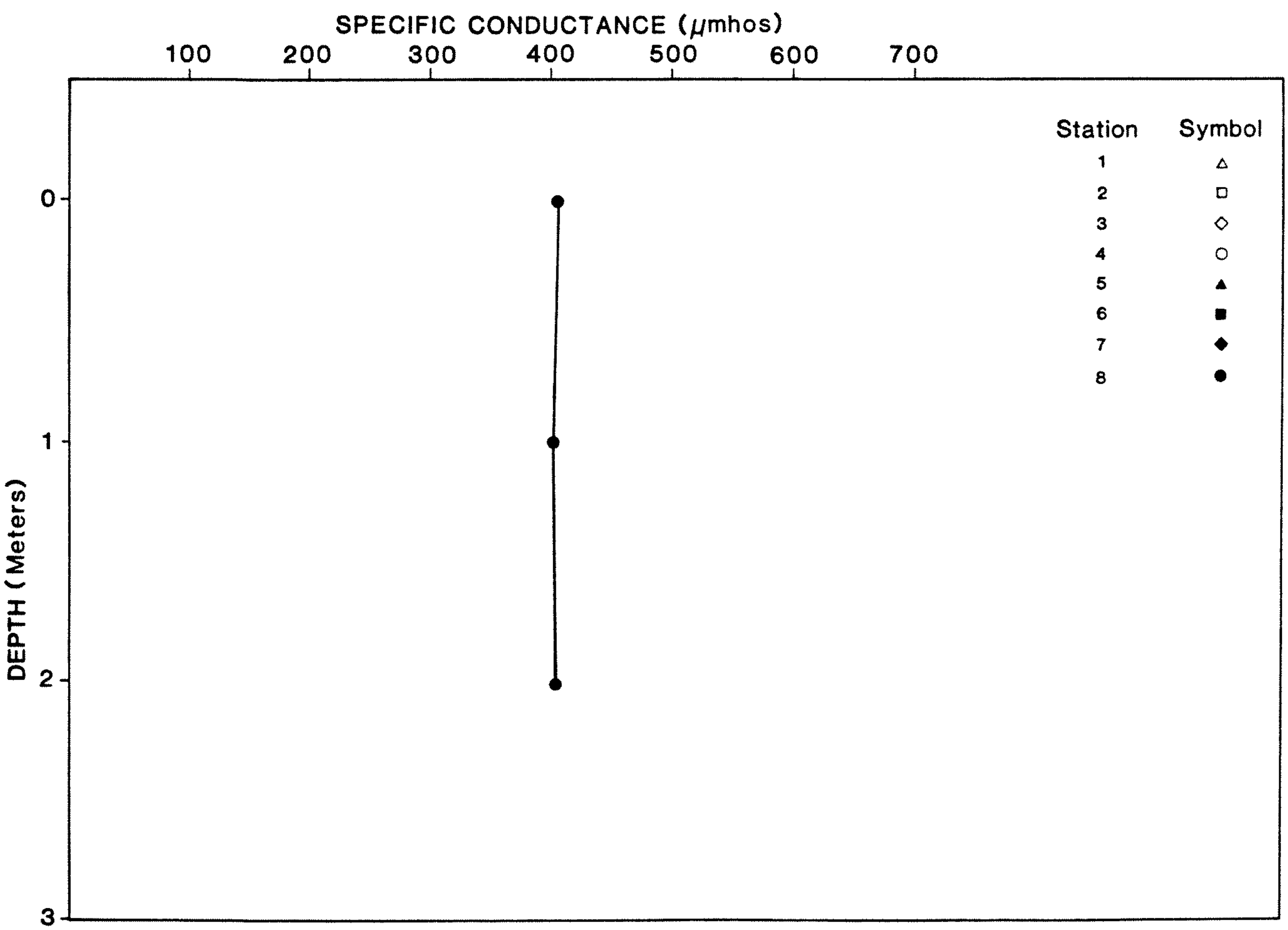

Figure 12. Vertical profile of specific conductance made 9 November 1982 on Ada City Lake.

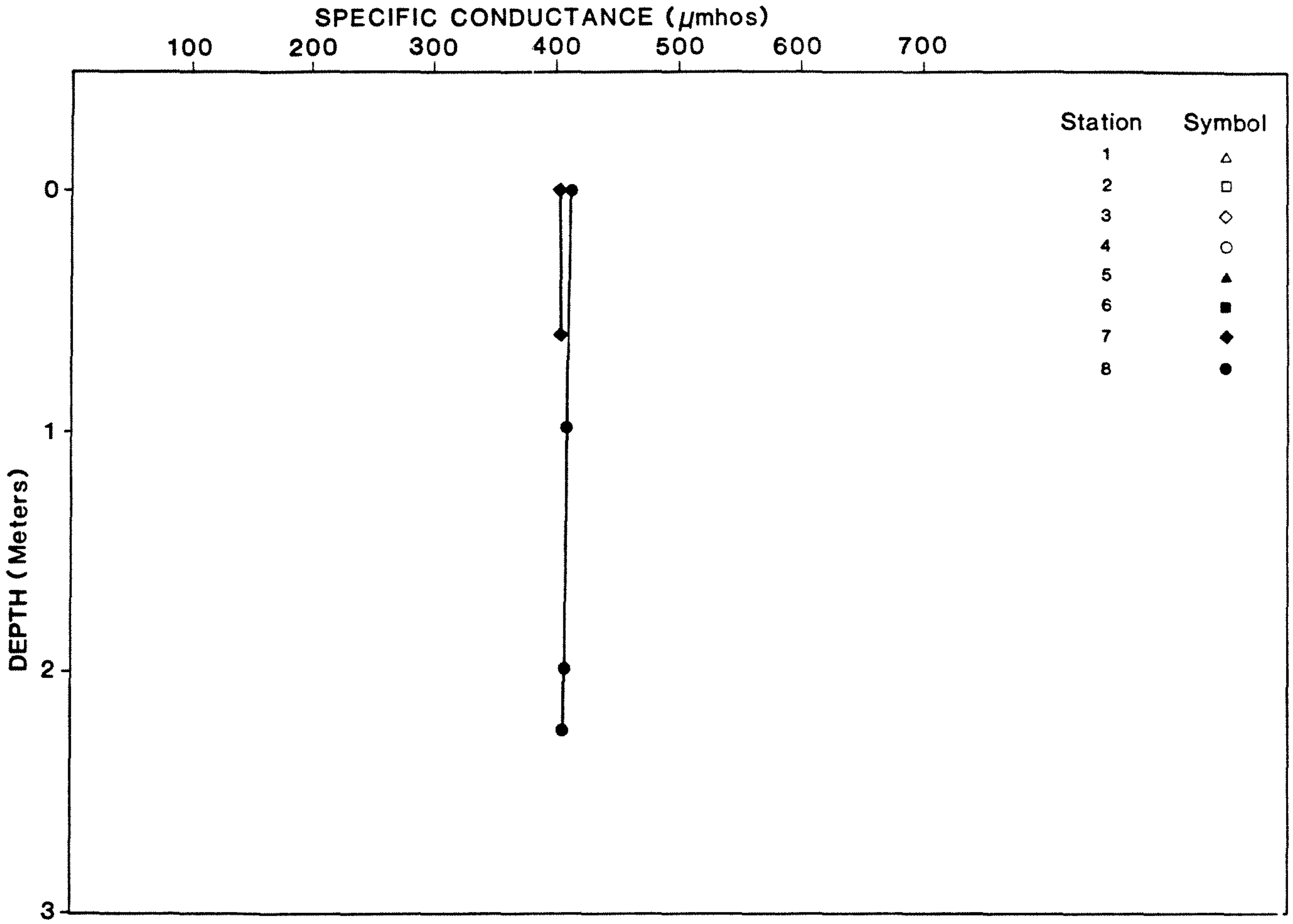

Figure 13. Vertical conductivity profile and ancillary specific conductance data collected 7 December 1982 on Ada City Lake.

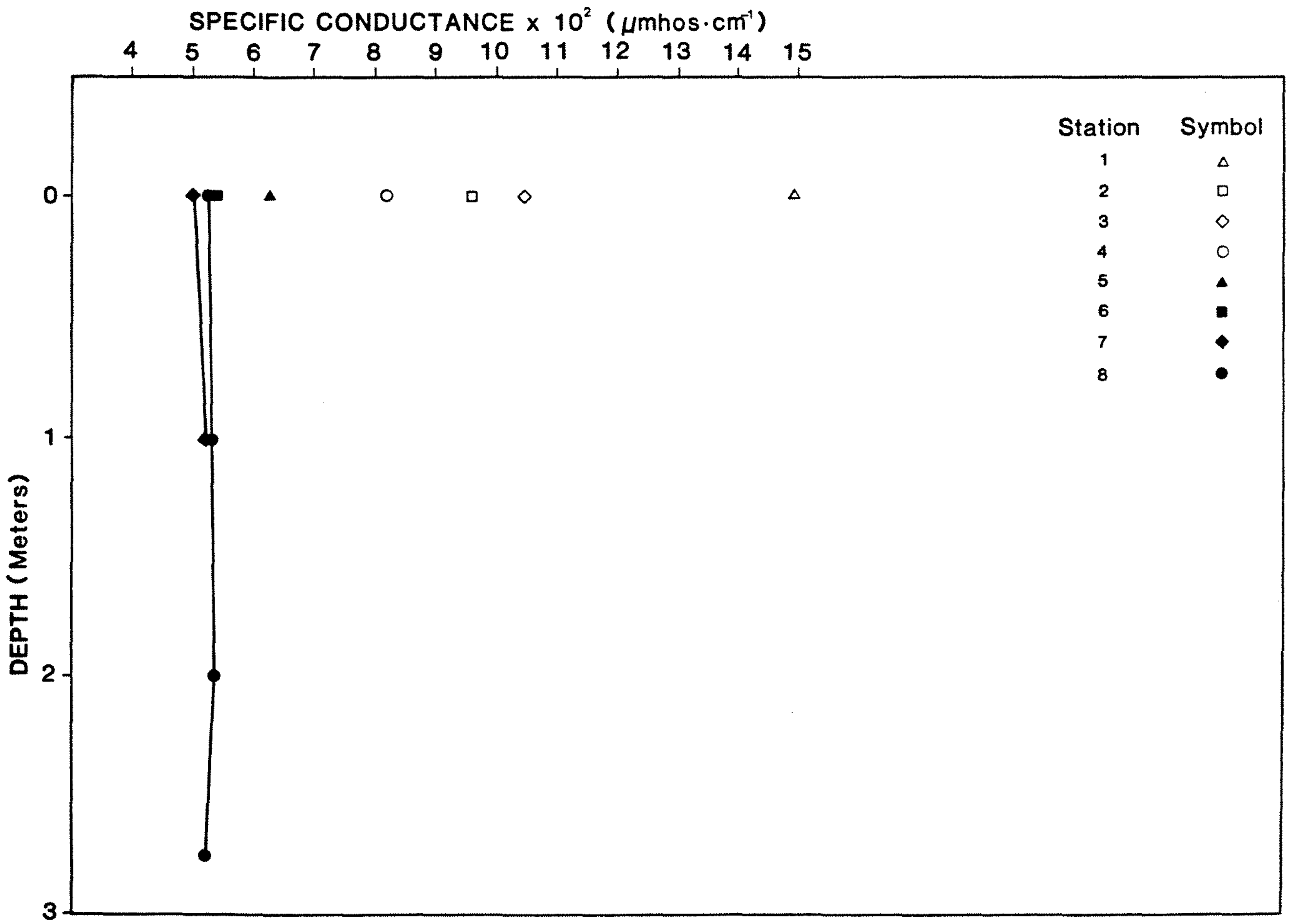

Figure 14. Vertical conductivity profile and ancillary specific conductance data collected 16 March 1983 on Ada City Lake.

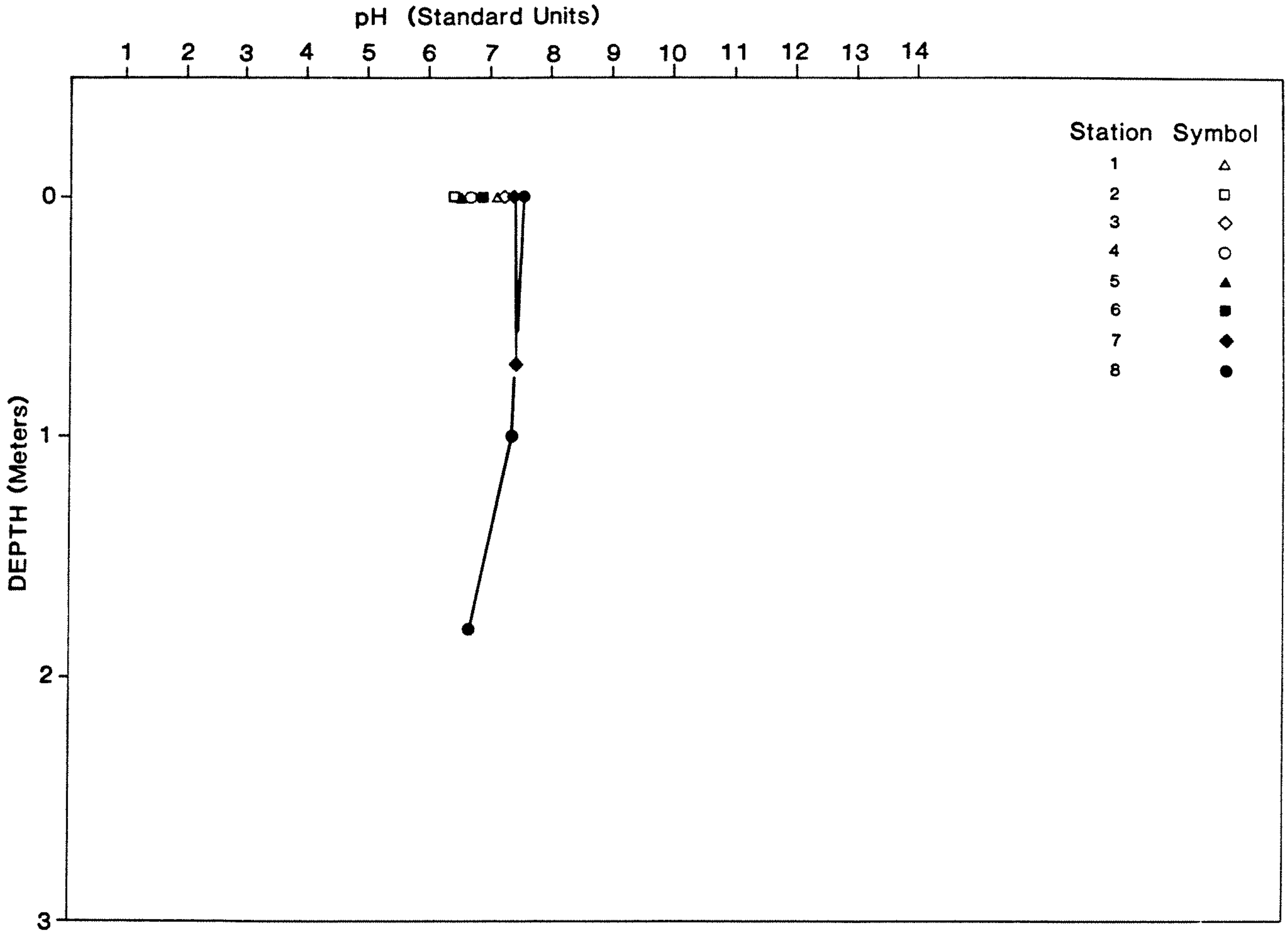

Figure 15. Vertical pH profile and ancillary pH data collected 11 August 1982 on Ada City Lake.

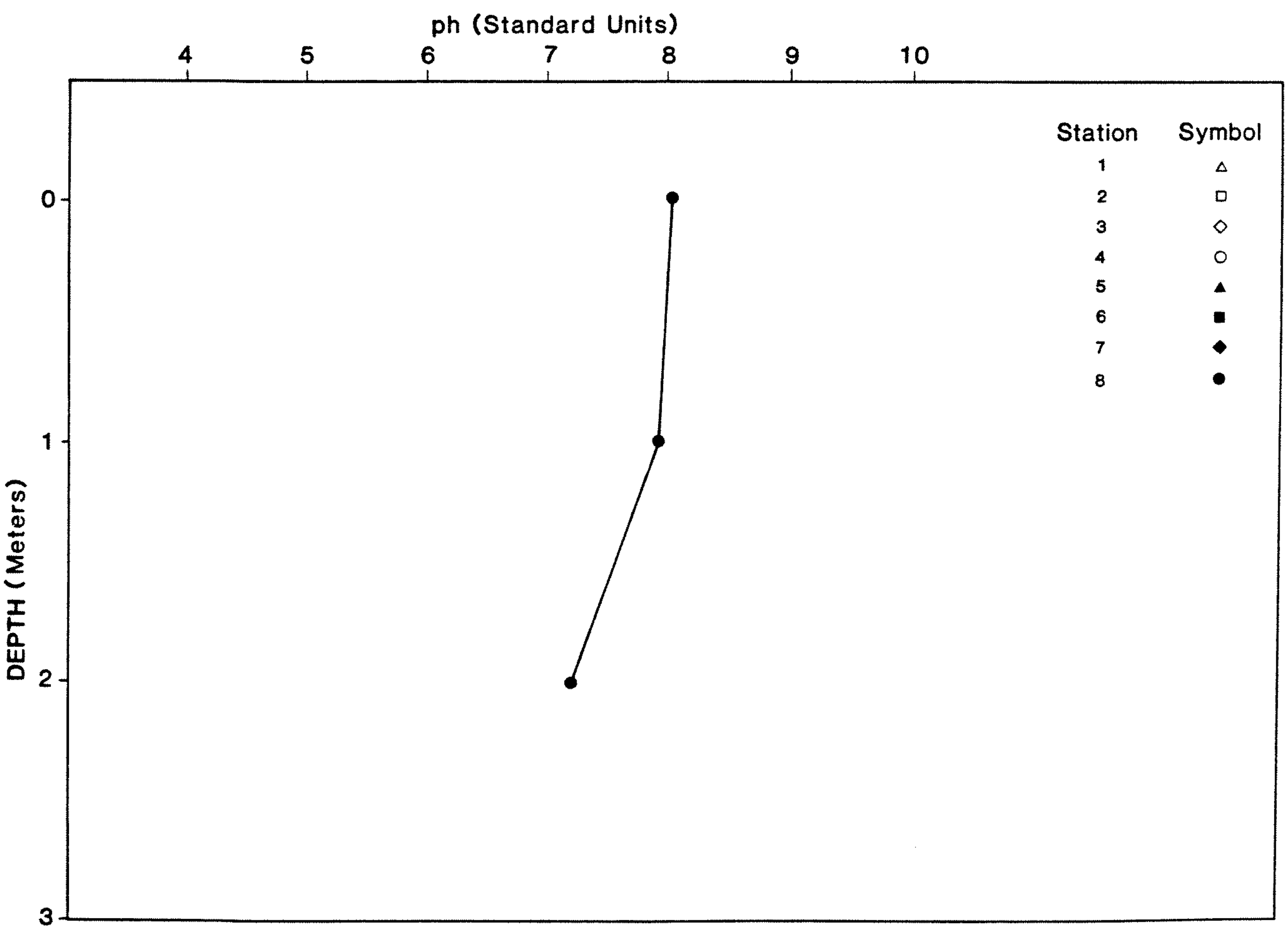

Figure 16. Vertical pH profile collected 30 September 1982 on Ada City Lake.

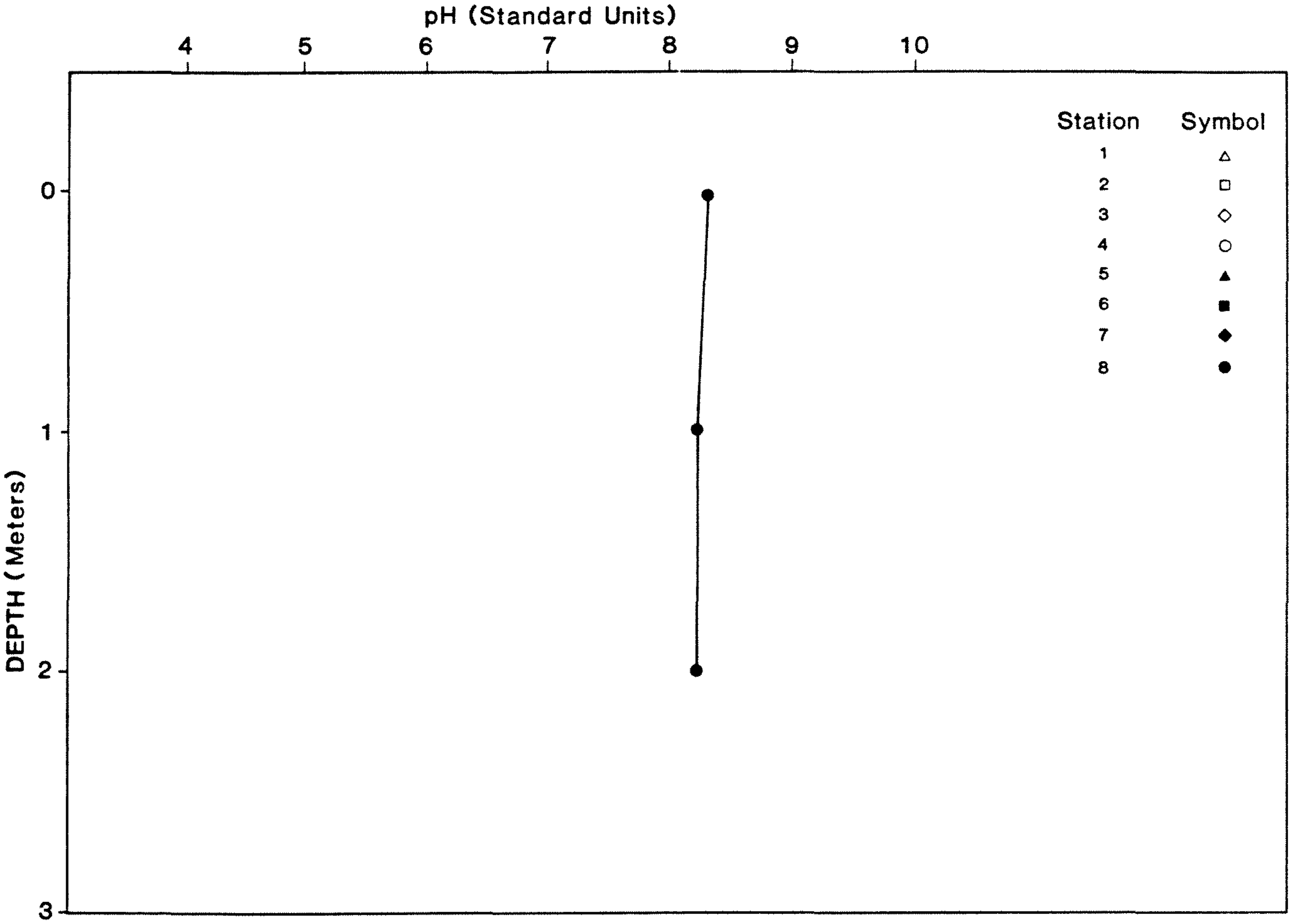

Figure 17. Vertical pH profile collected 9 November 1982 on Ada City Lake.

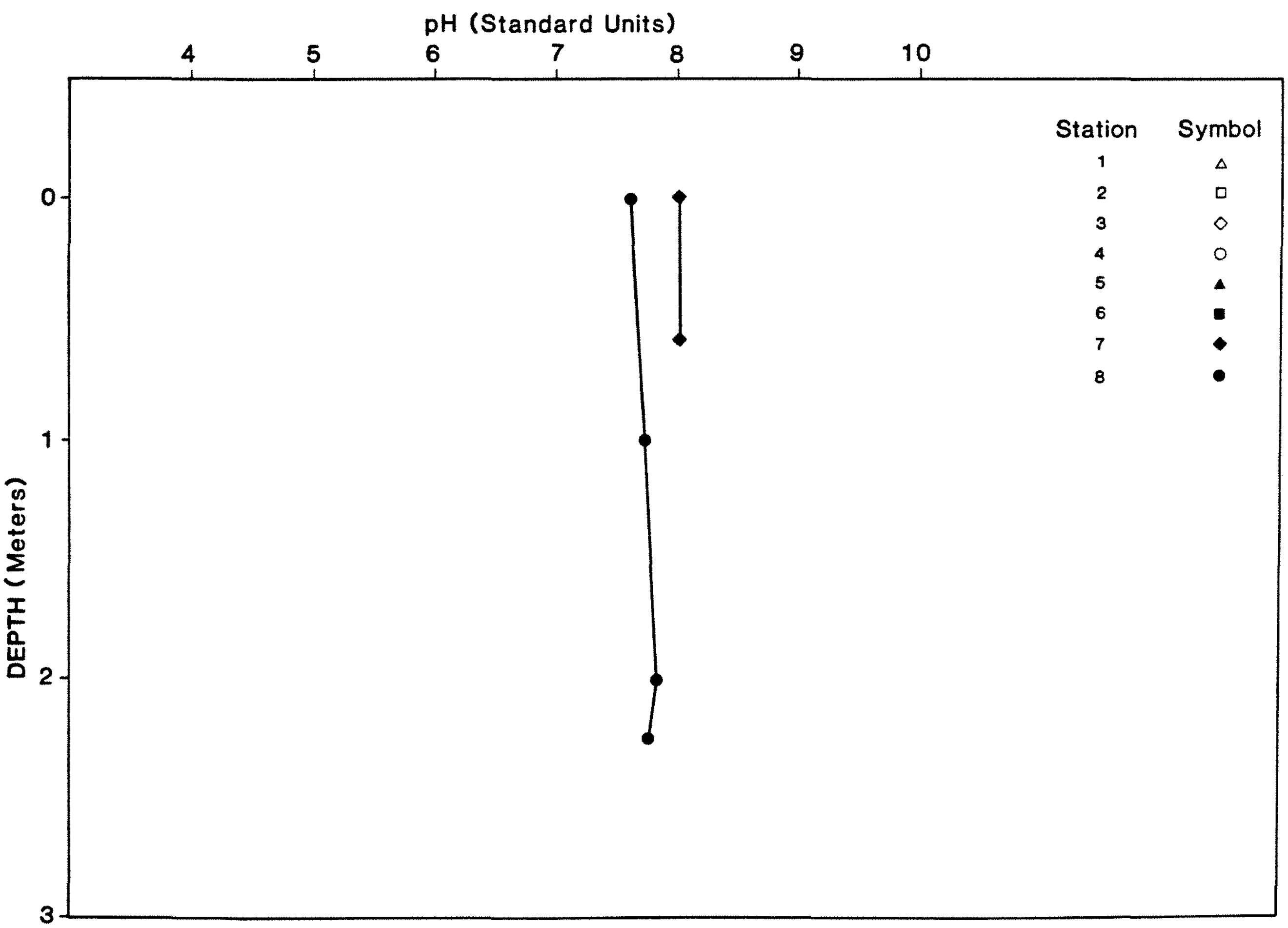

Figure 18. Vertical pH profile and ancillary pH data collected 7 December 1982 on Ada City Lake.

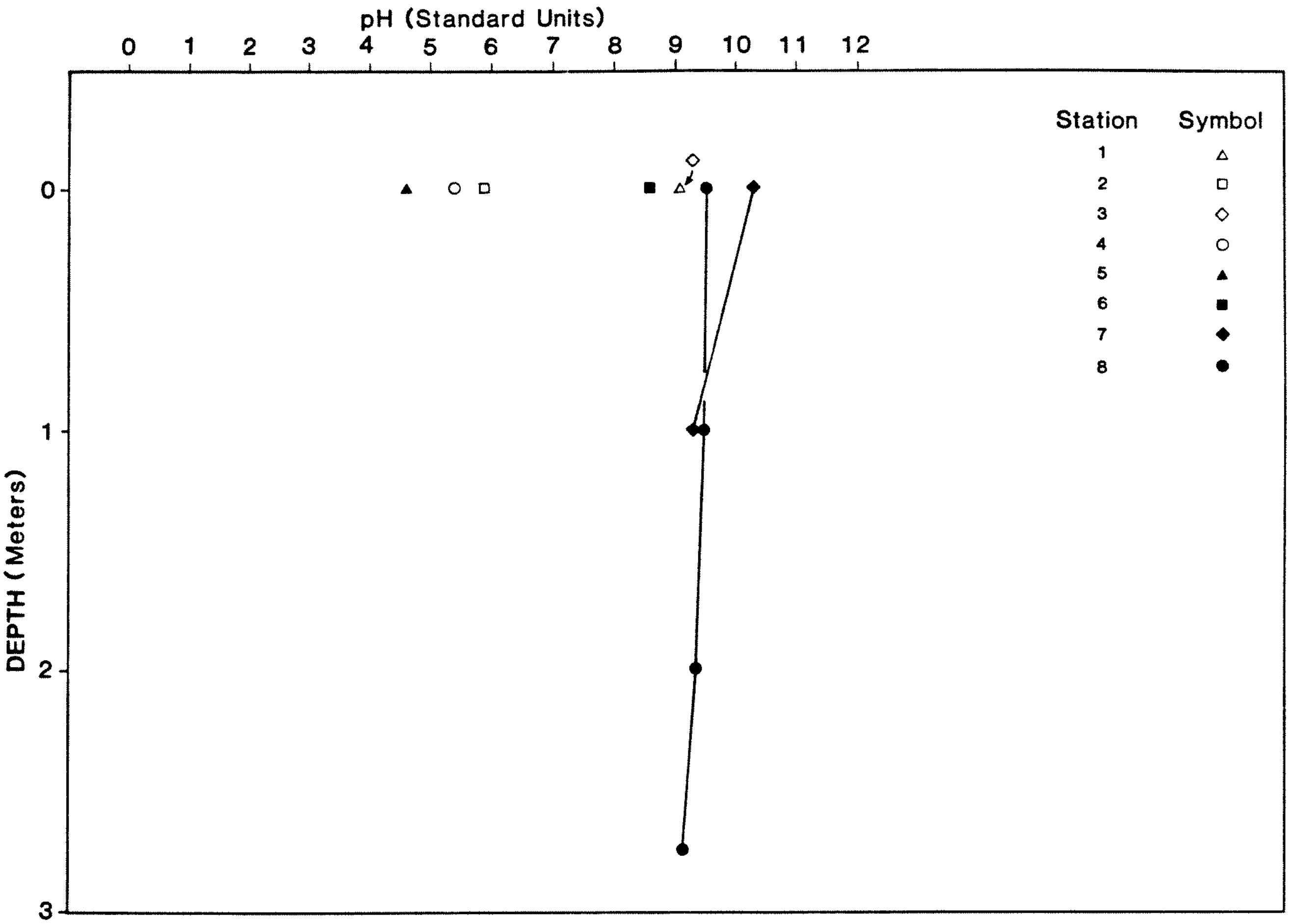

Figure 19. Vertical pH profile and ancillary pH data collected 16 March 1983 on Ada City Lake.

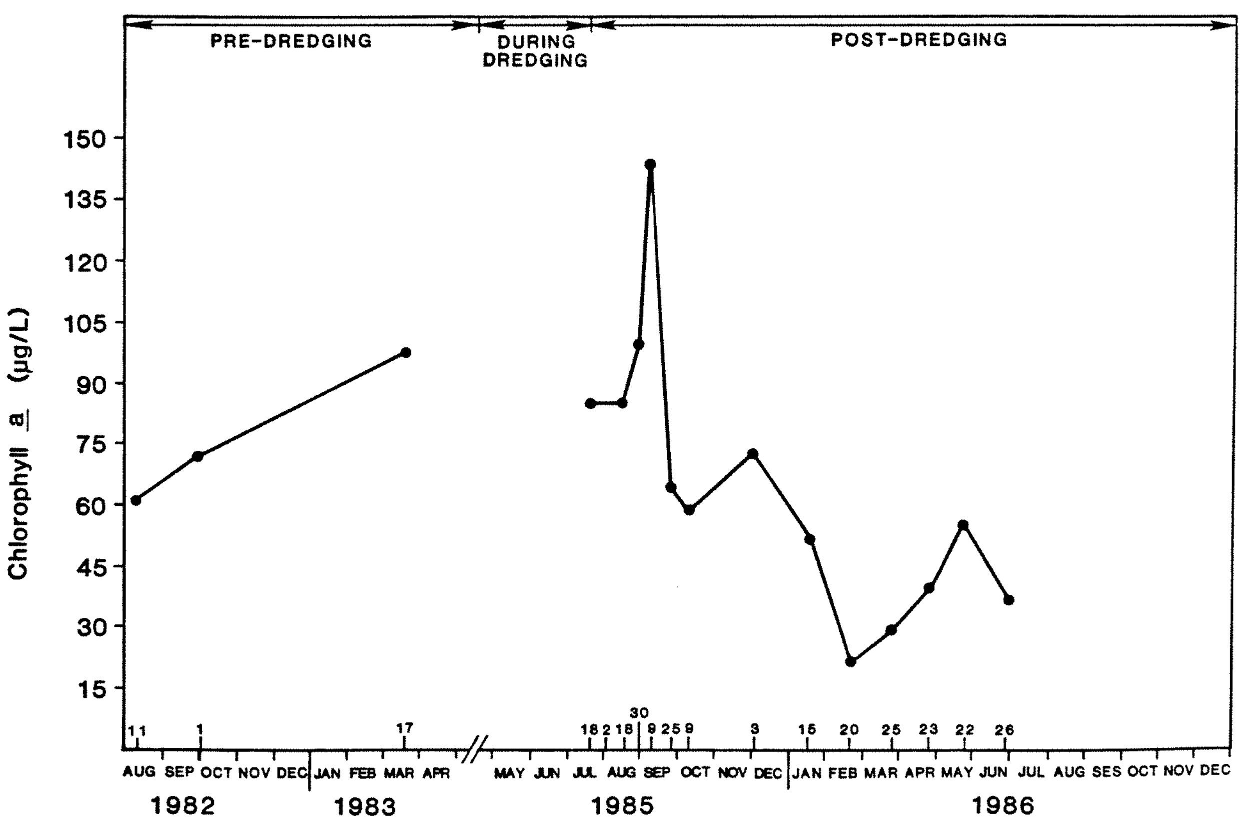

Figure 20. Temporal variation in the chlorophyll a content of samples obtained from Ada City Lake.

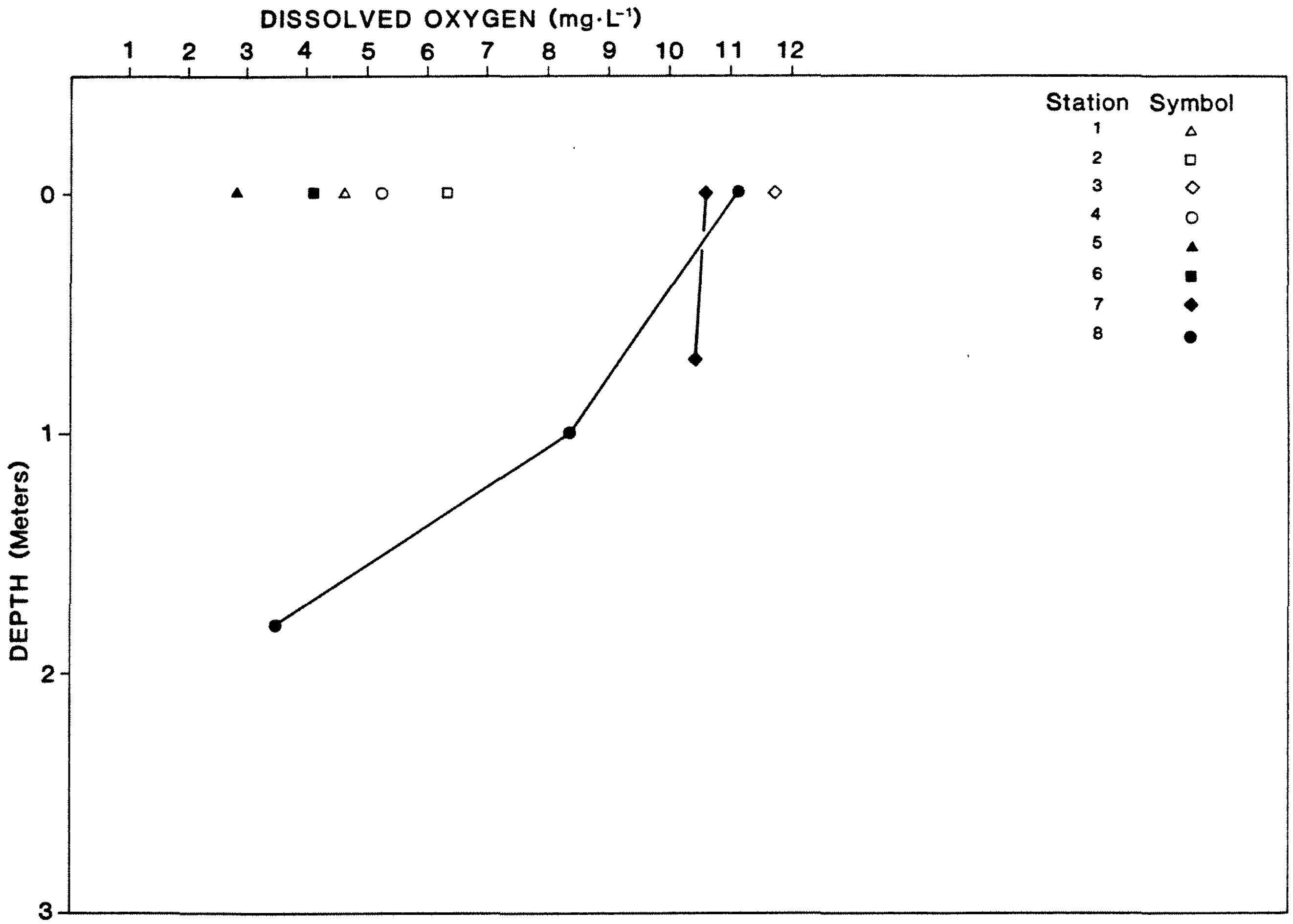

Figure 21. Vertical dissolved oxygen profile and ancillary dissolved oxygen data collected 11 August 1982 on Ada City Lake.

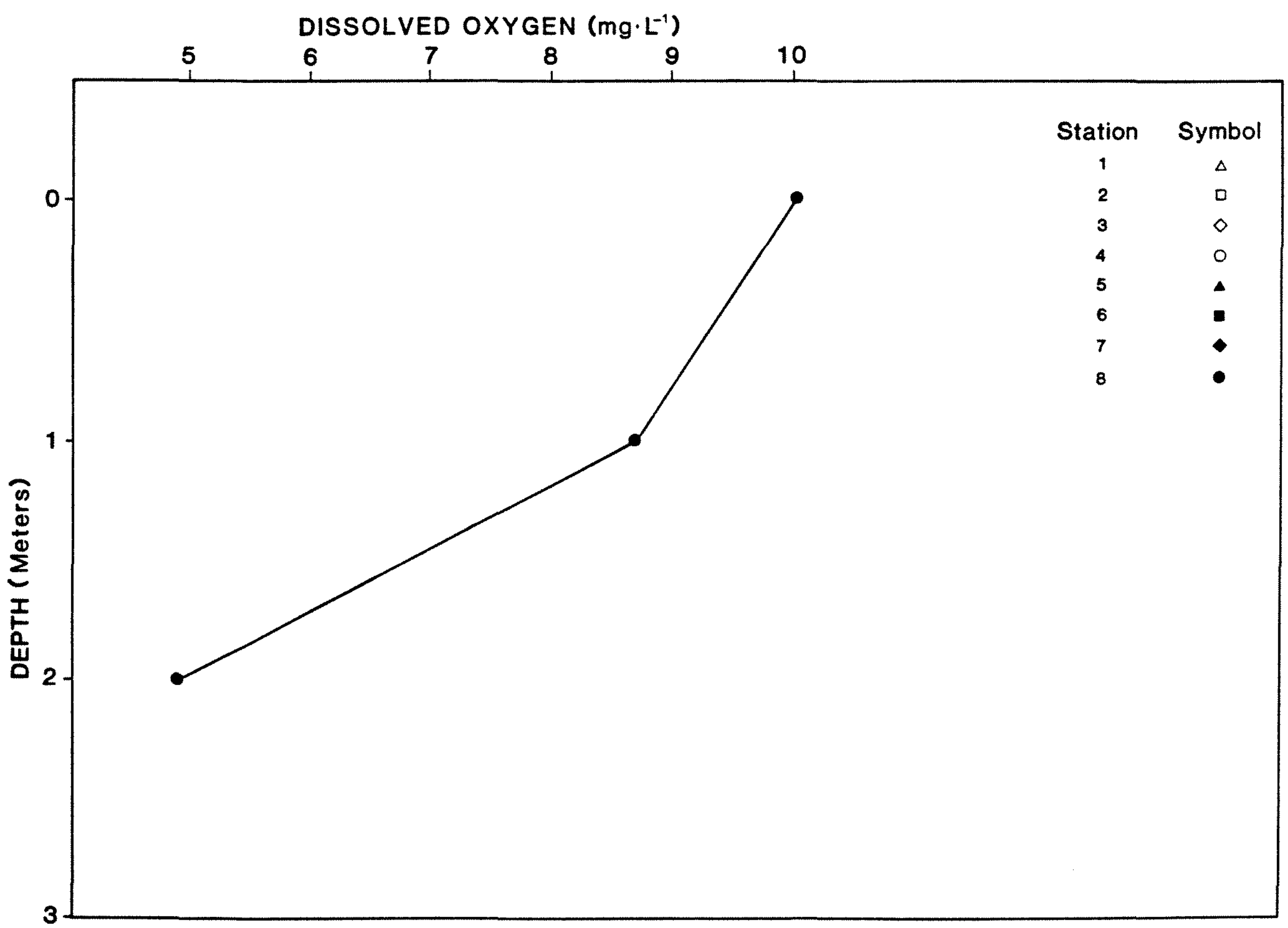

Figure 22. Vertical dissolved oxygen profile collected 30 September 1982 on Ada City Lake.

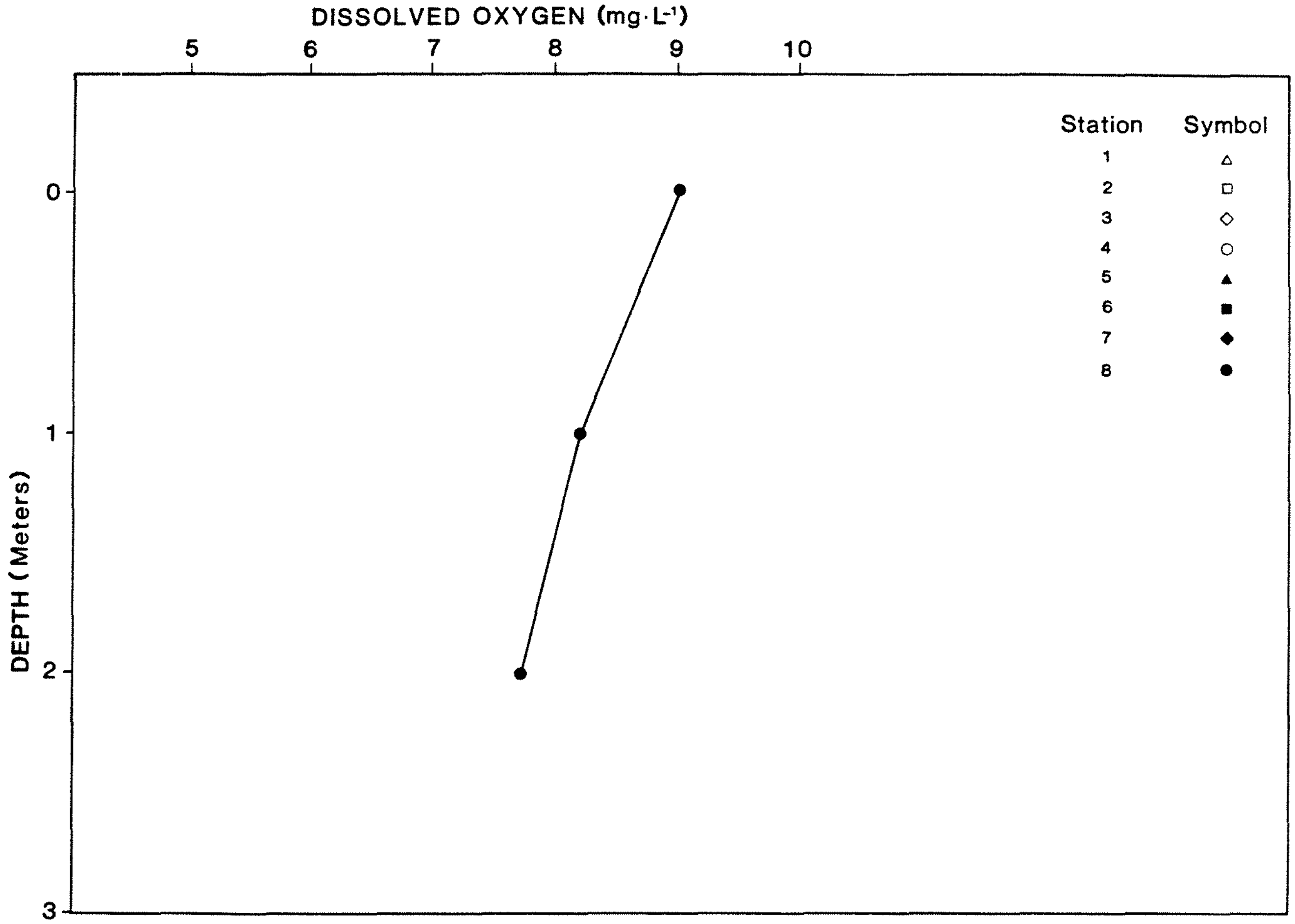

Figure 23. Vertical dissolved oxygen profile collected 9 November 1982 on Ada City Lake.

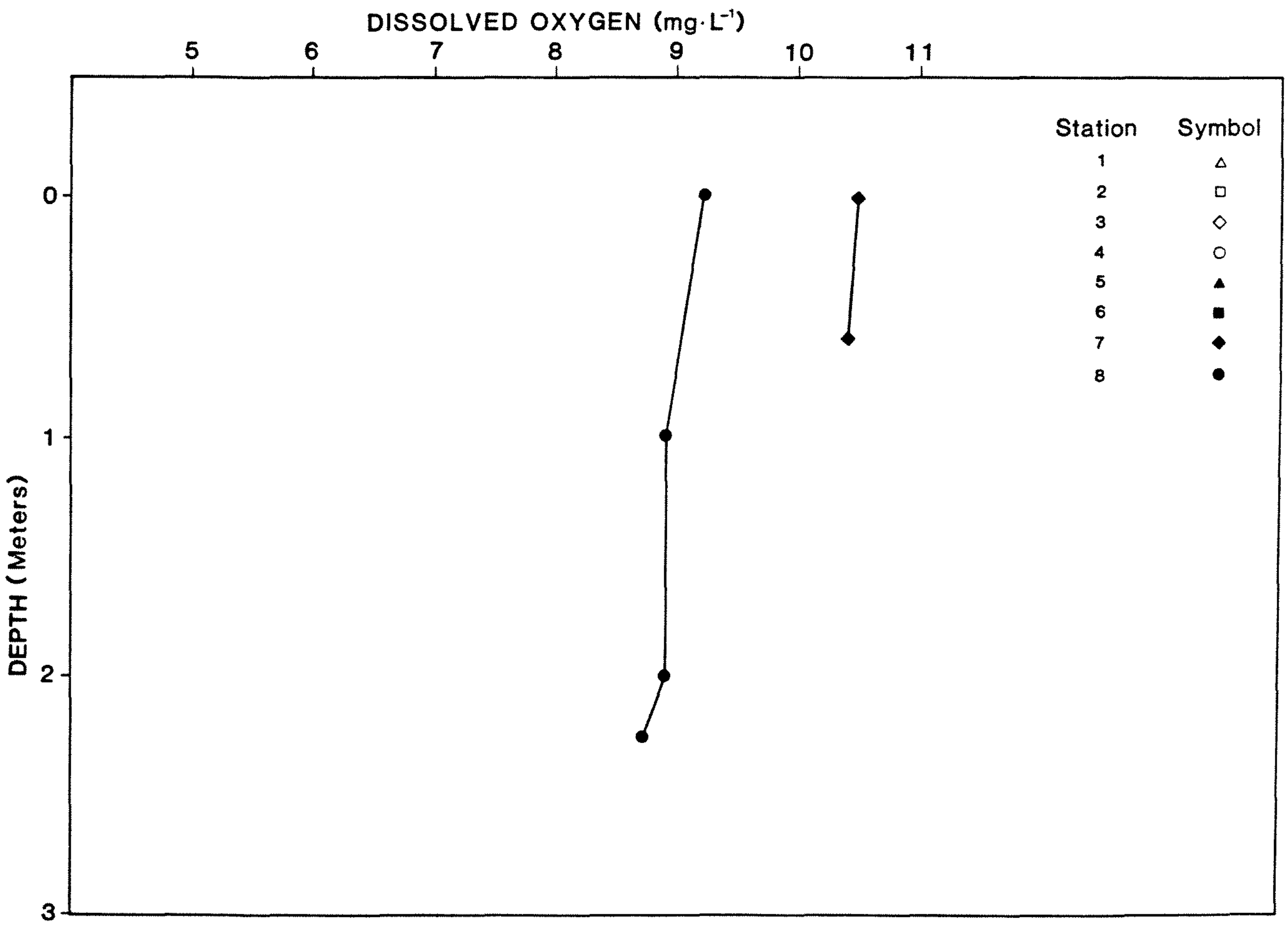

Figure 24. Vertical dissolved oxygen profile and ancillary dissolved oxygen data collected 7 December 1982 on Ada City Lake.

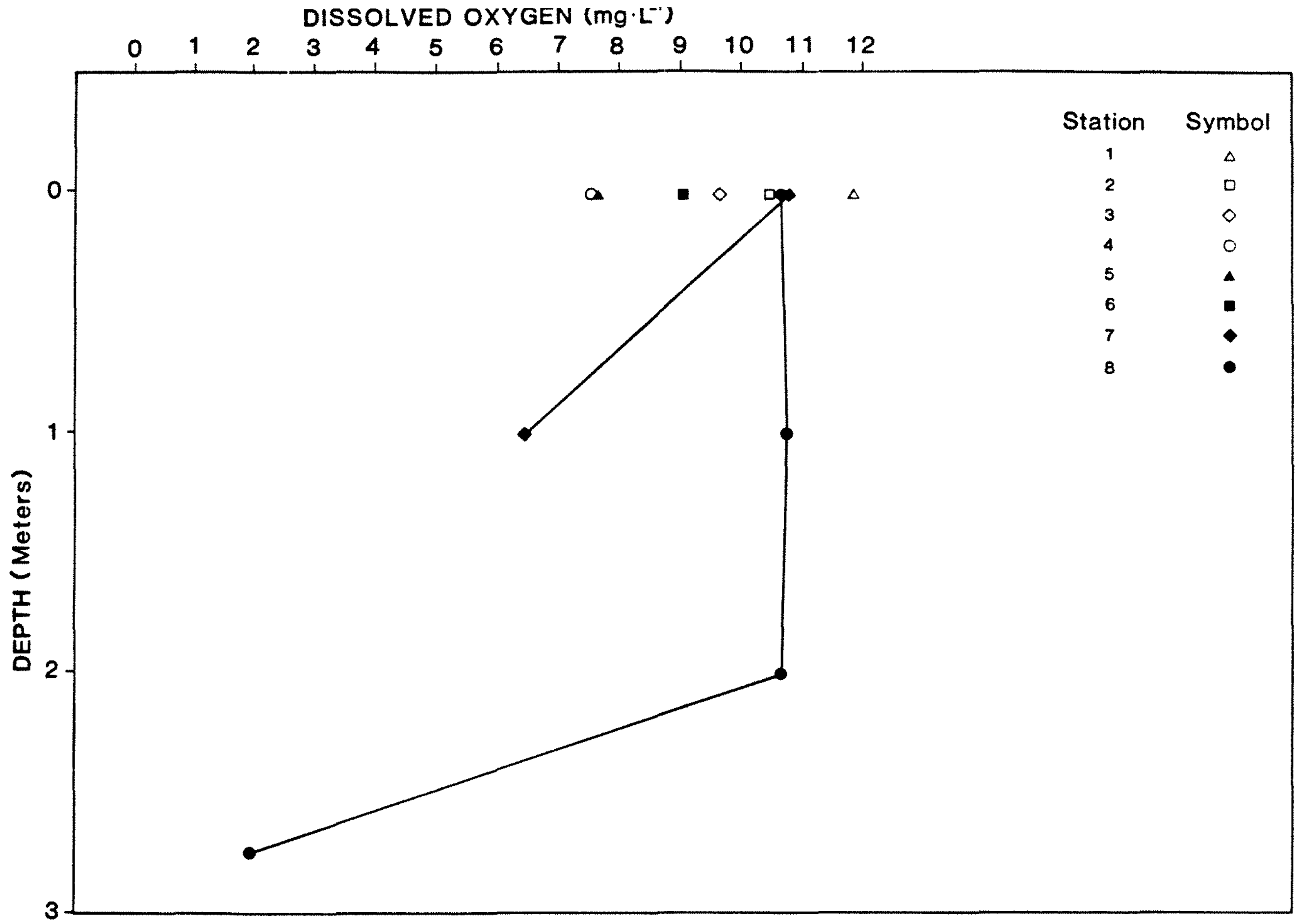

Figure 25. Vertical dissolved oxygen profile and ancillary dissolved oxygen data collected 16 March 1983 on Ada City Lake.

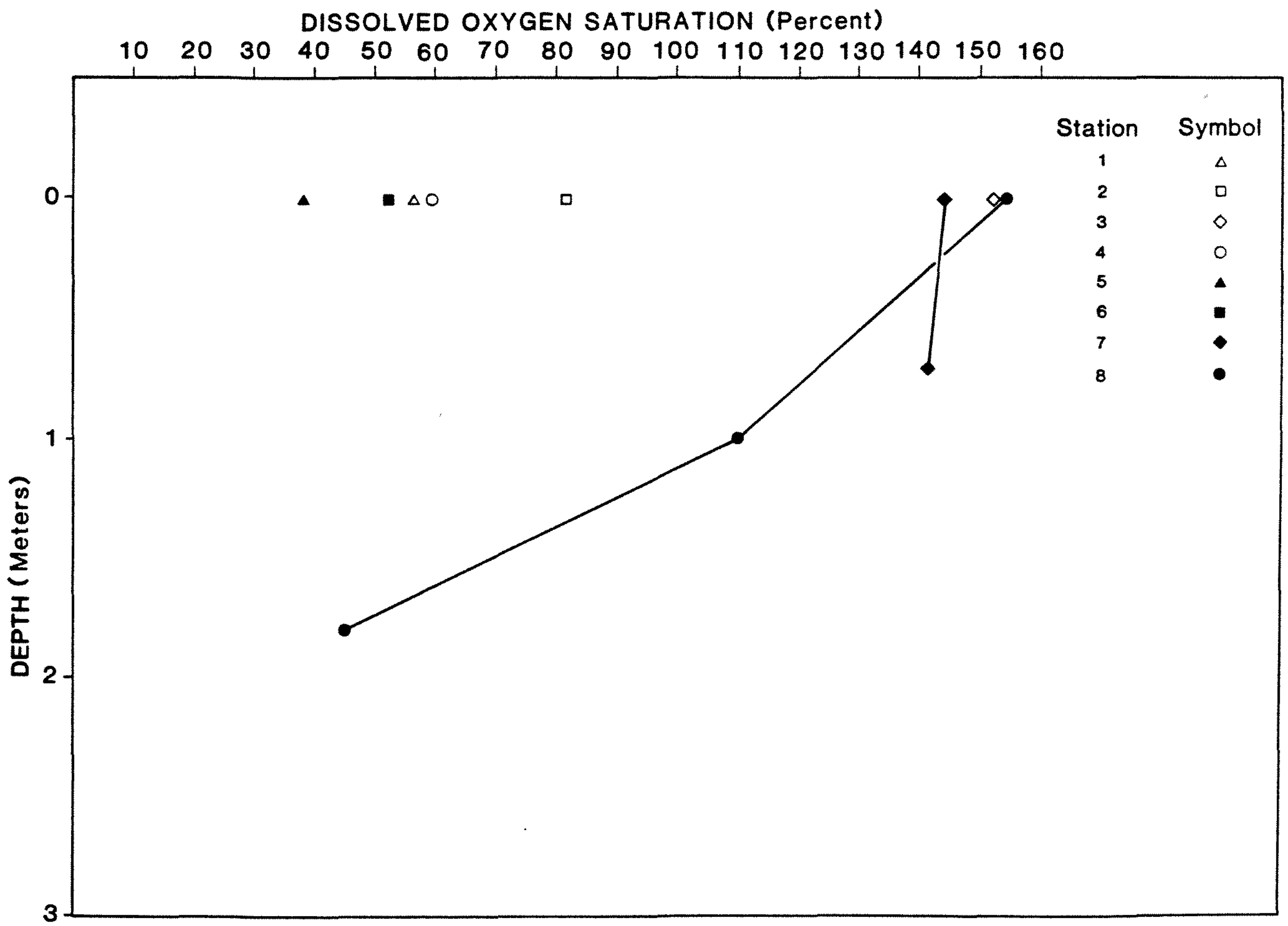

Figure 26. Vertical dissolved oxygen percent saturation profile and ancillary oxygen saturation data collected 10 and 11 August 1982 on Ada City Lake.

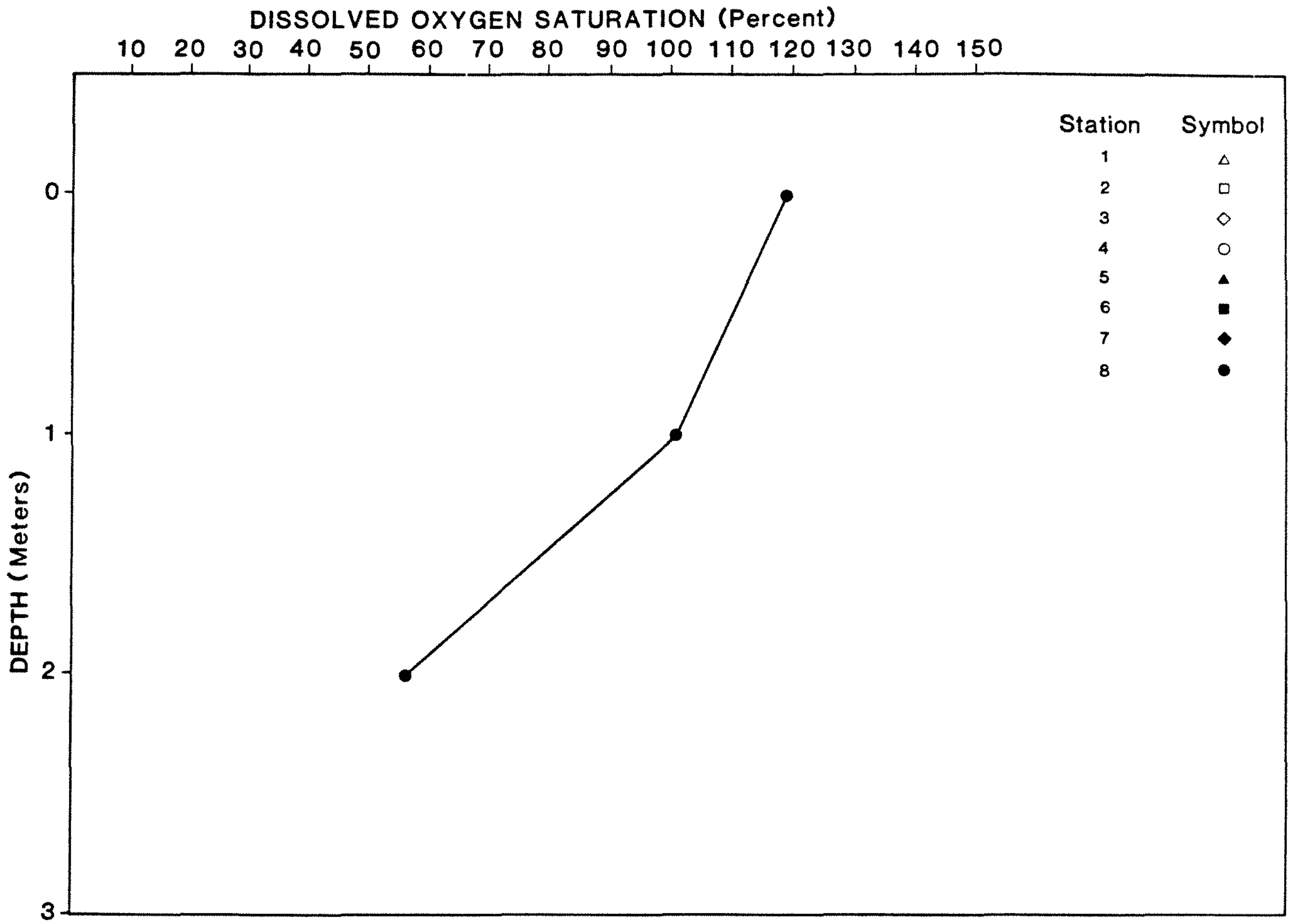

Figure 27. Vertical dissolved oxygen percent saturation profile collected 30 September 1982 on Ada City Lake.

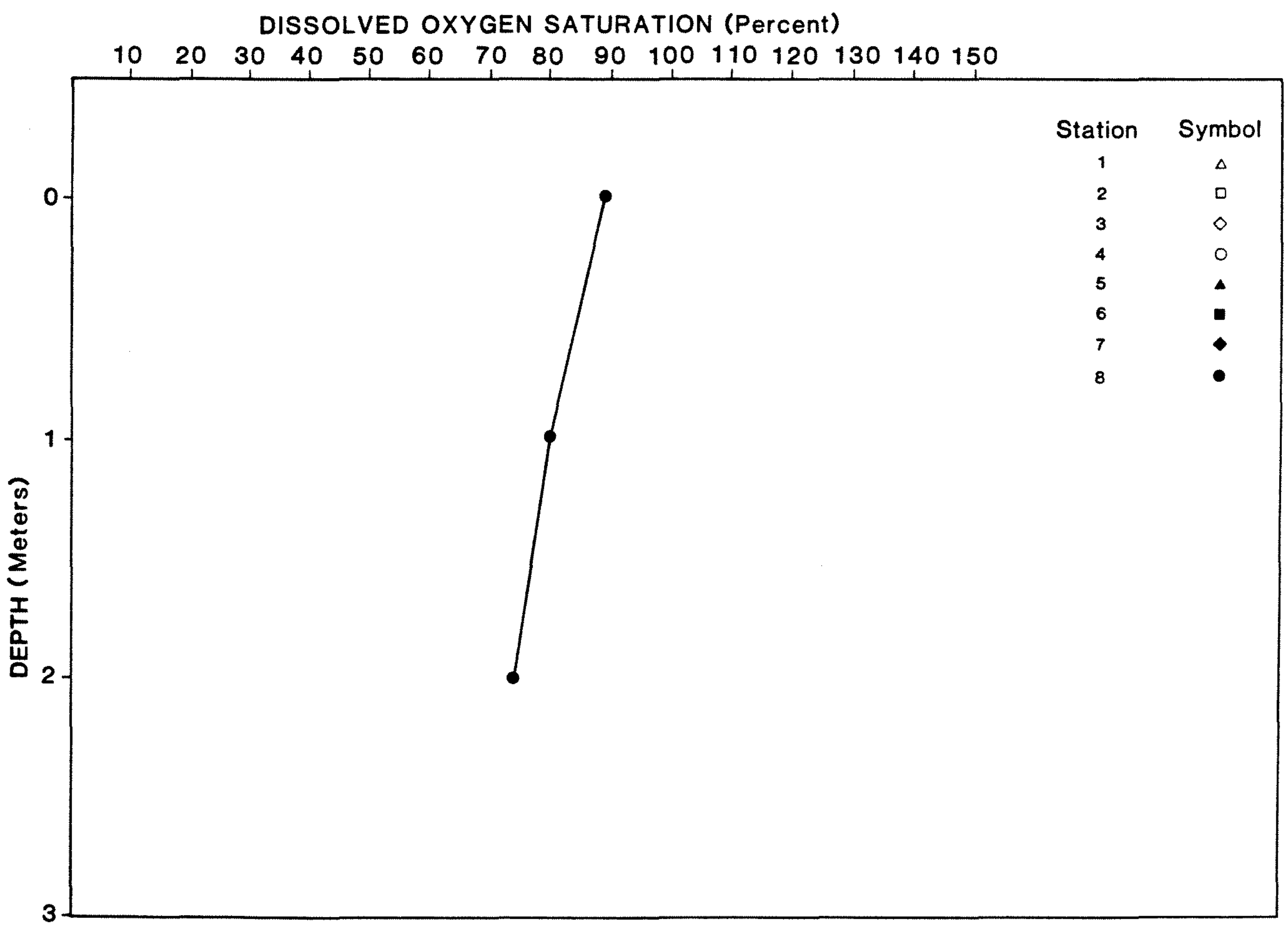

Figure 28. Vertical dissolved oxygen percent saturation profile collected 9 November 1982 on Ada City Lake.

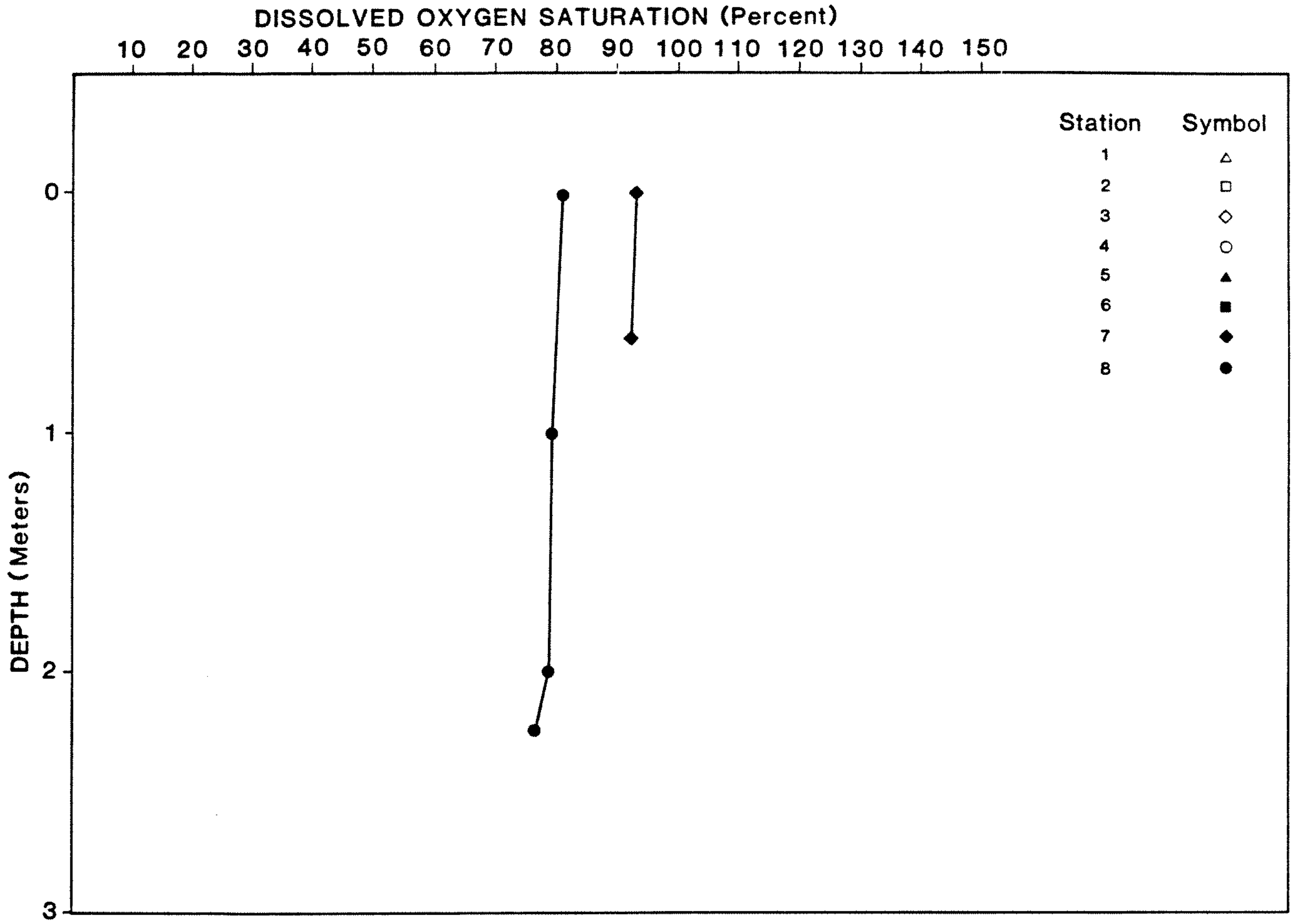

Figure 29. Vertical dissolved oxygen percent saturation profile and ancillary oxygen saturation data collected 7 December 1982 on Ada City Lake.

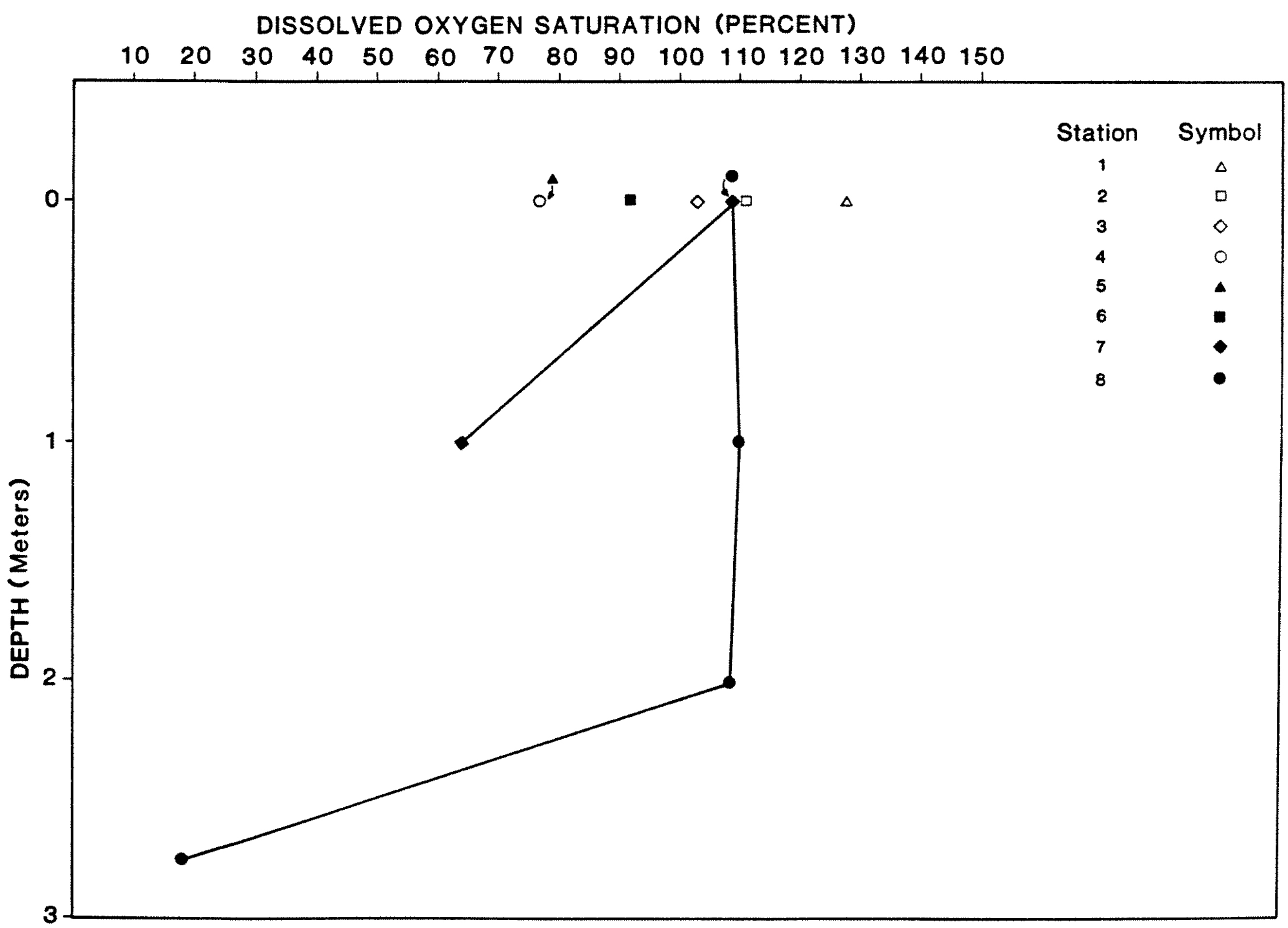

Figure 30. Vertical dissolved oxygen percent saturation profile and ancillary oxygen saturation data collected 16 March 1983 on Ada City Lake.

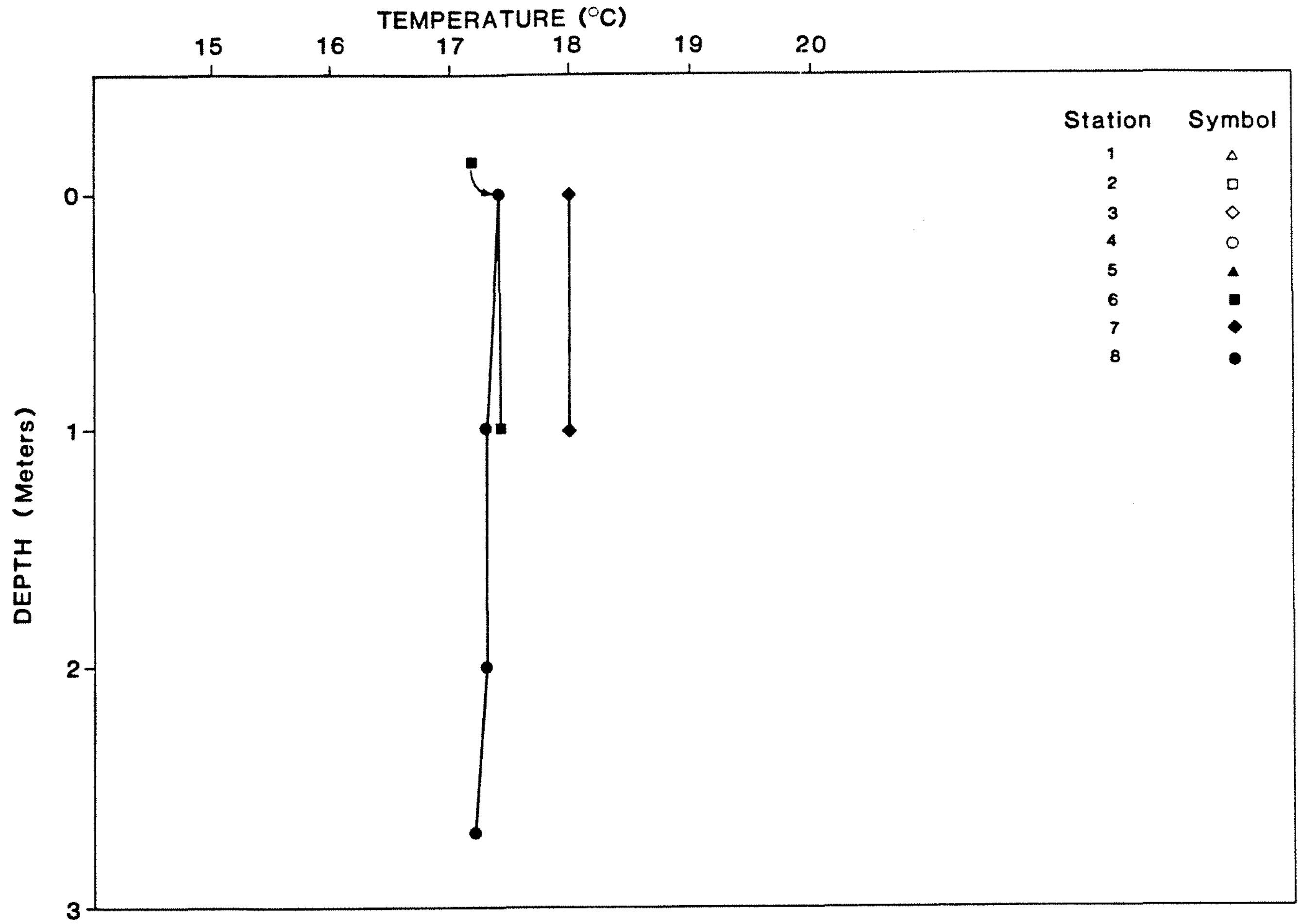

Figure 31. Vertical thermal profile and ancillary thermal data collected 18 October 1984 on Ada City Lake.

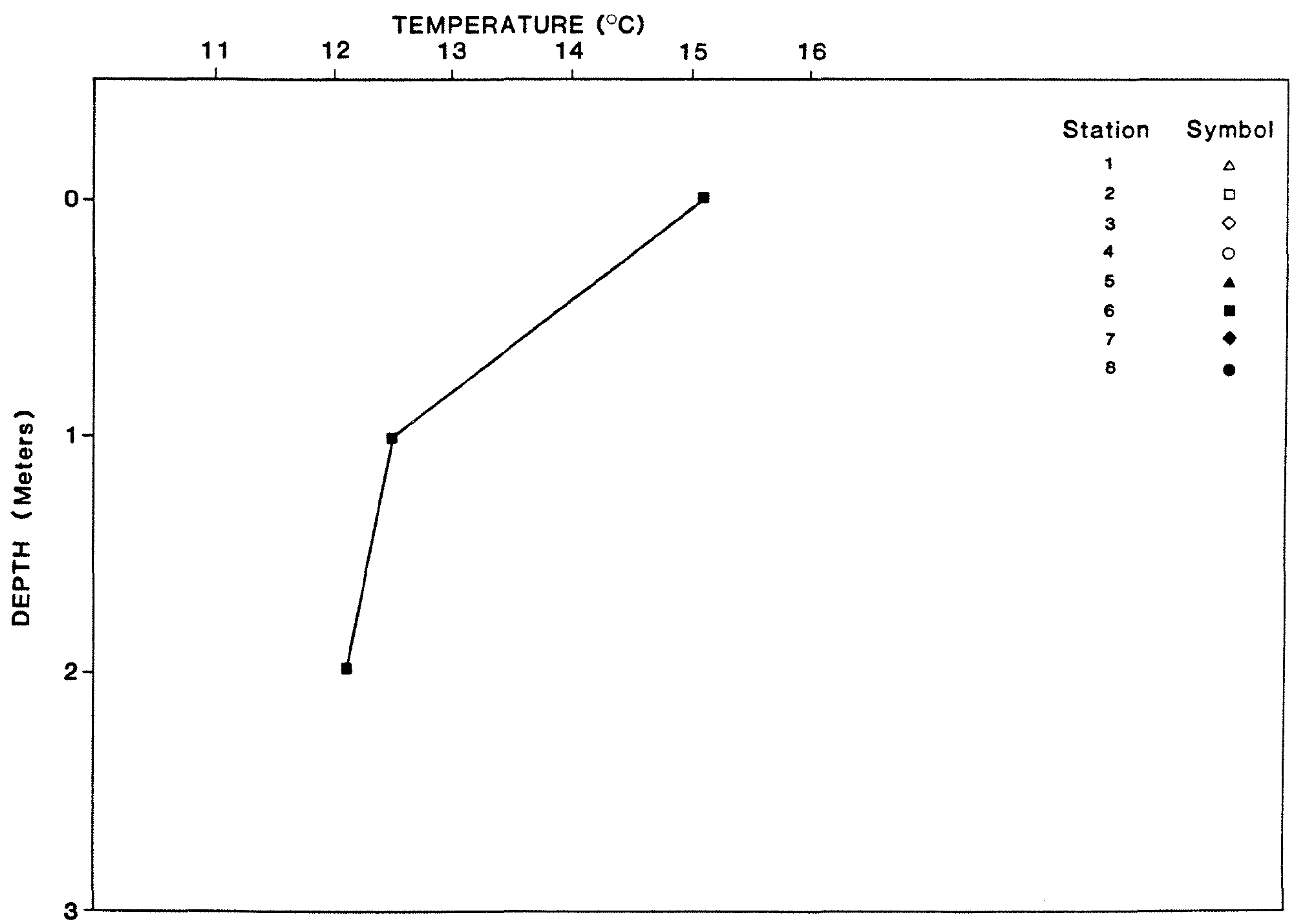

Figure 32. Vertical thermal profile collected 14 November 1984 on Ada City Lake.

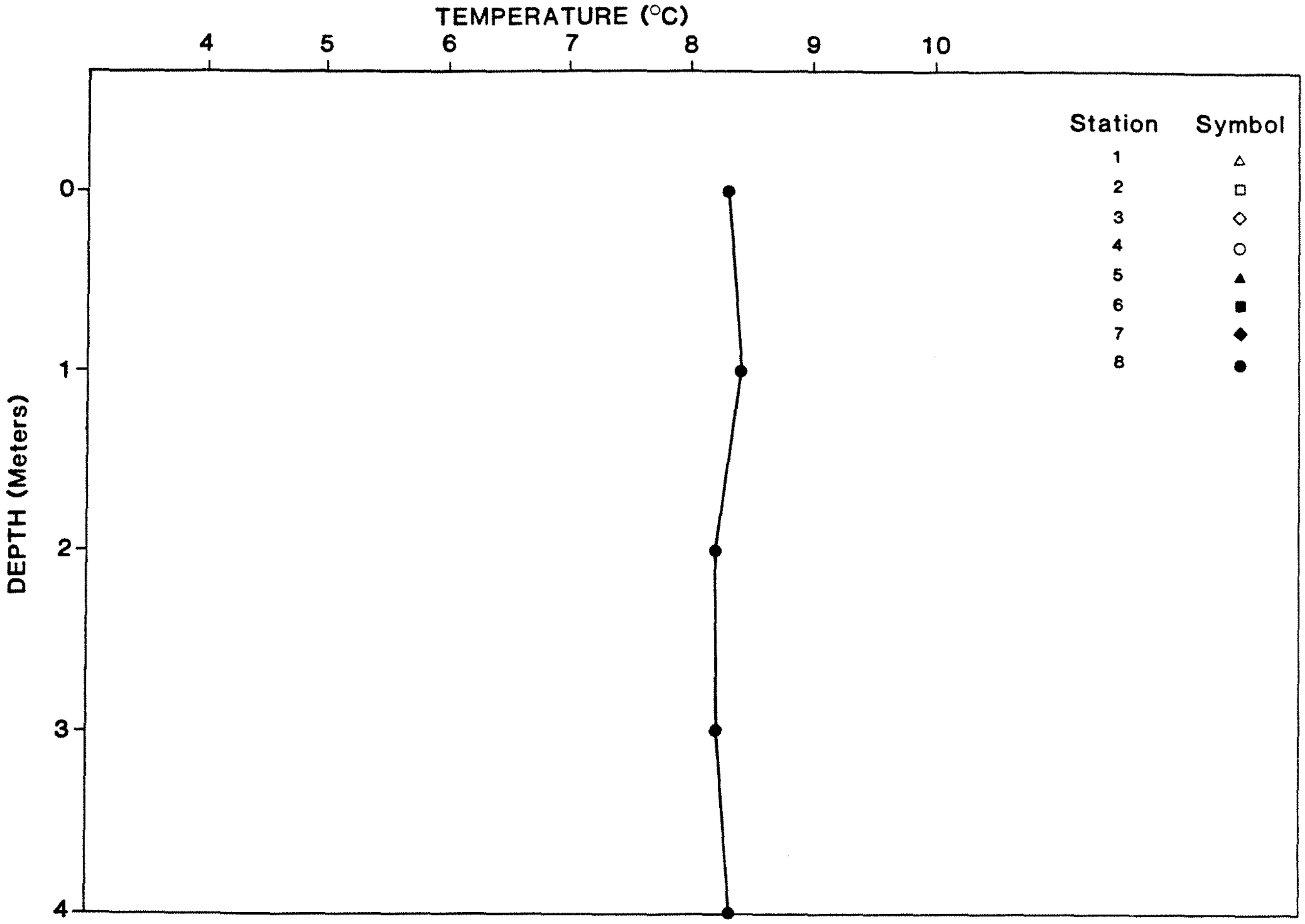

Figure 33. Vertical thermal profile collected 12 December 1984 on Ada City Lake.

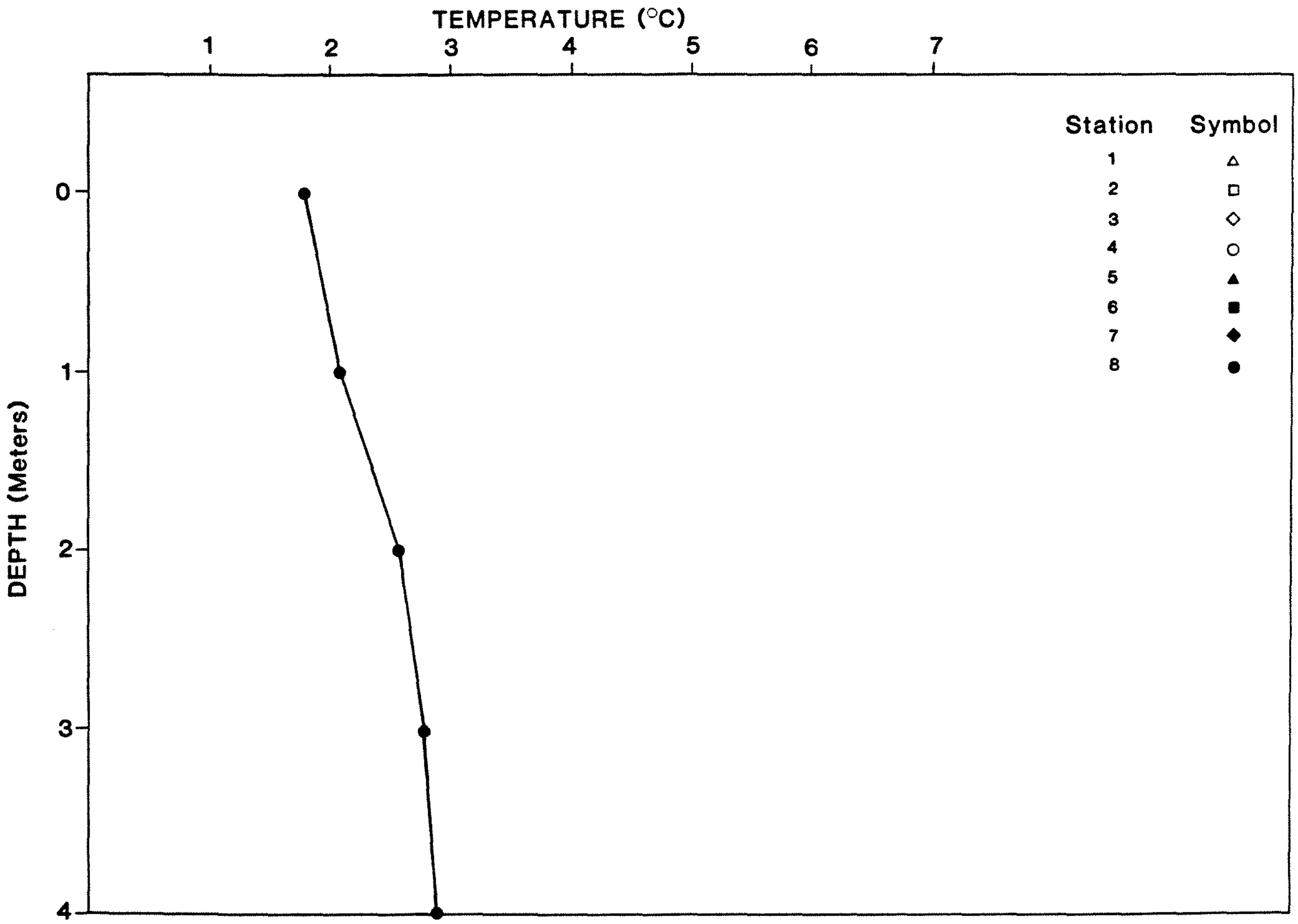

Figure 34. Vertical thermal profile collected 23 January 1985 on Ada City Lake.

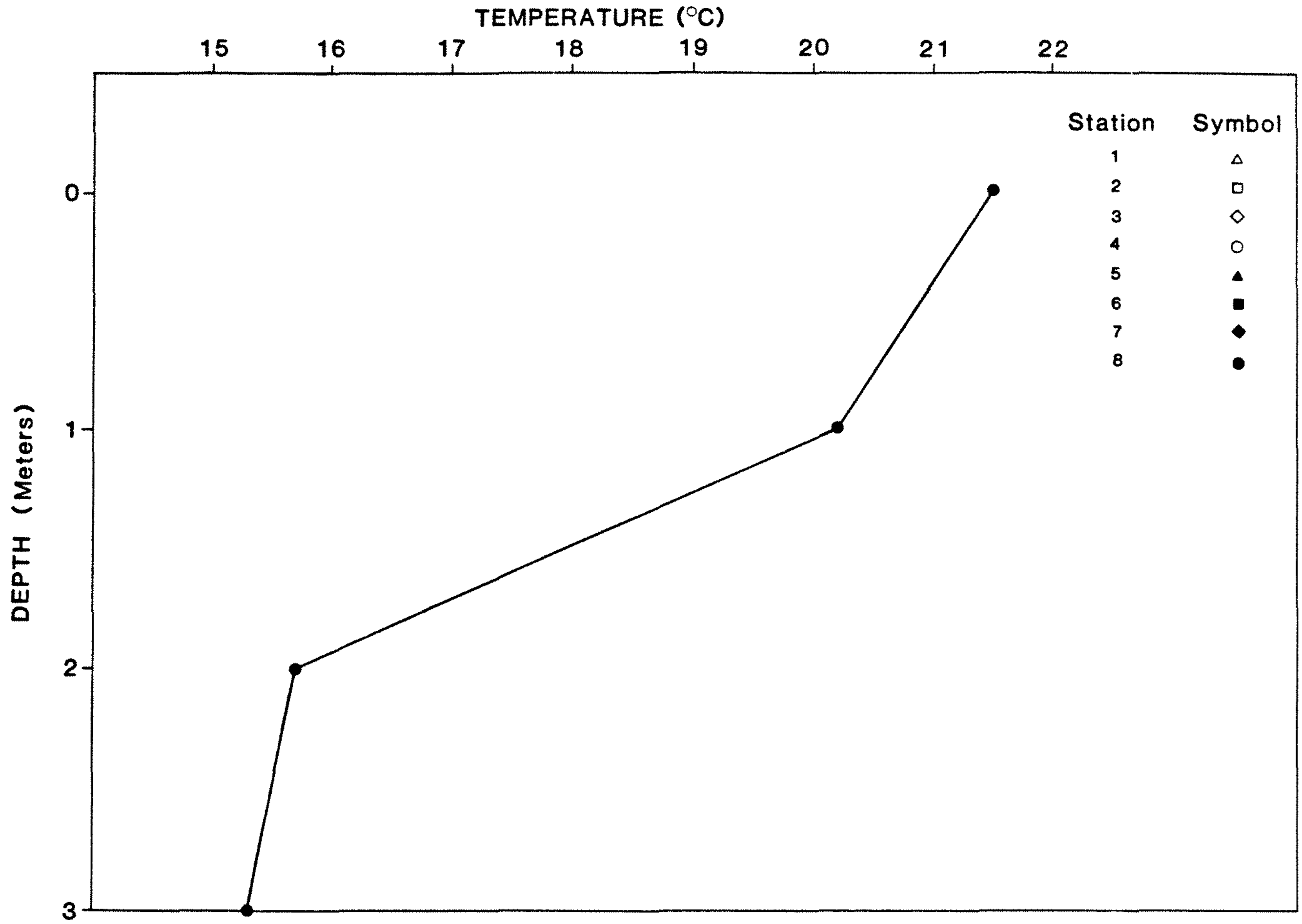

Figure 35. Vertical thermal profile collected 17 April 1985 on Ada City Lake.

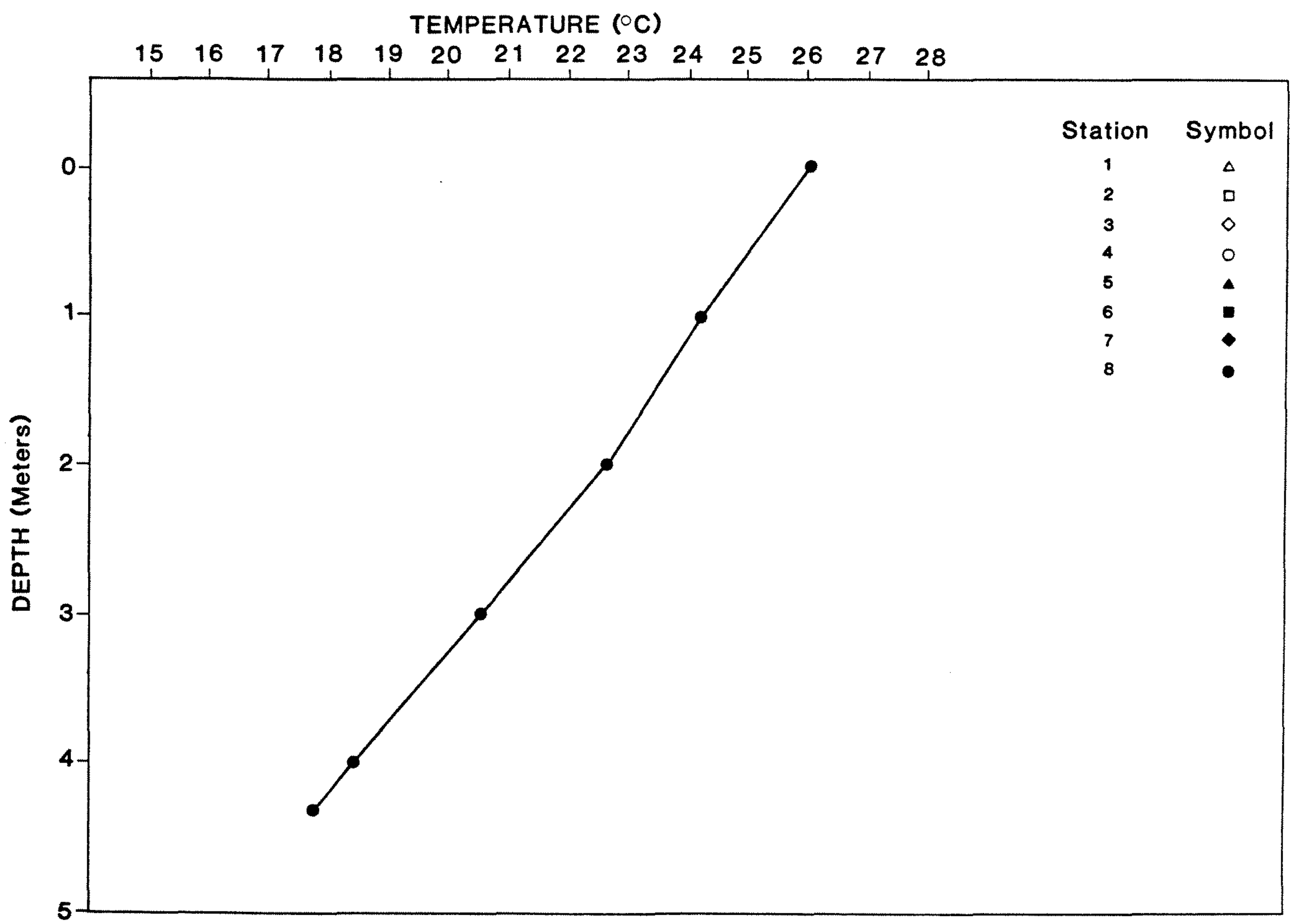

Figure 36. Vertical thermal profile collected 8 May 1985 on Ada City Lake.

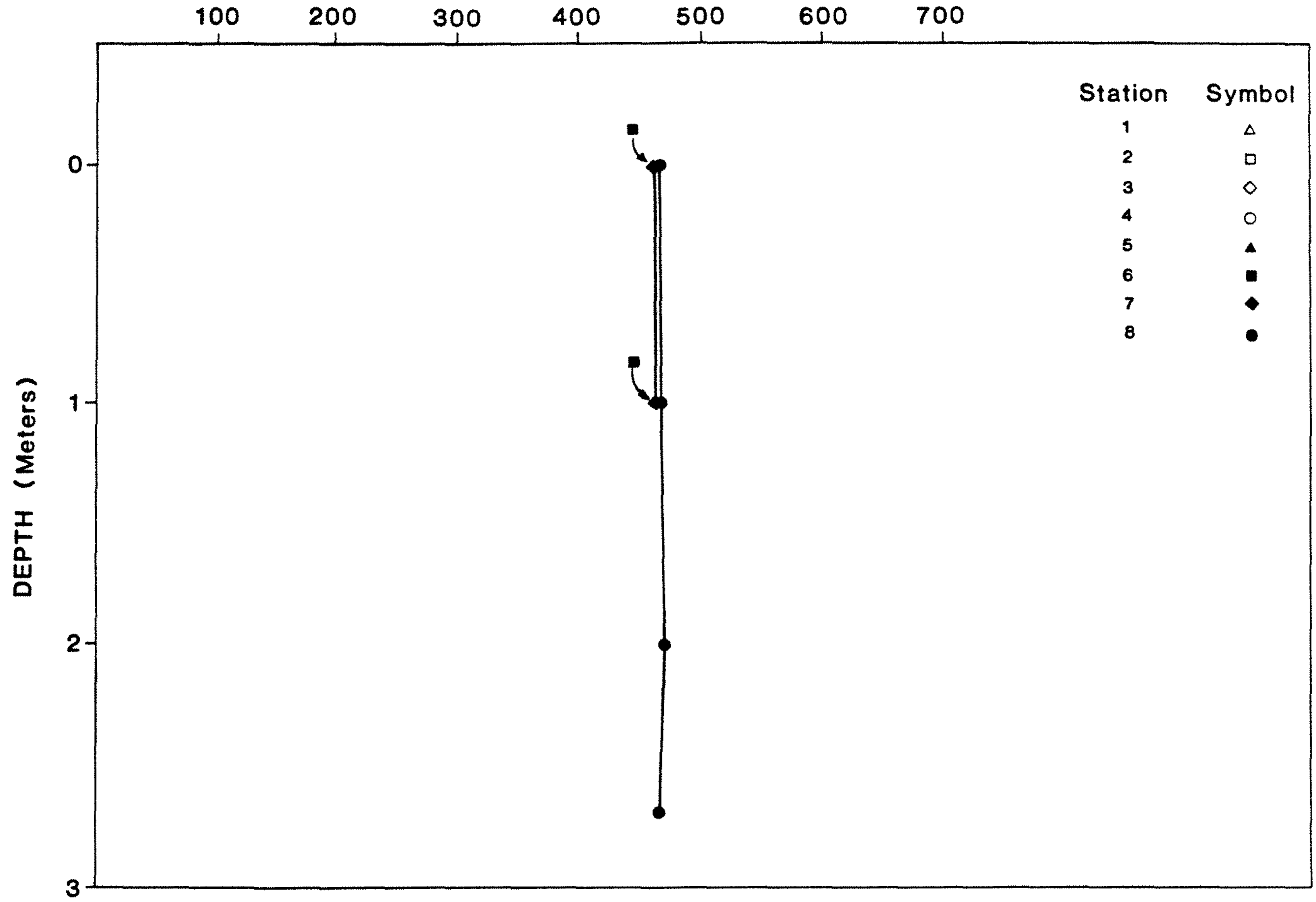

Figure 37. Vertical conductivity profile and ancillary specific conductance data collected 18 October 1984 on Ada City Lake

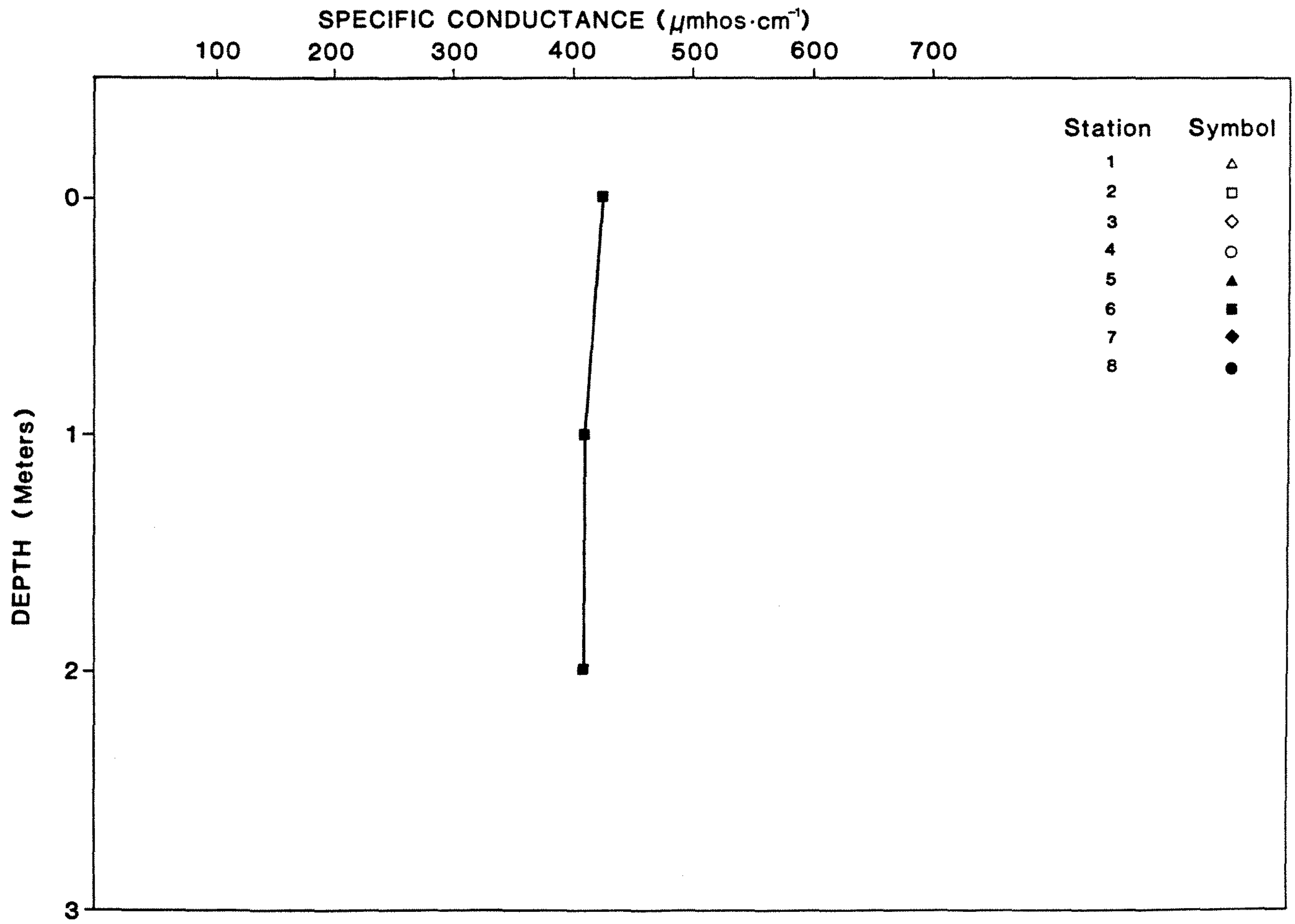

Figure 38. Vertical conductivity profile collected 14 November 1984 on Ada City Lake.

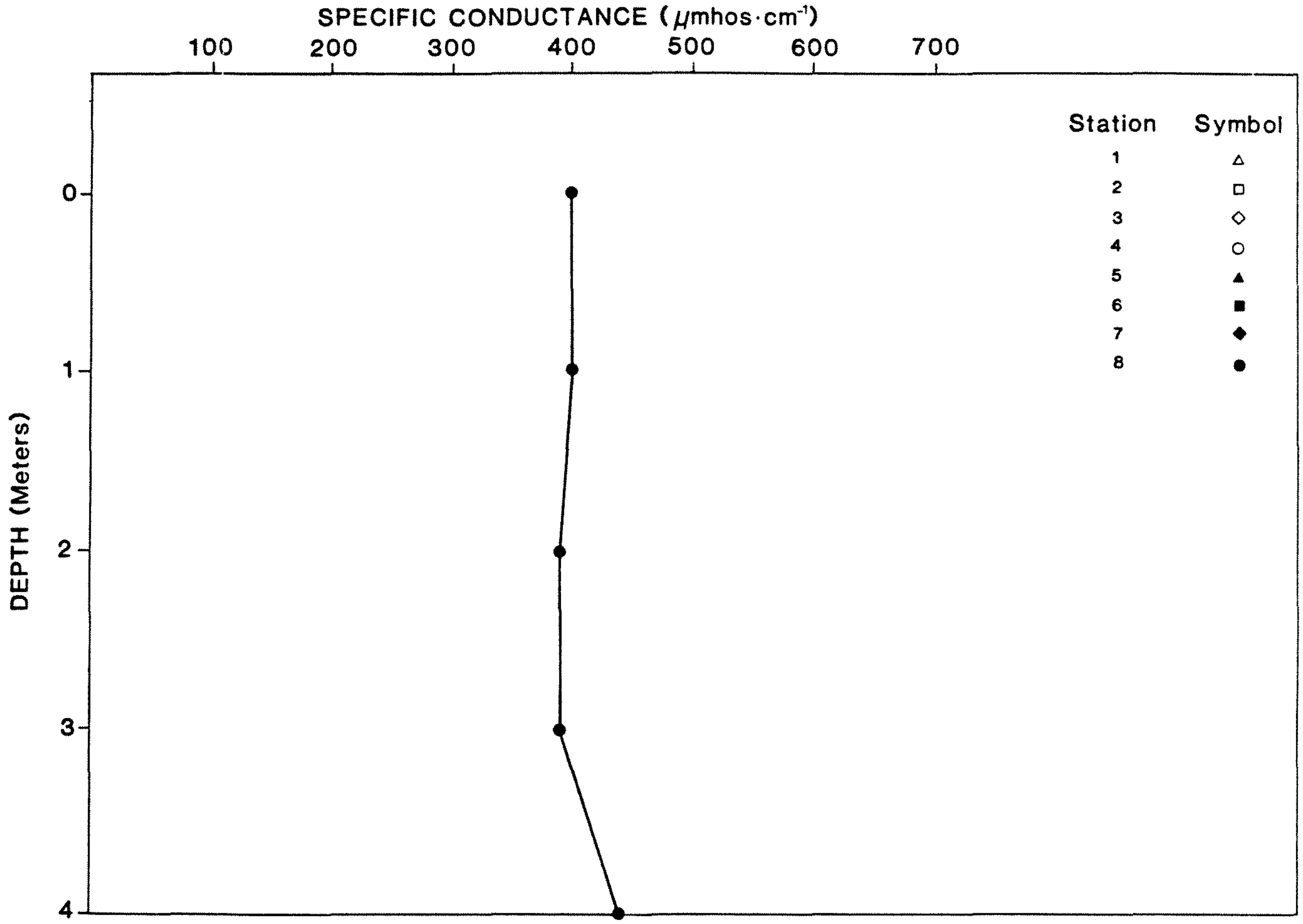

Figure 39. Vertical conductivity profile collected 12 December 1984 on Ada City Lake.

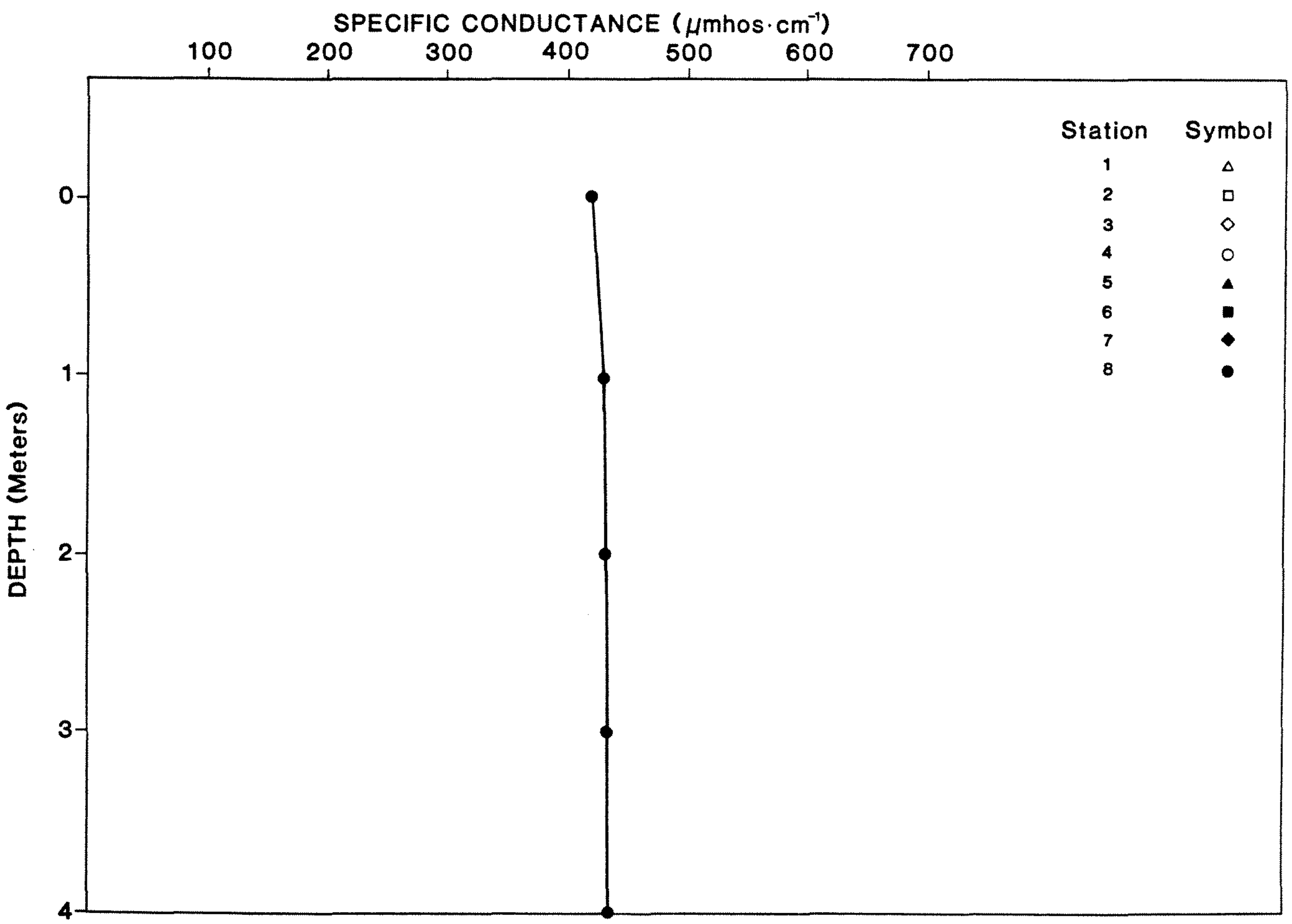

Figure 40. Vertical conductivity profile collected 23 January 1985 on Ada City Lake.

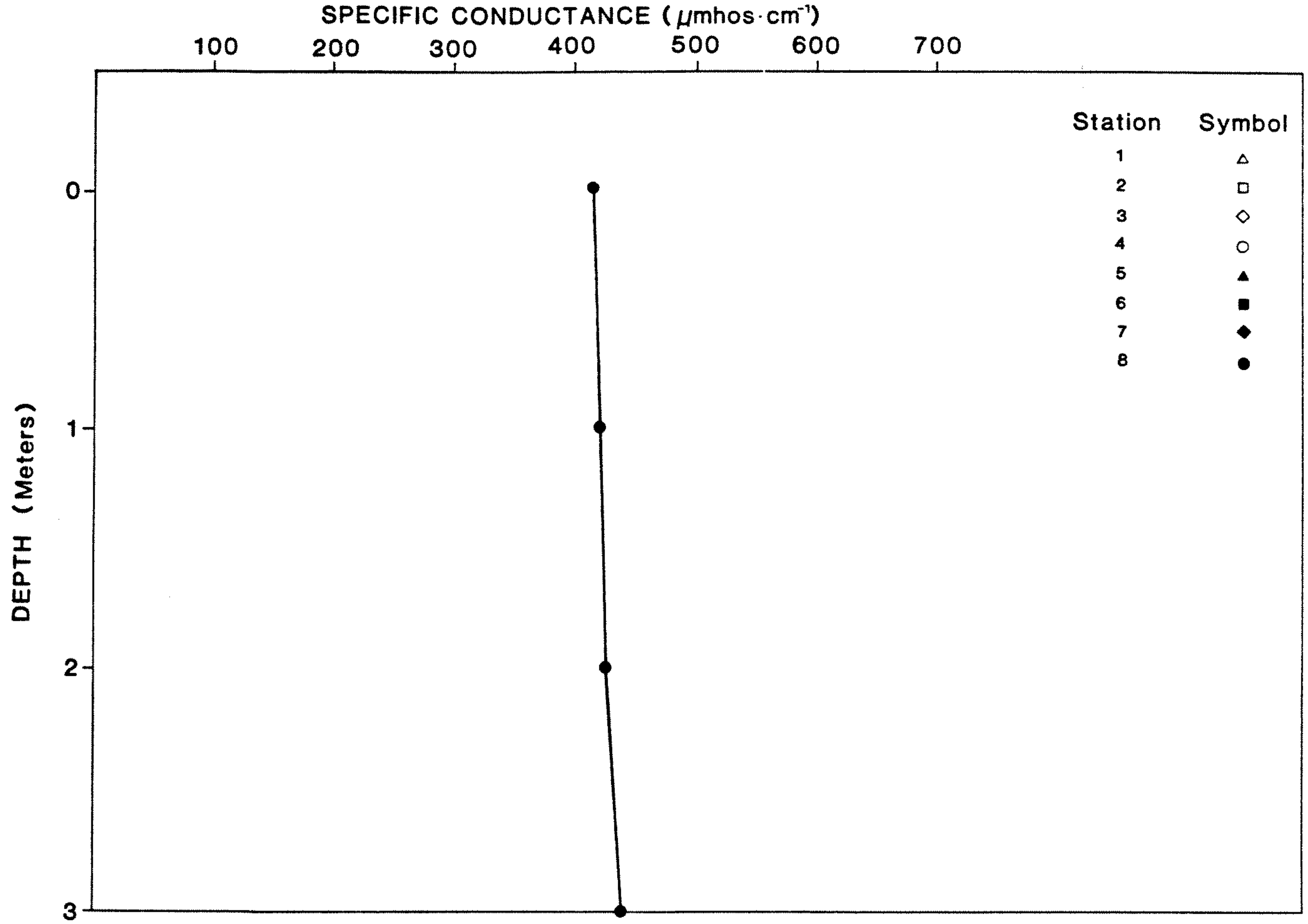

Figure 41. Vertical conductivity profile collected 17 April 1985 on Ada City Lake.

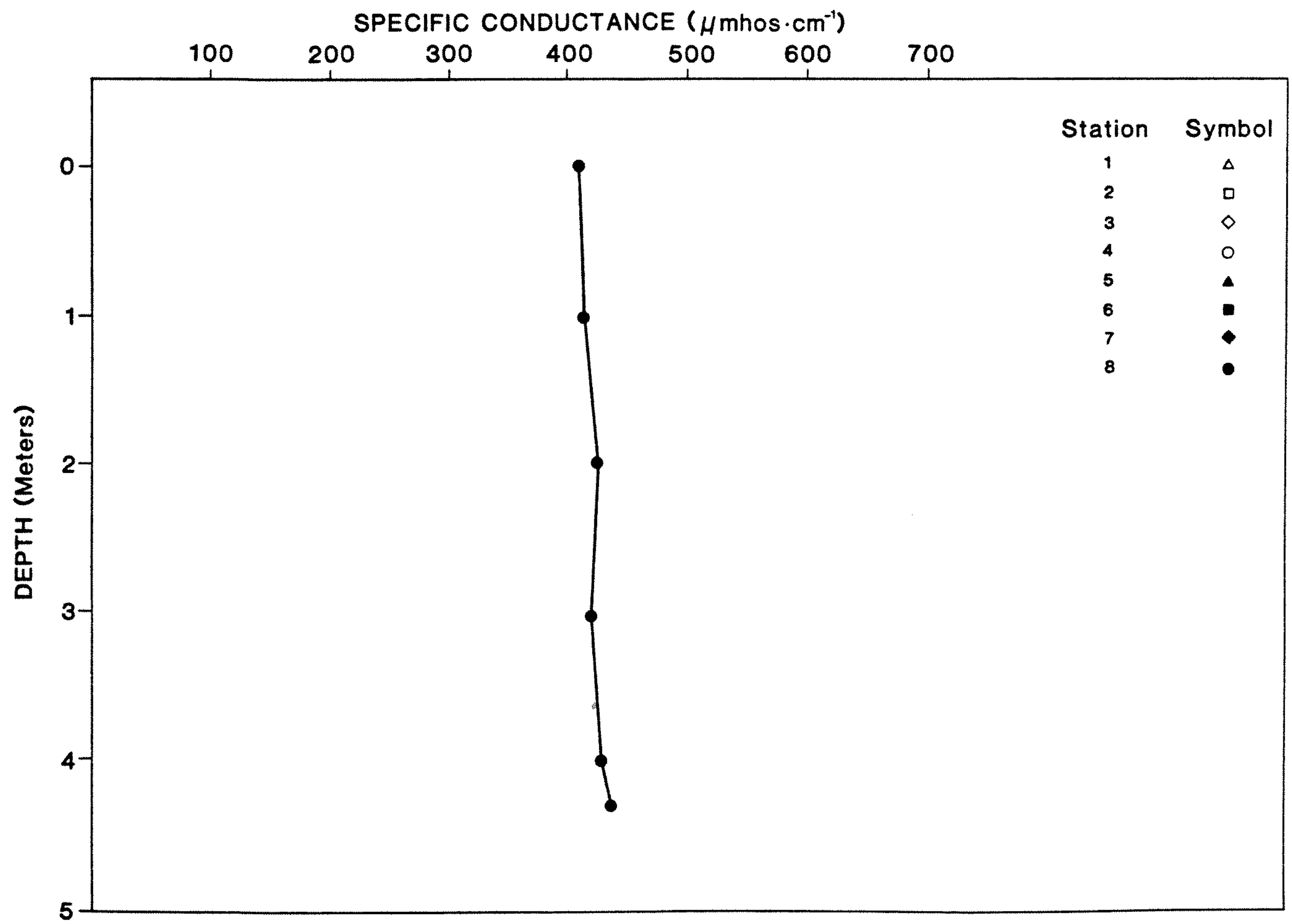

Figure 42. Vertical conductivity profile collected 8 May 1985 on Ada City Lake.

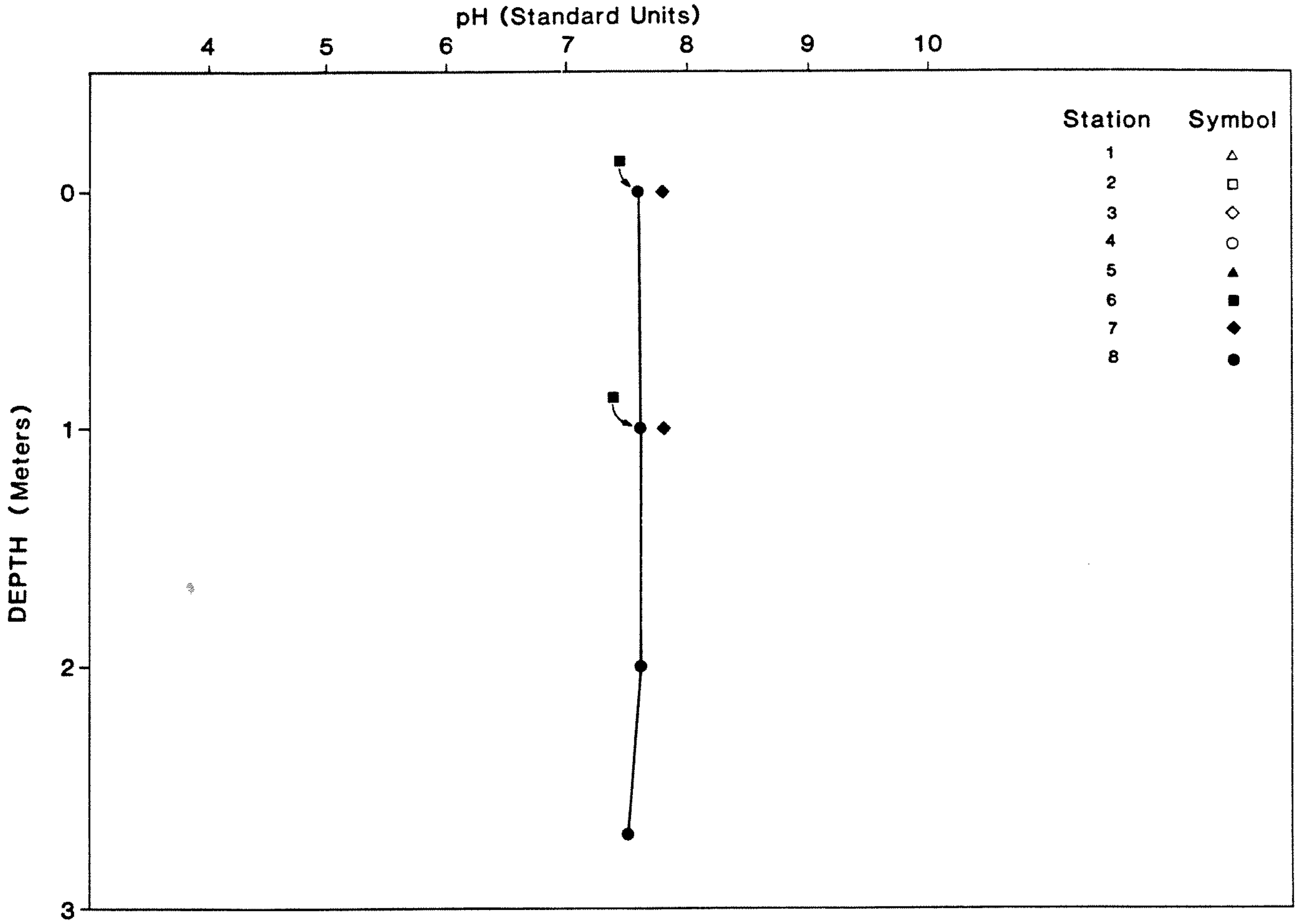

Figure 43. Vertical pH profile and ancillary pH data collected 18 October 1984 on Ada City Lake.

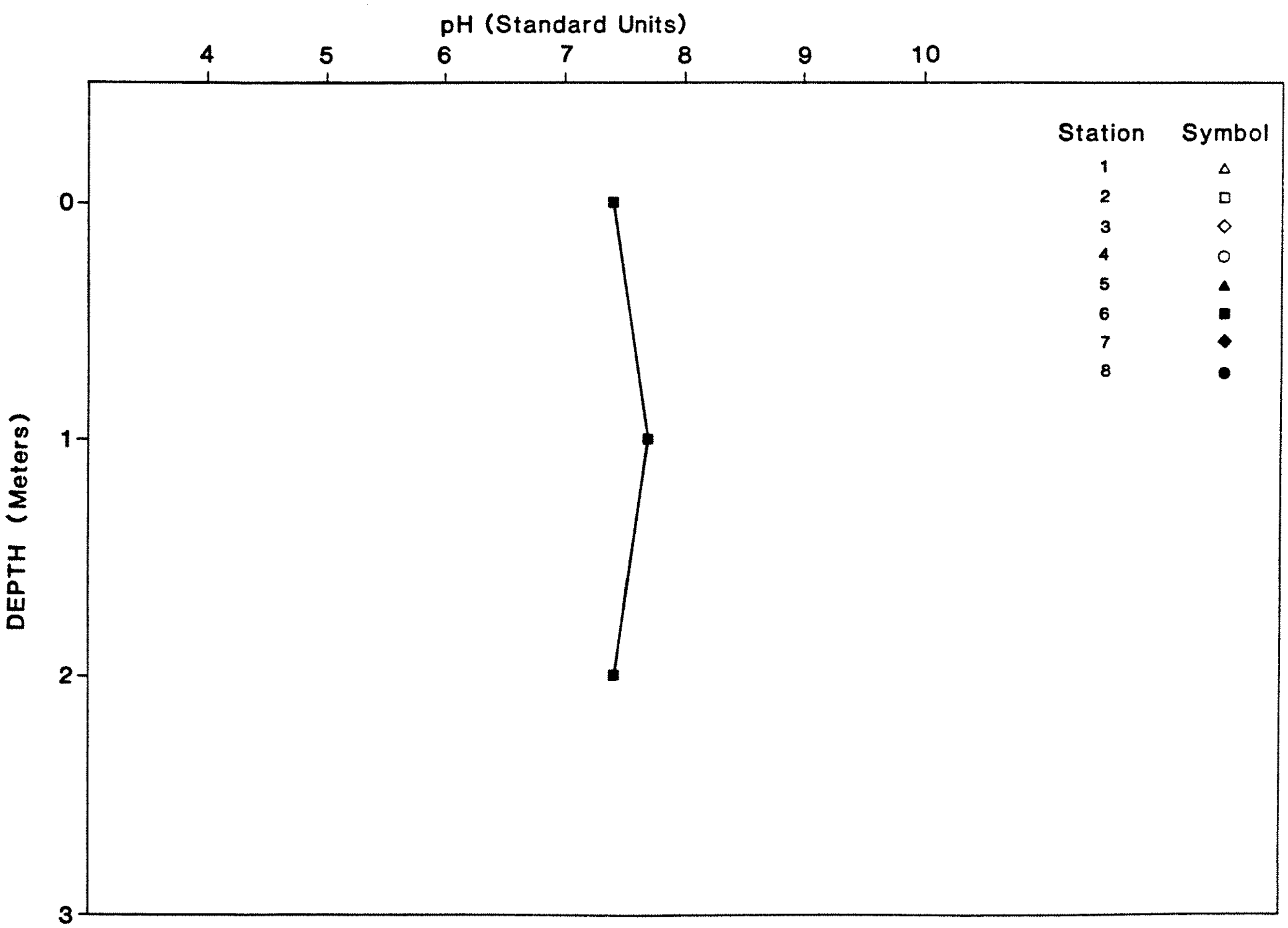

Figure 44. Vertical pH profile collected 14 November 1984 on Ada City Lake.

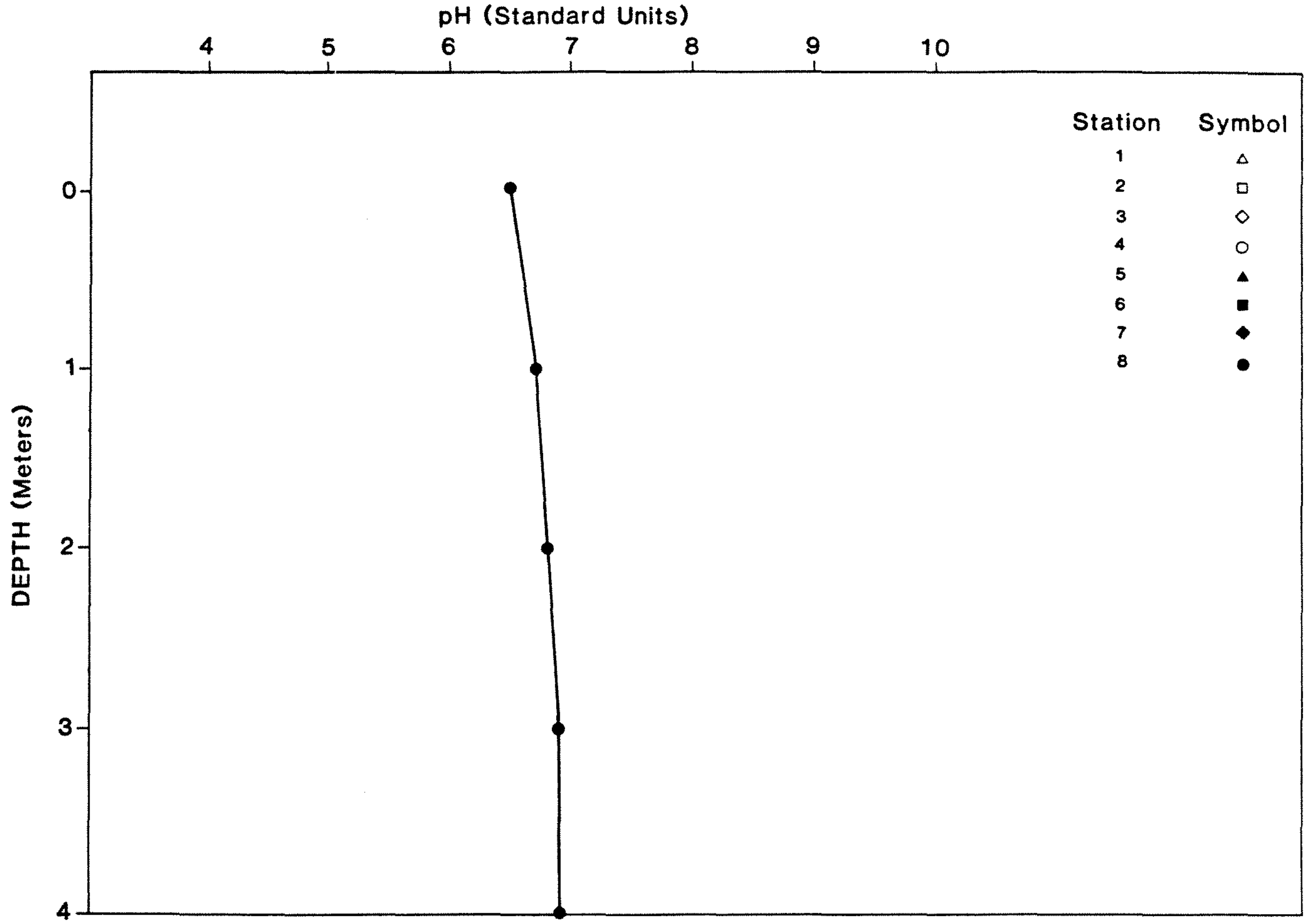

Figure 45. Vertical pH profile collected 12 December 1984 on Ada City Lake.

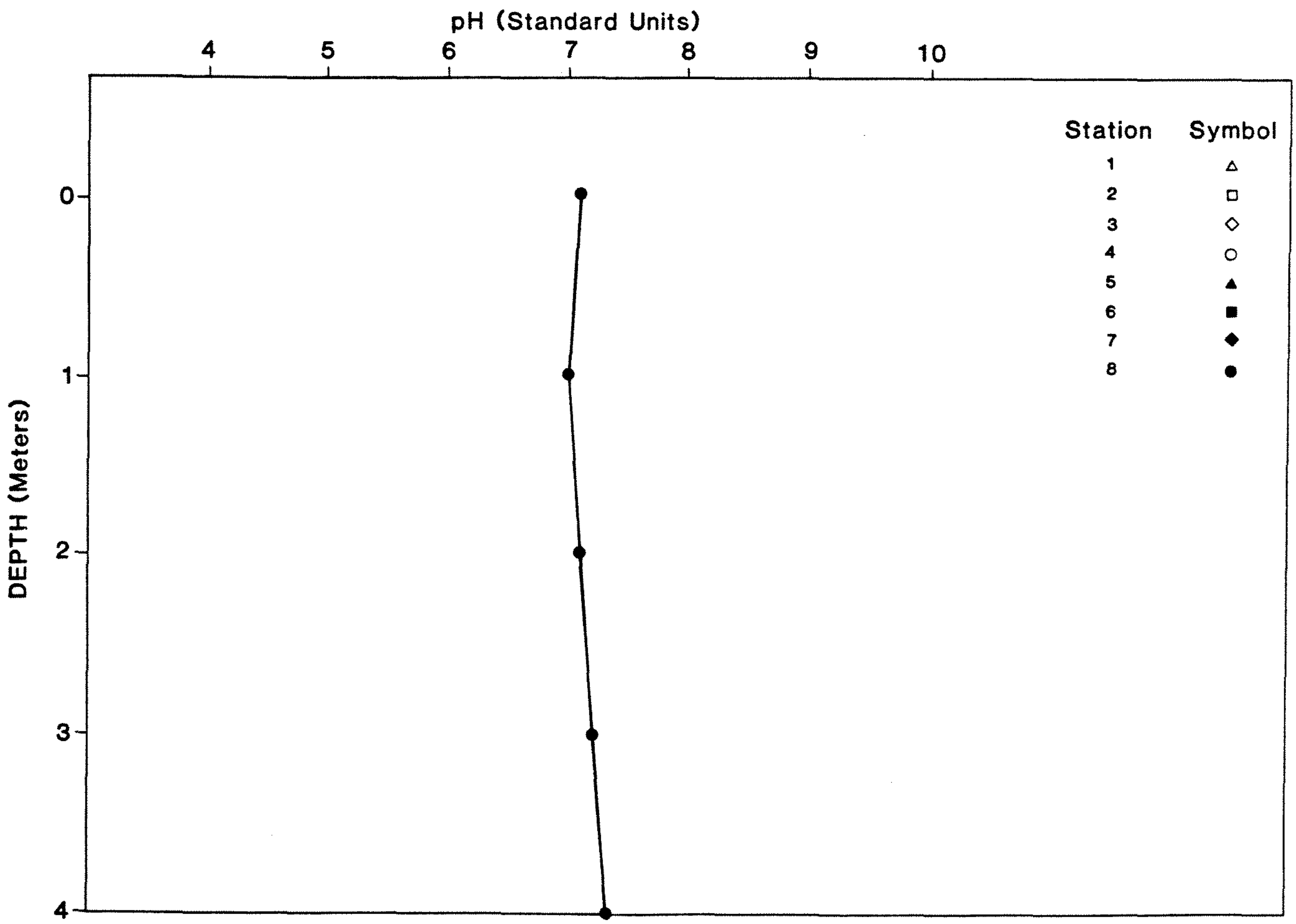

Figure 46. Vertical pH profile collected 23 January 1985 on Ada City Lake.

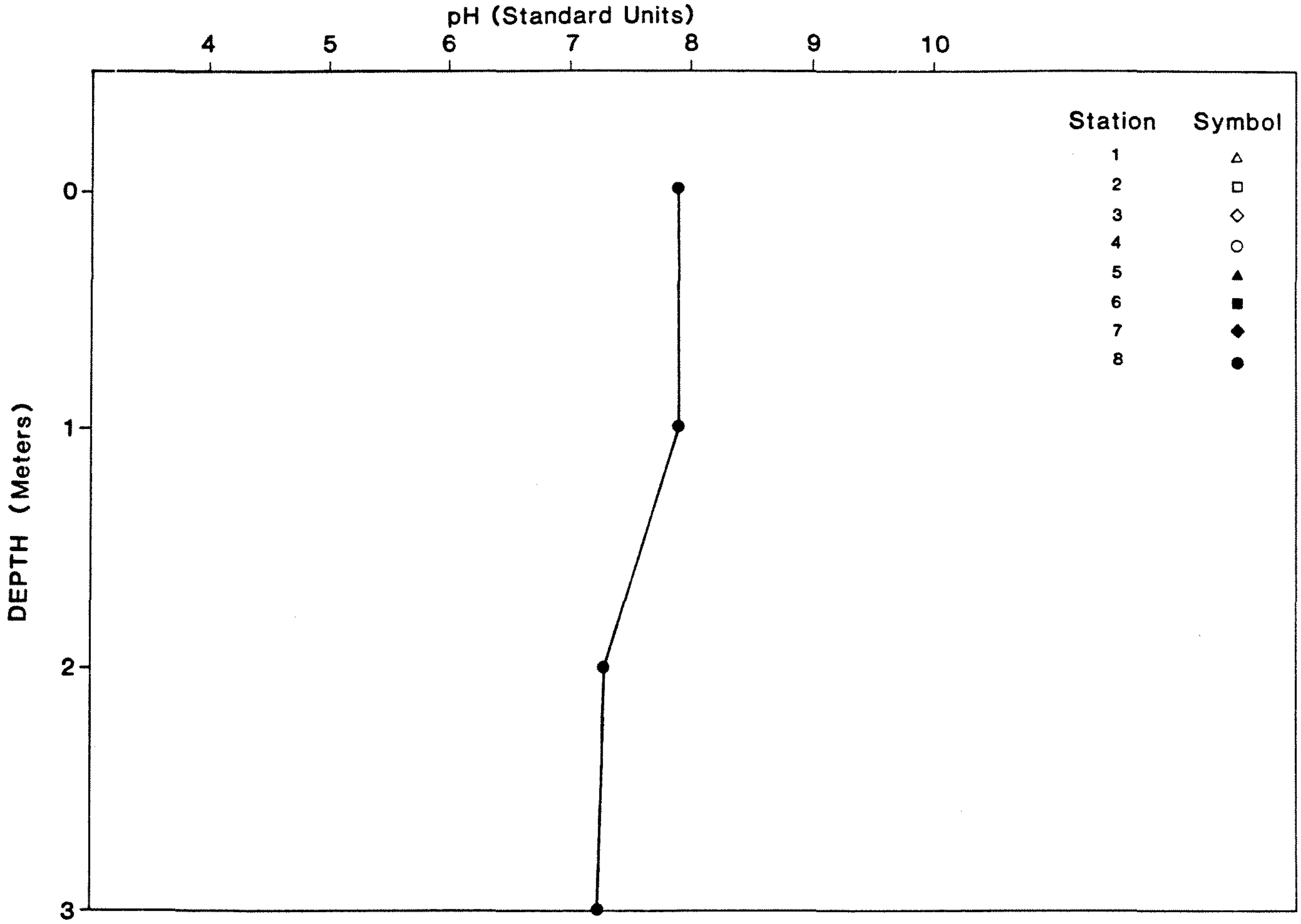

Figure 47. Vertical pH profile collected 17 April 1985 on Ada City Lake.

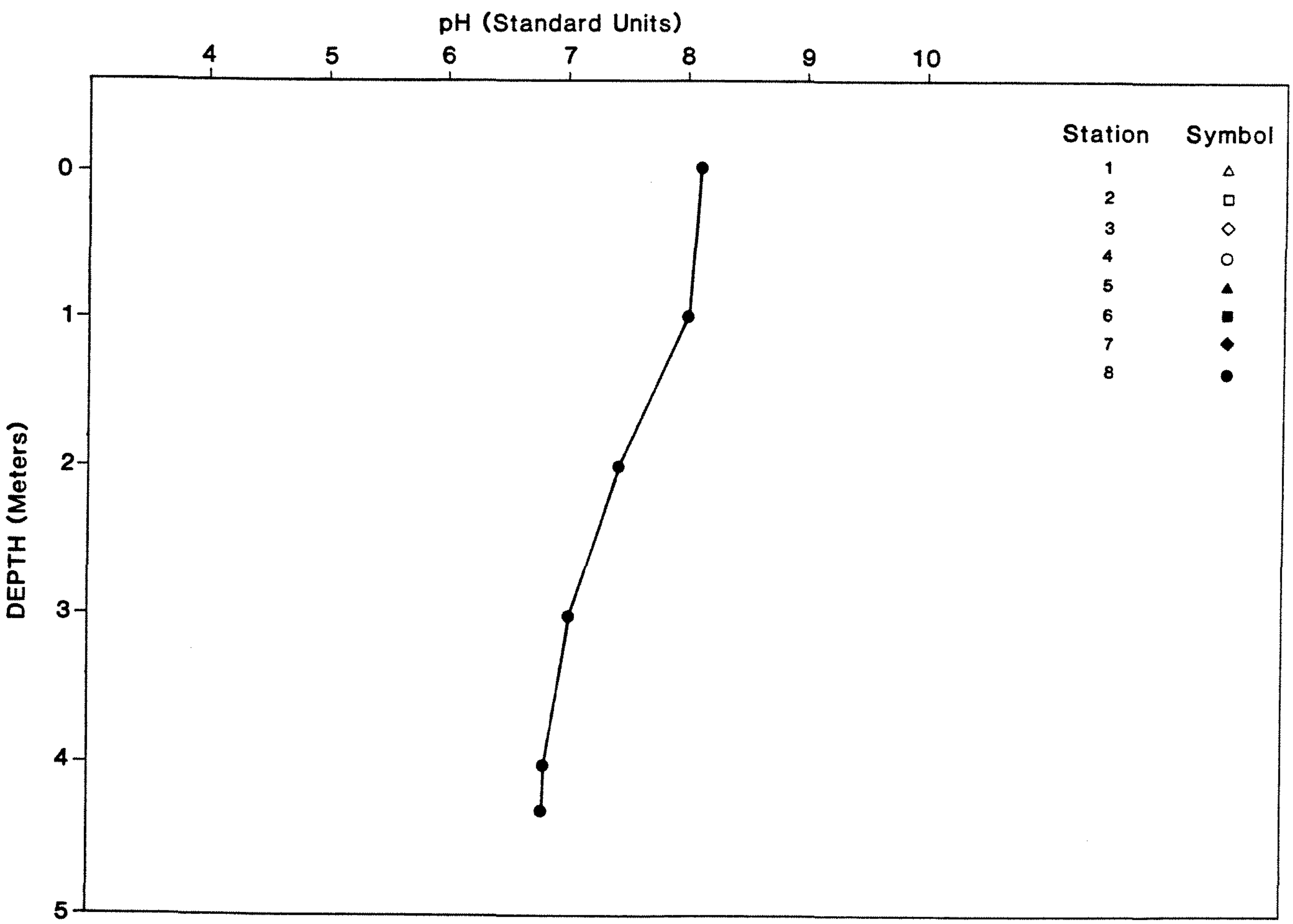

Figure 48. Vertical pH profile collected 8 May 1985 on Ada City Lake.

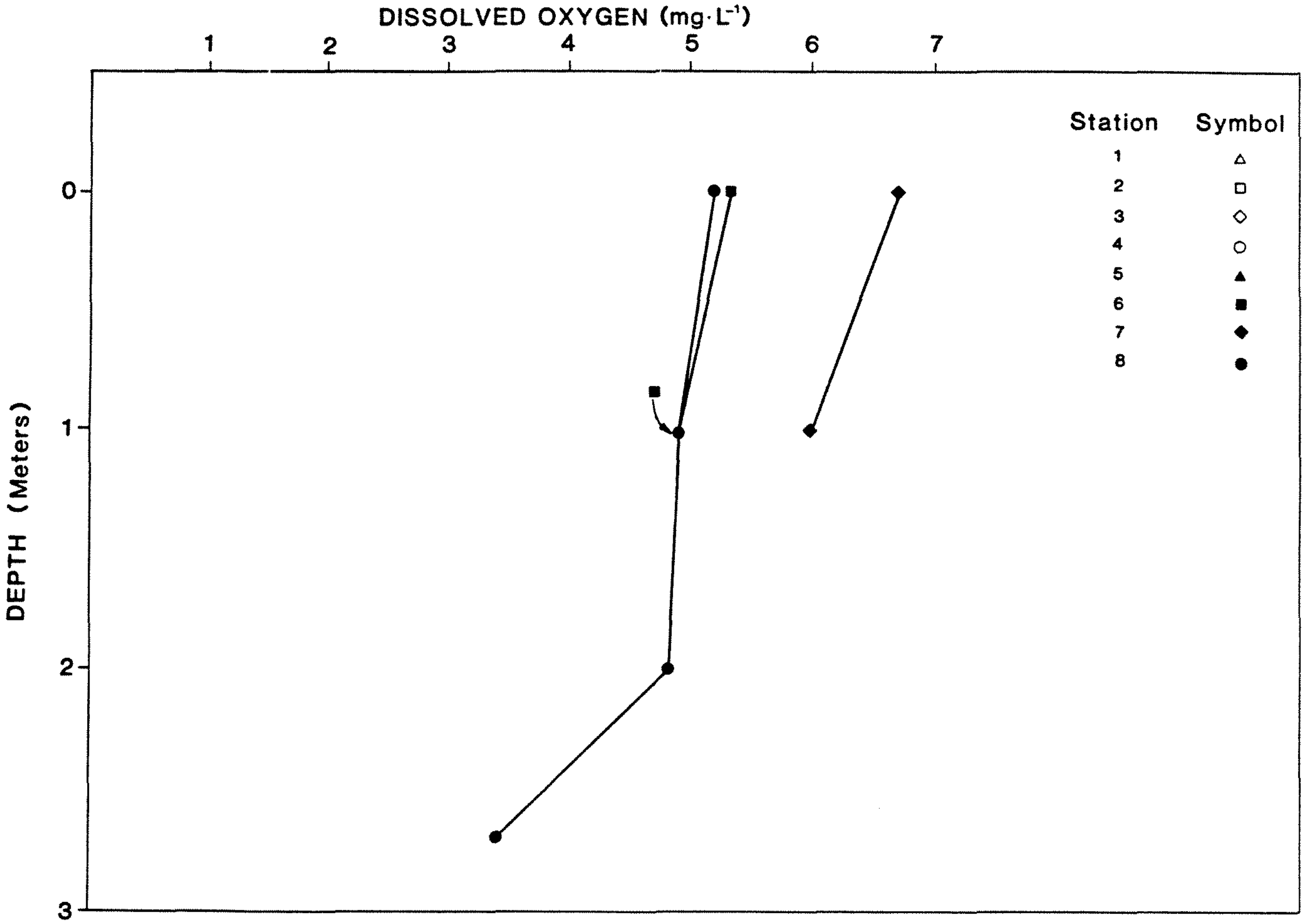

Figure 49. Vertical dissolved oxygen profile and ancillary dissolved oxygen data collected 18 October 1984 on Ada City Lake.

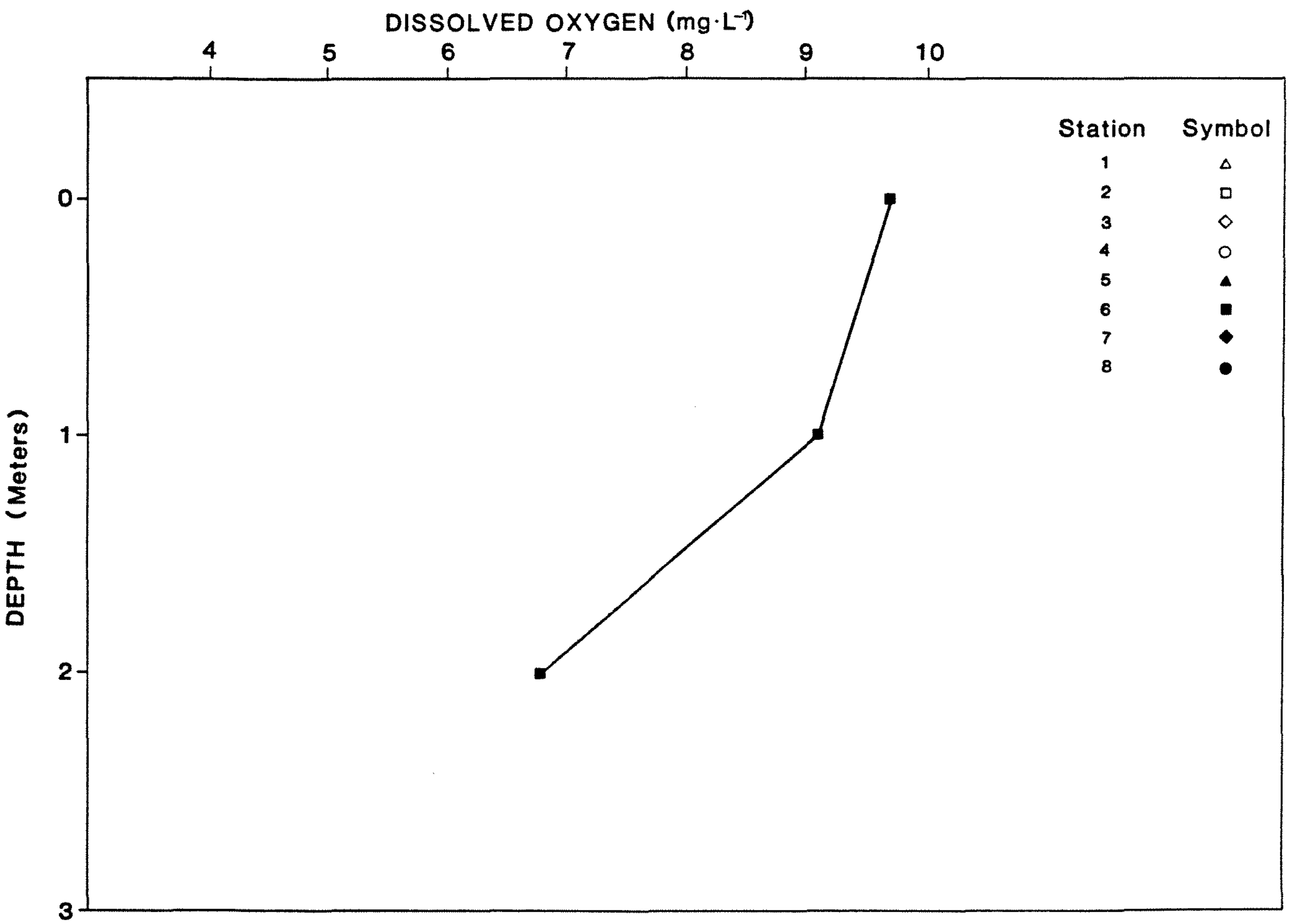

Figure 50. Vertical dissolved oxygen profile collected 14 November 1984 on Ada City Lake.

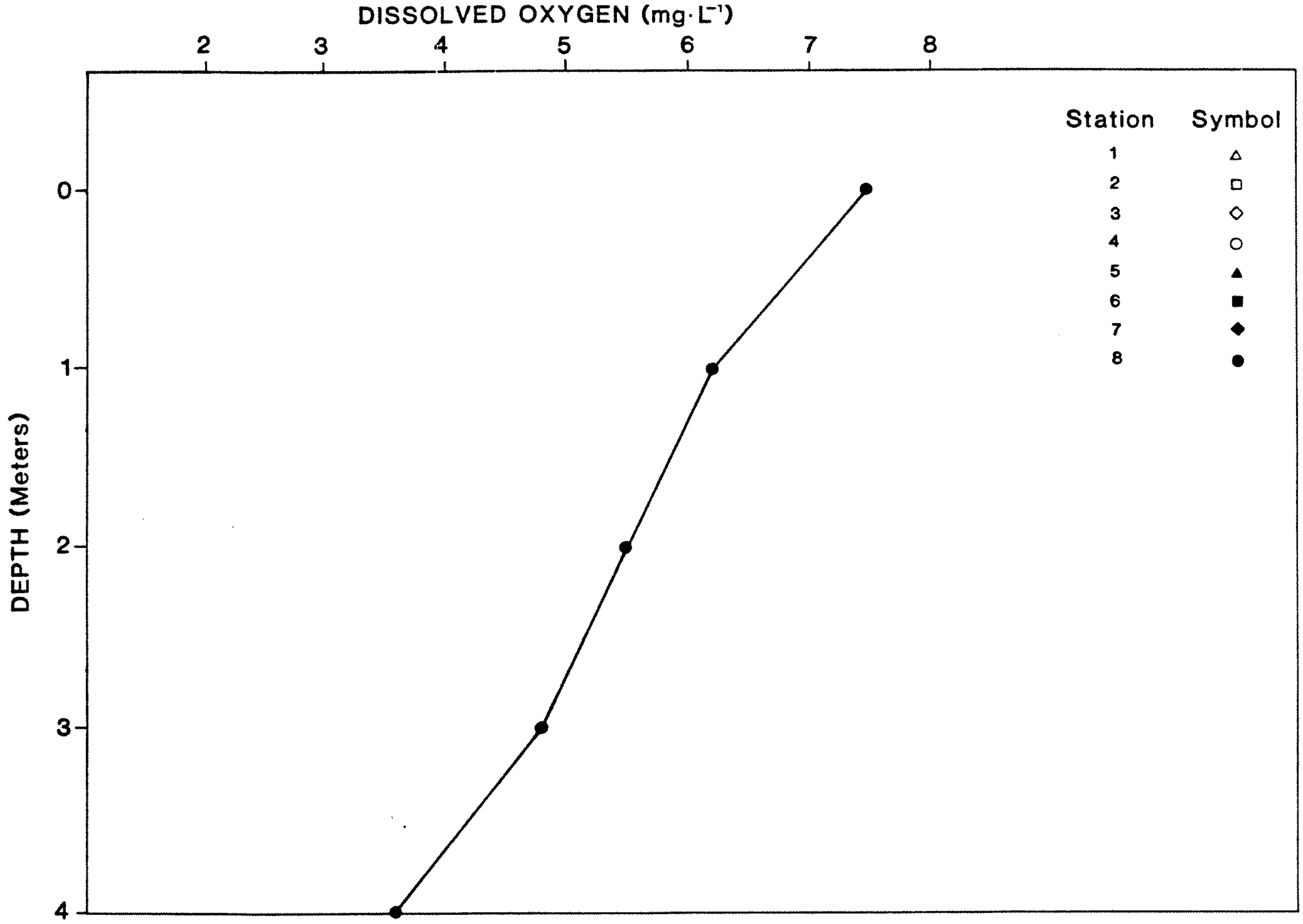

Figure 51. Vertical dissolved oxygen profile collected 12 December 1984 on Ada City Lake.

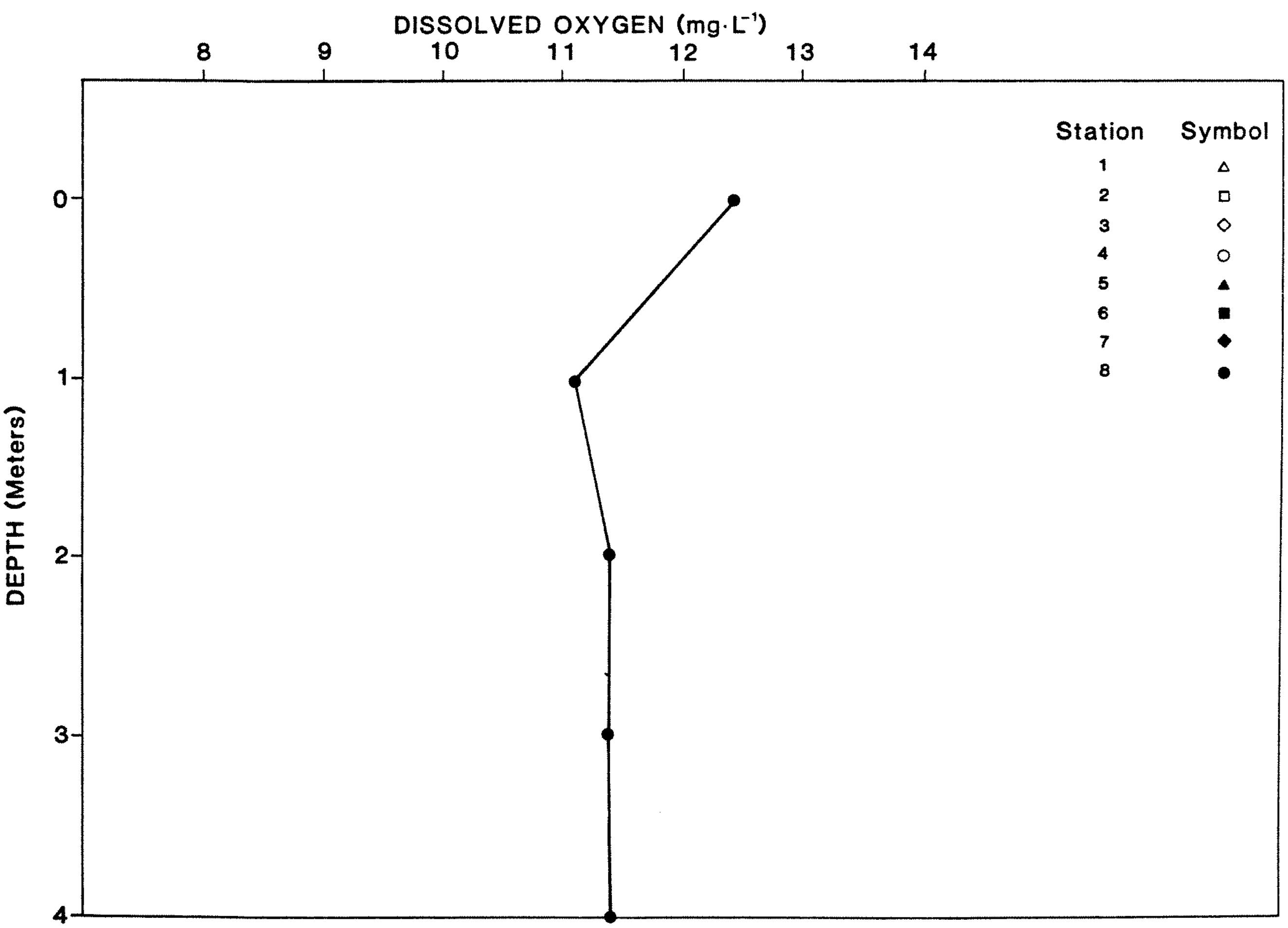

Figure 52. Vertical dissolved oxygen profile collected 23 January 1985 on Ada City Lake.

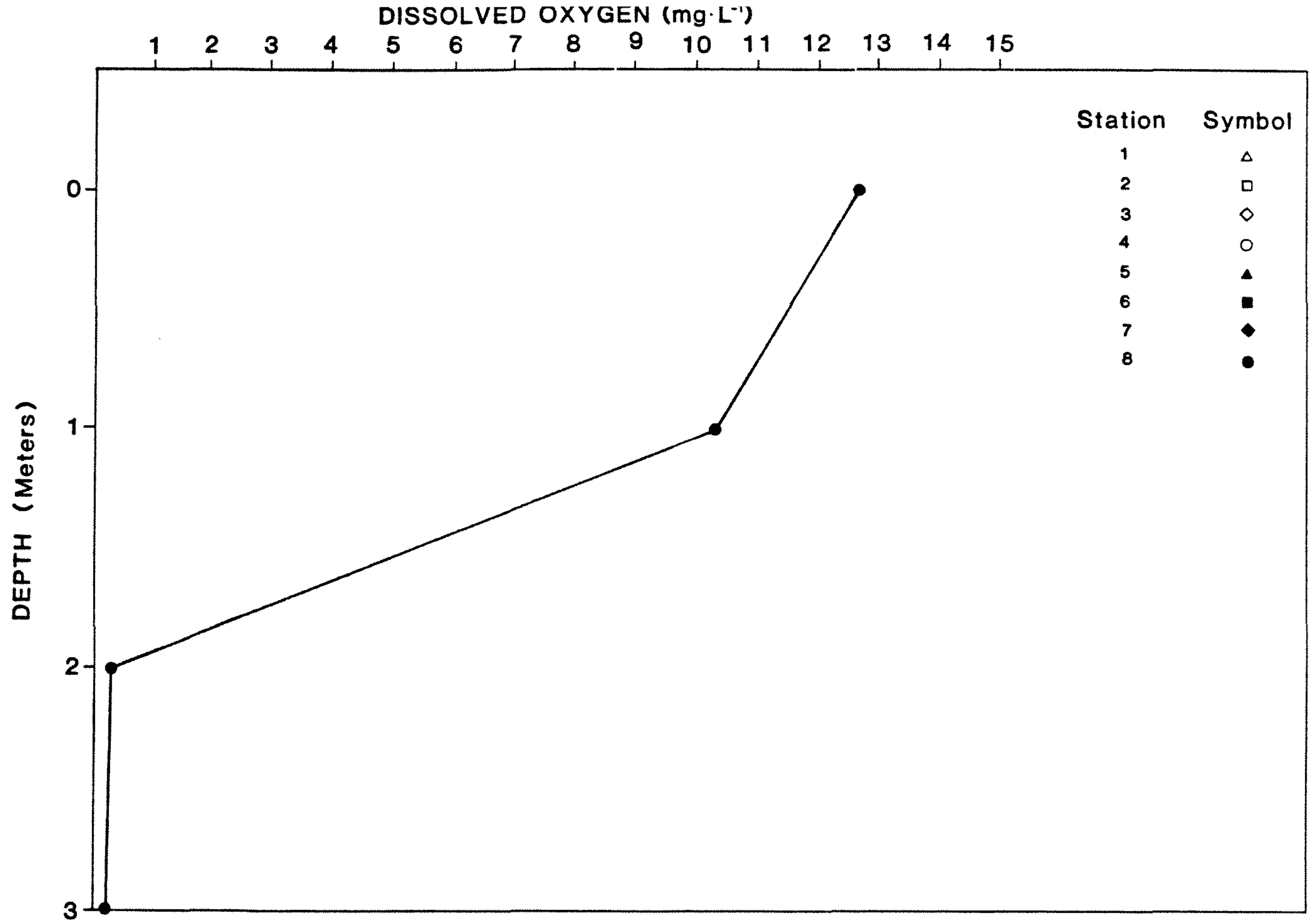

Figure 53. Vertical dissolved oxygen profile collected 17 April 1985 on Ada City Lake.

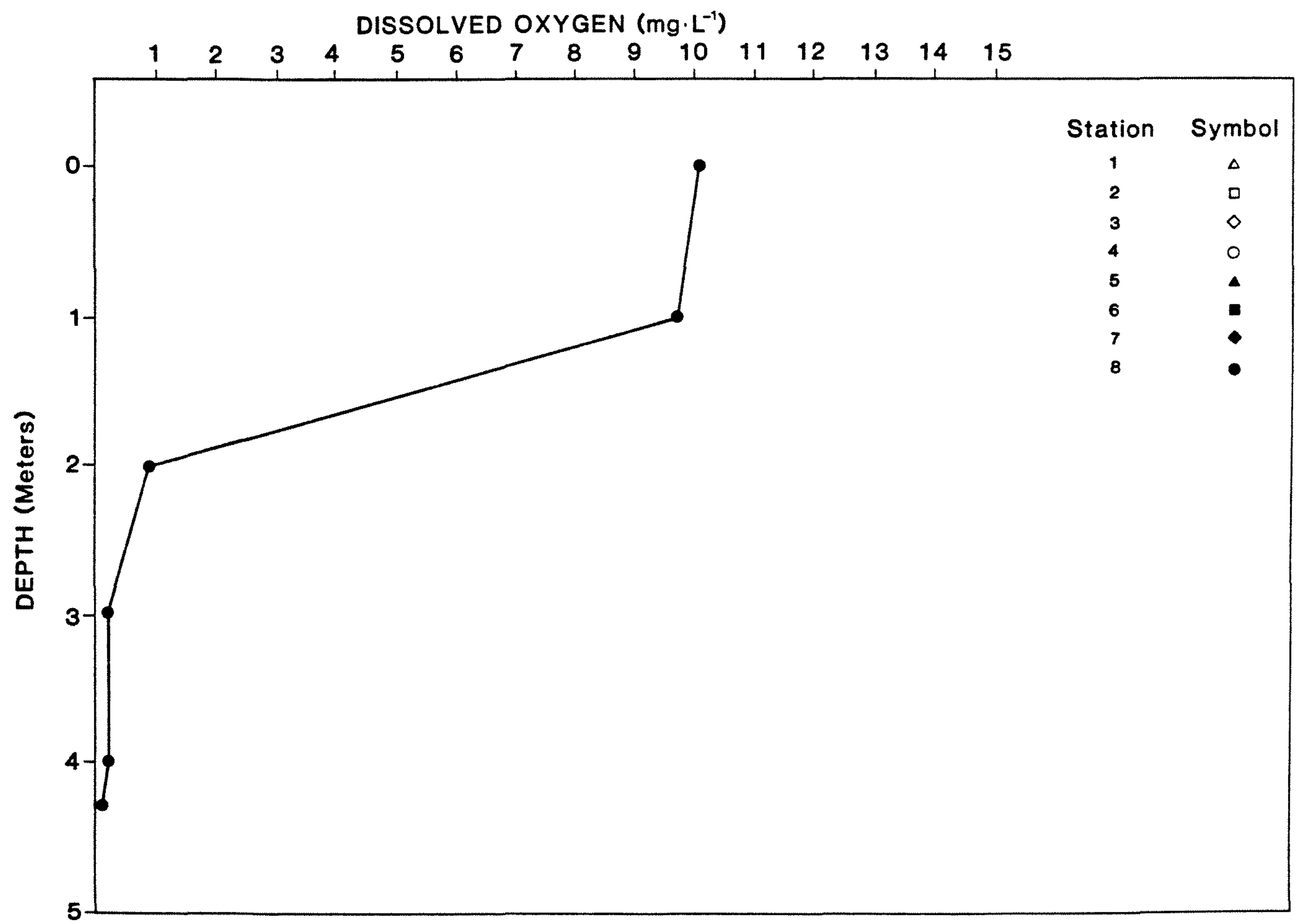

Figure 54. Vertical dissolved oxygen profile obtained 8 May 1985 on Ada City Lake.

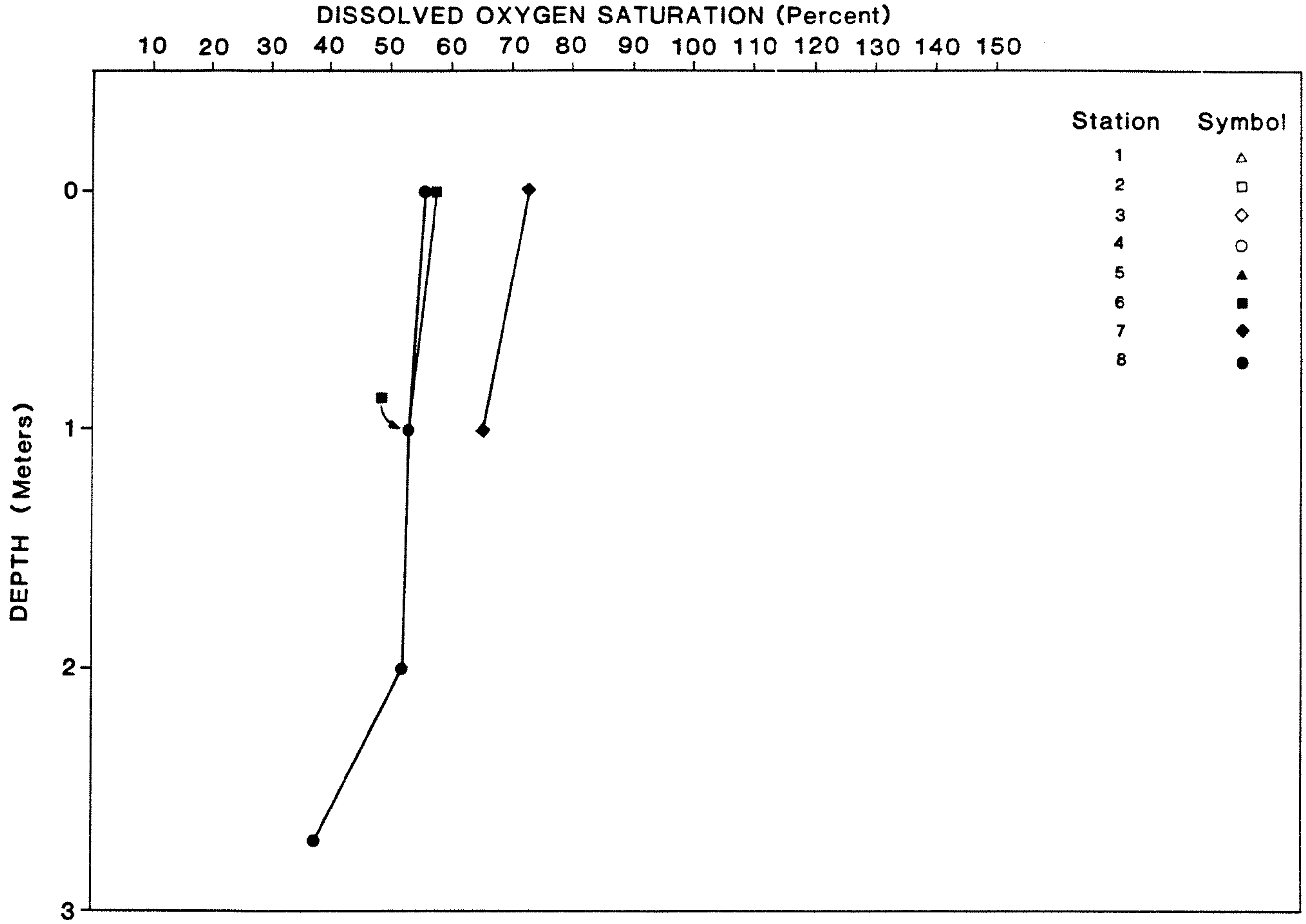

Figure 55. Vertical dissolved oxygen percent saturation profile and ancillary oxygen saturation data obtained 18 October 1984 on Ada City Lake.

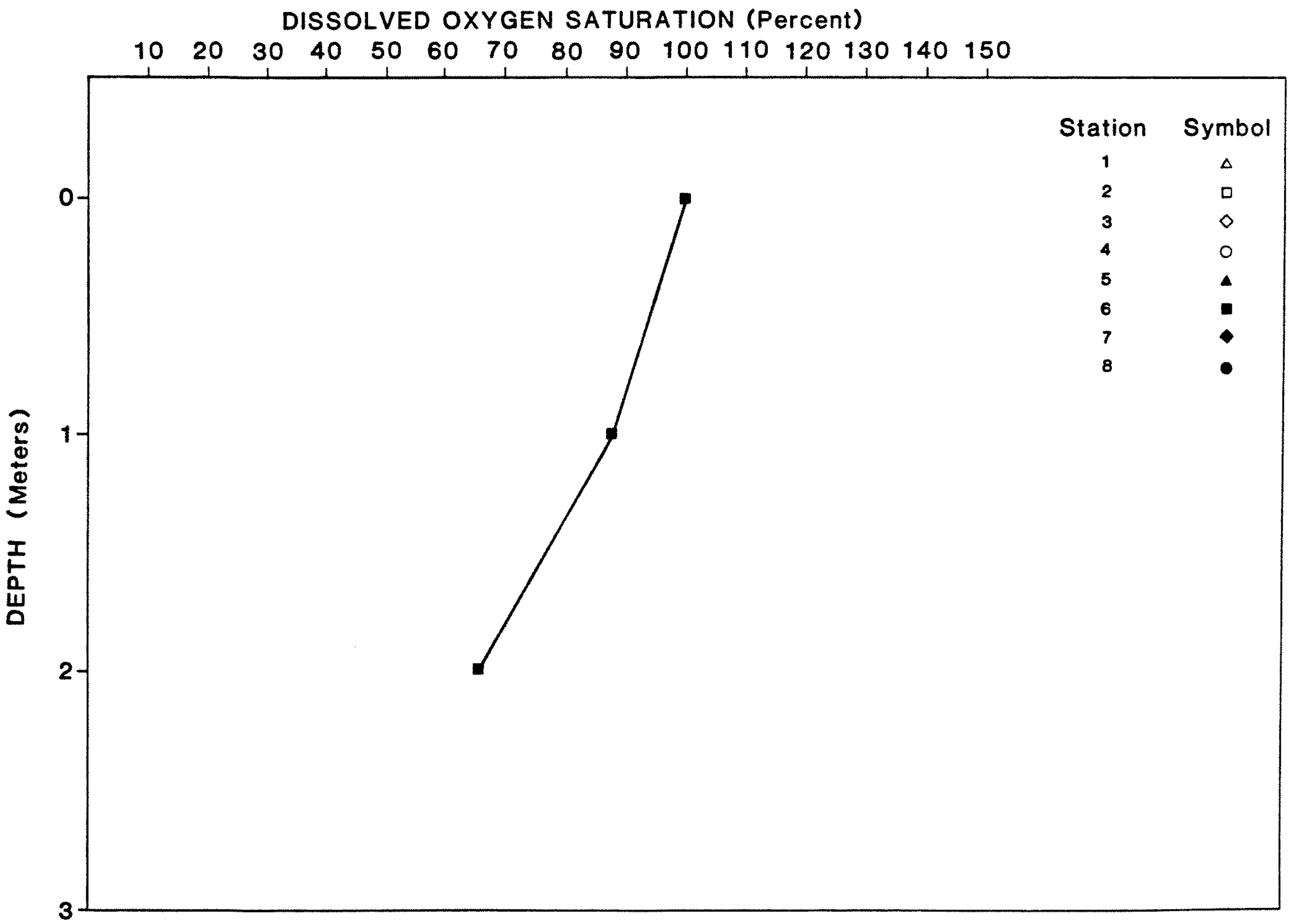

Figure 56. Vertical dissolved oxygen percent saturation profile obtained 14 November 1984 on Ada City Lake.

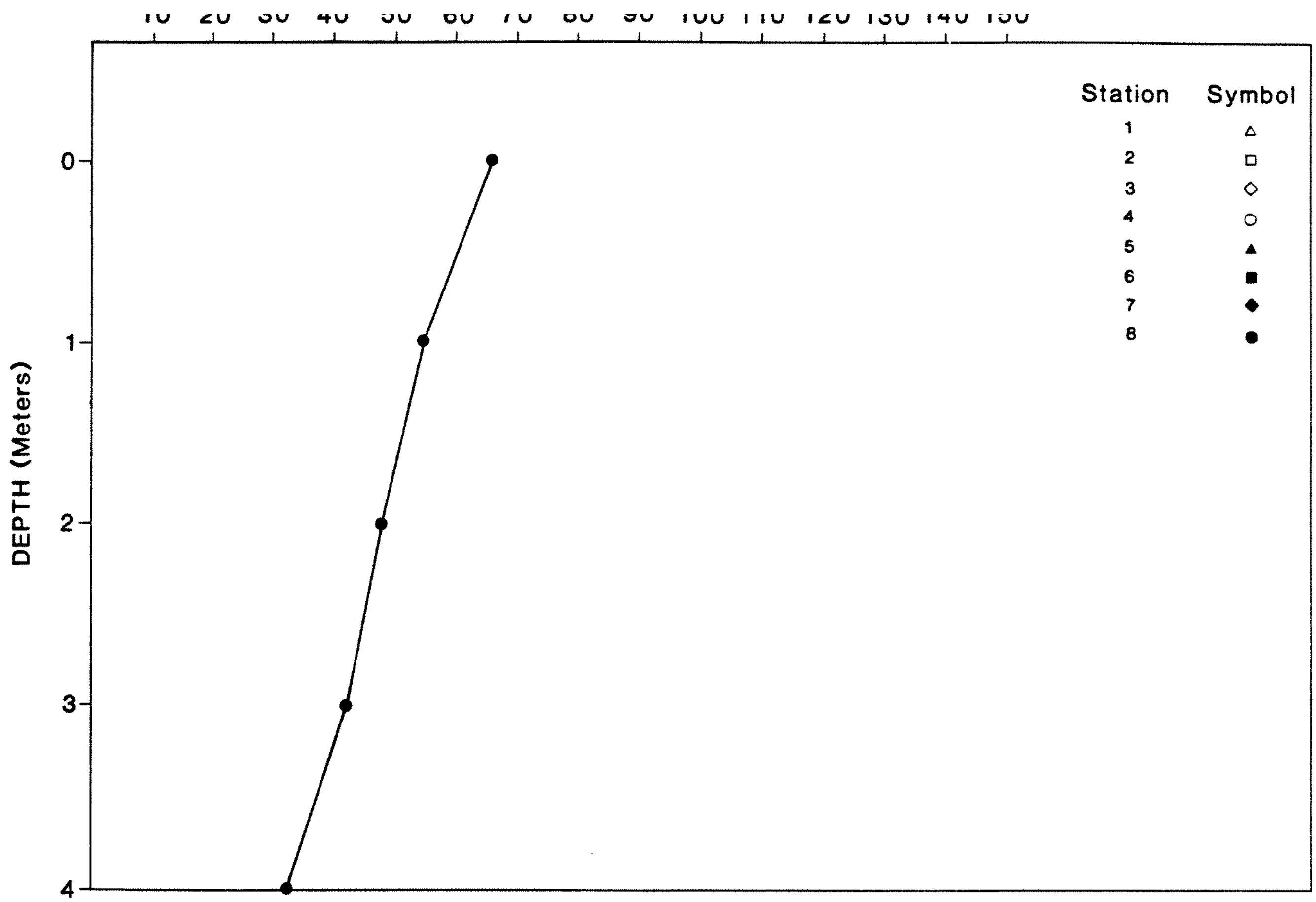

Figure 57. Vertical dissolved oxygen percent saturation profile obtained 12 December 1984 on Ada City Lake.

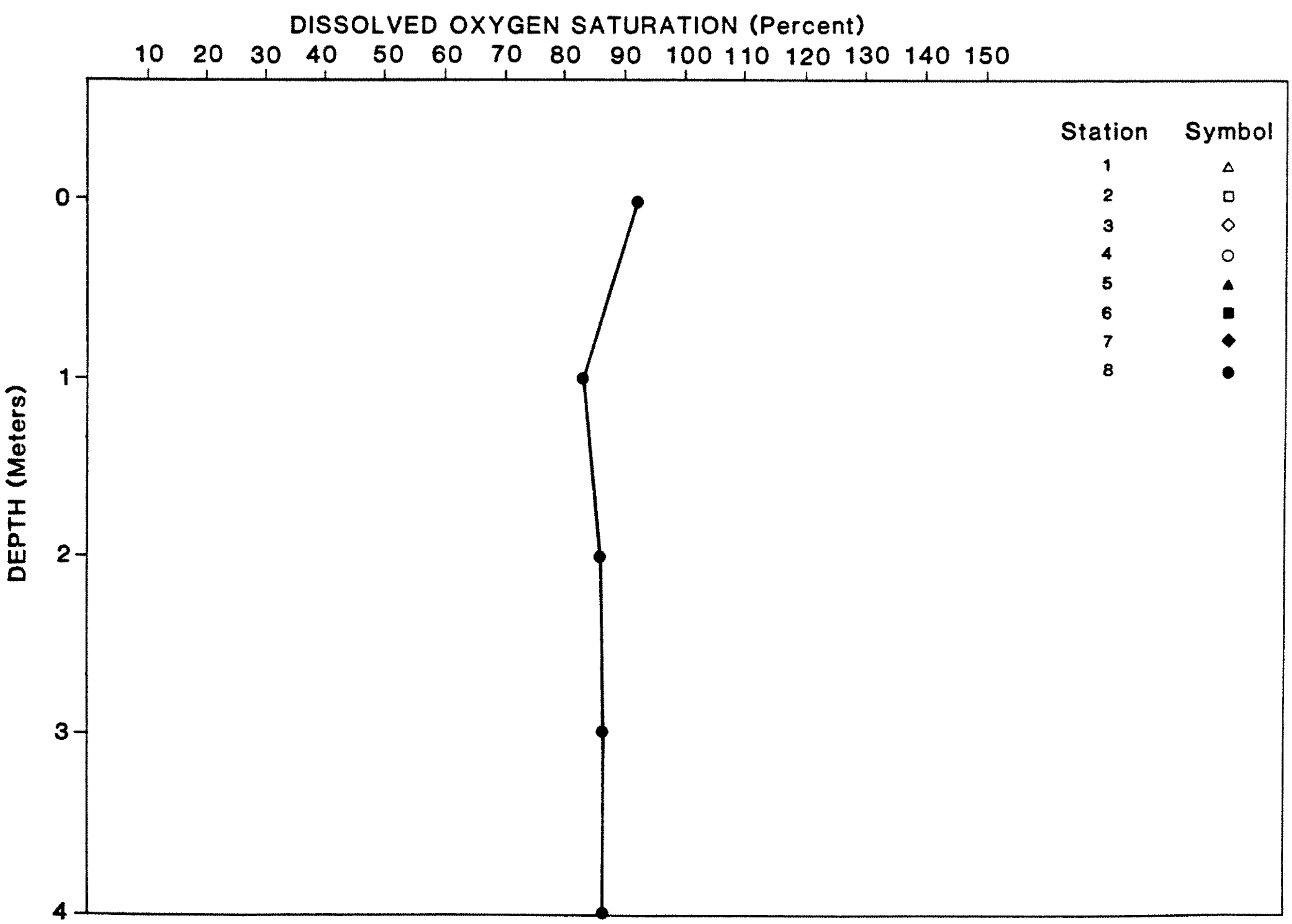

Figure 58. Vertical dissolved oxygen percent saturation profile obtained 23 January 1985 on Ada City Lake.

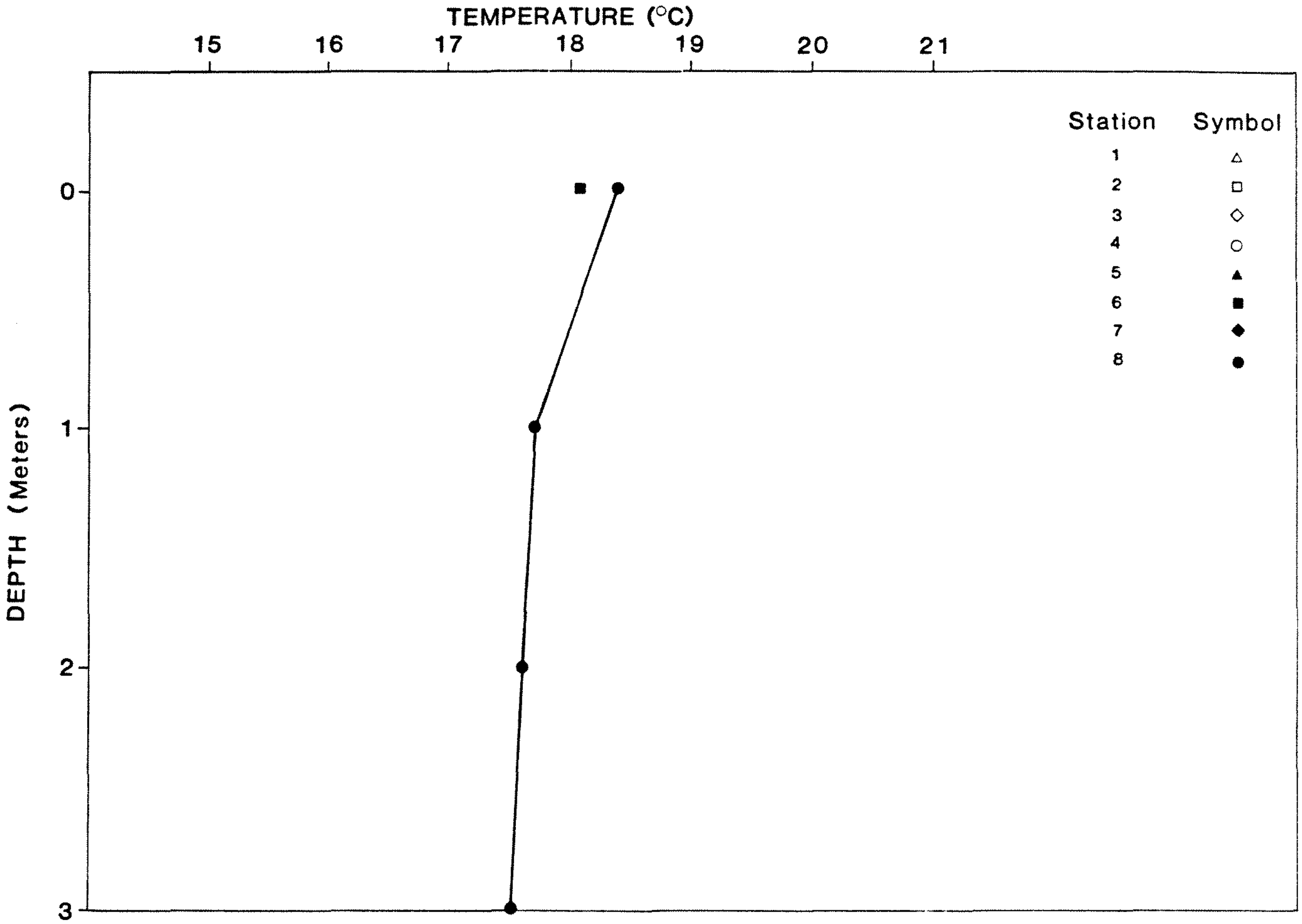

Figure 67. Vertical thermal profile and ancillary thermal data obtained 22 October 1985 on Ada City Lake.

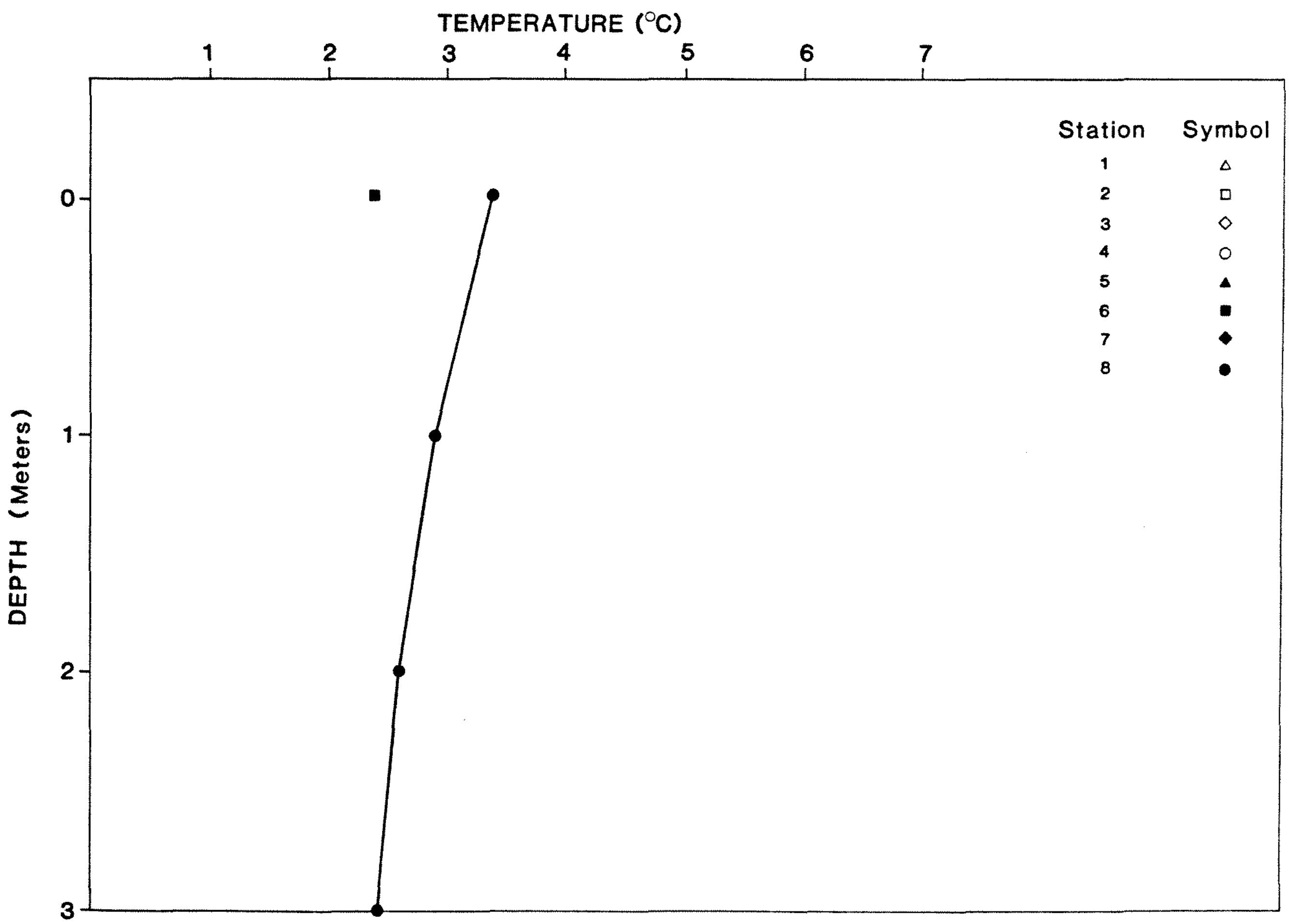

Figure 68. Vertical thermal profile and ancillary thermal data obtained 2 December 1985 on Ada City Lake.

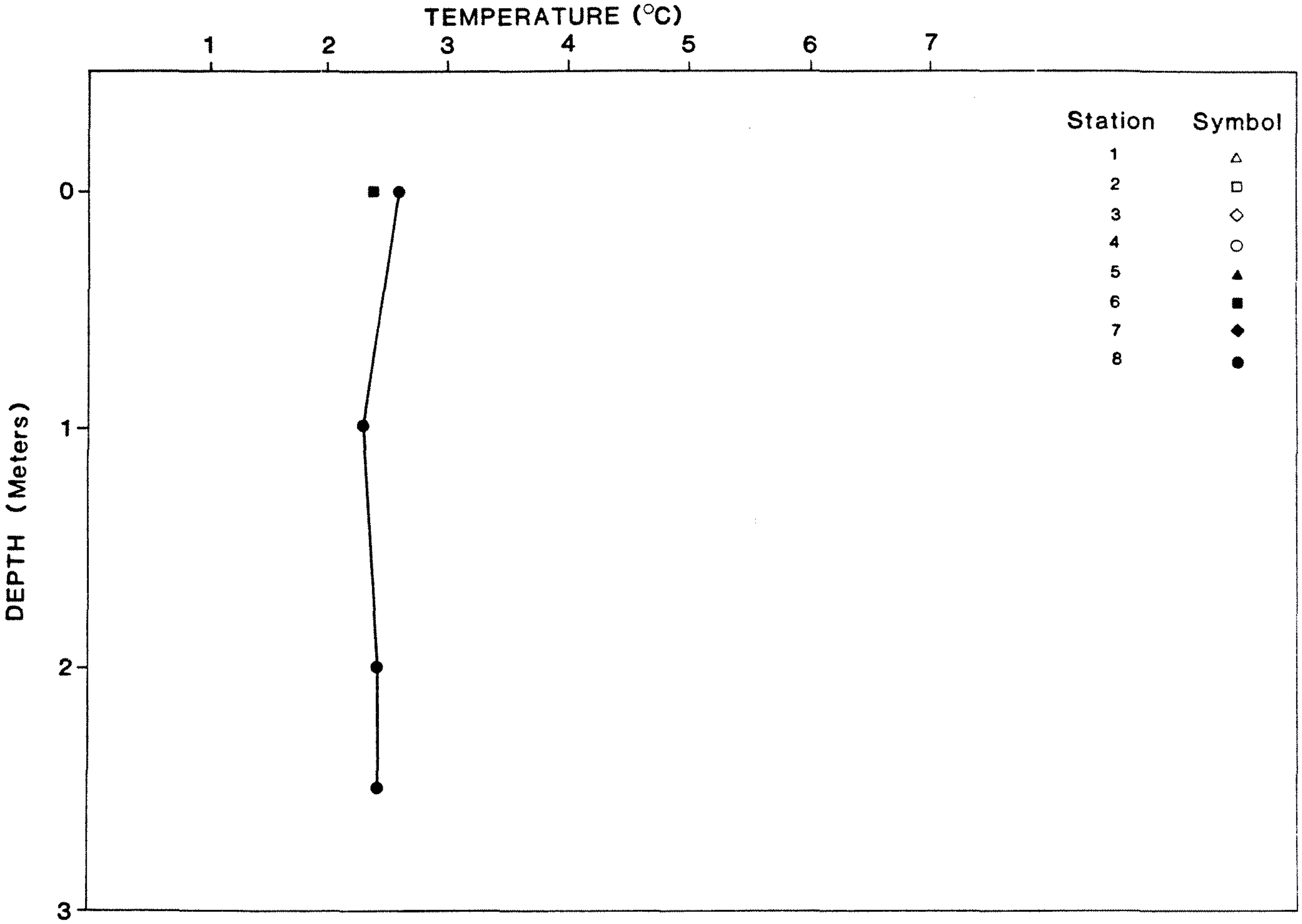

Figure 69. Vertical thermal profile and ancillary thermal data obtained 17 December 1985 on Ada City Lake.

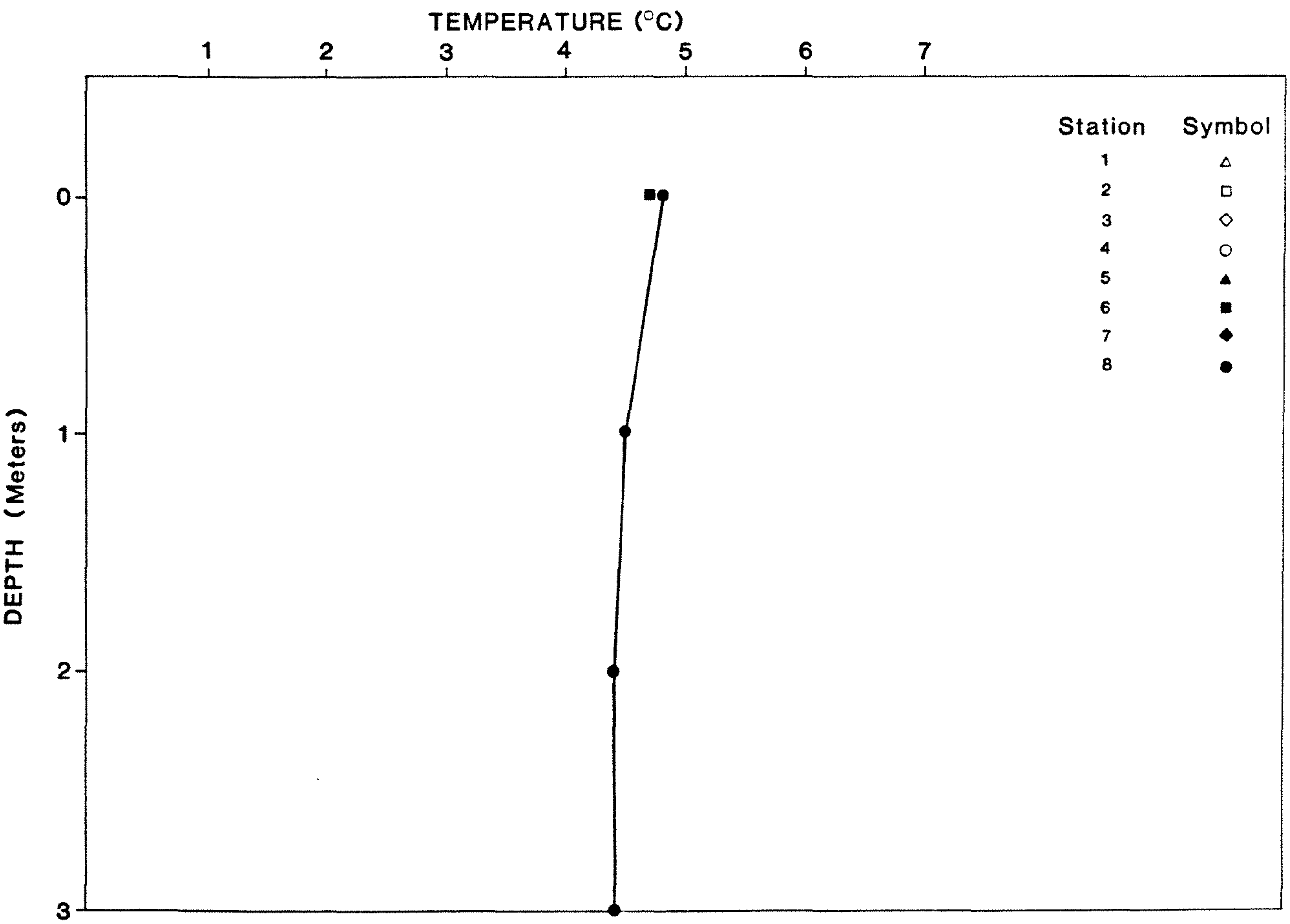

Figure 70. Vertical thermal profile and ancillary thermal data obtained 14 January 1986 on Ada City Lake.

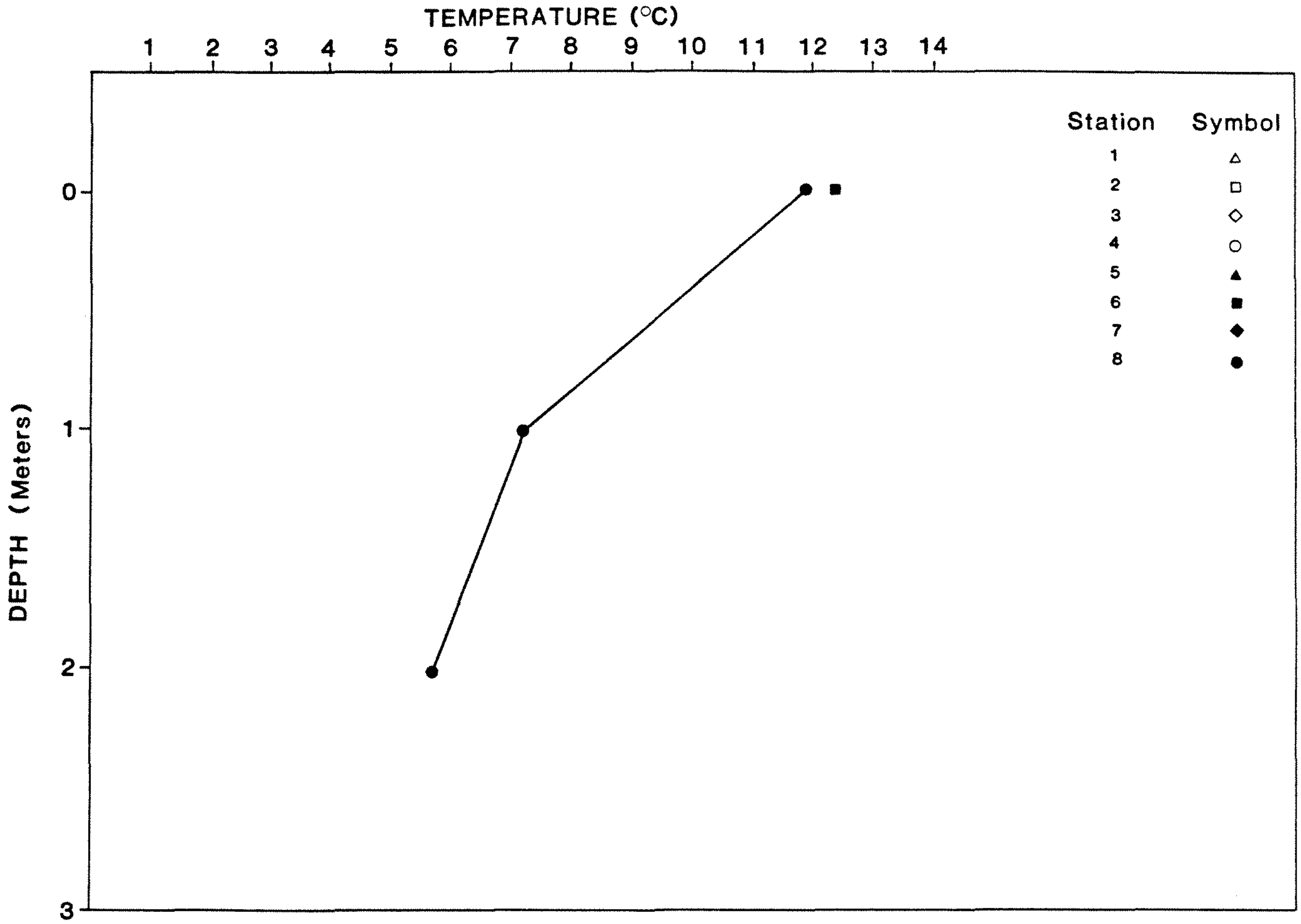

Figure 71. Vertical thermal profile and ancillary thermal data obtained 19 February 1986 on Ada City Lake.

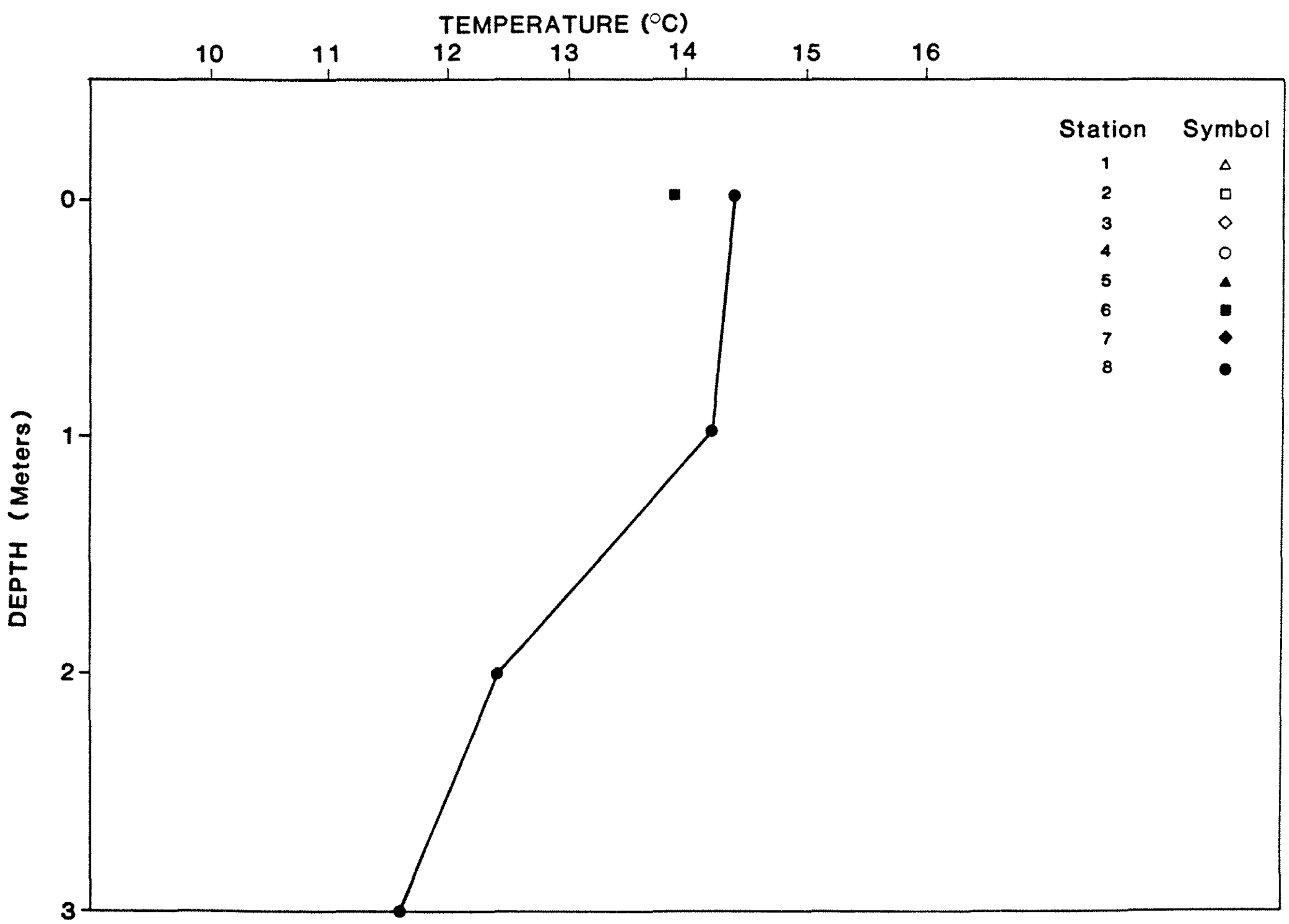

Figure 72. Vertical thermal profile and ancillary thermal data obtained 24 March 1986 on Ada City Lake.

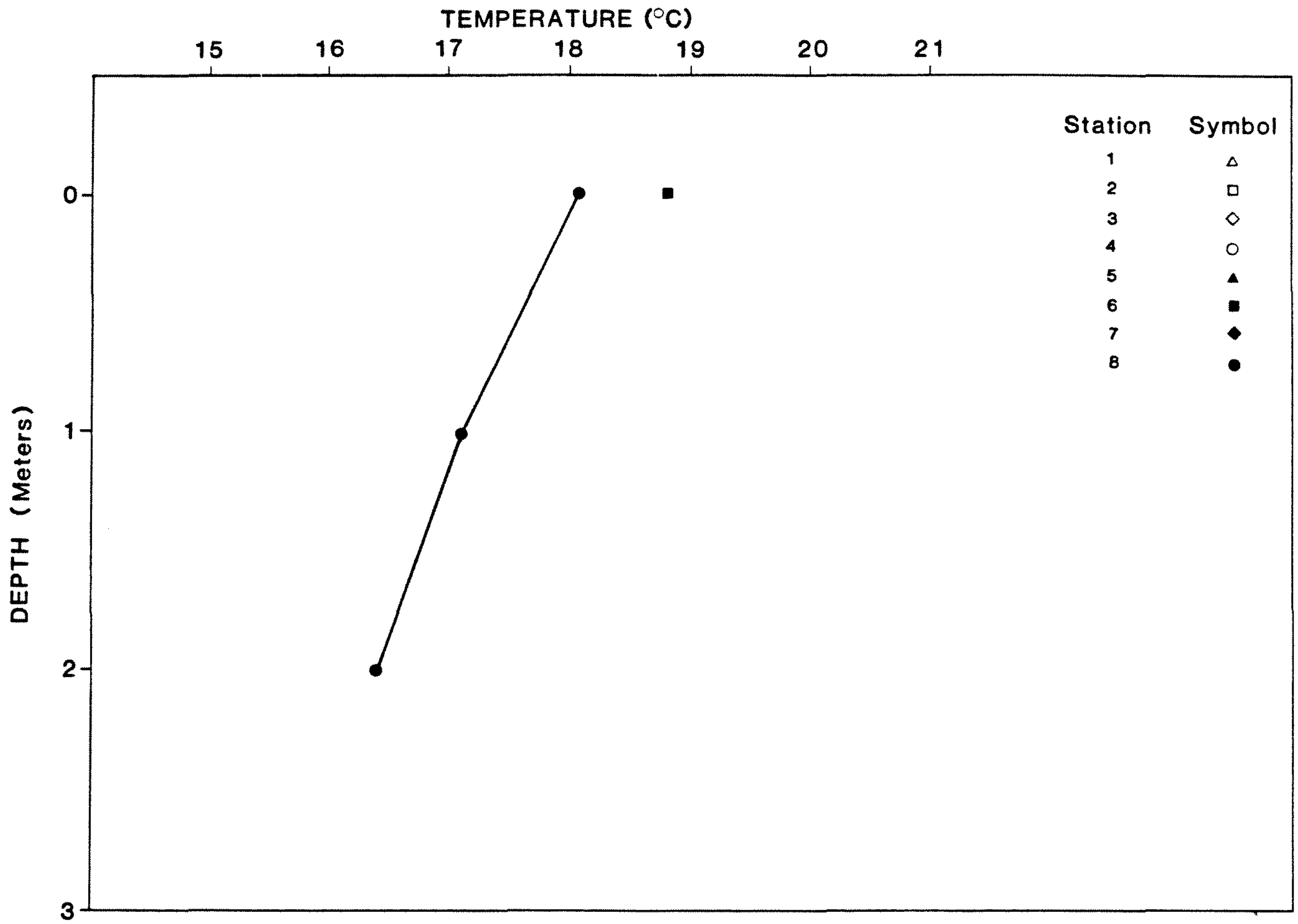

Figure 73. Vertical thermal profile and ancillary thermal data obtained 23 April 1986 on Ada City Lake.

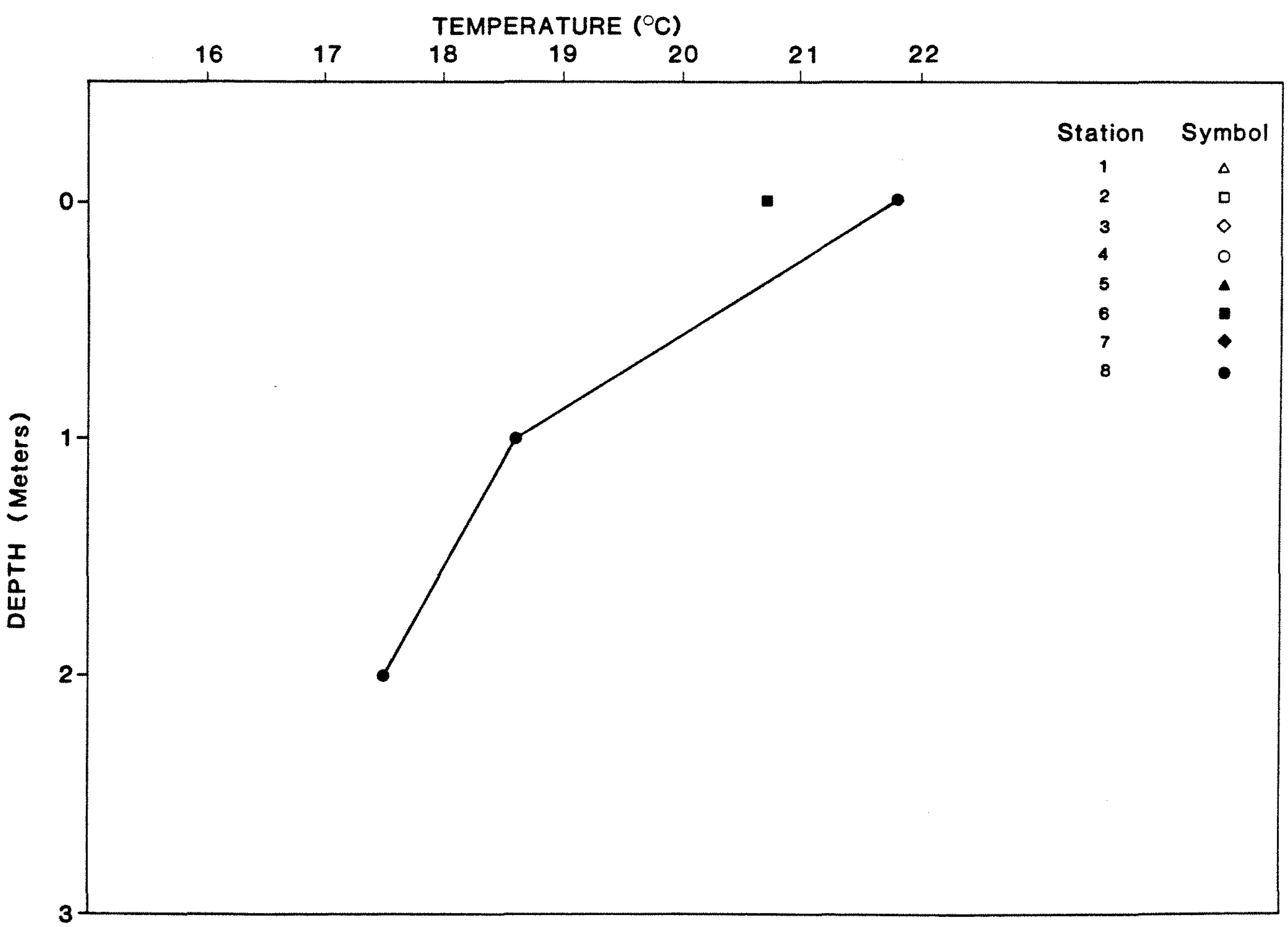

Figure 74. Vertical thermal profile and ancillary thermal data obtained 21 May 1986 on Ada City Lake.

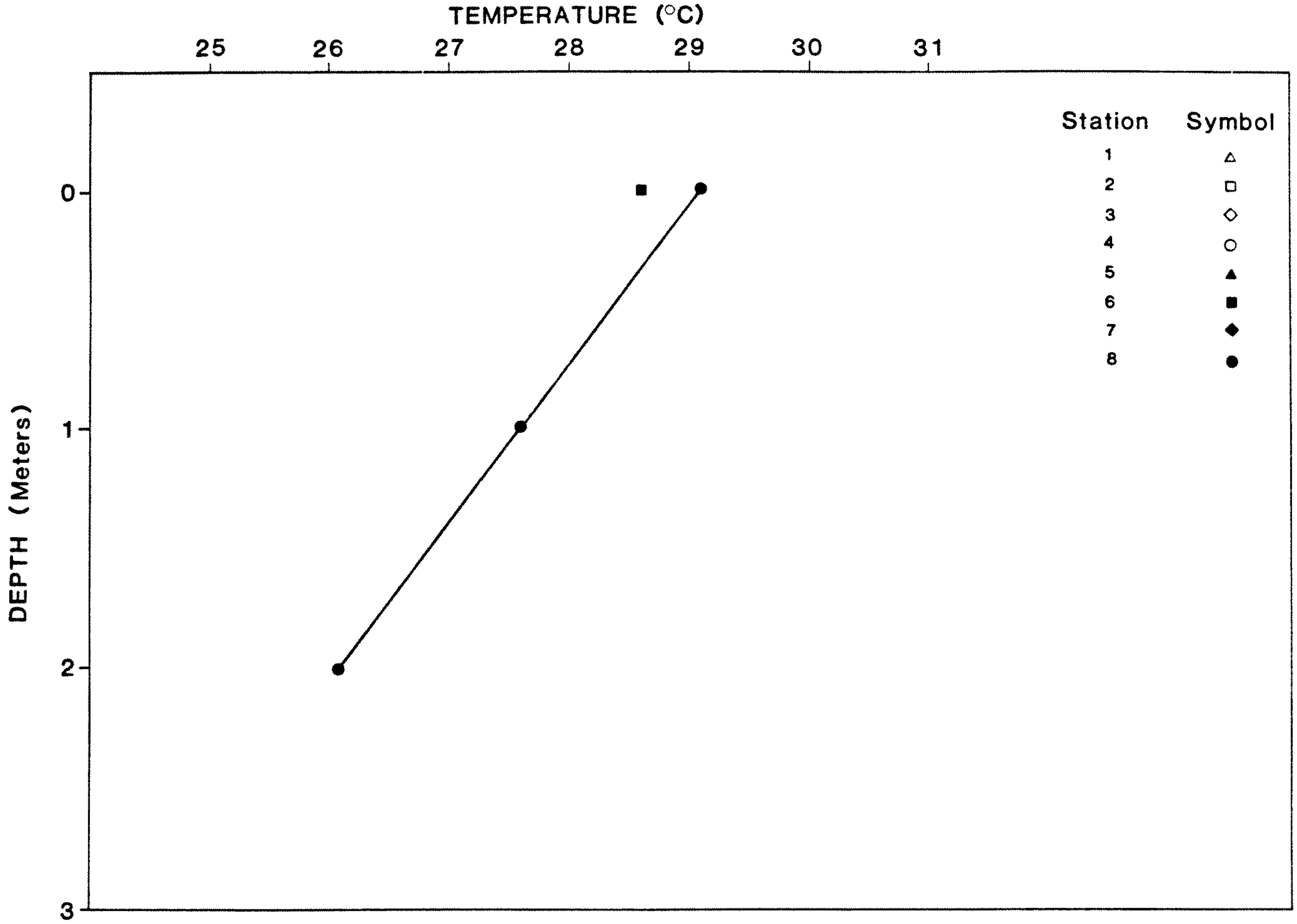

Figure 75. Vertical thermal profile and ancillary thermal data obtained 25 June 1986 on Ada City Lake.

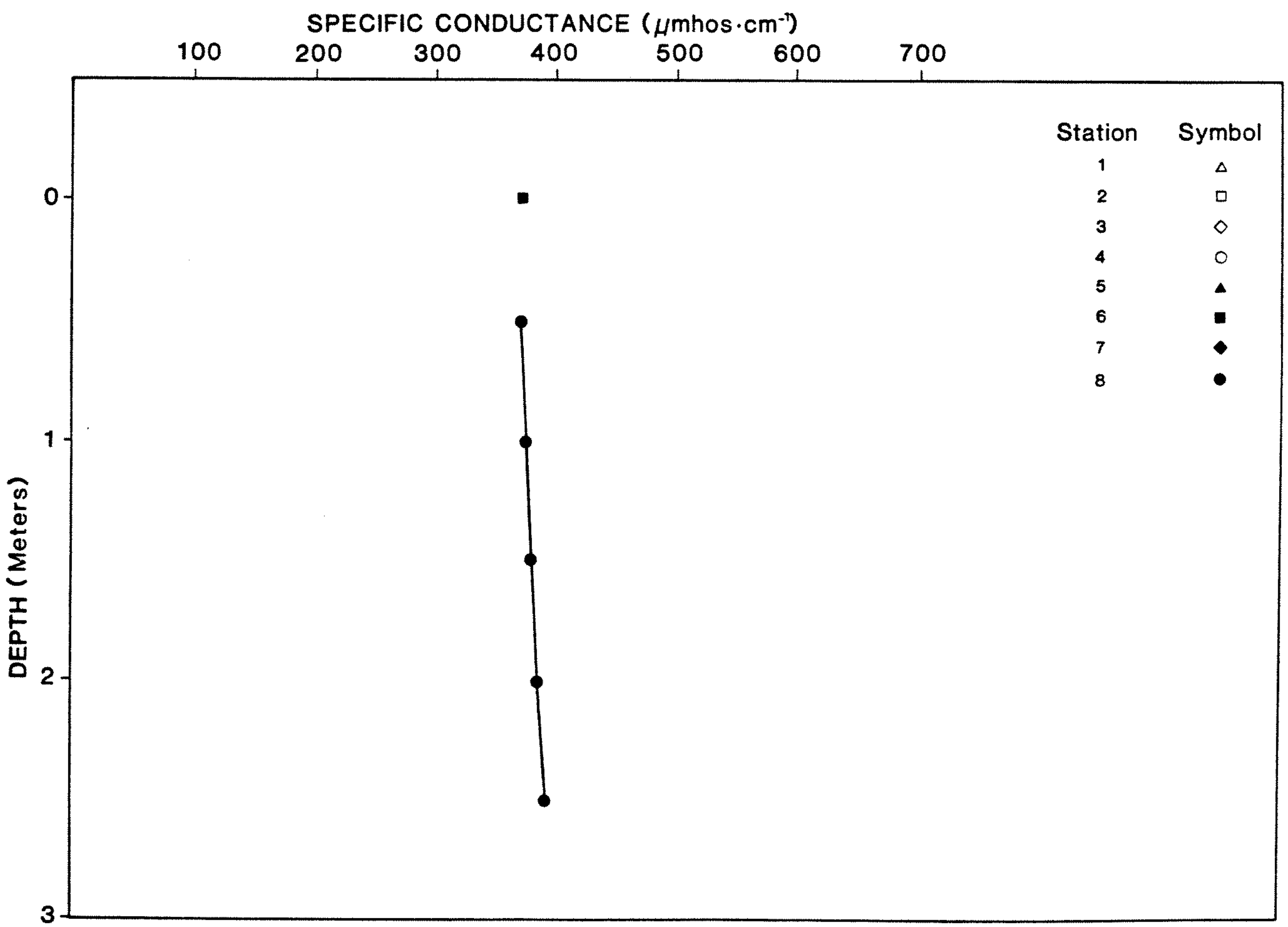

Figure 76. Vertical conductivity profile and ancillary specific conductance data obtained 17 July 1985 on Ada City Lake.

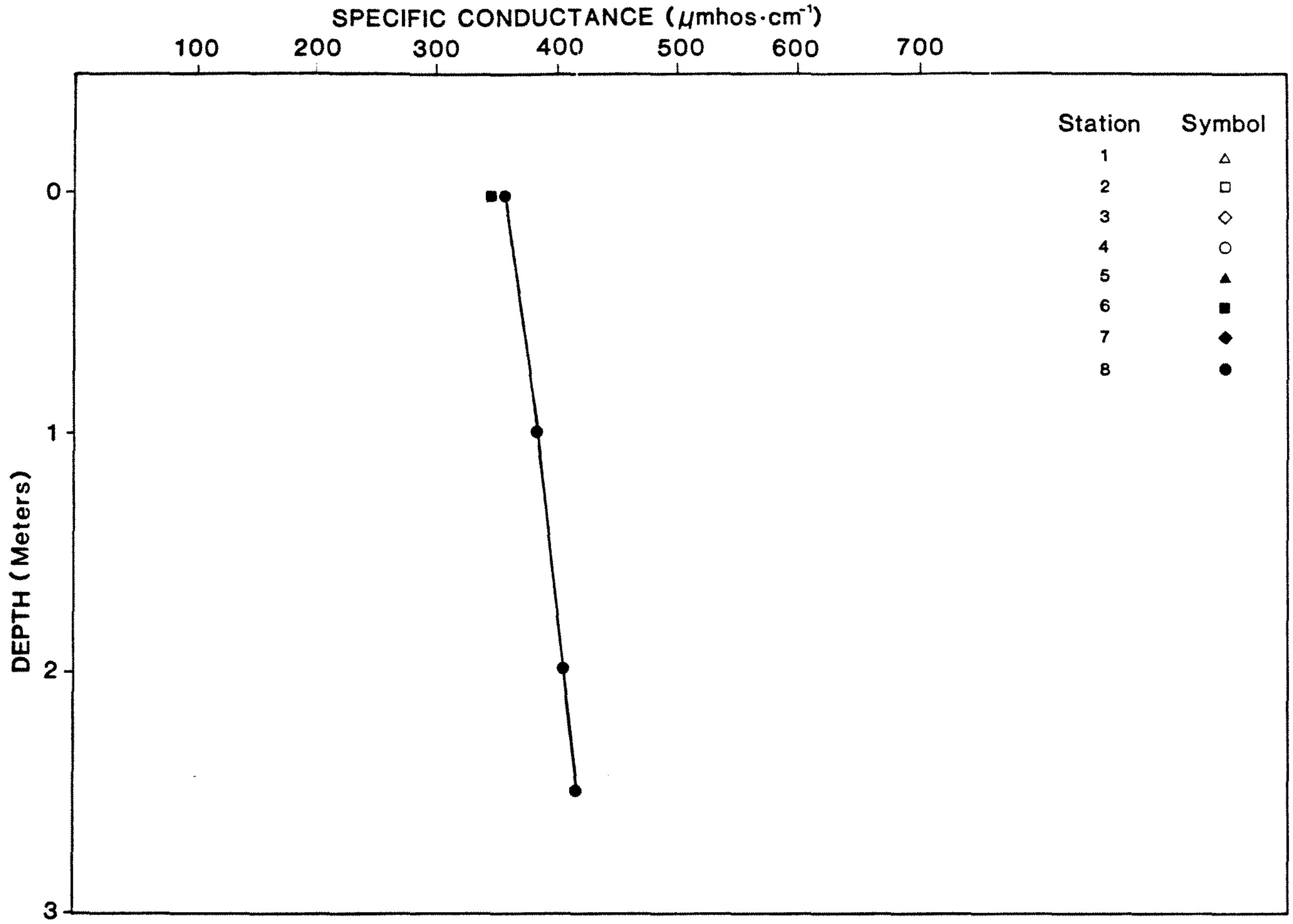

Figure 77. Vertical conductivity profile and ancillary specific conductance data obtained 1 August 1985 on Ada City Lake.

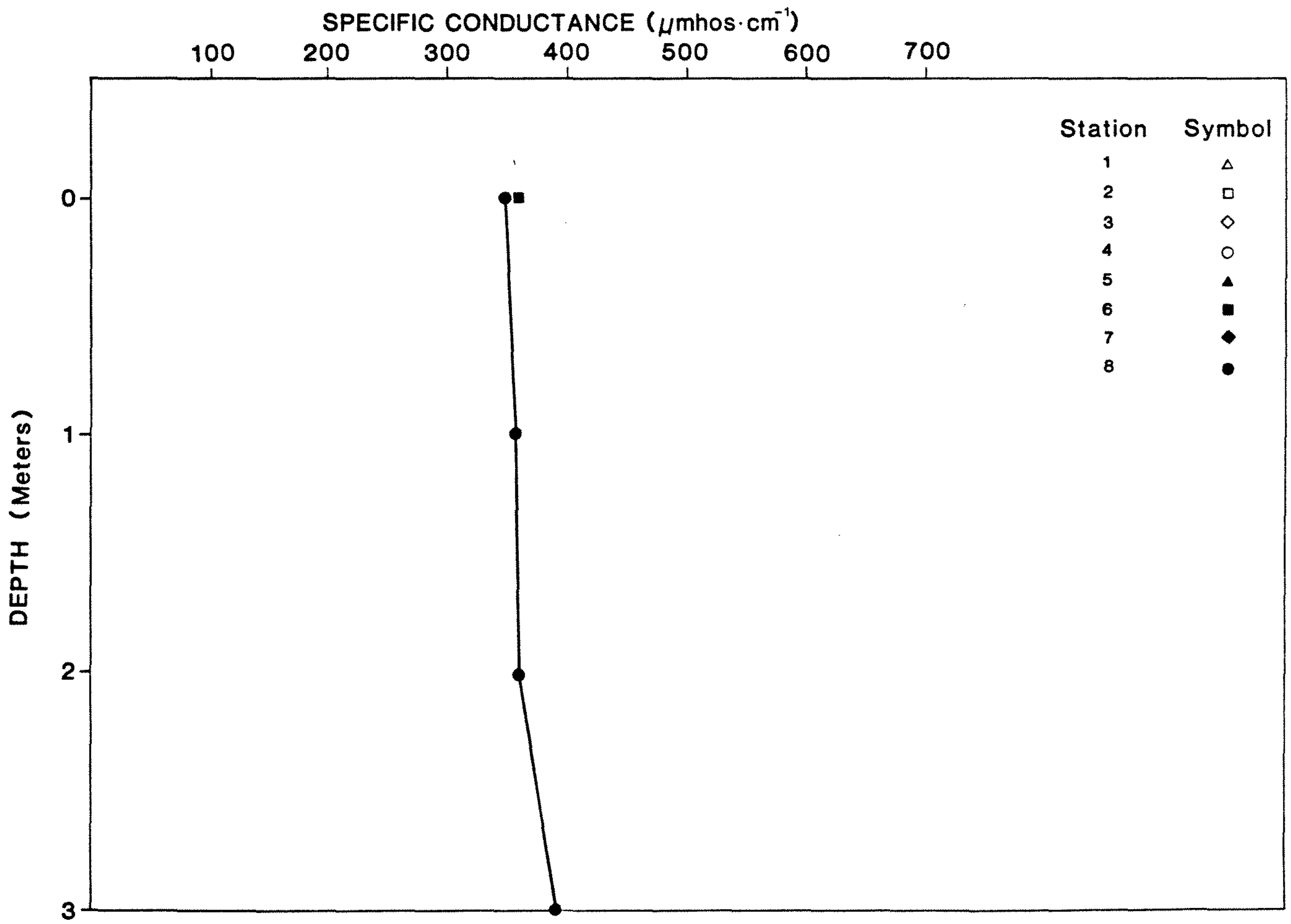

Figure 78. Vertical conductivity profile and ancillary specific conductance data obtained 18 August 1985 on Ada City Lake.

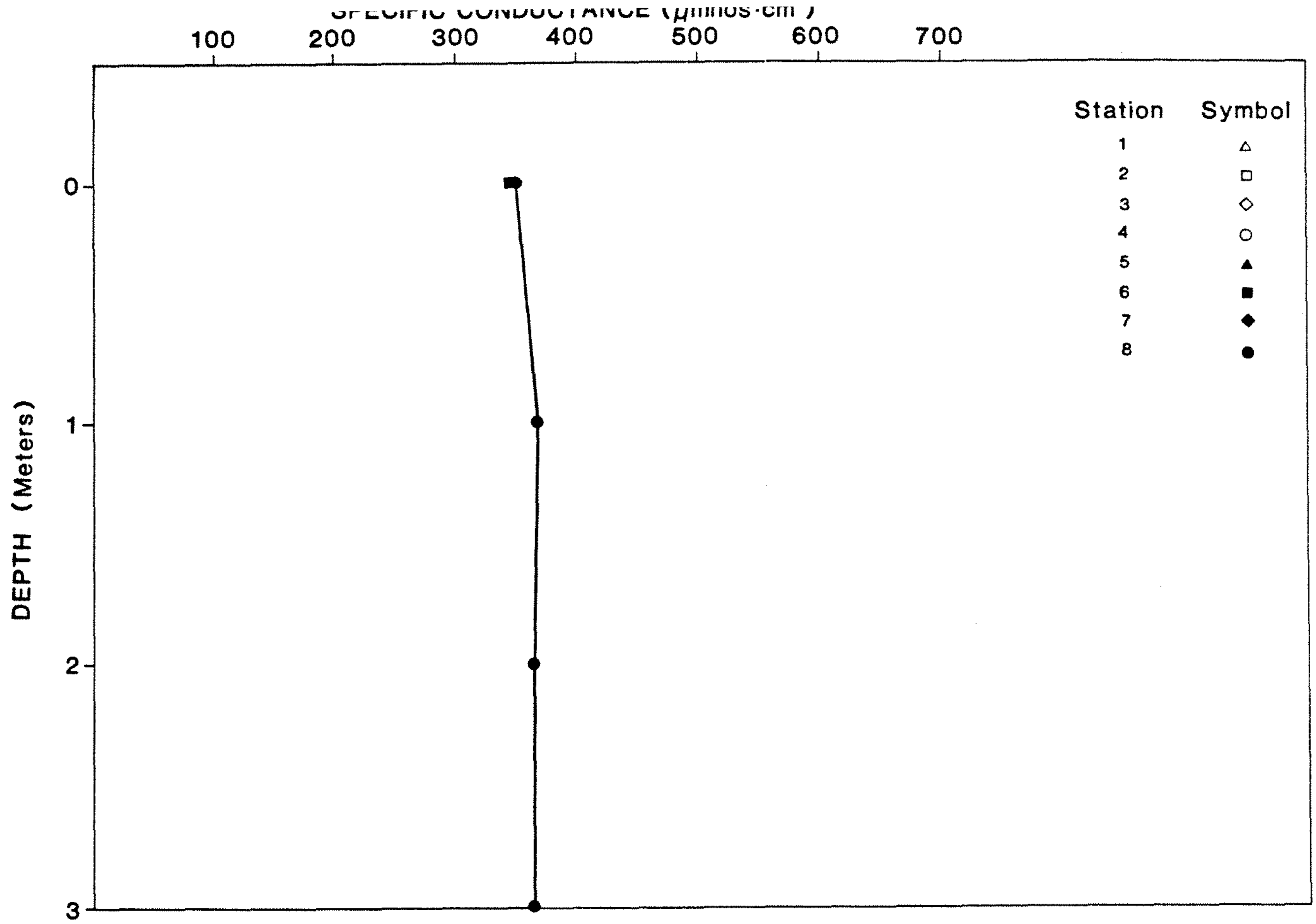

Figure 79. Vertical conductivity profile and ancillary specific conductance data obtained 29 August 1985 on Ada City Lake.

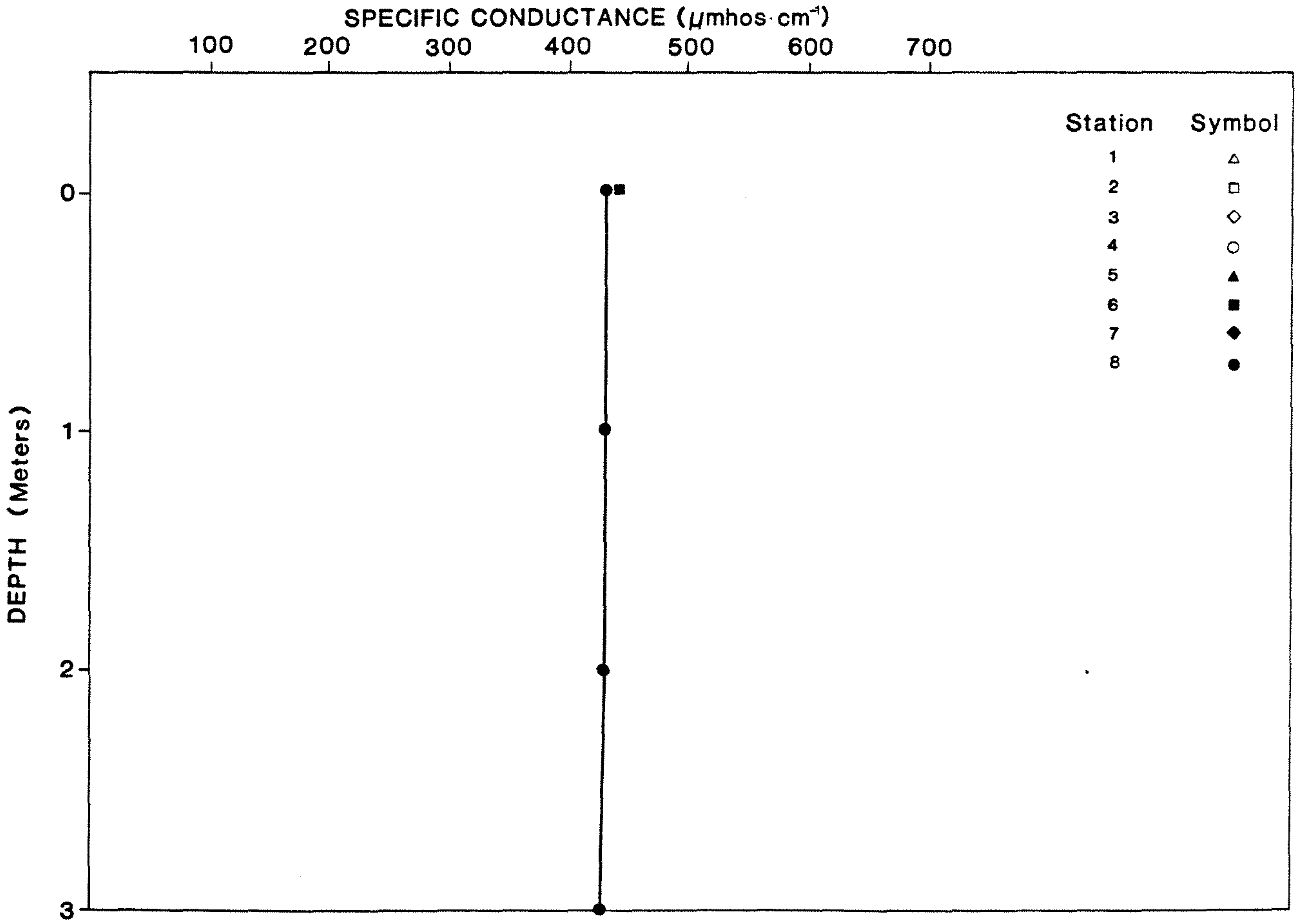

Figure 80. Vertical conductivity profile and ancillary specific conductance data obtained 24 September 1985 on Ada City Lake.

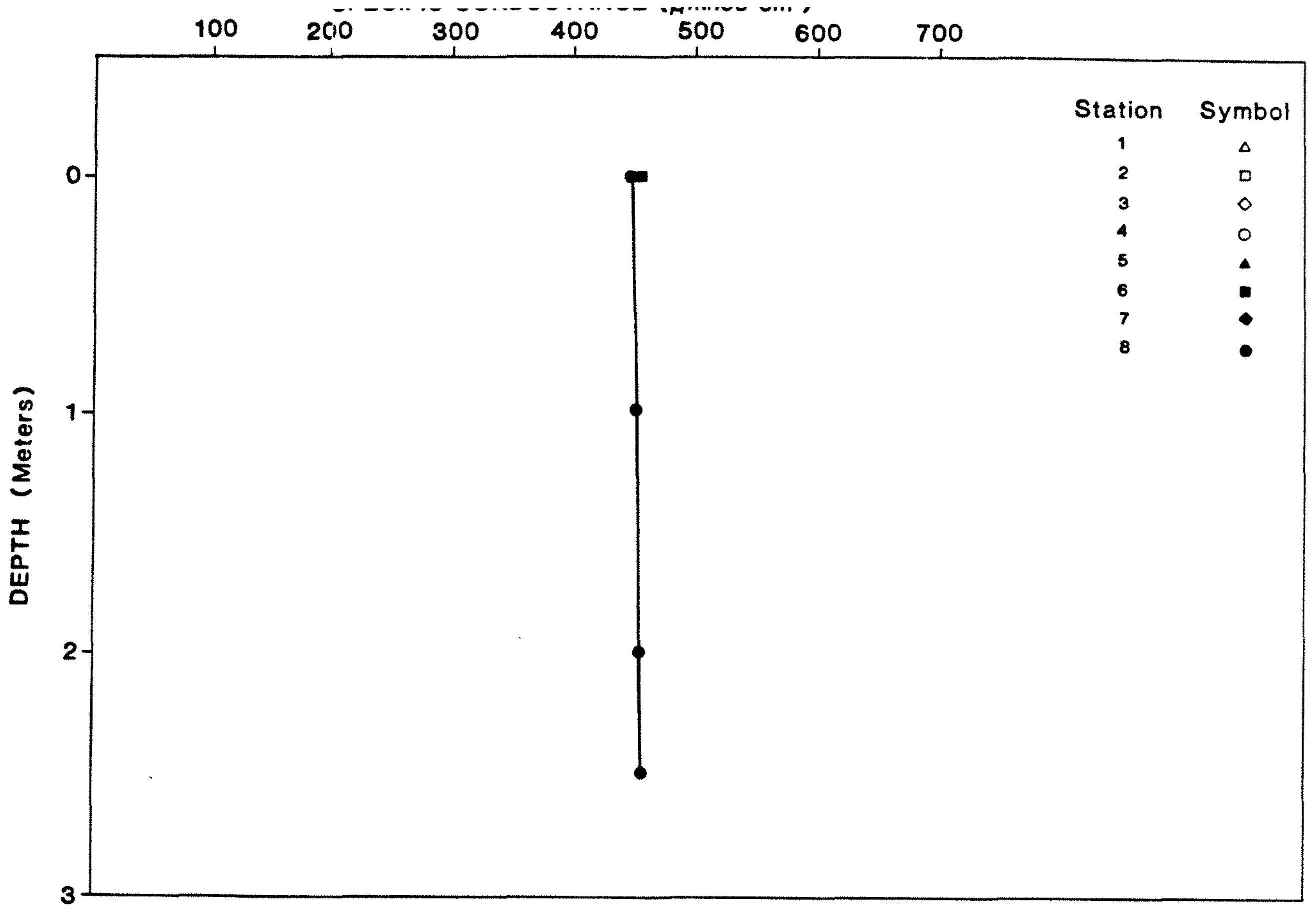

Figure 81. Vertical conductivity profile and ancillary specific conductance data obtained 8 October 1985 on Ada City Lake.

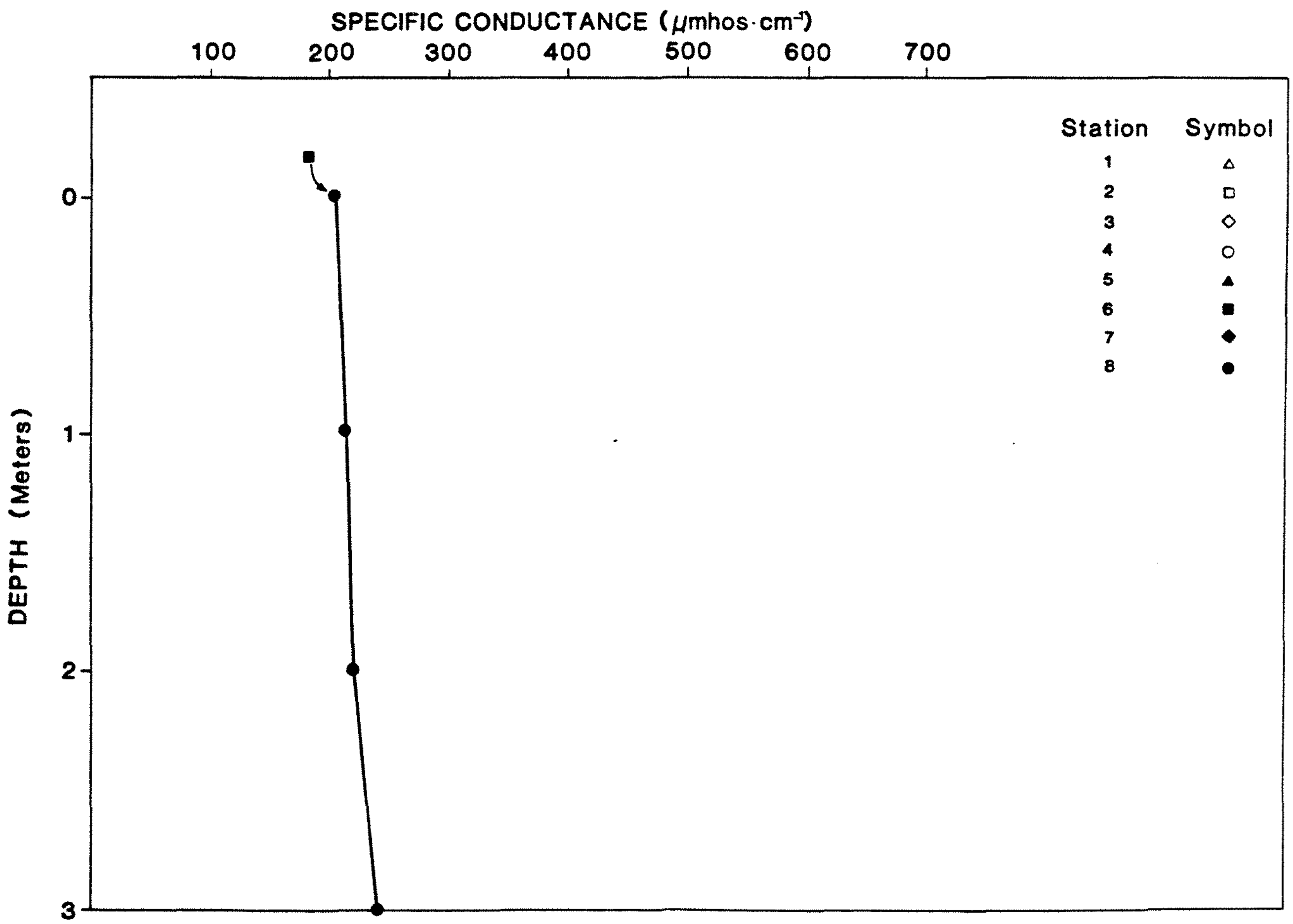

Figure 82. Vertical conductivity profile and ancillary specific conductance data obtained 22 October 1985 on Ada City Lake.

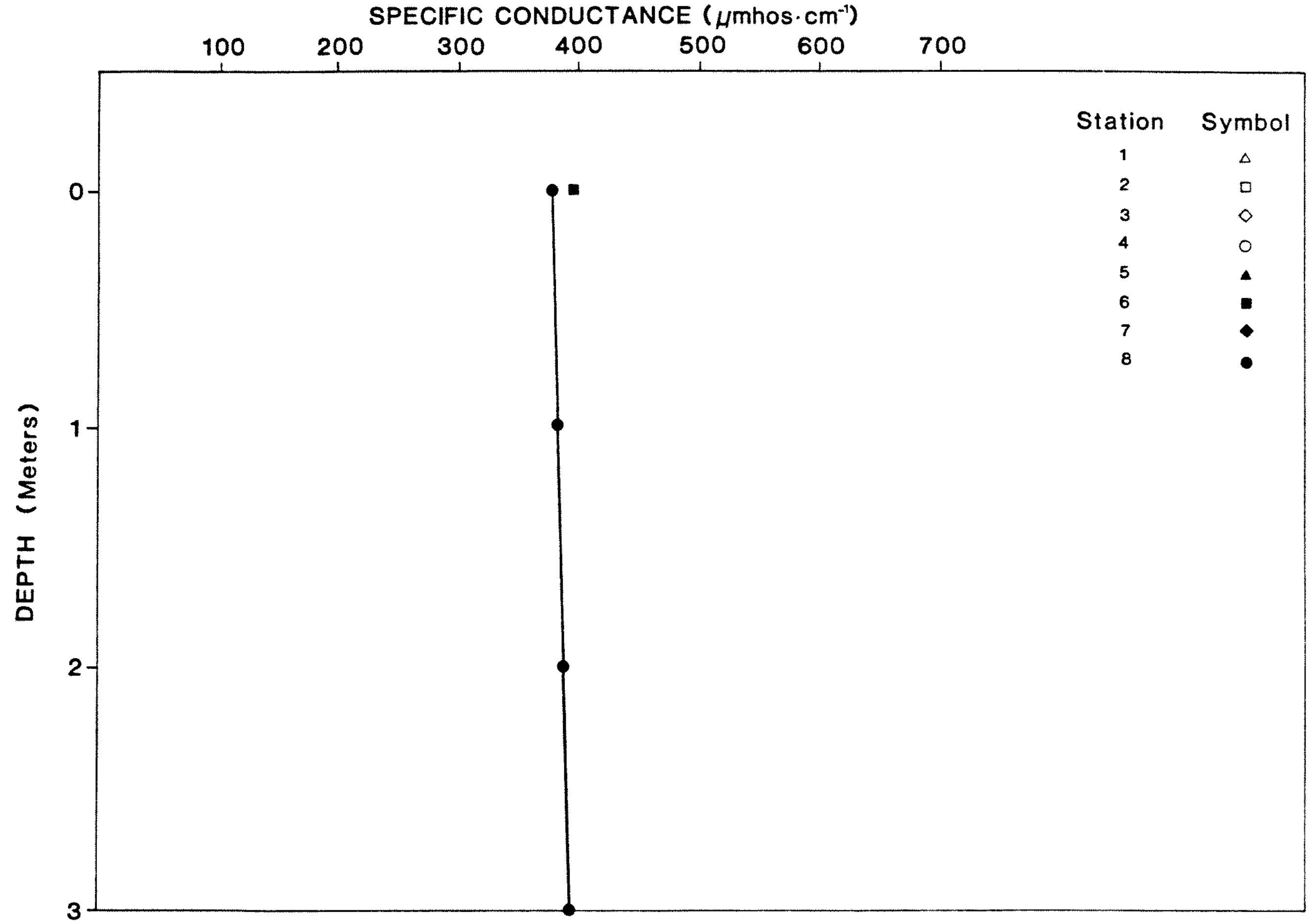

Figure 83. Vertical conductivity profile and ancillary specific conductance data obtained 2 December 1985 on Ada City Lake.

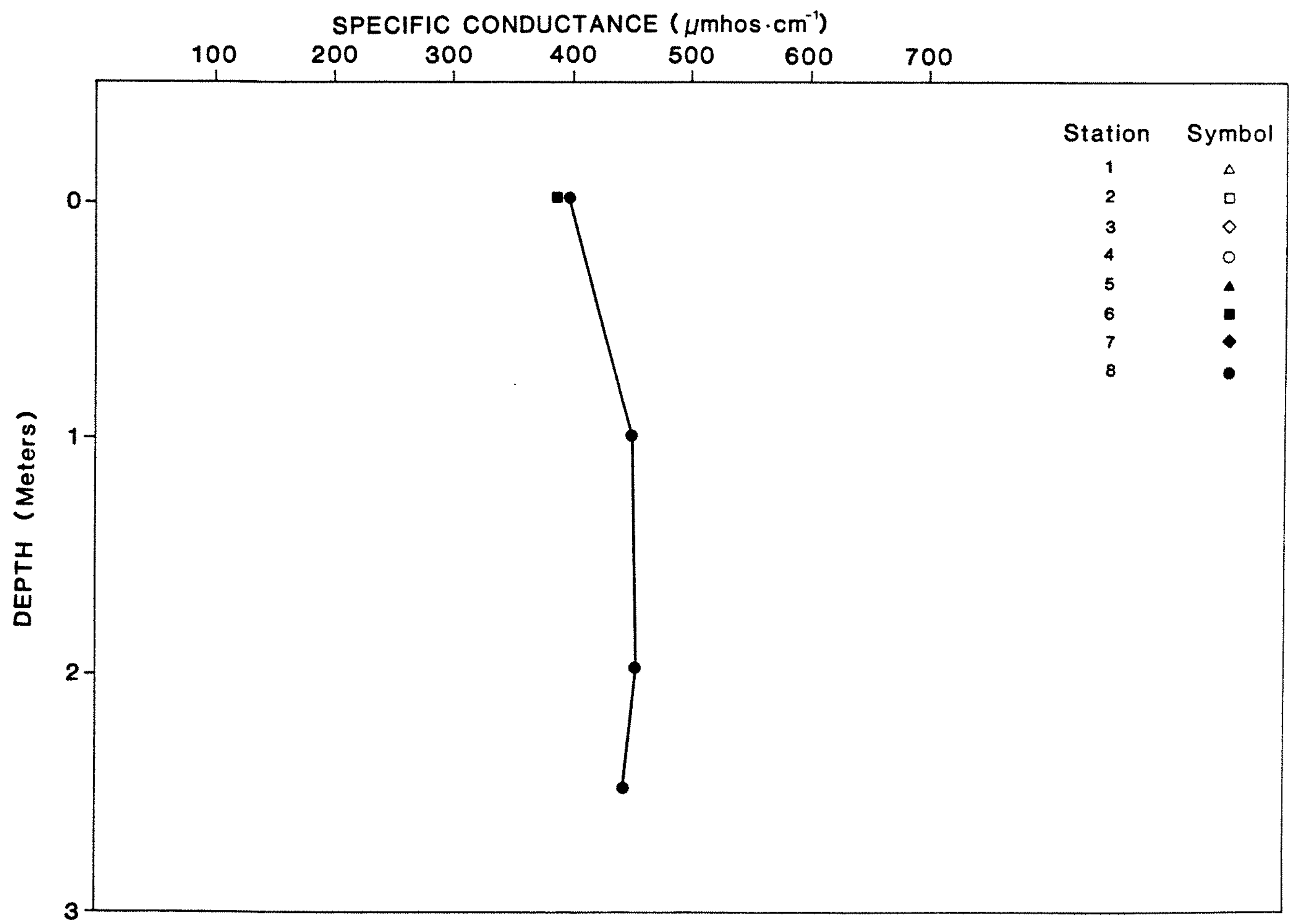

Figure 84. Vertical conductivity profile and ancillary specific conductance data obtained 17 December 1985 on Ada City Lake.

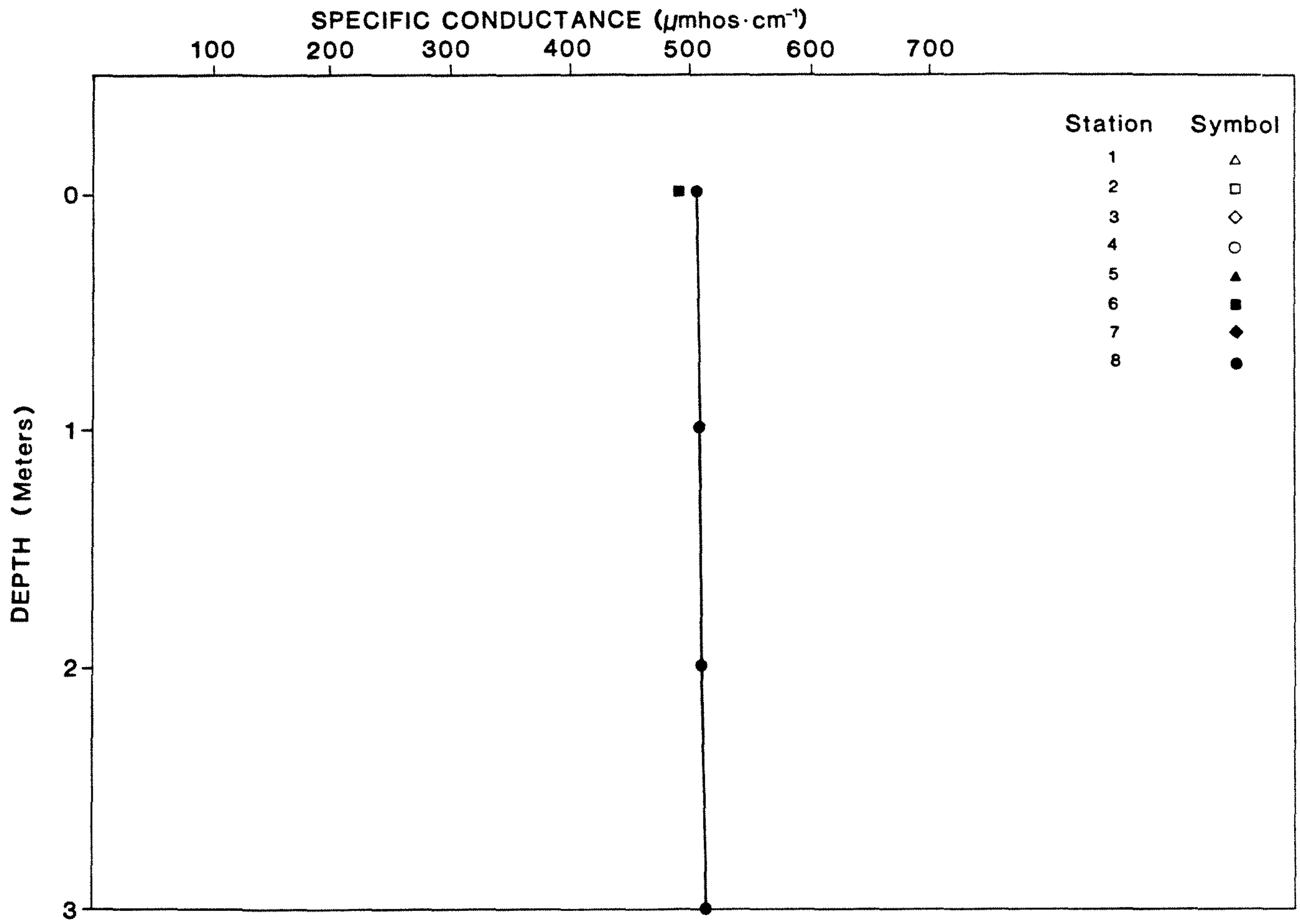

Figure 85. Vertical conductivity profile and ancillary specific conductance data obtained 14 January 1986 on Ada City Lake.

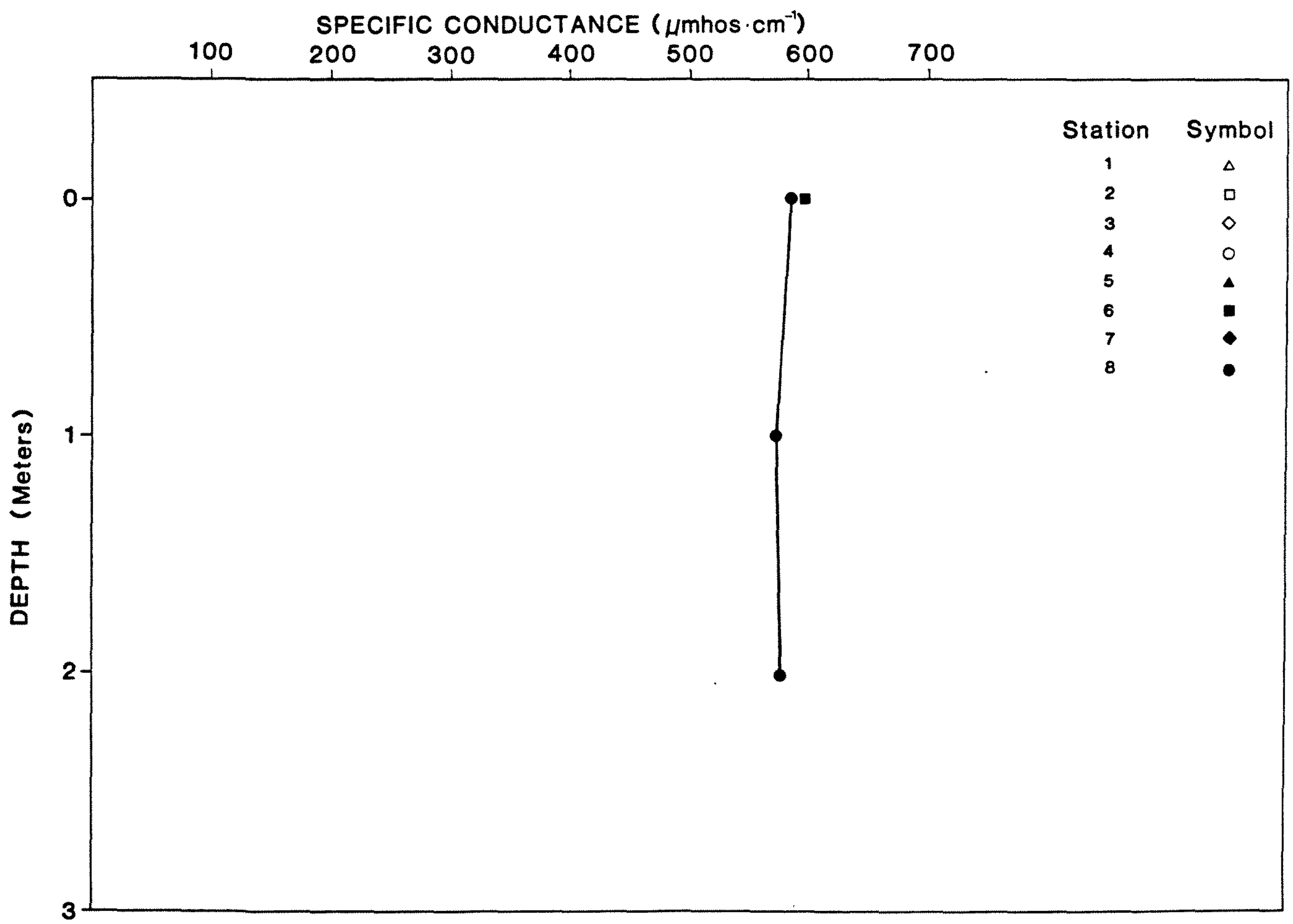

Figure 86. Vertical conductivity profile and ancillary specific conductance data obtained 19 February 1986 on Ada City Lake.

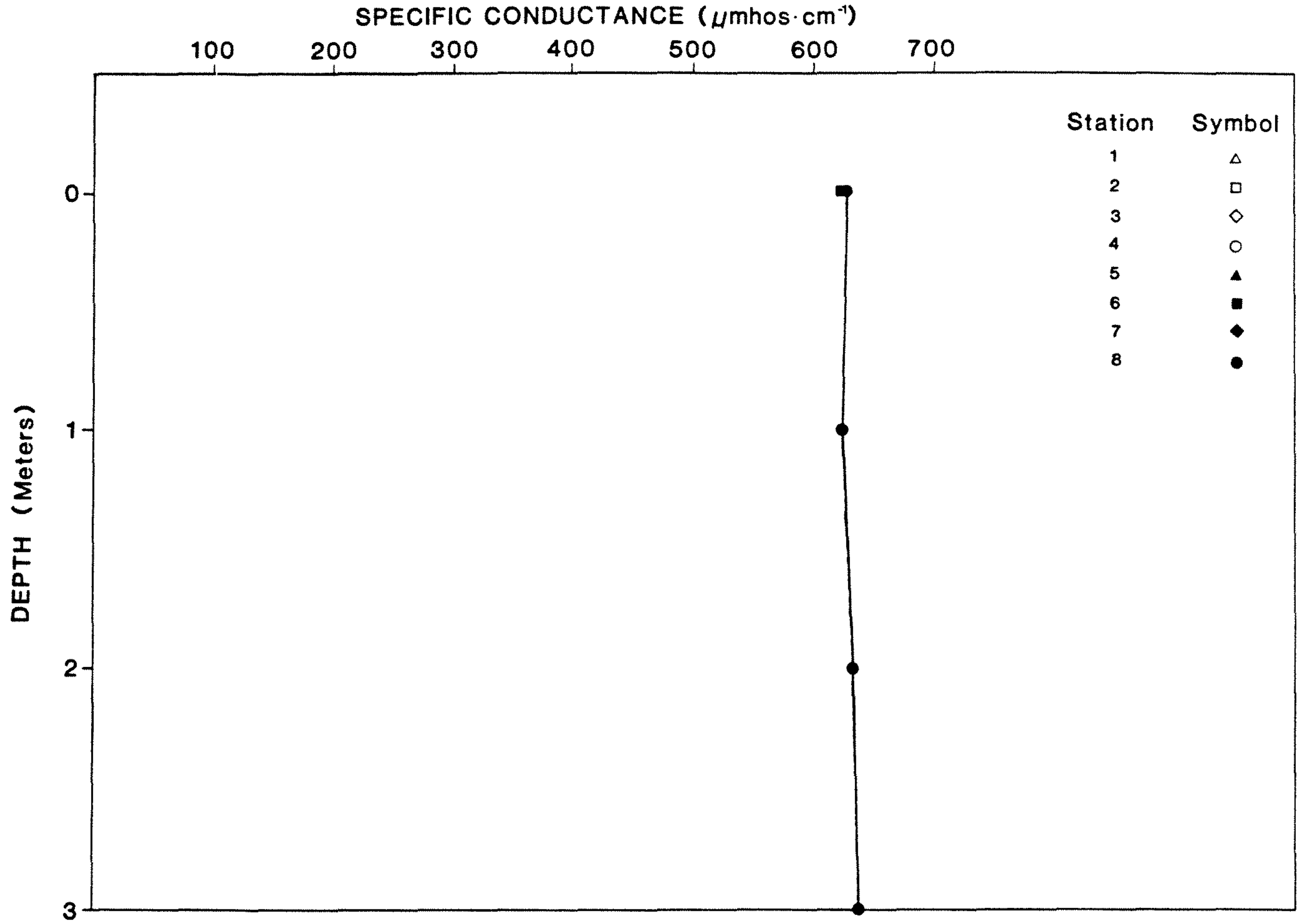

Figure 87. Vertical conductivity profile and ancillary specific conductance data obtained 24 March 1986 on Ada City Lake.

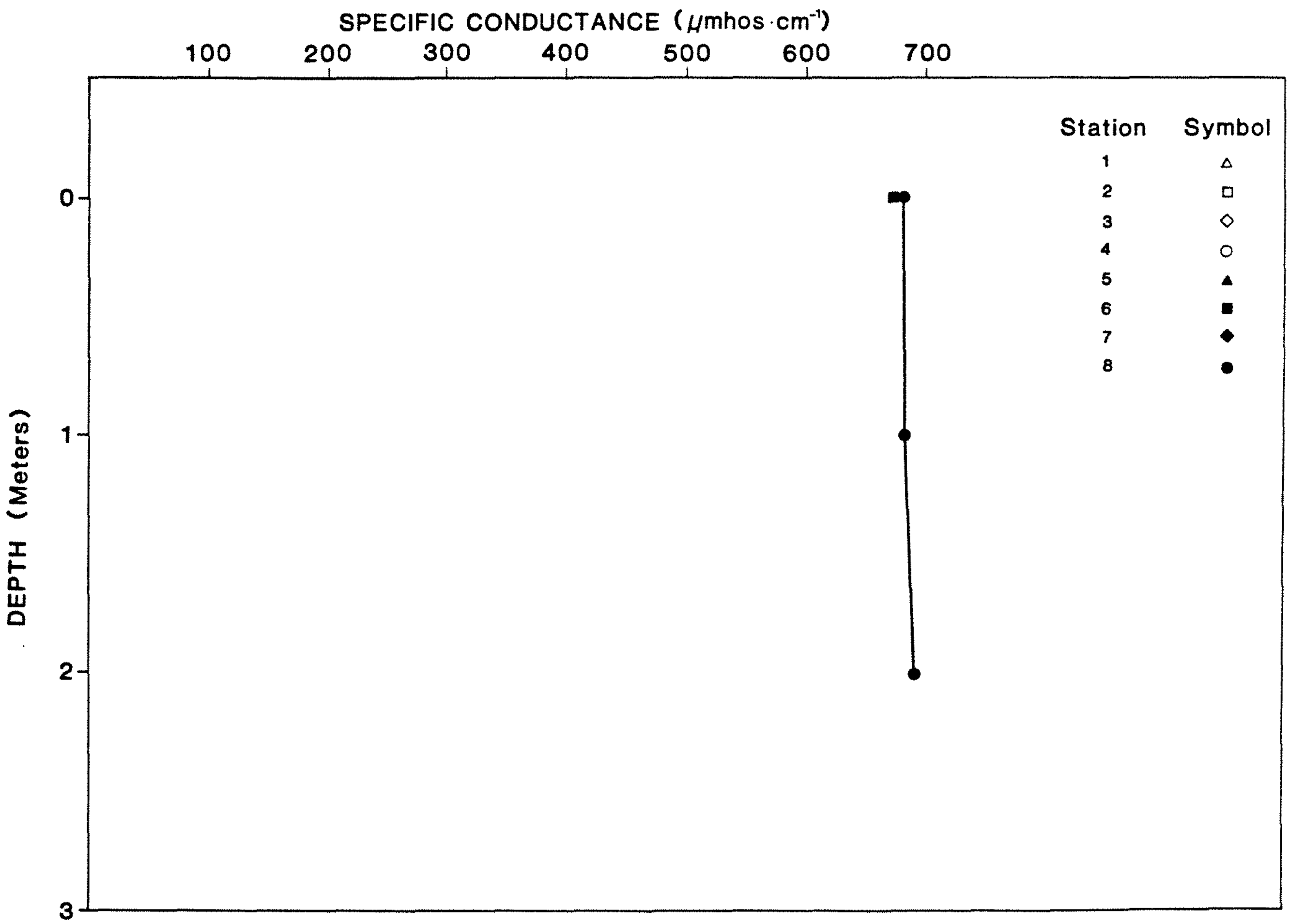

Figure 88. Vertical conductivity profile and ancillary specific conductance data obtained 23 April 1986 on Ada City Lake.

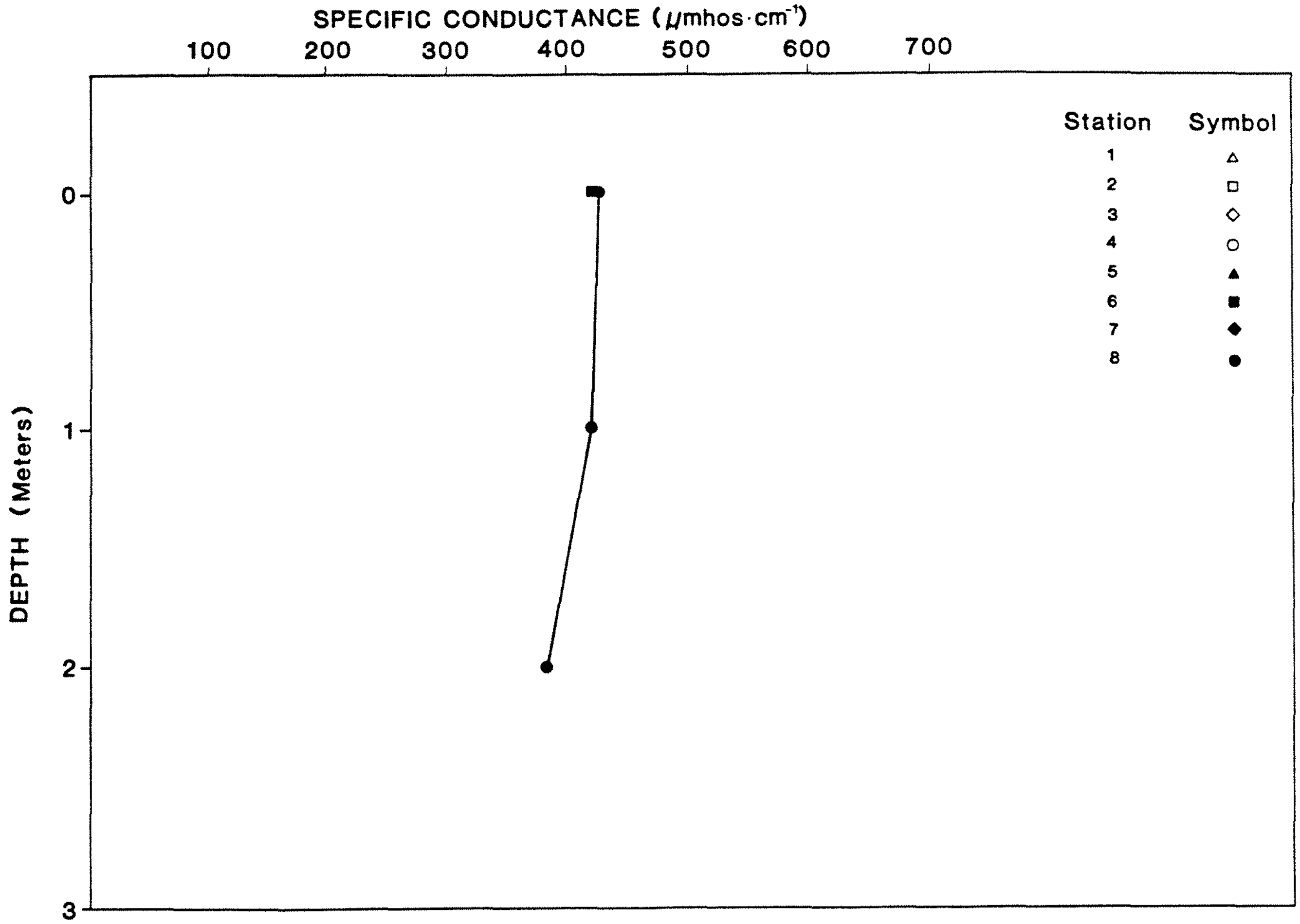

Figure 89. Vertical conductivity profile and ancillary specific conductance data obtained 21 May 1986 on Ada City Lake.

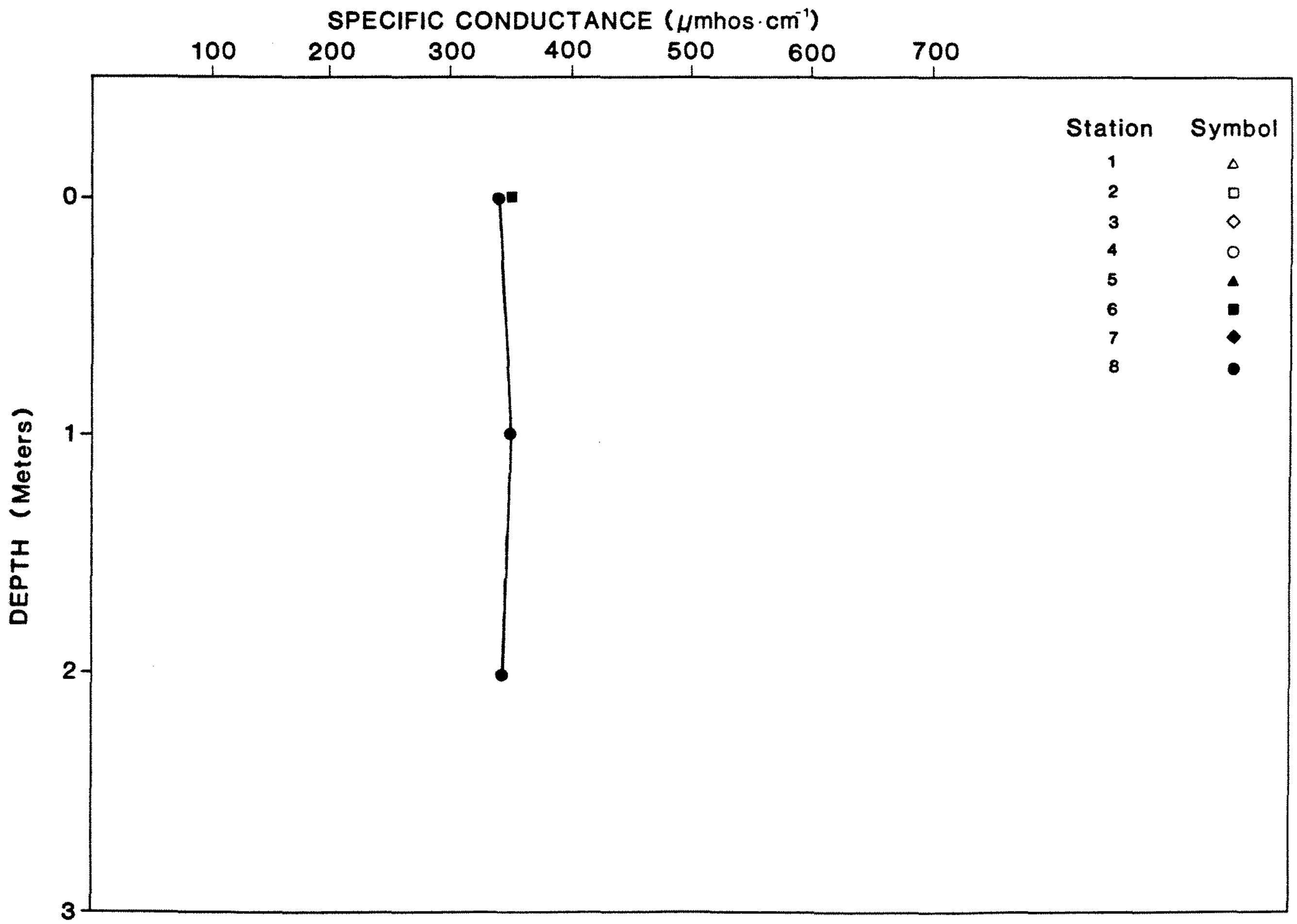

Figure 90. Vertical conductivity profile and ancillary specific conductance data obtained 25 June 1986 on Ada City Lake.

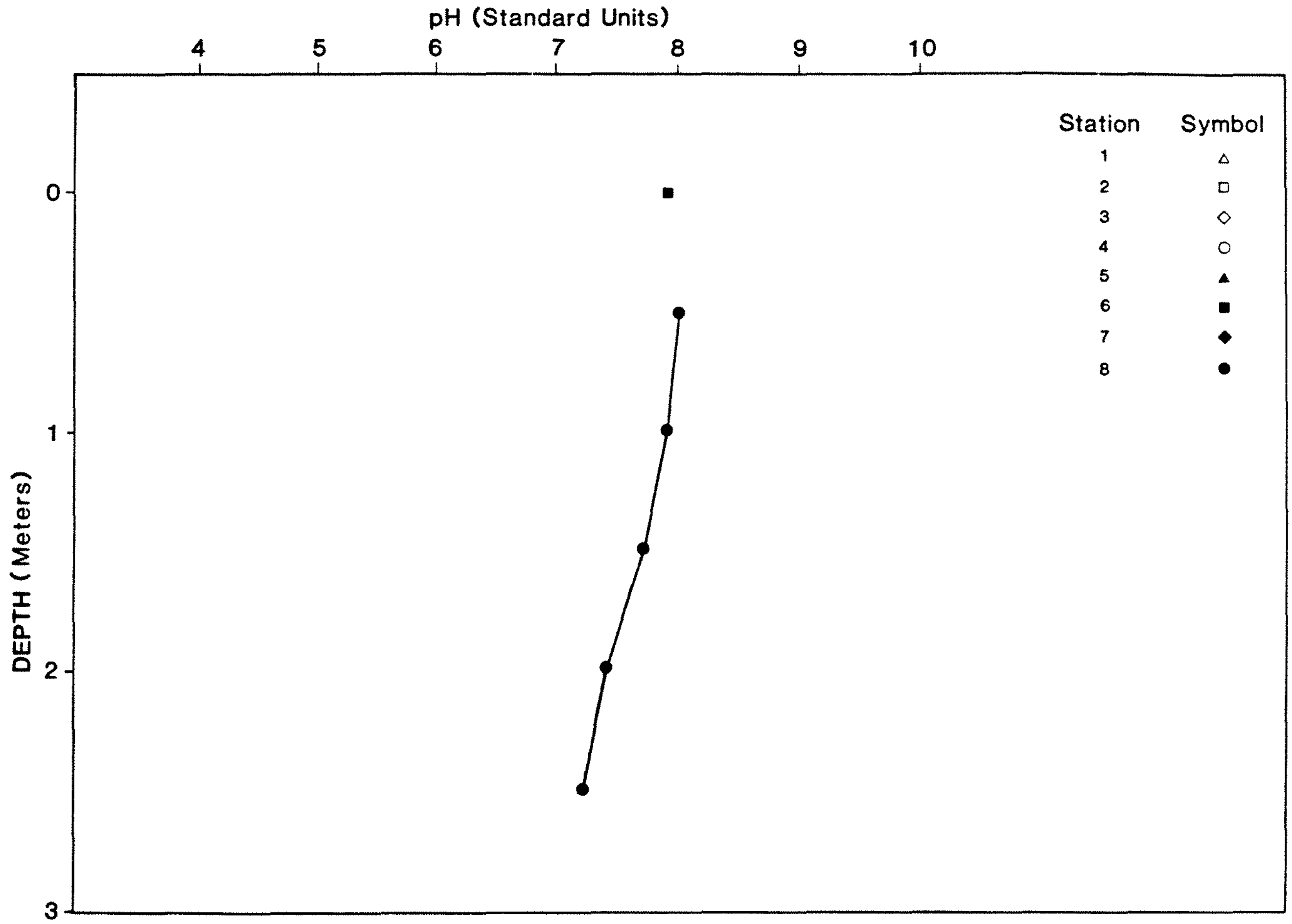

Figure 91. Vertical pH profile and ancillary pH data obtained 17 July 1985 on Ada City Lake.

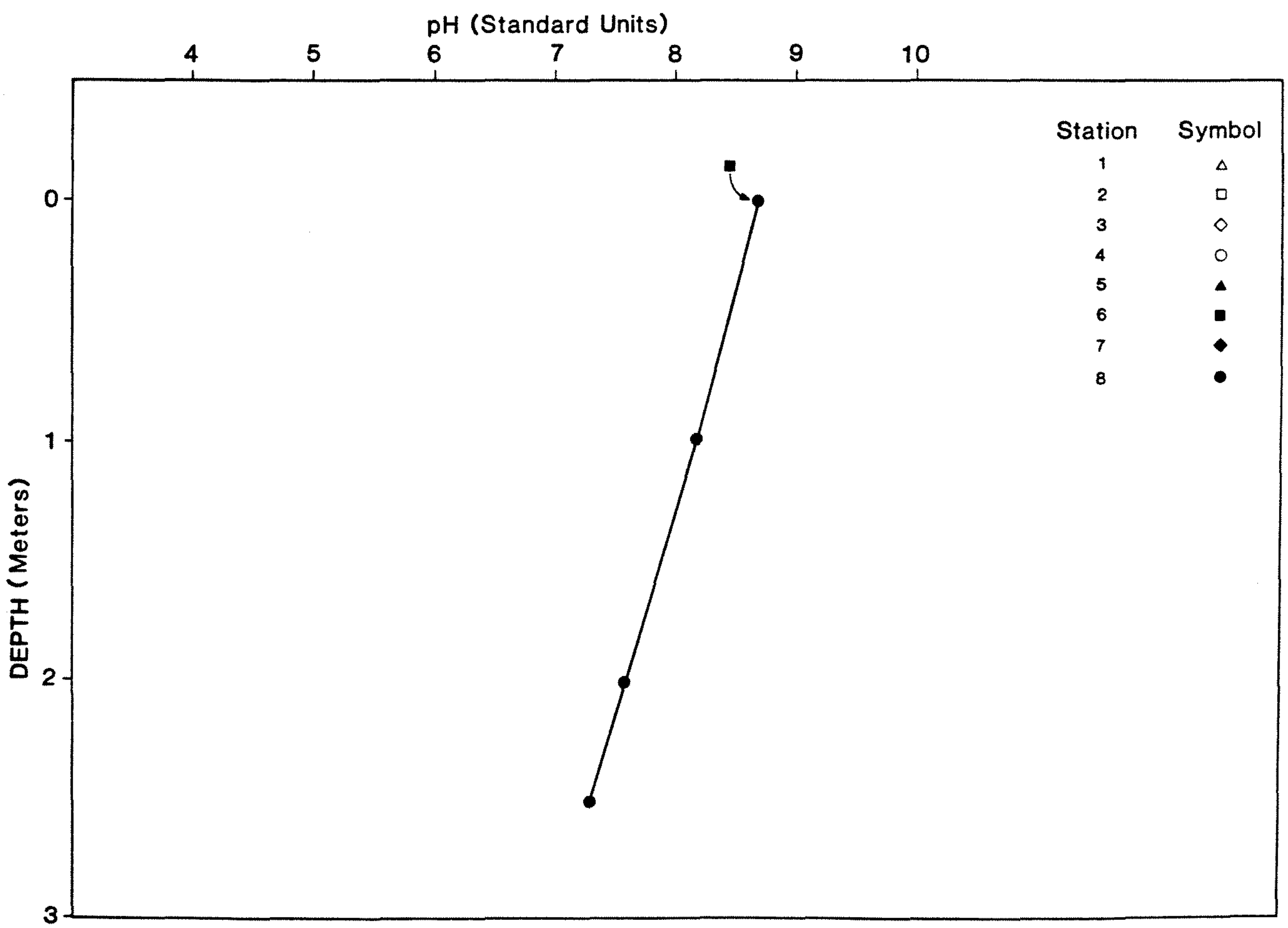

Figure 92. Vertical pH profile and ancillary pH data obtained 1 August 1985 on Ada City Lake.

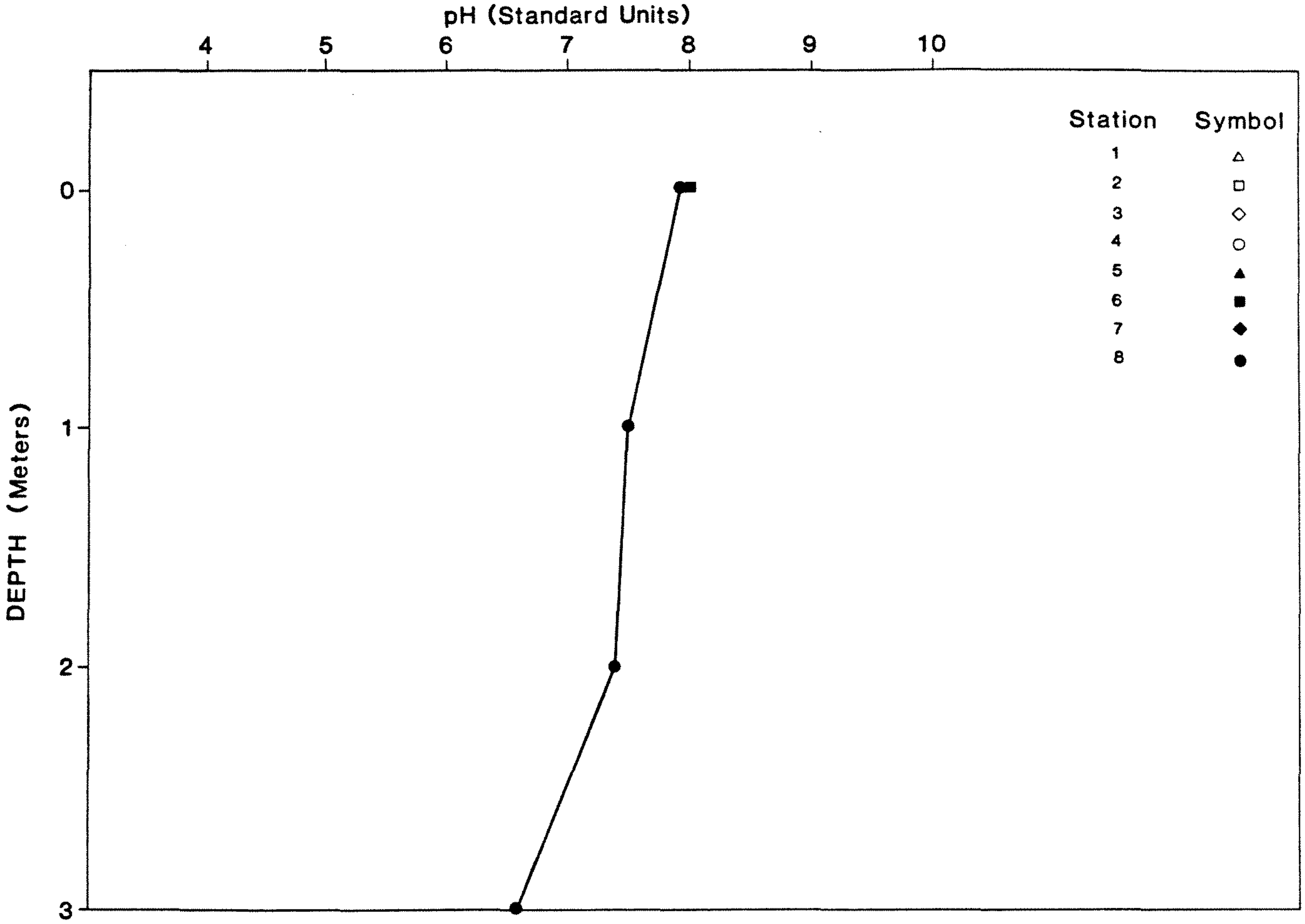

Figure 93. Vertical pH profile and ancillary pH data obtained 13 August 1985 on Ada City Lake.

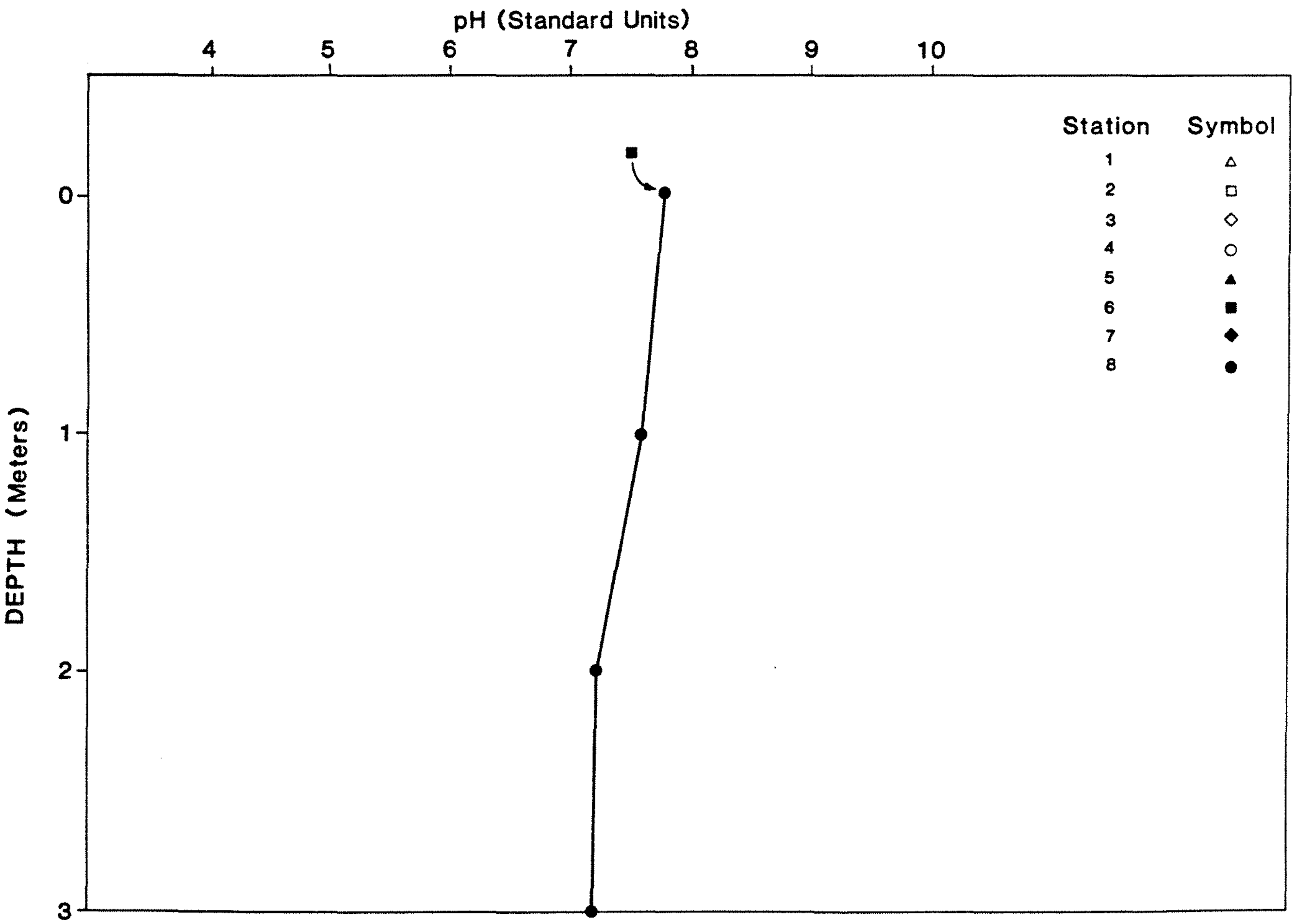

Figure 94. Vertical pH profile and ancillary pH data obtained 29 August 1985 on Ada City Lake.

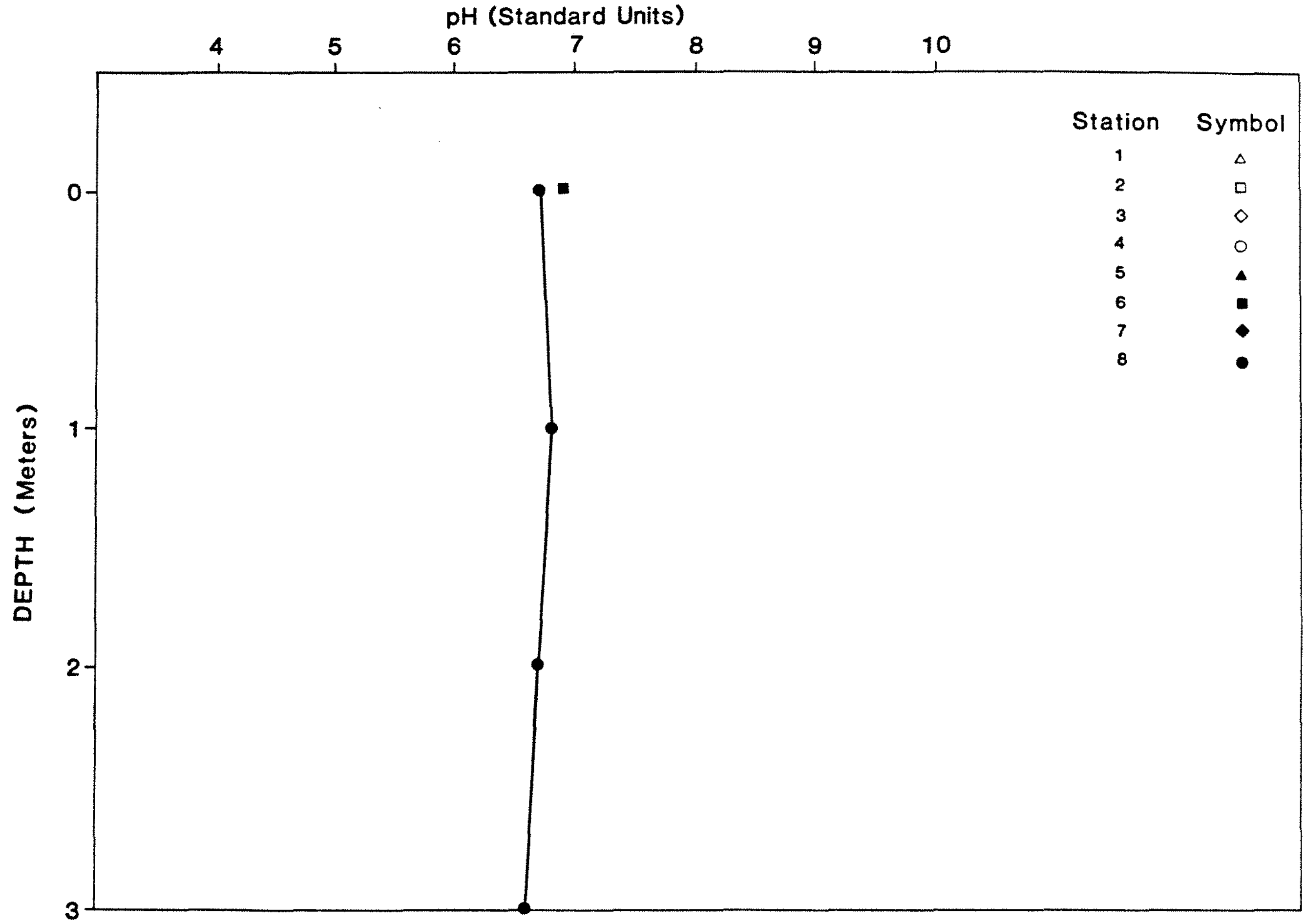

Figure 95. Vertical pH profile and ancillary pH data obtained 24 September 1985 on Ada City Lake.

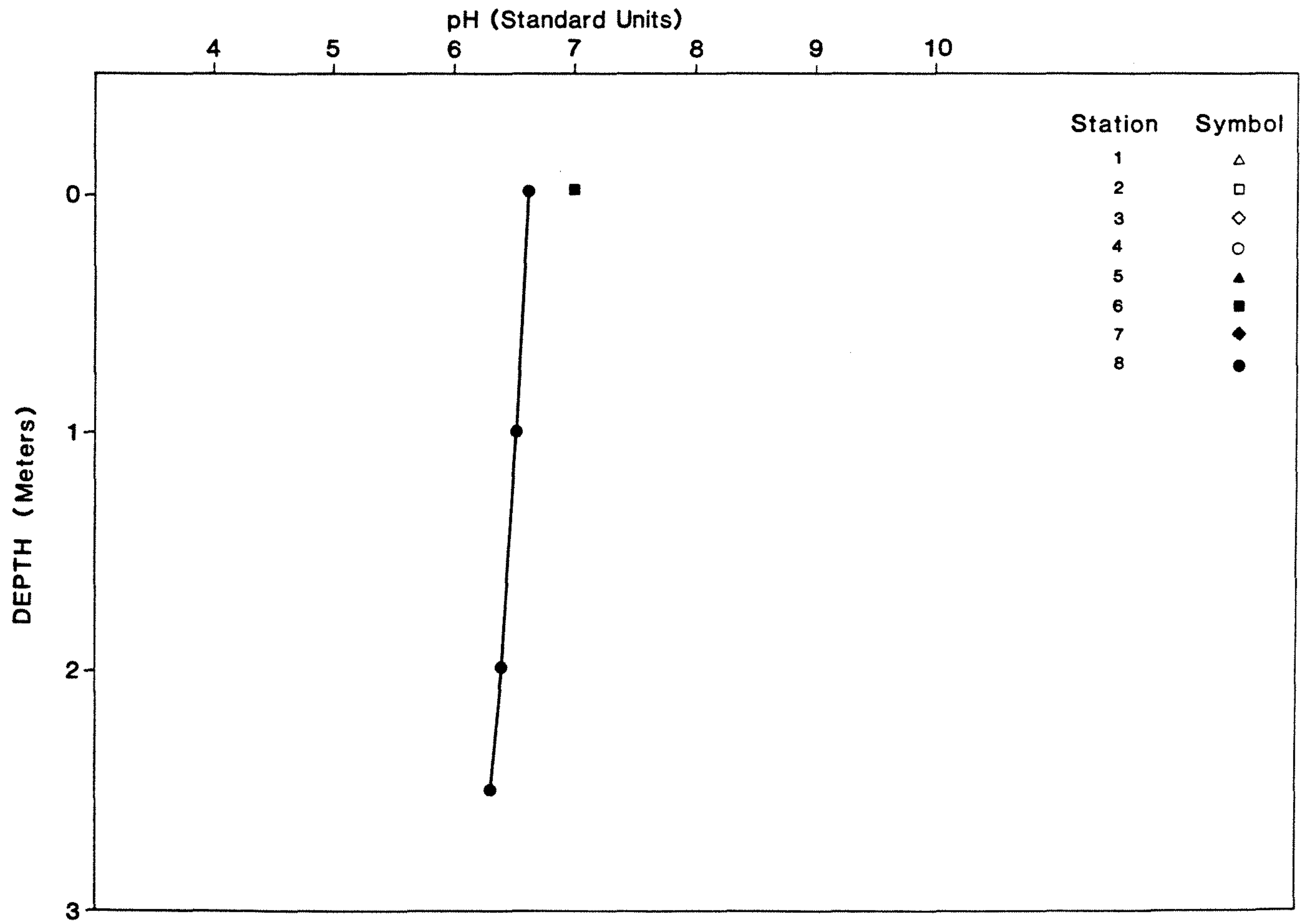

Figure 96. Vertical pH profile and ancillary pH data obtained 8 October 1985 on Ada City Lake.

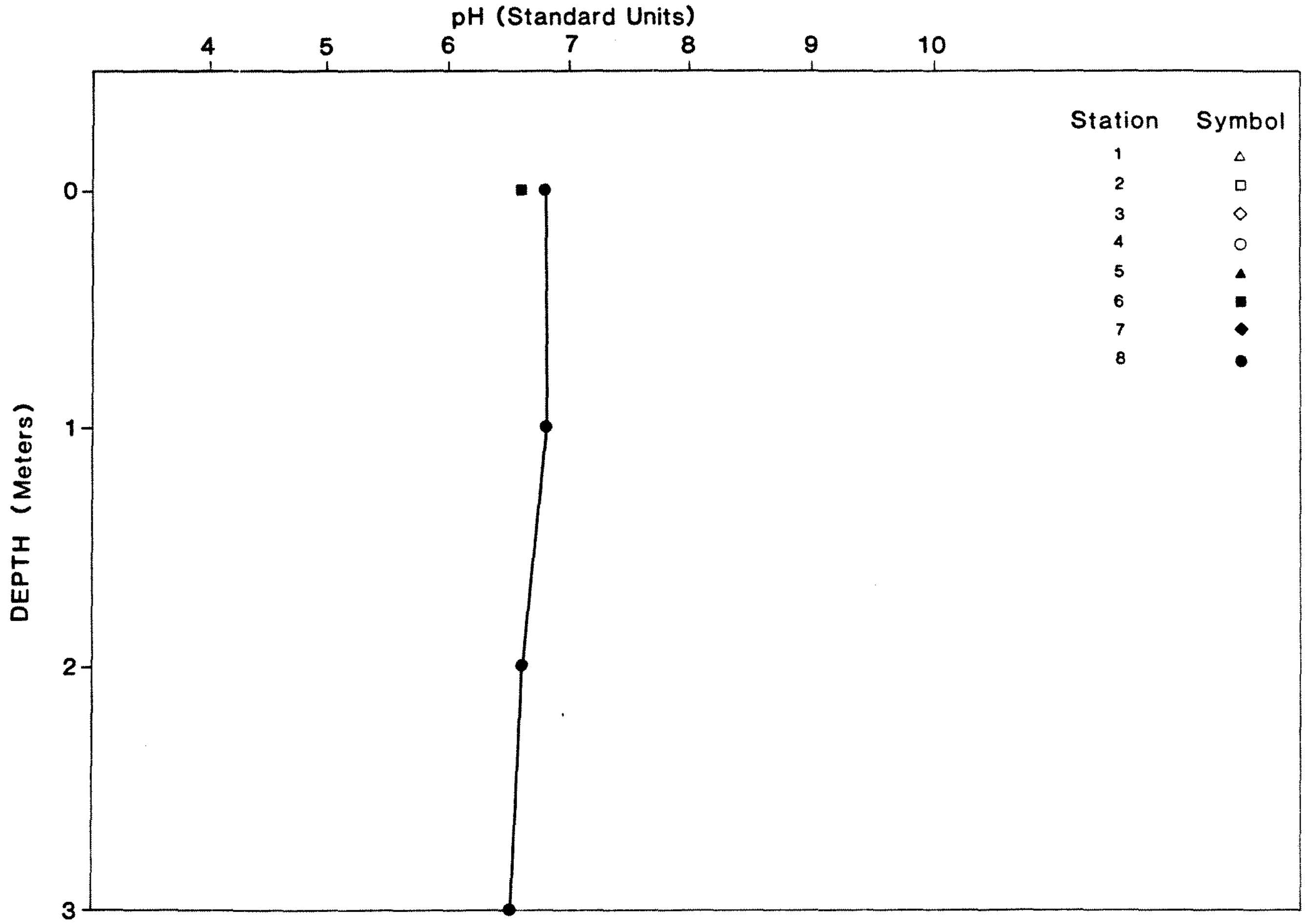

Figure 97. Vertical pH profile and ancillary pH data obtained 22 October 1985 on Ada City Lake.

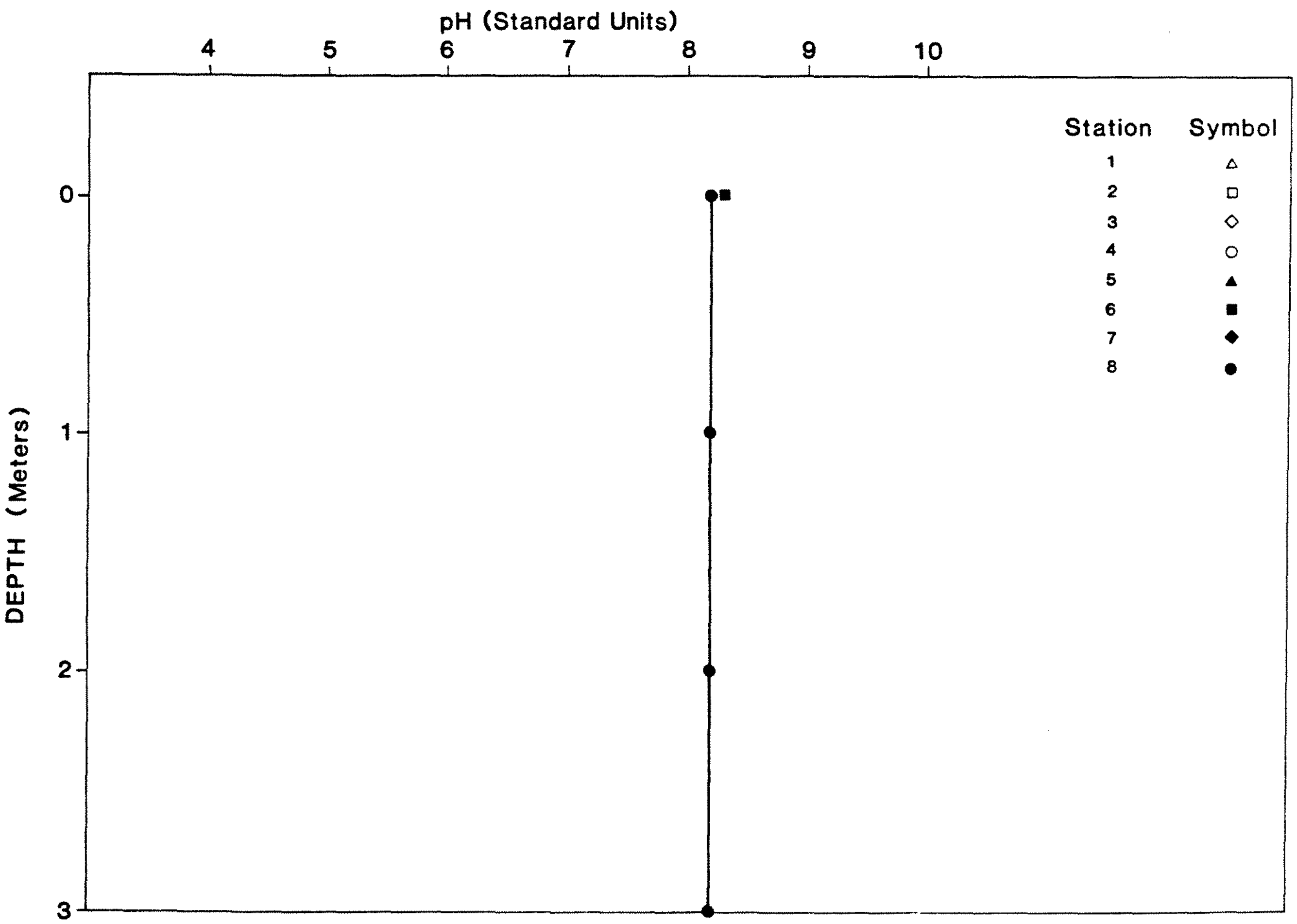

Figure 98. Vertical pH profile and ancillary pH data obtained 2 December 1985 on Ada City Lake.

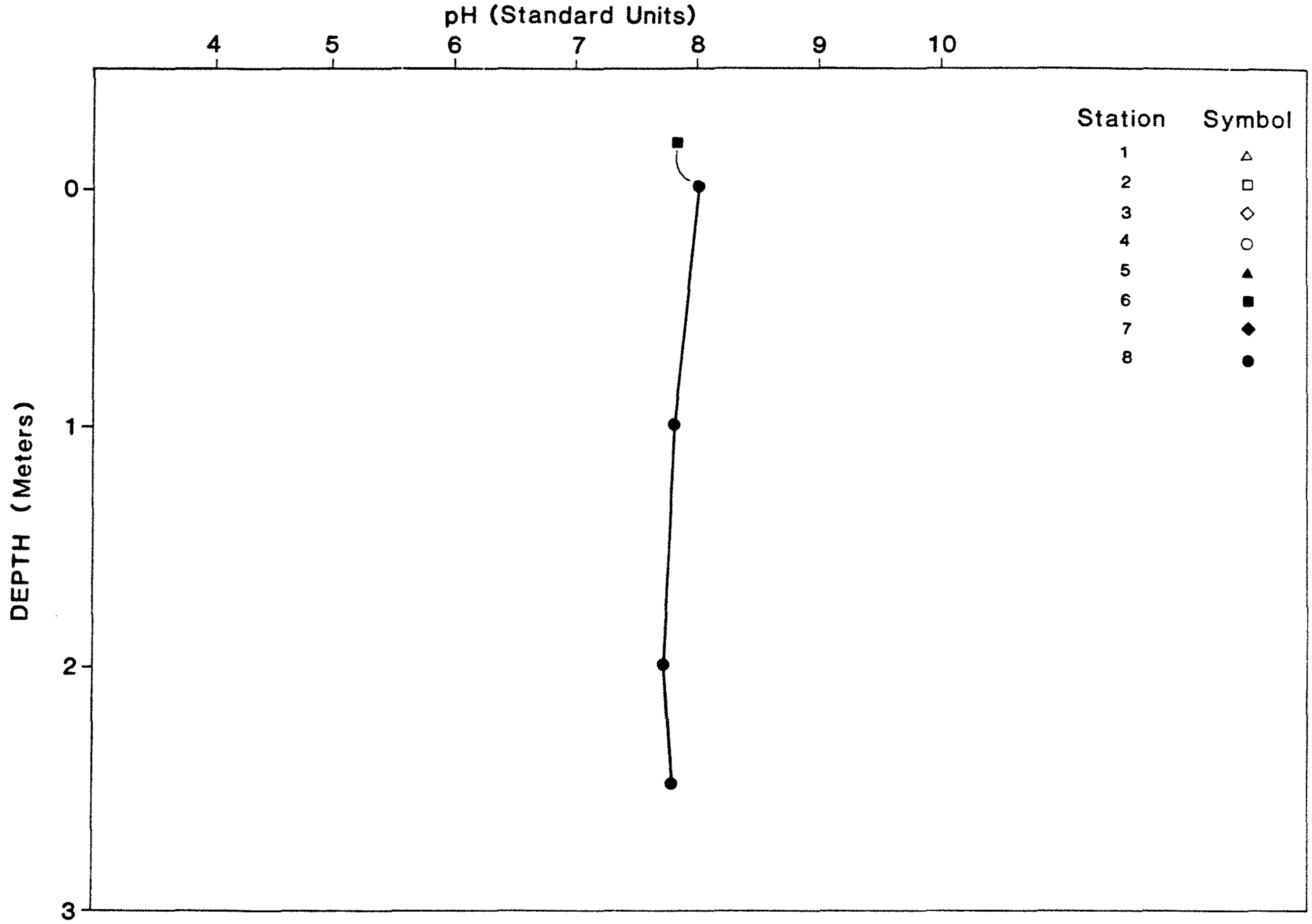

Figure 99. Vertical pH profile and ancillary pH data obtained 17 December 1985 on Ada City Lake.

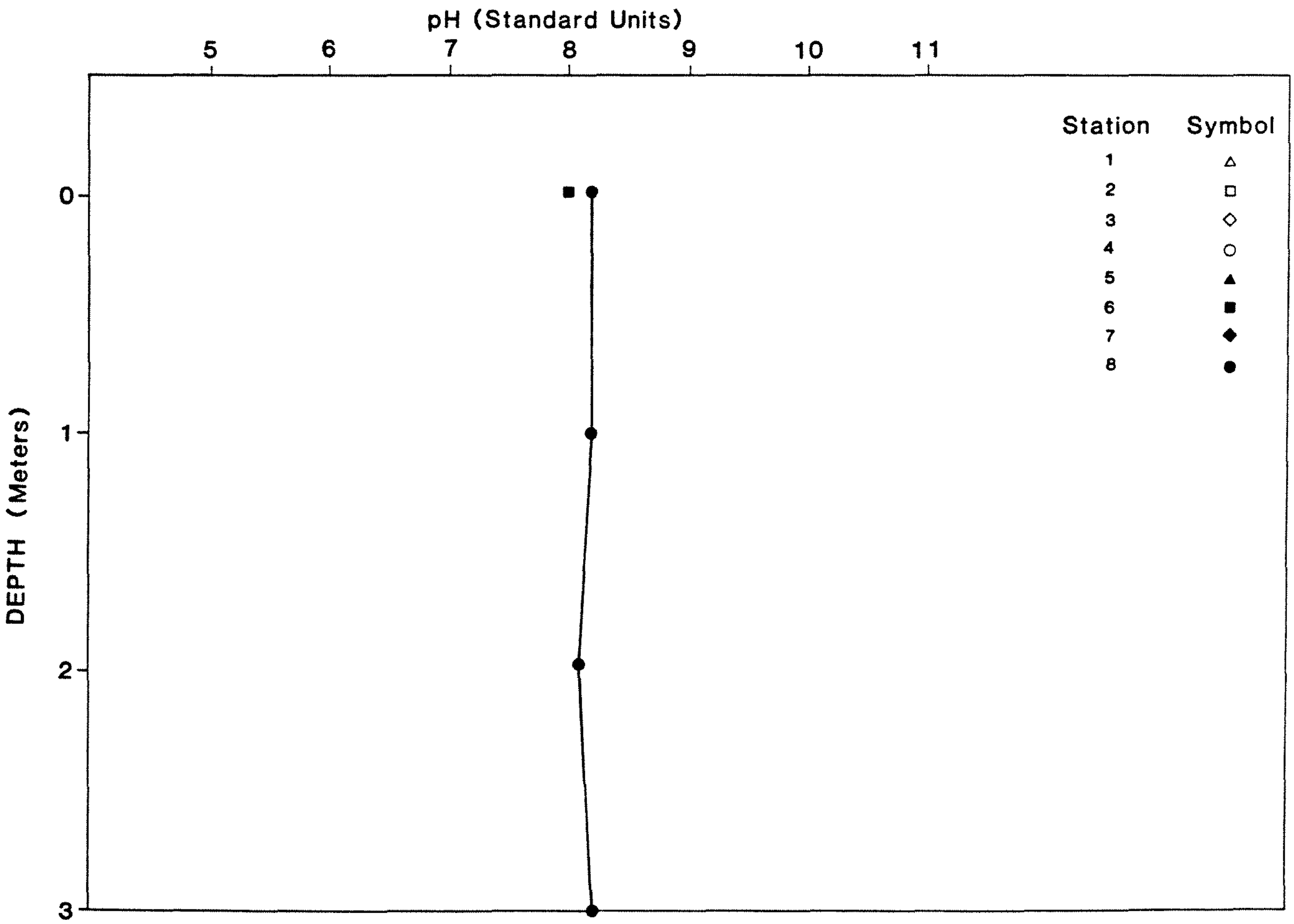

Figure 100. Vertical pH profile and ancillary pH data obtained 14 January 1986 on Ada City Lake.

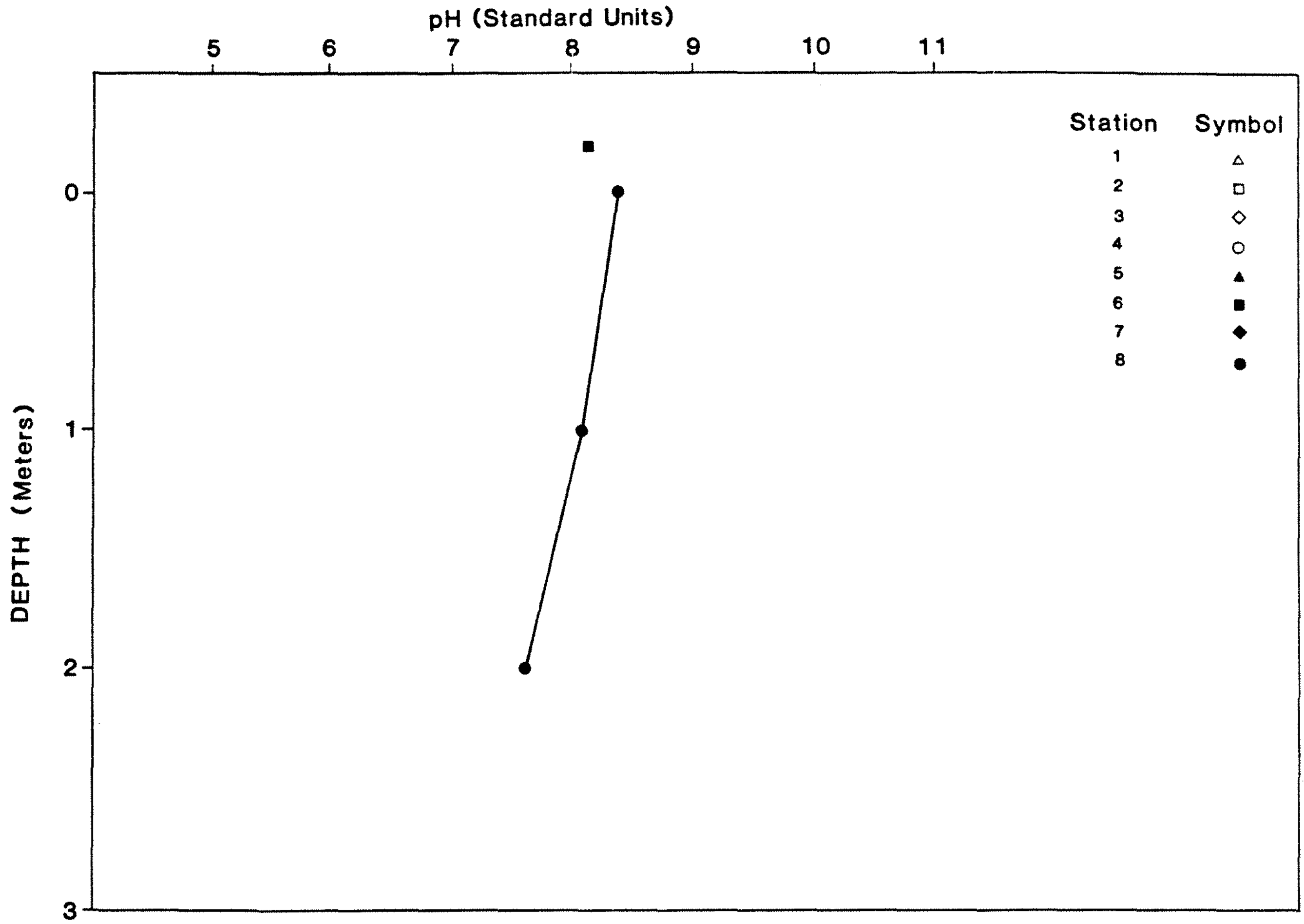

Figure 101. Vertical pH profile and ancillary pH data obtained 19 February 1986 on Ada City Lake.

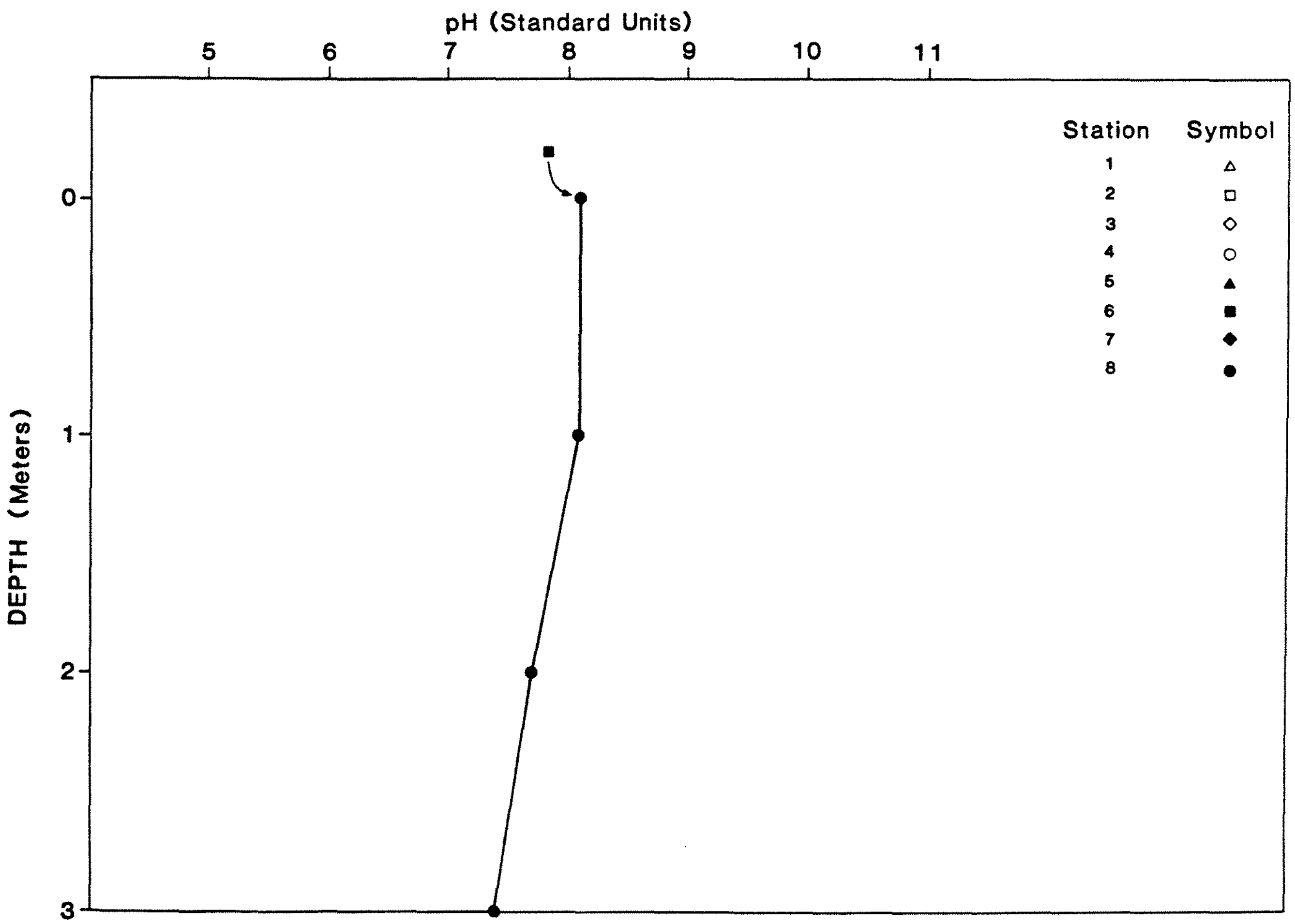

Figure 102. Vertical pH profile and ancillary pH data obtained 24 March 1986 on Ada City Lake.

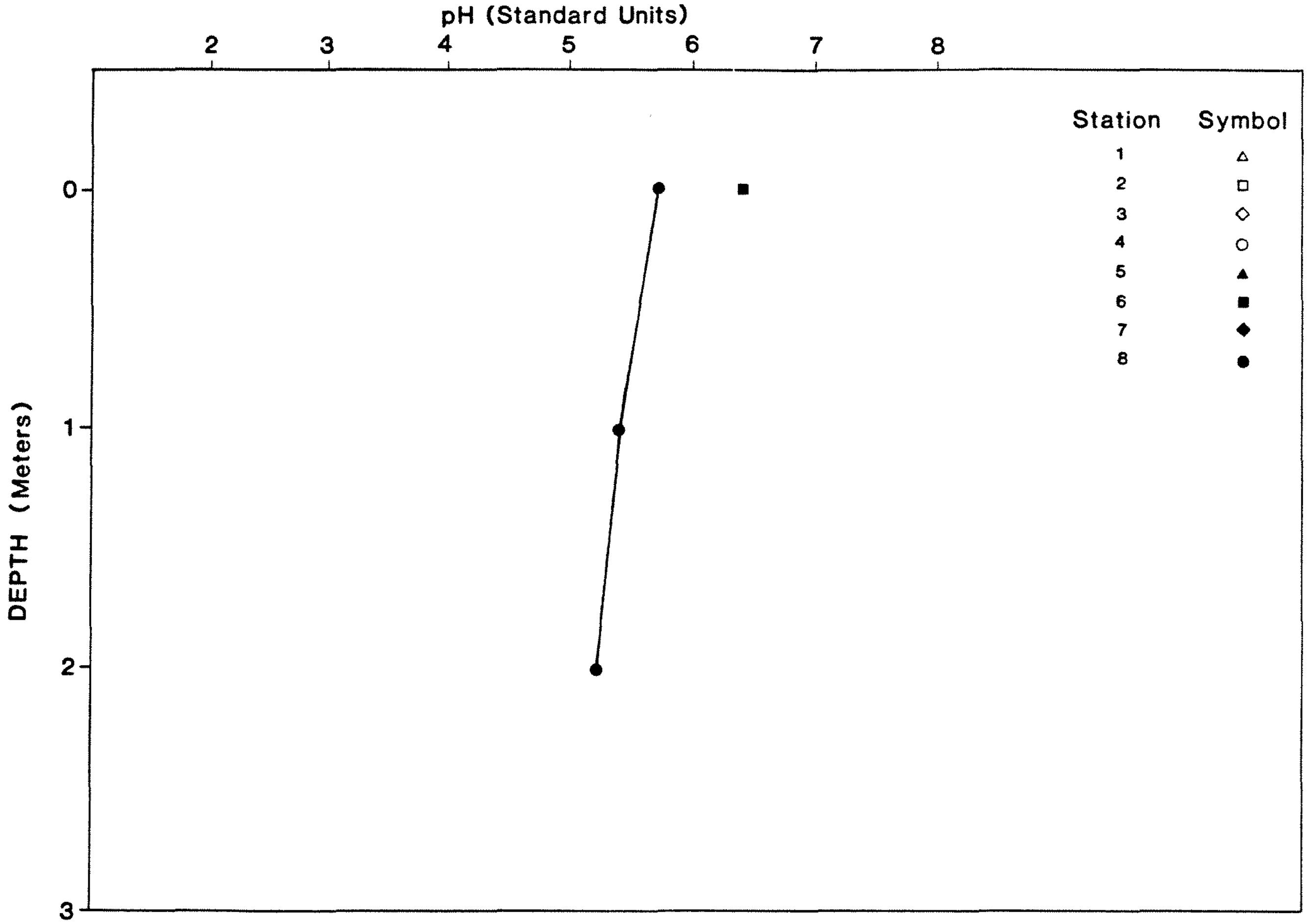

Figure 103. Vertical pH profile and ancillary pH data obtained 23 April 1986 on Ada City Lake.

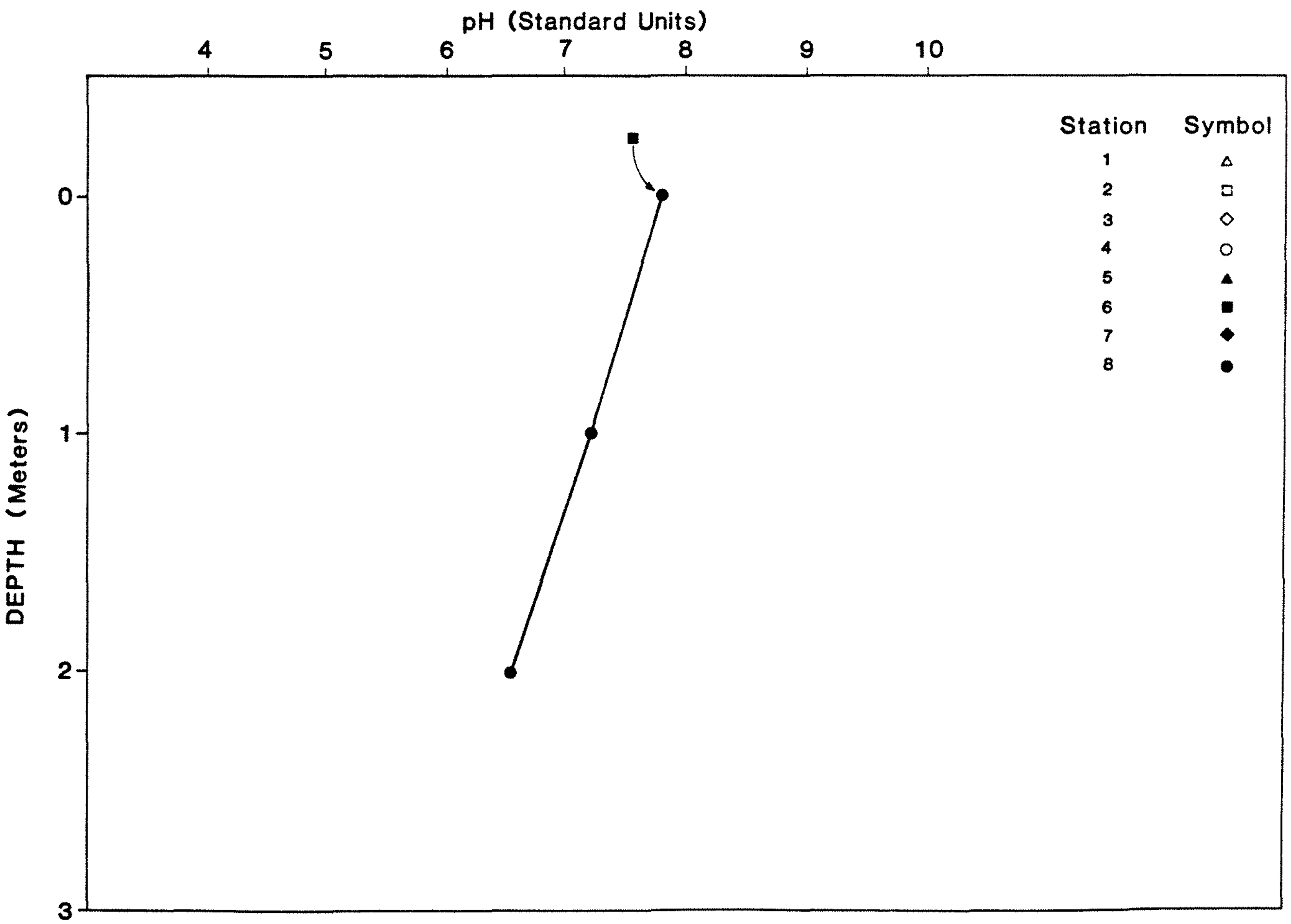

Figure 104. Vertical pH profile and ancillary pH data obtained 21 May 1986 on Ada City Lake.

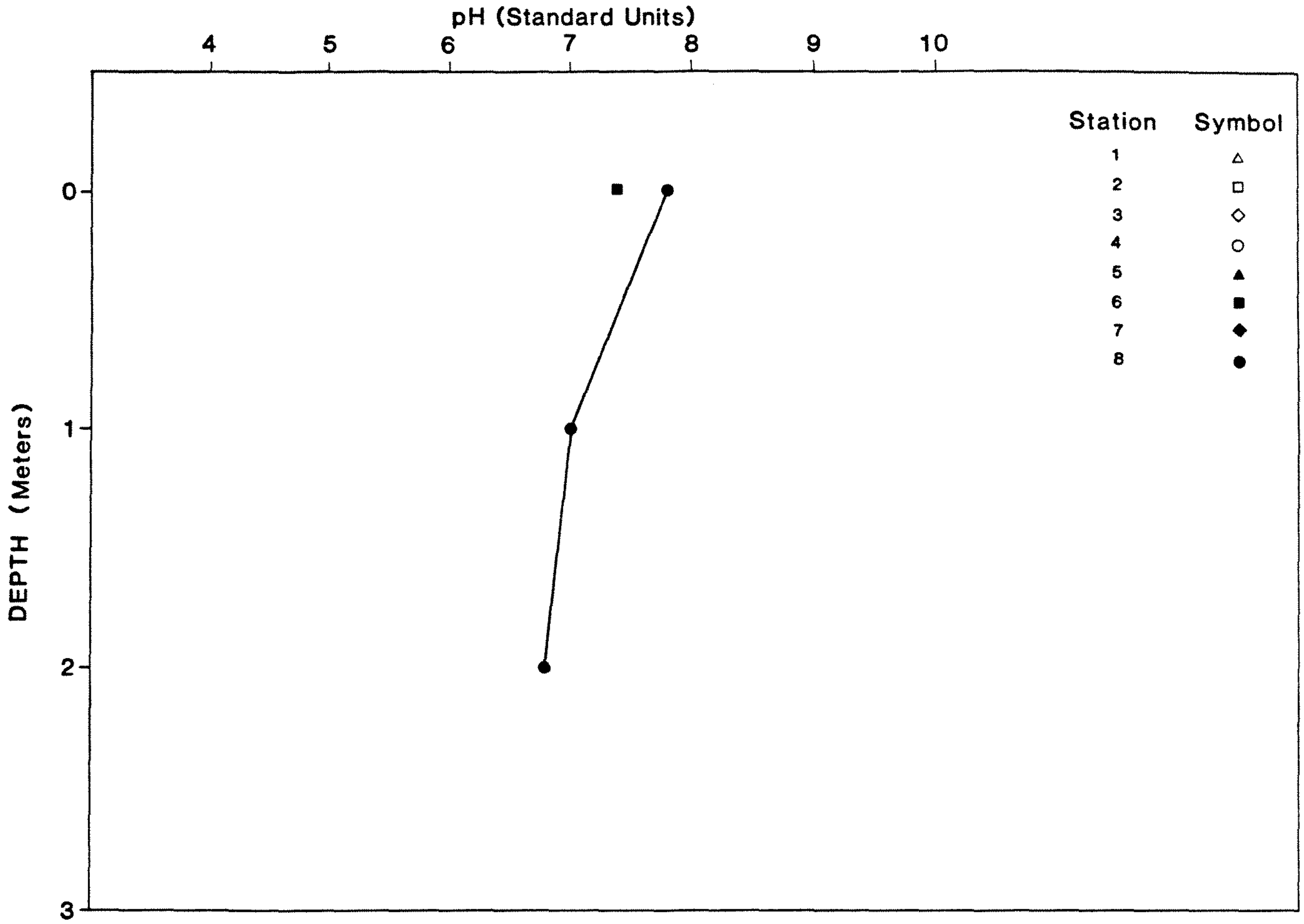

Figure 105. Vertical pH profile and ancillary pH data obtained 25 June 1986 on Ada City Lake.

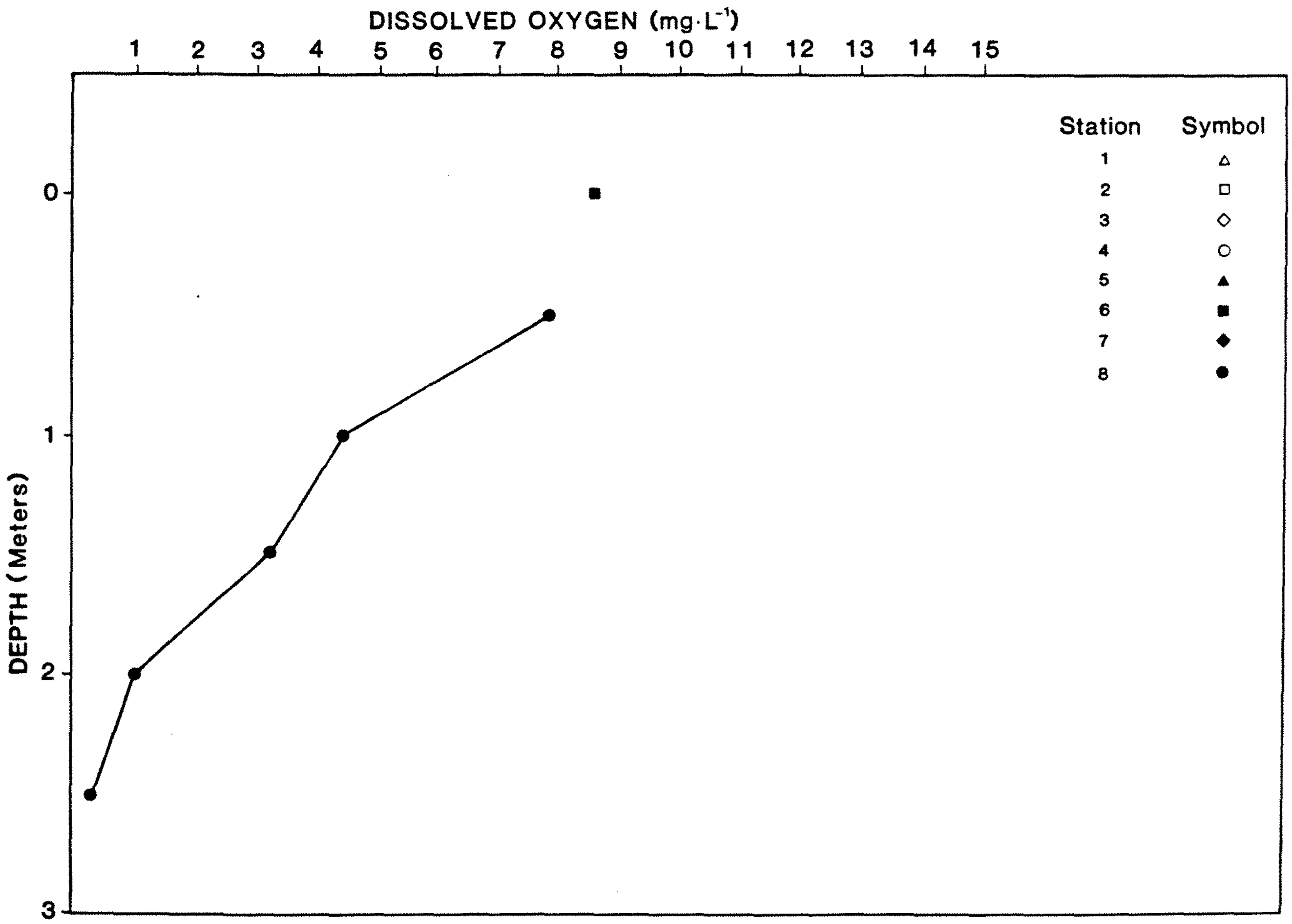

Figure 106. Vertical dissolved oxygen percent saturation profile and ancillary oxygen saturation data obtained 17 July 1985 on Ada City Lake.

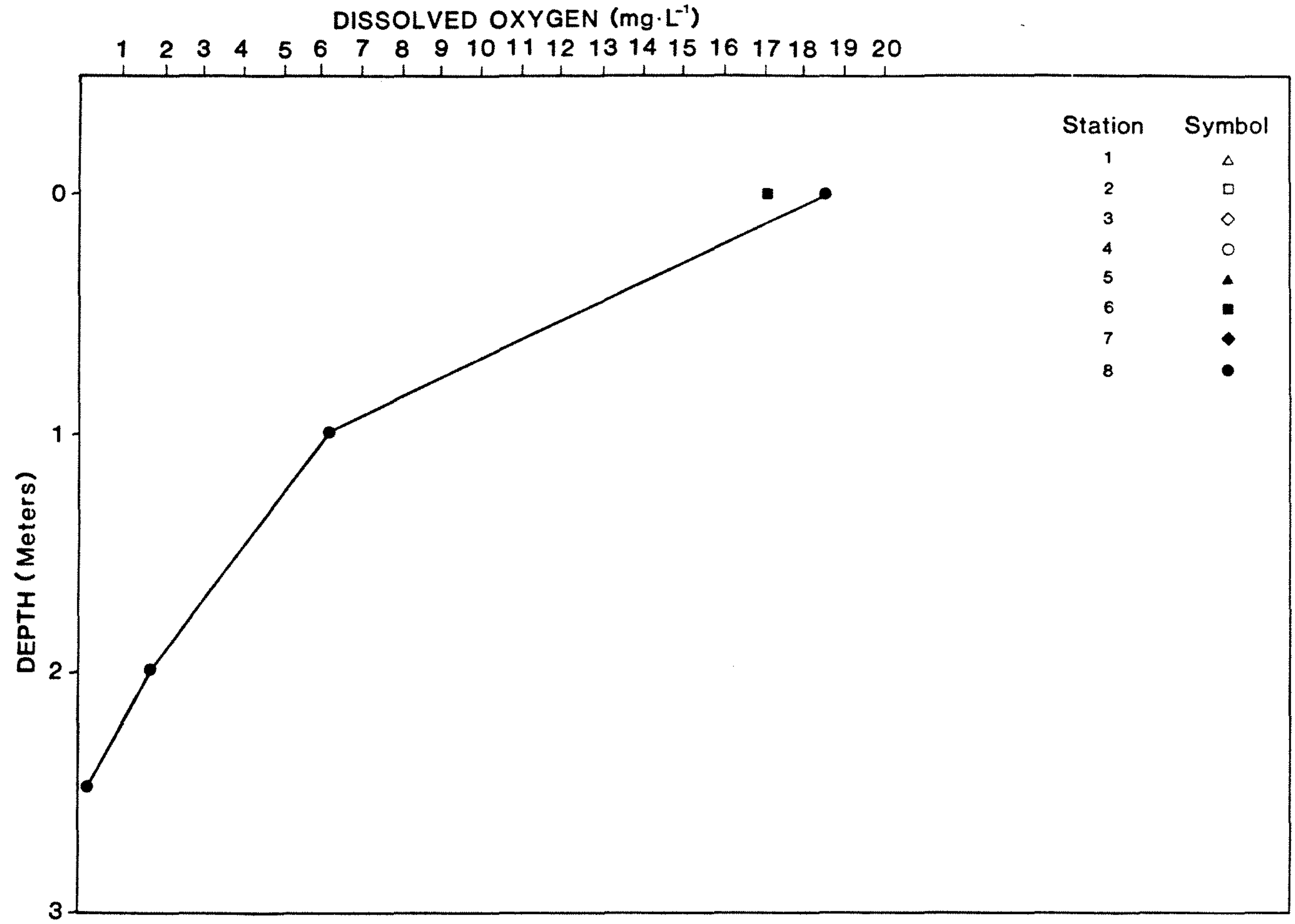

Figure 107. Vertical dissolved oxygen percent saturation profile and ancillary oxygen saturation data obtained 1 August 1985 on Ada City Lake.

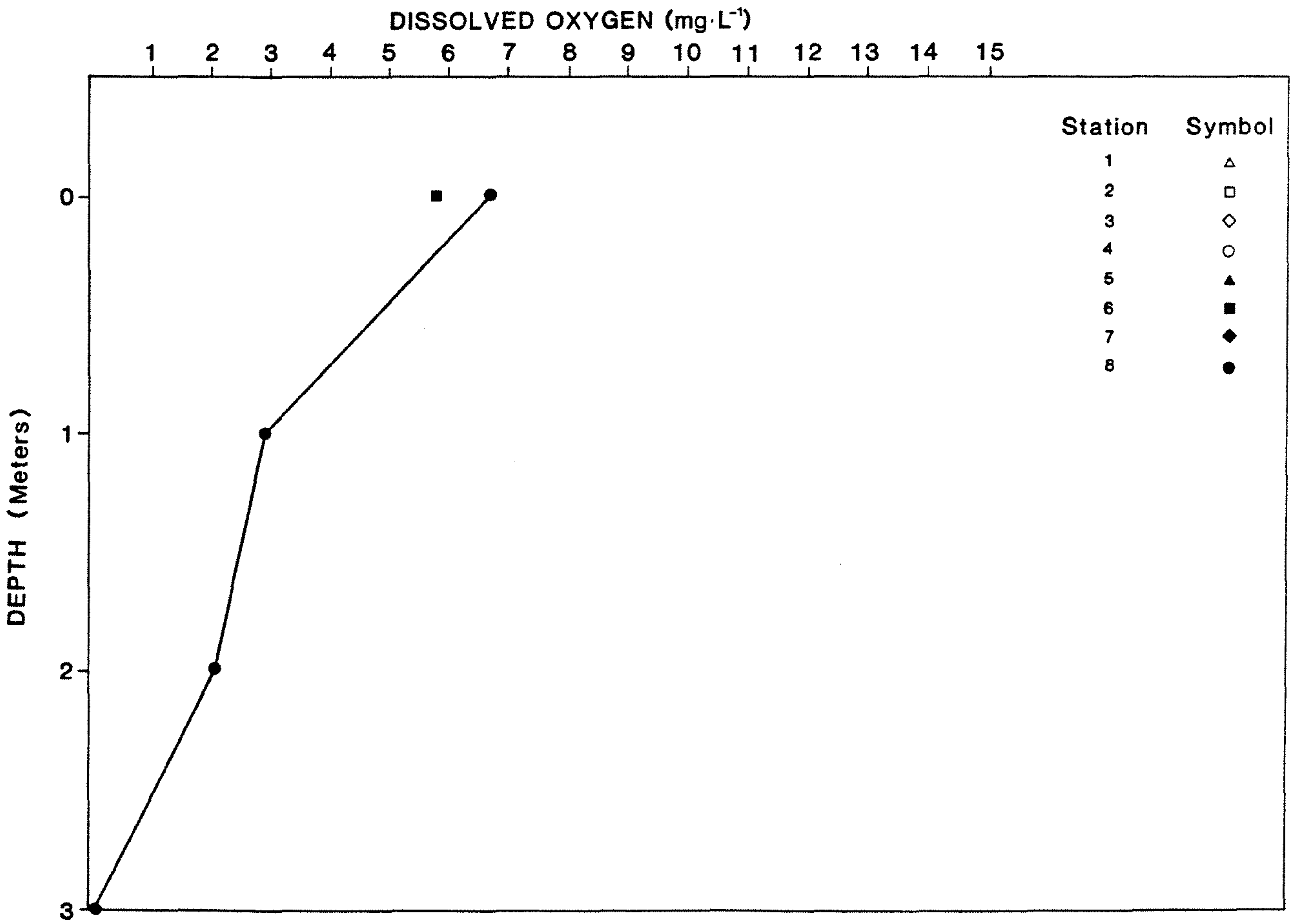

Figure 108. Vertical dissolved oxygen percent saturation profile and ancillary oxygen saturation data obtained 13 August 1985 on Ada City Lake.

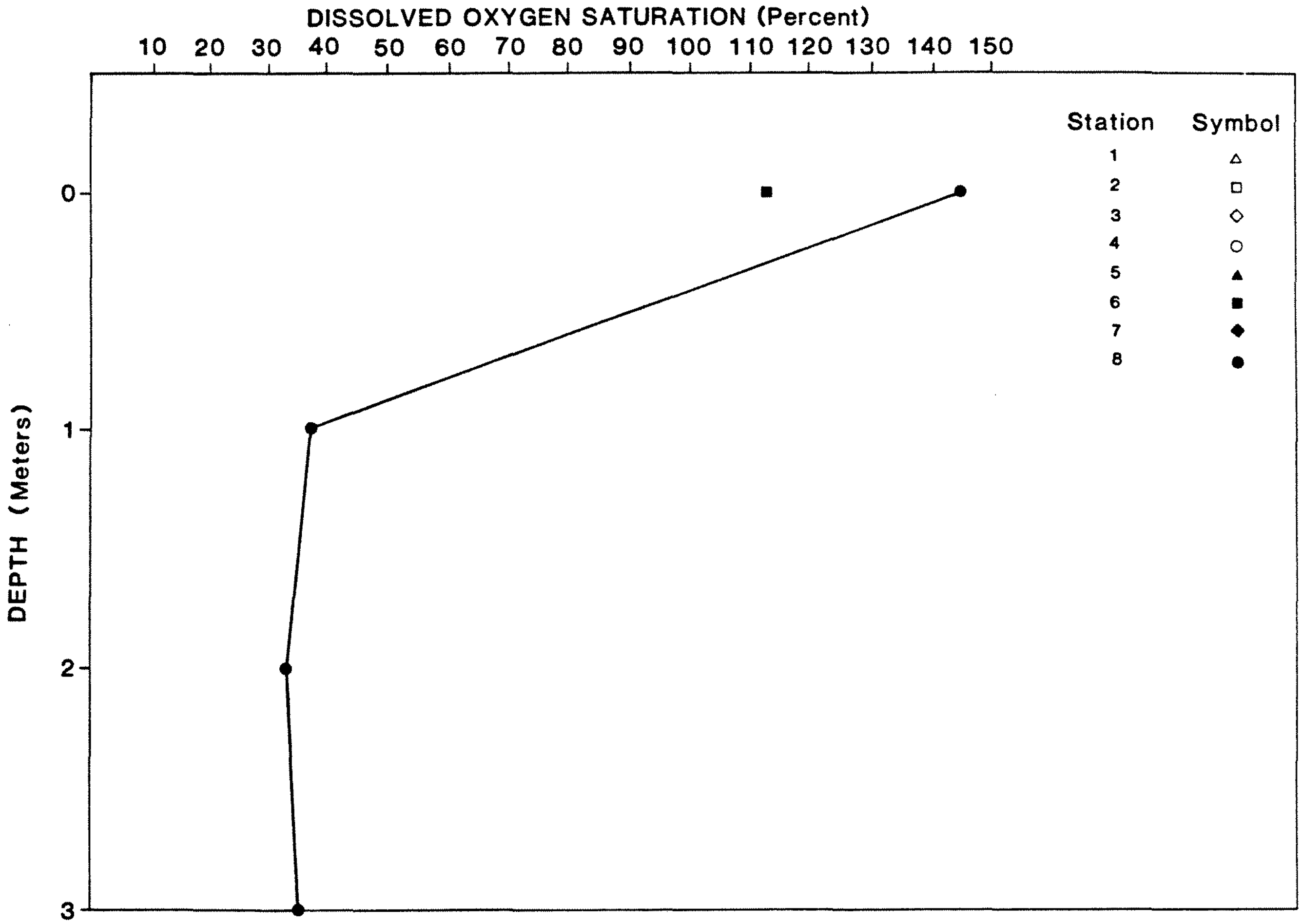

Figure 109. Vertical dissolved oxygen percent saturation profile and ancillary oxygen saturation data obtained 29 August 1985 on Ada City Lake.

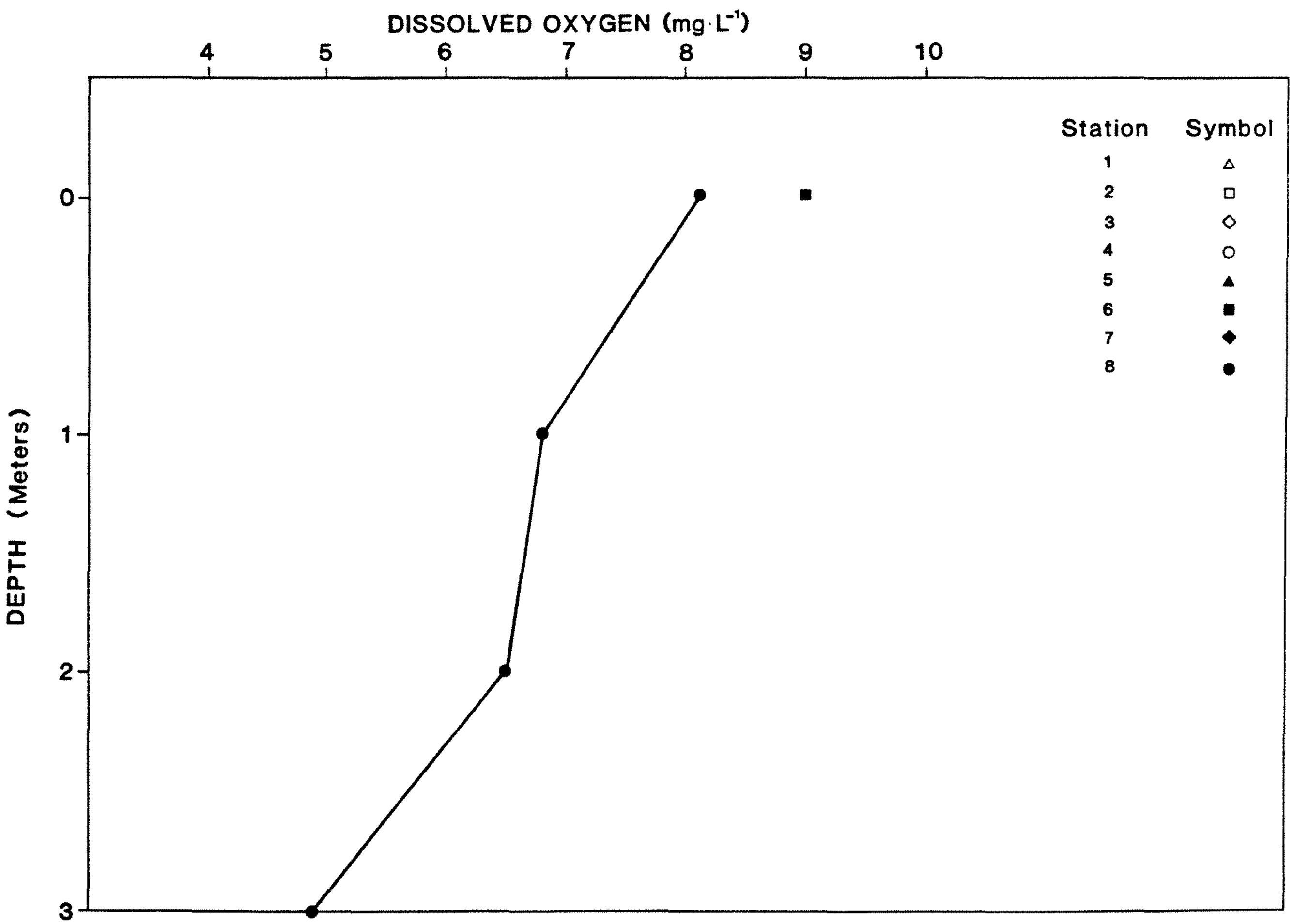

Figure 110. Vertical dissolved oxygen percent saturation profile and ancillary oxygen saturation data obtained 24 September 1985 on Ada City Lake.

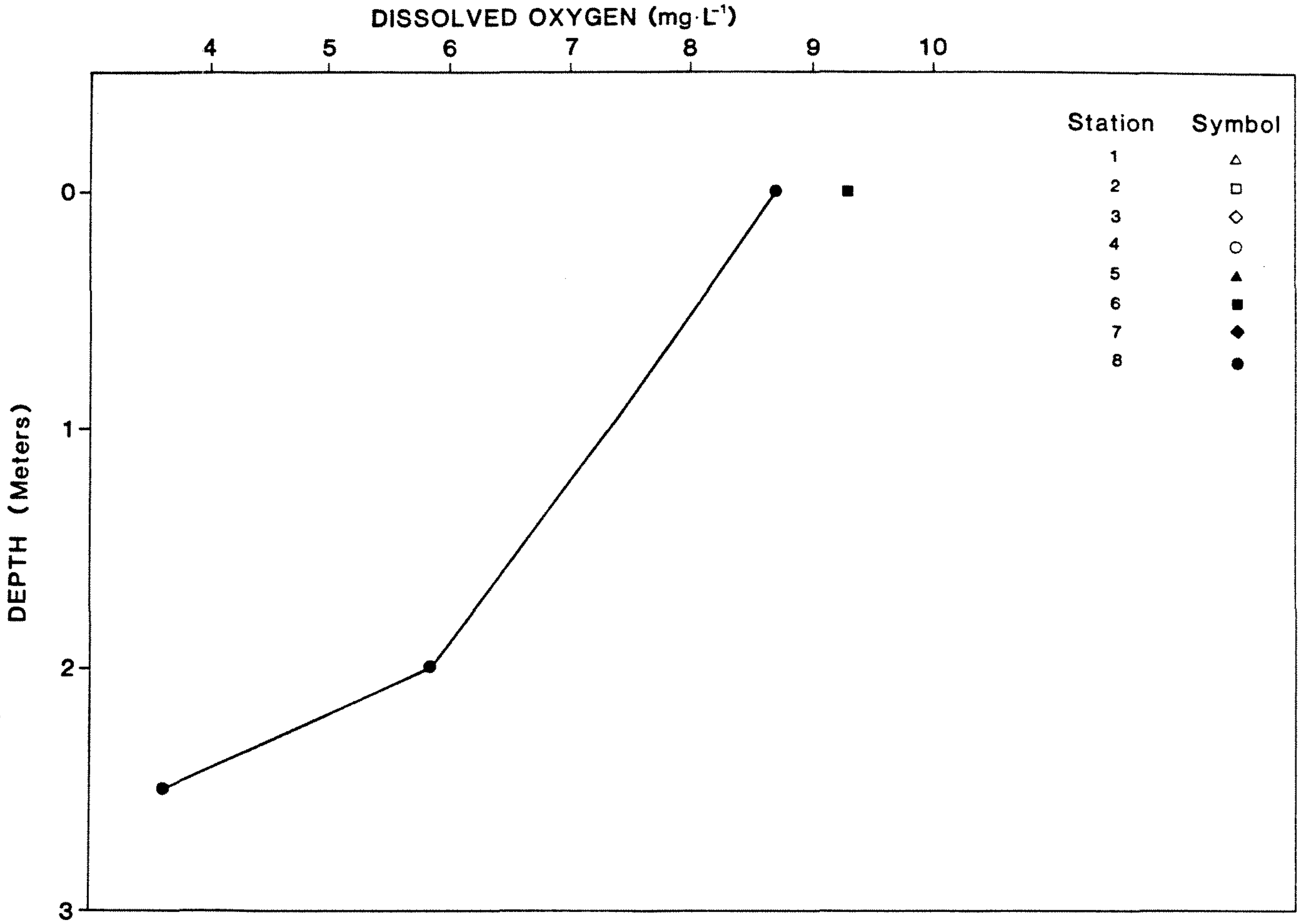

Figure 111. Vertical dissolved oxygen percent saturation profile and ancillary oxygen saturation data obtained 8 October 1985 on Ada City Lake.

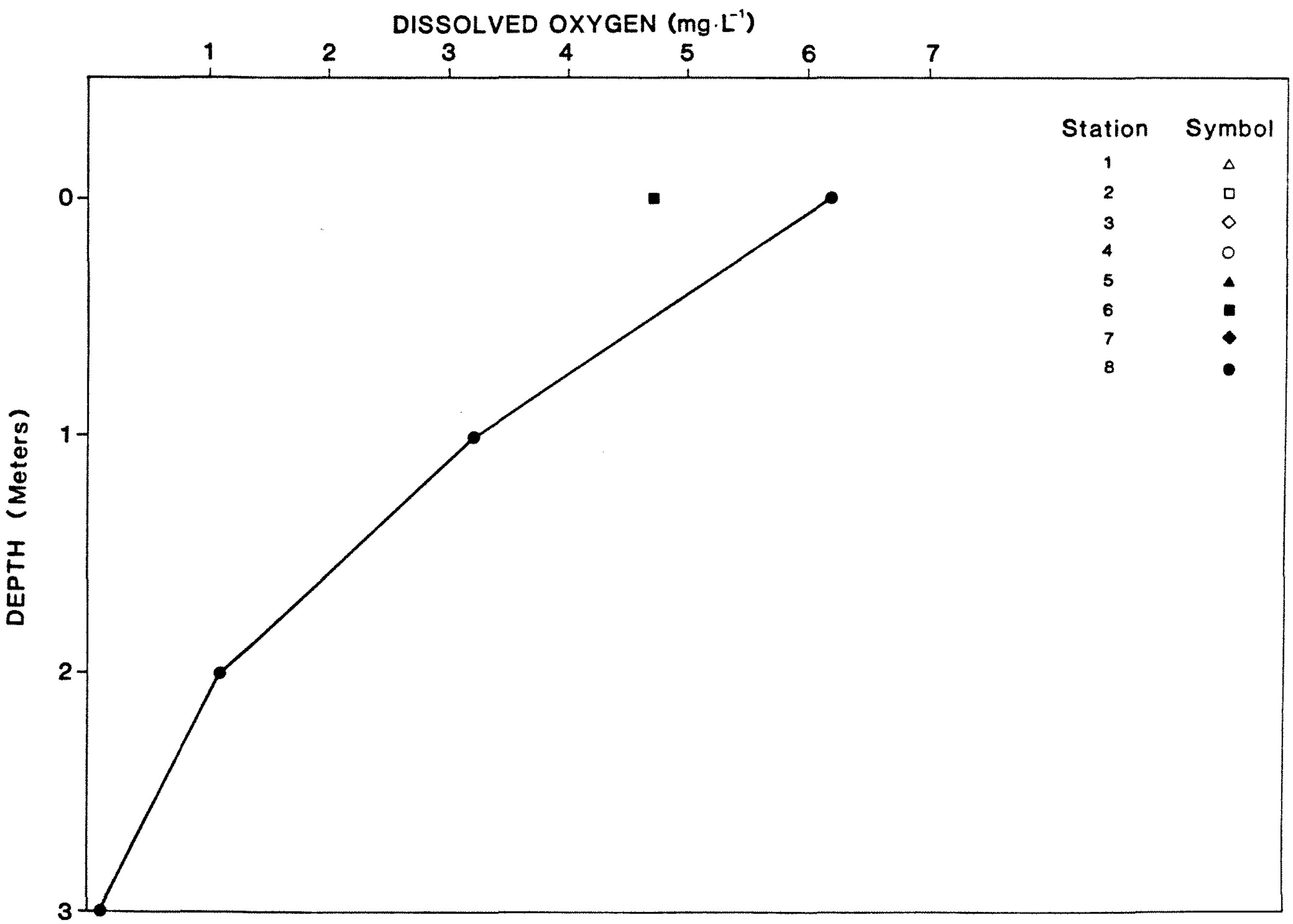

Figure 112. Vertical dissolved oxygen percent saturation profile and ancillary oxygen saturation data obtained 22 October 1985 on Ada City Lake.

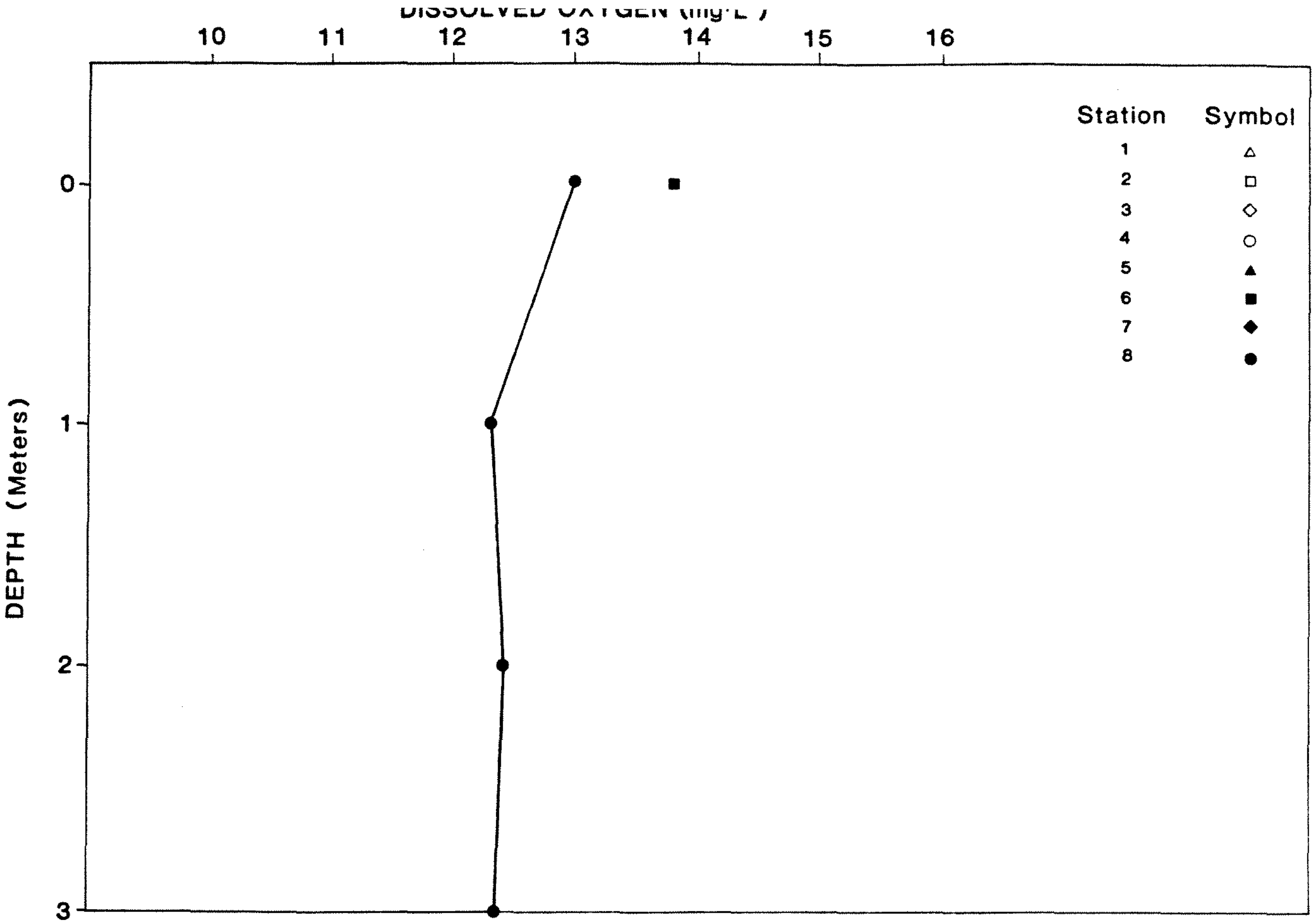

Figure 113. Vertical dissolved oxygen percent saturation profile and ancillary oxygen saturation data obtained 2 December 1985 on Ada City Lake.

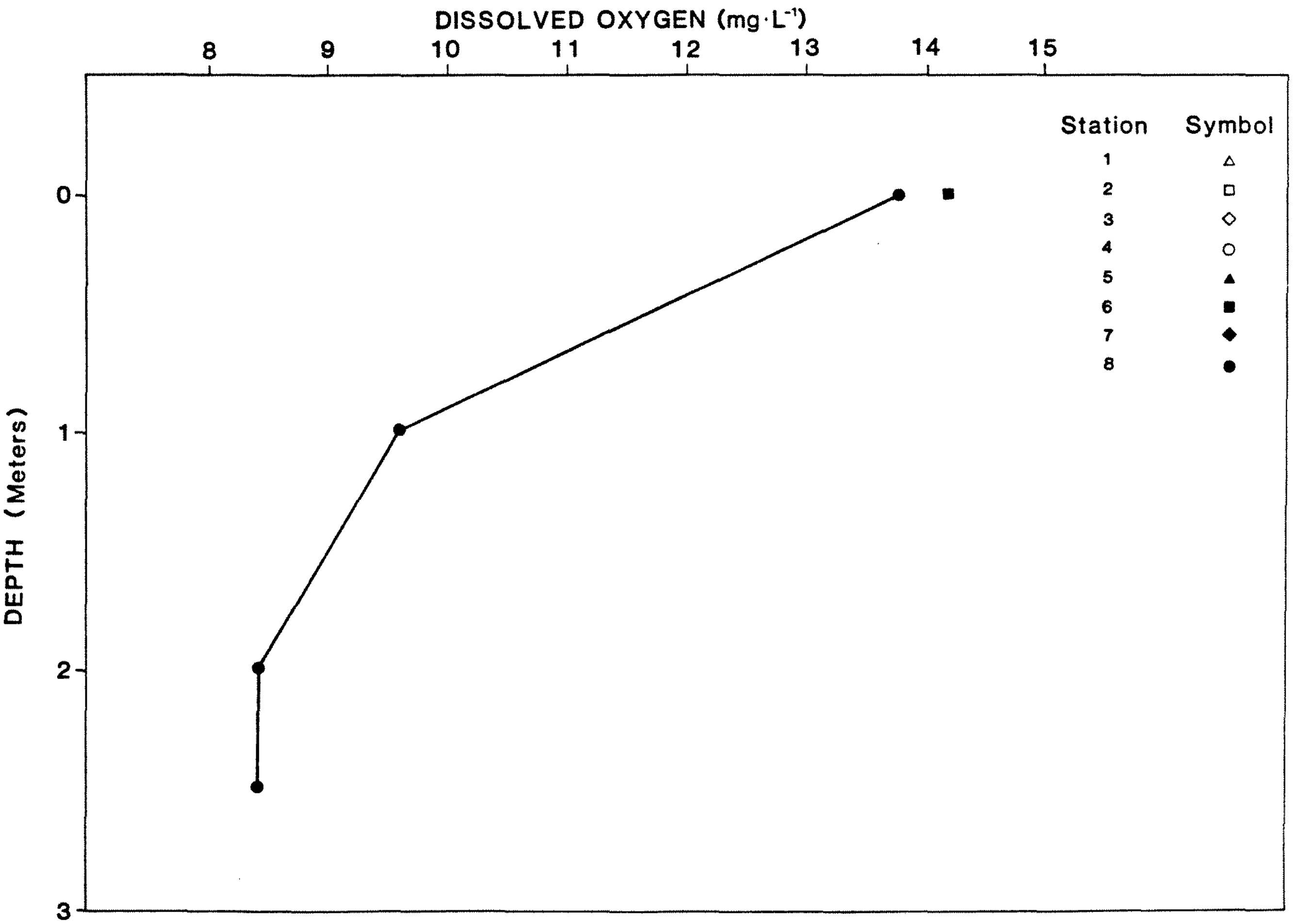

Figure 114. Vertical dissolved oxygen percent saturation profile and ancillary oxygen saturation data obtained 17 December 1985 on Ada City Lake.

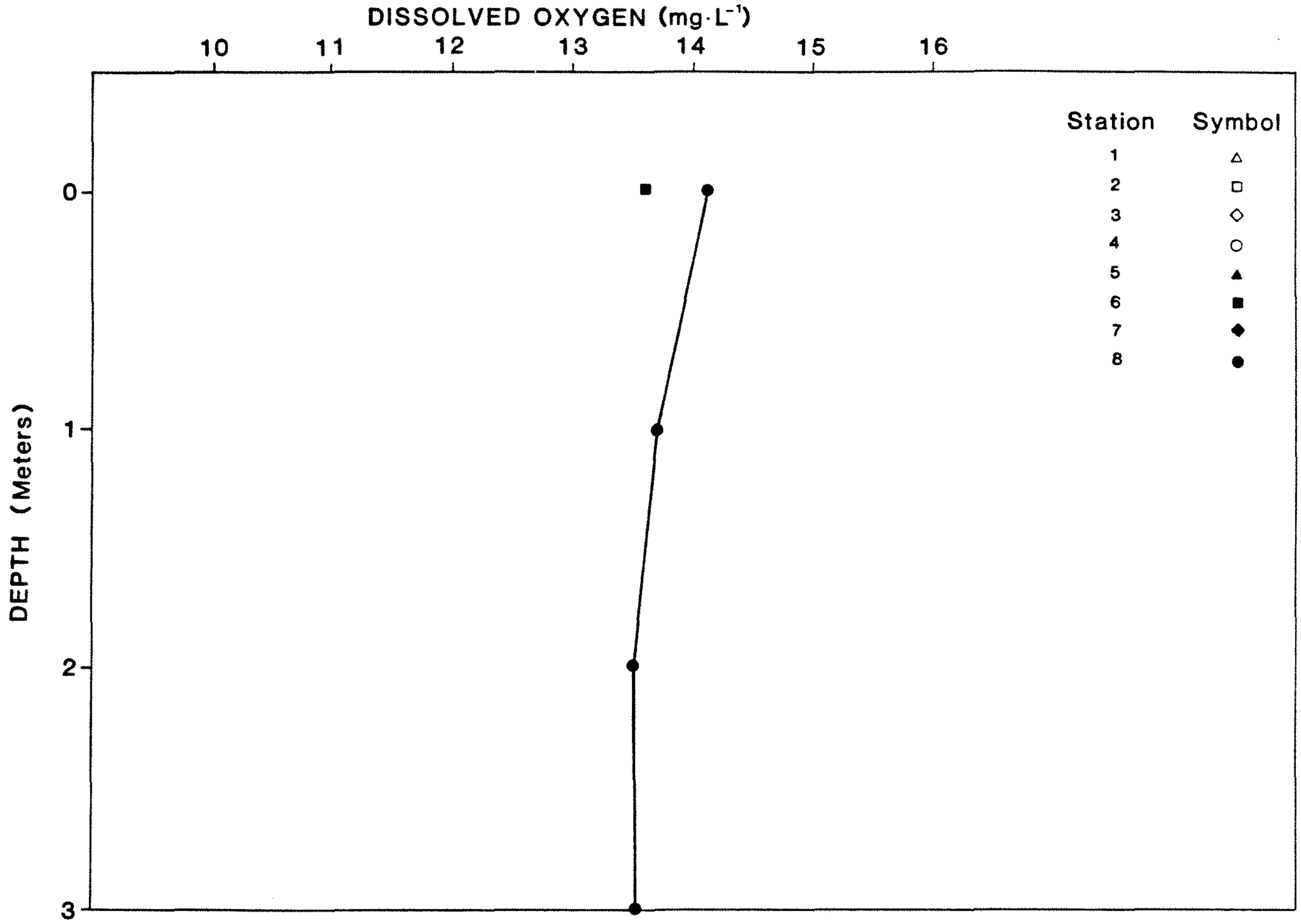

Figure 115. Vertical dissolved oxygen percent saturation profile and ancillary oxygen saturation data obtained 14 January 1986 on Ada City Lake.

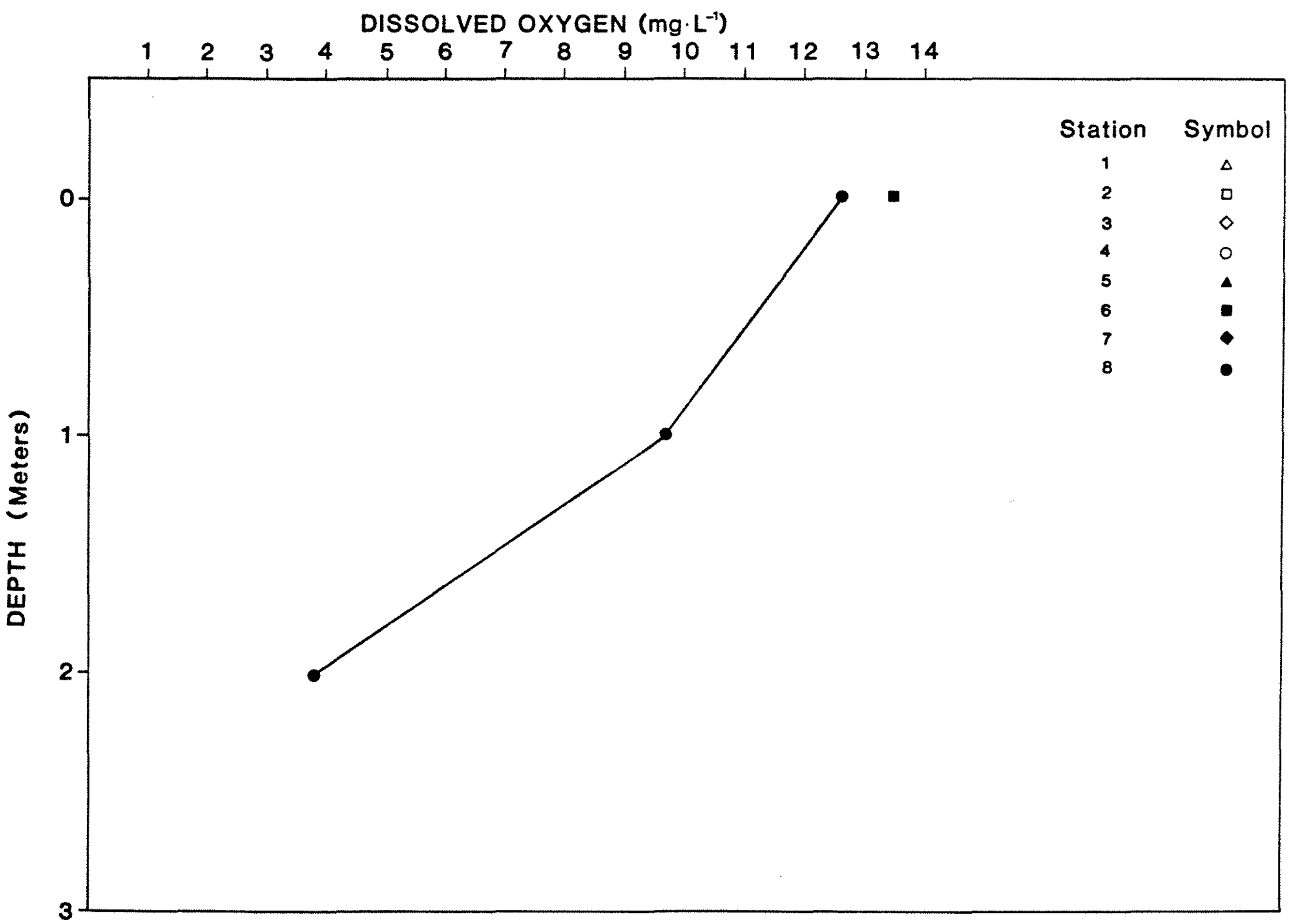

Figure 116. Vertical dissolved oxygen percent saturation profile and ancillary oxygen saturation data obtained 14 February 1986 on Ada City Lake.

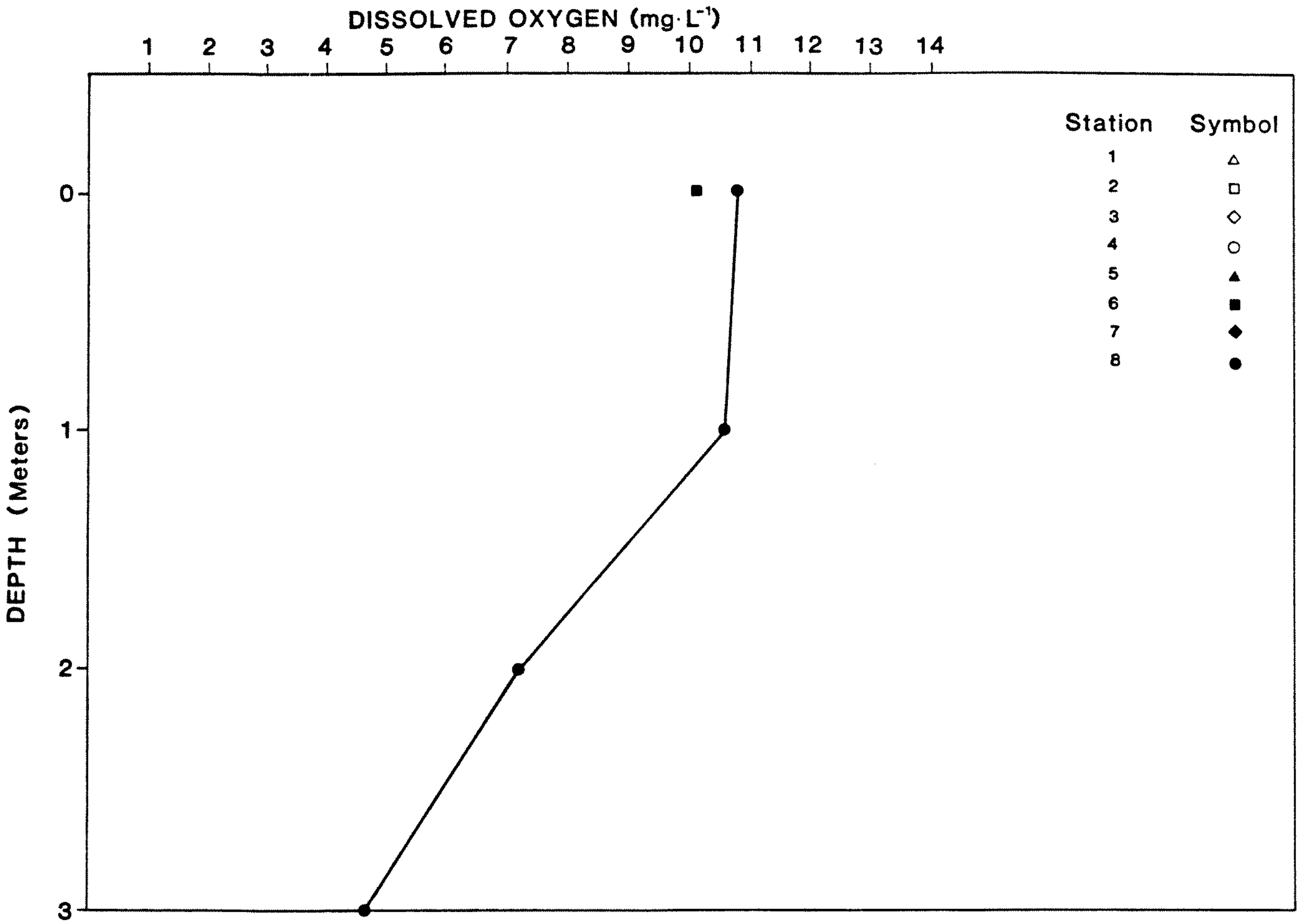

Figure 117. Vertical dissolved oxygen percent saturation profile and ancillary oxygen saturation data obtained 24 March 1986 on Ada City Lake.

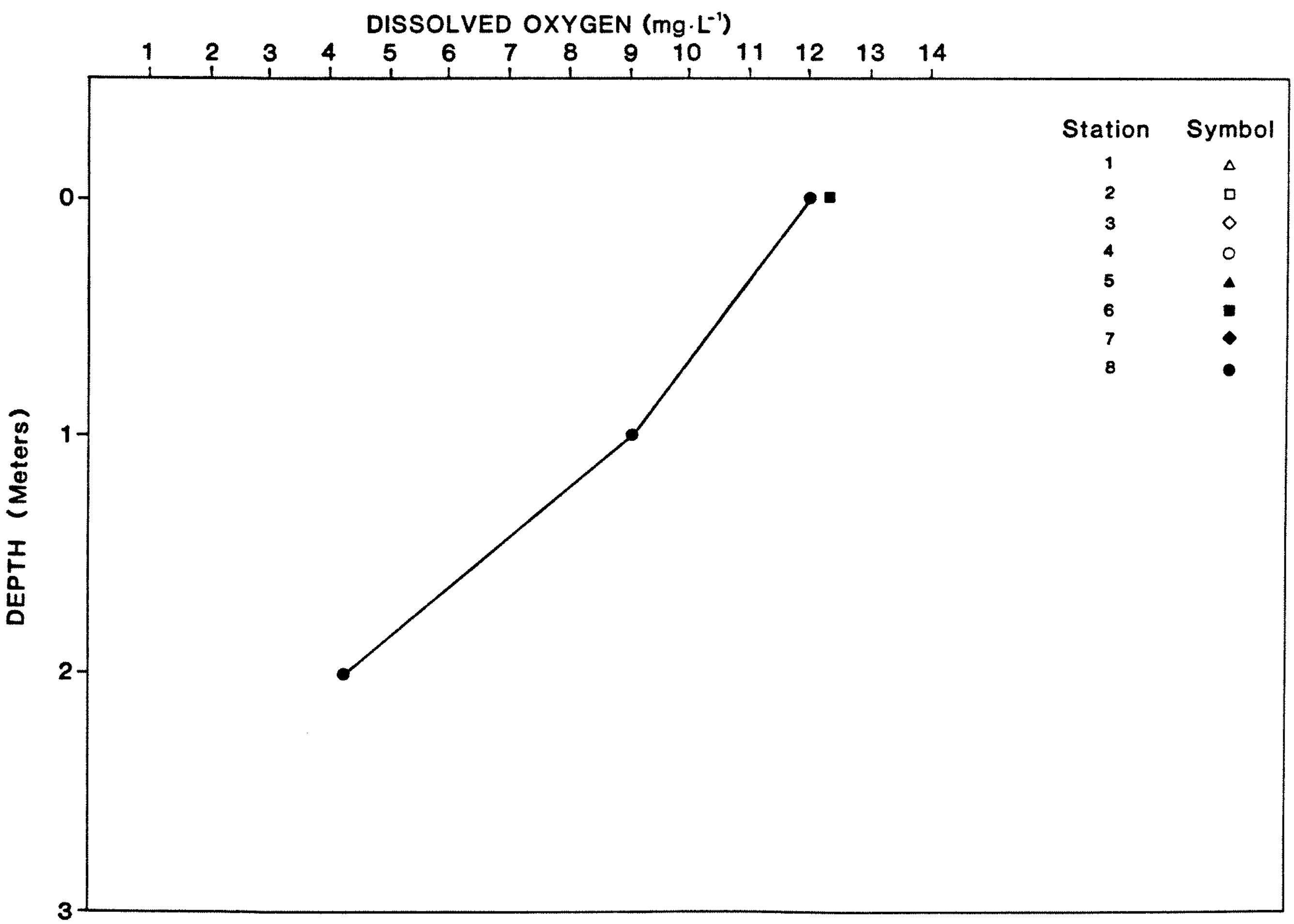

Figure 118. Vertical dissolved oxygen percent saturation profile and ancillary oxygen saturation data obtained 23 April 1986 on Ada City Lake.

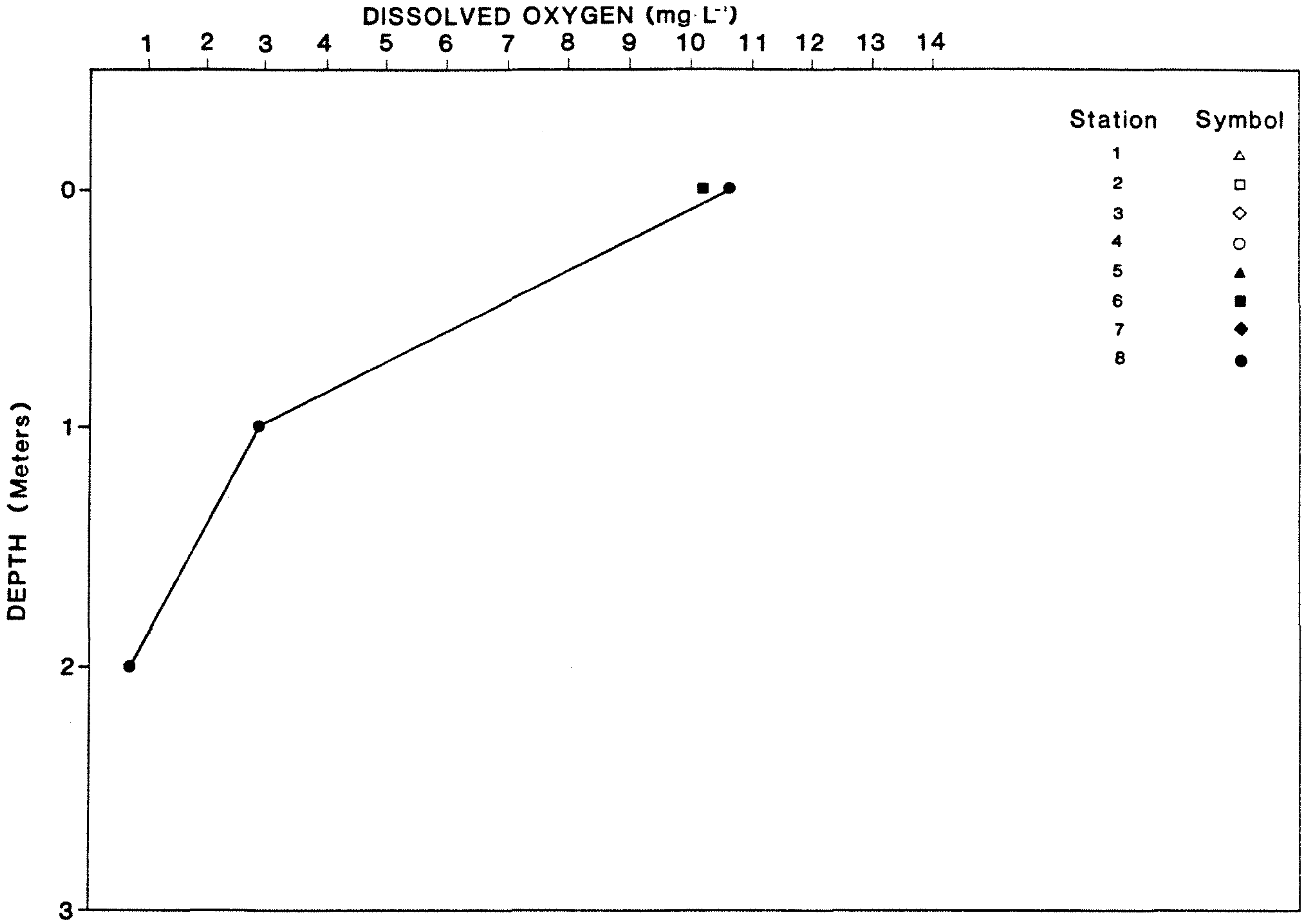

Figure 119. Vertical dissolved oxygen percent saturation profile and ancillary oxygen saturation data obtained 21 May 1986 on Ada City Lake.

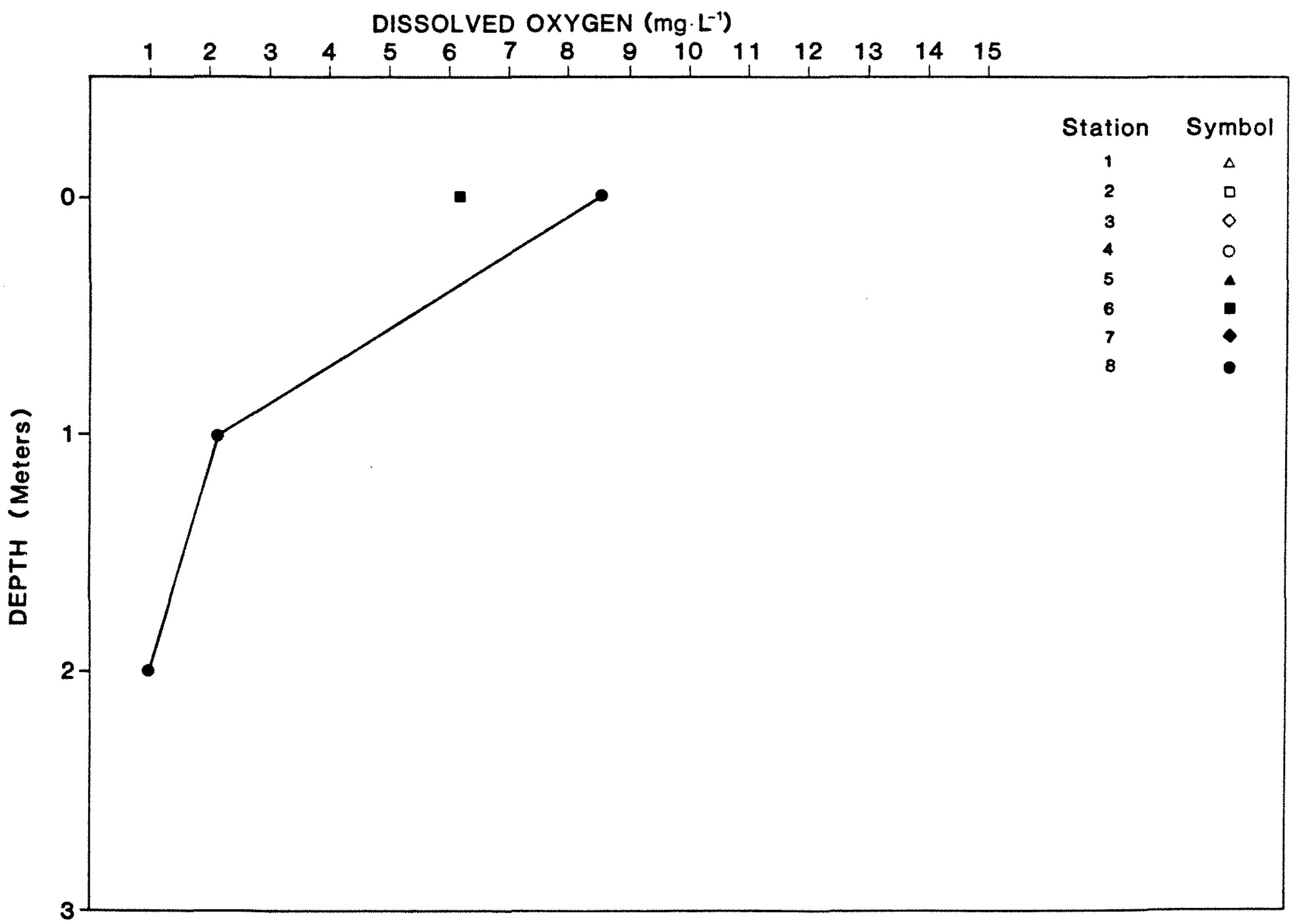

Figure 120. Vertical dissolved oxygen percent saturation profile and ancillary oxygen saturation data obtained 25 June 1986 on Ada City Lake.

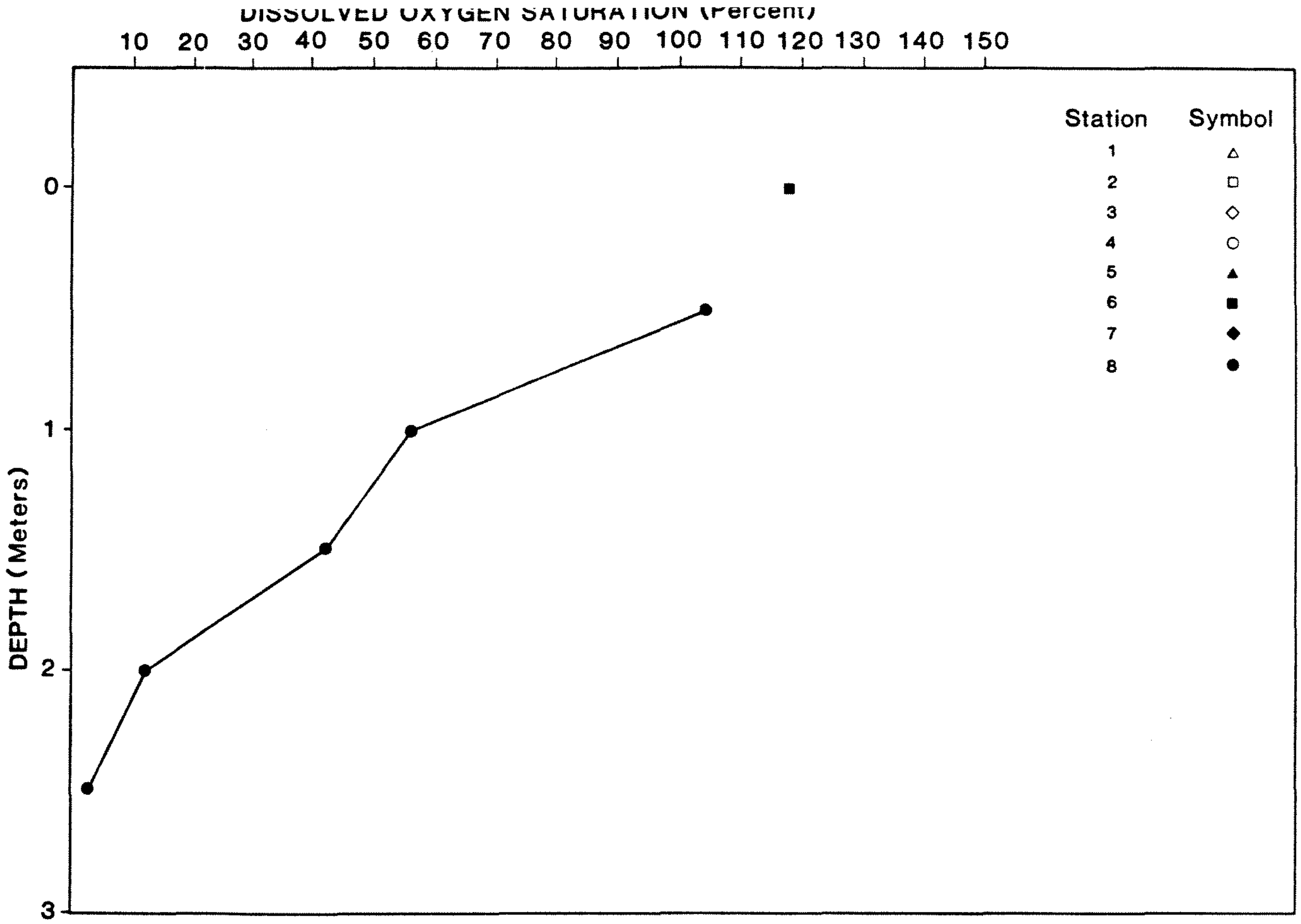

Figure 121. Vertical dissolved oxygen percent saturation profile and ancillary oxygen saturation data obtained 17 July 1985 on Ada City Lake.

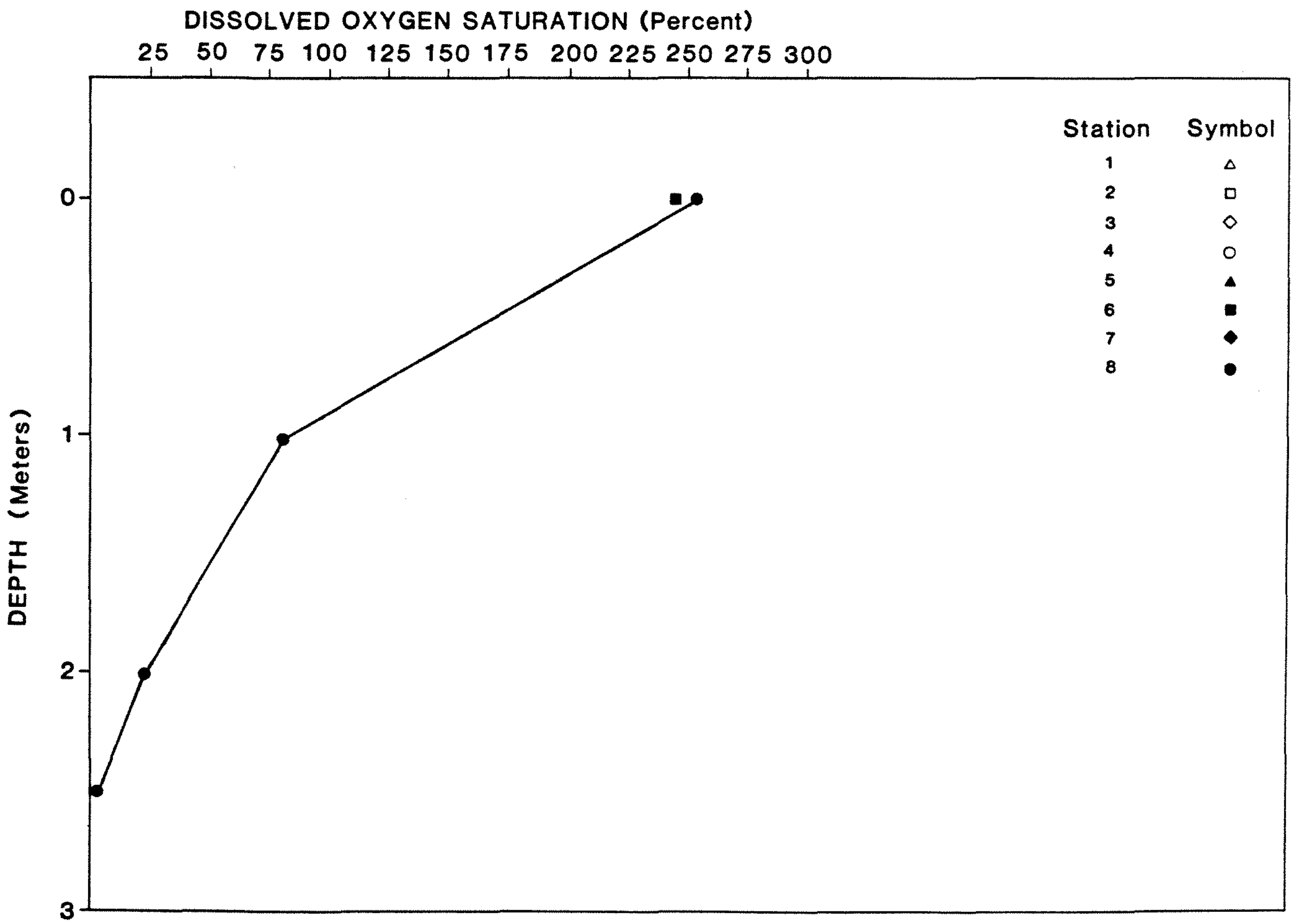

Figure 122. Vertical dissolved oxygen percent saturation profile and ancillary oxygen saturation data obtained 1 August 1985 on Ada City Lake.

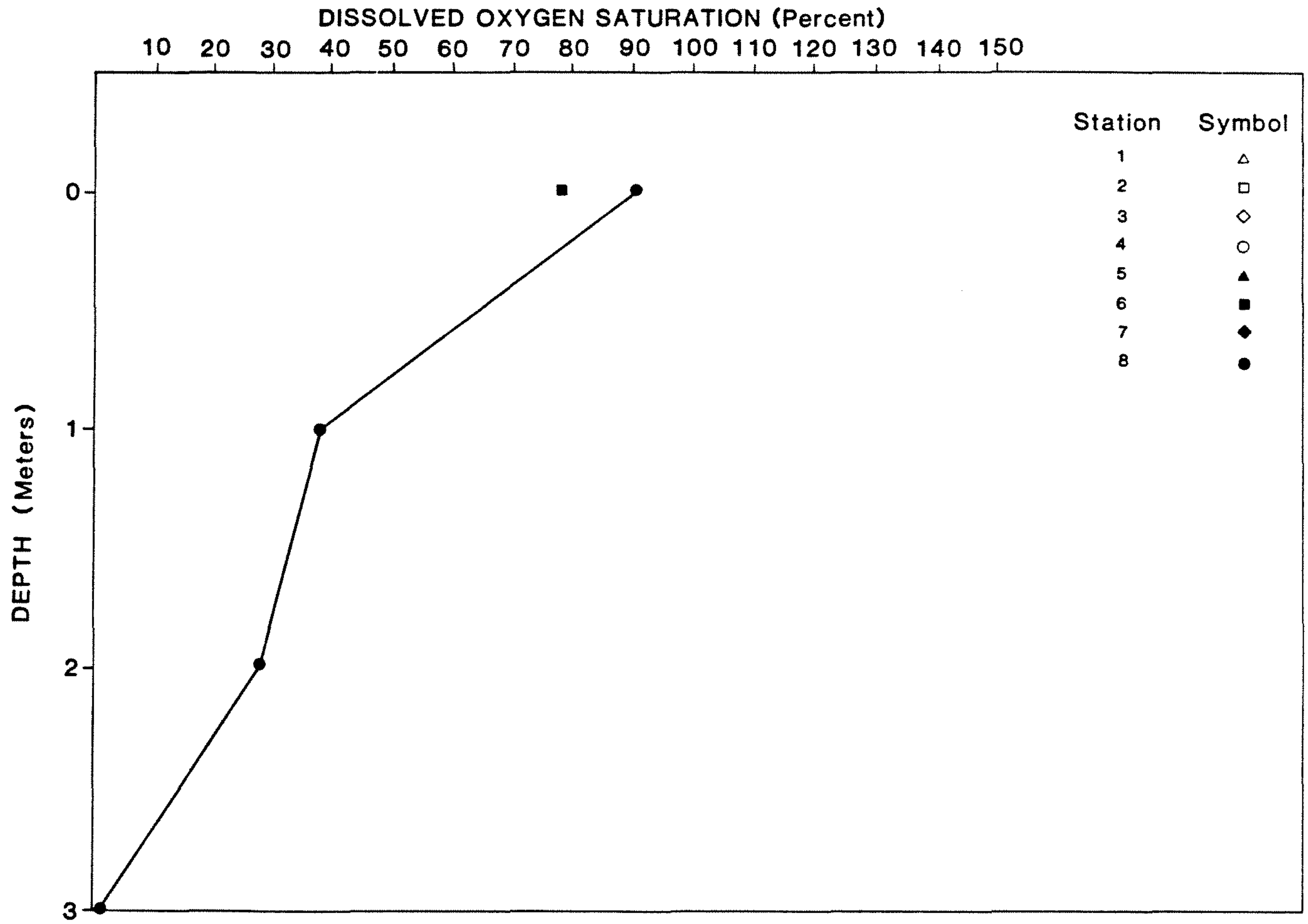

Figure 123. Vertical dissolved oxygen percent saturation profile and ancillary oxygen saturation data obtained 13 August 1985 on Ada City Lake.

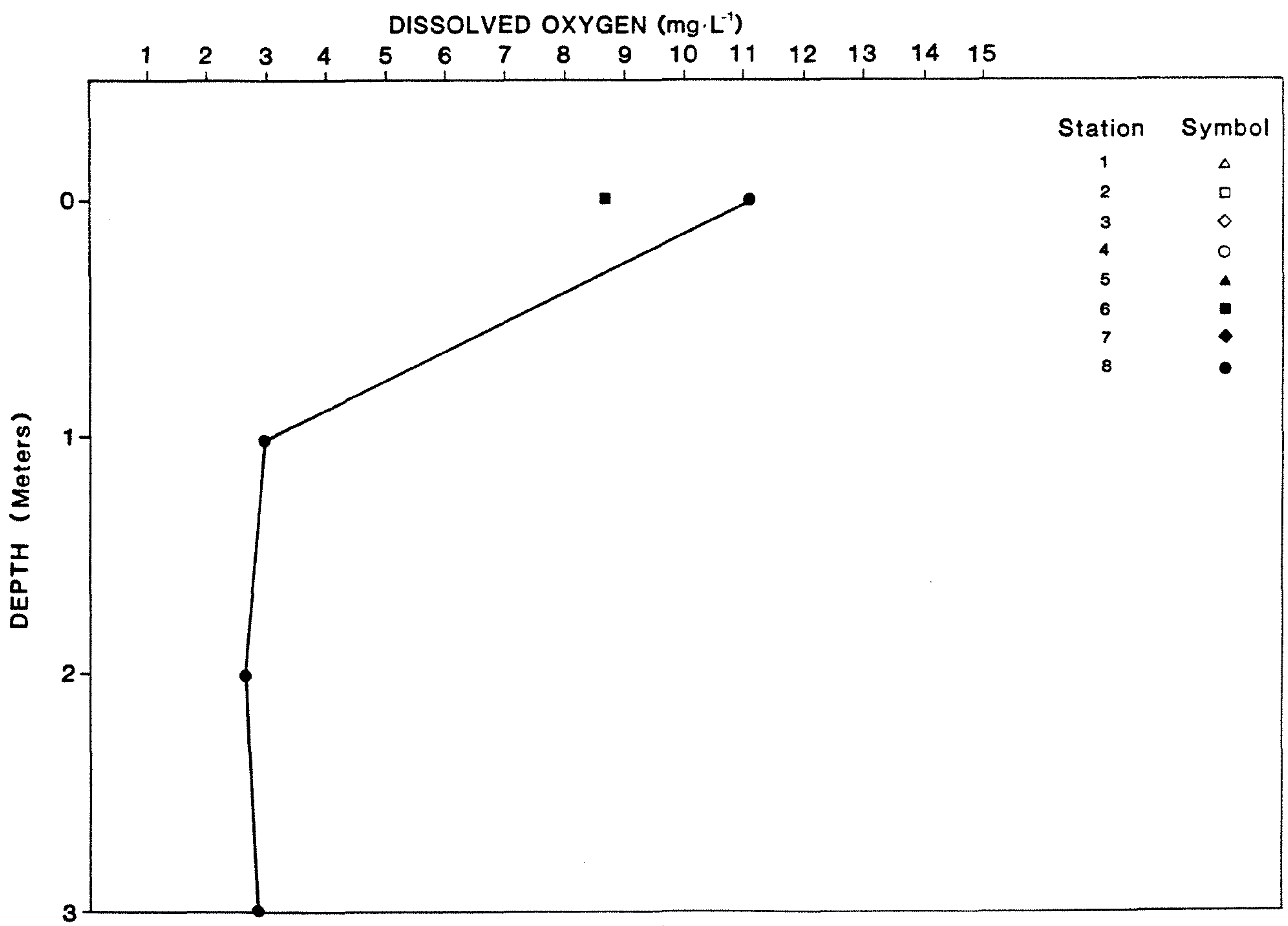

Figure 124. Vertical dissolved oxygen percent saturation profile and ancillary oxygen saturation data obtained 29 August 1985 on Ada City Lake.

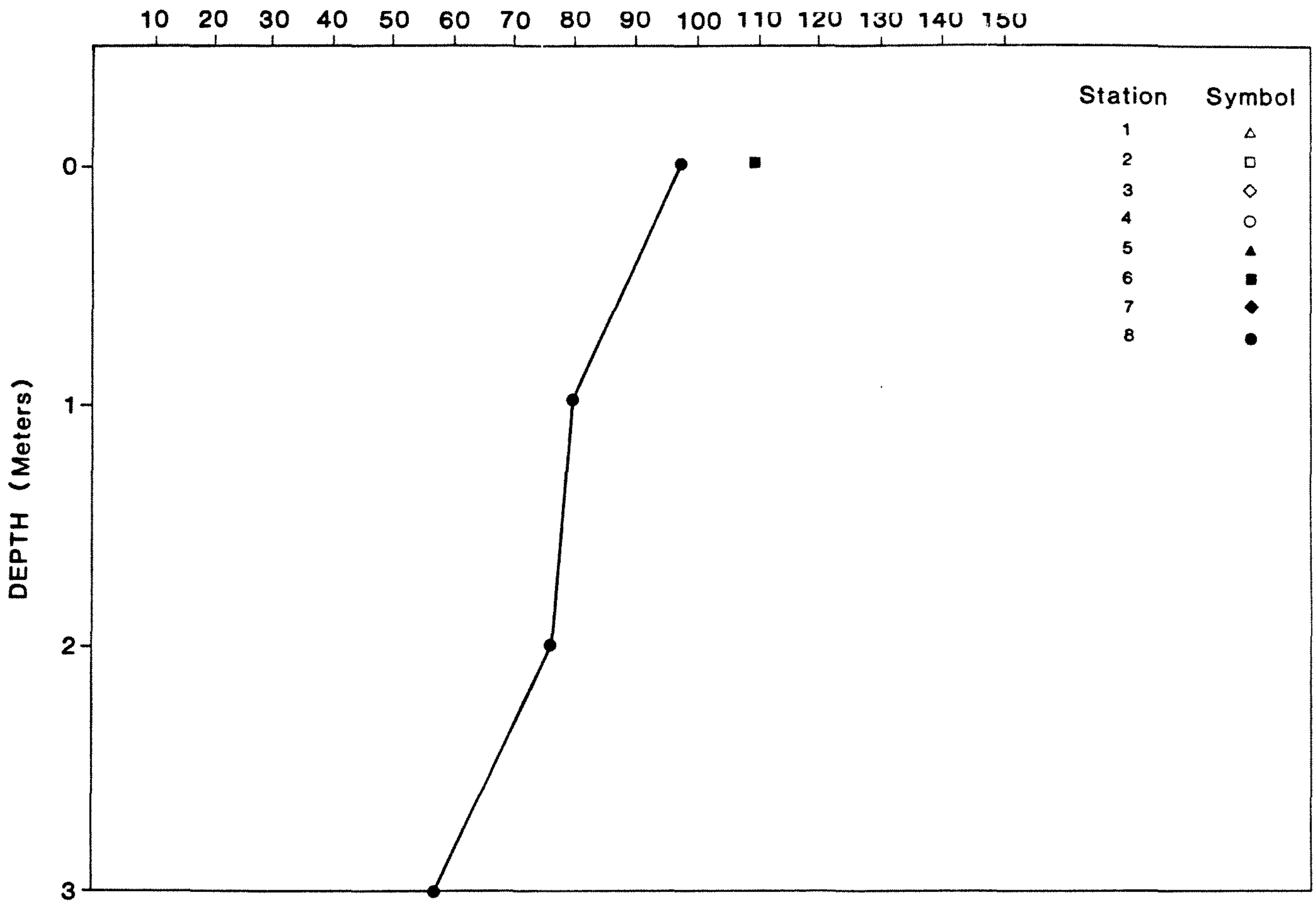

Figure 125. Vertical dissolved oxygen percent saturation profile and ancillary oxygen saturation data obtained 24 September 1985 on Ada City Lake.

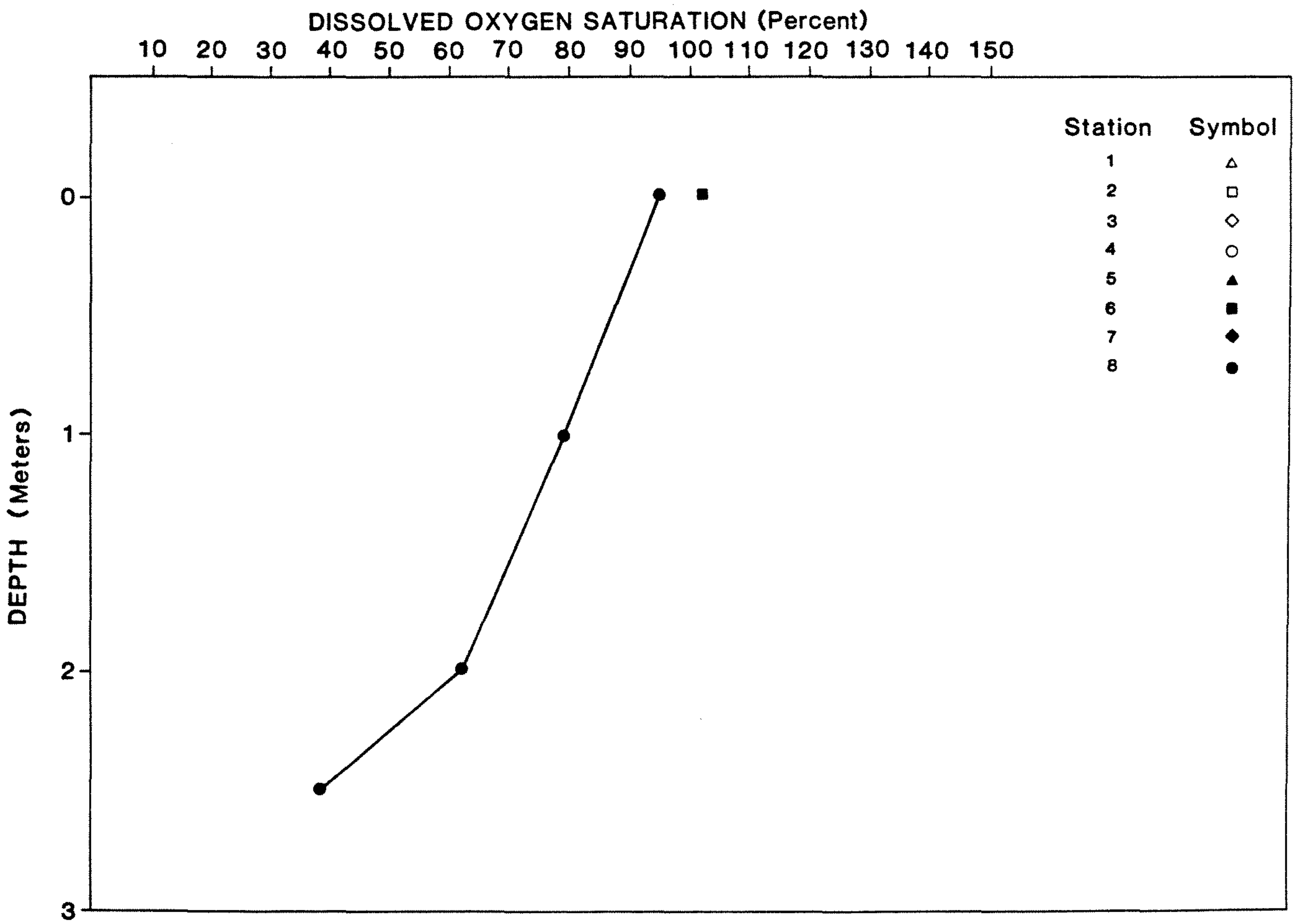

Figure 126. Vertical dissolved oxygen percent saturation profile and ancillary oxygen saturation data obtained 8 October 1985 on Ada City Lake.

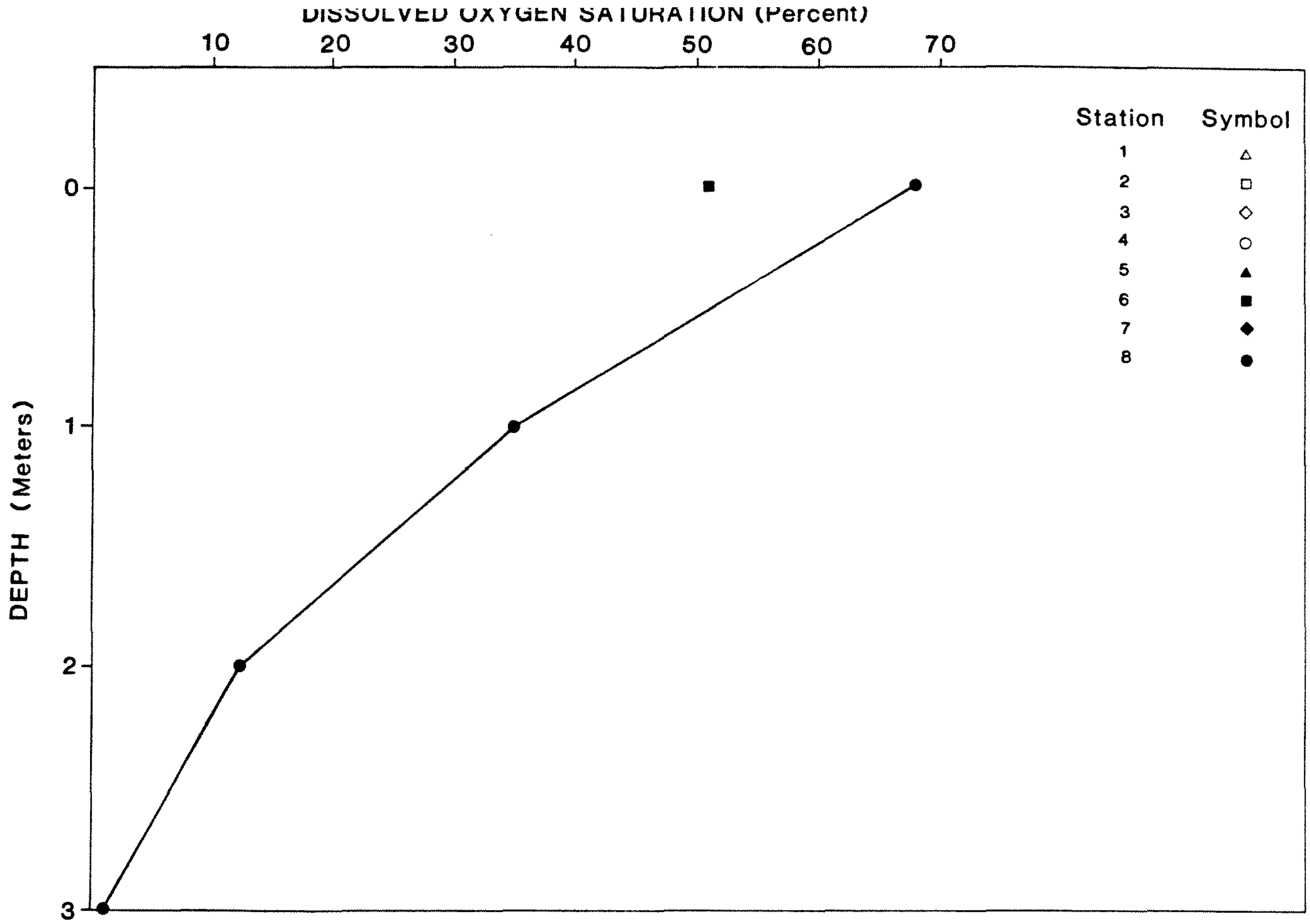

Figure 127. Vertical dissolved oxygen percent saturation profile and ancillary oxygen saturation data obtained 22 October 1985 on Ada City Lake.

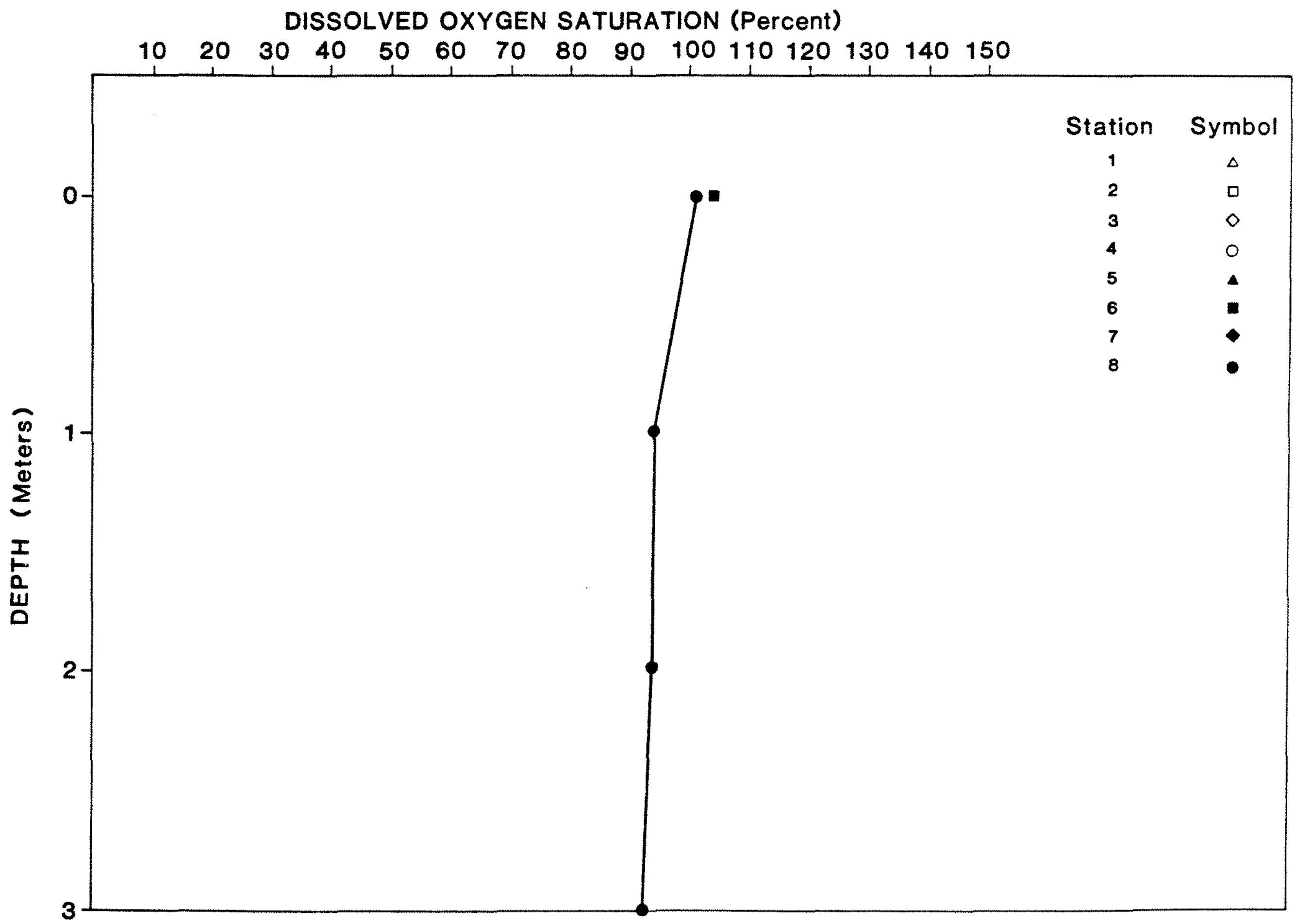

Figure 128. Vertical dissolved oxygen percent saturation profile and ancillary oxygen saturation data obtained 2 December 1985 on Ada City Lake.

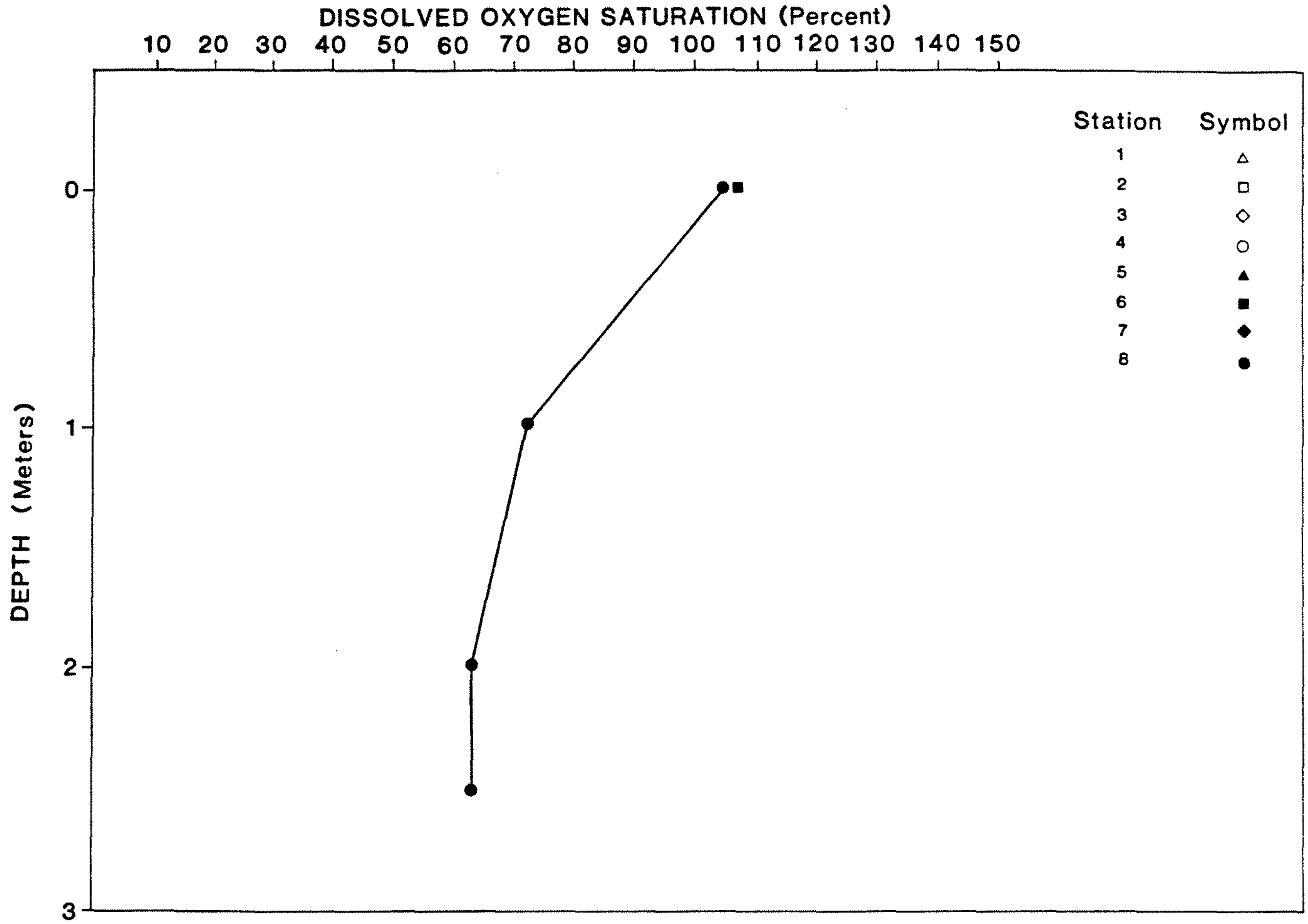

Figure 129. Vertical dissolved oxygen percent saturation profile and ancillary oxygen saturation data obtained 17 December 1985 on Ada City Lake.

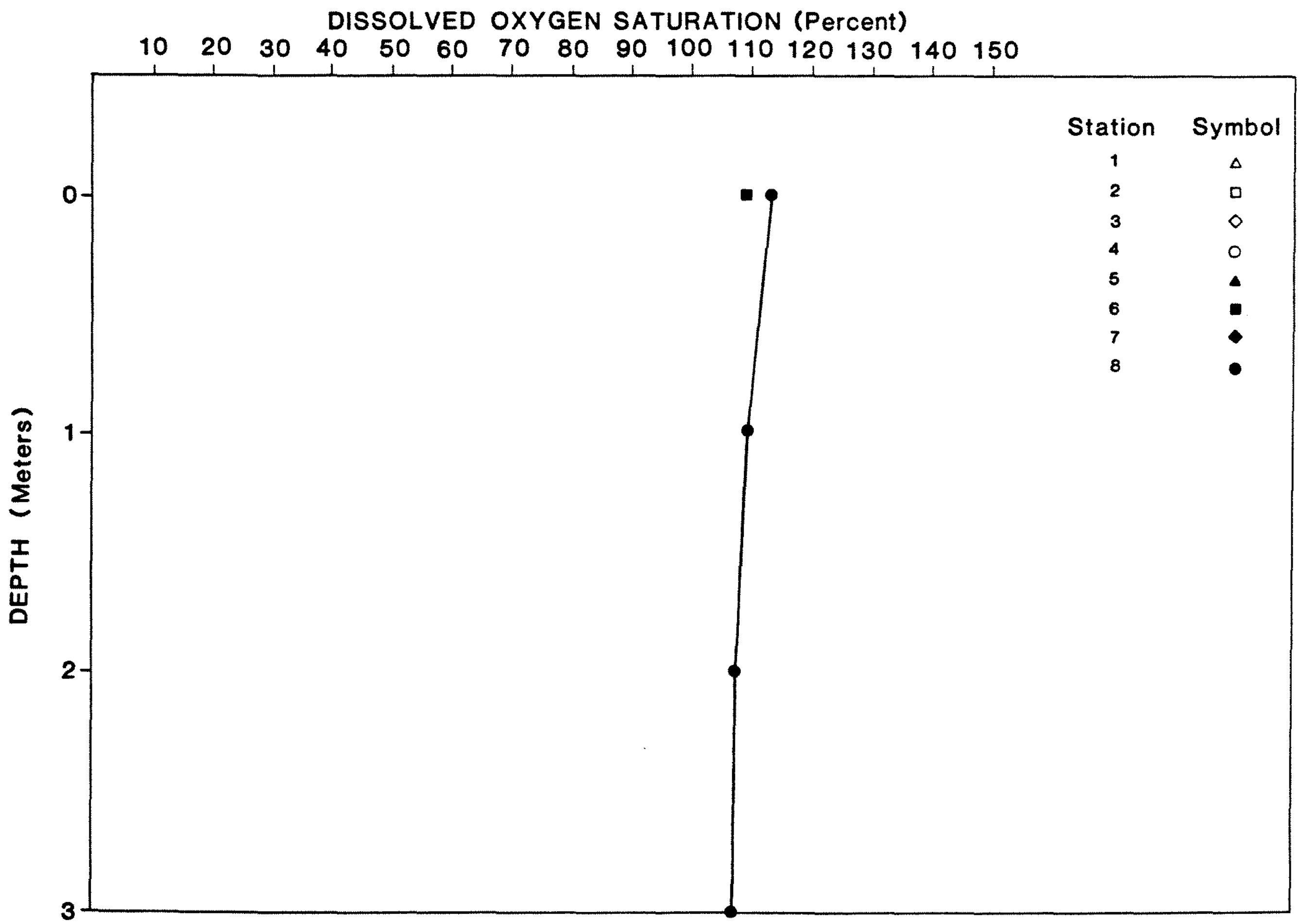

Figure 130. Vertical dissolved oxygen percent saturation profile and ancillary oxygen saturation data obtained 14 January 1986 on Ada City Lake.

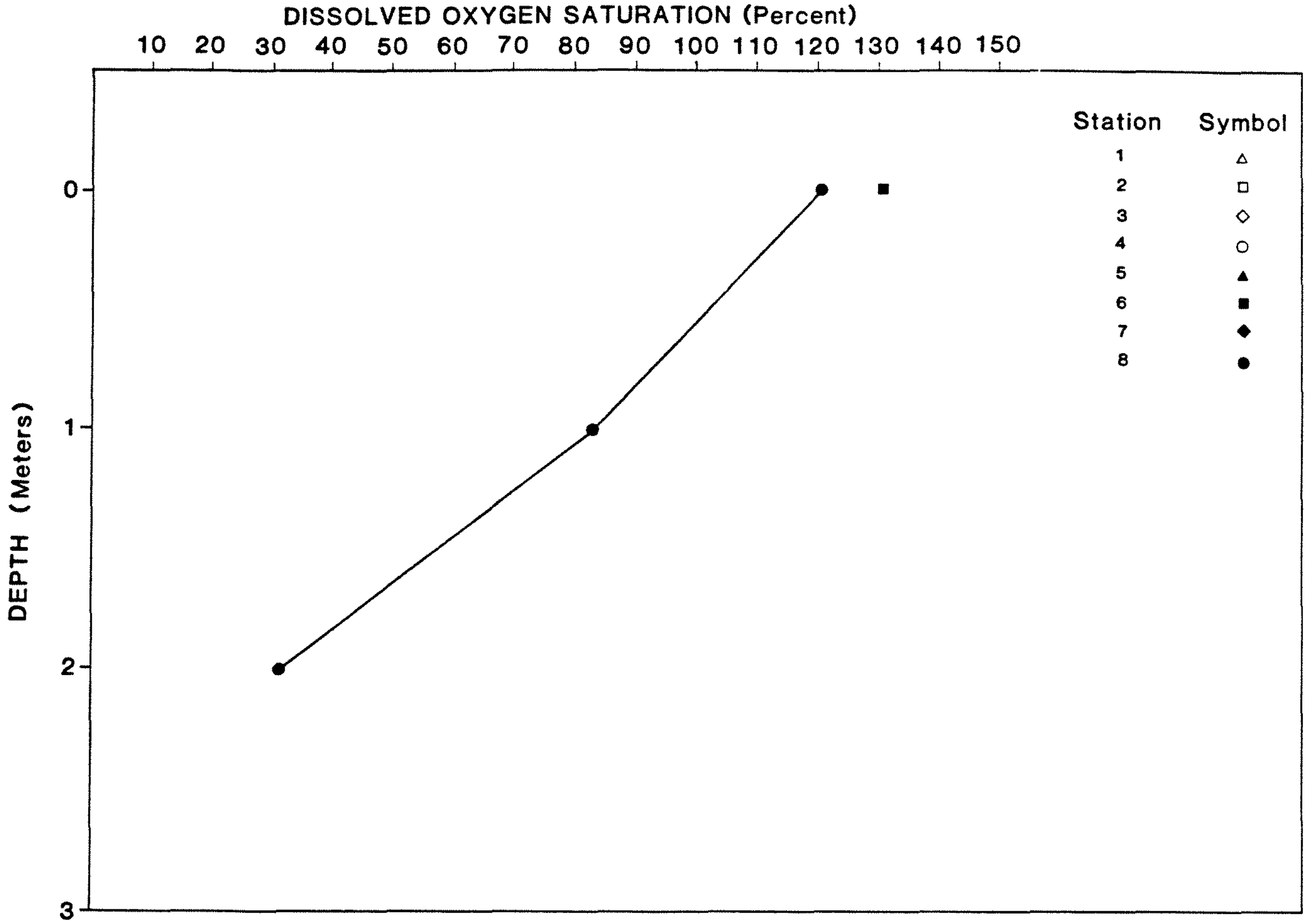

Figure 131. Vertical dissolved oxygen percent saturation profile and ancillary oxygen saturation data obtained 19 February 1986 on Ada City Lake.

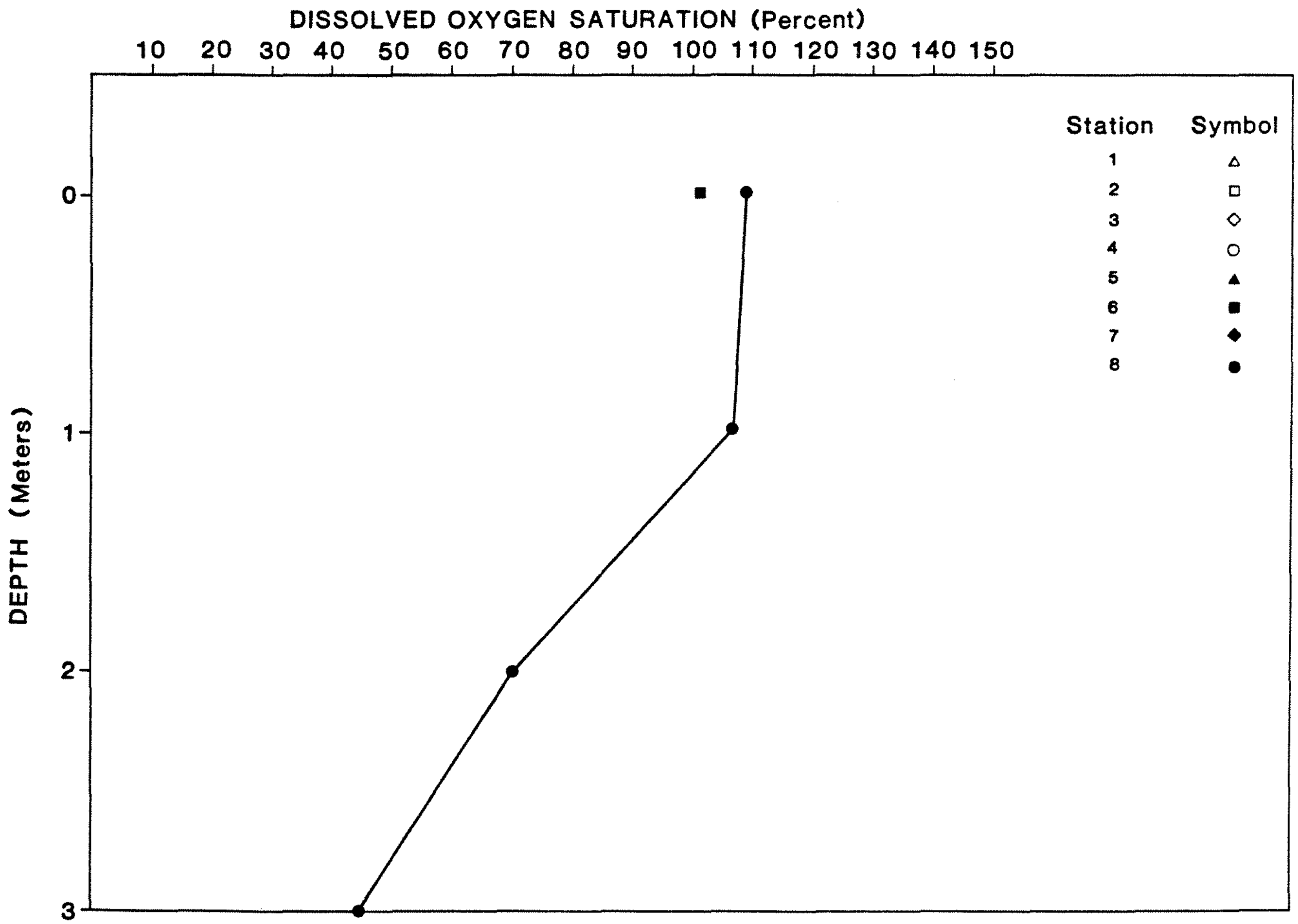

Figure 132. Vertical dissolved oxygen percent saturation profile and ancillary oxygen saturation data obtained 24 March 1986 on Ada City Lake.

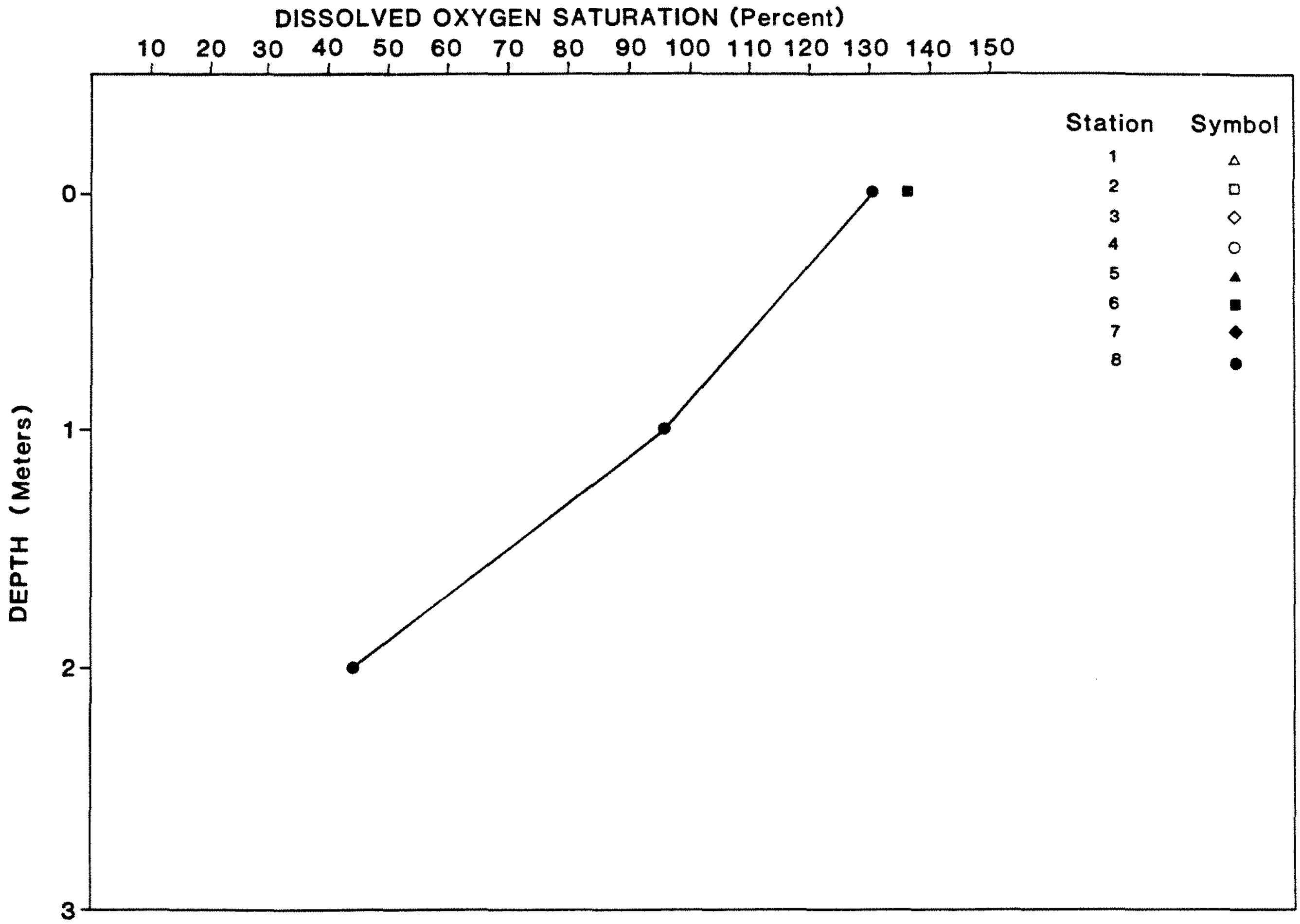

Figure 133. Vertical dissolved oxygen percent saturation profile and ancillary oxygen saturation data obtained 23 April 1986 on Ada City Lake.

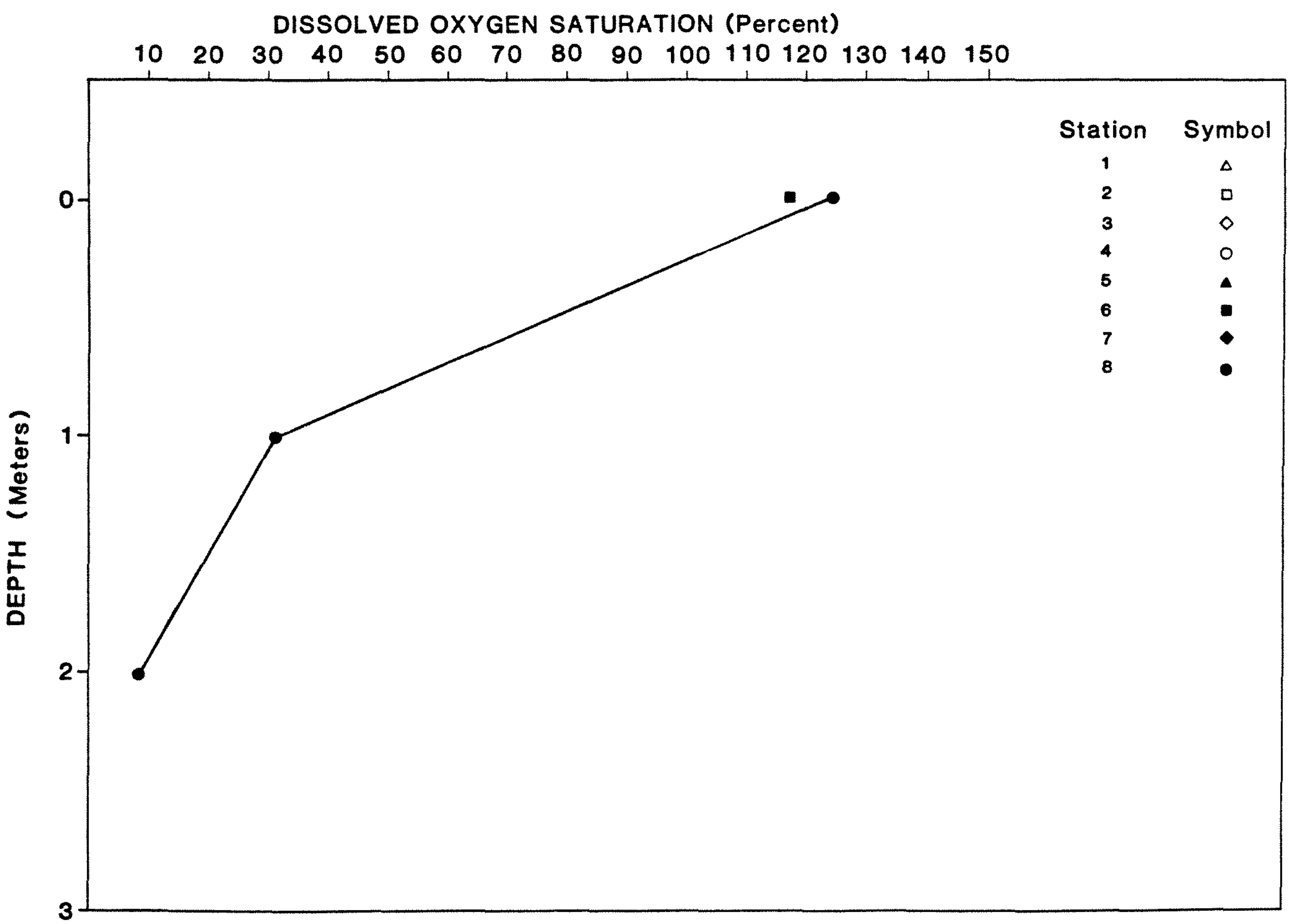

Figure 134. Vertical dissolved oxygen percent saturation profile and ancillary oxygen saturation data obtained 21 May 1986 on Ada City Lake.

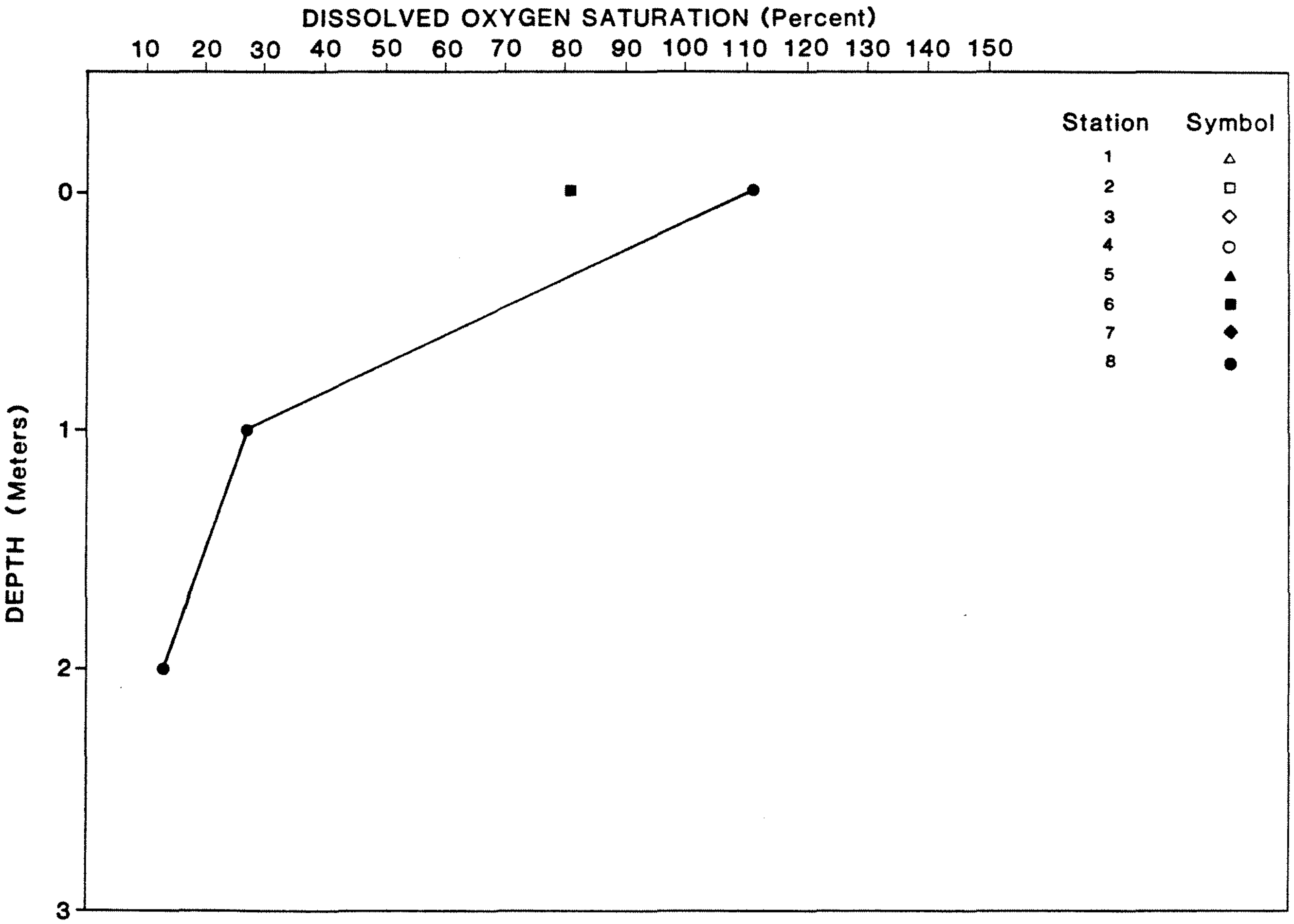

Figure 135. Vertical dissolved oxygen percent saturation profile and ancillary oxygen saturation data obtained 25 June 1986 on Ada City Lake.

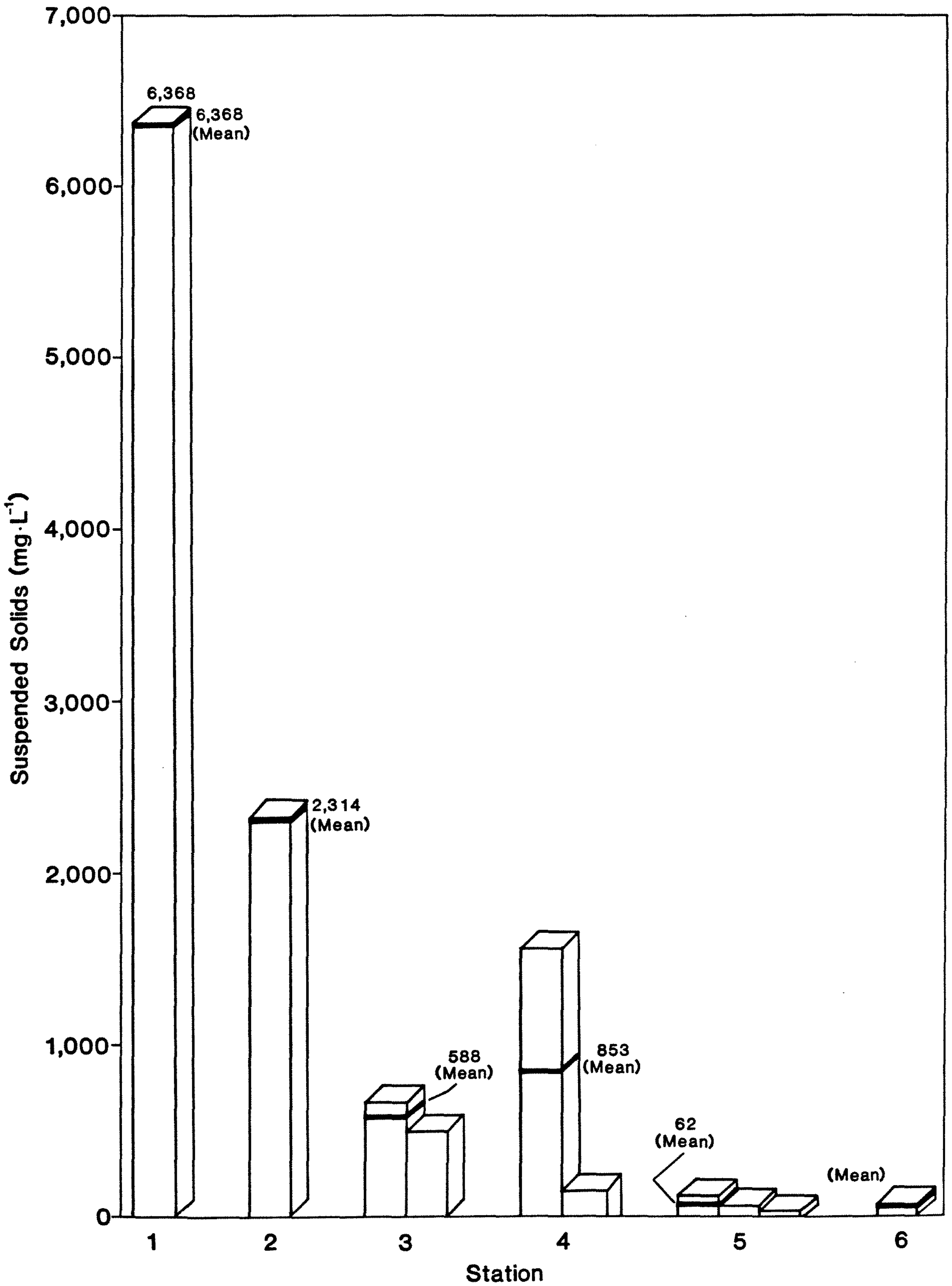

Figure 136. Three dimensional bar diagram of total suspended solids concentrations obtained in stormwater samples collected from tributaries to and the outlet from Ada City Lake.

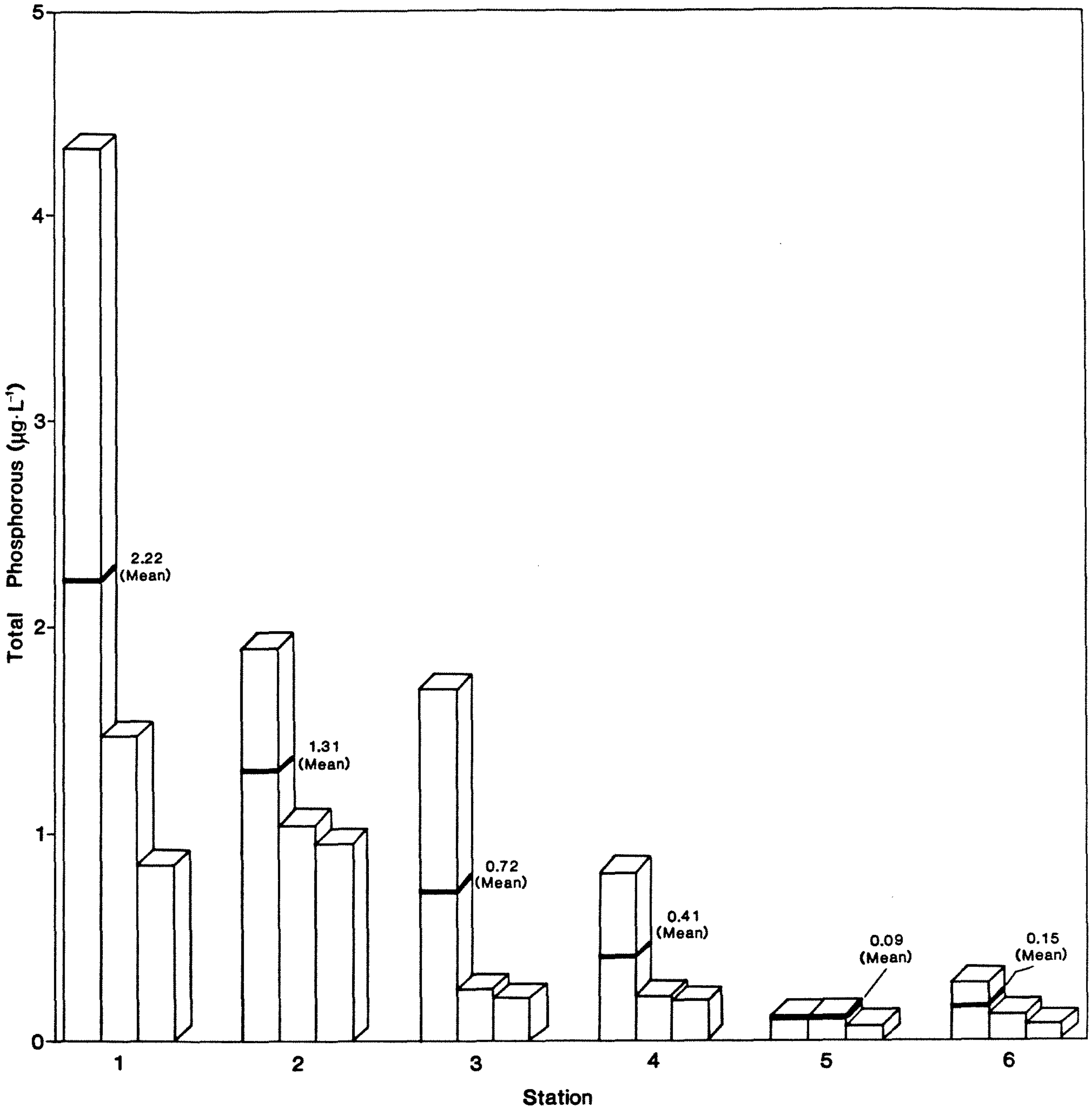

Figure 137. Three dimensional bar diagram of total phosphorous concentrations obtained in stormwater samples collected from tributaries to and the outlet from Ada City Lake.

Stations

Stations	1	2	3	4	5	6
1		10	13	15	15	15
2			8	15	15	15
3				10	15	13
4					15	13
5						13
6						

Critical Value
-at .05 is 16
-at .01 is 16
-at .10 is 15

Figure 138. Statistical comparison of total phosphorous concentrations obtained during stormwater monitoring of Ada City Lake.

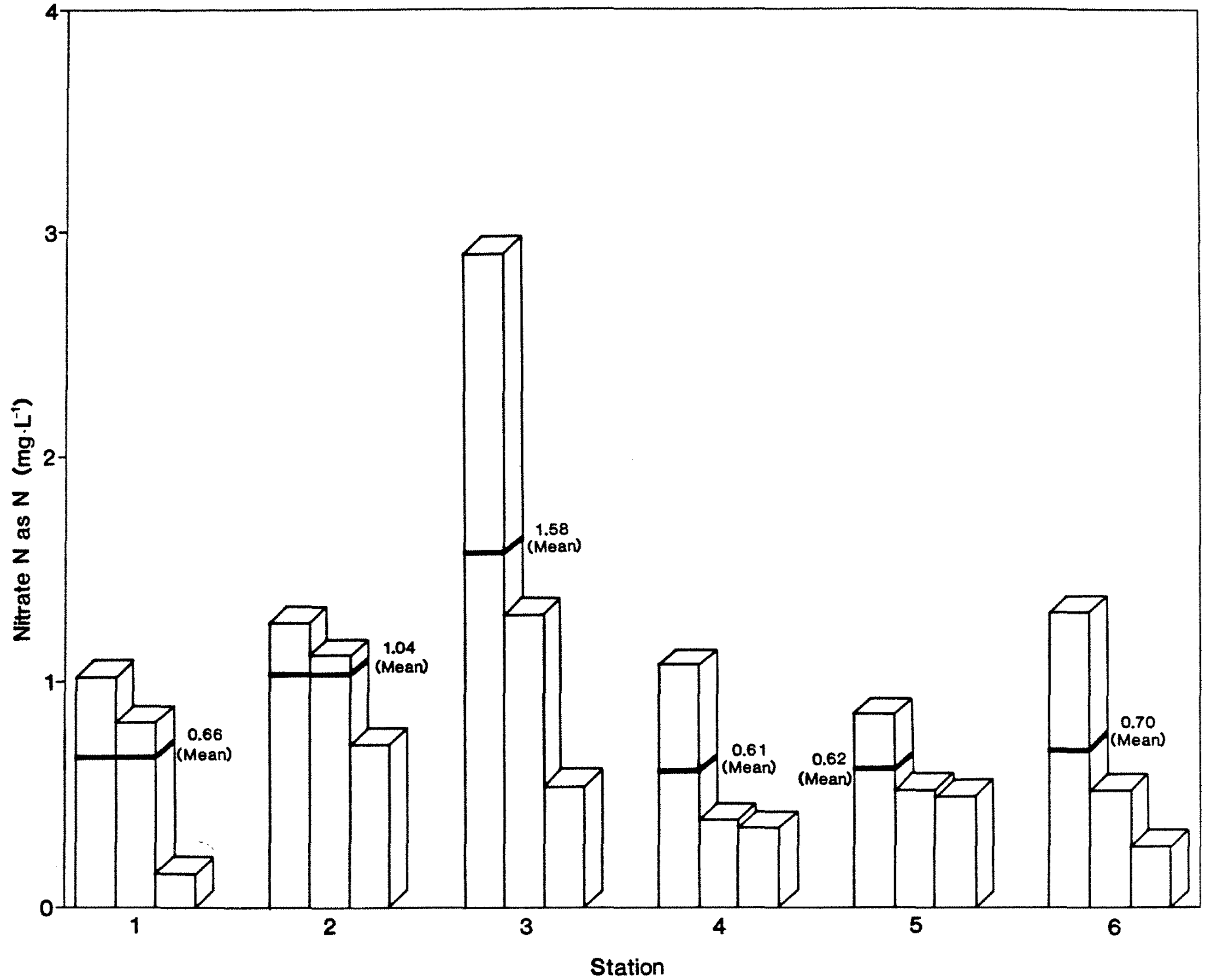

Figure 139. Three dimensional bar diagram of nitrate-nitrogen concentrations obtained in stormwater samples collected from tributaries to and the outlet from Ada City Lake.

Stations

Stations	1	2	3	4	5	6
1		8	13	10	10	11
2			8	14	14	12
3				13	14	13
4					9	12
5						10
6						

Critical Value
-at .05 is 16
-at .01 is 16
-at .10 is 15

Figure 140. Statistical comparison of nitrate-nitrogen concentrations obtained during stormwater monitoring of tributaries to and the outlet from Ada City Lake.

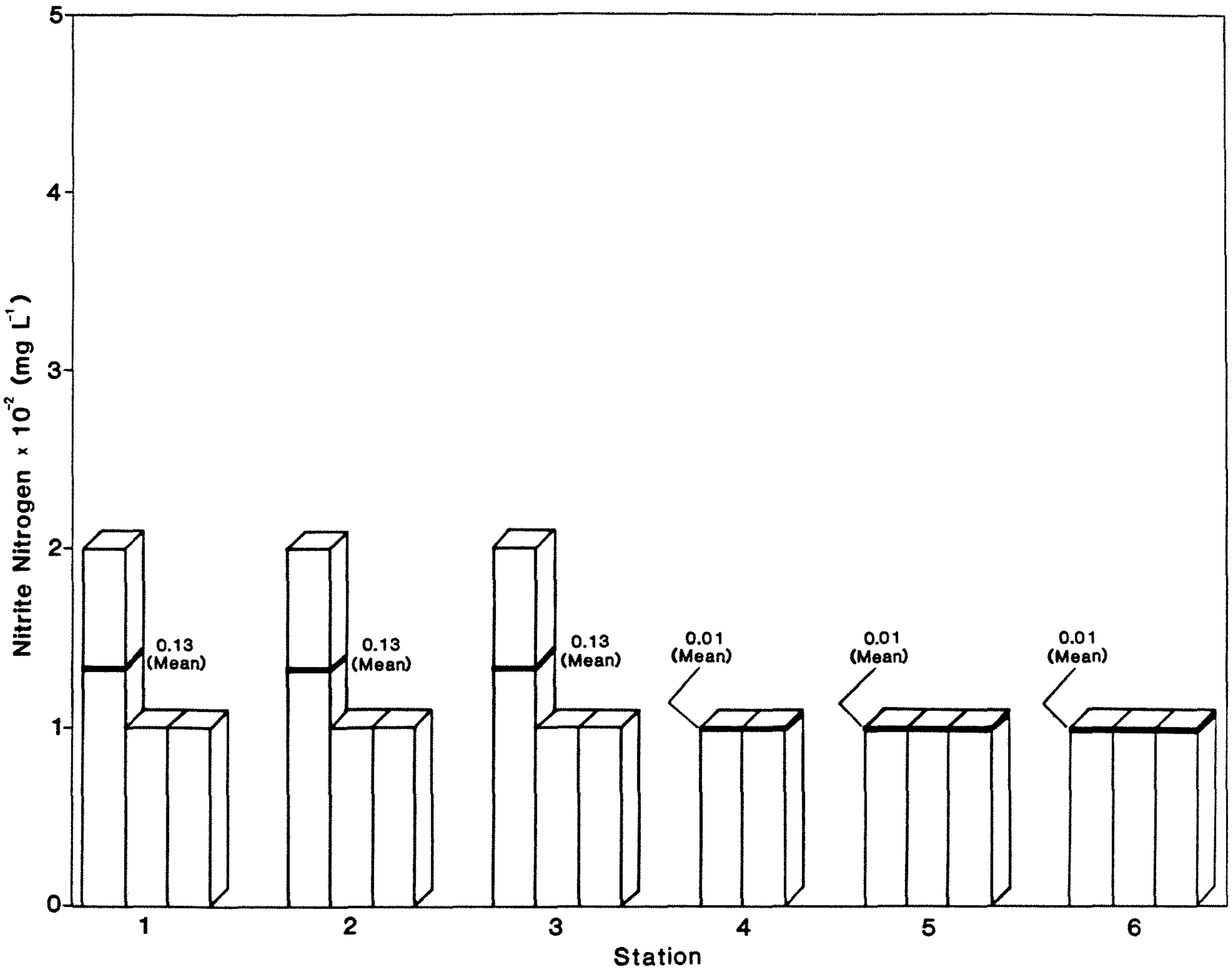

Figure 141. Three dimensional bar diagram of nitrite-nitrogen concentrations obtained in stormwater samples collected from tributaries to and the outlet from Ada City Lake.

Stations

Stations	1	2	3	4	5	6
1		10.5	10.5	---	10.5	9
2			10.5	---	9	9
3				---	9	9
4					---	---
5						10.5
6						

Critical Value
-at .05 is 16
-at .01 is 16
-at .10 is 15

Figure 142. Statistical comparison of nitrite-nitrogen concentrations obtained during stormwater monitoring of tributaries to and the outlet from Ada City Lake.

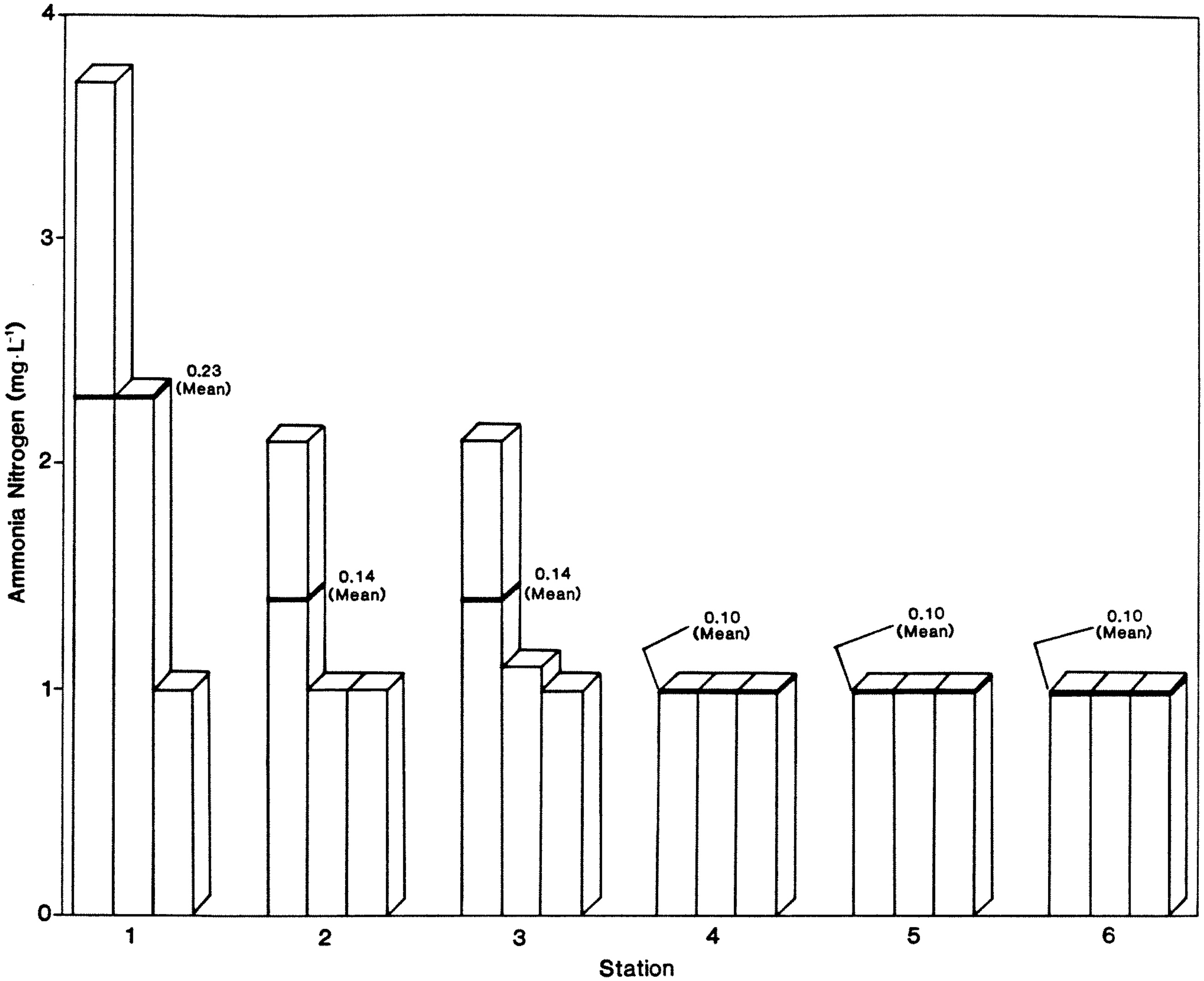

Figure 143. Three dimensional bar diagram of ammonia-nitrogen concentrations obtained in stormwater samples collected from tributaries to and the outlet from Ada City Lake.

Stations

Stations	1	2	3	4	5	6
1		8	8.5	13.5	13.5	13.5
2			9.5	9	9	9
3				7.5	7.5	7.5
4					10.5	10.5
5						10.5
6						

Critical Value
-at .05 is 16
-at .01 is 16
-at .10 is 15

Figure 144. Statistical comparison of ammonia-nitrogen concentrations obtained during stormwater monitoring of tributaries to and the outlet from Ada City Lake.

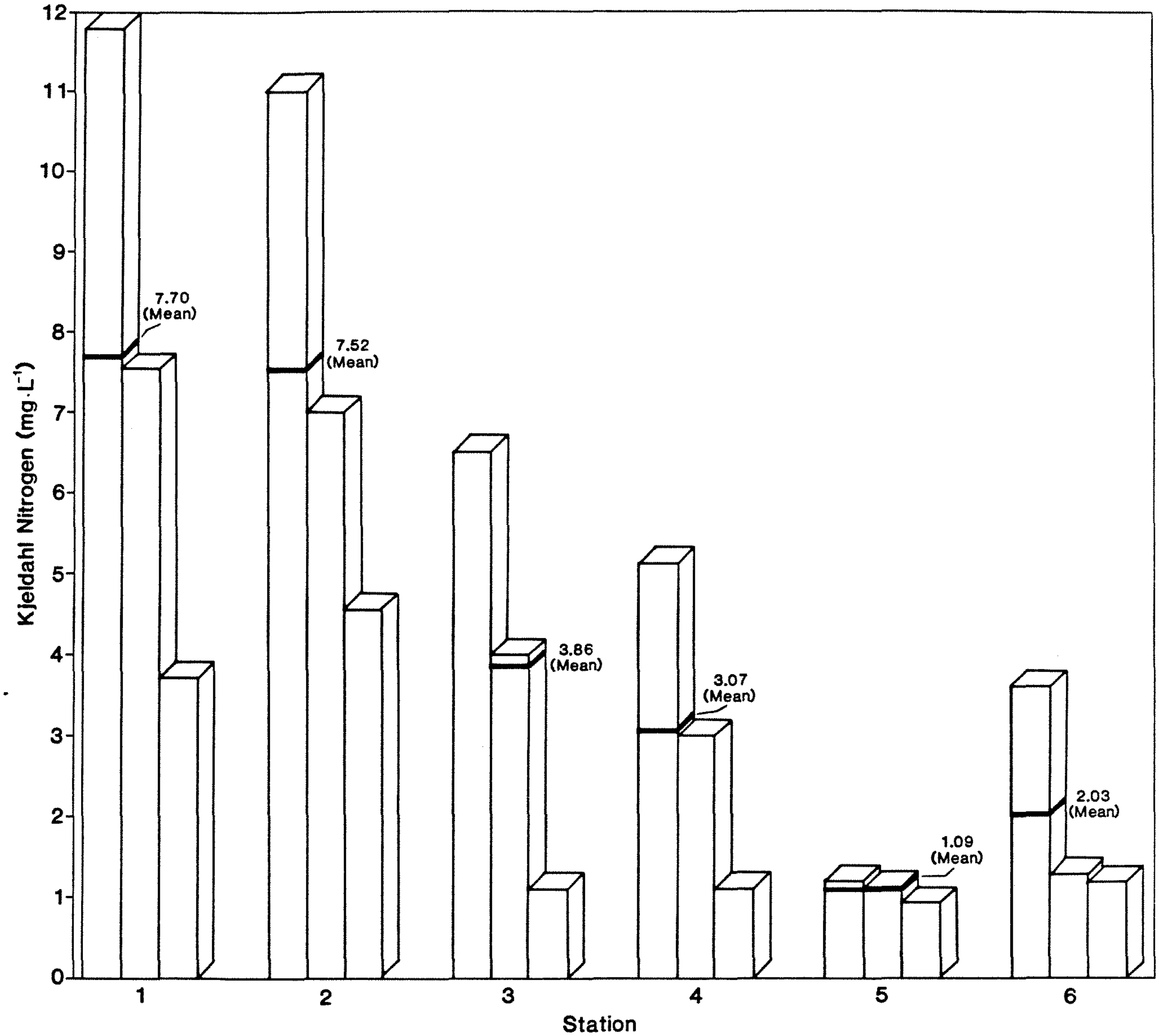

Figure 145. Three dimensional bar diagram of kjeldahl-nitrogen concentrations obtained in stormwater samples collected from tributaries to and the outlet from Ada City Lake.

Stations

Stations	1	2	3	4	5	6
1		10	13	14	15	15
2			14	14	15	15
3				9.5	15	12
4					13	10
5						7
6						

Critical Value
-at .05 is 16
-at .01 is 16
-at .10 is 15

Figure 146. Statistical comparison of kjeldahl-nitrogen concentrations obtained in stormwater samples collected from tributaries to and the outlet from Ada City Lake.

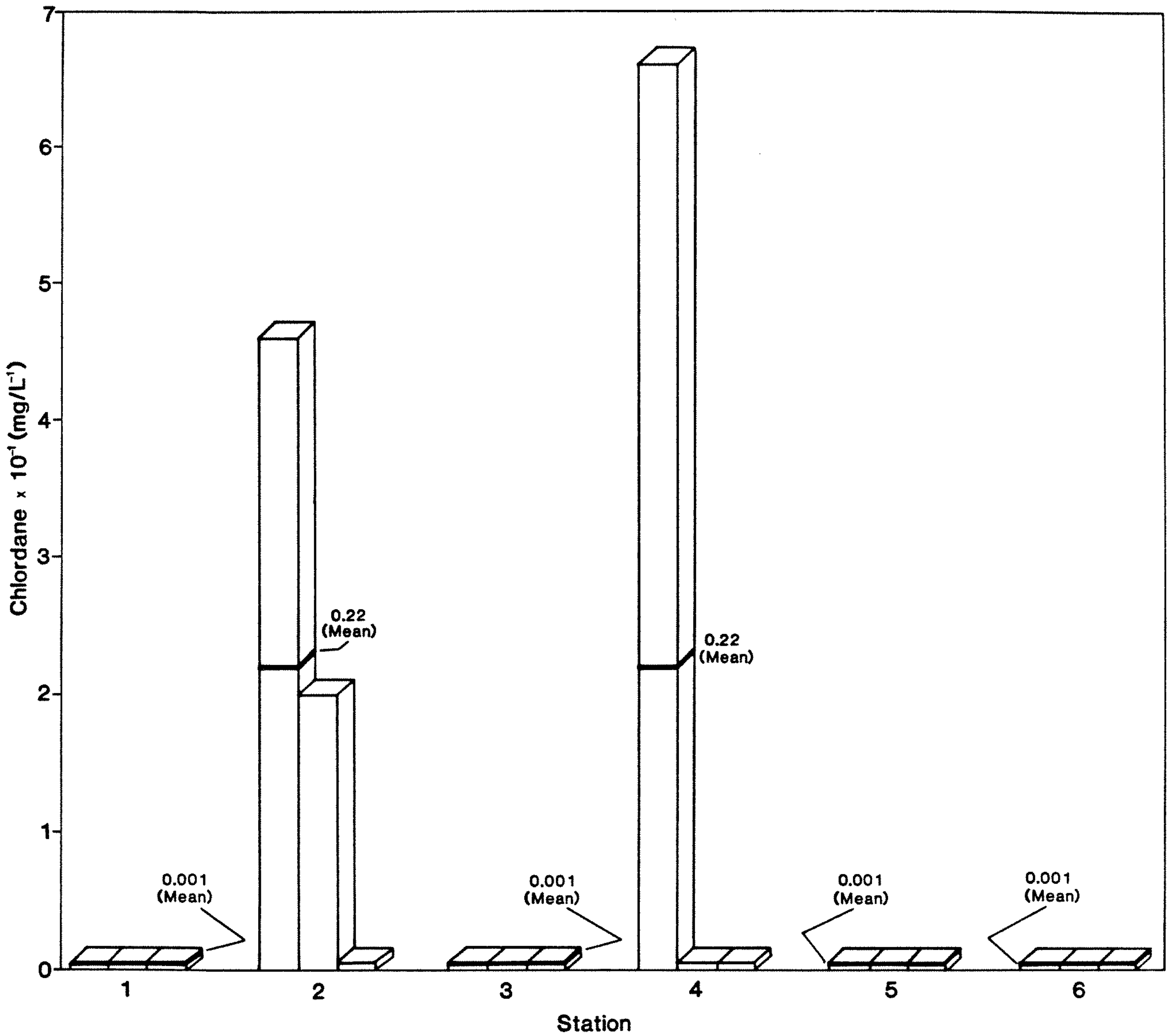

Figure 147. Three dimensional bar diagram of total chlordane concentrations obtained in stormwater samples collected from tributaries to and the outlet from Ada City Lake.

Stations

Stations	1	2	3	4	5	6
1		13.5	10.5	12	10.5	10.5
2			13.5	11	13.5	13.5
3				9	10.5	10.5
4					12	12
5						10.5
6						

Critical Value
-at .05 is 16
-at .01 is 16
-at .10 is 15

Figure 148. Statistical comparison of chlordane concentrations obtained in stormwater samples collected from tributaries to and the outlet from Ada City Lake.

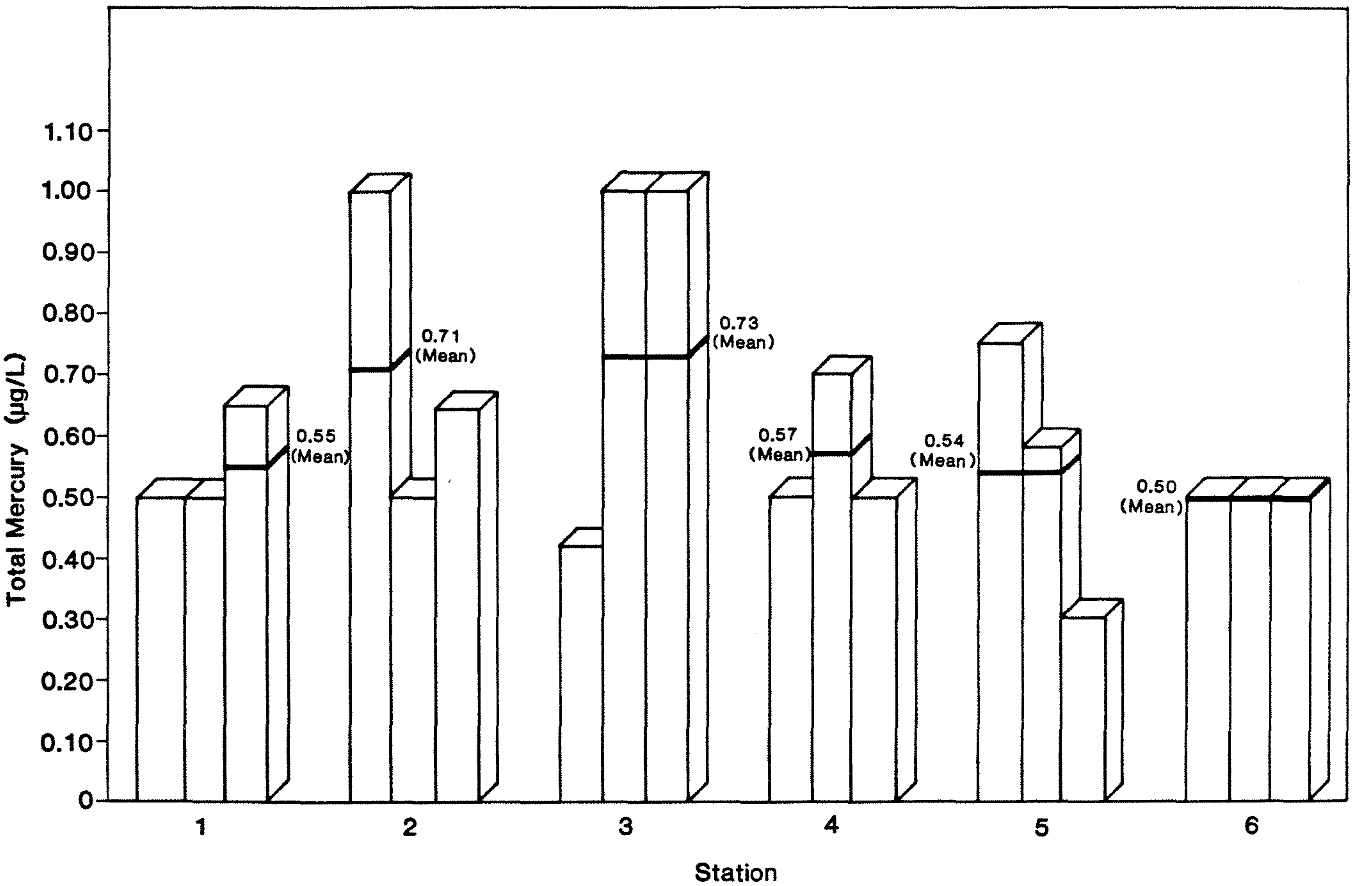

Figure 149. Three dimensional bar diagram of total mercury concentration obtained in stormwater samples collected from tributaries to and the outlet from Ada City Lake.

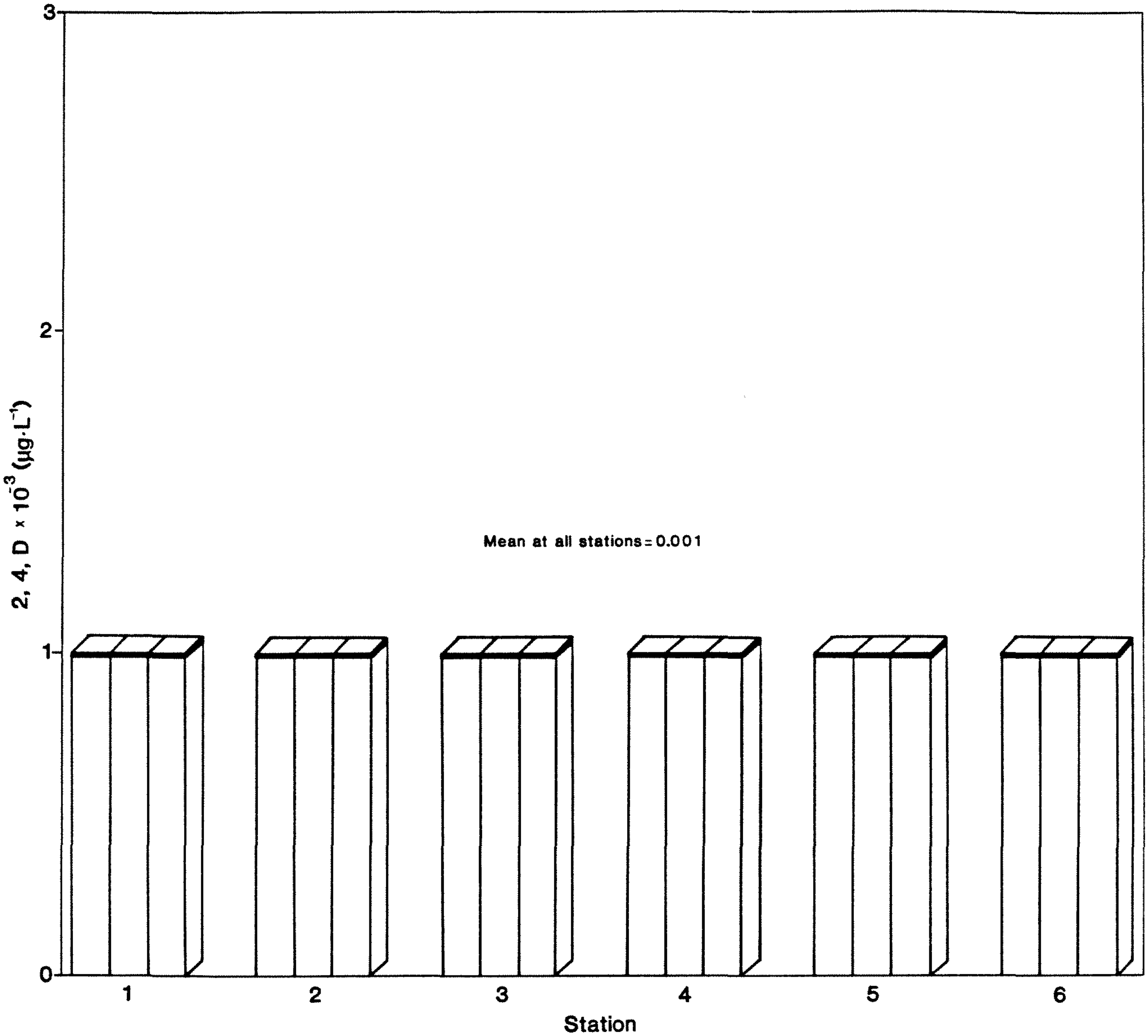

Figure 150. Three dimensional bar diagram of total 2,40-dichlorophenoxyacetic acid (2,4,D) concentrations obtained in stormwater samples collected from tributaries to and the outlet from Ada City Lake.

Stations

Stations	1	2	3	4	5	6
1		10.5	10.5	10.5	10.5	10.5
2			10.5	10.5	10.5	10.5
3				10.5	10.5	10.5
4					10.5	10.5
5						10.5
6						

Critical Value
-at .05 is 16
-at .01 is 16
-at .10 is 15

Figure 151. Statistical comparison of total 2,4-dichlorophenoxyacetic acid (2,4,D) concentrations obtained in stormwater samples collected from tributaries to and the outlet from Ada City Lake.

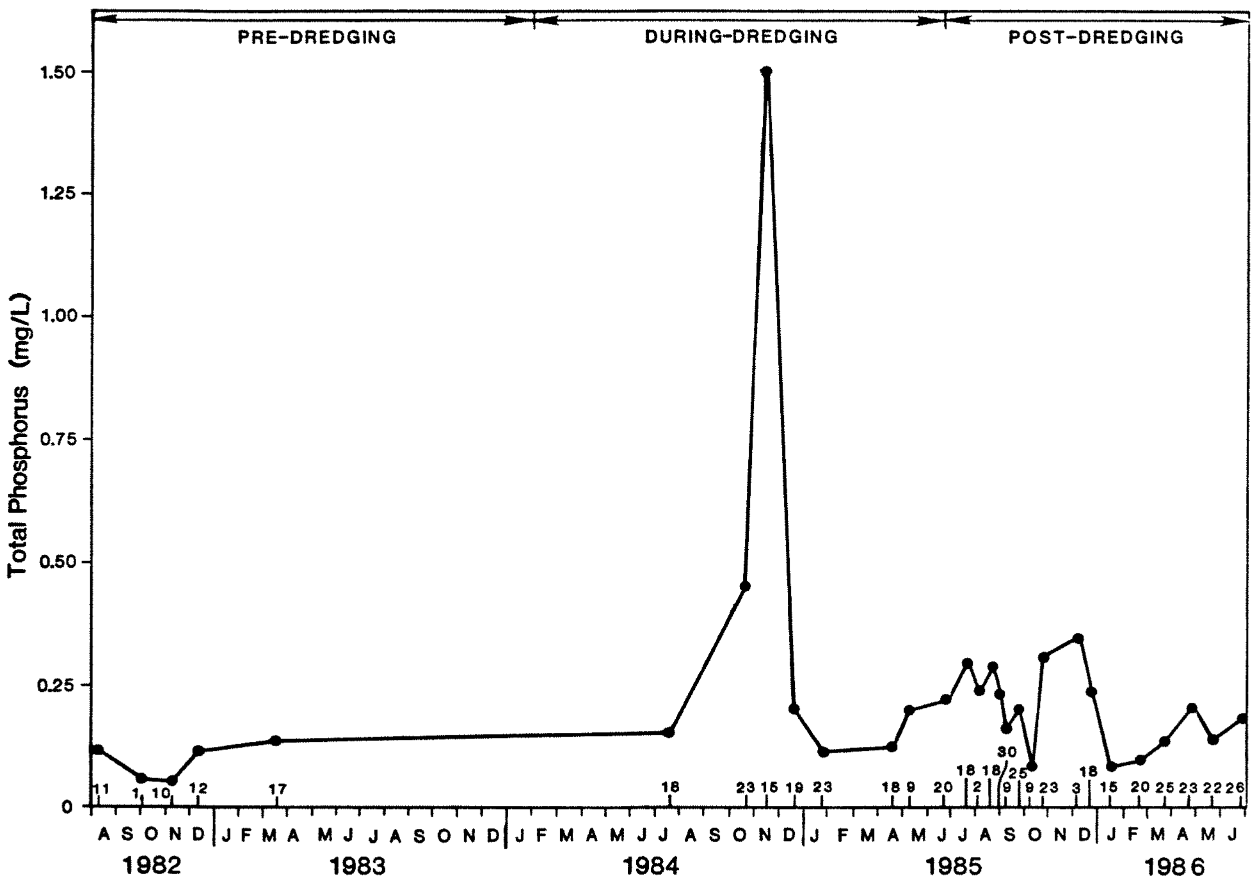

Figure 152. Temporal variation in the concentration of total phosphorus samples obtained from Ada City Lake.

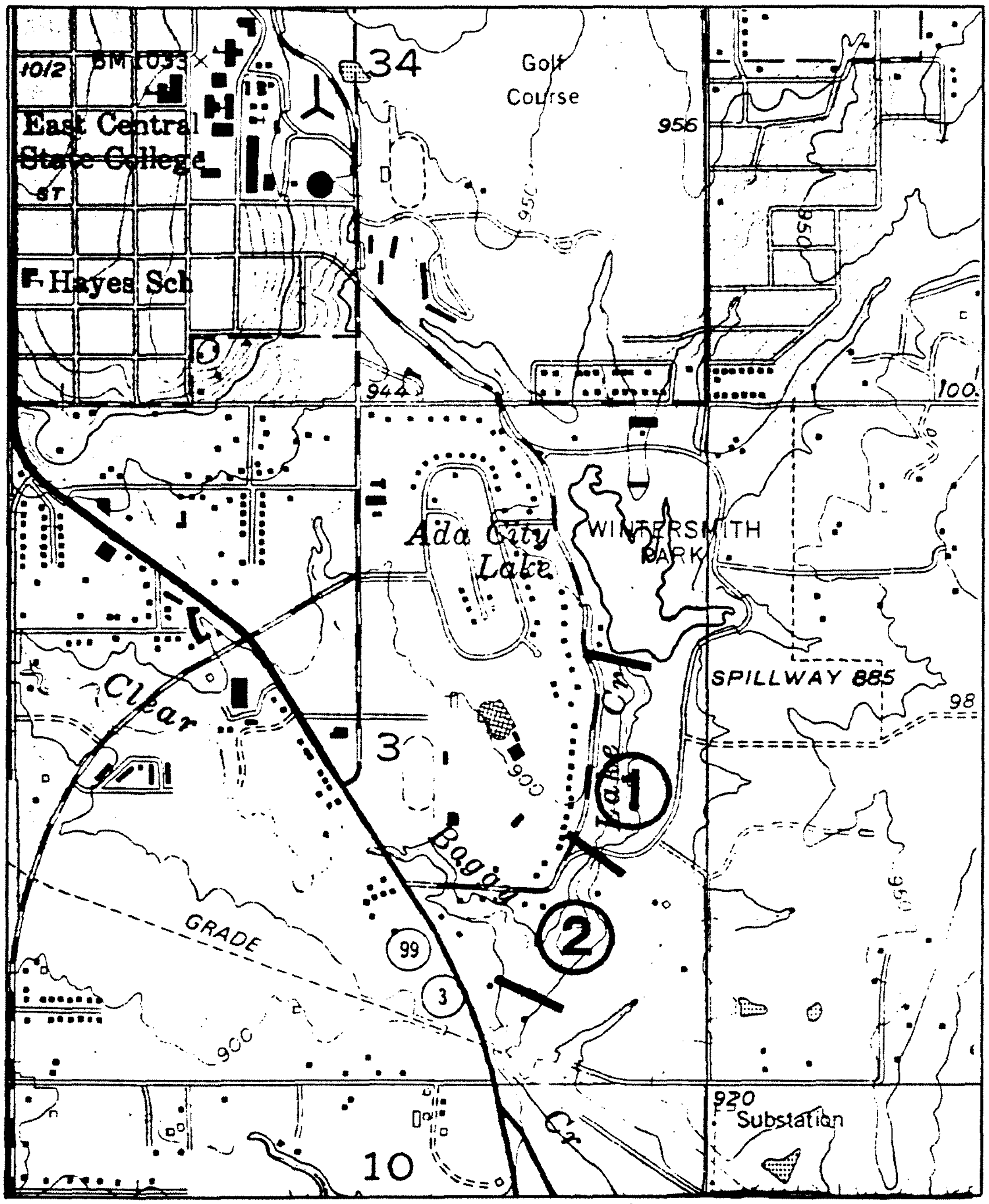

Figure 153. Location of Task Four Sampling Stations