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Kanawha River Basin Water Quality Modeling

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14. ABSTRACT
This report a study that's primary purpose was to apply newly developed computer technology to water quality analysis of a reservoir system network. Also, this report provides an example that will serve as a guide for those who are applying HEC-5Q to other river basins.

15. SUBJECT TERMS
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PREFACE

This study was performed by Mr. R. G. Willey with the technical assistance of Mr. Keith Knight. Mr. Don Smith of Resource Management Associates provided advice during critical parts of the study. The study was managed under the direction of Dr. Richard Punnett of the Huntington District who was also responsible for providing all of the data necessary for calibrating and verifying the HEC-5Q computer model.

The HEC-5Q computer model was originally developed under funding from the Corps' Environmental and Water Quality Operational Studies (EWQOS) program. This study serves as a field verification demonstration of HEC-5Q.

Mr. Vern Bonner is Chief of the Training Division and Mr. Willey's supervisor. Mr. Bill Eichert is Director of the Hydrologic Engineering Center.

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1. INTRODUCTION

1.1 PURPOSE

The primary purpose of this study is to apply newly developed computer technology to water quality analysis of the reservoir system network in the Kanawha River Basin, West Virginia. In May 1985, the Huntington District initiated a technical assistance project with the Hydrologic Engineering Center (HEC) to apply HEC-5Q to the Kanawha River Basin; this report summarizes the results of the project and is intended as a reference for the Huntington District.

A secondary purpose of this report is to provide an example that will serve as a guide for those who are applying the HEC-5Q computer program to other river basins. Although the details of the applications will change, the process described is expected to remain the same.

1.2 SCOPE

In 1979, the HEC began to develop the HEC-5Q computer program to provide better system water quality analysis capabilities in support of the Corps' water control management program. The focus of this program is to evaluate water quality conditions associated with proposed plans of reservoir system regulation or to determine improved reservoir system operations for multiple project purposes including water quality.

The computer program HEC-5Q is described in the Users Manual [HEC, 1984a] in addition to several technical papers [Duke, 1984 and Willey: 1983, 1985a and 1986] and reports [Willey, 1985b].

This report identifies the type of data necessary to execute HEC-5Q, where it is typically found and how it is manipulated prior to input to the program. It also describes the calibration and verification process, and finally shows the results of the executions.

1.3 AUTHORITY

The study was authorized by the Huntington District, with DA Form 2544 No. E86-85-HW-33 dated 29 May 1985. An increase in funds was authorized with a DA Form 2544, Change Order Number 1, dated 11 October 1985. Matching funds were provided by the Office of the Chief of Engineers as a demonstration project for Corps-wide technology transfer.

1.4 PROCEDURE

The study was initiated with a conference between staff from Huntington District, Ohio River Division, Office of the Chief of Engineers and the Hydrologic Engineering Center (HEC). A study proposal prepared by the HEC was discussed and a briefing on the HEC-5Q model was presented. The District decided to accept the proposal and have HEC begin work in June 1985.

The first step of the procedure involved data assembly. The District personnel were the most knowledgeable about data availability and were therefore responsible for obtaining the required data. The HEC, being more familiar with the model input, assumed responsibility for requesting the data necessary to execute the model.

The second step involved the manipulation of some data by utility programs prior to use as input to HEC-5Q. Usually meteorological data from the National Climatic Center and channel cross-section data are processed through independent utility programs (i.e., WEATHER, HEATX, and GEDA) which structure the data in the proper units and format required by HEC-5Q. This task was performed by HEC.

The third task involved model calibration. Model calibration is the most difficult step in the procedure. It involves modification of model inputs for each trial execution. The model inputs which usually change are parameters which are not easily measurable nor available. Examples of these include the reservoir diffusion coefficients, the distribution of absorbed radiation, and the estimated variation both spatially and temporally of the inflowing water quality concentrations at all boundaries. This task was performed by HEC with expert technical assistance by Mr. Donald J. Smith, a consultant engineer with Resource Management Associates of Lafayette, California.

Step four was model verification. Model verification involved applying the model to an independent period of data without modification of the previously mentioned calibration parameters.

All four steps in the procedure are discussed in detail in Section 4 of this report.

2. BASIN DESCRIPTION*

2.1 PHYSIOGRAPHY

The Kanawha River basin drains 12,300 square miles in North Carolina, Virginia, and West Virginia. It is a tributary to the Ohio River at Pt. Pleasant, West Virginia, as shown in Figure 2.1. The headwaters of the basin are in the northwest corner of North Carolina. From there, the New River flows about 340 miles through the southwest corner of Virginia and into southcentral West Virginia. Drainage from the Greenbrier River, which flows along the eastern border of West Virginia, joins the New River near Hinton. The Gauley River, which drains central West Virginia, joins the New River near Kanawha Falls. The confluence of the New and Gauley Rivers forms the Kanawha River which then flows 97 miles to the Ohio River. The Kanawha River is joined by the Elk River at Charleston, which also drains central West Virginia. The drainage areas of these tributaries are listed in Table 2.1. The area of concern in this report includes the Elk and Gauley River drainage and the New River from Hinton downstream to Winfield Lock and Dam (23 miles downstream of Charleston) on the Kanawha River.

The channels of the New River and its tributaries are confined by mountainous terrain to narrow valleys. As a result, the flood plain is often only slightly wider than the low-water channel which varies in width from 200 to 1,000 feet. In many locations, banks are sheer bluffs rising from the edge of the river. The channels of the Gauley and Elk Rivers are also characterized by narrow valleys and gorges. The main channel from Kanawha Falls to Winfield consists of lock-and-dam navigation pools. In this reach, banks of the river are relatively high, ranging from 25 to 55 feet above low water. The width of the river at normal stage varies from 500 to 800 feet.

Topography of the Kanawha basin is highly dissected with local relief ranging from about 350 to 1500 feet. Surface slopes in excess of 25% are common. The elevation of the ridge bordering the watershed ranges from about 4000 feet in the south, to 2000 feet in the east, to 800 feet in the northwest near the Ohio River. Most of the mountains are forested.

Table 2.1

Kanawha River Basin
Principal Rivers

River	Drainage Area (square miles)	Elevation of Source (feet)	Elevation of Mouth (feet)	Average Slope (feet/mile)
New	6920	3800	652	9.2
Kanawha	12300	652	538	1.2
Greenbrier	1653	2675	1360	87.4
Gauley	440	4000	652	31.0
Elk	1536	3600	563	16.8

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*Partially from Real-Time Flood Forecasting and Reservoir Control for the Kanawha River Basin [HEC, 1984b]

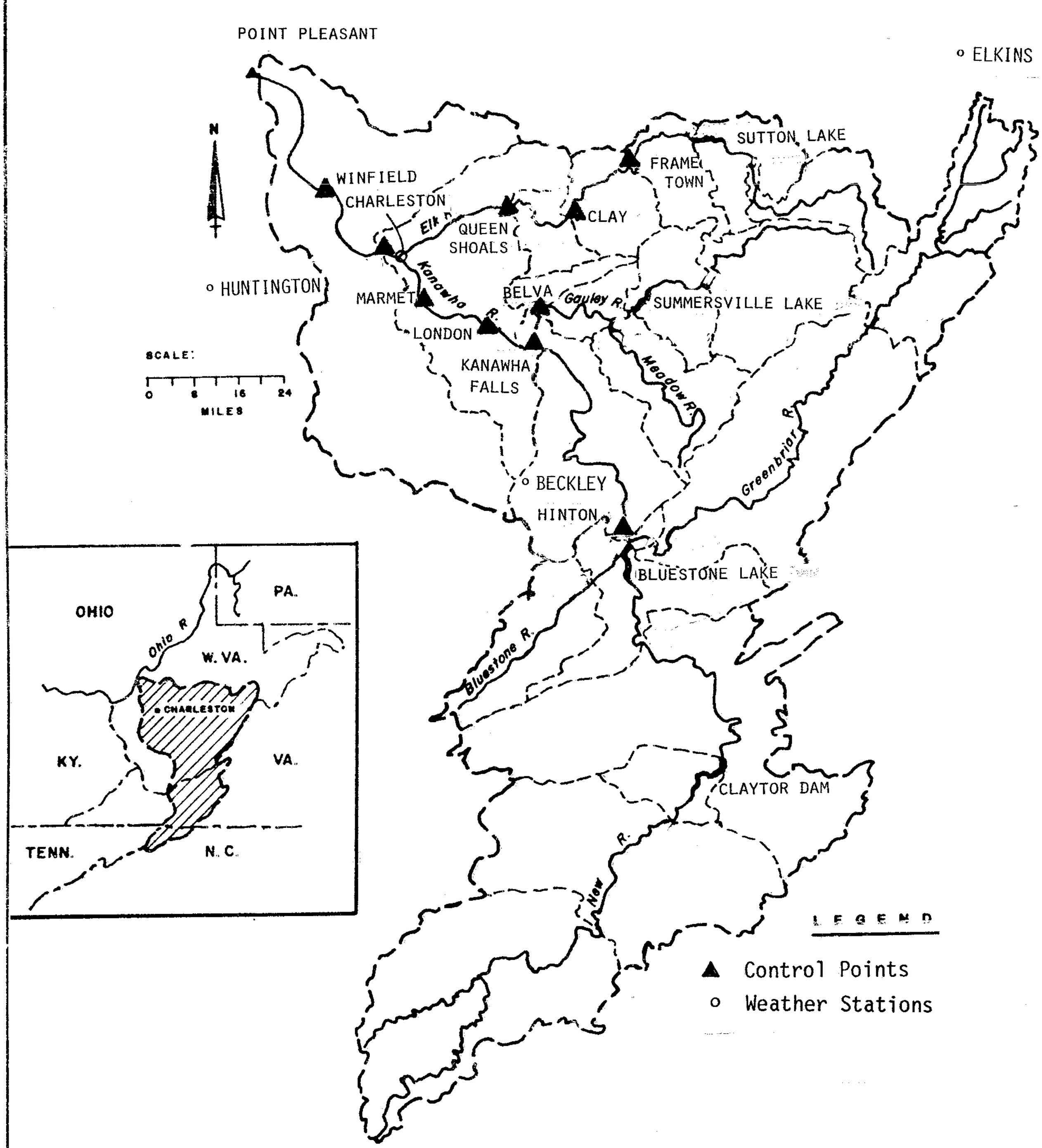

FIGURE 2.1
KANAWHA RIVER BASIN

As shown in Table 2.1, streambed slopes of the principal rivers vary from 1.2 to 87.4 feet per mile. Slopes of the tributaries are much higher; most are in excess of 100 feet per mile and many exceed 400 feet per mile.

2.2 CLIMATOLOGY

The Kanawha River Basin lies beyond the immediate climatic effect of the Atlantic Ocean, and is therefore characterized by a marked temperature contrast between summer and winter. The basin is affected by prevailing westerly winds which are frequently interrupted by northward and southward surges of relatively warm and cold air, respectively. These atmospheric movements are accompanied by the passage of high- and low-pressure areas which move in a generally easterly direction across the United States in the colder half of the year. From May through October, the basin is affected by showers and thunderstorms that occur in the broad current of air that tends to sweep northeastward from the Gulf of Mexico. Winter climate throughout the basin is moderately severe with frequent alternations of fair and stormy weather. Summer is marked by hot and showery weather, with cooler temperatures and frequent thunderstorms in the mountains. Thunderstorms occur on an average of 40 to 50 days per year, with the greatest frequency in June and July.

2.3 RESERVOIR SYSTEM

Three of the four major storage impoundments in the Kanawha River Basin are operated by the Corps of Engineers. The Corps projects are Sutton Lake on the Elk River, Summersville Lake on the Gauley River, and Bluestone Lake on the New River. The fourth project is Claytor Dam, a hydropower project owned and operated by Appalachian Power Company. Claytor Dam is above Bluestone Lake Dam and therefore of limited interest in this study. Basic characteristics of the reservoirs are presented in Table 2.2.

Table 2.2

Kanawha River Basin
Major Reservoirs

Reservoir Name	Drainage Area (square miles)	Flood Control Storage Winter* (ac-ft)	Flood Control Storage Summer* (ac-ft)
Claytor Reservoir	2,382	**	**
Bluestone Lake	4,603	600,100	592,600
Summersville Lake	803	355,524	221,884
Sutton Lake	543	236,130	205,570

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* Different winter and summer storages reflect the seasonal potential for runoff. Winter reservation is for the period 1 December through 15 April.

** An active power storage of 95,000 ac-ft (.75 inches) provides incidental flood control during minor floods.

The Kanawha River Basin reservoirs are operated to control flows at designated control points on the Kanawha and its tributaries. Control points were selected based on flood-damage surveys, flood operation procedures, and availability of reliable streamflow rating stations to permit satisfactory data collection. The control points and their pertinent characteristics are shown in Table 2.3. A schematic of the Kanawha River Basin reservoirs and control points are shown in Figure 2.2.

Table 2.3

Kanawha River Basin
Control Points

Control Point Location	Stream	Channel Capacity (cfs) Winter*	Channel Capacity (cfs) Summer*
Sutton Dam	Elk River	12,000	8,000
Frametown	Elk River	17,600	14,800
Clay	Elk River	35,200	35,200
Queen Shoals	Elk River	28,600	28,600
Summersville Dam	Gauley River	20,500	20,500
Belva	Gauley River	42,500	42,500
Hinton	New River	90,200	90,200
Kanawha Falls	Kanawha River	146,000	146,000
London L/D	Kanawha River	150,000	150,000
Marmet L/D	Kanawha River	150,000	150,000
Charleston**	Kanawha River	150,000	150,000
Winfield L/D	Kanawha River	45***	45***

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* Different winter and summer capacities reflect the greater potential for damages to agricultural areas during the growing season. Winter is from 1 December through 15 April.

** Old Lock No. 6 gage with a slope rating; control discharge estimated.

*** Stage in feet.

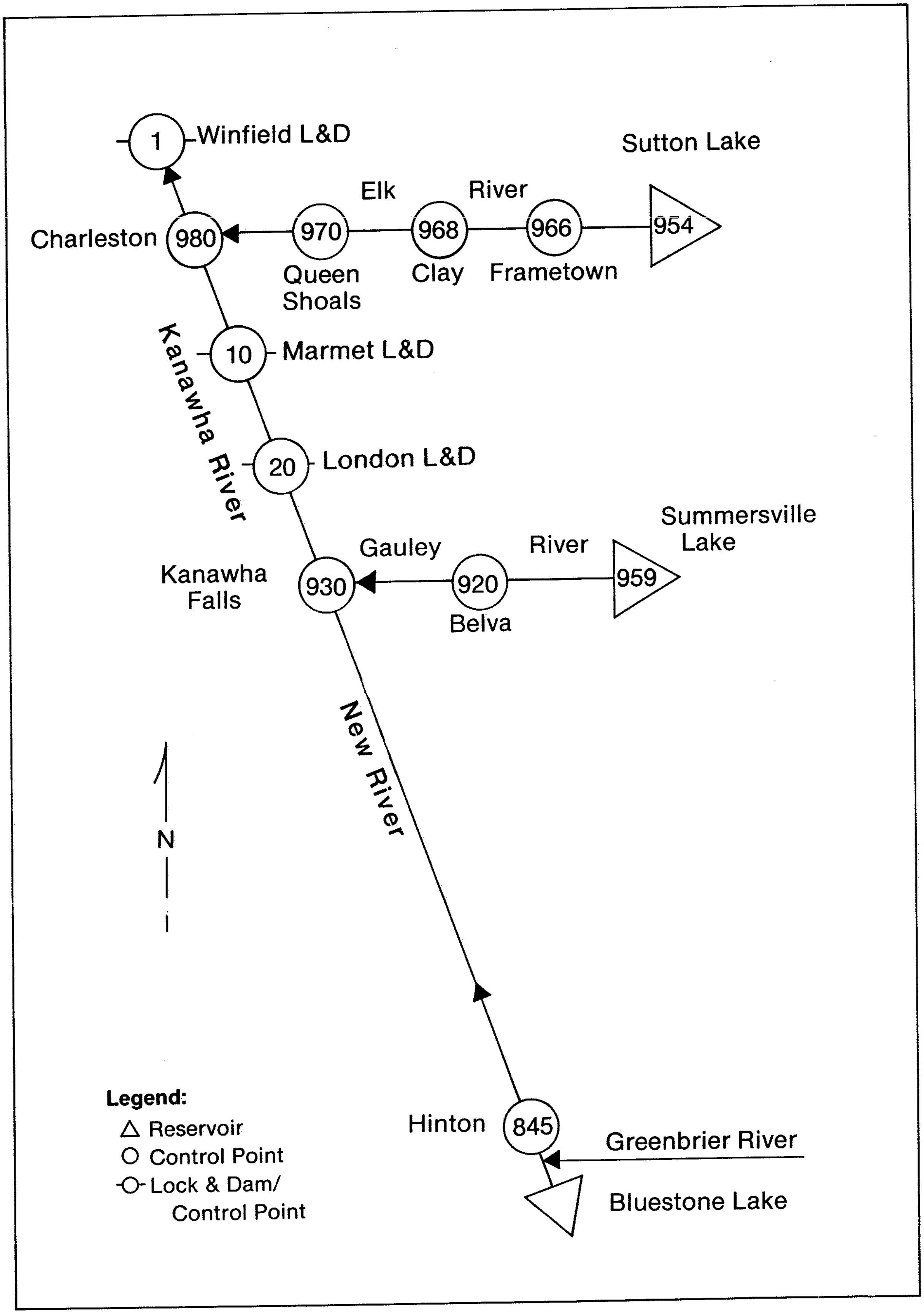

Figure 2.2

KANAWHA RIVER BASIN SCHEMATIC *

*From HEC-5Q: System Water Qaulity Modeling [Willey, 1986]

HEC-5Q RESERVOIR REGULATION MODEL

The "HEC-5Q, Simulation of Flood Control and Conservation Systems (Including Water Quality Analysis)" computer model [HEC, 1984a] has been developed specifically for evaluating the type of problem shown in Figure 2.2. The model is capable of evaluating a reservoir system of up to ten reservoirs and thirty control points. The model will analyze a best system operation for water quantity and quality by evaluating operational concerns like flood control, hydropower, water supply, irrigation diversions and other instream flow needs.

3.1 FLOW SIMULATION MODULE

In addition to assisting in the sizing of the flood control and conservation storage requirements for each recommended project, the flow simulation module was developed to assist in planning studies for evaluating proposed reservoirs in a system. The program can also be useful for selecting proper reservoir operational releases in order to maximize water quality conditions or other operational downstream targets.

3.2 WATER QUALITY SIMULATION MODULE

The water quality simulation module was developed to simulate temperature, as well as three user-selected conservative and three user-selected non-conservative constituents. The model also allows dissolved oxygen to be simulated if the user selects either carbonaceous or nitrogenous oxygen demanding constituents. An option for phytoplankton evaluation is also available.

The water quality simulation module accepts system flows generated by the flow simulation module and computes the distribution of all the water quality constituents in the reservoirs and their associated downstream reaches. The program also selects the gate openings for reservoir withdrawal structures to meet user-specified water quality objectives at downstream control points. With these capabilities, the planner may evaluate the effects of proposed reservoir-stream modifications on water quality and determine how a reservoir intake structure should be operated to achieve desired water quality objectives within the system.

The reservoirs are represented conceptually by one-dimensional horizontal elements. Each horizontal element is characterized by an area, thickness and volume. In the aggregate, the assemblage of layered volume elements is a geometric representation of the prototype reservoir. This one-dimensional representation has been shown to adequately represent water quality conditions in many deep, well-stratified reservoirs by Baca [1977] and Water Resources Engineers [1968, 1969a, 1969b].

Each horizontal layer is assumed to be completely mixed with all isopleths parallel to the water surface both laterally and longitudinally. External inflows and withdrawals occur as sources or sinks within each layer and are instantaneously dispersed and homogeneously mixed throughout each element from the headwaters of the impoundment to the dam. It is not possible, therefore, to look at longitudinal variations in water quality constituents. Simulation results are most representative of conditions in the main reservoir body.

Vertical advection is governed by the location of inflow to, and outflow from, the reservoir. Thus, the computation of the zones of distribution and withdrawal for inflows and outflows are of considerable significance in operation of the model. The WES withdrawal method [Bohan, 1973] is used for determining the allocation of outflow. The Debler inflow allocation method [Debler, 1959] is used for the placement of inflows.

Vertical advection is the net interelement flow and is one of two transport mechanisms used in the module to transport water quality constituents between elements. Effective diffusion is the other transport mechanism. The effective diffusion is composed of molecular and turbulent diffusion and convective mixing.

The stream system is represented conceptually as a linear network of segments or volume elements. Each element is characterized by length, width, cross sectional area, hydraulic radius, Manning's n and a flow and depth relationship. Flow rates at stream control points are calculated within the flow simulation module using any one of several programmed hydrologic routing methods. Within the flow simulation module, incremental local flows (i.e., inflow between adjacent control points) are assumed to be located at the nearest control point.

Within the water quality simulation module, the incremental local flow may be divided into components and placed at different locations within the stream reach (i.e., that portion of the stream bounded by the two control points). A flow balance is used to determine the flow rate at element boundaries. Any flow imbalance (i.e., the difference between the flow at the upstream control point, including all tributary inflows, and the flow at the downstream control point) is distributed uniformly to the flows at each element boundary. Once interelement flows are established, the depth, surface width, and cross sectional area are computed at each element boundary assuming normal depth.

3.3 GATE SELECTION

Once the desired reservoir release and the target water quality needed to meet downstream requirements have been computed, the gate selection algorithm determines which ports should be open and what flow rate should pass through each open port in order to maximize a particular function of the downstream water quality target concentrations. Solution of this problem is accomplished by using mathematical optimization techniques. The objective function is related to meeting downstream target qualities subject to various hydraulic constraints on the individual ports.

The algorithm considers a sequence of problems, each representing a different combination of open ports. For each combination, the optimal allocation of total flow to ports is first determined; and then a water quality index is determined for the optimal allocation of flows. The combination of open ports with the highest water quality index and its associated allocation of flows defines the optimal operation strategy for the time period under consideration.

3.4 FLOW ALTERATIONS

The flow alteration routine is designed to change the reservoir releases, computed by the flow simulation module, to better satisfy the stream control point water quality objectives. The routine is designed about a mass balance for all reservoir releases and all control points affected by those releases. Tributary inflows and other flow changes are included. Second order effects, such as changes in reaeration and external heating due to increased or decreased stream surface area, are not included.

Thus the flow augmentation requirement can be computed for each control point and for each constituent. The various computed flow rates are then combined by using the coefficients of the linear programming objective function and the deviation of the respective constituent concentrations from the target concentrations at each respective control point.

Once the flow augmentation requirement is determined, the flow simulation module is recalled; and the daily computations for flow and water quality are solved again for the final results. On this simulation, second order effects are included in the analysis.

3.5 SUMMARY

The HEC-5Q model is capable of simulating the operational effects of as many as ten reservoirs on the stream network of the basin. Each reservoir may be operated to satisfy a number of objectives including flood control, low flow, hydropower production, water supply and water quality control. The water quality portion of the model will simulate temperature and eight water quality constituents including dissolved oxygen and phytoplankton. The model will internally determine the water quality needed from all reservoir releases to meet specified downstream water quality objectives and will determine the gate openings in each reservoir that will yield the appropriate reservoir release water quality. Should it be necessary, flows will be altered to ensure that downstream water quality objectives are met. The model selects the best solution for system-wide reservoir operation on a daily basis.

4. METHOD OF STUDY

Input data to simulate reservoir regulation for evaluation of water quality impacts was developed based on the generalized reservoir system simulation program HEC-5Q [HEC, 1984a]

Development of the HEC-5Q input data comprised the following tasks:

1) Determining the basin network configuration needed to adequately describe the reservoir system, as well as an appropriate simulation period and time interval;
2) Compiling project data describing the reservoir system;
3) Selecting low-flow events for simulation; compiling time series data on the selected low-flow events; and calibrating the data models by successive trial and error adjustments of appropriate variables.

4.1 BASIN NETWORK AND TIME CONSIDERATIONS

The basin network was identical in design to the network previously used in the Real-Time Flood Forecasting Study report [HEC, 1984b] except that the upstream boundary on the New River was Hinton and the downstream boundary on the Kanawha River was Winfield Lock and Dam. The Elk and Gauley River analysis began with known inflow to Sutton and Summersville Lakes respectively. The schematic of the network is shown in Figure 2.2. The reason for different boundary limits on the New/Kanawha Rivers can be attributed to a District decision based on interests in water quality conditions.

The HEC-5Q model presently simulates either daily or monthly data. This study used the daily time interval. The District selected four years of specific water quality interest: 1976, 1979, 1980 and 1983. The season of interest was June through September.

The data for 1976 was unavailable prior to October, so a trial analysis was performed for October 1976. This case had a minimum of calibration data available.

The data for 1979 and 1980 were sufficient for viable calibration attempts. The data for 1983 was not readily available for calibration but was made available at a later date for verification analysis.

4.2 PROJECT DATA FOR RESERVOIR SYSTEM

Project data defines the pertinent physical and operational characteristics of the prototype reservoir system which are relatively fixed in time. For example, project data include reservoir storage, surface area, and pool elevation relationships; outflow and elevation relationships; and routing parameters. Certain operation parameters are also relatively static, such as storage allocations and channel capacities.

The primary sources of project data were the reservoir regulation manuals for the individual reservoirs [U.S. Army, 1953, 1961, 1966a] and the master manual for reservoir regulation [U.S. Army, 1966b].

4.2.1 Storage, Elevation and Outflow

Relationships between storage, area, outflow and elevation are represented in HEC-5Q by tables of corresponding linearly interpolated points. Points were selected to obtain acceptable piecewise linear functions to represent curvilinear relationships. Outflow capabilities were specified as the sum of spillway and main outlet capacities where appropriate. Sutton, which has a gated spillway, has full combined sluice gate and spillway capacity for elevations above the spillway crest. Summersville, which has an overflow spillway, has total main outlet capacity below the spillway crest; for elevations above the spillway crest, the outflow capability is specified as the spillway plus any available main outlet capability.

4.2.2 Storage Allocations

Reservoir storage allocations were assigned among five zones: inactive, buffer, conservation, flood control, and emergency flood surcharge storage. Zones were defined by storage values at the tops of the zones. Seasonal pool variations of conservation pools were included where appropriate. Some of the buffer or inactive storage levels were not specifically defined in project manuals; consequently, values were estimated.

4.2.3 Control Points and Channel Capacities

The control points and their channel capacities are shown in Table 2.3. The channel capacities were obtained from the reservoir regulation manuals for the individual reservoirs, when available. At Summersville, the channel capacity was made equal to the maximum capacity of the three main outlet valves, about 20,500 cfs, as specified in the manual. A seasonal channel capacity was specified for Sutton in accordance with its manual.

4.2.4 Minimum Flows

Minimum releases specified in project manuals for the Corps reservoirs were included in the HEC-5Q model. The minimum releases for Summersville and Sutton are 100 and 75 cfs, respectively.

4.2.5 Rates of Change

No rate-of-change criteria were specified in project manuals for Sutton or Summersville. For the model, these locations were assigned a rate-of-change equal to the maximum channel capacity per hour at that location.

4.2.6 Emergency Pre-Release

Whenever forecasts during an event indicate that the storage remaining in the Kanawha reservoirs will not be adequate to hold inflows while continuing to operate and keep downstream flows at channel capacity, larger releases are required so that maximum flood control storage is not exceeded. The larger releases are minimized by releasing the excess inflow values over the longest possible period of time. The pre-release procedure is an option in HEC-5Q and was included in the Kanawha model.

4.2.7 Streamflows and Reservoir Discharges

Daily streamflow data, for inflow to and discharge from both reservoirs, were obtained from the District office records. Daily streamflows at most other control points were obtained from the USGS WATSTORE data system. All control points without observed data (e.g., London and Marmet Locks and Dams for all periods, and Clay and Frametown for some periods) were calculated by HEC-5Q to minimize negative local flows.

Using the observed or calculated flows at all control points, the local subbasin flows were calculated by HEC-5Q. The model routes the flow from an upstream control point to the next downstream control point and combines similarly routed flows from major tributaries (e.g., Elk or Gauley Rivers). This routed flow was subtracted from the downstream control point flow to determine the local subbasin flow. Some negative local flows will occur but they are minimized by adjusting routing criteria.

4.2.8 Reservoir Storages

The reservoir inflows are routed through each reservoir with known discharge and estimated evaporation to determine a calculated reservoir storage and associated elevation. The calculated elevation was compared to the observed elevation. Accuracy of the results is discussed in Section 4.2.9.

4.2.9 Evaporation and Precipitation

The net evaporation data (evaporation minus precipitation) used for HEC-5Q was obtained from EM 1110-2-1701 [U.S. Army, 1952] for a critical period type analysis. Although the data is not necessarily appropriate for the actual historical period, the simulations demonstrate average daily reservoir elevation accuracy to within ±0.7 feet, on the average, at both reservoirs for 1976, 1979, and 1980.

Demonstration of the validity of this type of data allows its use for real-time prediction.

4.2.10 Weather Conditions

The meteorological data was obtained from the NOAA National Climatic Center in Asheville, North Carolina. Four stations were obtained for the period 1961-1983 with some periods missing at some stations. The stations obtained were Huntington (elev. 827), Beckley (elev. 2504), Charleston (elev. 939) and Elkins (elev. 1992). The HEC-5Q model is able to use any one of the stations in any part of the basin analysis.

4.2.11 Intake Level and Discharge Capacity

The physical description of the intake design and the discharge capacity were obtained from the reservoir regulation manuals. Sutton and Summersville Lakes intake data are shown in Table 4.1.

Table 4.1

Intake Elevations and Discharge Capacities

Outlet Type	Sutton (feet/cfs)	Summersville (feet/cfs)
Low flow outlet	910.0/ 1,500	1400.0/ 318
Flood flow outlet	830.0/ 23,900	1398.4/ 17,650
Emergency spillway	972.0/222,000	1710.0/412,000

4.2.12 Reservoir Width and Length

The width and effective length of the reservoir were estimated based on plan view diagrams in the reservoir regulation manuals. The effective lengths were eventually decreased by one-half for improved reproduction of observed data. Final values used for widths and lengths for Sutton and Summersville Lakes are shown in Table 4.2.

Table 4.2

Reservoir Widths and Effective Lengths

Reservoir	Eff. Length (feet)	Widths/Elevations (feet/feet)		
Sutton	34,000	275/ 825	300/ 850	325/ 870
		350/ 895	375/ 910	400/ 922
		425/ 940	450/ 960	475/ 972
		500/ 976	525/ 980	550/ 985
		575/ 990	600/1000	625/1001.5
		650/1003	675/1005	700/1009
Summersville	21,000	400/1391	600/1535	800/1555
		1000/1575	1200/1600	1400/1620
		1600/1652	1800/1680	2000/1710
		2200/1712	2400/1714	2600/1716
		2800/1722	3000/1728	3200/1735

4.2.13 Reservoir Clarity and Diffusion

The clarity of Sutton Reservoir is less than that of Summersville, and their respective visibilities are assumed to be 8 and 15 feet for average study period secchi disk readings. These values are based on annual ranges obtained from the District of 5-15 feet and 10-30 feet, respectively.

Other required model data that effect solar radiation calculations are XQPCT and XQDEP as defined in the HEC-5Q Users Manual [HEC, 1984a]. These are shown in Table 4.3.

Reservoir diffusion using the stability method was initially estimated from the HEC-5Q Users Manual (page 43) and then calibrated to reproduce observed reservoir temperature profiles obtained from the EPA STORET data system. The final values for diffusion with the stability method are also shown in Table 4.3.

Table 4.3

Solar Radiation and Diffusion (Stability Method) Data

Reservoir	XQPCT (fraction)	XQDEP (feet)	A1	GSWH	A3
Sutton	.6	3	1.0×10^{-4}	0.9×10^{-6}	-.7
Summersville	.6	6	2.3×10^{-4}	0.9×10^{-6}	-.7

Slight improvements in reproduction were detected by changing to the wind mixing diffusion method and using GMIN, GSWH, A1, A2 and A3 equal to 0, 10^{-7}, 10^{-5}, 4.6 and 2×10^{-5} respectively.

4.2.14 Decay Coefficients

The decay coefficients used in the reservoirs and river network were the recommended model default values. No attempt was made to modify these values during the model calibration.

4.2.15 Stream Network

The stream network was subdivided into stream reaches. A stream reach is defined between each pair of control points shown in Figure 2.1. The reach numbers, the upstream and downstream control points numbers and river mile identification for each reach, and the element length (i.e., distance between computation nodes) are shown in Table 4.4.

Table 4.4

Stream Reach Network

Reach Number (#)	Upstream CP (#)	Upstream RM (mile)	Downstream CP (#)	Downstream RM (mile)	Element Length (miles)
1	954	101.1	966	80.8	1.015000
2	966	80.8	968	52.5	1.010714
3	968	52.5	970	25.8	0.988889
4	970	25.8	980	0	0.992308
5	959	34.3	920	6.9	1.014815
6	920	6.9	930	0	0.985714
7	845	159.0	930	94.5	1.954545
8	930	94.5	20	82.8	0.975000
9	20	82.8	10	67.7	1.006667
10	10	67.7	980	54.3	1.030769
11	980	54.3	1	31.1	1.008696

4.2.16 Cross Sections and Energy Slope

The cross section data was obtained from the District office. Some sections were in graphical form and some were in HEC-2 [HEC, 1982] format on magnetic media. The energy slope for all river reaches was estimated from hydraulic slopes provided on the navigation river atlas [U.S. Army, 1985] or on copies of profile sheets from past studies in the District files.

4.2.17 Water Quality Concentrations

Water quality concentrations for all reservoir inflows and initial reservoir profile conditions were obtained from the U.S. EPA STORET data system, as were other upstream boundary flows (i.e., at Hinton), all local subbasin inflows and numerous points in the New, Kanawha, Gauley and Elk Rivers. All of the data, except for the later points, were considered to be only initial values which were ultimately calibrated to final values by reproducing the results along the stream network. The adopted concentration and seasonal variations (but constant pattern from year-to-year) are shown in Table 4.5. The HEC-5Q model uses linear interpolation of the input for seasonal variations. Demonstration of the validity of using the same seasonal values for each year simulated allows the model to be used for real-time prediction.

Table 4.5

Water Quality Inflow Concentrations

Location	Date	Temp* (°C)	EC (micromho)	BOD (mg/ℓ)	DO (% Sat.)
Sutton Lake Inflow					
	6/1	-4	50	2	70
	9/1	0	100	2	70
	10/31	0	110	2	70
Summersville Lake Inflow					
	6/1	-8	45	3	90
	9/1	-5	80	3	80
	10/31	-5	80	3	80
Hinton Local					
	6/1	-2	160	2	85
	9/1	+3	160	2	80
	10/31	+3	160	2	80
Frametown Local					
	6/1	-2	130	3	55
	9/1	-2	80	2	55
	10/31	-2	80	2	55

* Temperature departure in °C from the equilibrium temperature.

Table 4.5 (cont.)

Location	Date	Temp* (°C)	EC (micromho)	BOD (mg/ℓ)	DO (% Sat.)
Clay Local					
	6/1	-2	20	2	35
	9/1	-2	20	2	35
	10/31	-2	20	2	35
Queen Shoals Local					
	6/1	-2	420	5	30
	9/1	-2	420	5	30
	10/31	-2	420	5	30
Belva Local					
	6/1	-4	450	10	100
	9/1	-4	450	10	100
	10/31	-4	450	10	100
Kanawha Falls Local					
	6/1	-4	120	4	85
	9/1	-1	120	4	75
	10/31	0	120	4	75
London L/D Local					
	6/1	-4	400	4	75
	9/1	-1	400	4	75
	10/31	0	400	4	75
Marmet L/D Local					
	6/1	-4	400	4	95
	9/1	-1	400	4	95
	10/31	0	400	4	95
Charleston Local					
	6/1	-2	800	50	20
	9/1	-1	800	50	20
	10/31	0	800	50	20
Winfield L/D Local					
	6/1	-2	160	10	90
	9/1	+1	160	10	85
	10/31	+2	160	10	85

* Temperature departure in °C from the equilibrium temperature.

4.2.18 Control Point Water Quality Targets

The water quality targets at all control points were provided by the District based on locally desired water quality conditions. Maximum acceptable temperature of 24°C and minimum acceptable dissolved oxygen of 6 mg/ℓ were used as target values at all control points except Sutton, Frametown, Clay and Queen Shoals. These control points on the Elk River were control for minimizing acceptable temperatures of 24°C which causes the use of the high rise outlet at Sutton. These values are used when making operational executions which allow the program to decide gates settings and/or reservoir discharges.

4.3 DATA MANIPULATION

Two types of data (i.e., channel geometry and weather) require independent manipulation with utility programs prior to input to the HEC-5Q model. The channel cross-section data is normally found in either graphical form or already processed into a format used for the HEC-2 program [HEC, 1982]. When only the graphical form was available, a utility program was first used in conjunction with a graphics tablet to process the data into the HEC-2 format. Once the cross-sections are available in the HEC-2 format, they are input to program GEDA [HEC, 1981] which processes them for direct input to HEC-5Q.

The NOAA National Climatic Center weather data was obtained in their CD144 format. The file was processed through a utility program WEATHER [HEC, 1986]. The output file from WEATHER is input to the HEATX utility program [U.S. Army, 1977] which processes the data for direct input to HEC-5Q.

Procedures for executing GEDA, WEATHER and HEATX are documented in Appendix D.

4.4 MODEL CALIBRATION CONSIDERATIONS

The objective of calibration was to make the model simulate the actual regulation of the Kanawha Basin system as closely as possible.

The calibration process generally consisted of assigning estimated values to unmeasurable or unmeasured data. If the results of the simulation were not appropriate or satisfactory, other values were assigned and the simulation and evaluation were repeated. In circumstances where the relationships between variables and results were ambiguous due to interactions, interacting variables were calibrated on separate steps. Calibration on a full range of possible events was not possible because of the limited availability of calibration data. Instead, calibration focused upon three of the four events chosen by the Huntington District. The fourth event was used for verification data. All four events were representative of the more frequent low flow condition.

4.4.1 Data

Data for October 1976 and June through September 1979 and 1980 were used for calibration purposes. Data from the events reflected typical low flow reservoir regulation periods very similar to the type of periods during which the model will be used as a forecasting tool.

Data for the calibration events were average daily flows and instantaneous water quality samples. Weather data was daily average except cloud cover which was averaged over the daylight hours only (this parameter is used for attenuation of solar radiation).

4.4.2 Water Quantity Calibration

The water quantity aspects of calibration effect both the reservoir continuity and the routing and combining of discharges from local subbasin flows. The water quantity part of the data, with the exception of evaporation, had been previously calibrated and documented in the Real-Time Flood Forecasting Report [HEC, 1984b].

4.4.2.1 Evaporation

The evaporation data, used in the real-time model, was modified (because a low flow season has more evaporation than flood events) by values calculated according to EM 1110-2-1701 [U.S. Army, 1952], and the reservoir continuity was checked by comparing reservoir pool elevations during all three study periods. The results were accurate to within ±0.65 feet (average for all three events).

4.4.2.2 Channel Routing

No routing is necessary for daily flows over reaches having travel times which are much less than one-day. Only the one reach from Hinton to Kanawha Falls had a travel time exceeding a half day (i.e., about 18 hours) and routing criteria were estimated using reproduction of observed streamflow data as the evaluation criteria.

4.4.3 Water Quality Calibration

The water quality calibration involves adjustment of four reservoir diffusion coefficients (A1, A2, A3 and GSWH) and three solar energy distribution coefficients (EDMAX, XQPCT, and XQDEP). Sensitivity studies were used to select the most appropriate weather station to represent the weather at each reservoir and within each stream reach. Since local subbasin inflow quality is relatively unknown, sensitivity studies were also used to adjust those values. All of the above are adjusted through numerous trials to best reproduce observed reservoir profiles and observed time series data at river sampling locations.

4.4.3.1 Diffusion Effects

The GSWH and A3 are minimum and maximum diffusion coefficients. The higher the A1 value, the more heat that is transferred up to a maximum value of A3. The A2 value impacts the shape of the diffusion function with depth. The A2 value is recommended to be held constant at 4.6. Magnitudes of GSWH, A1, and A3 derived by successive trials for both Sutton and Summersville are 10^{-7}, 10^{-5}, 2×10^{-5} respectively.

4.4.3.2 Solar Radiation Distribution

The EDMAX (Secchi disk) controls the depth of light penetration which effects the distribution of the solar radiation which then penetrates the water surface. The larger the EDMAX, the deeper the solar energy penetration. Secchi disk readings are field observations of reservoir clarity performed by gradually lowering a black and white disk to a depth where it can no longer be seen. The depth where it disappears from sight is recorded.

The fraction of the total solar energy penetrating the water surface, which is absorbed near the surface of the reservoir, is defined as XQPCT. The larger the value, the warmer the water surface.

The depth of water that absorbs XQPCT is defined as XQDEP. The deeper XQDEP, the smaller the actual temperature increase of the surface water.

The value of EDMAX depends on observed data in each reservoir. At Sutton, the EDMAX was estimated to be 8 feet and at Summersville, it was 15 feet. The magnitudes of XQPCT and XQDEP are not usually measured, but estimated values of 0.6 and 75% of the top layer depth were used.

4.4.3.3 Weather Station Selection

To decide on the most representive weather stations to use, a sensitivity study was performed. Initial trials at each reservoir used the closest weather station to their geographical location. Similarly, each river reach was assigned the closest weather station. Eventually, the Elkins weather station was selected because it provided the best representation of weather conditions for both reservoirs and all the river reaches. Use of the Beckley data provides only minor variations.

4.4.3.4 Subbasin Inflow Quality

The data from the STORET system is the best starting place for determination of subbasin inflow quality. Unfortunately, the data is sparce in time and space. The data is normally measured about once per month on a few tributaries. Even this limited data may not be available near the downstream end of the tributary. Due to these limitations, STORET data only provides a "ballpark" concentration level and a trend for its seasonal variation. Final input data must be determined through calibration or sensitivity studies. Section 4.2 of this report previously defined the subbasin inflow concentrations finally adopted. It is important to note that since they were kept constant for all three years at all subbasins, the same values should also be acceptable for real-time prediction use.

4.5 CALIBRATION RESULTS

Using the calibration coefficients and parameters previously discussed, the model is capable of satisfactory reproduction of the 1976, 1979, and 1980 observed reservoir and stream quality data. Evaluation of the final results must be examined in terms of all study years, all seasonal variations and all geographical locations. Changing a coefficient or parameter at one point in time and space can seriously effect other locations and points in time (i.e., seasonal variations).

Several examples of the graphical reproductions are included in this report as Appendix A. The Sutton (pages A1-A8) and Summersville (pages A9-A16) reservoir profiles for temperature and dissolved oxygen (DO) have been included for the four low-flow months of either 1979 or 1980, depending on the amount of observed data available. The Sutton temperature profile reproductions are generally of comparable shape and within ±2°C. The Sutton DO profile reproductions are of similar shape except at the deepest levels. In general the accuracy is with ±1 mg/ℓ.

Summersville temperature and DO profile reproductions are all of similar shape except for the deepest levels and within similar accuracy to Sutton. At the deeper levels, the computed temperatures are warmer and the computed DO higher. The computed DO cannot reproduce the observed DO spike which occurs at approximately 220 feet of depth.

The accuracy of profile reproduction at both reservoirs is sufficient to provide accurate predicted discharge water quality for downstream analysis.

The Gauley River temperature (pages A17-A18) and DO (pages A19-A20) low-flow time series for 1979 have been shown for below Summersville Dam and near Belva. The accuracy of reproduction is within ±2°C for temperature and ±.5 mg/ℓ for DO. The graphs on pages A17 and A19 support the previous statement regarding the adequacy of the calculated reservoir profile accuracy in Summersville.

The Elk River temperature (pages A21-A29) and DO (pages A30-A38) time series for 1980 are shown for four locations between Sutton Dam and Frametown (RM98-RM90), for one location between Frametown and Clay (RM62), for one between Clay and Queen Shoals (RM52) and for three locations between Queen Shoals and Charleston (RM25-RM4). The accuracy of reproduction is generally within ±2 C for temperature and ±1 mg/ℓ for DO. The graphs on pages A21 and A30 support the previous statement regarding the adequacy of the calculated reservoir profile accuracy in Sutton.

The New/Kanawha River temperature (pages A39-A42) and DO (pages A43-A46) time series for 1979 are shown for four locations including Hinton (RM161), above Kanawha Falls (RM98), and the Marmet pool (RM73) and in the Winfield pool below Charleston (RM46). The accuracy of reproduction is generally within ±2°C for temperature and ±1 mg/ℓ for DO. The graphs on pages A39 and A43 show that the boundary conditon at Hinton, which is analyzed as a "dummy" reservoir, is a sufficiently adequate representation of the physical condition.

Graphs for other years having less observed data, and for electrical conductance (EC) and biochemical oxygen demand (BOD) have been furnished to Huntington District under separate cover. Because EC and BOD are of less concern to the District and the impracticality of including about five times as many graphs as have been shown, these other graphs have been excluded. It should be noted, however, that data for other time periods are of similar accuracy to those shown and that the accuracy of EC and BOD reproductions are generally within ±50 micromhos and ±1 mg/ℓ respectively.

In general, the reservoir reproductions are good and the river reproductions are very good overall. The calibrations shown in Appendix A were accomplished with more attention paid to determining inflow concentrations that can be used for future real-time forecasting than obtaining an exact reproduction of a given value on a specific date or location.

The error that can be observed in the results shown in Appendix A is the same magnitude of error expected in real-time work. As more experience with the model is gained, additional fine tuning may result in small improvements in calibration. Any time the user decides to try a model modification, these calibration data should be rerun and the new graphical output compared to these results.

4.6 MODEL VERIFICATION

Model verification is the best available proof-of-model-validity for use in real-time prediction or for use under proposed future system structural changes. The verification test must use all the calibration coefficients and parameters as constants (i.e., these values cannot be changed on the verification case).

The verification case chosen by the District was June through September 1983. The input data for this case included the same physical description data for the reservoirs and stream channel as used previously for the calibration cases. The weather data and observed water quality data from the STORET system were obtained for the 1983 period. The local subbasin flow quantity was determined by the model and the flow quality was held constant at the calibration concentrations.

The inflow to both reservoirs and the discharges from them were obtained from Huntington District.

A sample of the graphical results of the verification test case are shown in Appendix B. The results were quite satisfactory in the river network. No observed reservoir profiles were available, but the comparisions of magnitude and shape to previous years' profiles were satisfactory. The order of the graphs and the locations provided are generally similar to the calibration graphs in Appendix A except that the reservoir profiles are not included and observed values were available at fewer locations.

The stream temperatures were slightly low and the DO slightly high. This is a normal relationship to be expected due to the dissolved oxygen saturation functions. Again, as discussed above, further fine-tuning of the model may be necessary as more conditions are examined; but for prediction of these 1983 verification results, the reproduction is reasonable.

The model having passed the verification test is available and recommended for field use. Caution must still be applied to interpreting the model results, as with any new product. If any anomalies are observed, additional calibration may be necessary to fine-tune the model.

4.7 OPERATIONAL CAPABILITY

The data files for the four study years have also been used in an operational mode where the model decides the reservoirs' discharges. As shown in Appendix C, the low-flow (regulated) discharges determined by the model (dashed line) are almost identical reproductions of the observed discharges (solid line) at the dam site and at downstream control points for all three study years (1976, 1979 and 1980). Comparison of calculated water quality to observed water quality is similar in accuracy to the calibration results for the same periods and generally the same locations provided in Appendix A.

The modifications to the calibration data files to develop operational capability include removal of the specified reservoir releases and substituting local flows for observed USGS data on the IN records. The J3.6 index is changed to -1 to notify the model of this change in input. Other modifications include changing the J9.4 index to 0 and removing the G1 and G2 data.

4.8 REAL-TIME CAPABILITY

For forecasting at a given time using the operational capability type data file, update the RL.2 storage value to the current data, as well as all of the local flows on the IN records (or ZR records using DSS). The number of days to be forecasted and the current date must be updated on BF.2, BF.5, JA.2 and JA.3. The reservoir water quality initial condition profiles (L9 through C7) and the weather data (ET) must also be updated.

If the IN and ET records are defined for dry, wet, and average conditions for the whole dry season, the updating of these records for each weekly forecast can be eliminated.

For forecasting water quality conditions with specified reservoir releases, add QA records after the IN records which define the reservoir releases for the forecast period.

5. SUMMARY

The purpose of the Kanawha River Basin water quality study was to provide a computer model capable of evaluating water quality conditions that occur throughout the basin during June through September for a given operation of Sutton and Summersville Dams.

Within acceptable tolerances, the study has accomplished this purpose, as well as providing a tool for better understanding and management of the data being collected by various agencies. Better input boundary conditions (i.e., inflow quality to both reservoirs and water quality at Hinton) are needed for improved reproductions in both reservoirs and at all locations in the upper stream reaches of the New, Gauley and Elk Rivers. More water quality data on subbasin inflows would be beneficial in the Clay to Charleston area of the Elk River Basin. In general, data needs exist for all inflowing concentrations. This data is generally unavailable and yet crucial to the study.

The study helped define better procedures for using and interfacing various HEC models and utility programs. It is the intent of HEC to provide this report not only as a final project document but as a procedure guide to other water quality studies having reservoir system operations of multipurpose projects. A companion reference procedure guide for HEC-5Q studies is available from HEC [Willey, 1985b].

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APPENDIX A

GRAPHICAL RESULTS OF CALIBRATION

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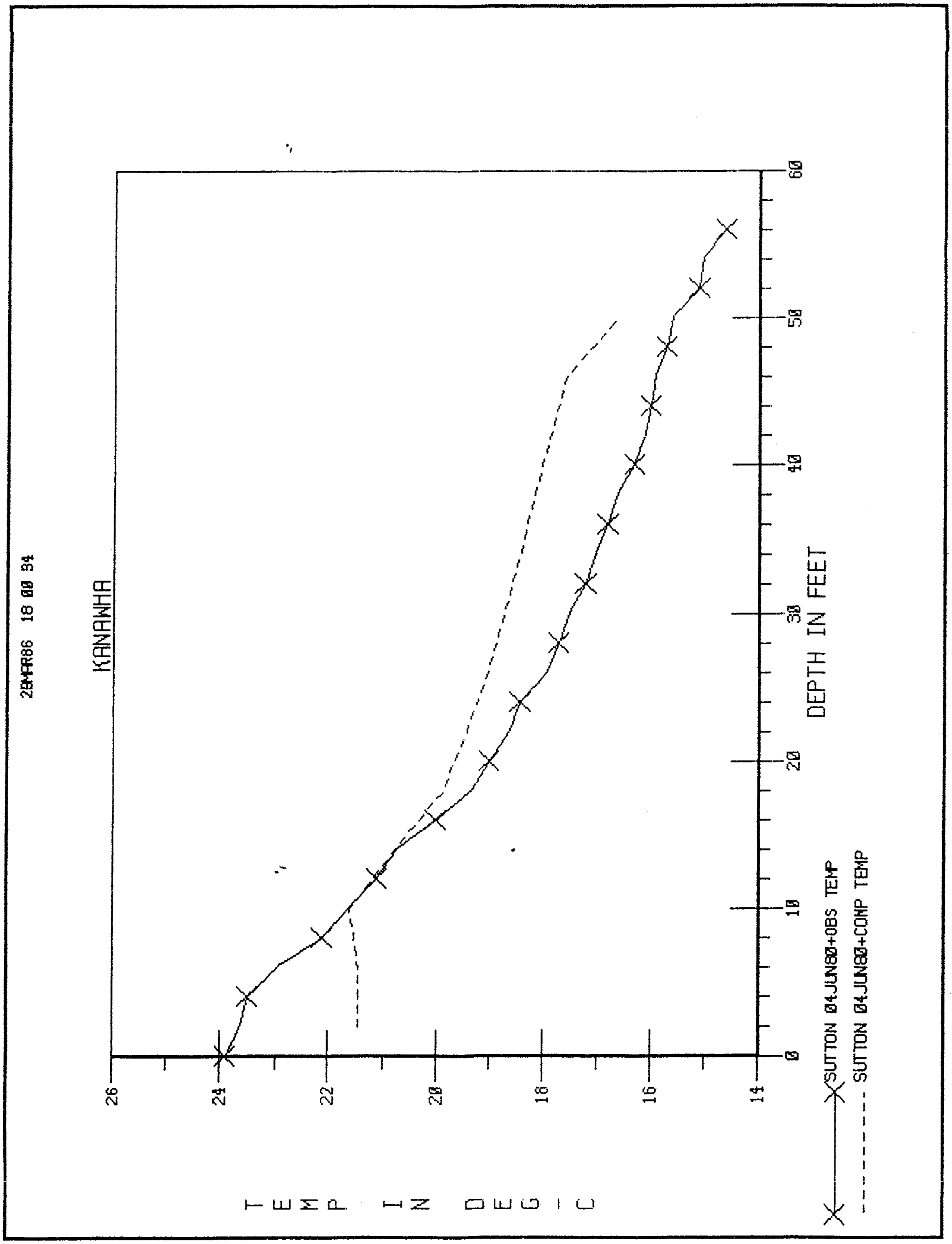
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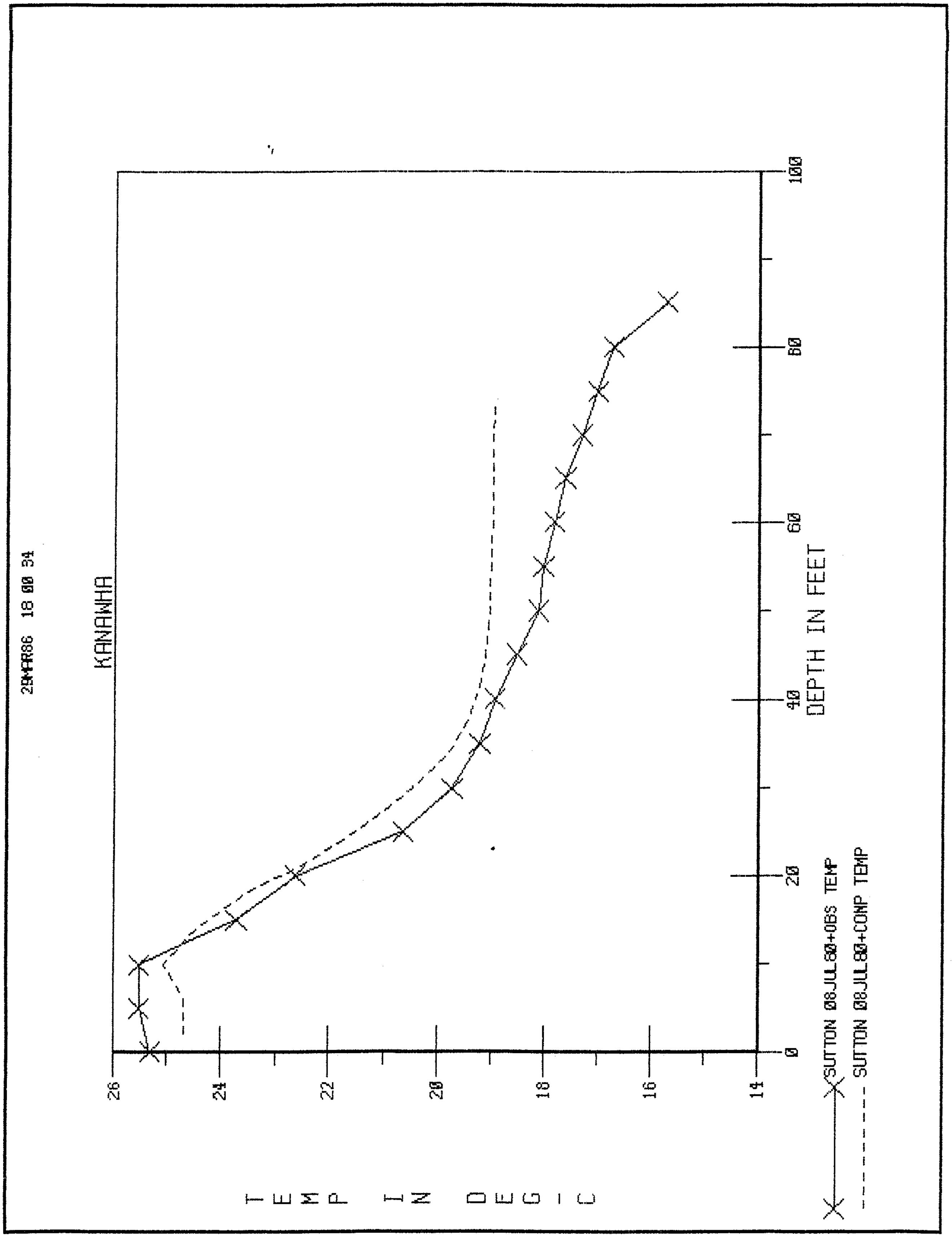
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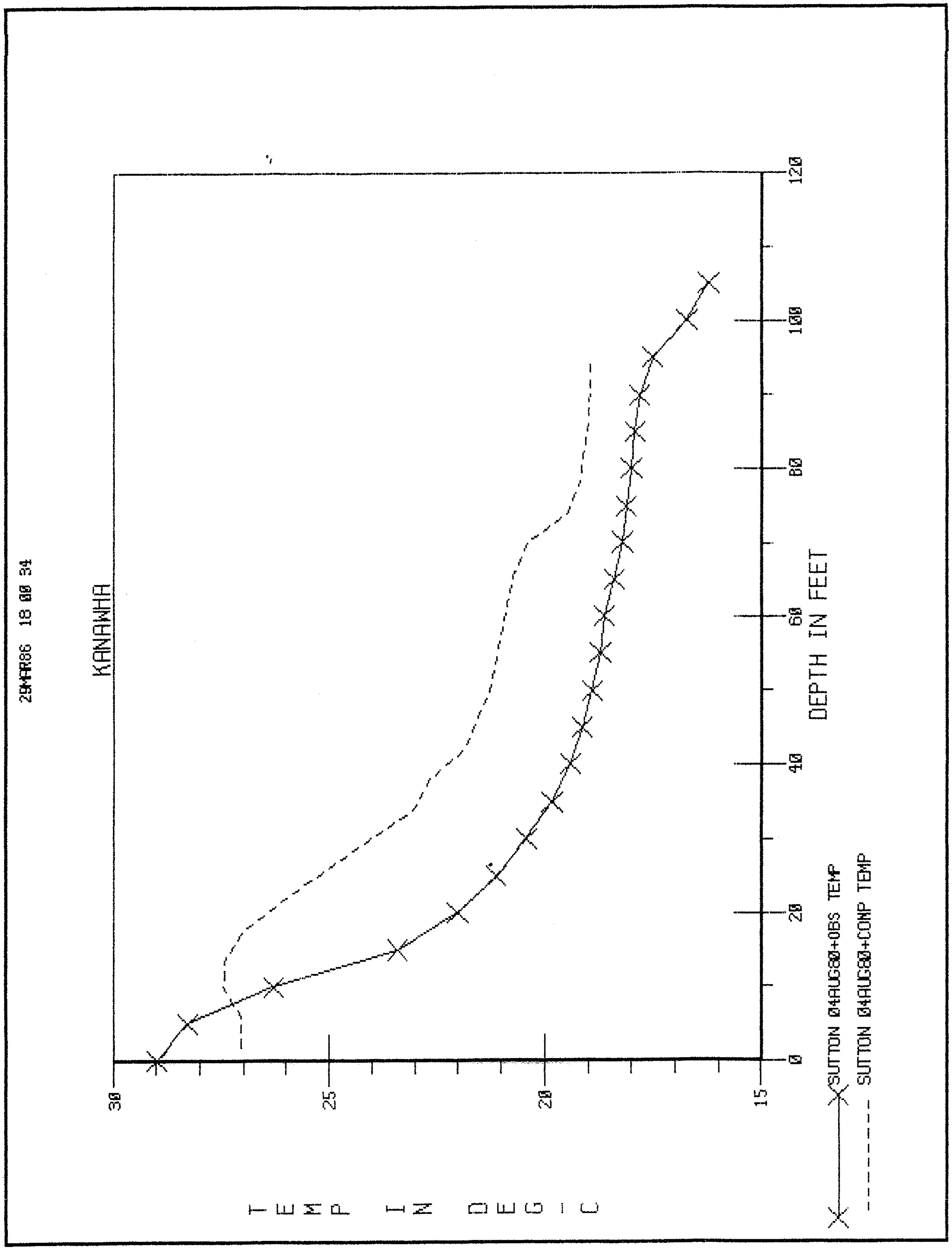
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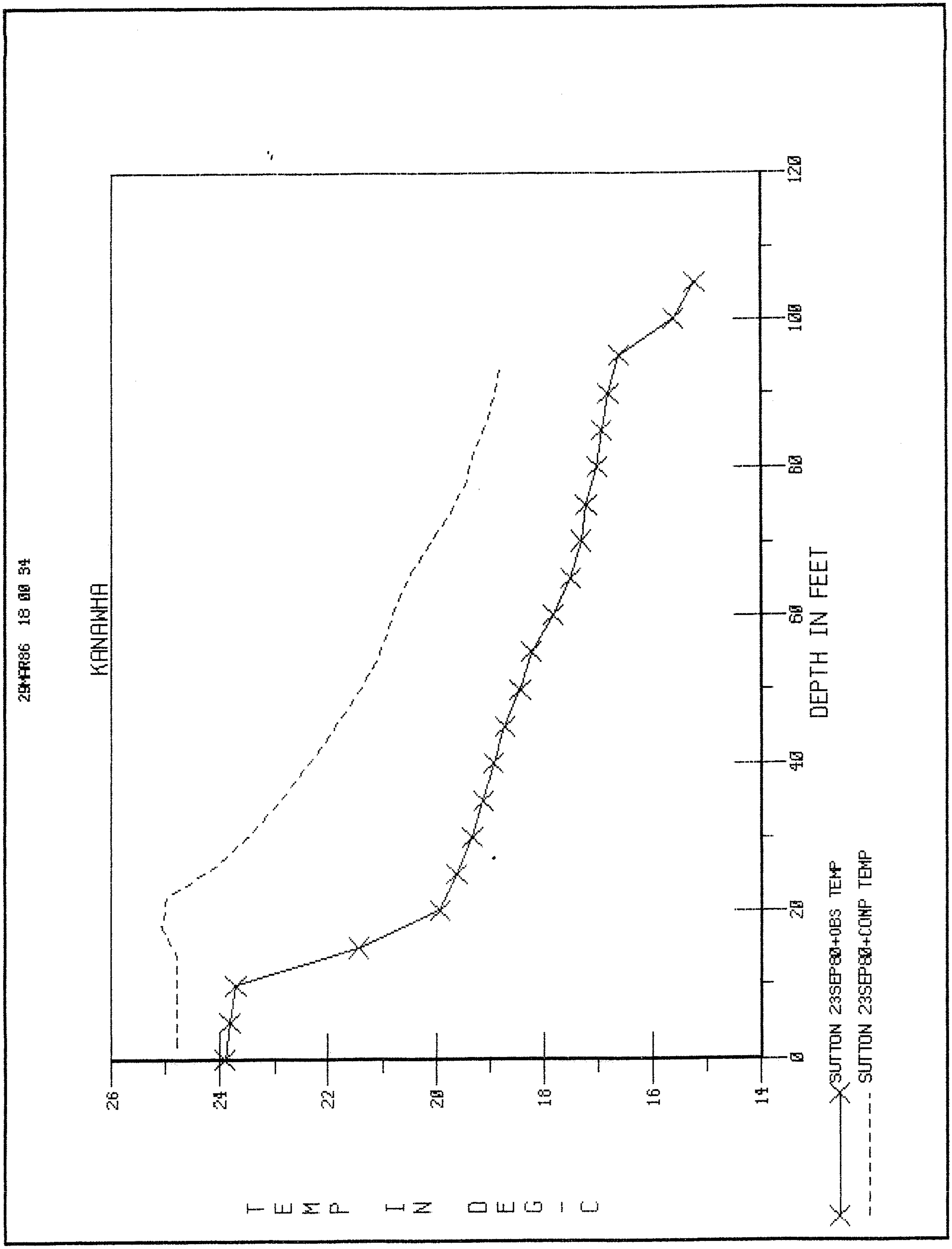
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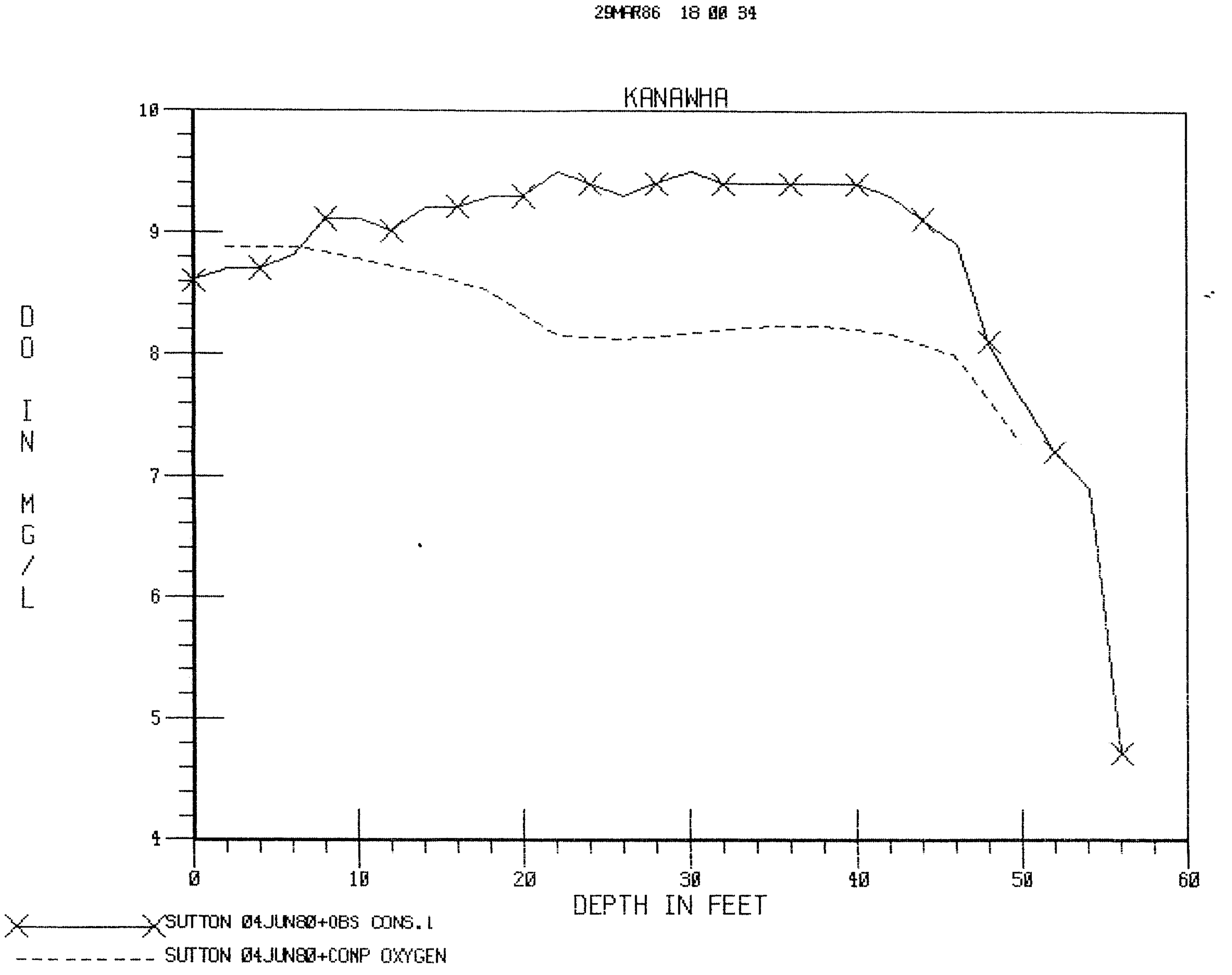
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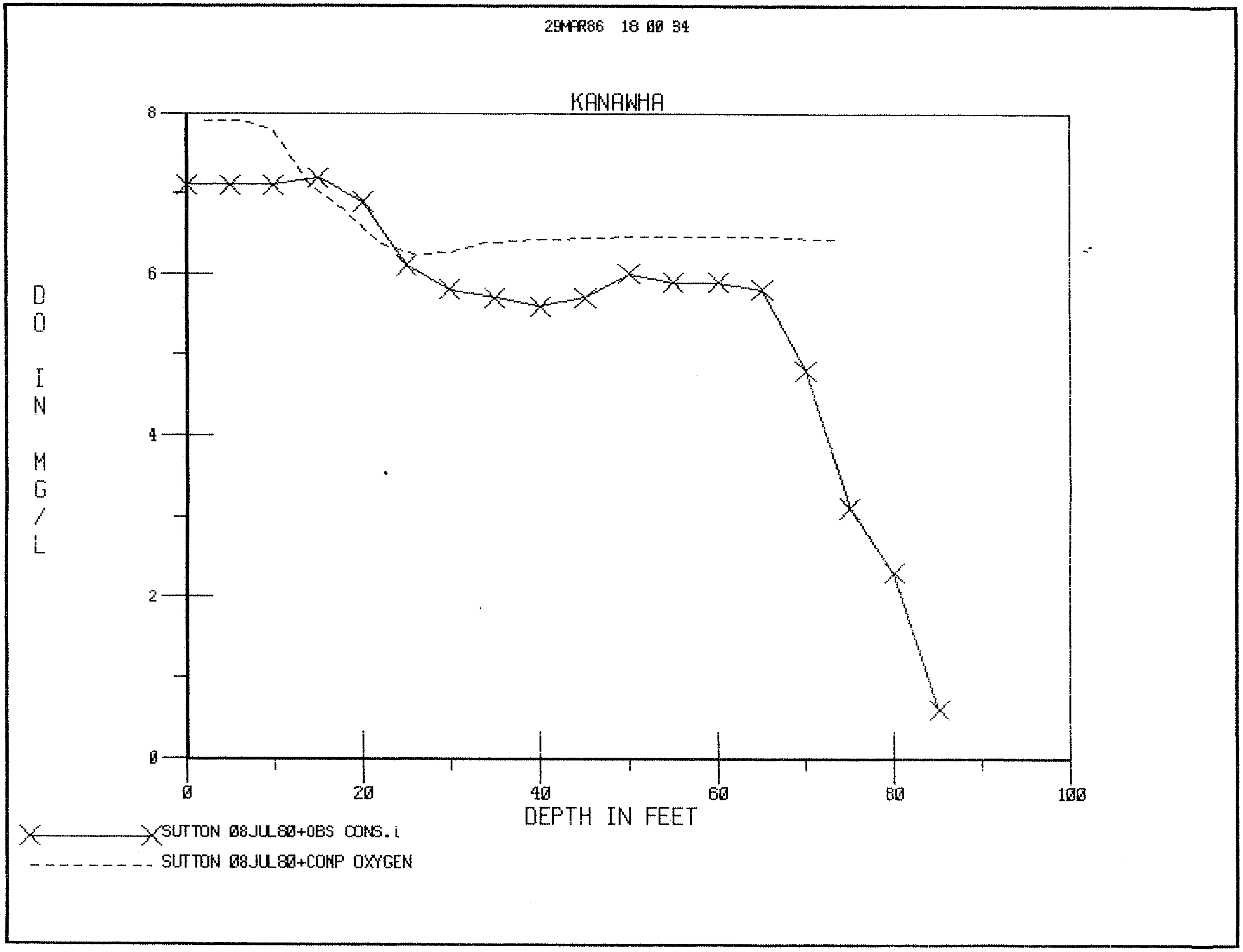
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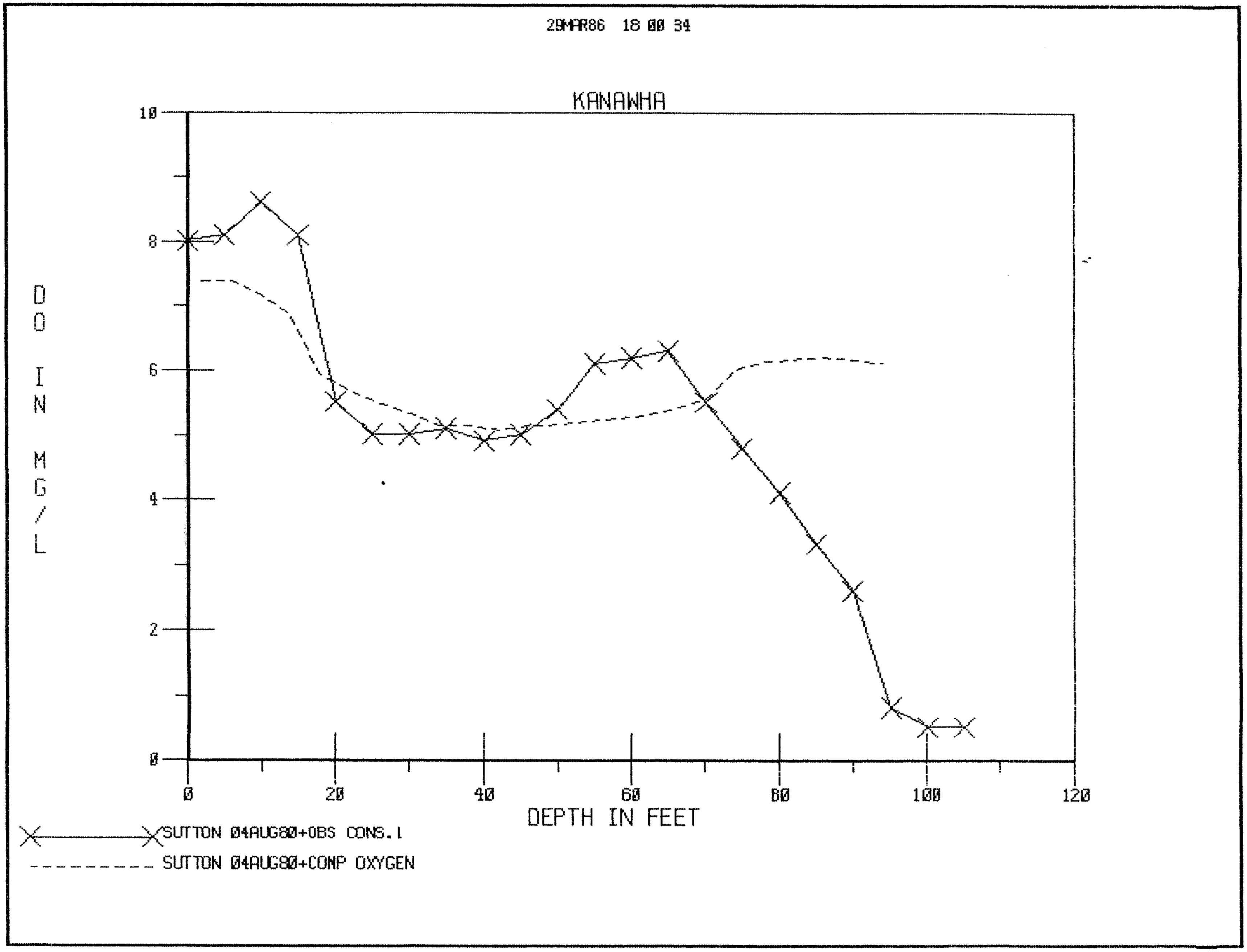
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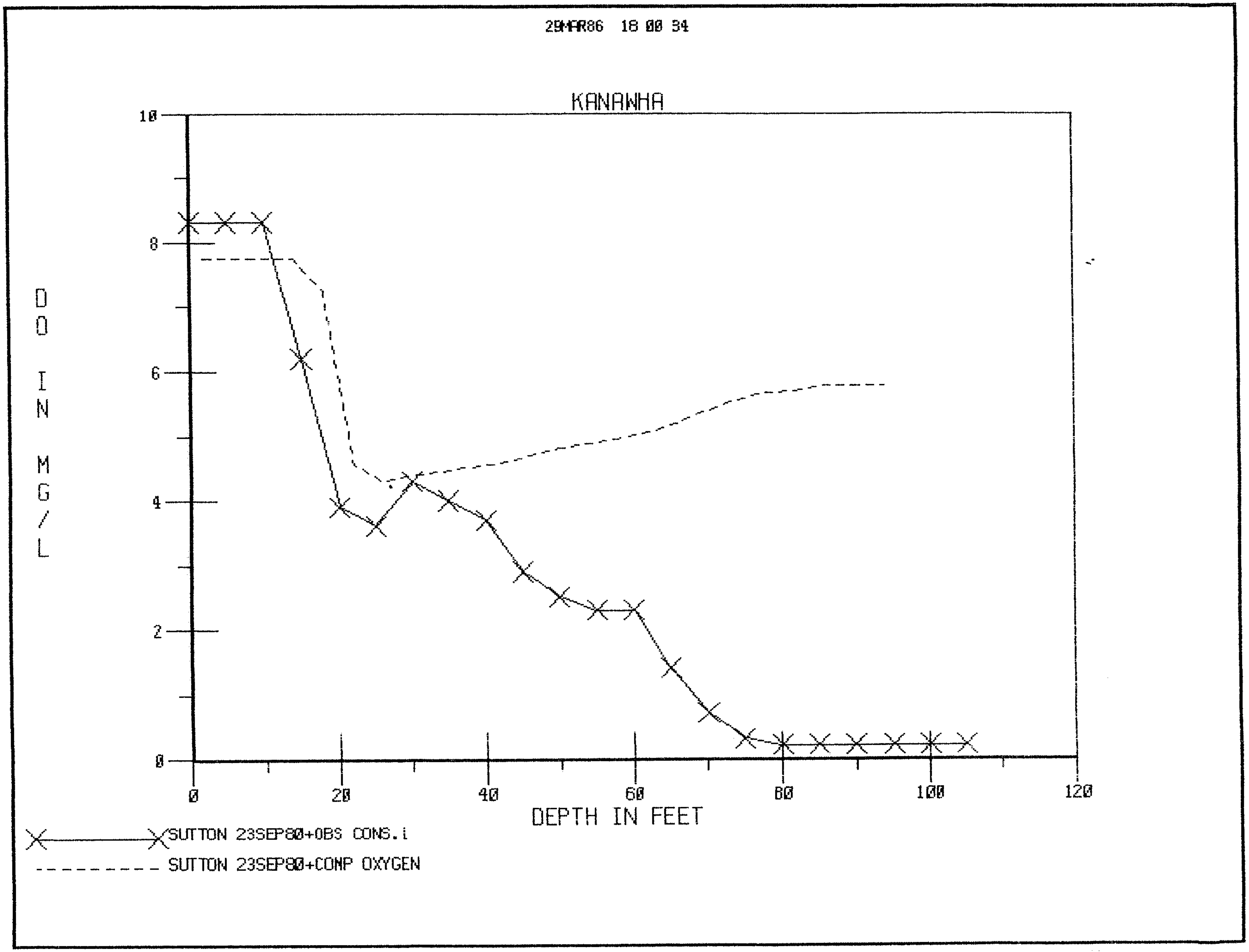
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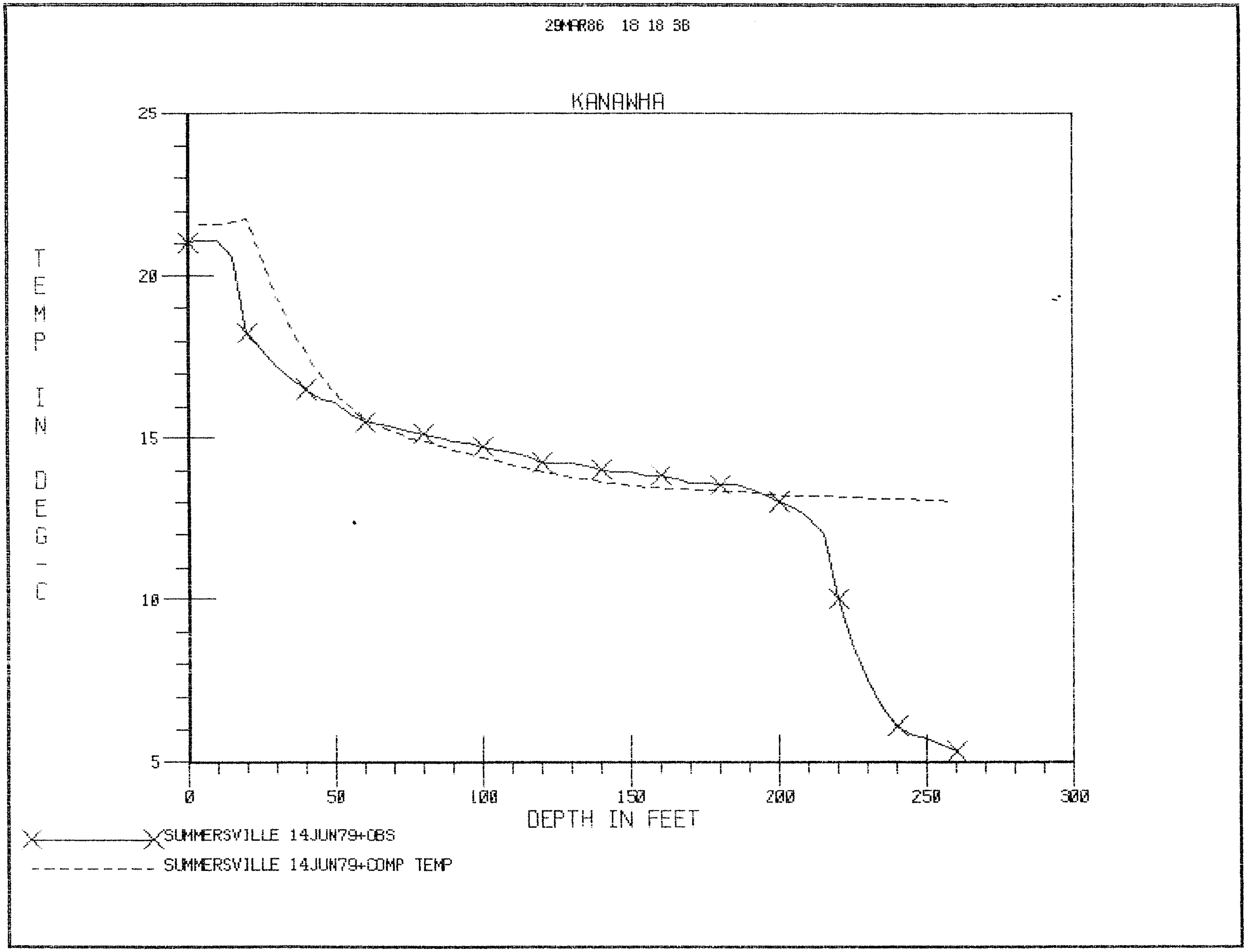

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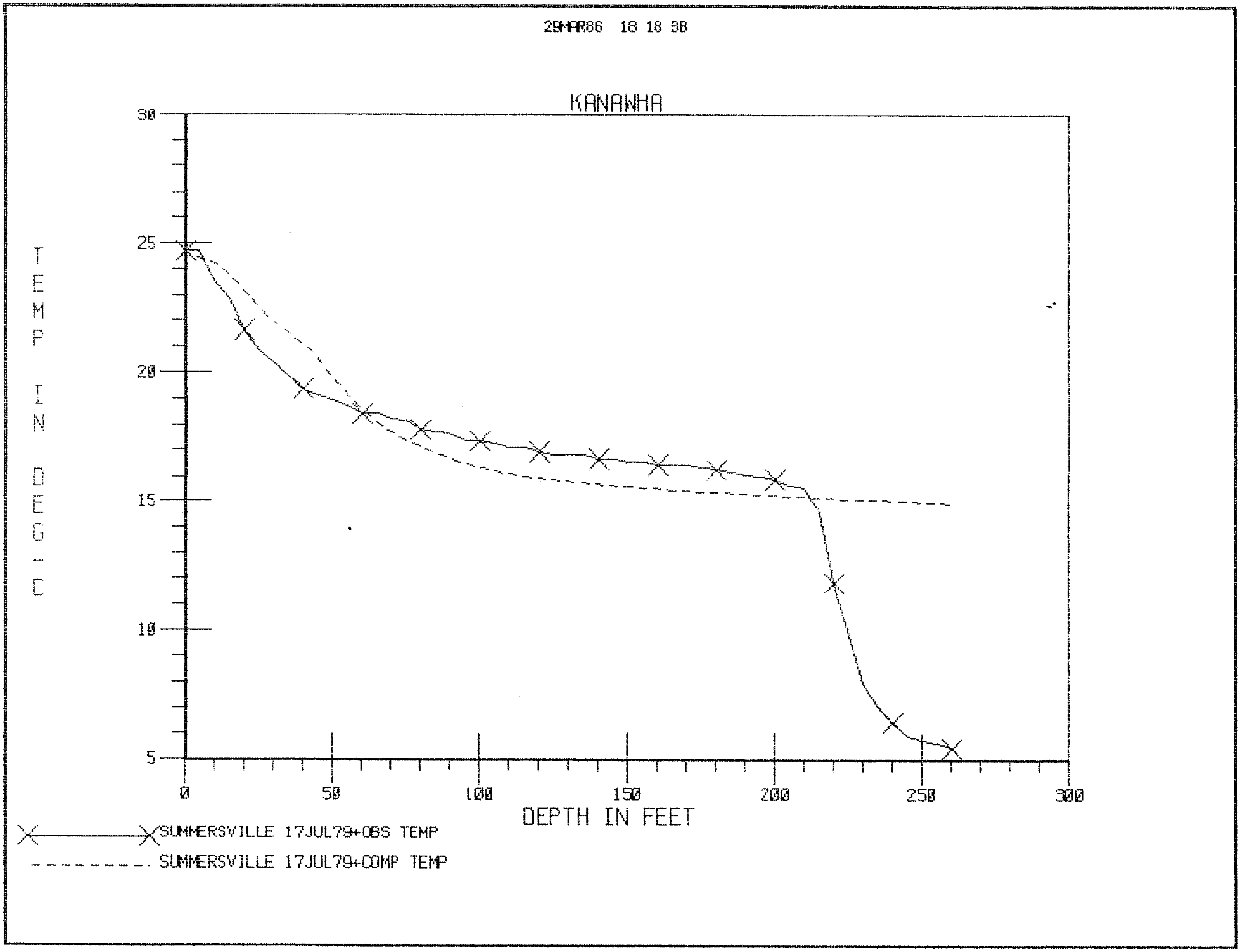
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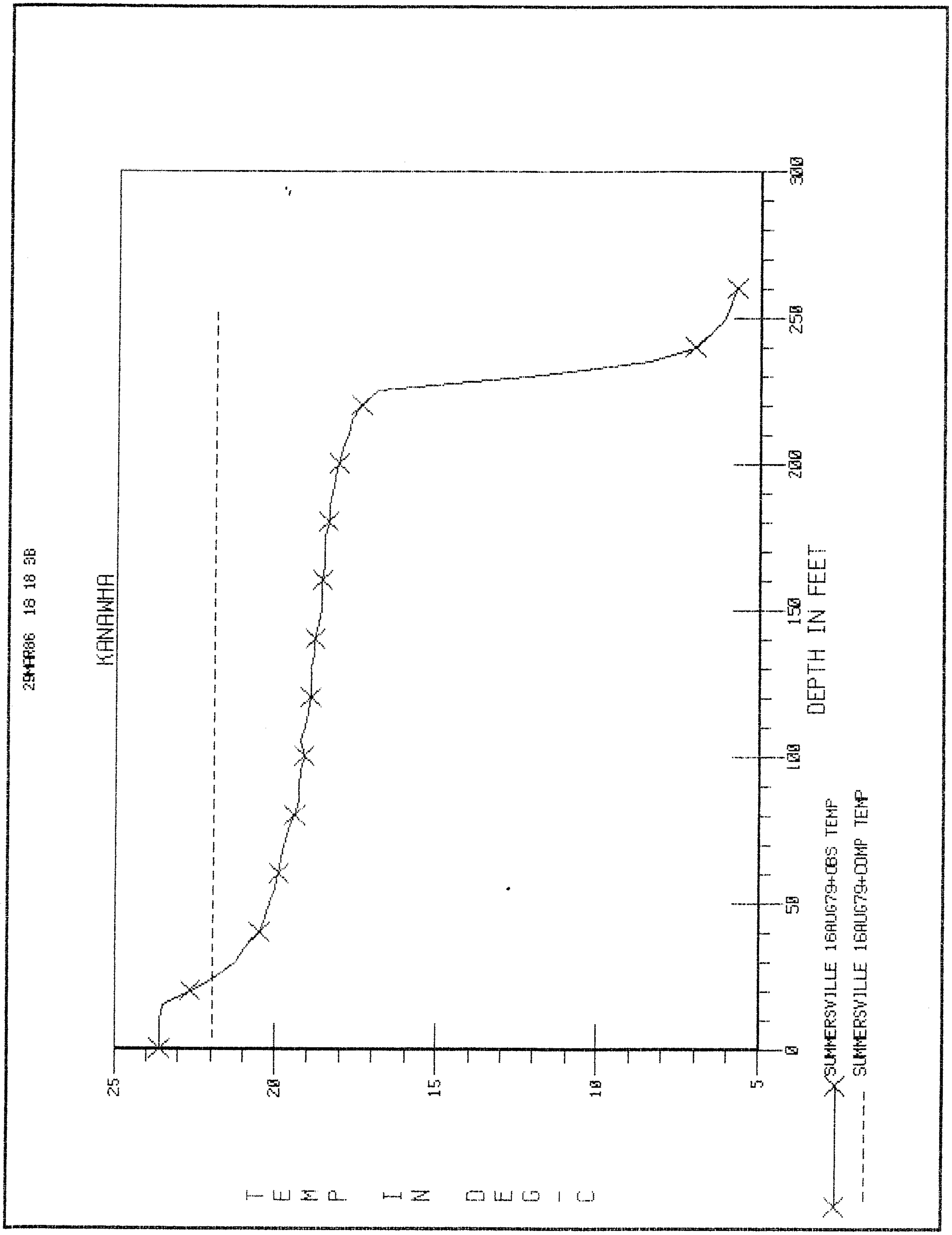
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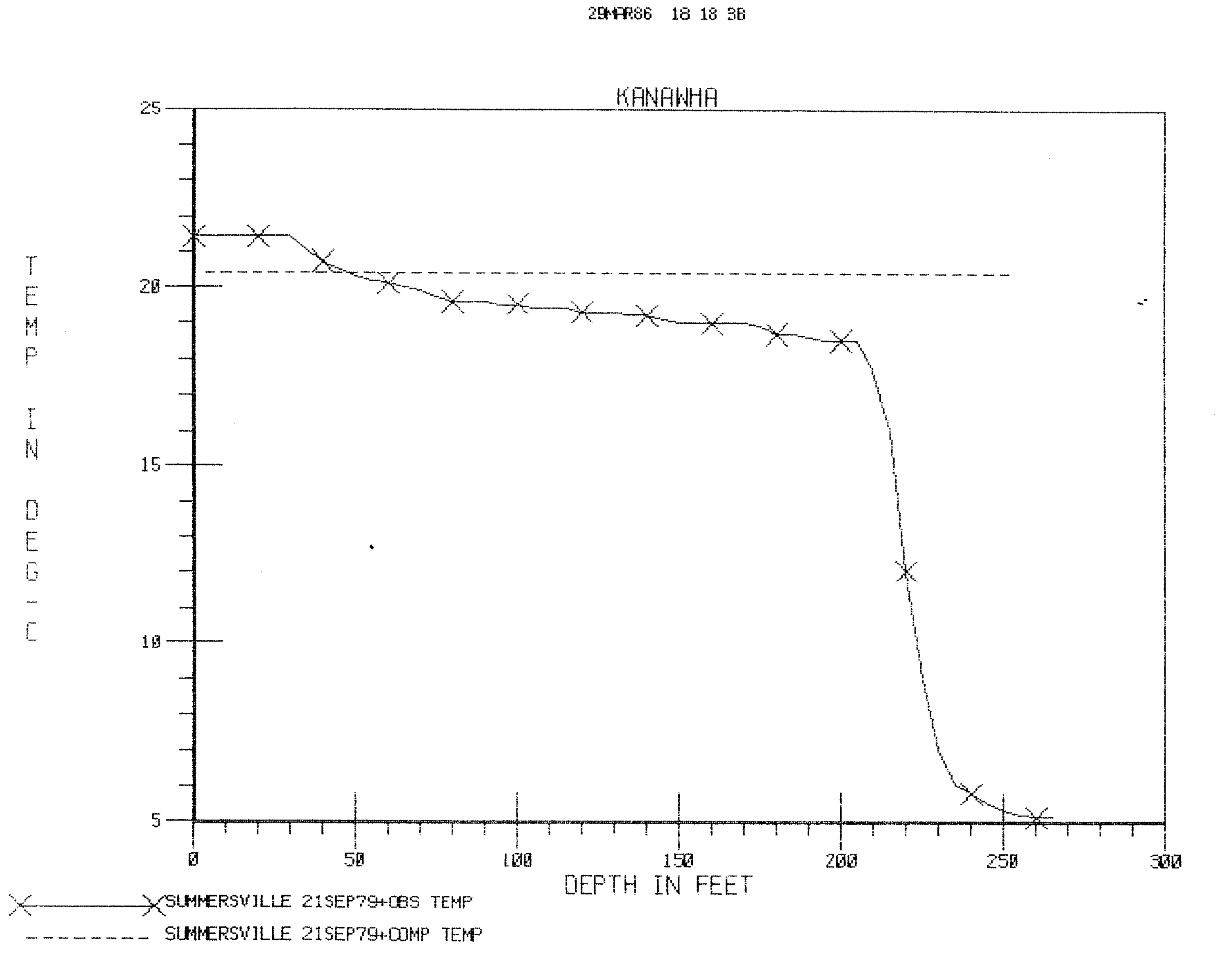
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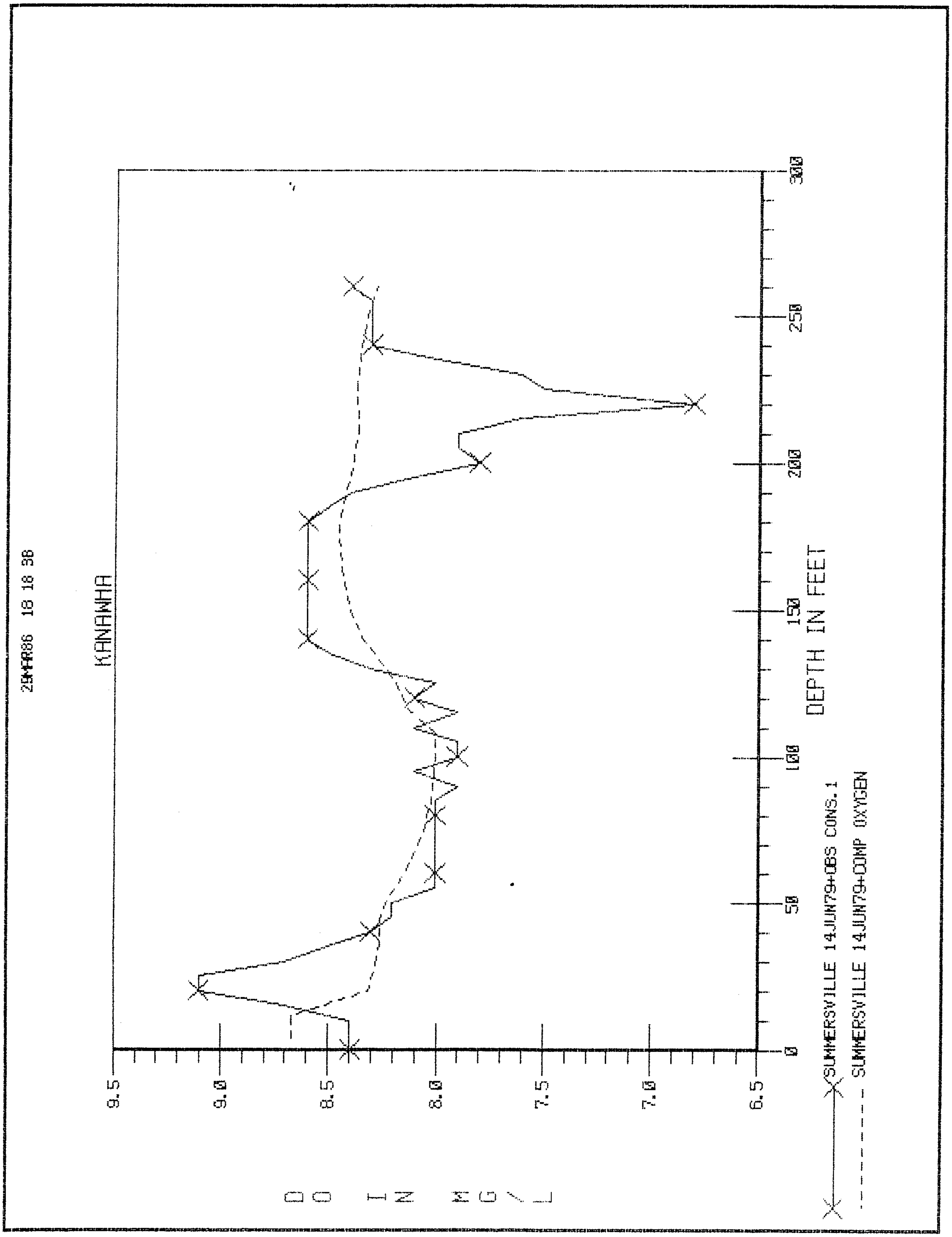
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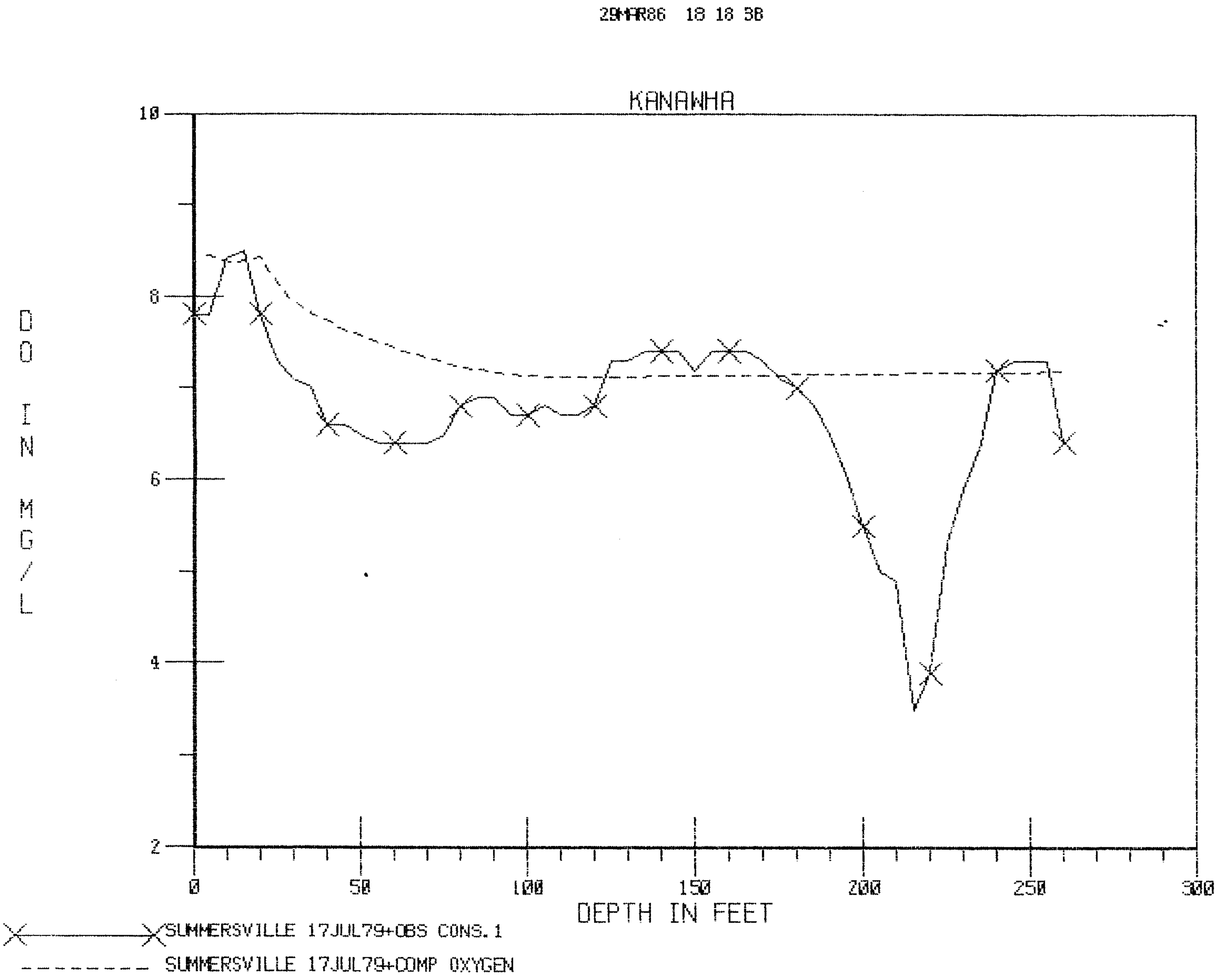
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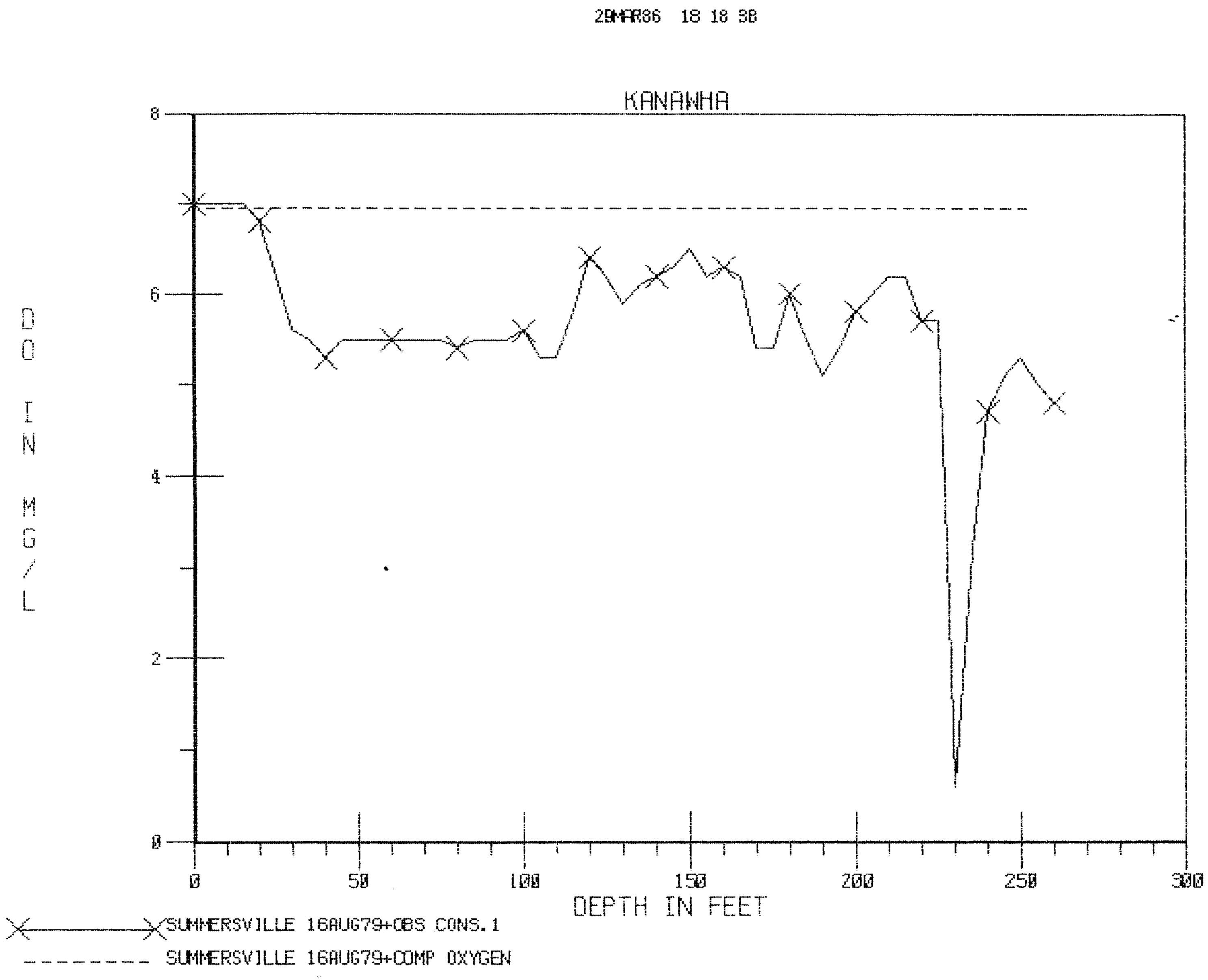
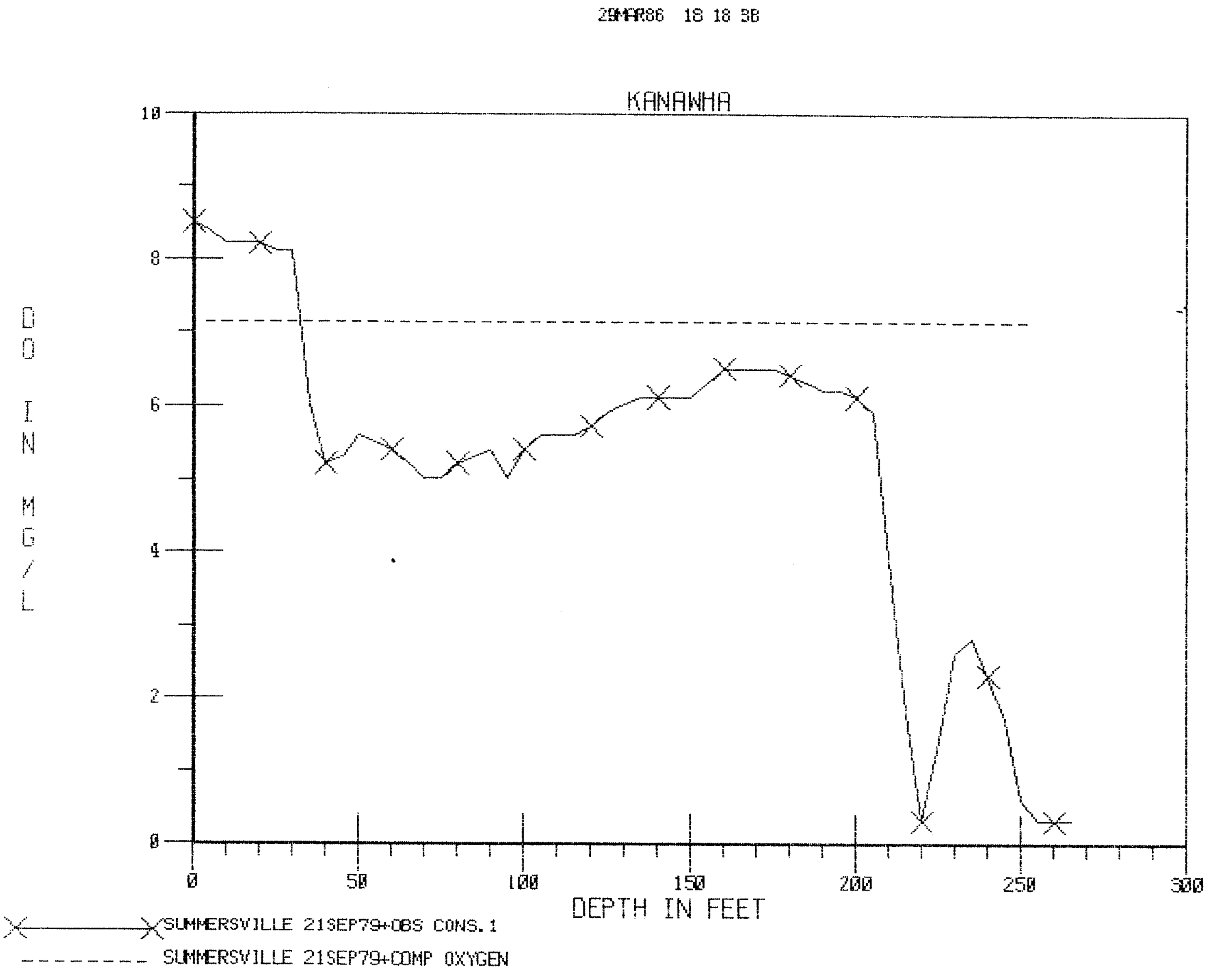
KANAWHA
DO IN MG/L
10
8
6
4
2
0
50
100
150
200
250
300
DEPTH IN FEET
SUMMERSVILLE 17JUL79+OBS CONS.1
SUMMERSVILLE 17JUL79+COMP OXYGEN


29MAR86 18 18 38
KANAWHA
DO IN MG/L
8
6
4
2
0
0
50
100
150
200
250
300
DEPTH IN FEET
SUMMERSVILLE 16AUG79+OBS CONS.1
SUMMERSVILLE 16AUG79+COMP OXYGEN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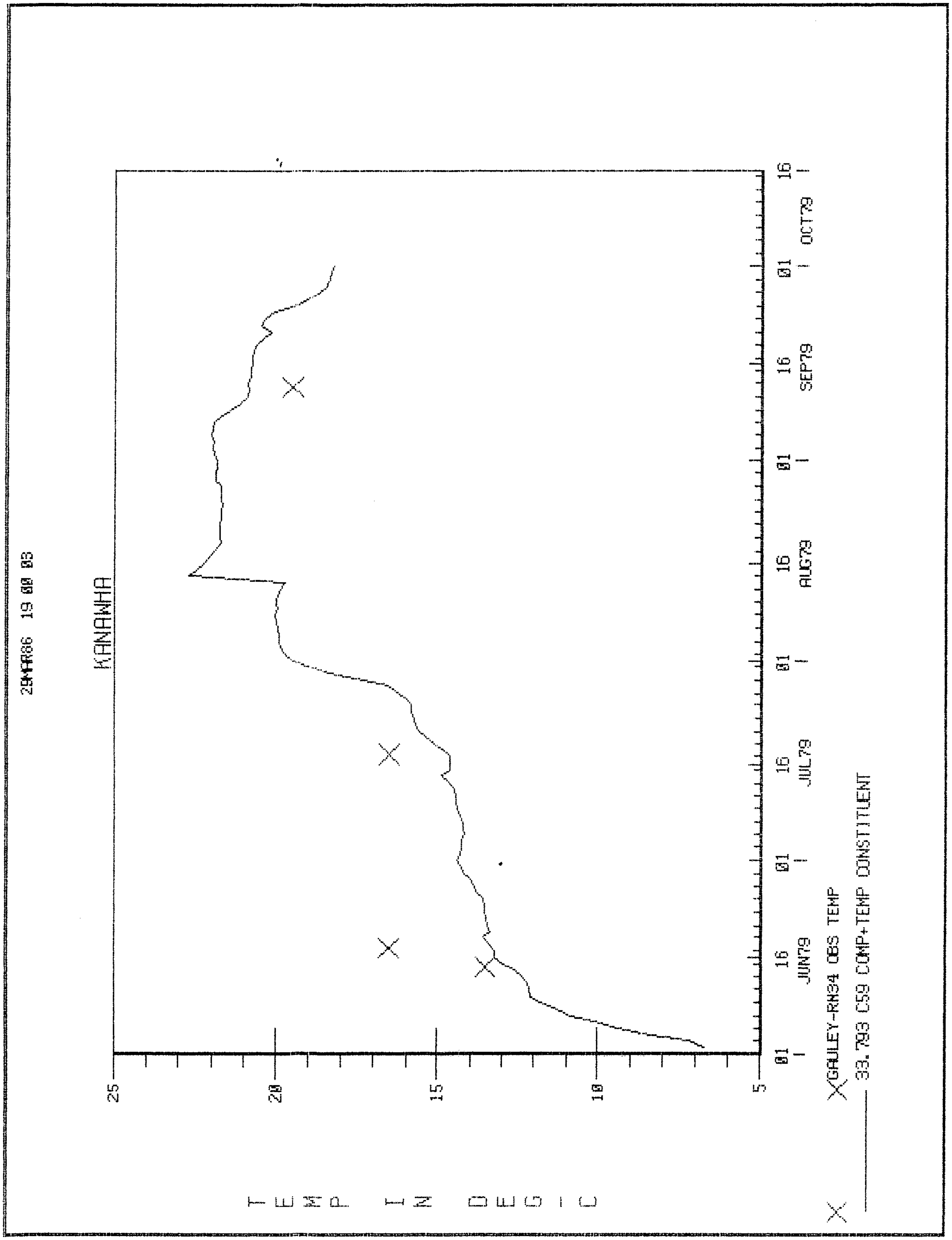
KANAWHA
DO IN MG/L
10
8
6
4
2
0
0
50
100
150
200
250
300
DEPTH IN FEET
SUMMERSVILLE 21SEP79+OBS CONS.1
SUMMERSVILLE 21SEP79+COMP OXYGEN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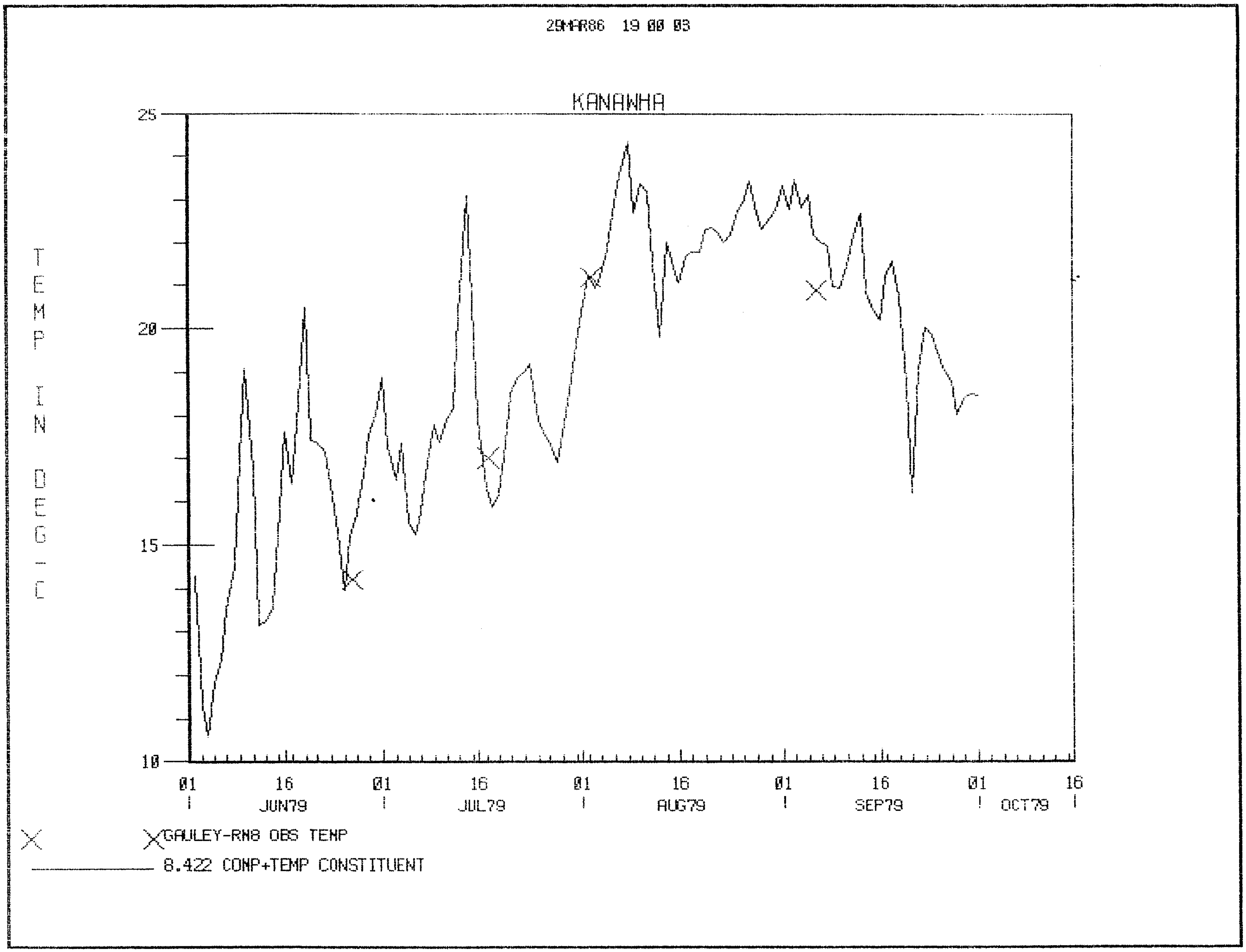
KANAWHA
TEMP IN DEG C
25
20
15
10
5
01
16
JUN79
01
16
JUL79
01
16
AUG79
01
16
SEP79
01
OCT79
16
GAULEY-RM34 OBS TEMP
33.793 C59 COMP+TEMP CONSTITUENT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KANAWHA
TEMP IN DEG-C
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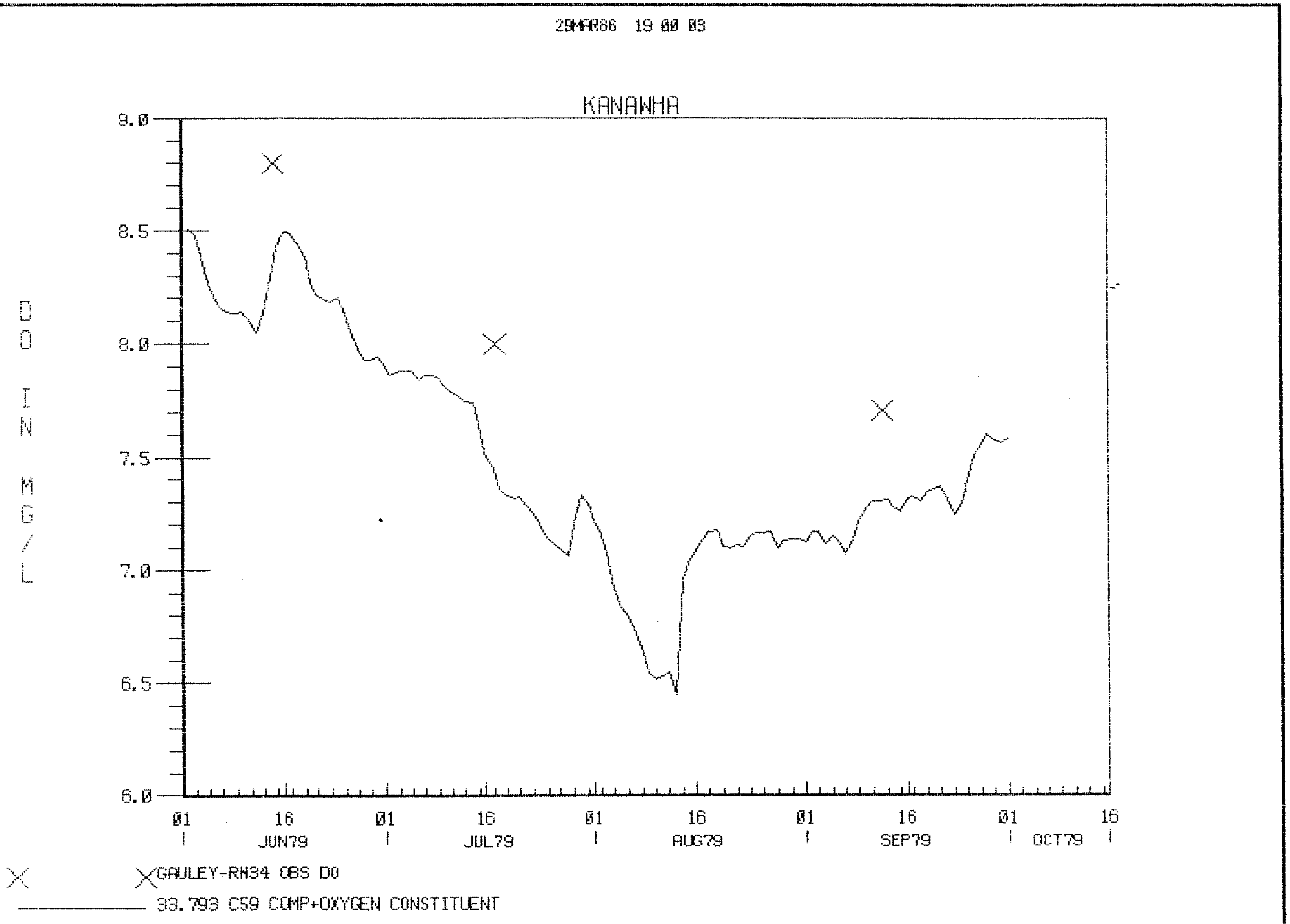
10
01
16
JUN79
01
16
JUL79
01
16
AUG79
01
16
SEP79
01
OCT79
16
GAULEY-RN8 OBS TEMP
8.422 COMP+TEMP CONSTITUENT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KANAWHA
DO IN MG/L
9.0
8.5
8.0
7.5
7.0
6.5
6.0
01
16
JUN79
01
16
JUL79
01
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AUG79
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SEP79
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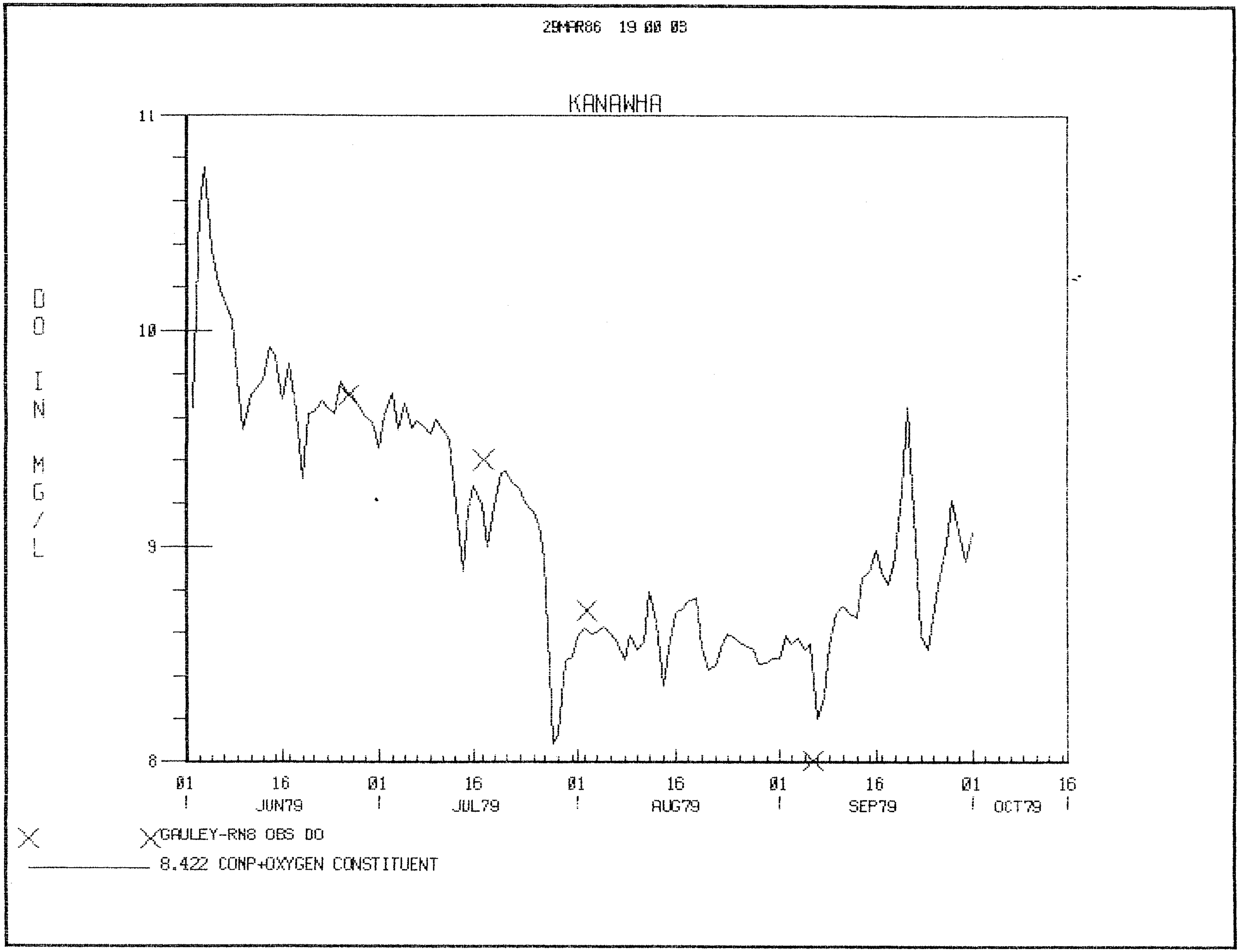
OCT79
16
GAULEY-RN34 OBS DO
33.793 C59 COMP+OXYGEN CONSTITUENT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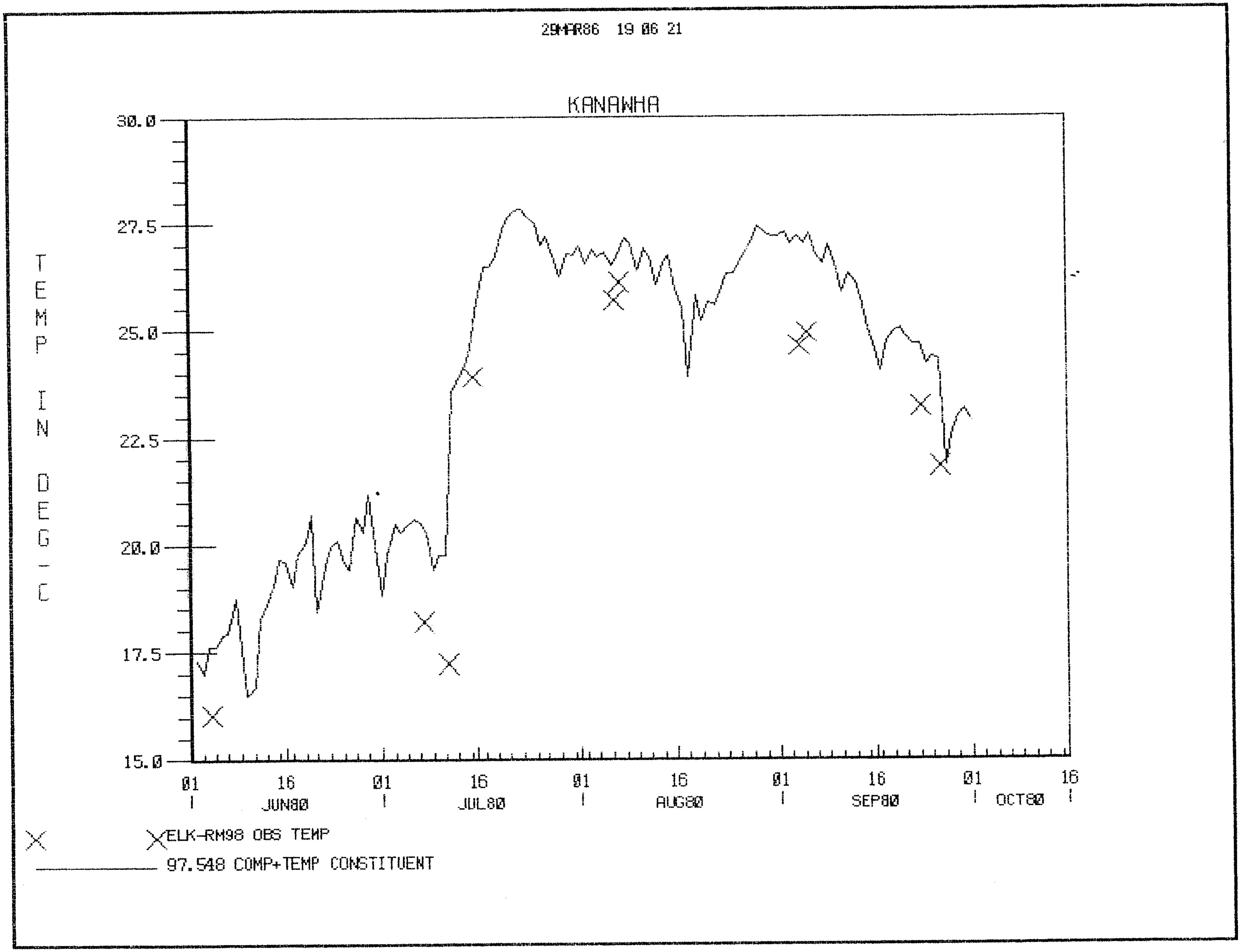
KANAWHA
DO IN MG/L
11
10
9
8
01
16
JUN79
01
16
JUL79
01
16
AUG79
01
16
SEP79
01
OCT79
16
GAULEY-RN8 OBS DO
8.422 CONP+OXYGEN CONSTITUENT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25.0
22.5
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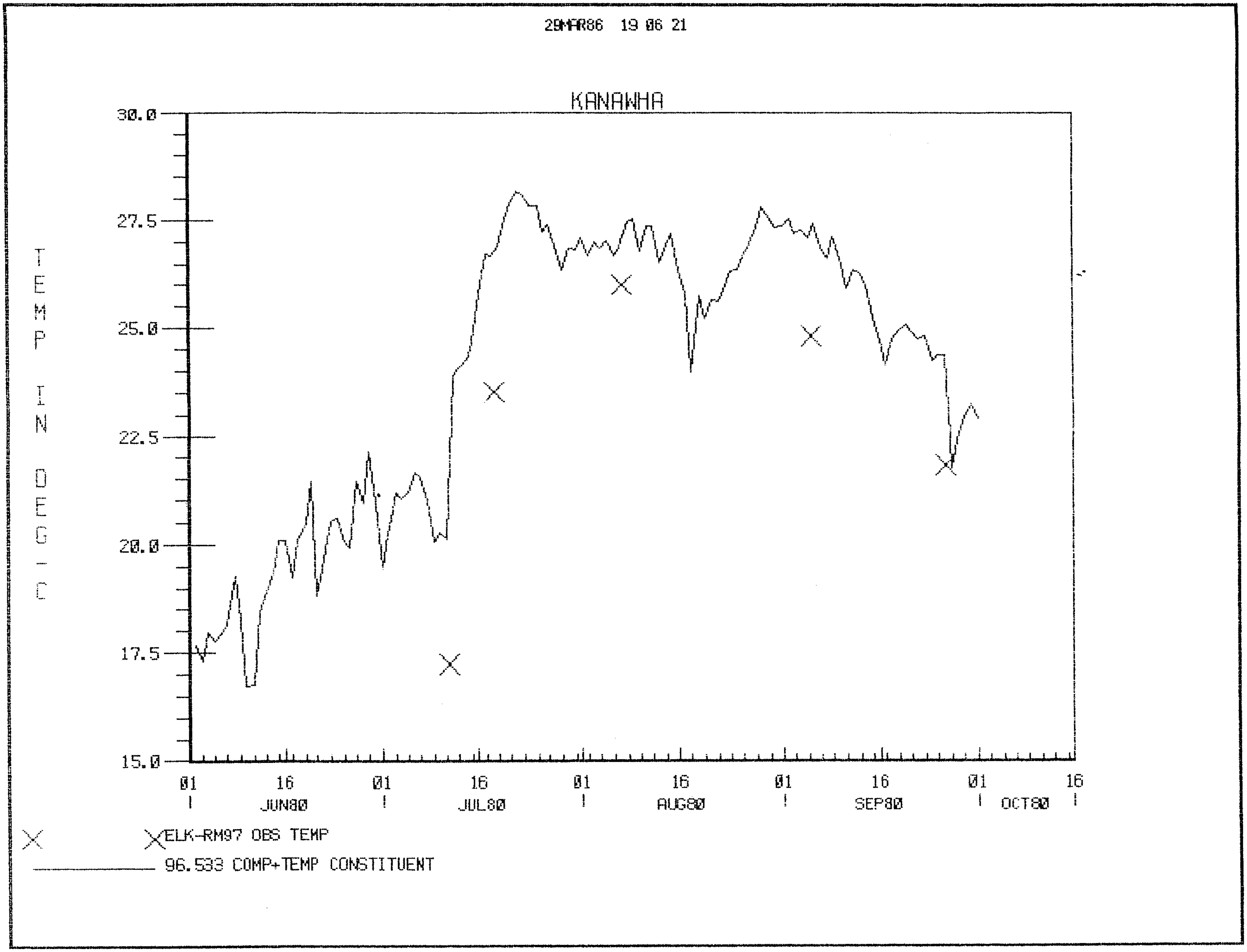
17.5
15.0
01
16
JUN80
01
16
JUL80
01
16
AUG80
01
16
SEP80
01
OCT80
16
ELK-RM98 OBS TEMP
97.548 COMP+TEMP CONSTITUENT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KANAWHA
TEMP IN DEG-C
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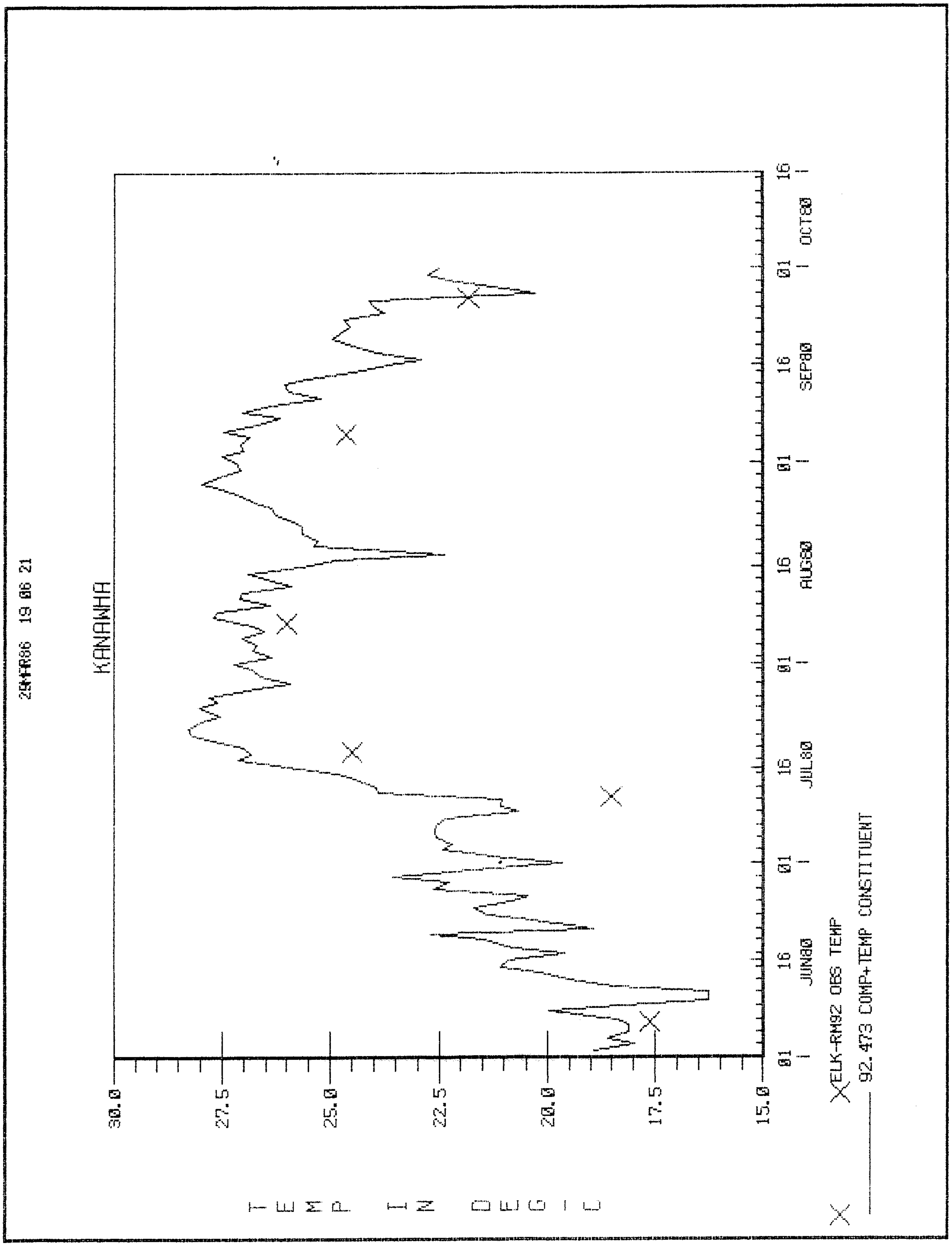
25.0
22.5
20.0
17.5
15.0
01
16
JUN80
01
16
JUL80
01
16
AUG80
01
16
SEP80
01
OCT80
16
ELK-RM97 OBS TEMP
96.533 COMP+TEMP CONSTITUENT



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KANAWHA
TEMP IN DEG C
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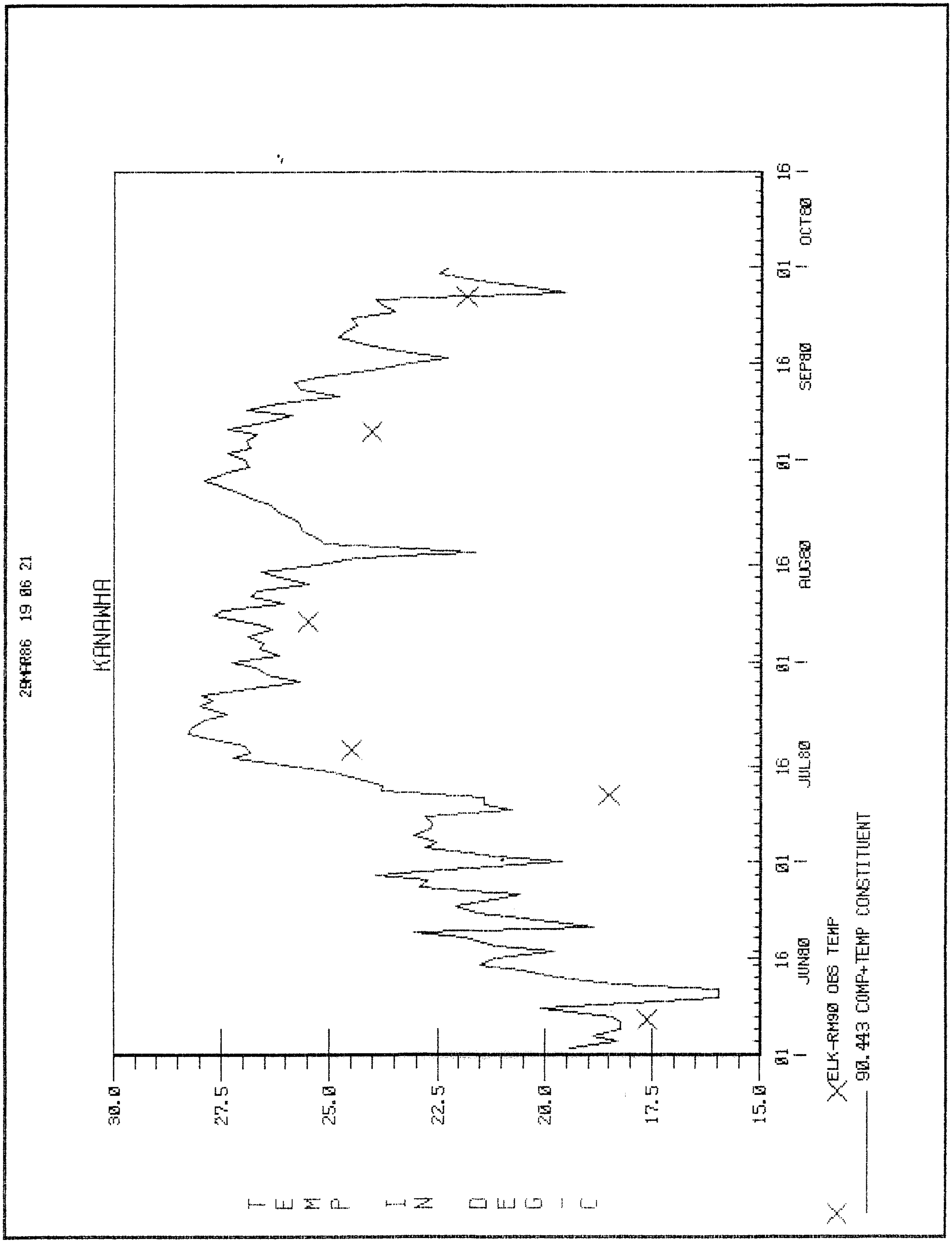
25.0
22.5
20.0
17.5
15.0
01
16
JUN80
01
16
JUL80
01
16
AUG80
01
16
SEP80
01
OCT80
16
ELK-RM92 OBS TEMP
92.473 COMP+TEMP CONSTITUENT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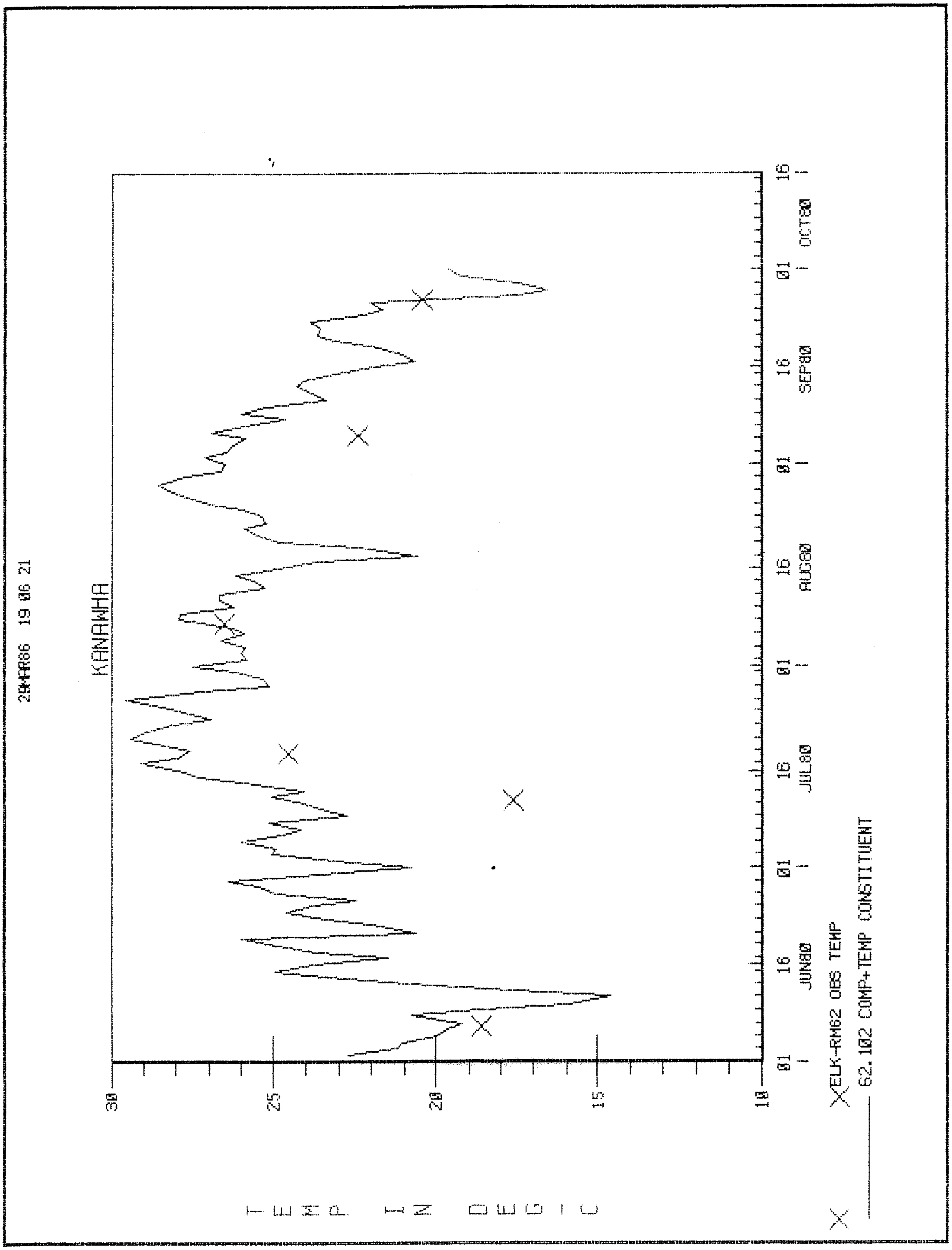
KANAWHA
TEMP IN DEG C
30.0
27.5
25.0
22.5
20.0
17.5
15.0
01
16
JUN80
01
16
JUL80
01
16
AUG80
01
16
SEP80
01
OCT80
16
ELK-RM90 OBS TEMP
90.443 COMP+TEMP CONSTITUENT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KANAWHA
TEMP IN DEG C
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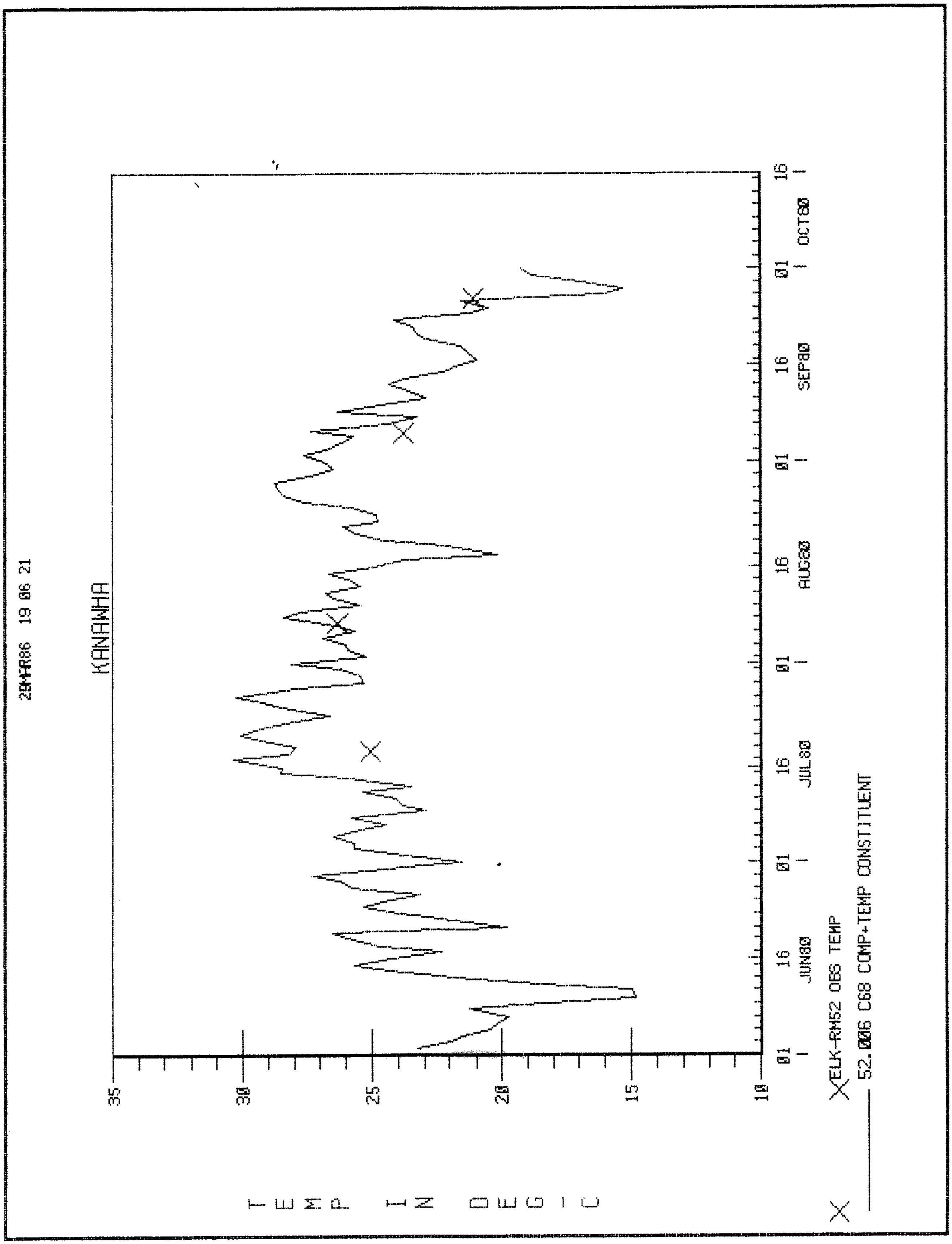
25
20
15
10
01
16
JUN80
01
16
JUL80
01
16
AUG80
01
16
SEP80
01
OCT80
16
ELK-RM62 OBS TEMP
62.102 COMP+TEMP CONSTITUENT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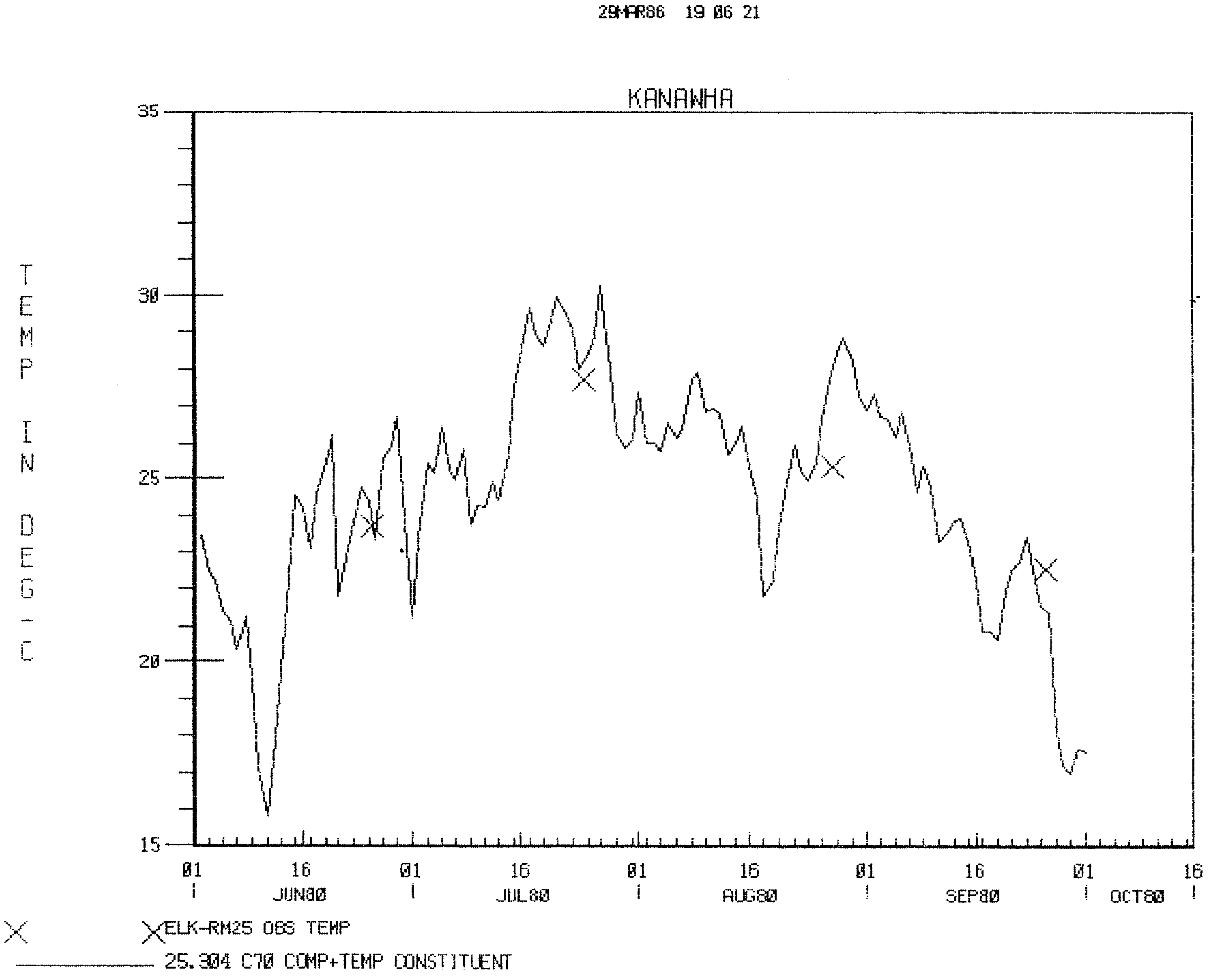
KANAWHA
TEMP IN DEG C
35
30
25
20
15
10
01
16
JUN80
01
16
JUL80
01
16
AUG80
01
16
SEP80
01
OCT80
16
ELK-RM52 OBS TEMP
52.006 C68 COMP+TEMP CONSTITUENT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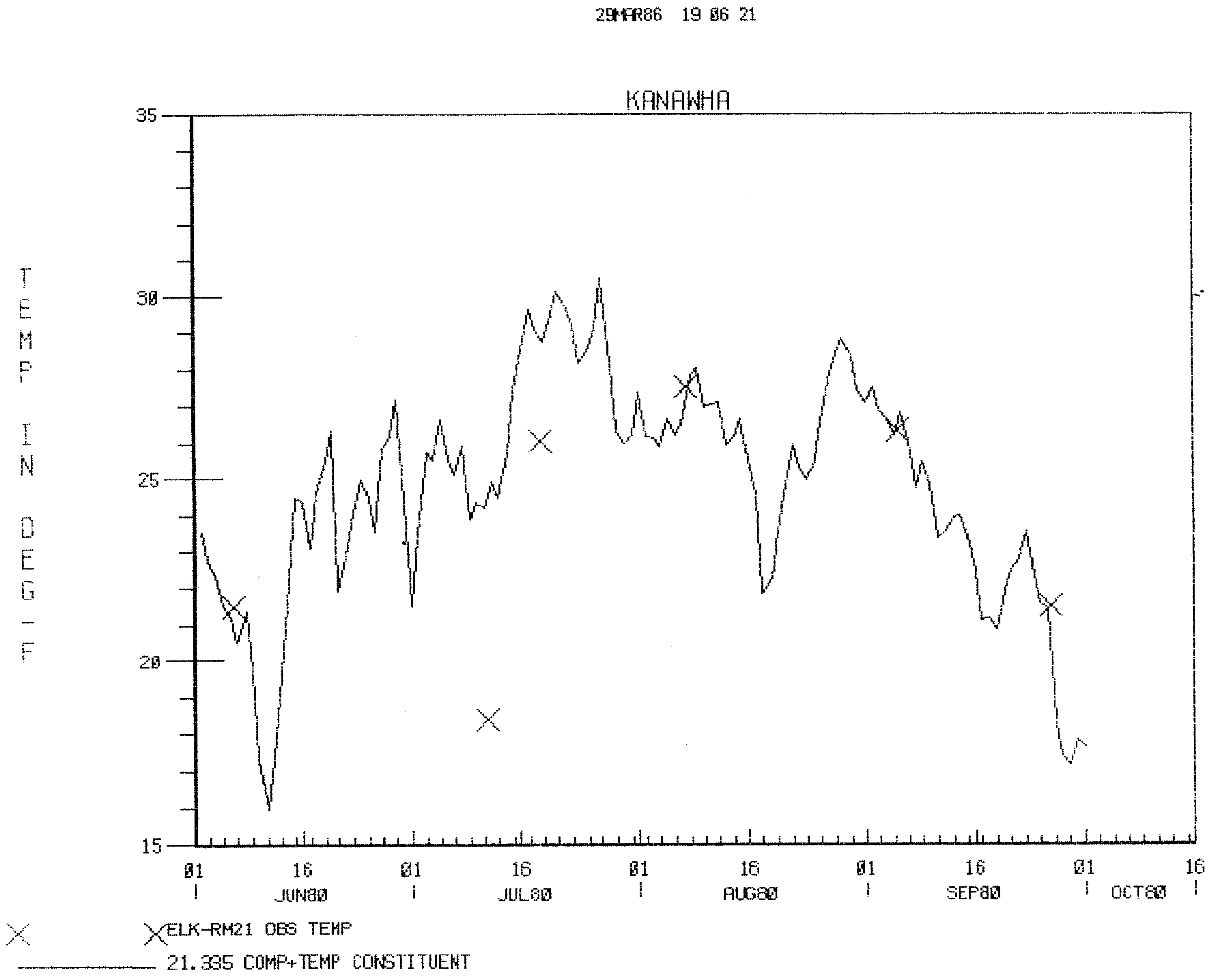
KANAWHA
TEMP IN DEG-C
35
30
25
20
15
01
16
JUN80
01
16
JUL80
01
16
AUG80
01
16
SEP80
01
OCT80
16
ELK-RM25 OBS TEMP
25.304 C70 COMP+TEMP CONSTITUENT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TEMP IN DEG-F
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30
25
20
15
01
16
JUN80
01
16
JUL80
01
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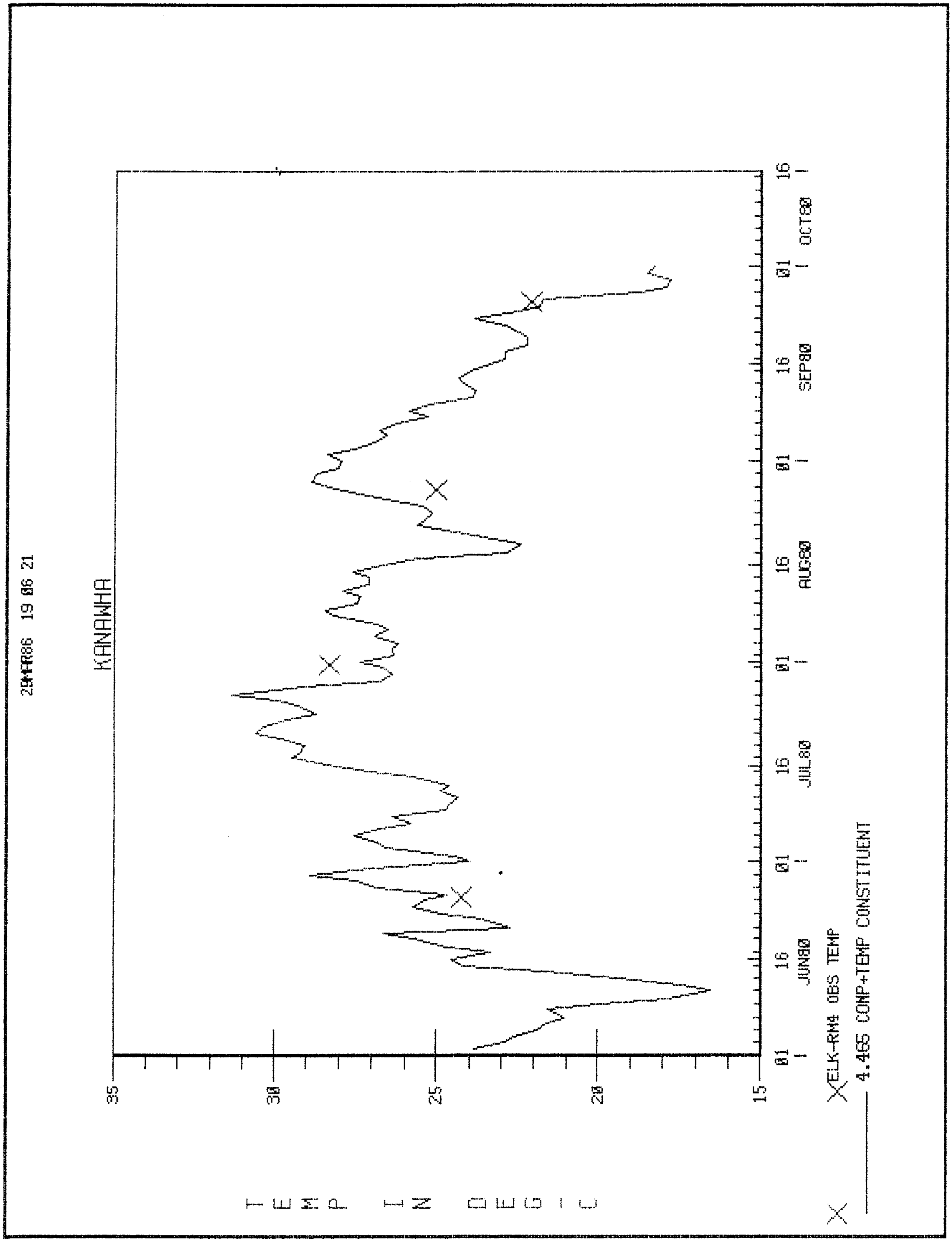
AUG80
01
16
SEP80
01
OCT80
16
ELK-RM21 OBS TEMP
21.335 COMP+TEMP CONSTITUENT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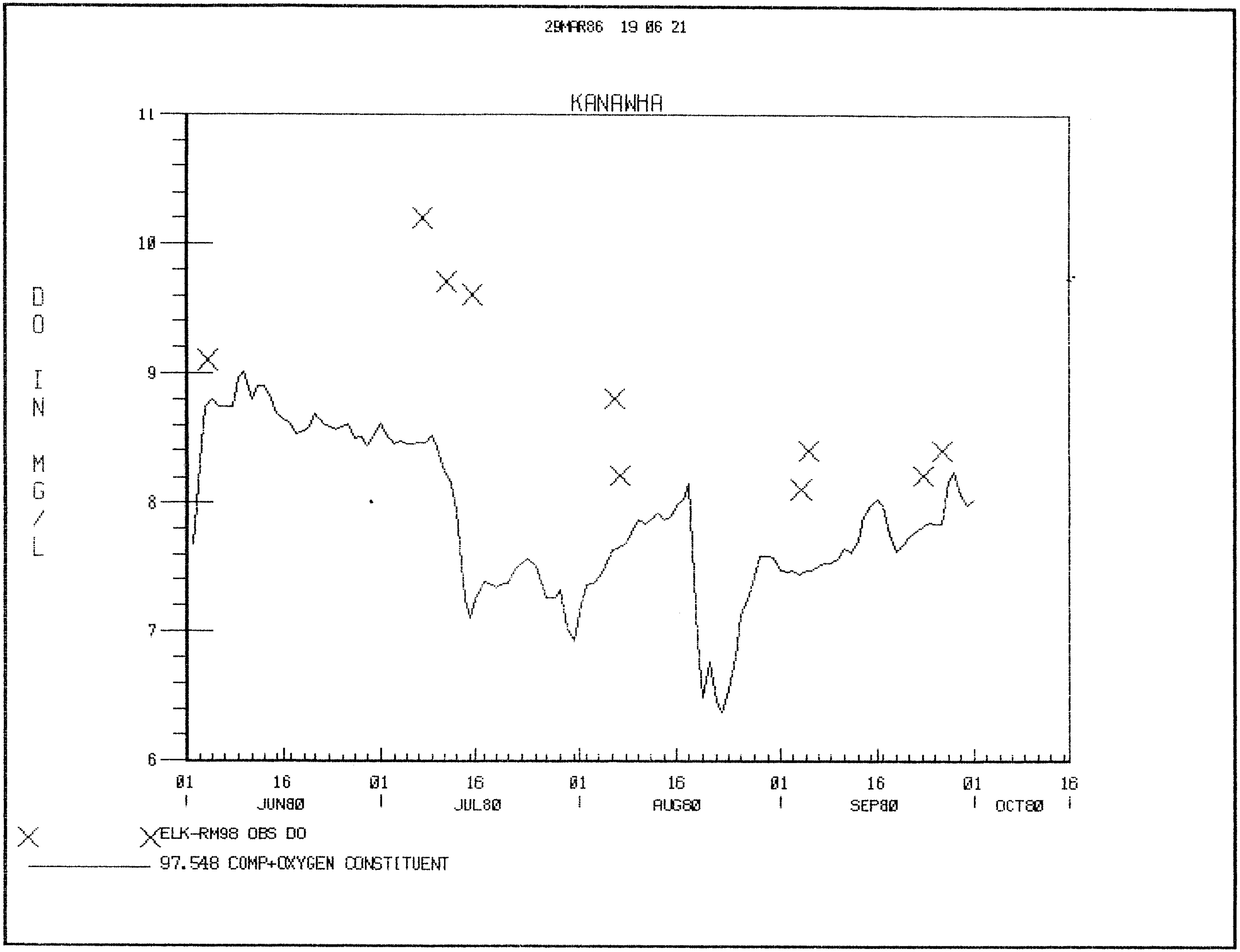
KANAWHA
TEMP IN DEG C
35
30
25
20
15
01
16
JUN80
01
16
JUL80
01
16
AUG80
01
16
SEP80
01
16
OCT80
ELK-RM4 OBS TEMP
4.465 COMP+TEMP CONSTITUENT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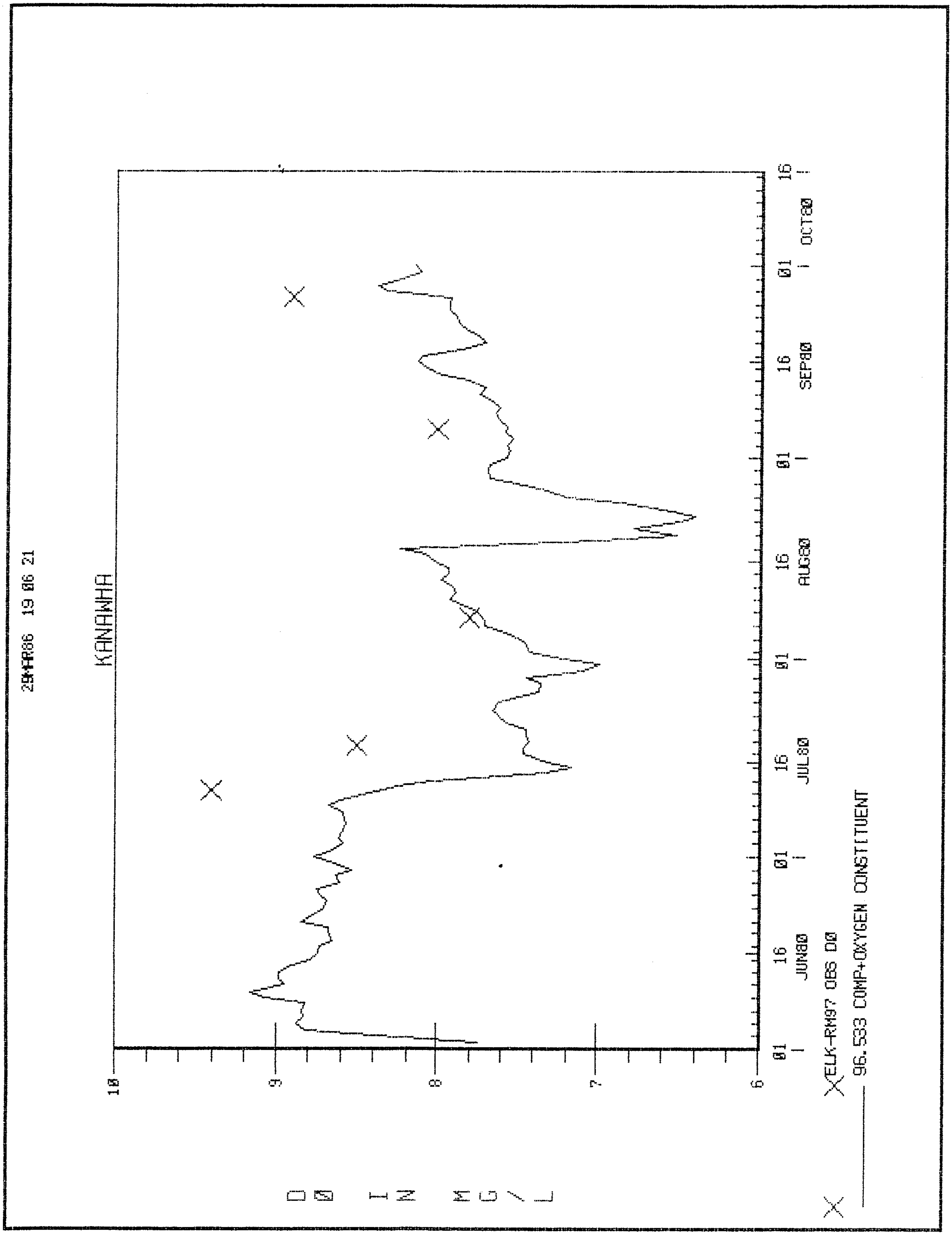
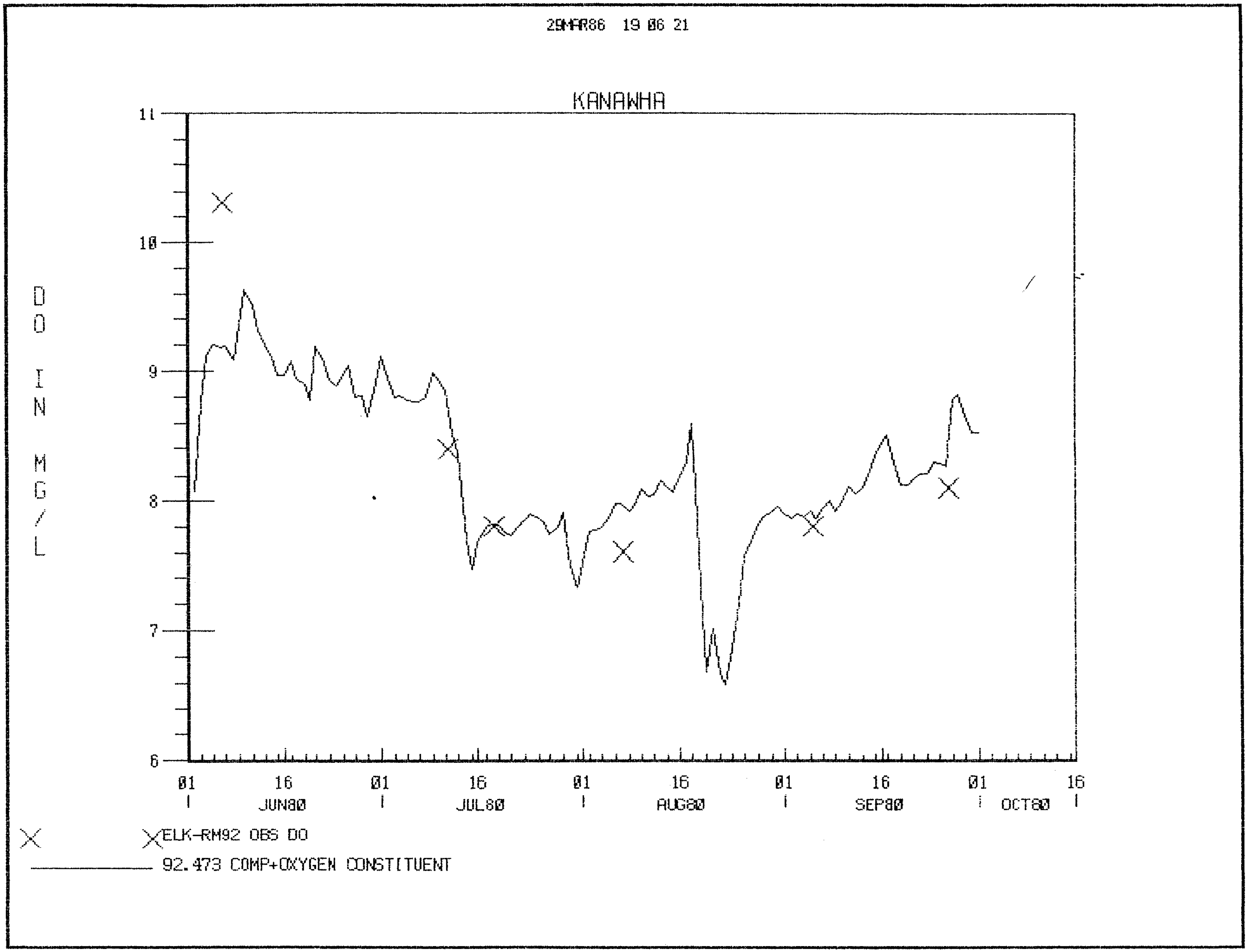
KANAWHA
DO IN MG/L
11
10
9
8
7
6
01
16
JUN80
01
16
JUL80
01
16
AUG80
01
16
SEP80
01
OCT80
16
ELK-RM98 OBS DO
97.548 COMP+OXYGEN CONSTITUENT


29MAR86 19 06 21
KANAWHA
DO IN MG/L
10
9
8
7
6
01
16
JUN80
01
16
JUL80
01
16
AUG80
01
16
SEP80
01
16
OCT80
ELK-RM97 OBS DO
96.533 COMP+OXYGEN CONSTITUENT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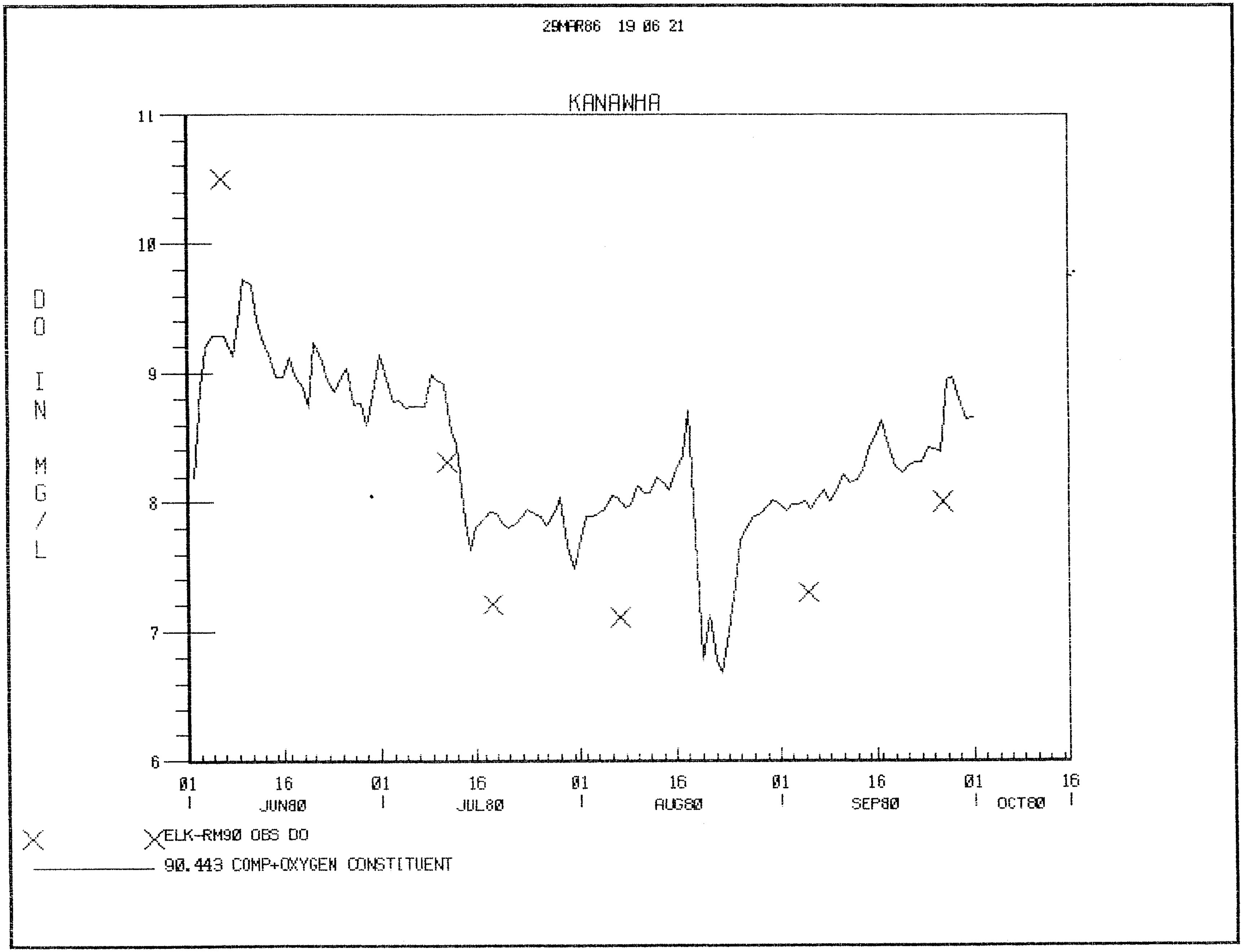
KANAWHA
DO IN MG/L
11
10
9
8
7
6
01
16
JUN80
01
16
JUL80
01
16
AUG80
01
16
SEP80
01
OCT80
16
ELK-RM92 OBS DO
92.473 COMP+OXYGEN CONSTITUENT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KANAWHA
DO IN MG/L
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10
9
8
7
6
01
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AUG80
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SEP80
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OCT80
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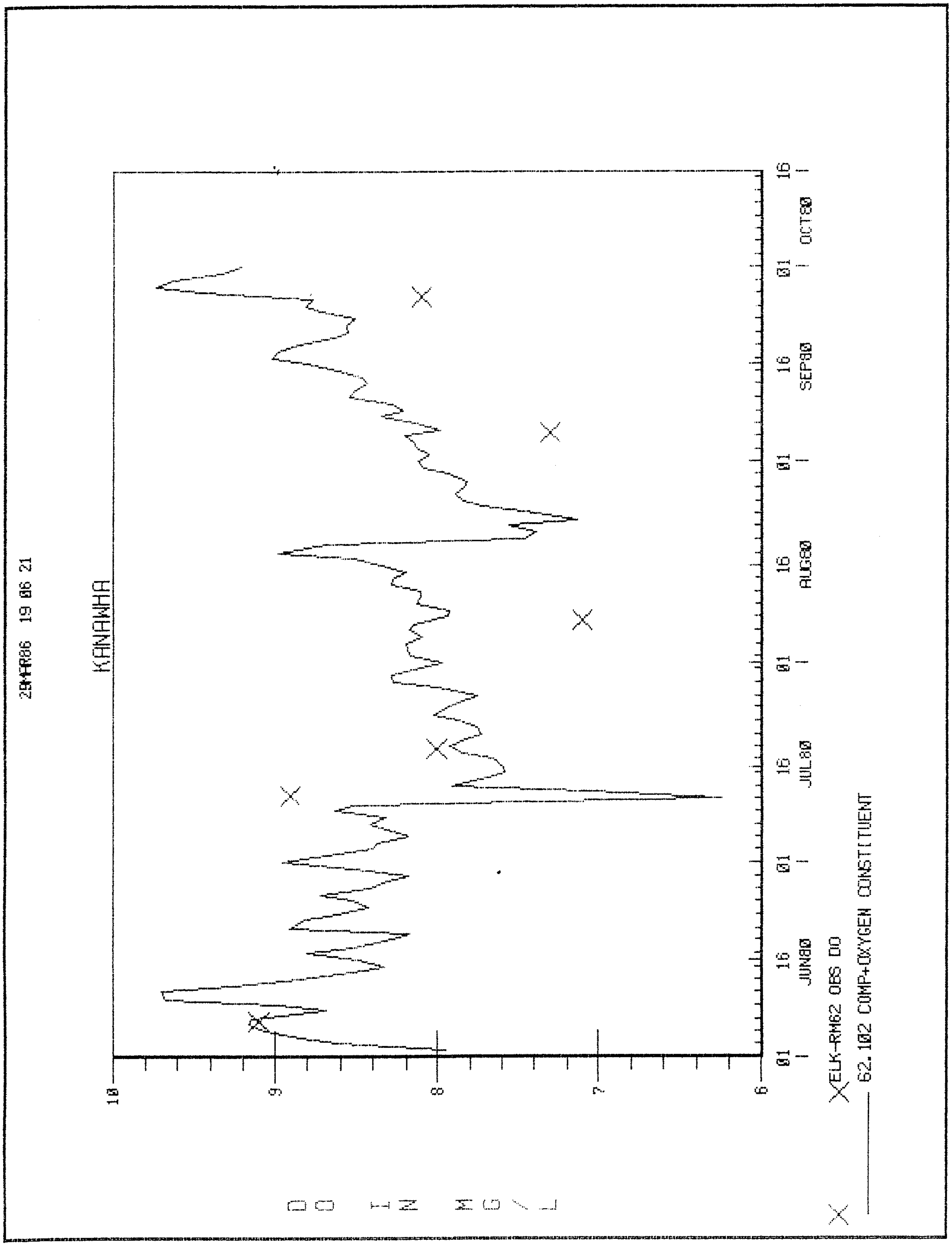
ELK-RM90 OBS DO
90.443 COMP+OXYGEN CONSTITUENT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KANAWHA
DO IN MG/L
10
9
8
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6
01
16
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JUL80
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AUG80
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SEP80
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OCT80
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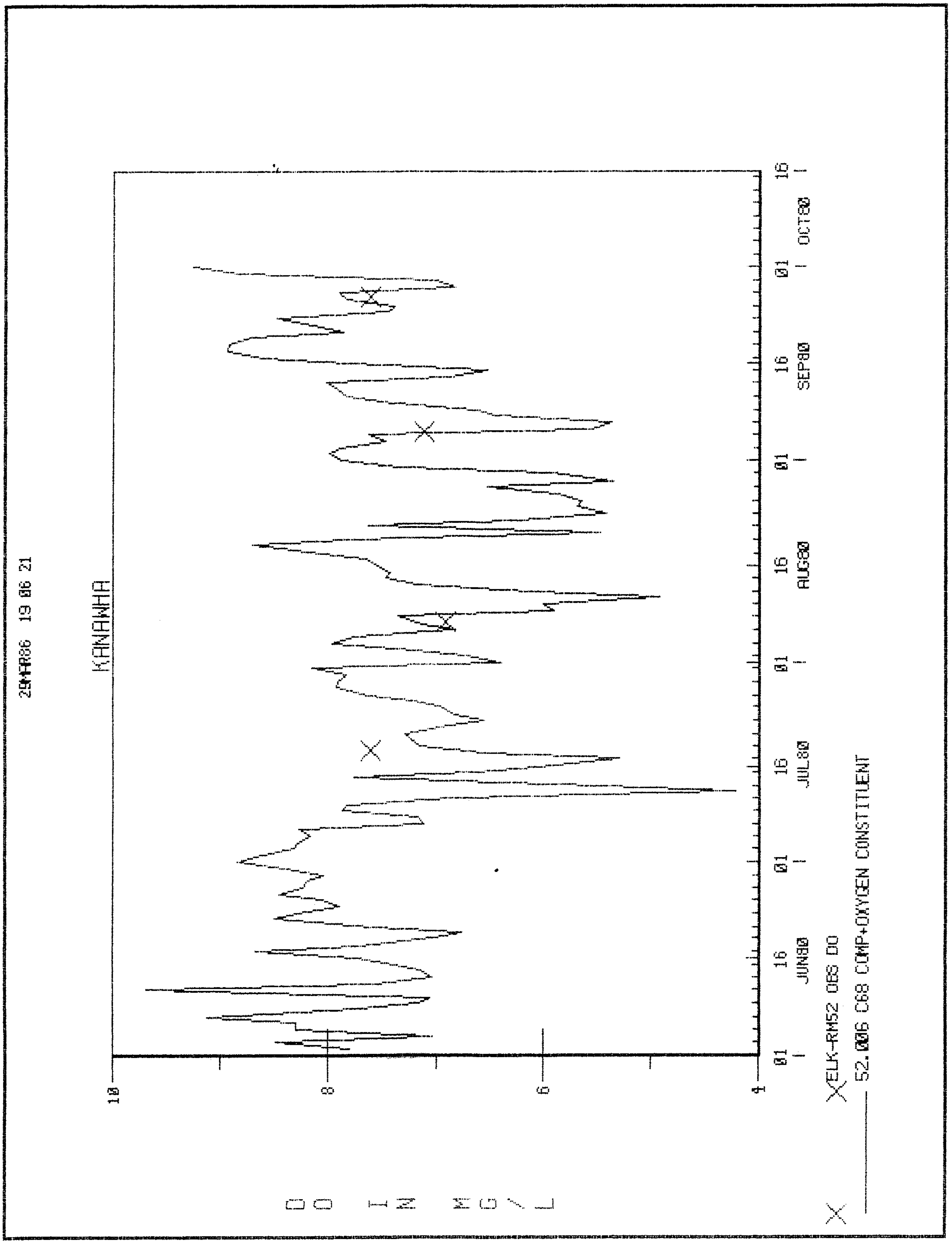
ELK-RM62 OBS DO
62.102 COMP+OXYGEN CONSTITUENT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8
6
4
01
16
JUN80
01
16
JUL80
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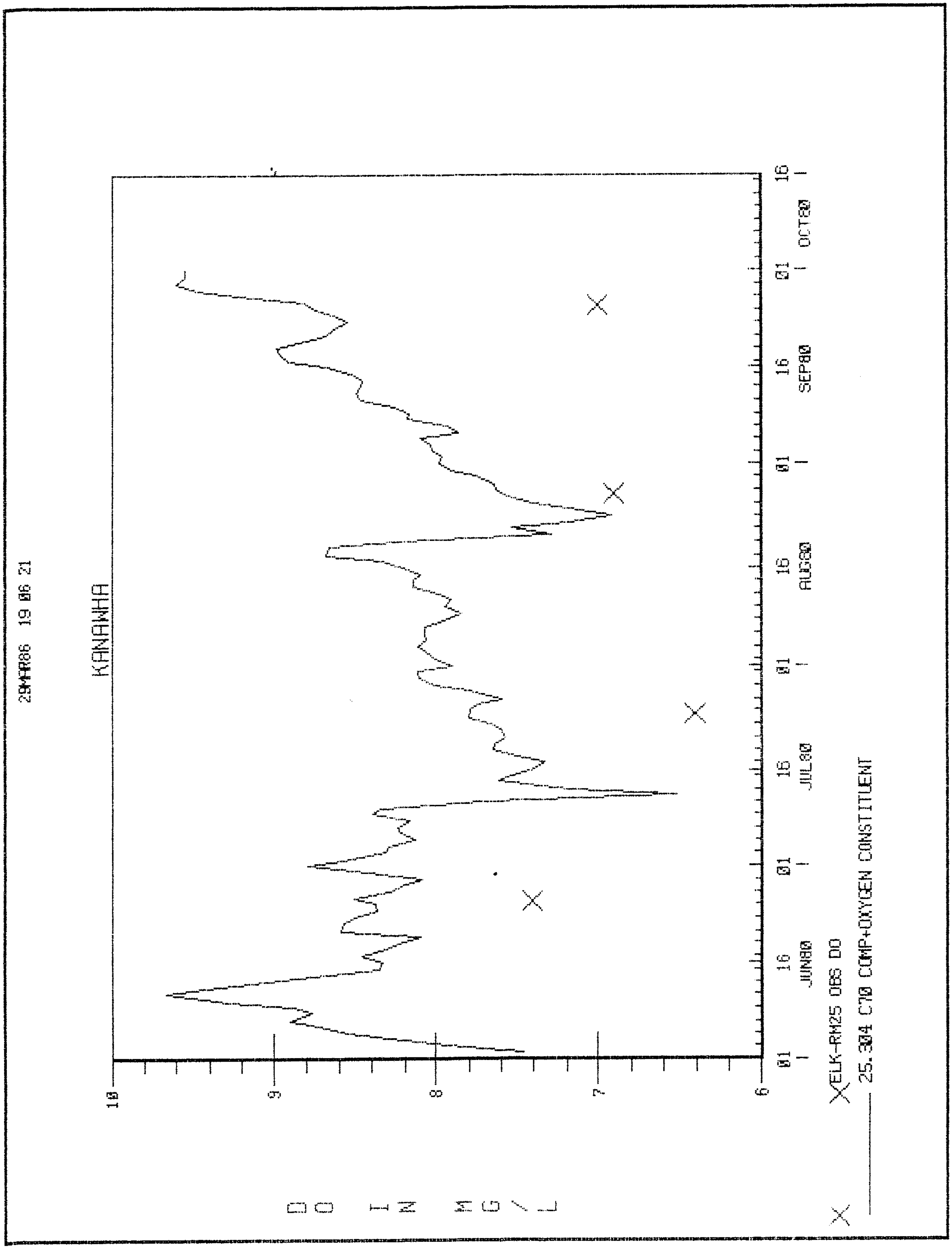
AUG80
01
16
SEP80
01
16
OCT80
ELK-RM52 OBS DO
52.006 C68 COMP+OXYGEN CONSTITUENT

29MAR86 19 06 21
KANAWHA
DO IN MG/L
10
9
8
7
6
01
JUN80
16
01
16
JUL80
01
16
AUG80
01
16
SEP80
01
16
OCT80
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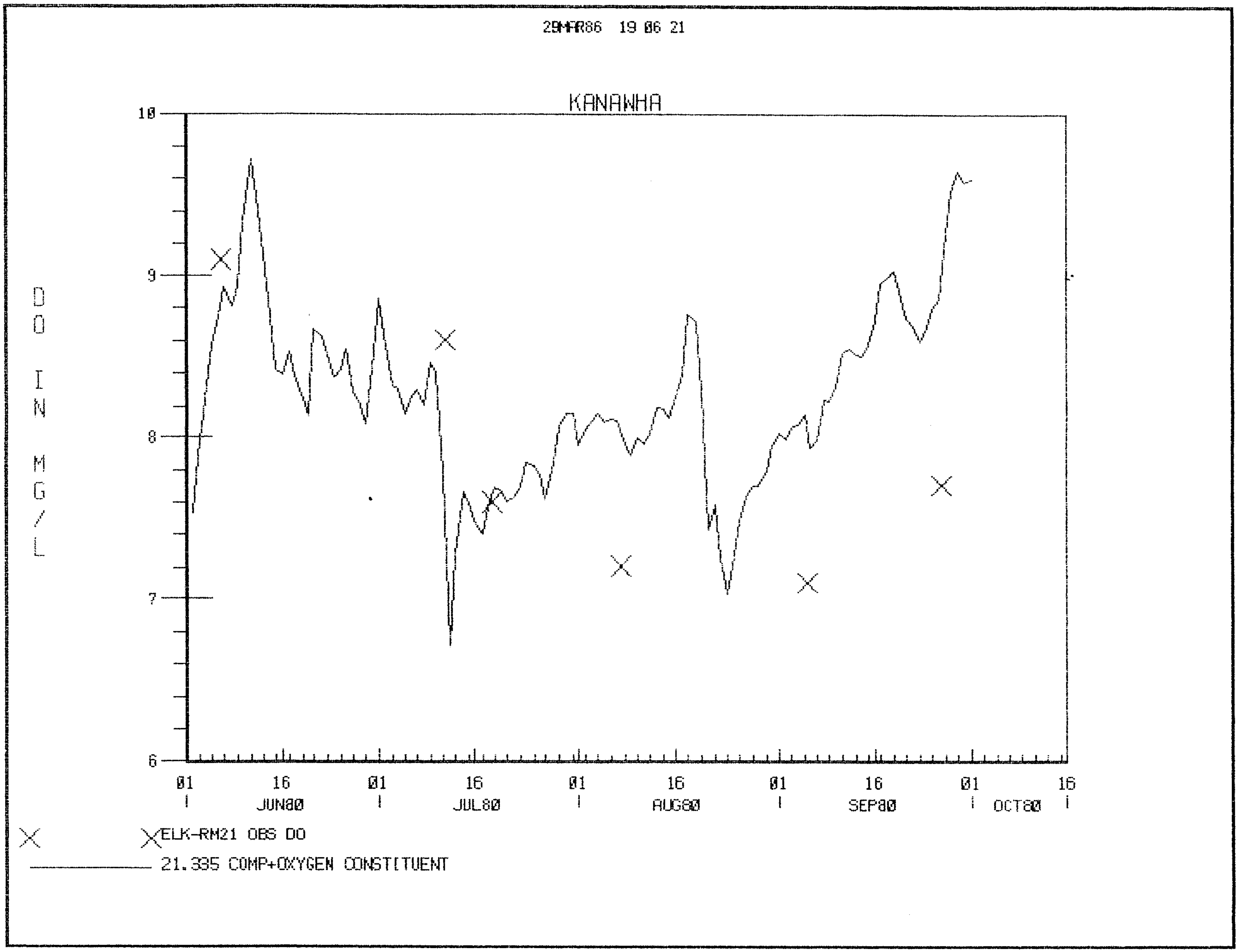
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KANAWHA
DO IN MG/L
10
9
8
7
6
01
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JUN80
01
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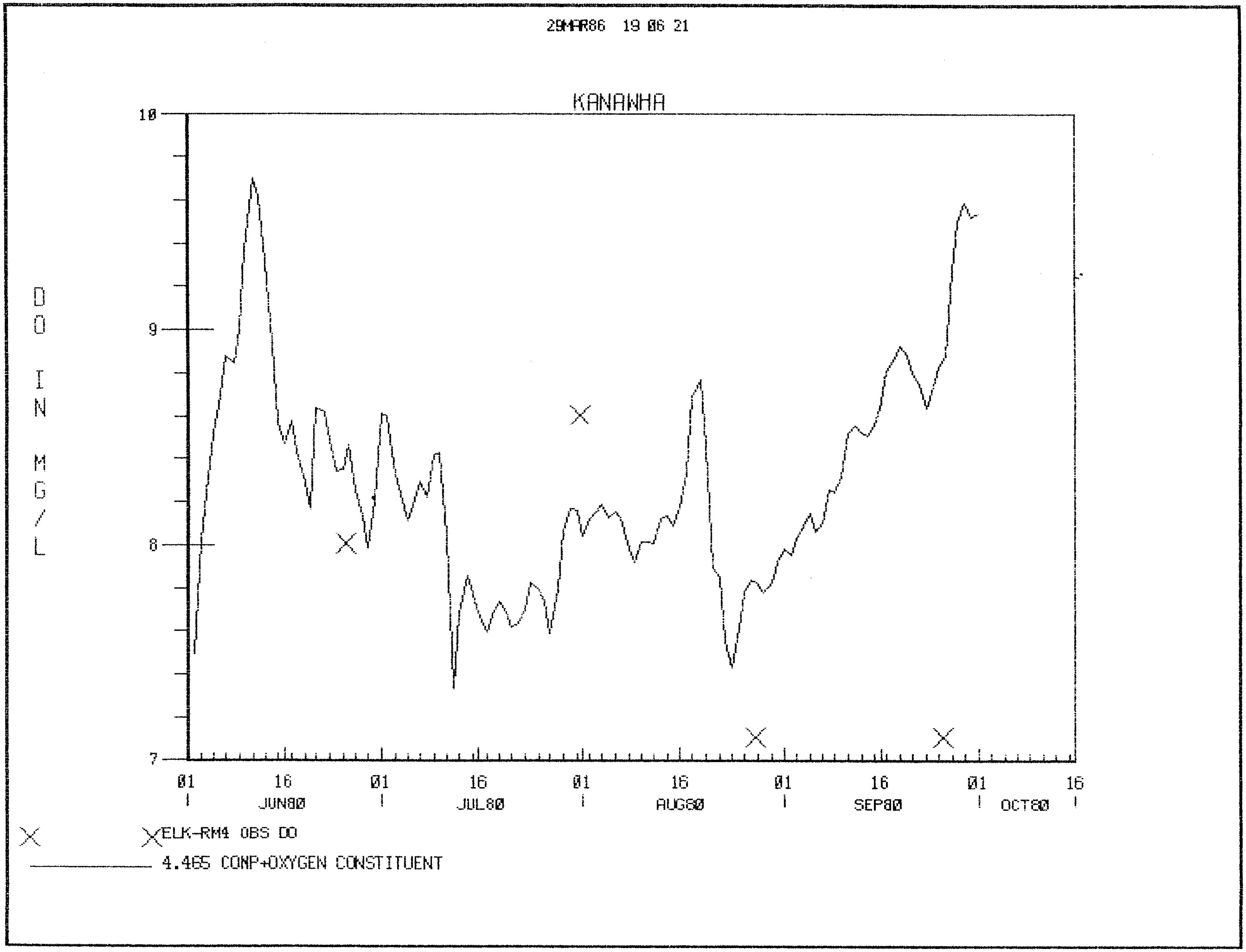
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9
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7
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SEP80
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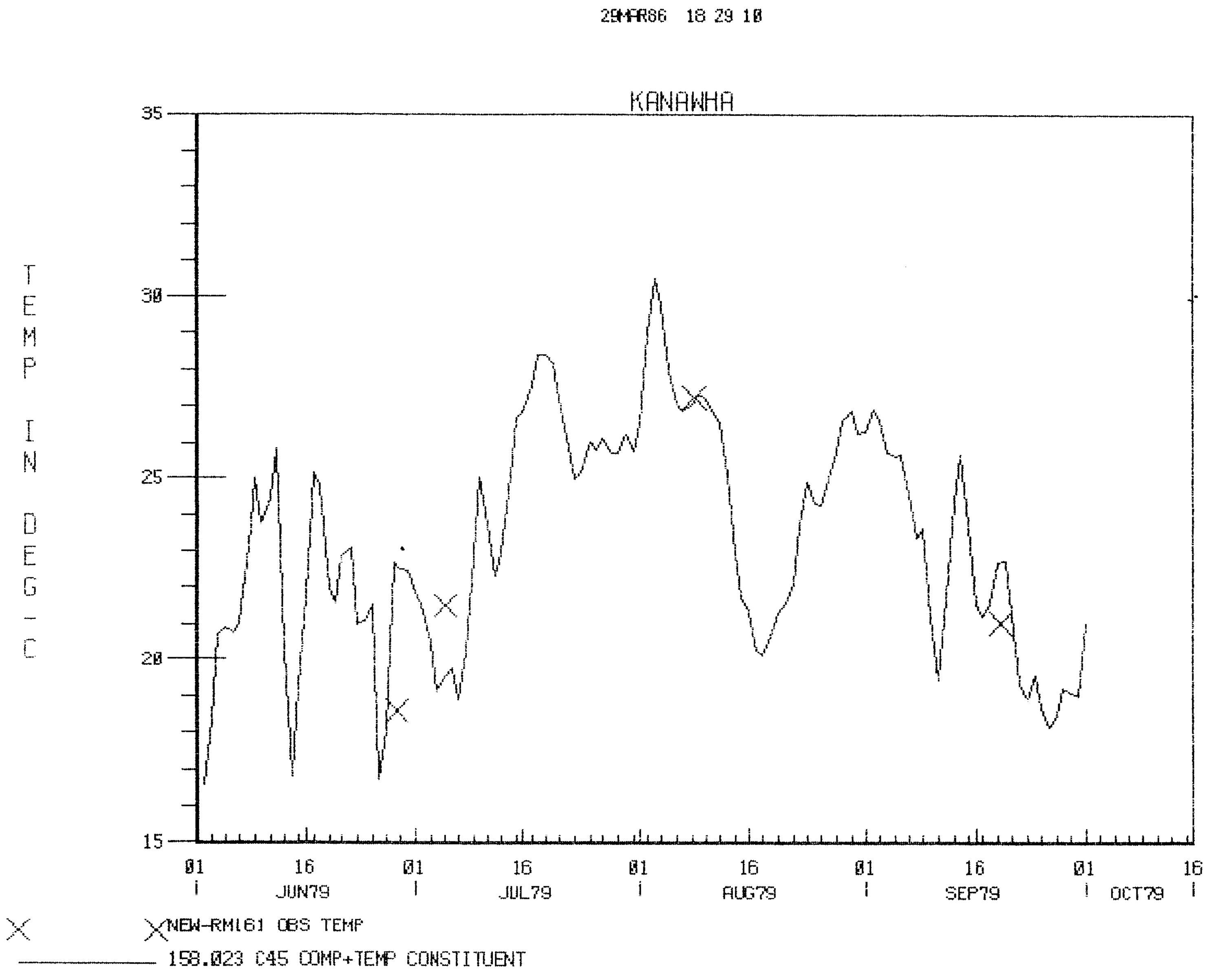
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30
25
20
15
01
16
JUN79
01
16
JUL79
01
16
AUG79
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16
SEP79
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OCT79
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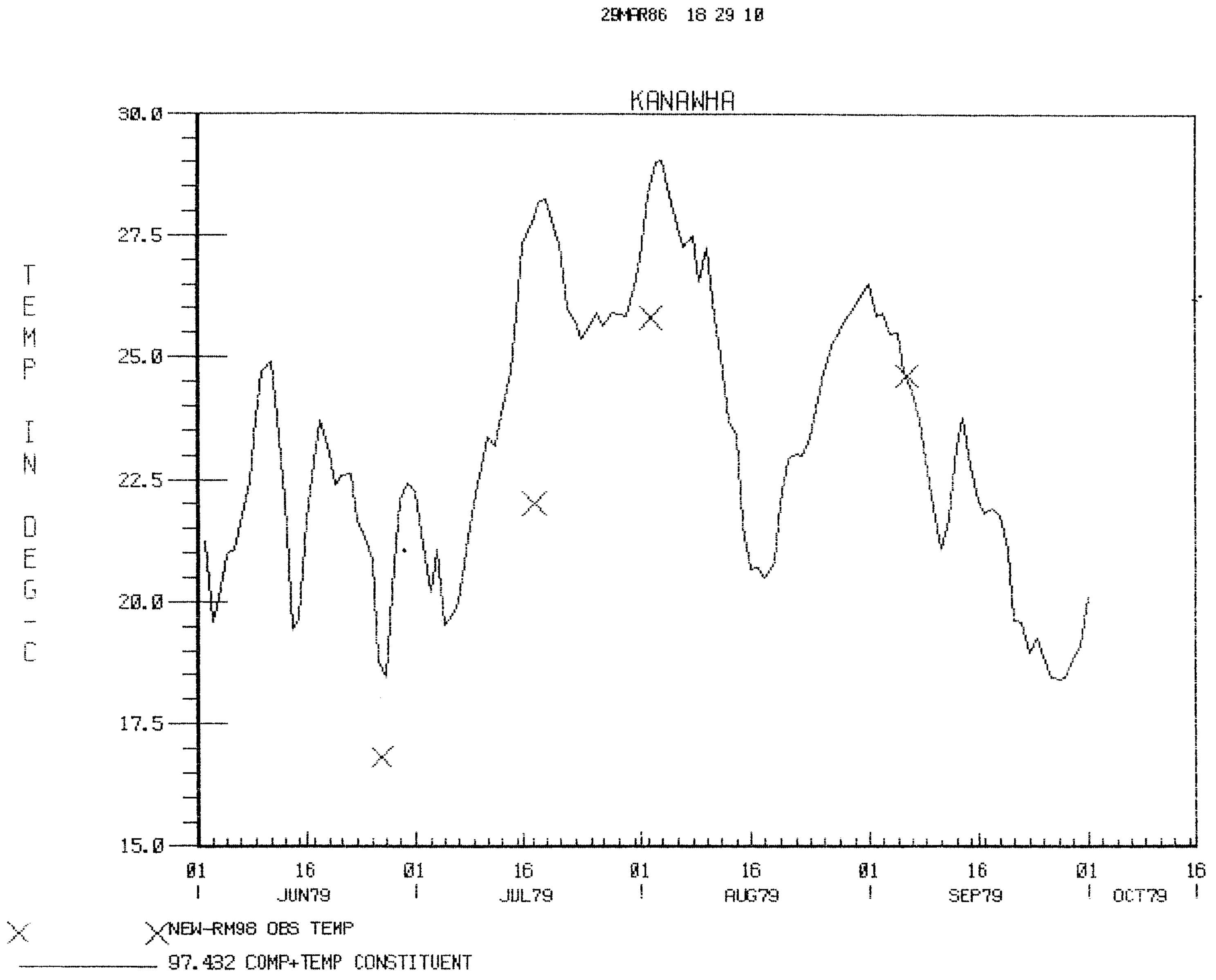
NEW-RM161 OBS TEMP
158.023 C45 COMP+TEMP CONSTITUENT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27.5
25.0
22.5
20.0
17.5
15.0
01
16
JUN79
01
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JUL79
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SEP79
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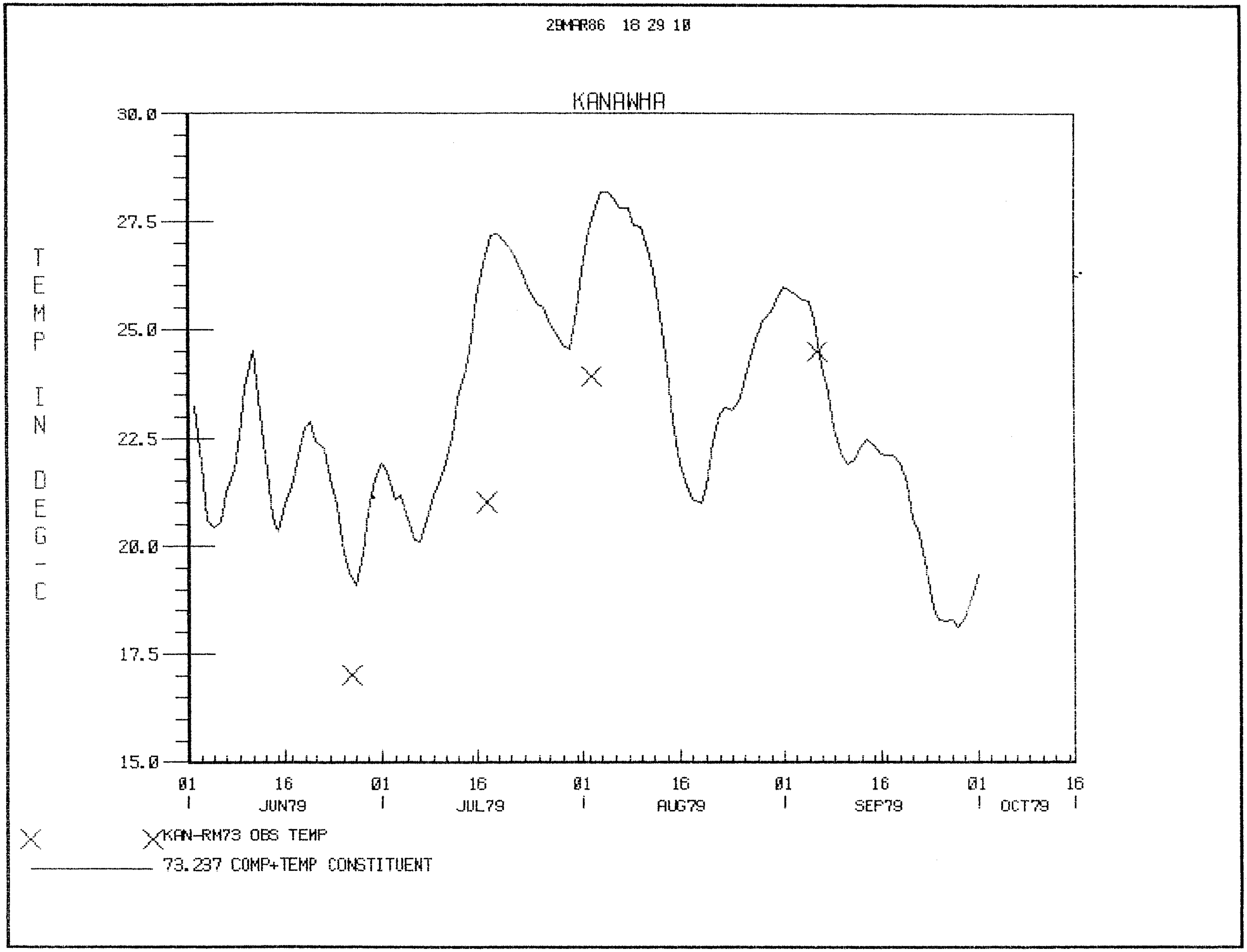
97.432 COMP+TEMP CONSTITUENT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TEMP IN DEG-C
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17.5
15.0
01
16
JUN79
01
16
JUL79
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SEP79
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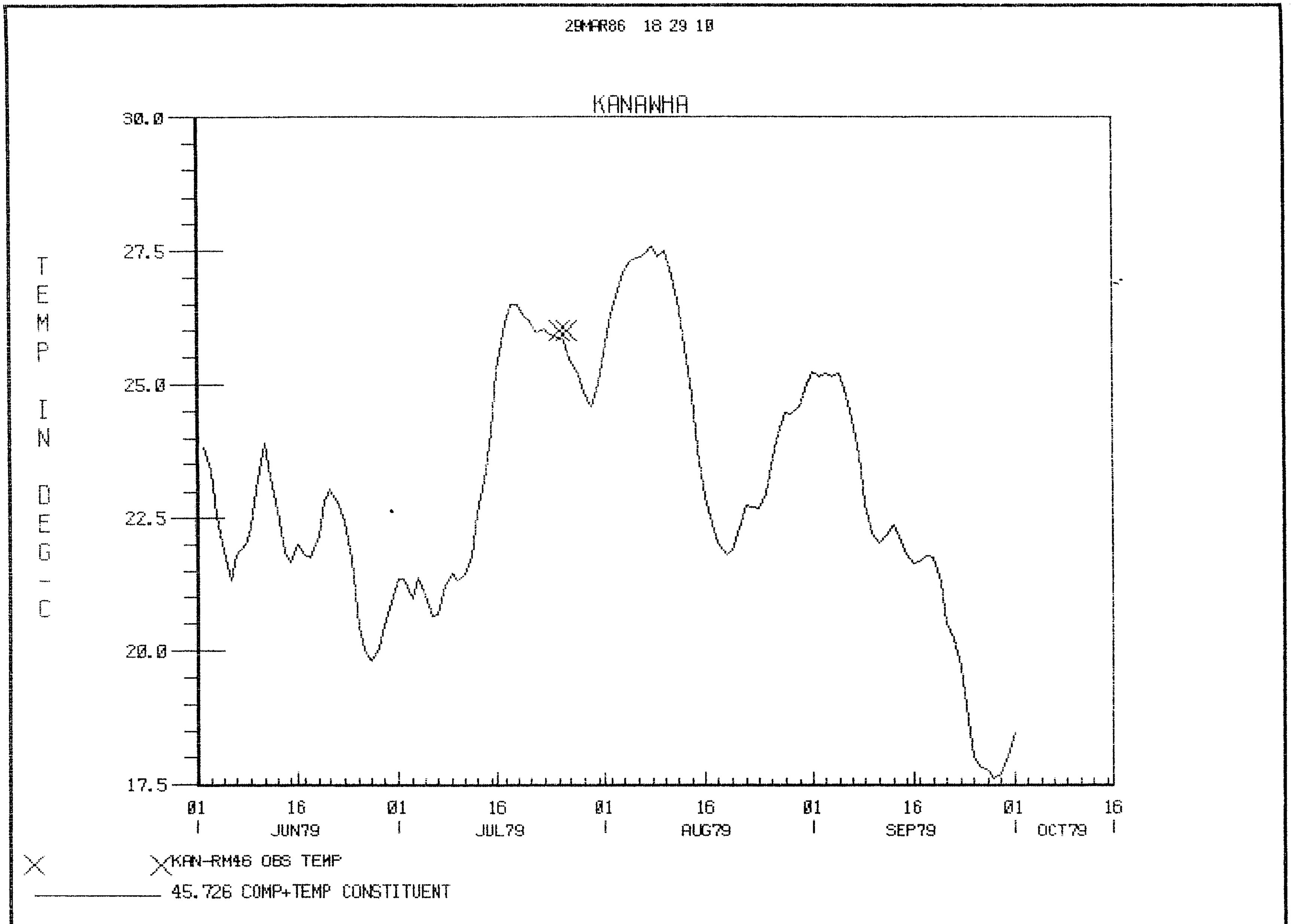
73.237 COMP+TEMP CONSTITUENT

29MAR86 18 29 10
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TEMP IN DEG-C
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25.0
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01
16
JUN79
01
16
JUL79
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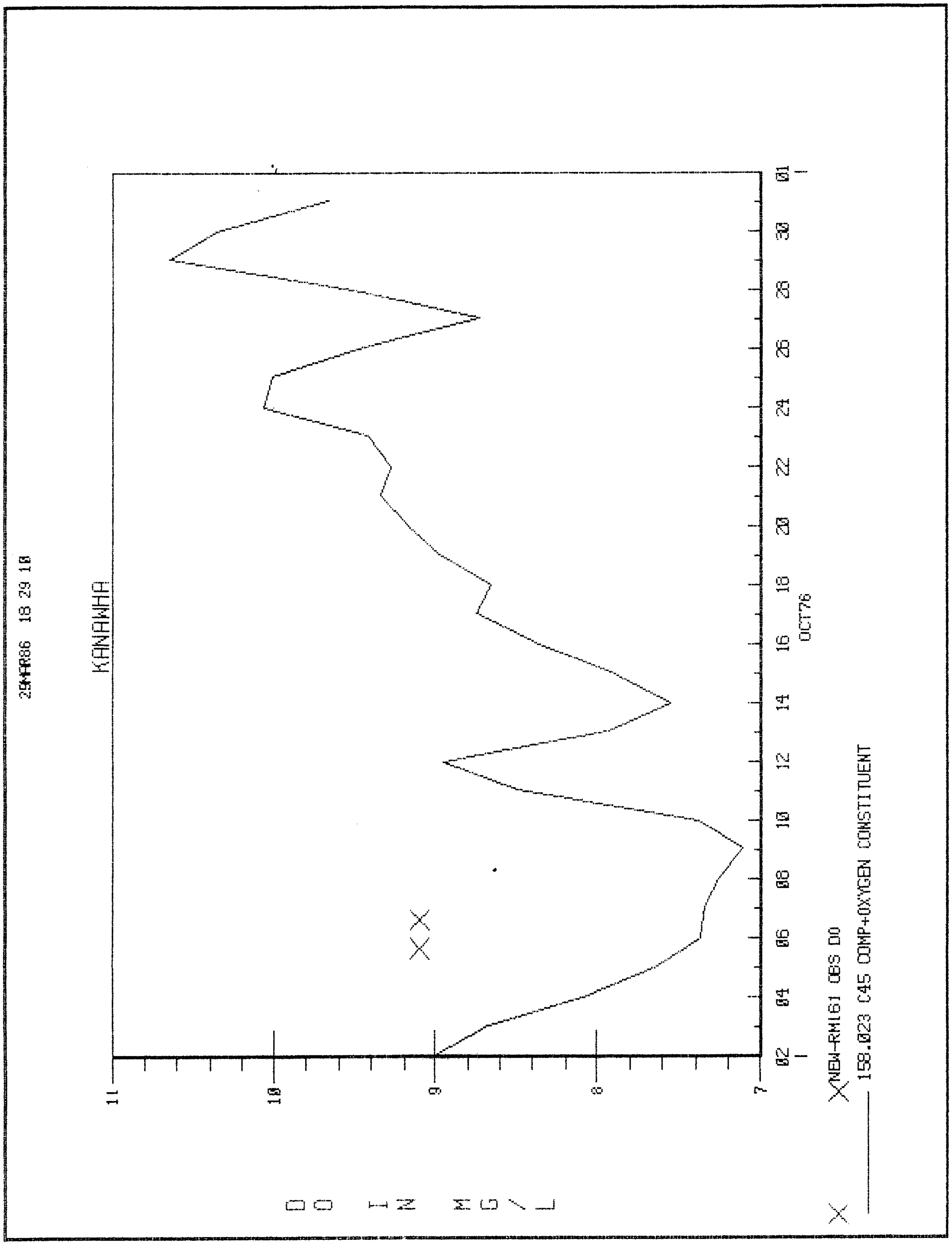
KAN-RM46 OBS TEMP
45.726 COMP+TEMP CONSTITUENT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DO IN MG/L
11
10
9
8
7
02
04
06
08
10
12
14
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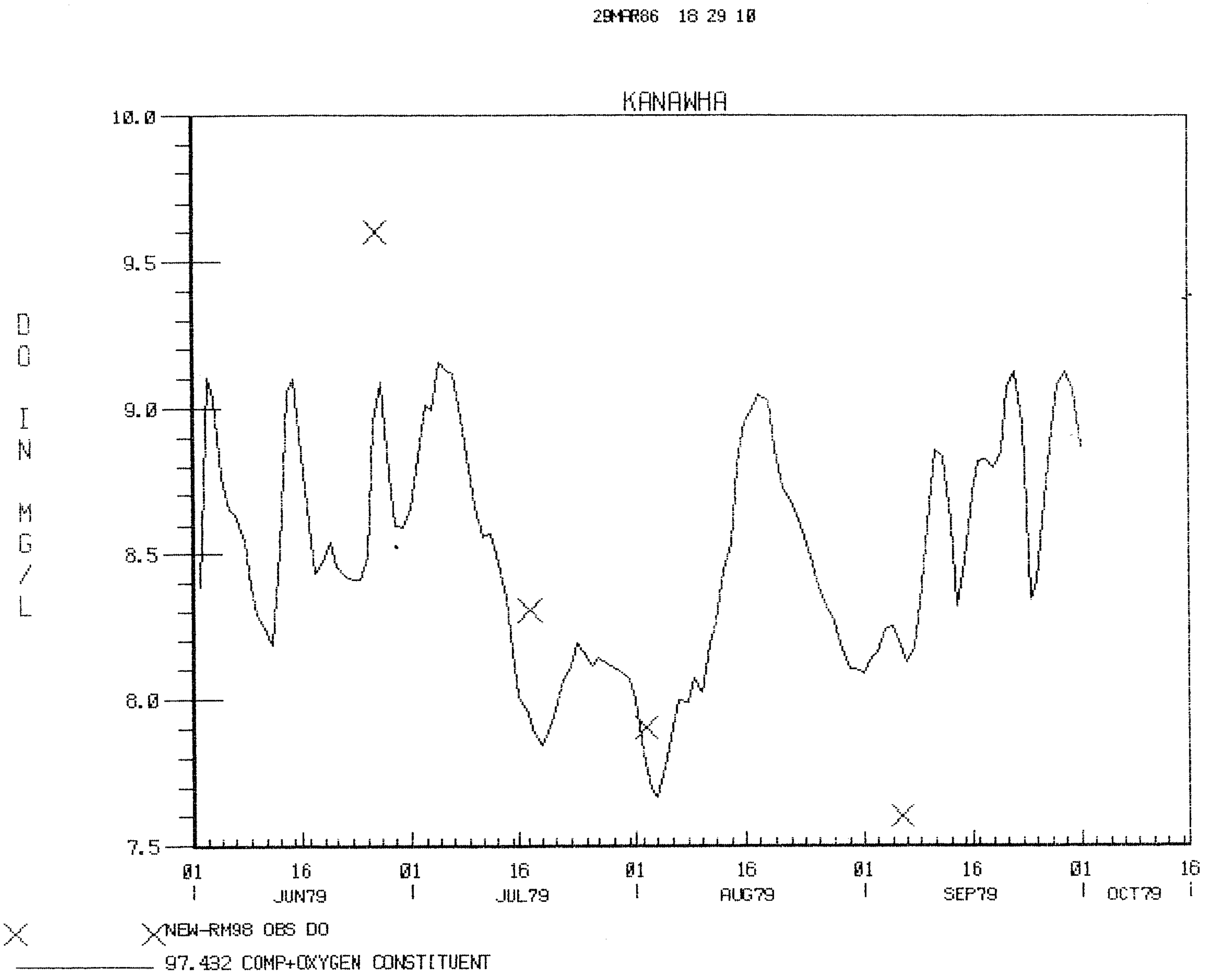
18
20
22
24
26
28
30
01
OCT76
X NEW-RM161 OBS DO
158.023 C45 COMP+OXYGEN CONSTITUENT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DO IN MG/L
10.0
9.5
9.0
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7.5
01
16
JUN79
01
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JUL79
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SEP79
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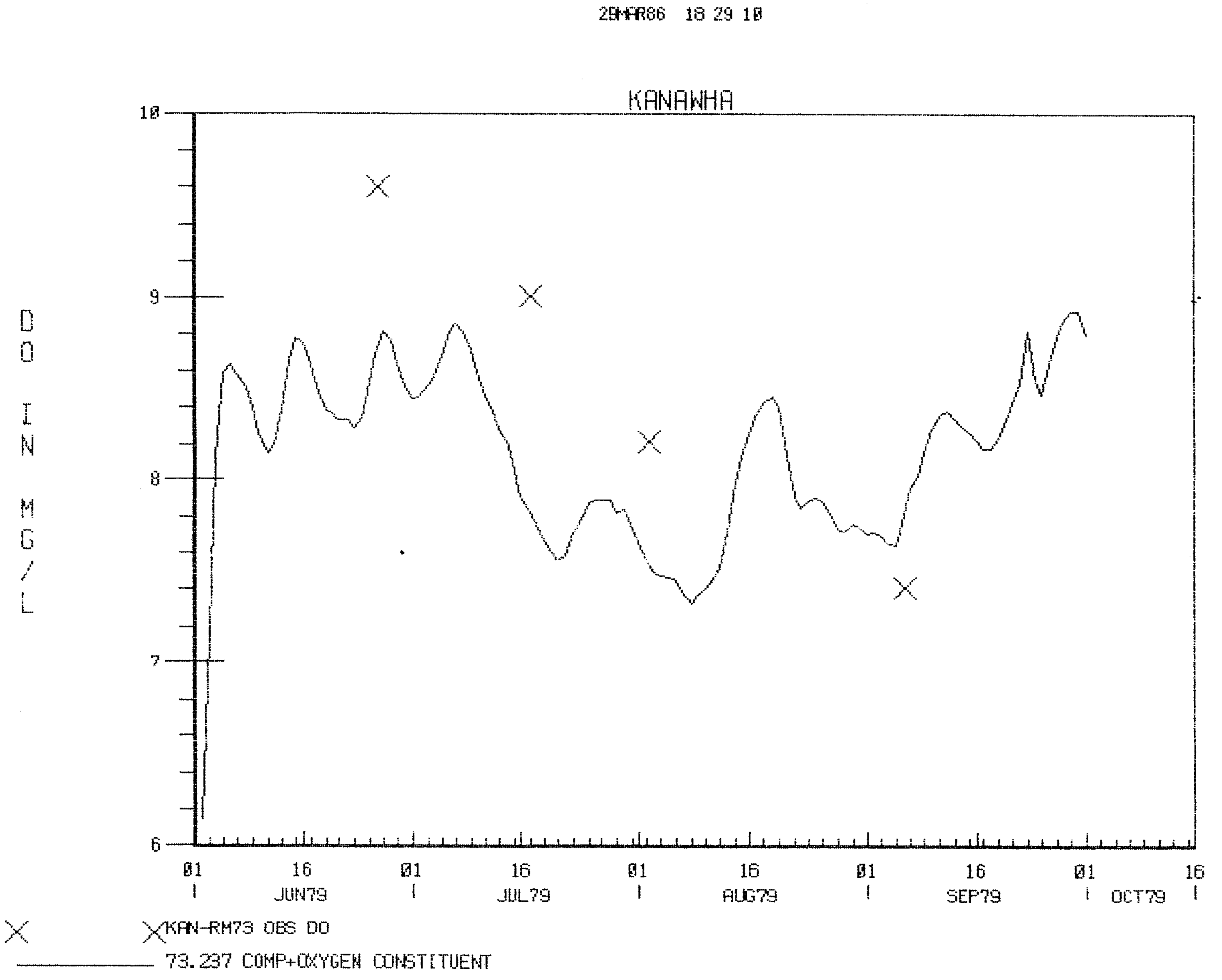
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DO IN MG/L
10
9
8
7
6
01
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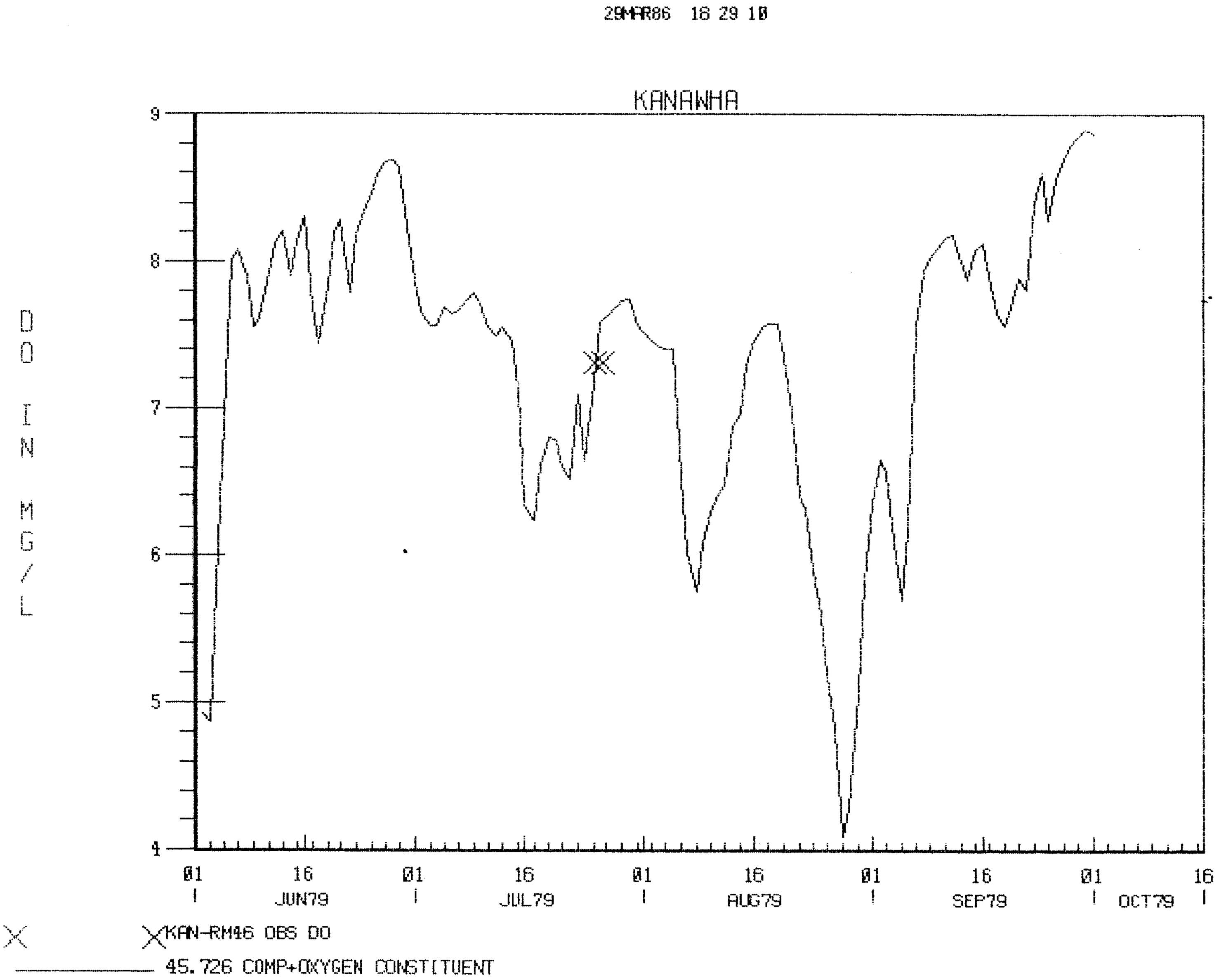
KAN-RM73 OBS DO
73.237 COMP+OXYGEN CONSTITUENT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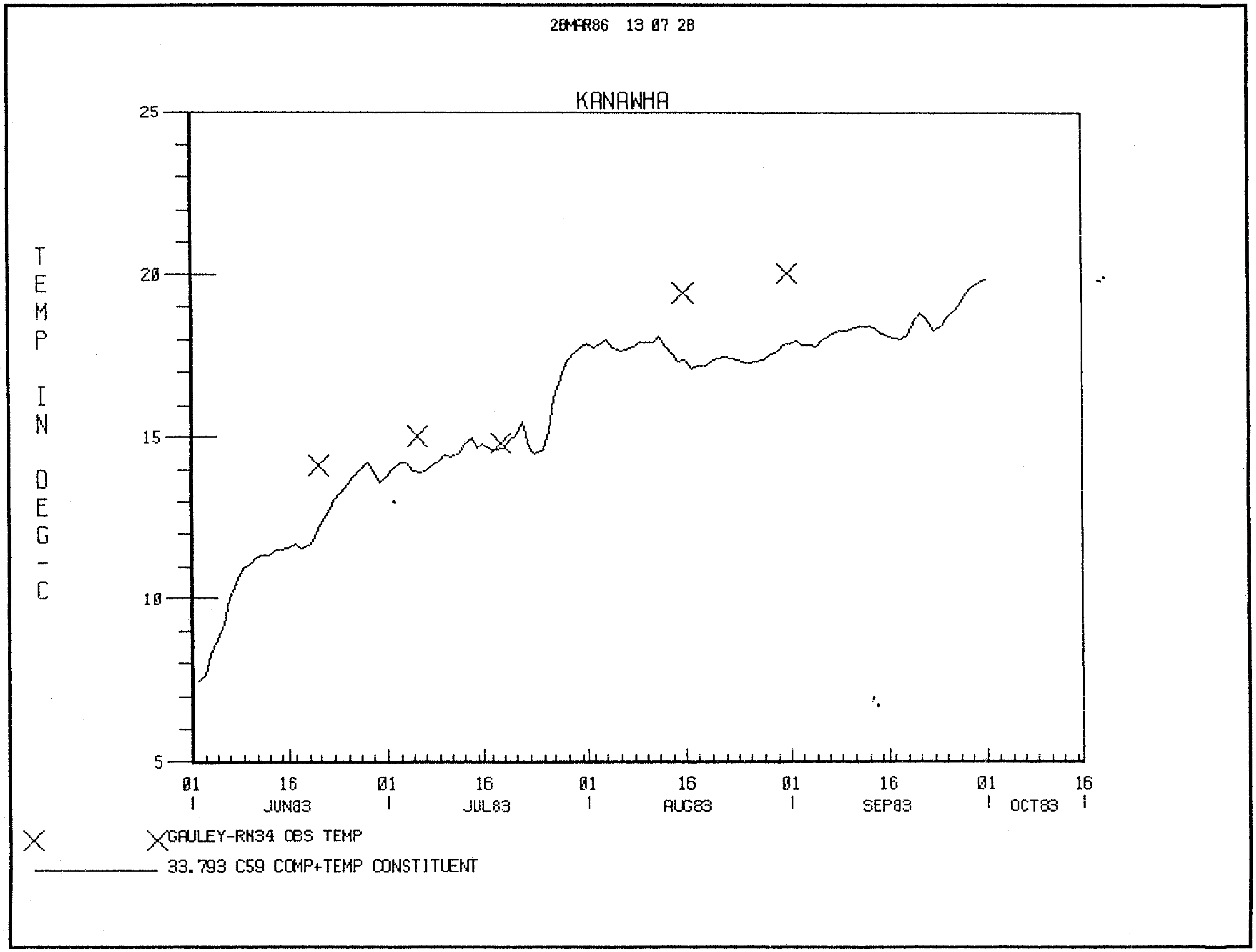
DO IN MG/L
9
8
7
6
5
4
01
16
JUN79
01
16
JUL79
01
16
AUG79
01
16
SEP79
01
OCT79
16
KAN-RM46 OBS DO
45.726 COMP+OXYGEN CONSTITUENT

APPENDIX B

GRAPHICAL RESULTS OF VERIFICATION

TABLE OF CONTENTS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15
10
5
01
16
JUN83
01
16
JUL83
01
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AUG83
01
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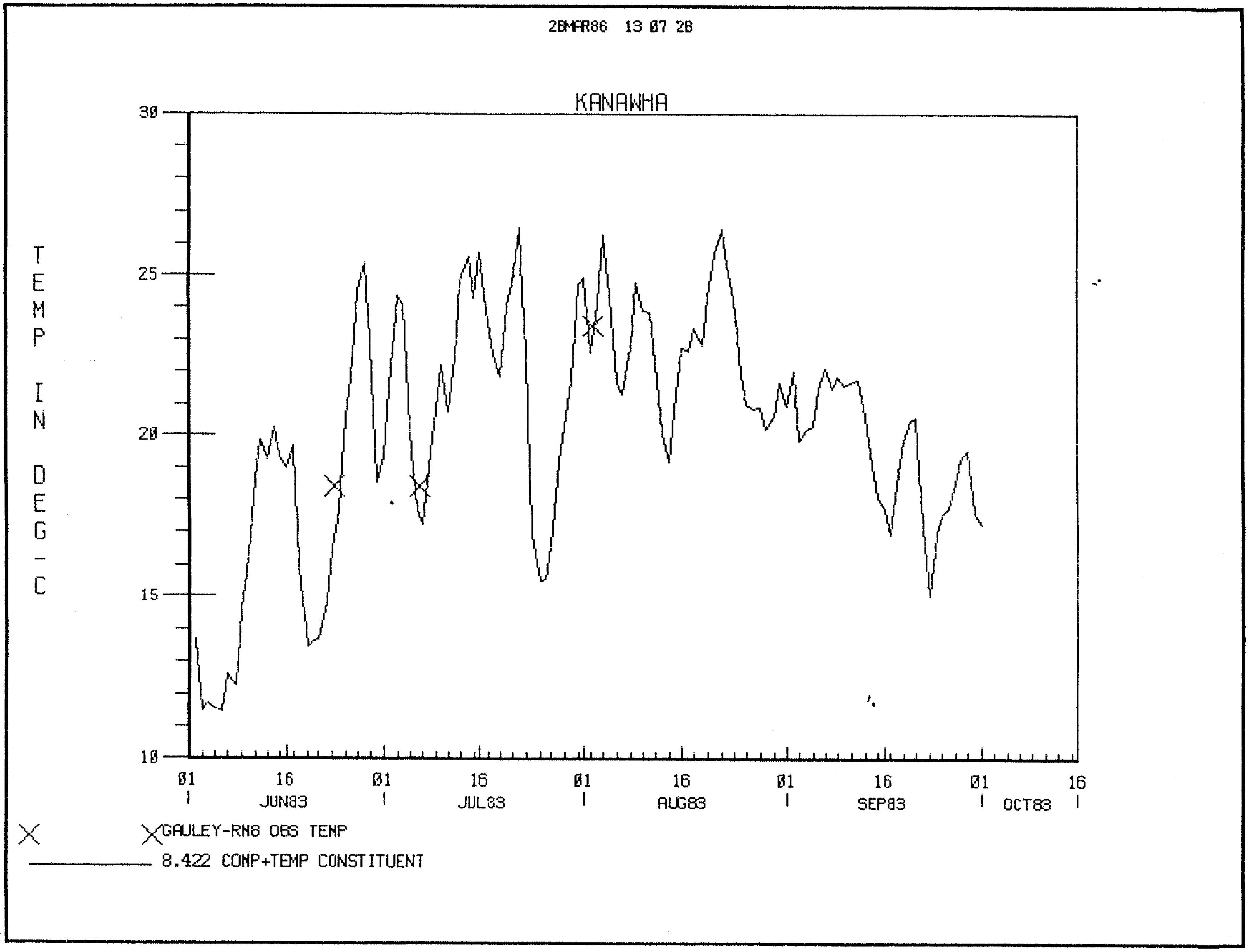
SEP83
01
OCT83
16
GAULEY-RN34 OBS TEMP
33.793 C59 COMP+TEMP CONSTITUENT



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KANAWHA
TEMP IN DEG-C
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25
20
15
10
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JUN83
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SEP83
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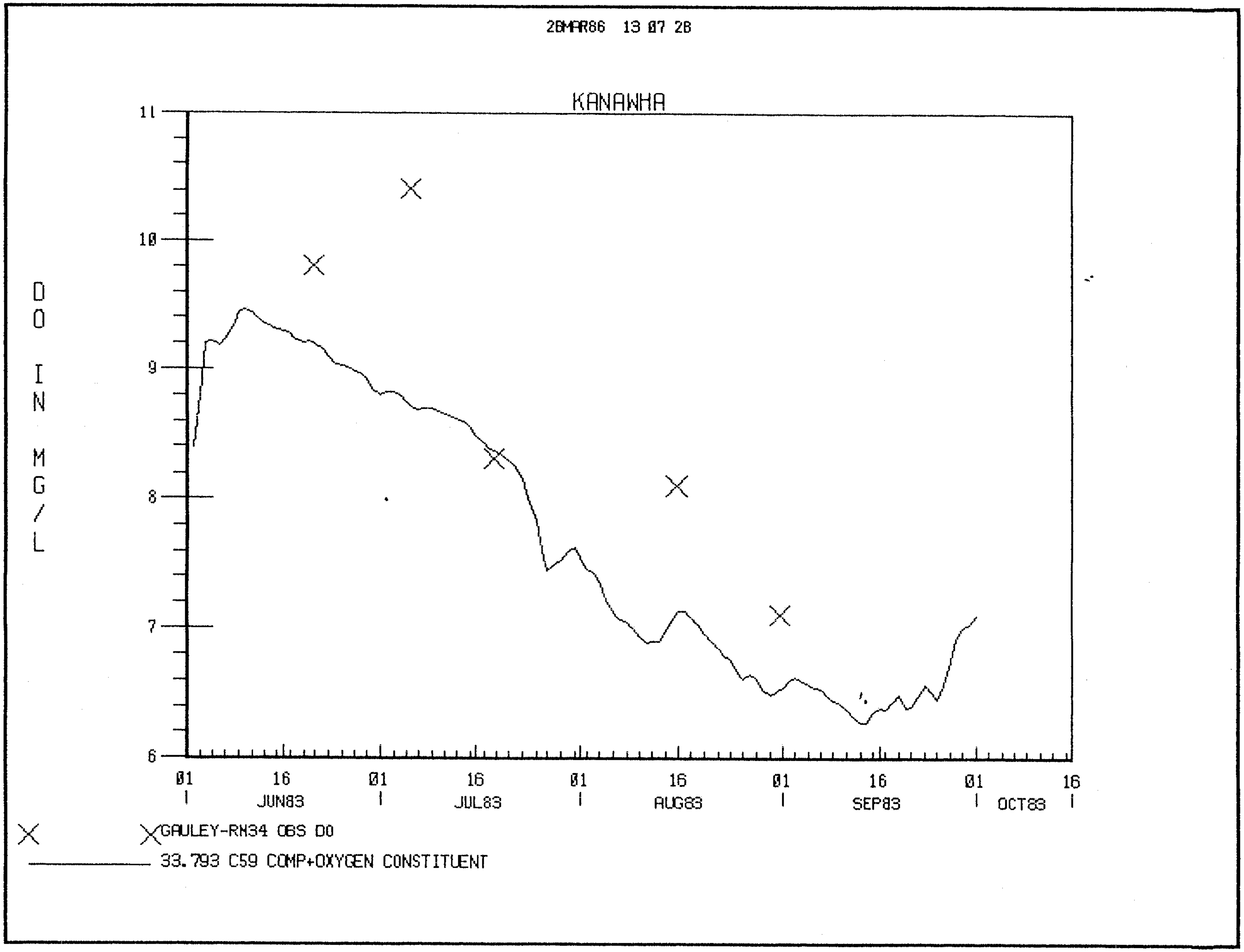
GAULEY-RN8 OBS TEMP
8.422 COMP+TEMP CONSTITUENT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DO IN MG/L
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10
9
8
7
6
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JUN83
01
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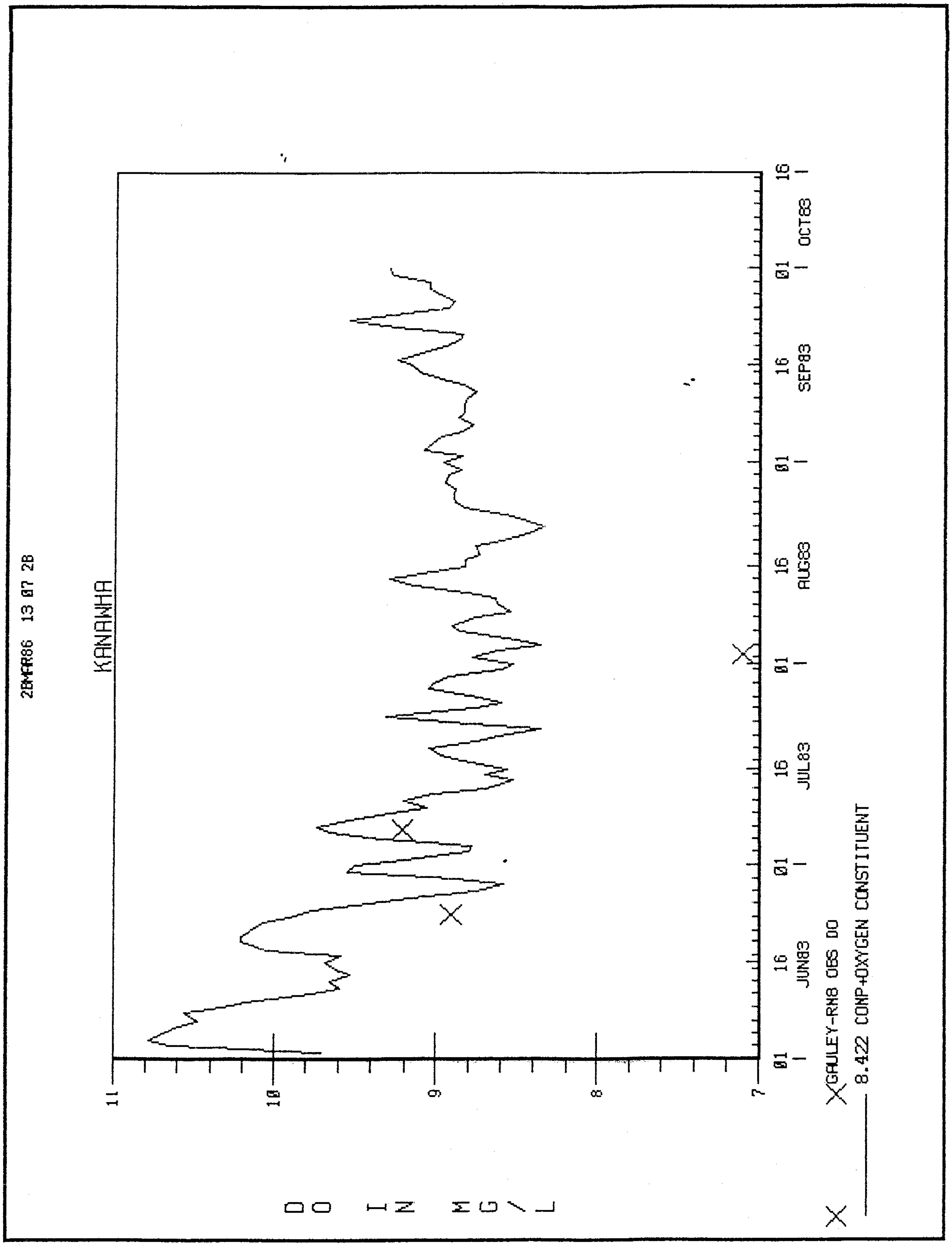
JUL83
01
16
AUG83
01
16
SEP83
01
OCT83
16
GAULEY-RM34 OBS DO
33.793 C59 COMP+OXYGEN CONSTITUENT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KANAWHA
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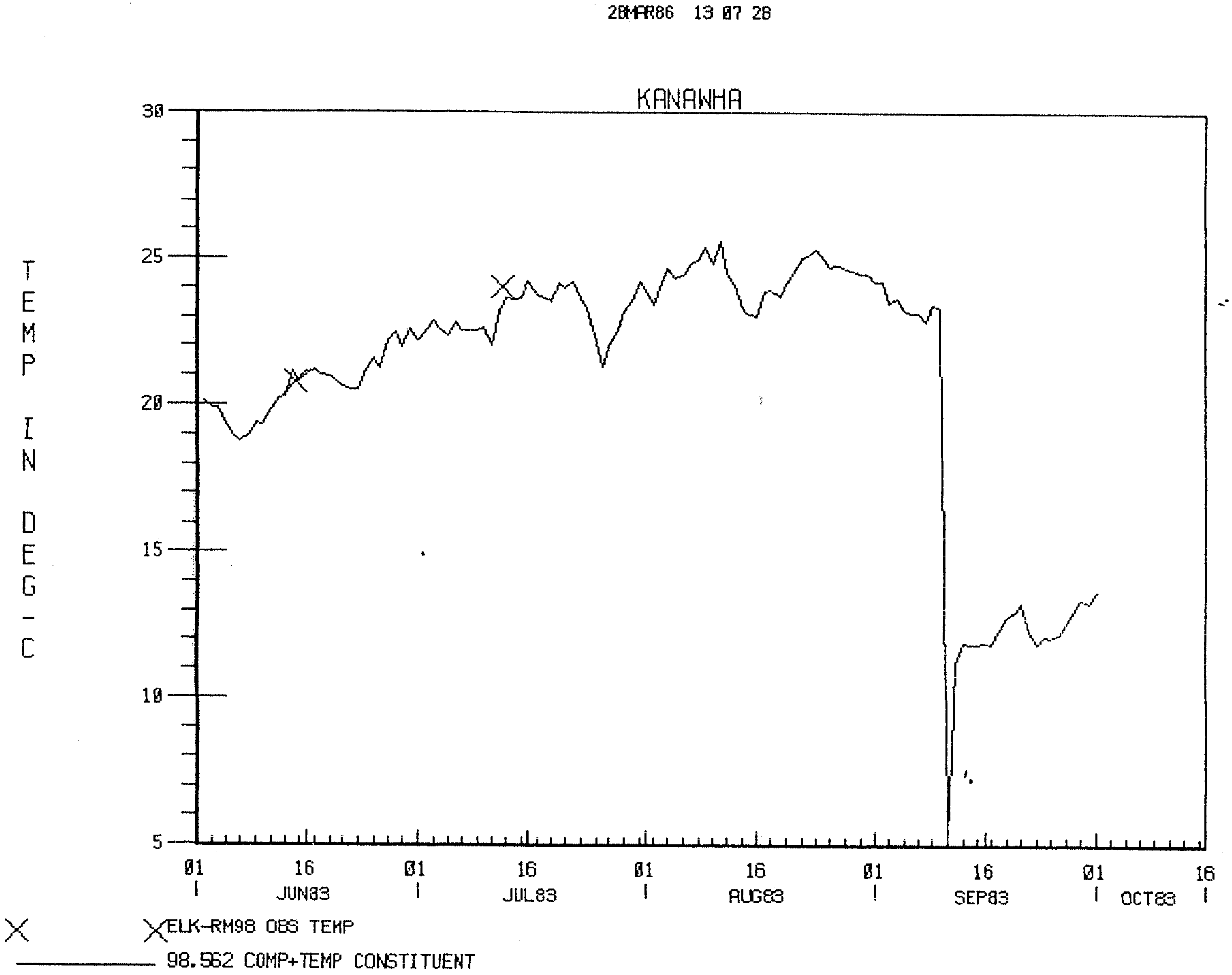
11
10
9
8
7
01
16
JUN83
01
16
JUL83
01
16
AUG83
01
16
SEP83
01
16
OCT83
GAULEY-RM8 OBS DO
8.422 COMP+OXYGEN CONSTITUENT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KANAWHA
TEMP IN DEG-C
30
25
20
15
10
5
01
16
JUN83
01
16
JUL83
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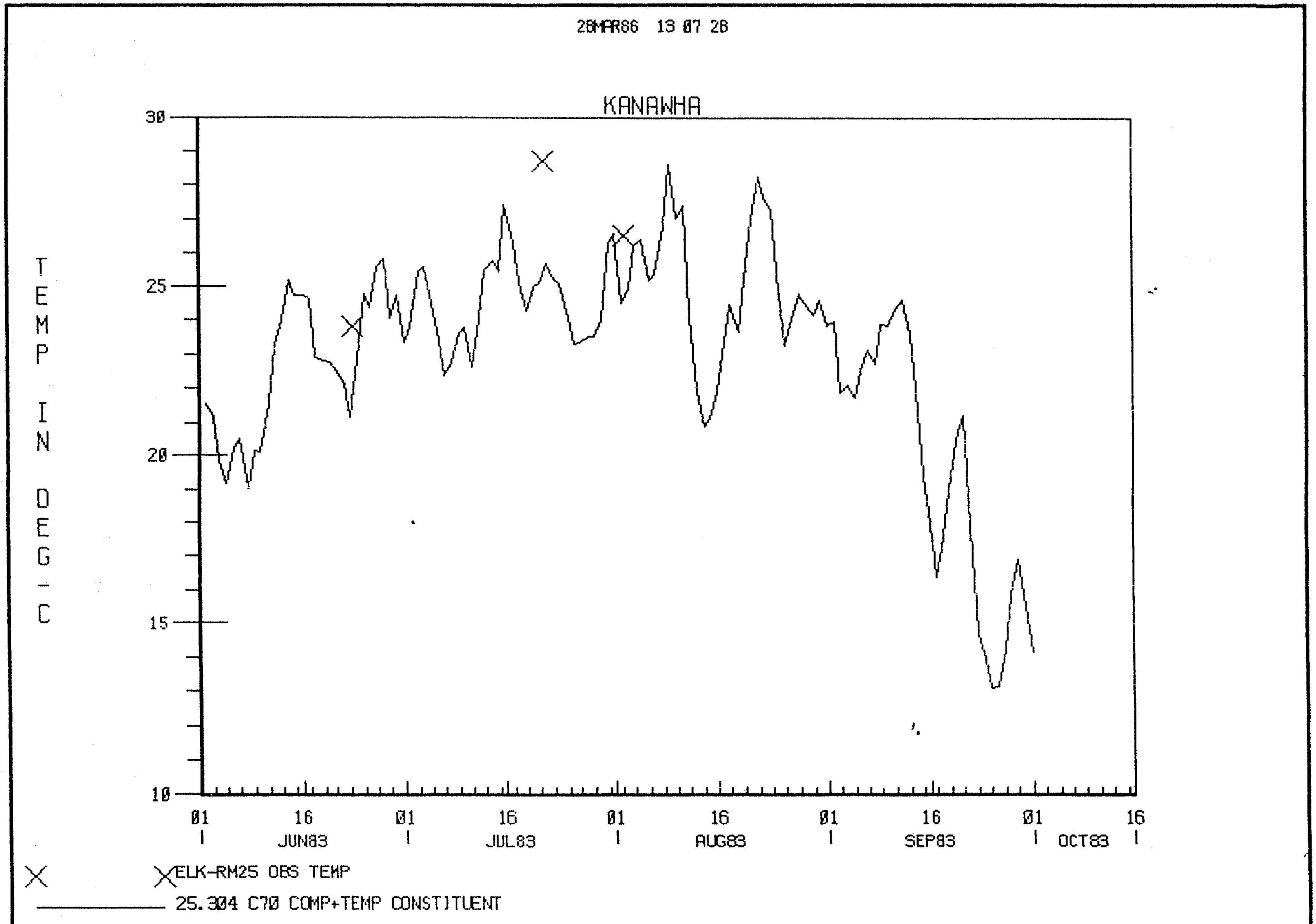
AUG83
01
16
SEP83
01
OCT83
16
ELK-RM98 OBS TEMP
98.562 COMP+TEMP CONSTITUENT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KANAWHA
TEMP IN DEG C
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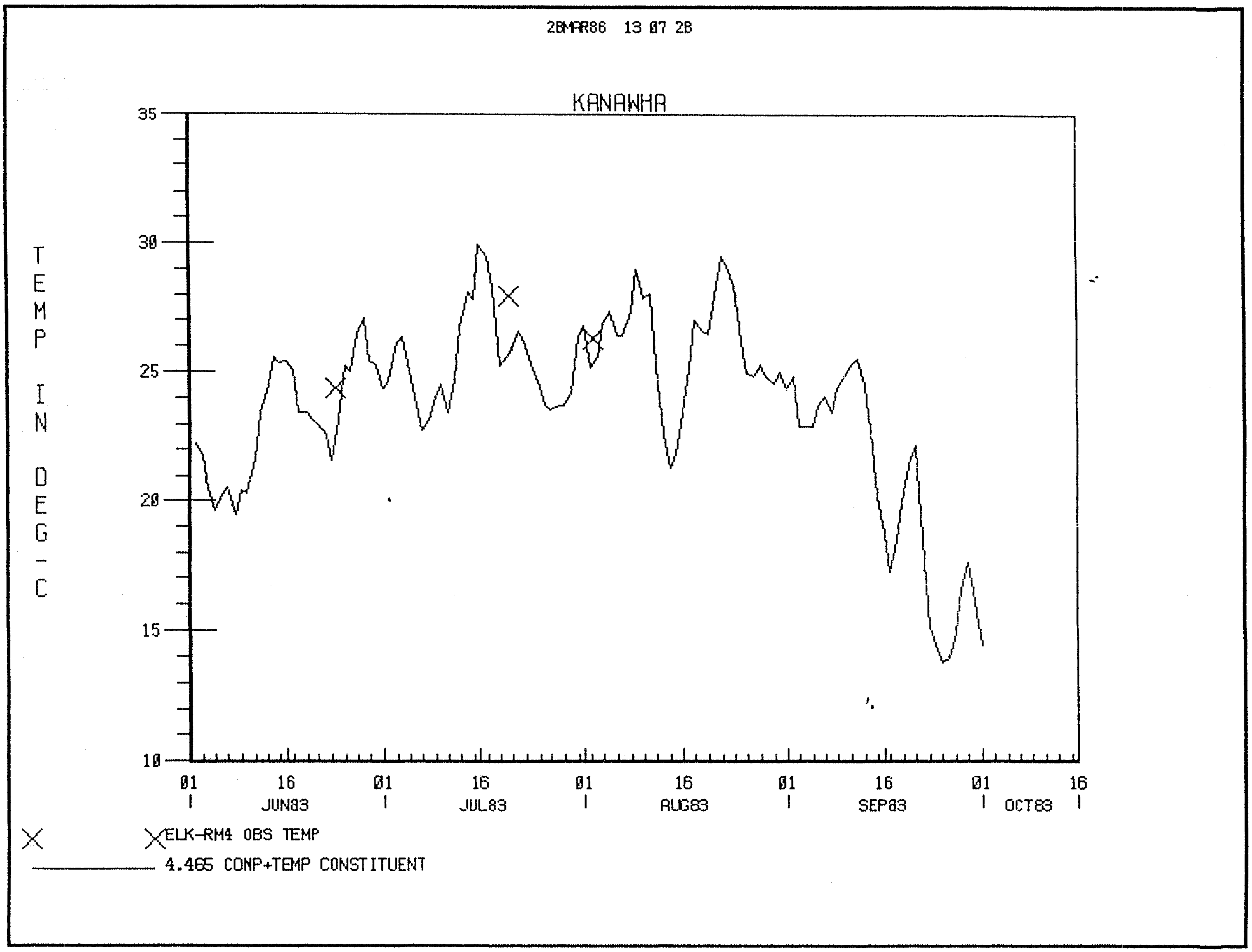
ELK-RM25 OBS TEMP
25.304 C70 COMP+TEMP CONSTITUENT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TEMP IN DEG-C
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30
25
20
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10
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JUN83
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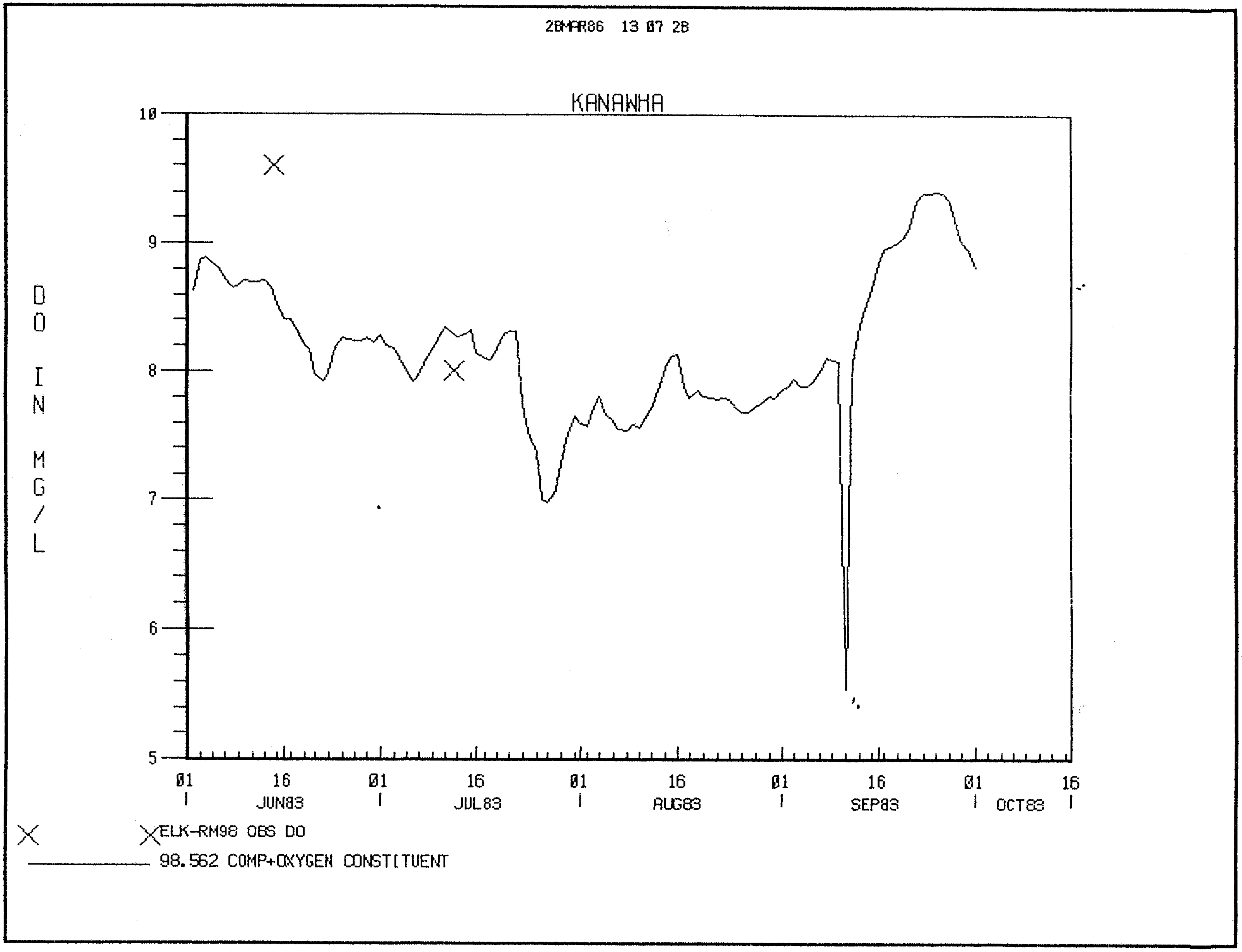
ELK-RM4 OBS TEMP
4.465 COMP+TEMP CONSTITUENT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KANAWHA
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10
9
8
7
6
5
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JUN83
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ELK-RM98 OBS DO
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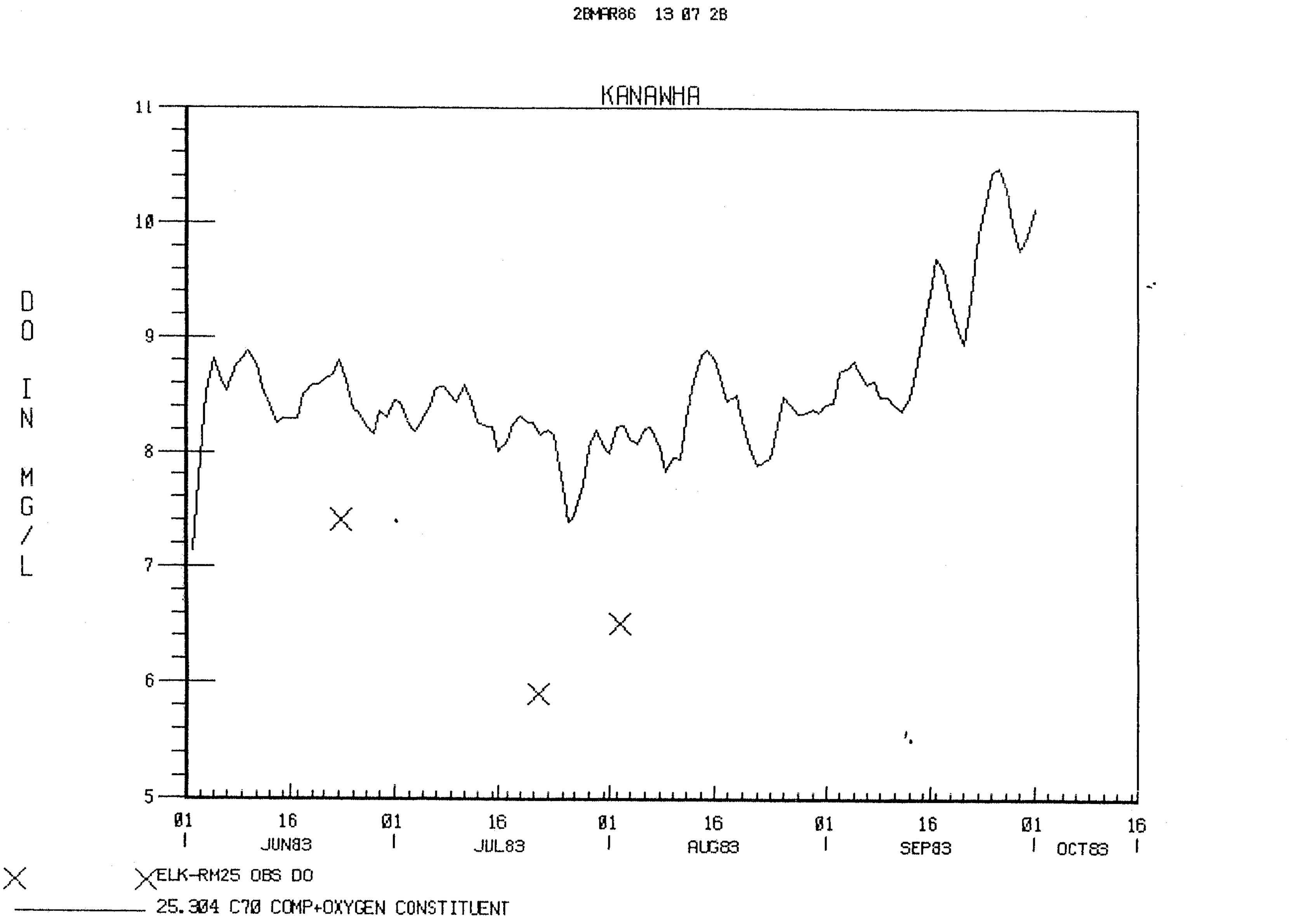
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10
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8
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JUN83
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JUL83
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SEP83
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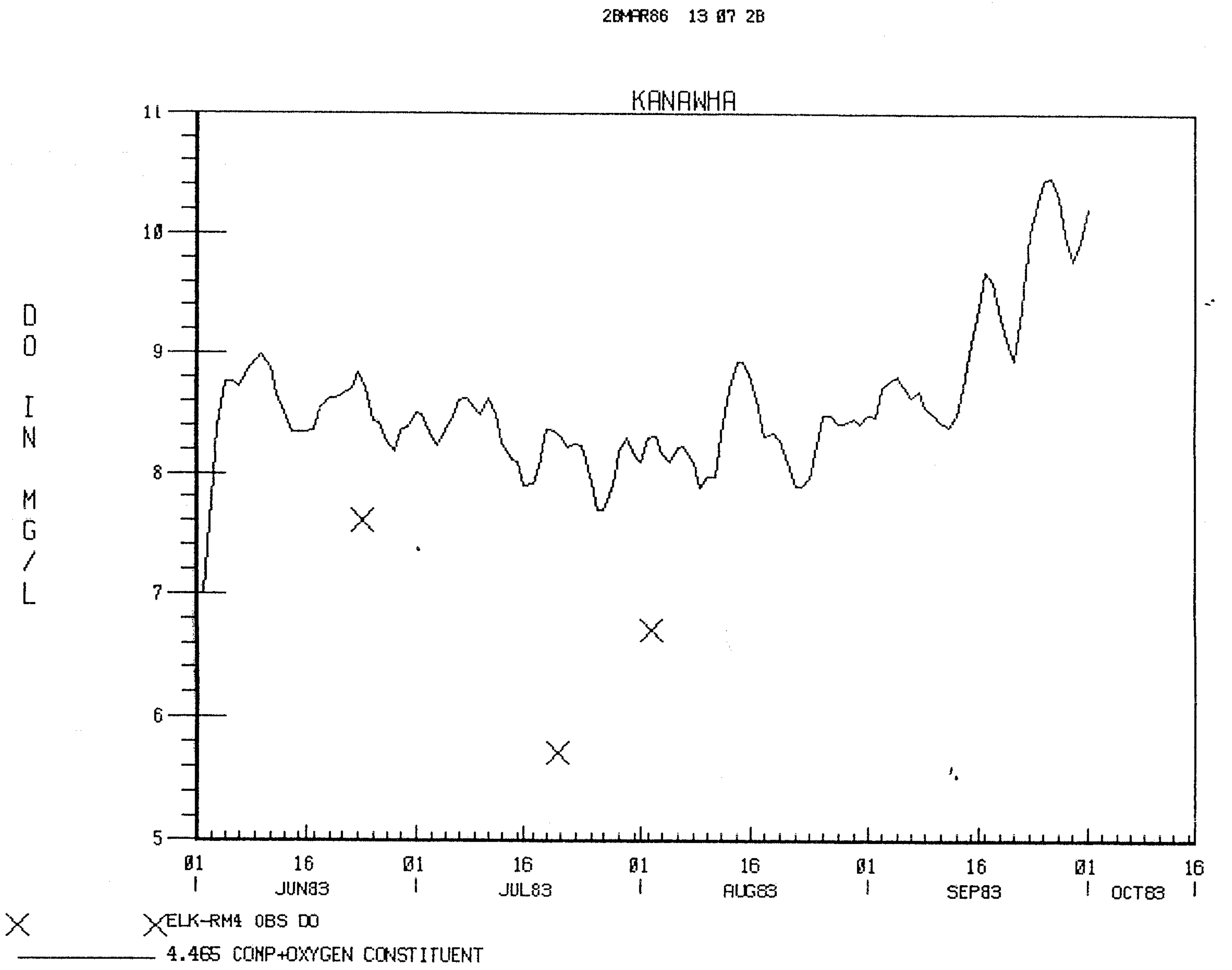
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DO IN MG/L
11
10
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8
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JUN83
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SEP83
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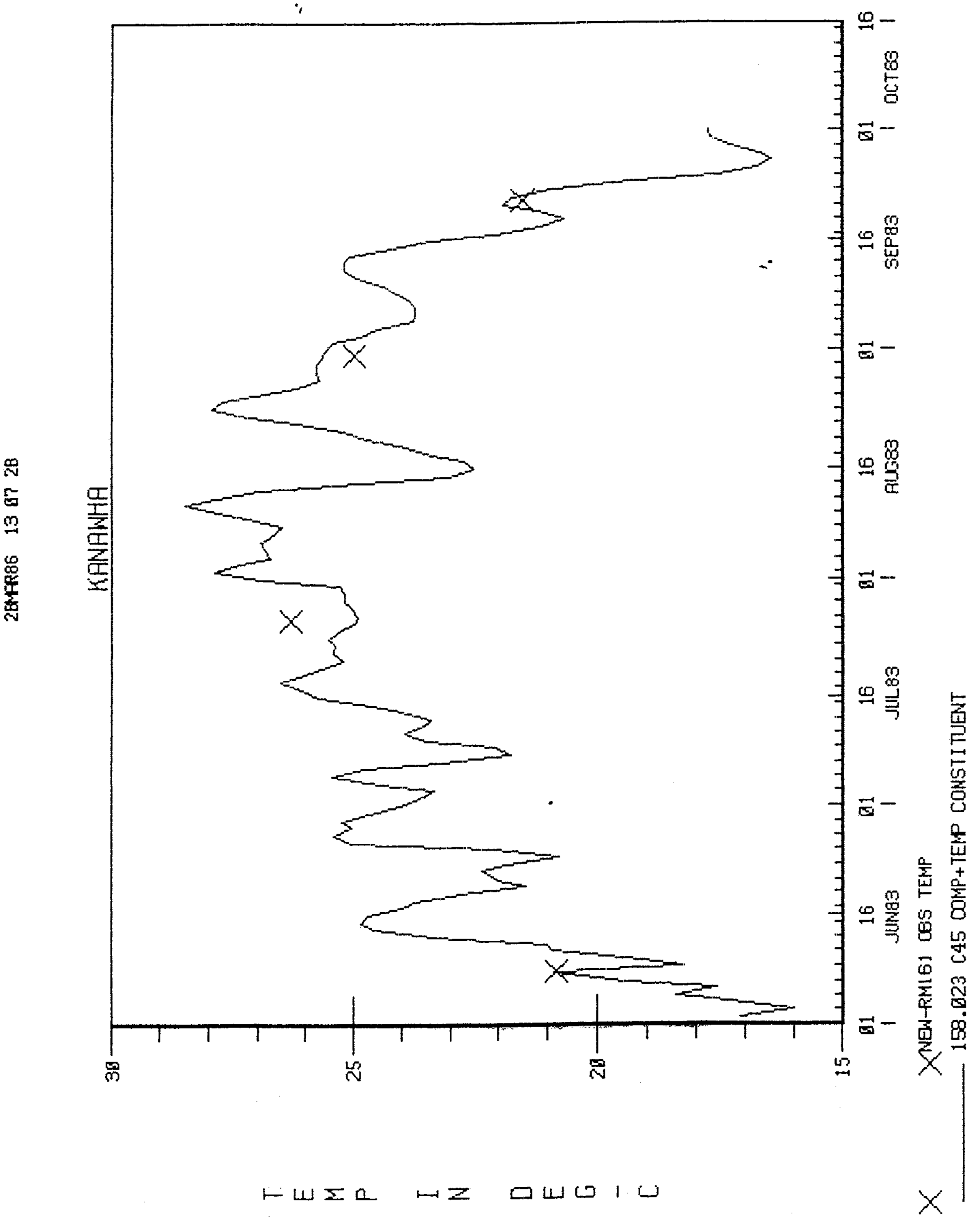
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25
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SEP83
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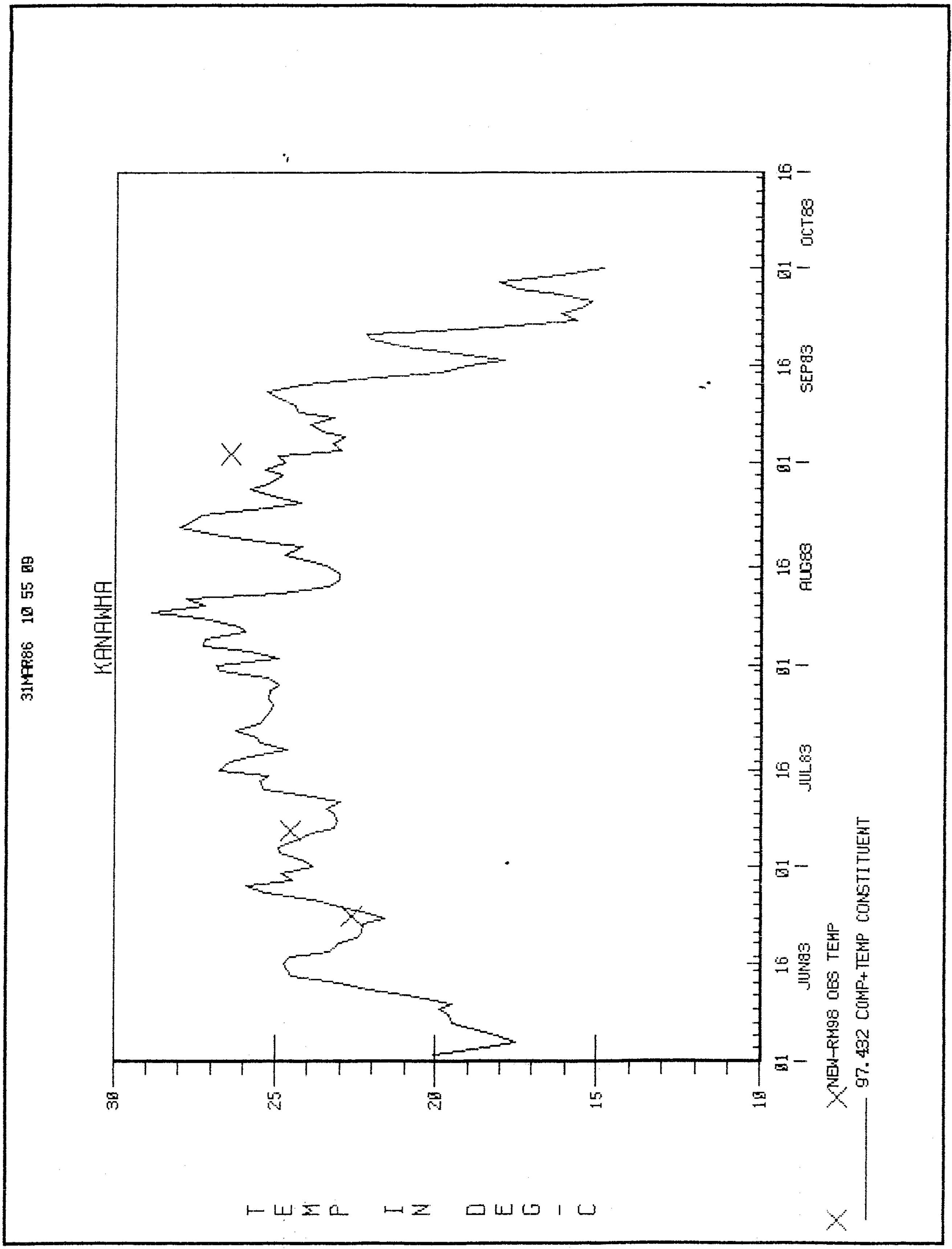
NEW-RM161 OBS TEMP
158.023 C45 COMP+TEMP CONSTITUENT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KANAWHA
TEMP IN DEG-C
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25
20
15
10
01
16
JUN83
01
16
JUL83
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SEP83
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OCT83
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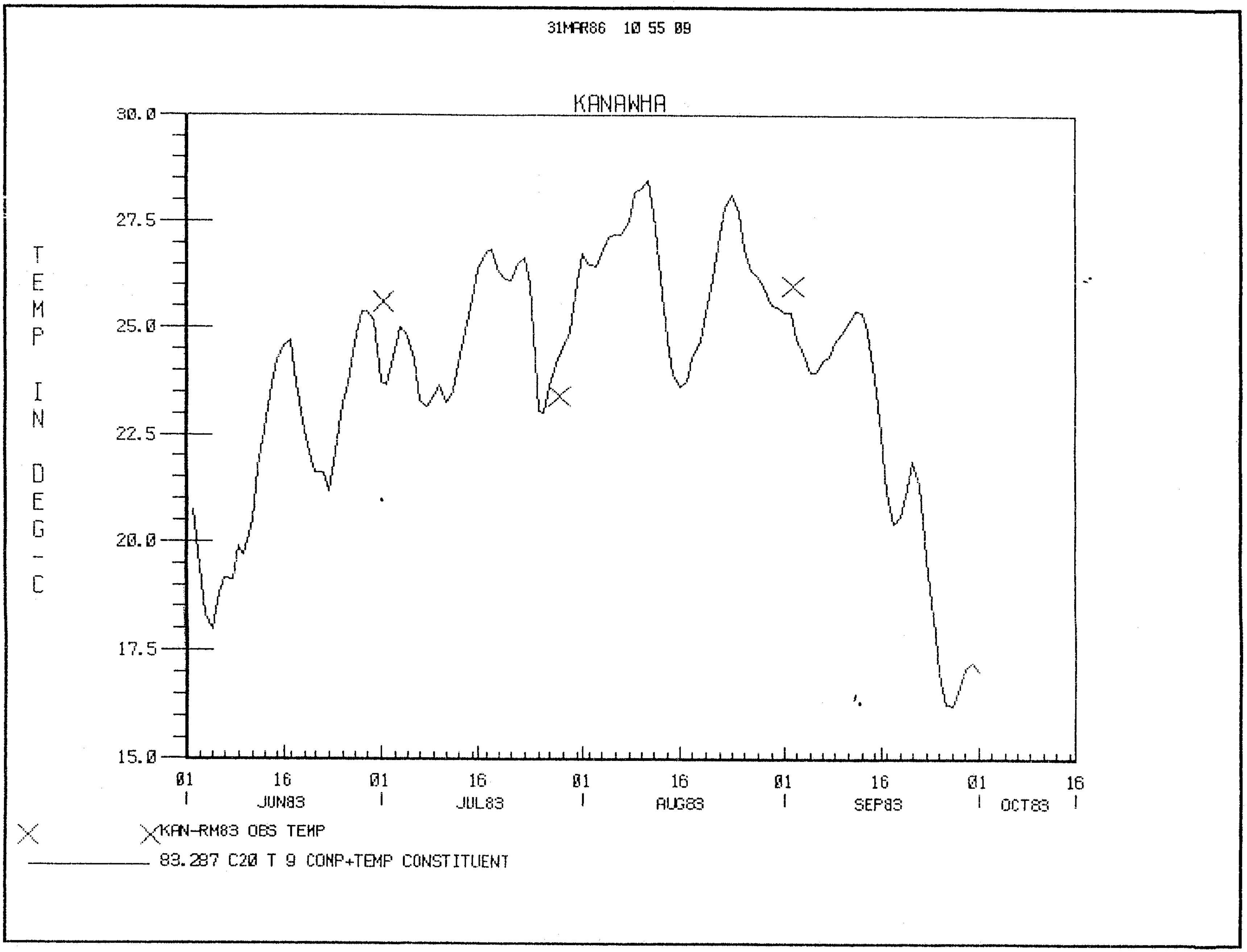
NEW-RM98 OBS TEMP
97.432 COMP+TEMP CONSTITUENT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30.0
27.5
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17.5
15.0
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16
JUN83
01
16
JUL83
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AUG83
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SEP83
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OCT83
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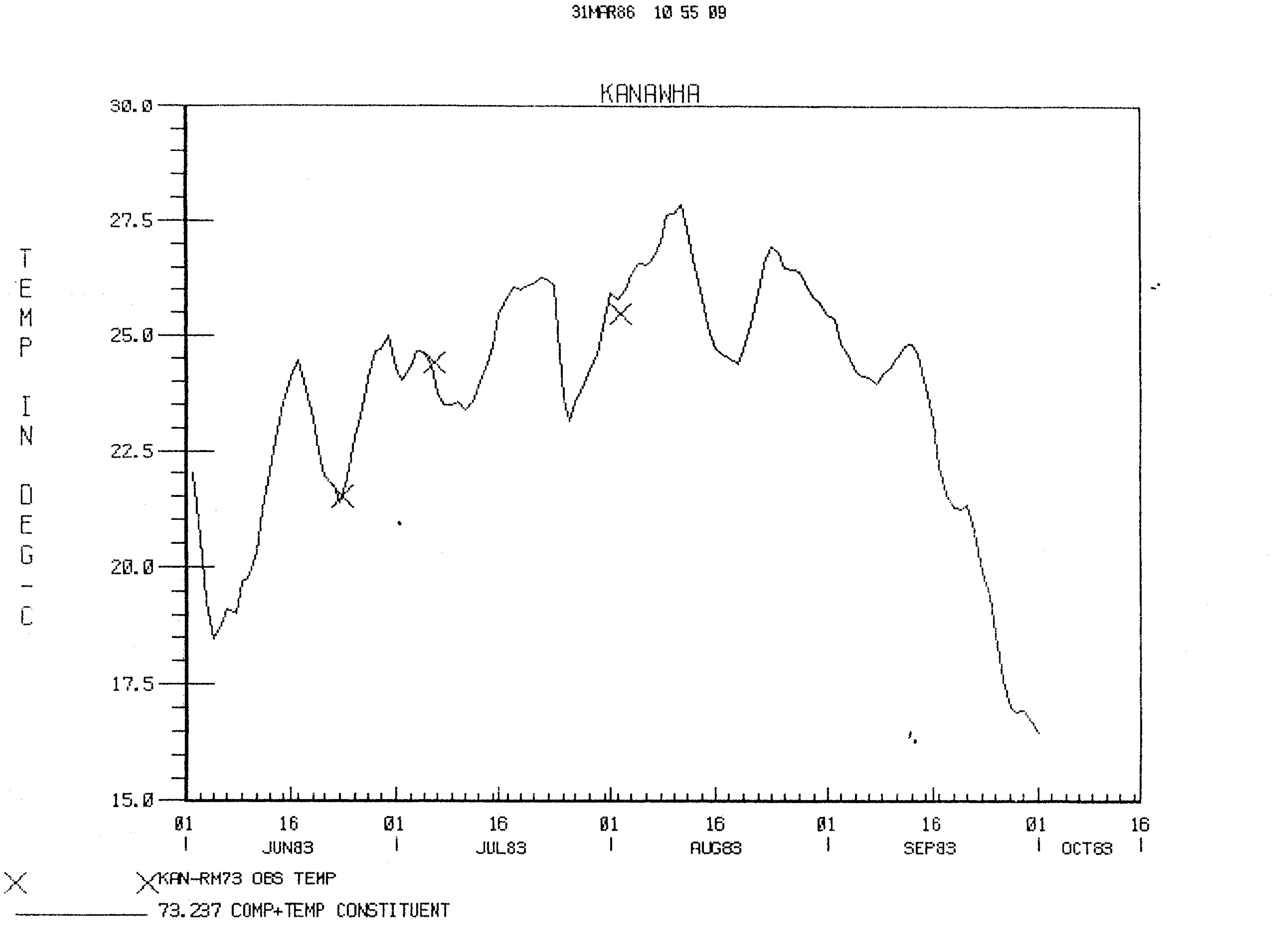
KAN-RM83 OBS TEMP
83.287 C20 T 9 COMP+TEMP CONSTITUENT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27.5
25.0
22.5
20.0
17.5
15.0
01
16
JUN83
01
16
JUL83
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AUG83
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SEP83
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OCT83
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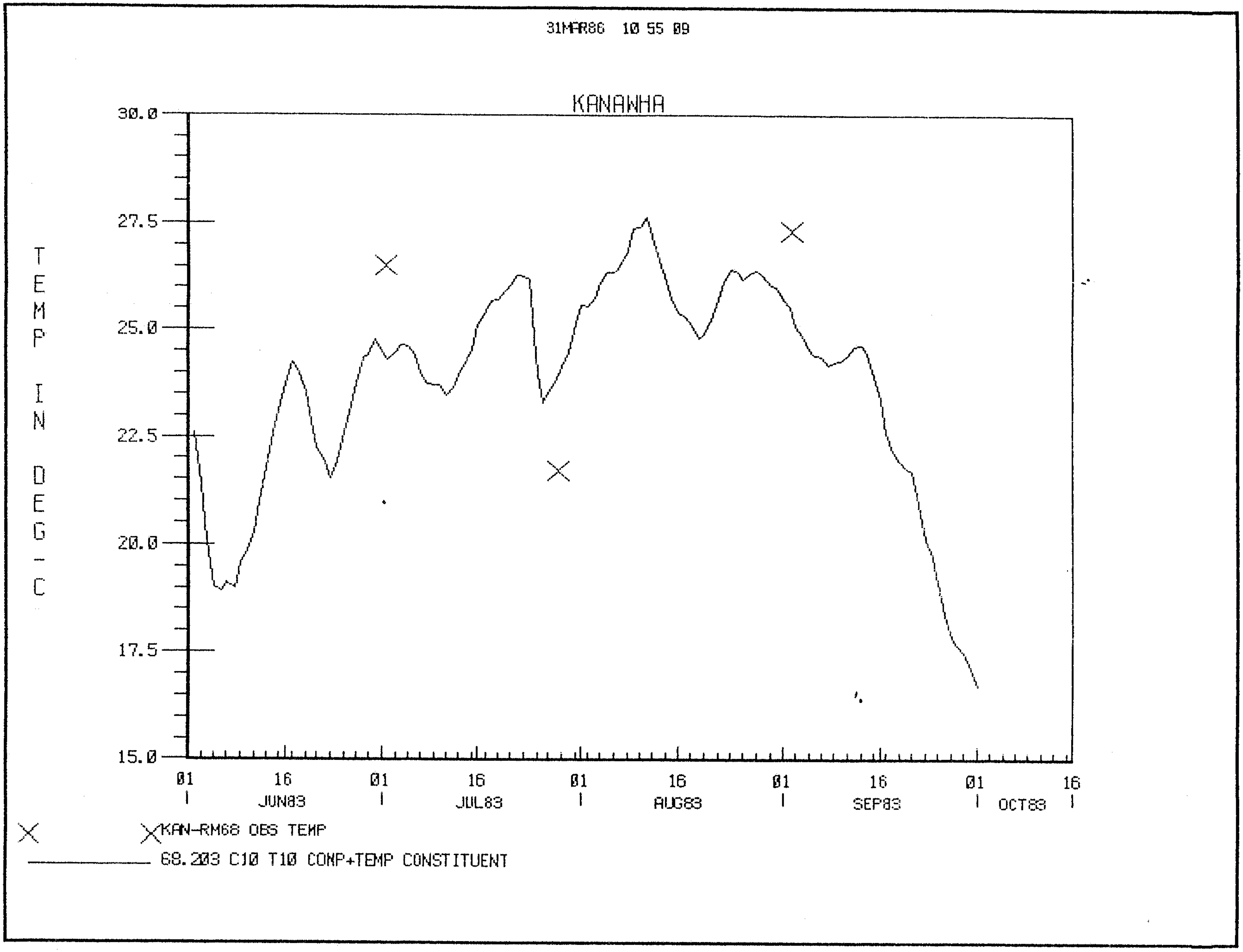
KAN-RM73 OBS TEMP
73.237 COMP+TEMP CONSTITUENT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20.0
17.5
15.0
01
16
JUN83
01
16
JUL83
01
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AUG83
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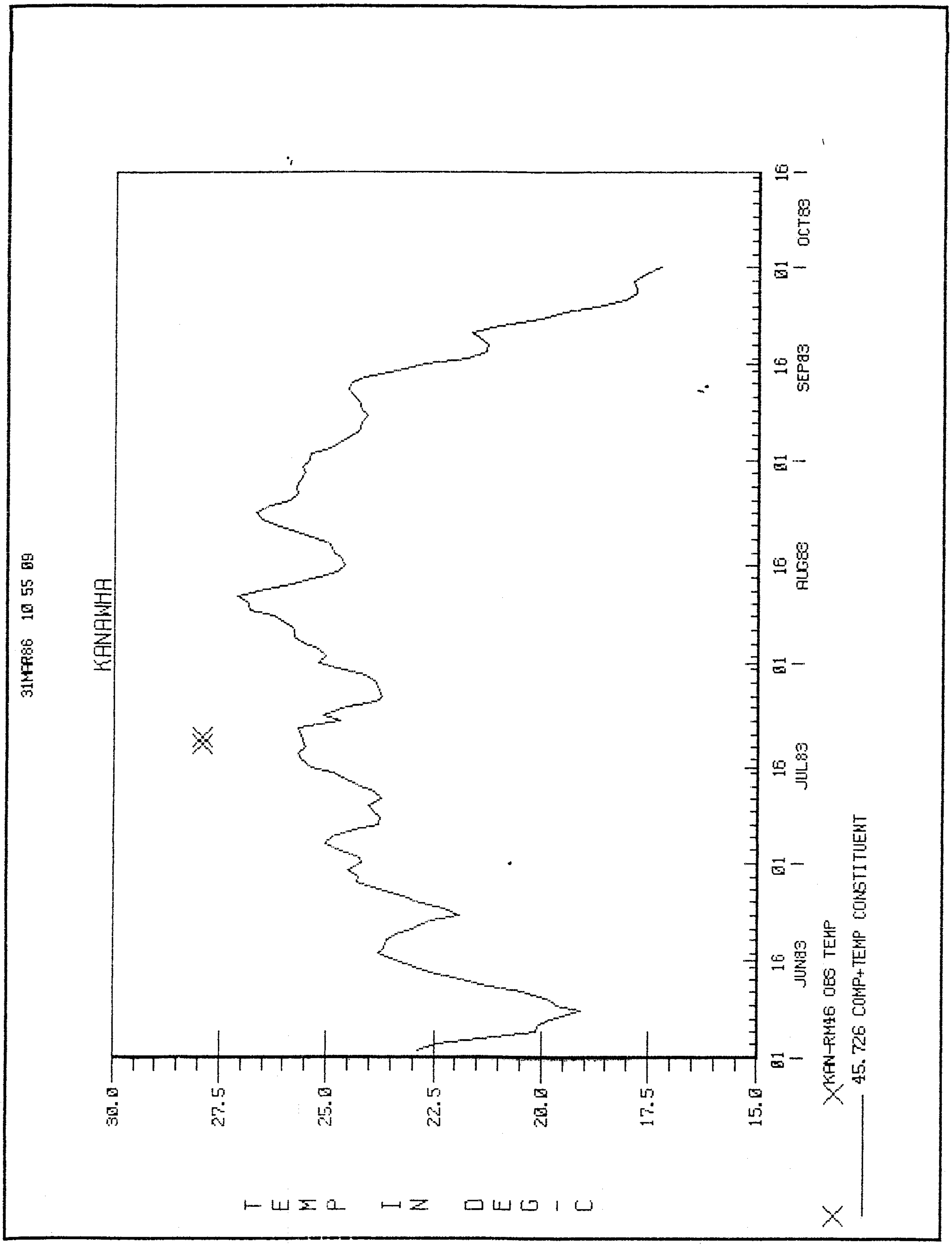
SEP83
01
OCT83
16
KAN-RM68 OBS TEMP
68.203 C10 T10 COMP+TEMP CONSTITUENT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25.0
22.5
20.0
17.5
15.0
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JUN83
01
16
JUL83
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AUG83
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SEP83
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OCT83
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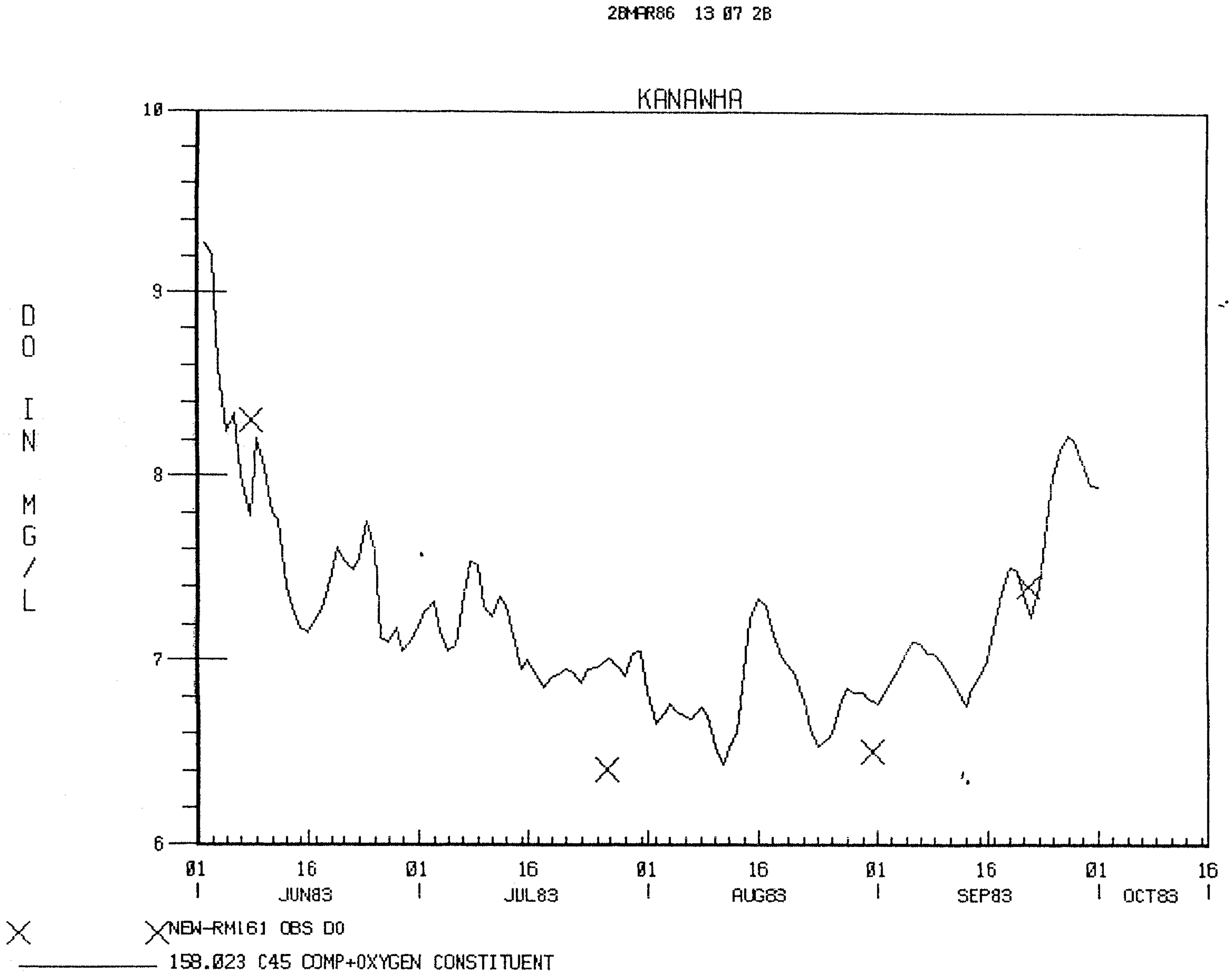
KAN-RM46 OBS TEMP
45.726 COMP+TEMP CONSTITUENT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KANAWHA
DO IN MG/L
10
9
8
7
6
01
16
JUN83
01
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JUL83
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AUG83
01
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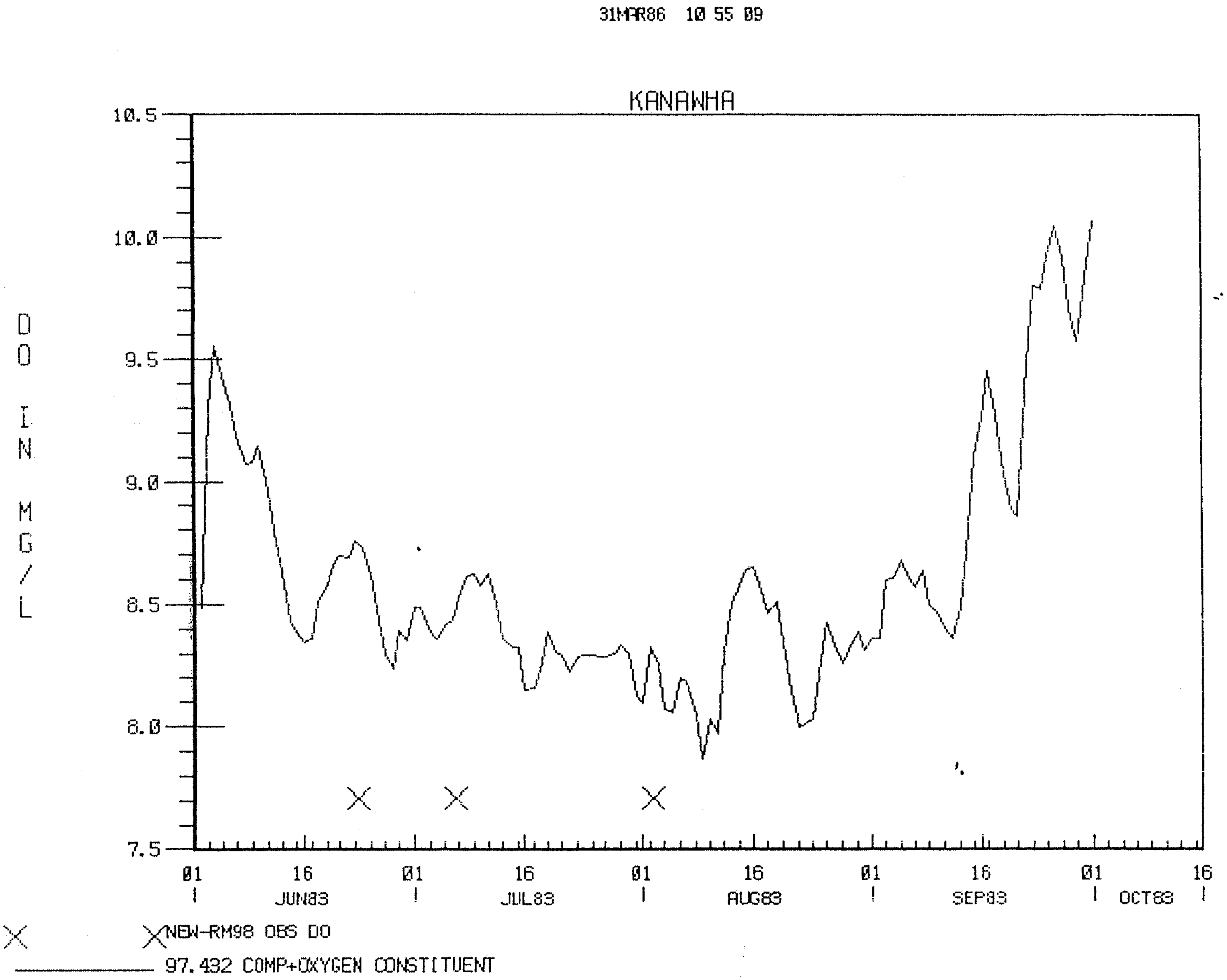
SEP83
01
OCT83
16
NEW-RM161 OBS DO
158.023 C45 COMP+OXYGEN CONSTITUENT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10.0
9.5
9.0
8.5
8.0
7.5
01
16
JUN83
01
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SEP83
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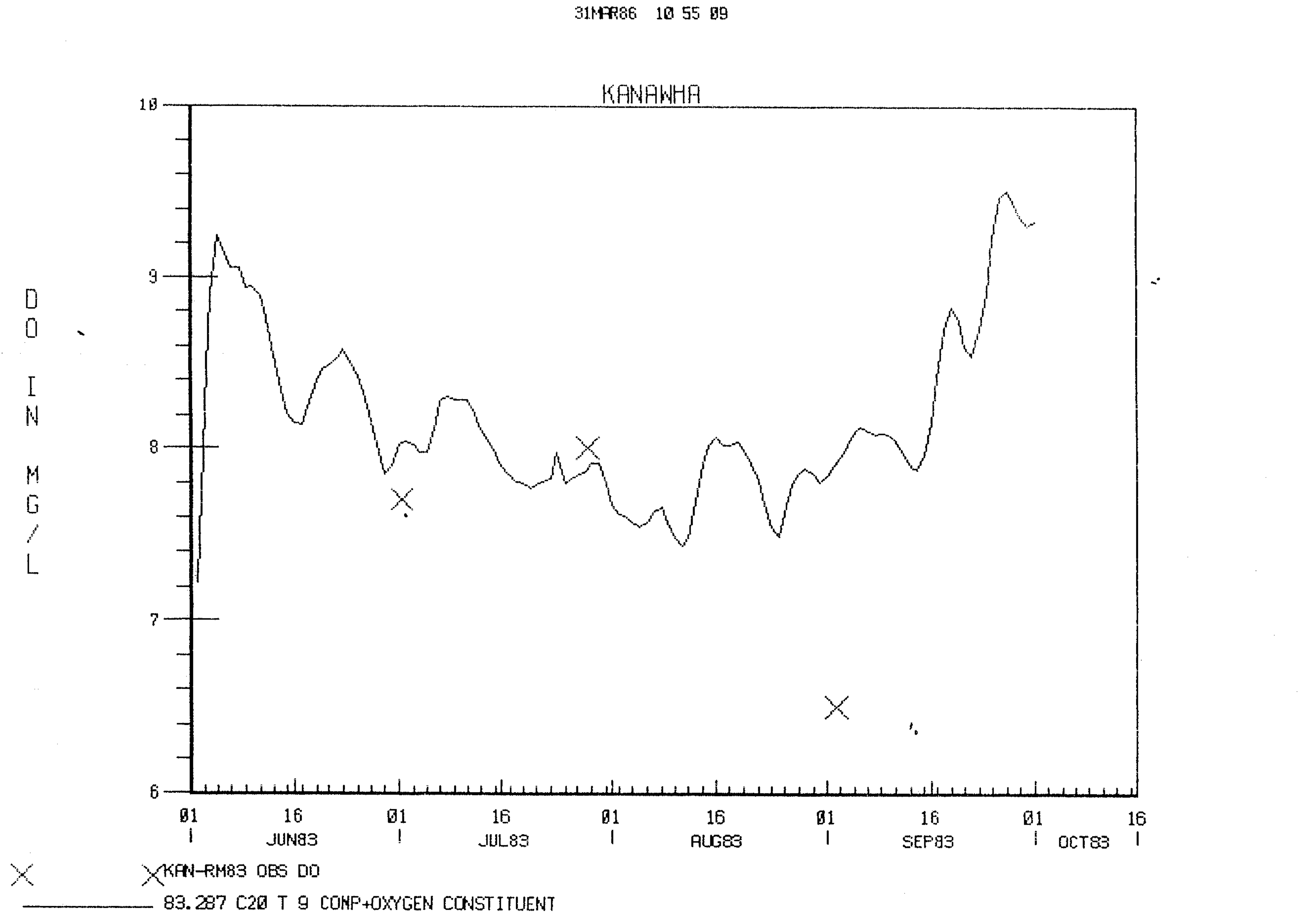
OCT83
16
NEW-RM98 OBS DO
97.432 COMP+OXYGEN CONSTITUENT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KANAWHA
DO IN MG/L
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9
8
7
6
01
16
JUN83
01
16
JUL83
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AUG83
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SEP83
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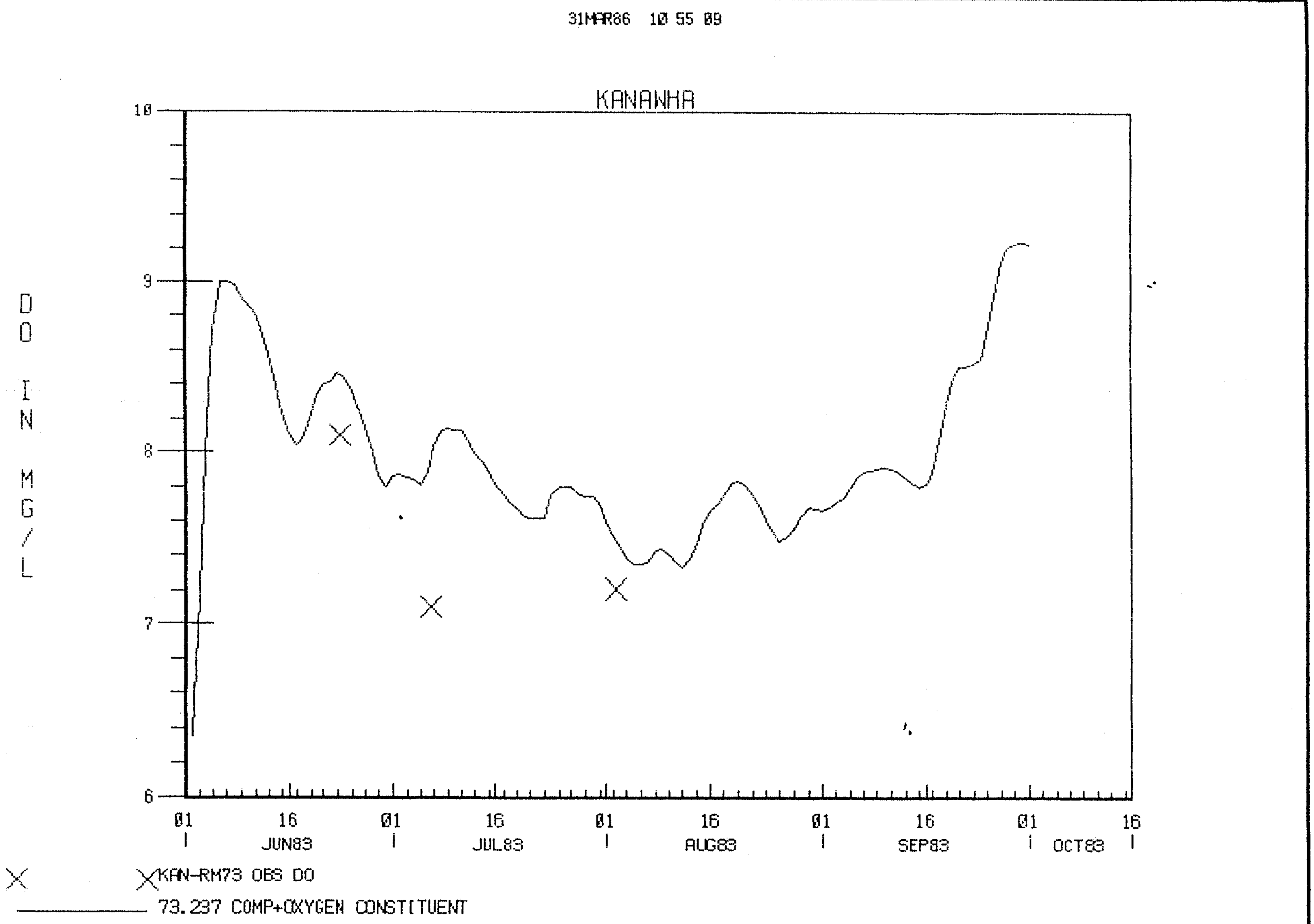
OCT83
16
KAN-RM83 OBS DO
83.287 C20 T 9 COMP+OXYGEN CONSTITUENT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KANAWHA
DO IN MG/L
10
9
8
7
6
01
16
JUN83
01
16
JUL83
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AUG83
01
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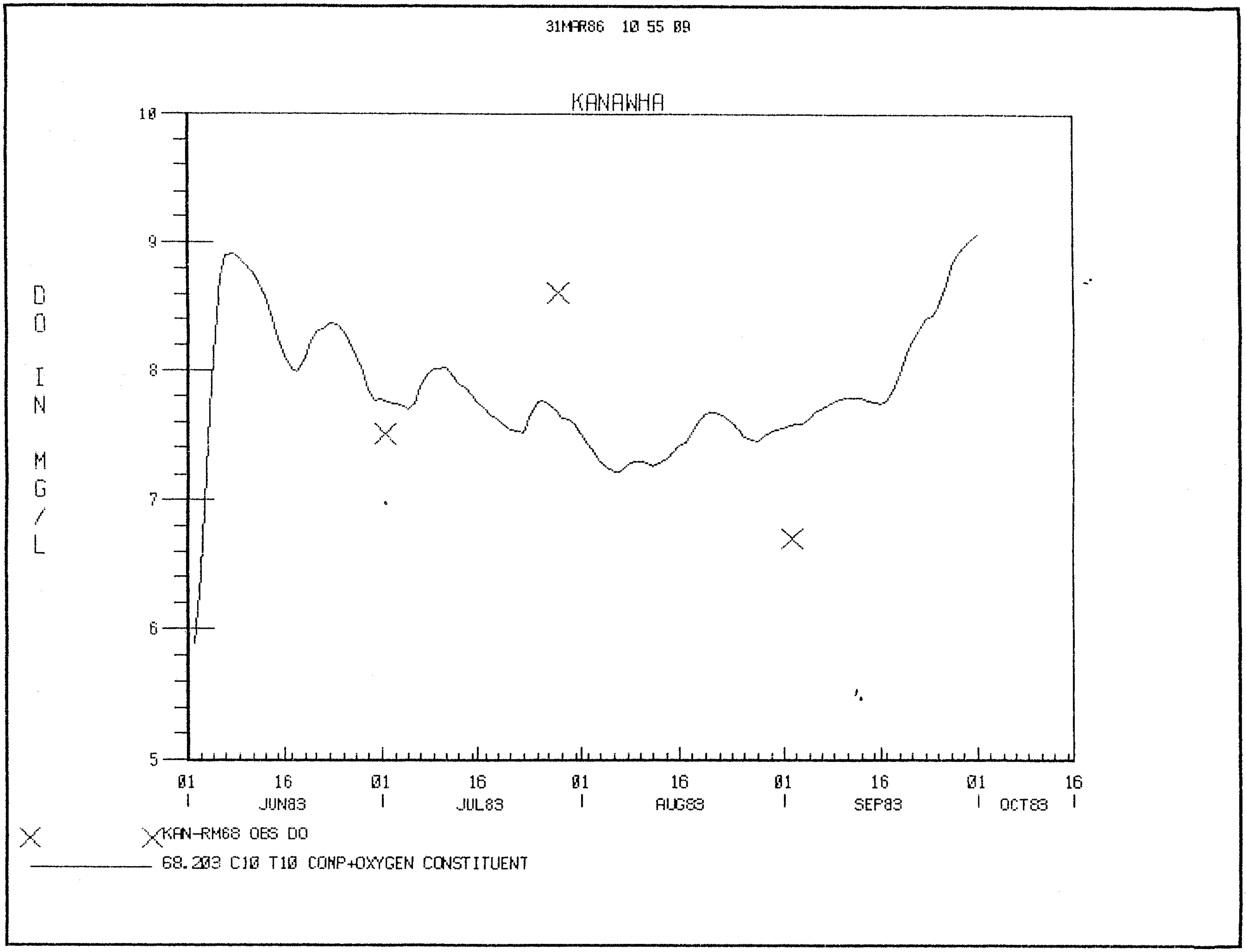
SEP83
01
OCT83
16
KAN-RM73 OBS DO
73.237 COMP+OXYGEN CONSTITUENT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KANAWHA
DO IN MG/L
10
9
8
7
6
5
01
16
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01
16
01
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JUN83
JUL83
AUG83
SEP83
OCT83
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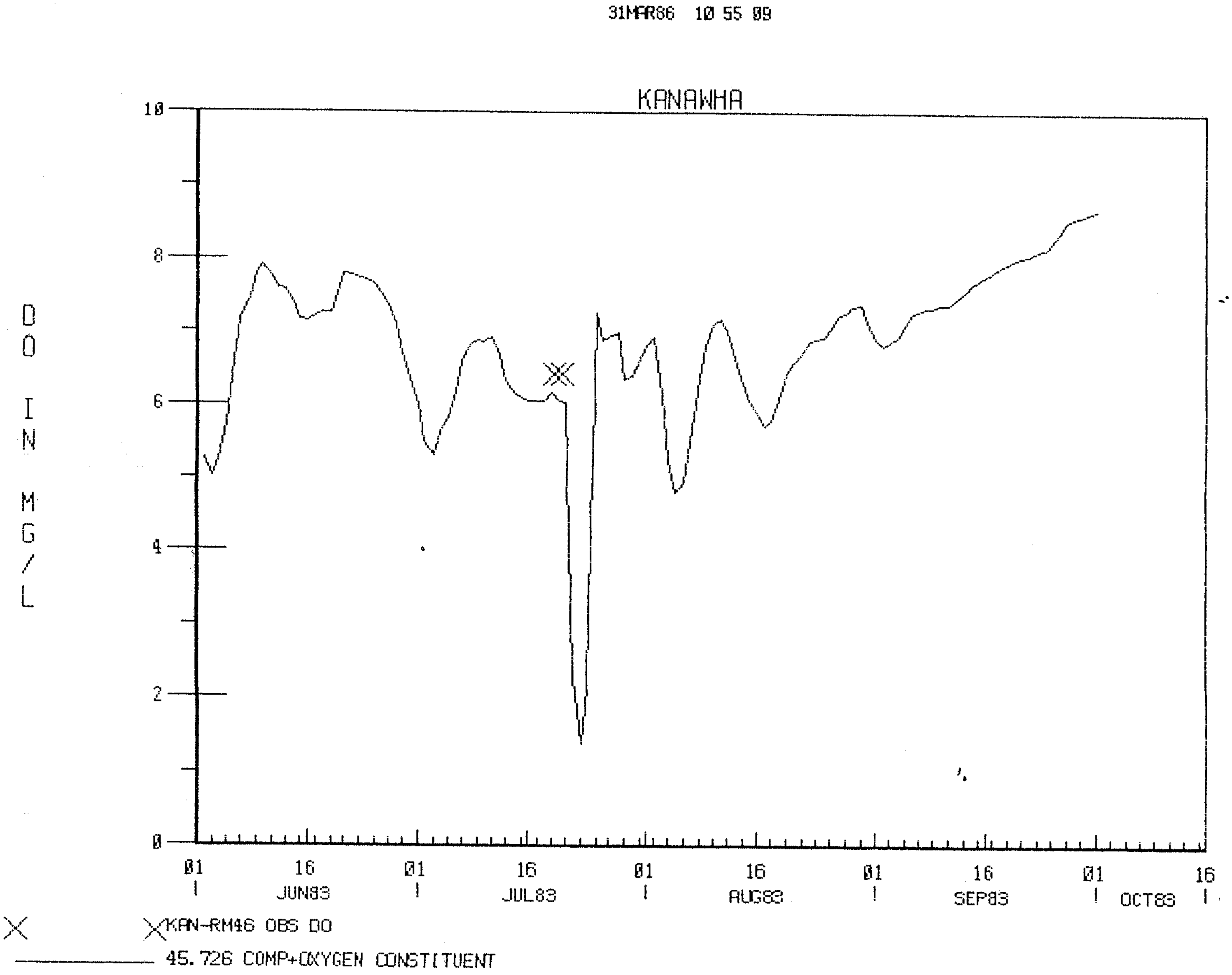
68.203 C10 T10 COMP+OXYGEN CONSTITUENT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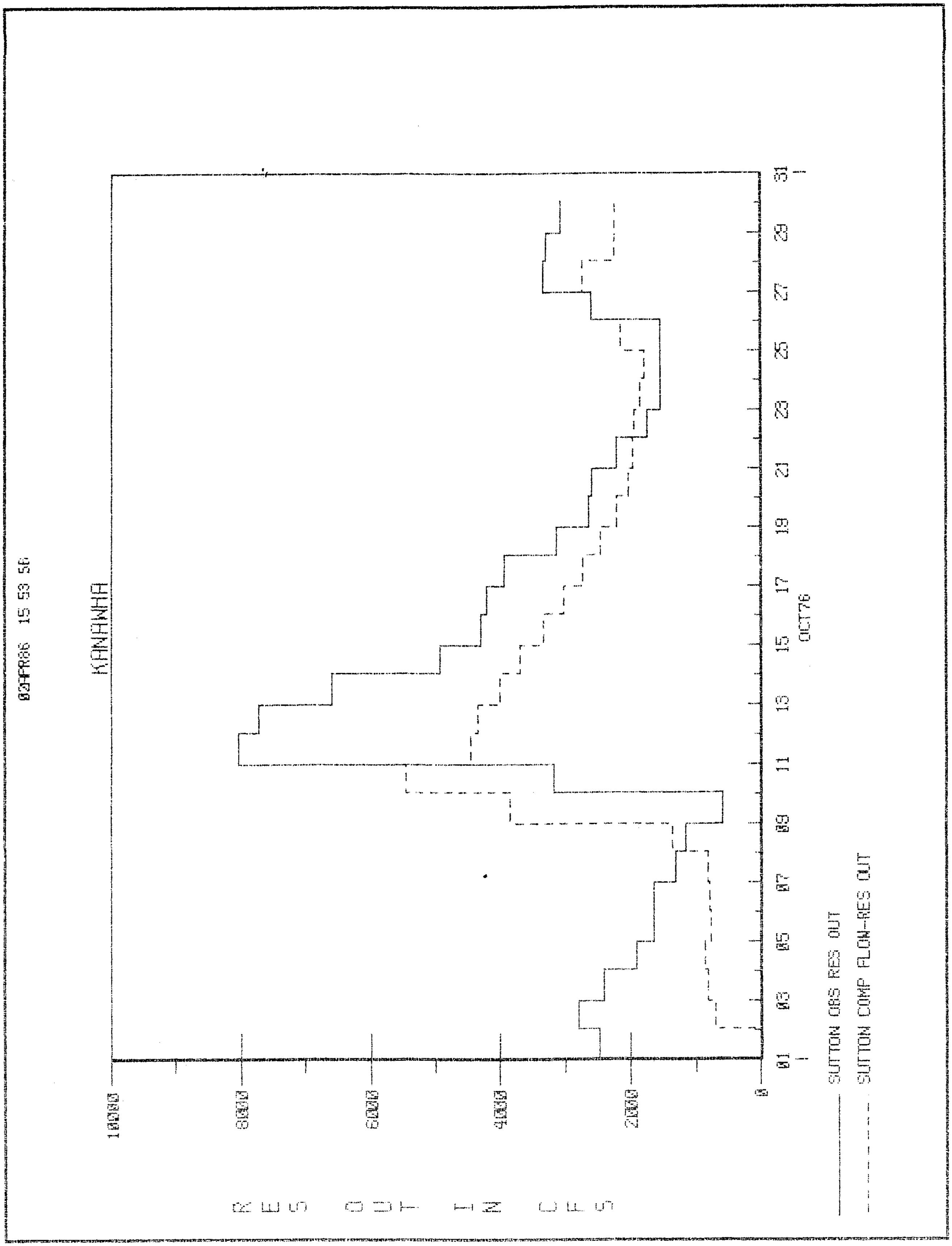
KANAWHA
DO IN MG/L
10
8
6
4
2
0
01
16
JUN83
01
16
JUL83
01
16
AUG83
01
16
SEP83
01
OCT83
16
KAN-RM46 OBS DO
45.726 COMP+OXYGEN CONSTITUENT

APPENDIX C

GRAPHICAL RESULTS OF OPERATIONAL CAPABILITY

TABLE OF CONTENTS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KANAWHA
RES OUT IN CFS
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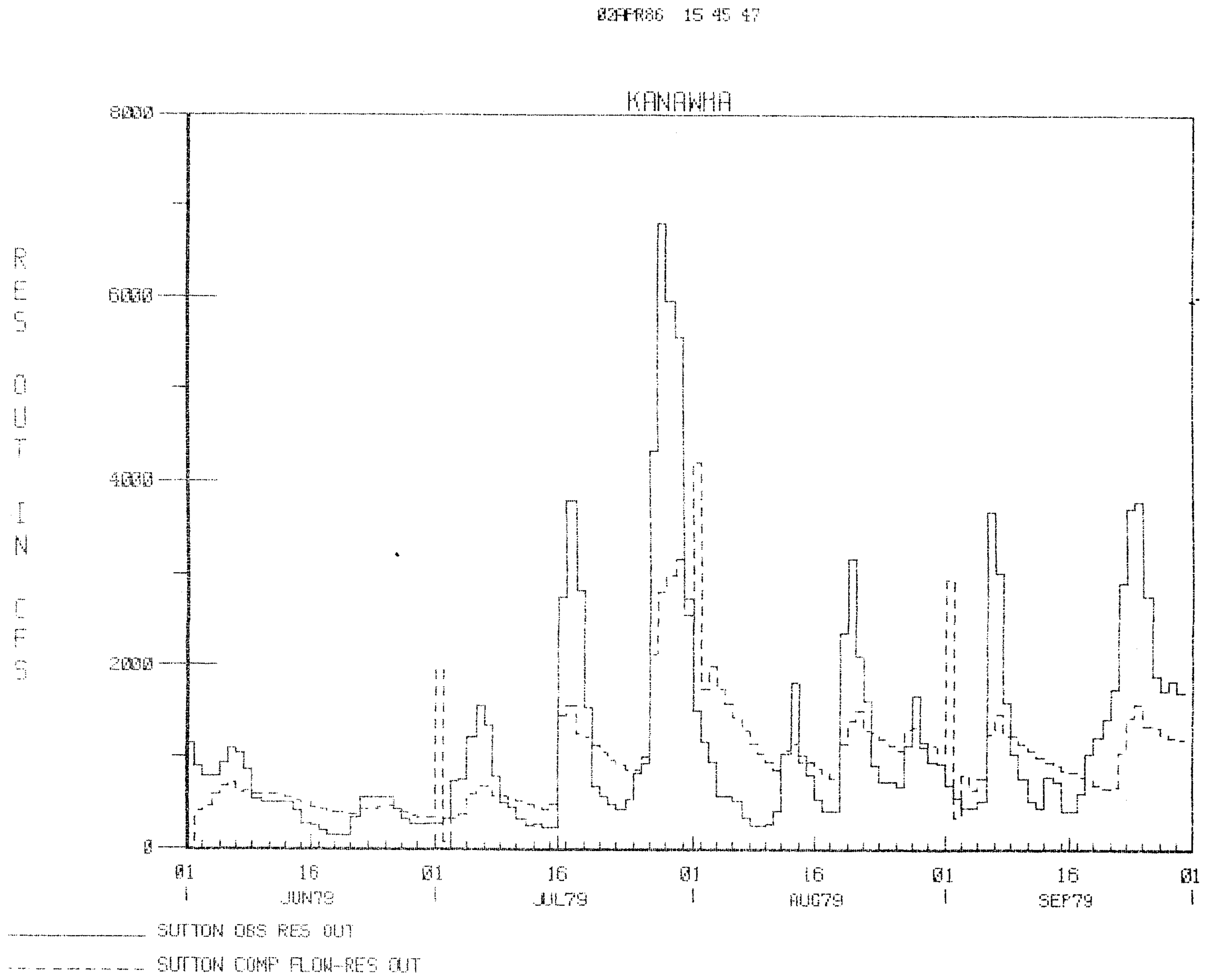
8000
6000
4000
2000
0
01
03
05
07
09
11
13
15
17
19
21
23
25
27
29
31
OCT76
SUTTON OBS RES OUT
SUTTON COMP FLOW-RES OUT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01
16
JUN79
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AUG79
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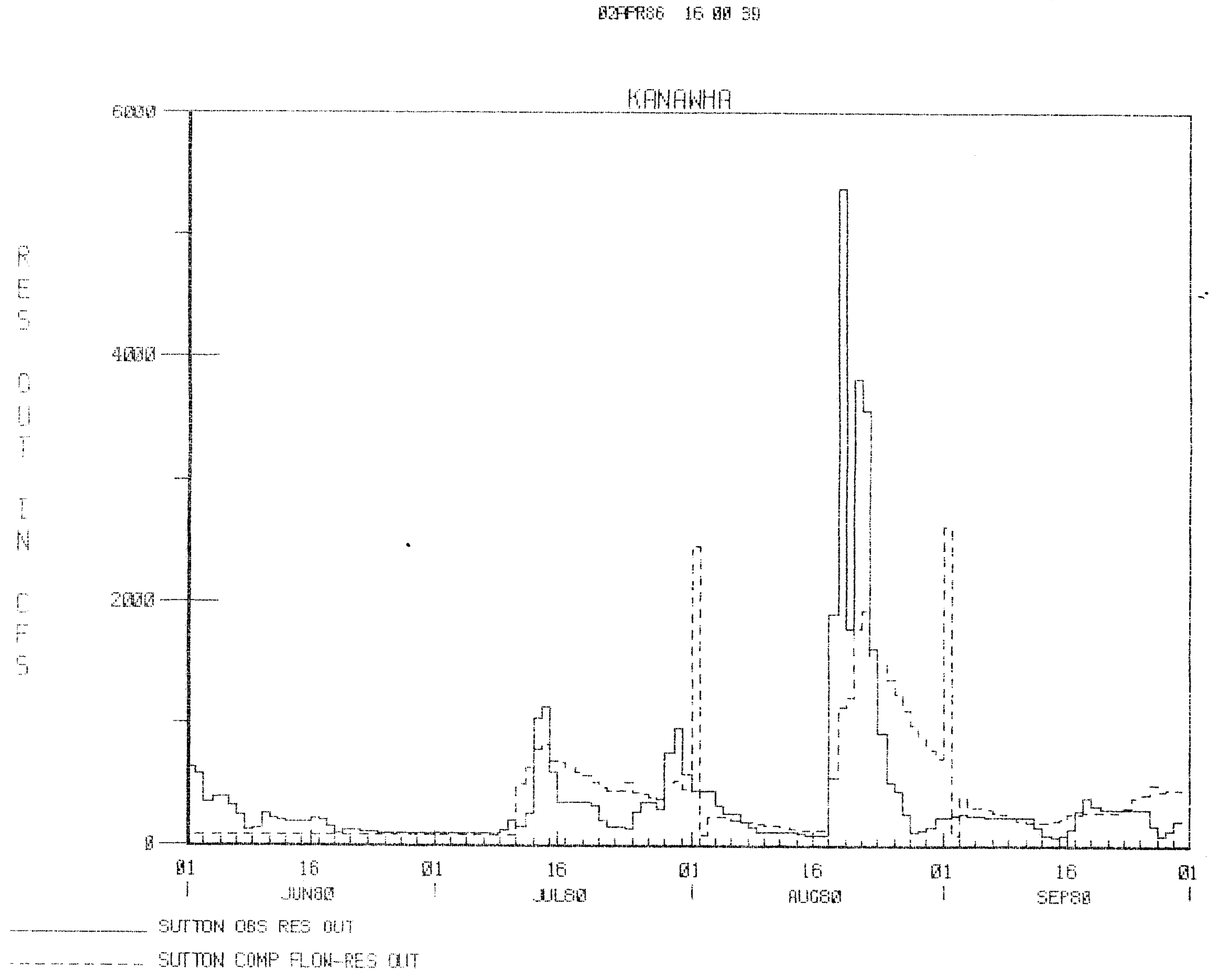
16
SEP79
01
SUTTON OBS RES OUT
SUTTON COMP FLOW-RES OUT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4000
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0
01
16
JUN80
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JUL80
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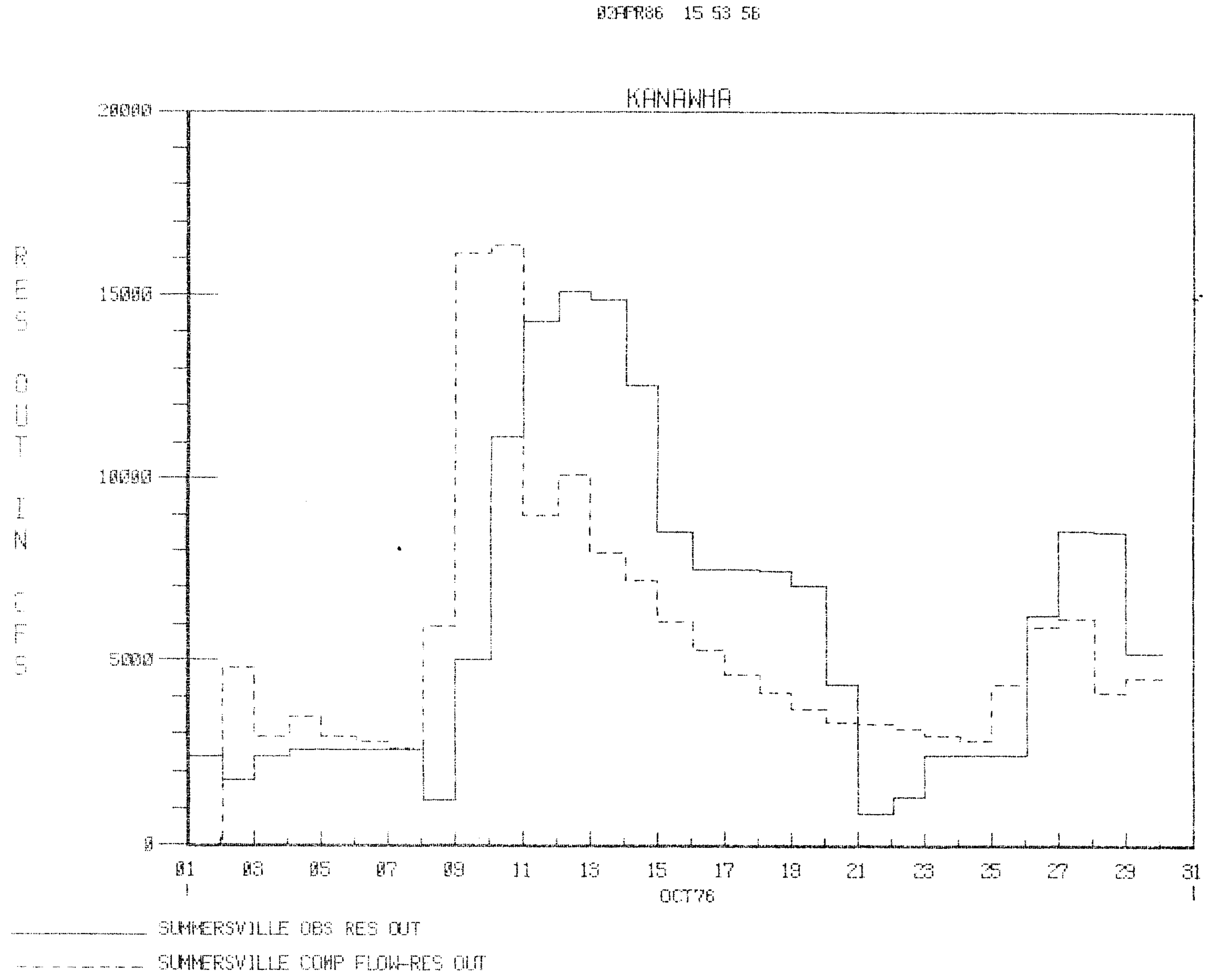
AUG80
01
16
SEP80
01
SUTTON OBS RES OUT
SUTTON COMP FLOW-RES OUT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10000
5000
0
01
03
05
07
09
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19
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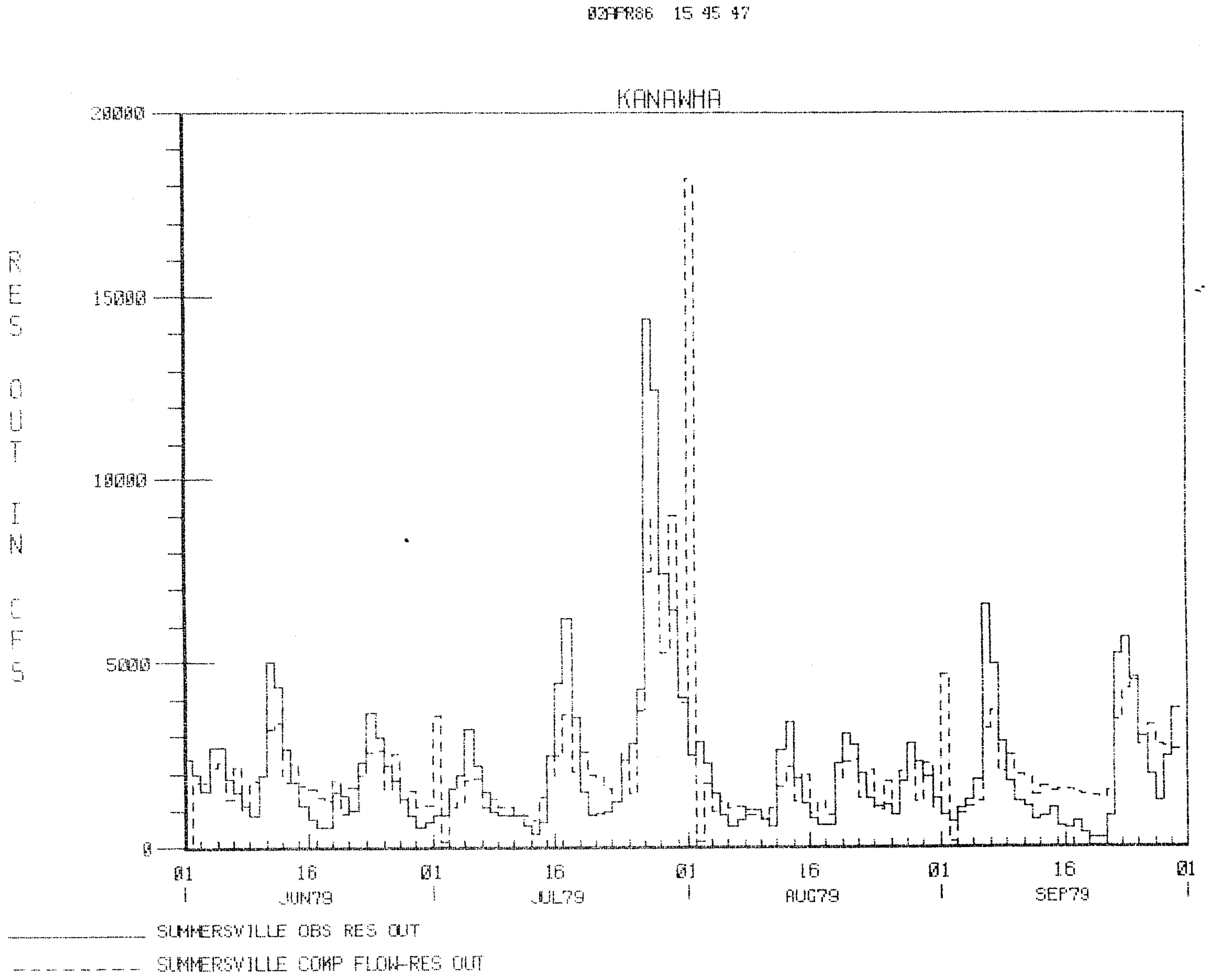
27
29
31
OCT76
SUMMERSVILLE OBS RES OUT
SUMMERSVILLE COMP FLOW-RES OUT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KANAWHA
RES OUT IN CFS
20000
15000
10000
5000
0
01
16
JUN79
01
16
JUL79
01
16
AUG79
01
16
SEP79
01
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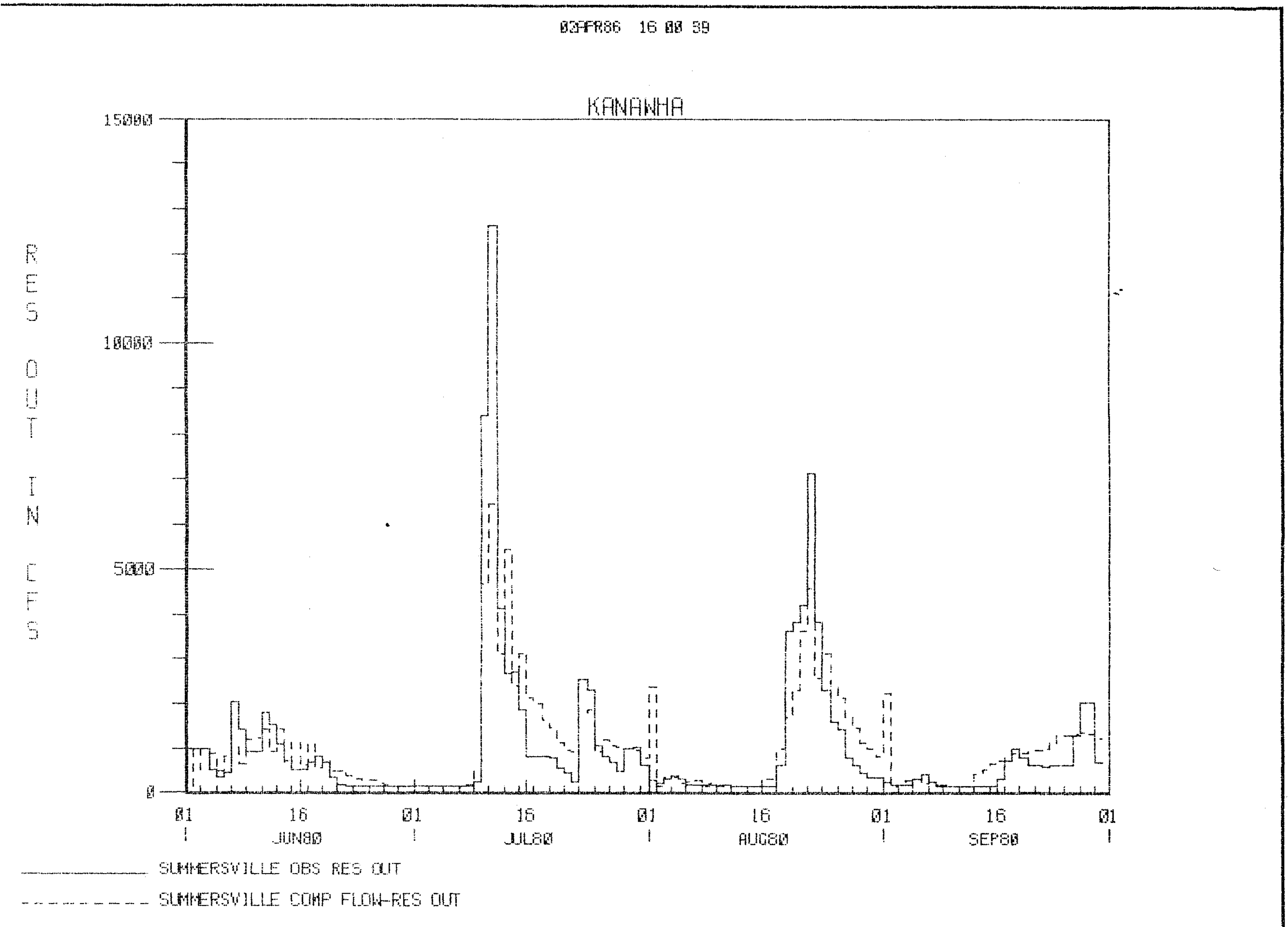
SUMMERSVILLE COMP FLOW-RES OUT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0
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JUN80
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AUG80
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SEP80
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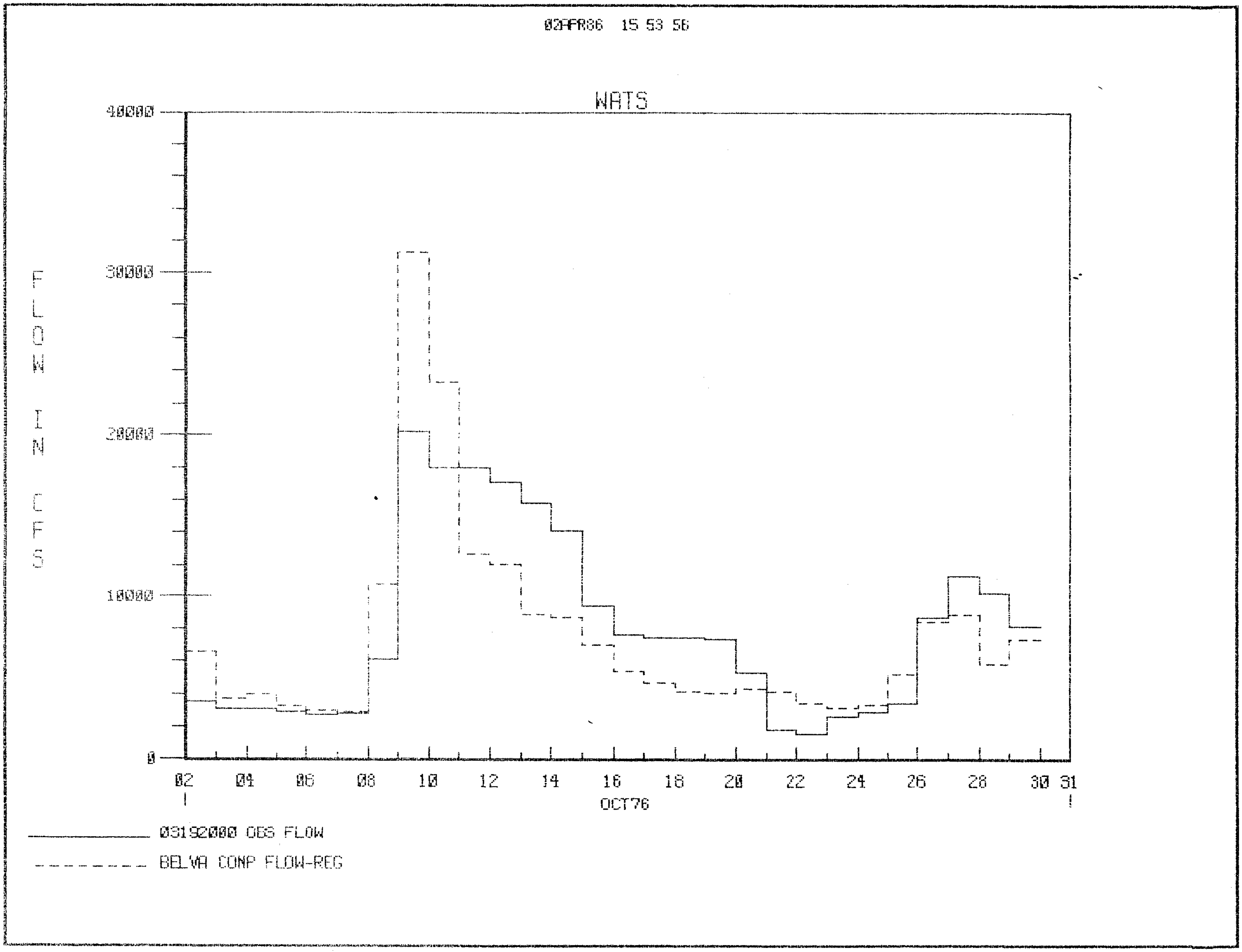
SUMMERSVILLE COMP FLOW-RES OUT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30000
20000
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0
02
04
06
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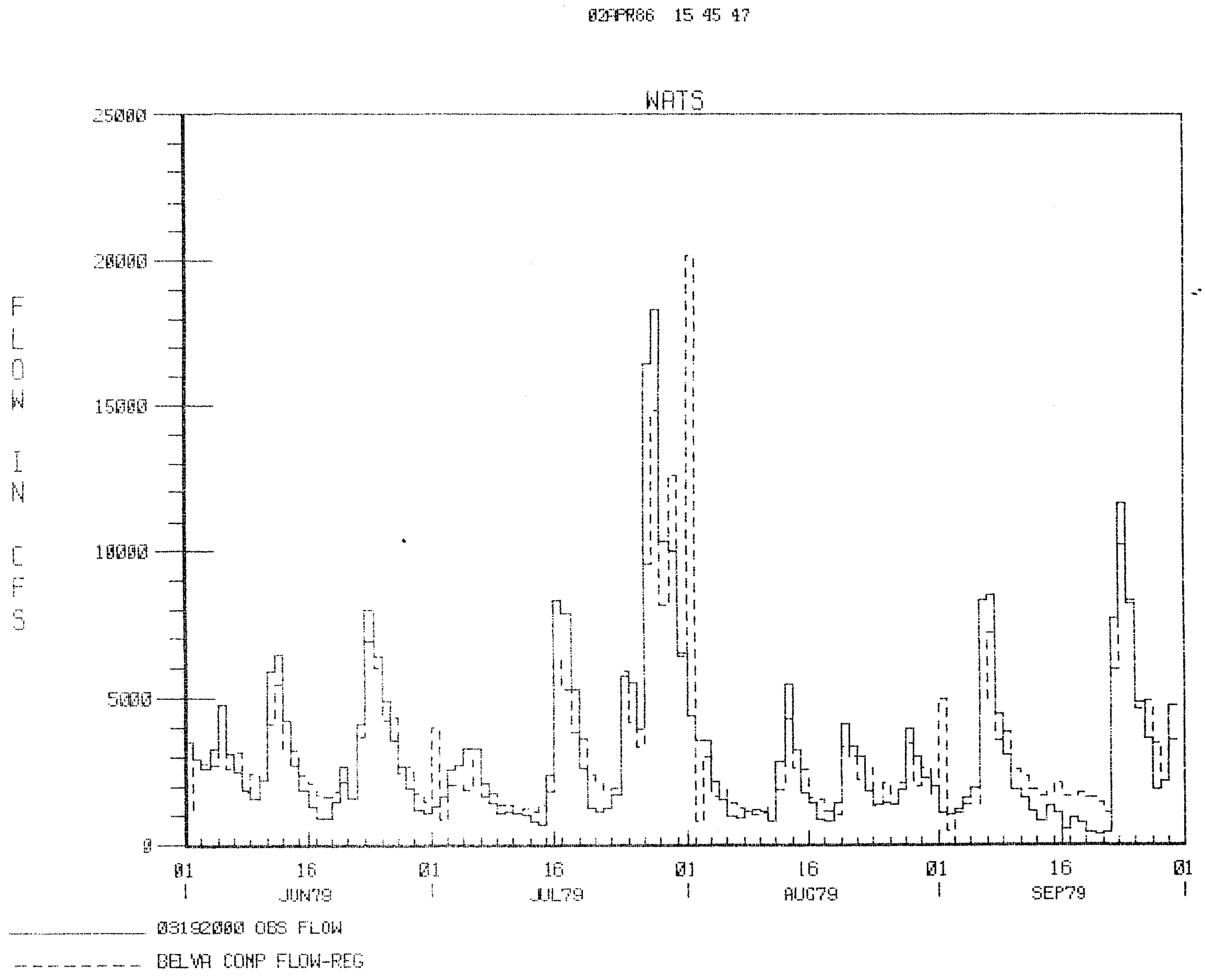
31
OCT76
03192000 OBS FLOW
BELVA COMP FLOW-REG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5000
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JUL79
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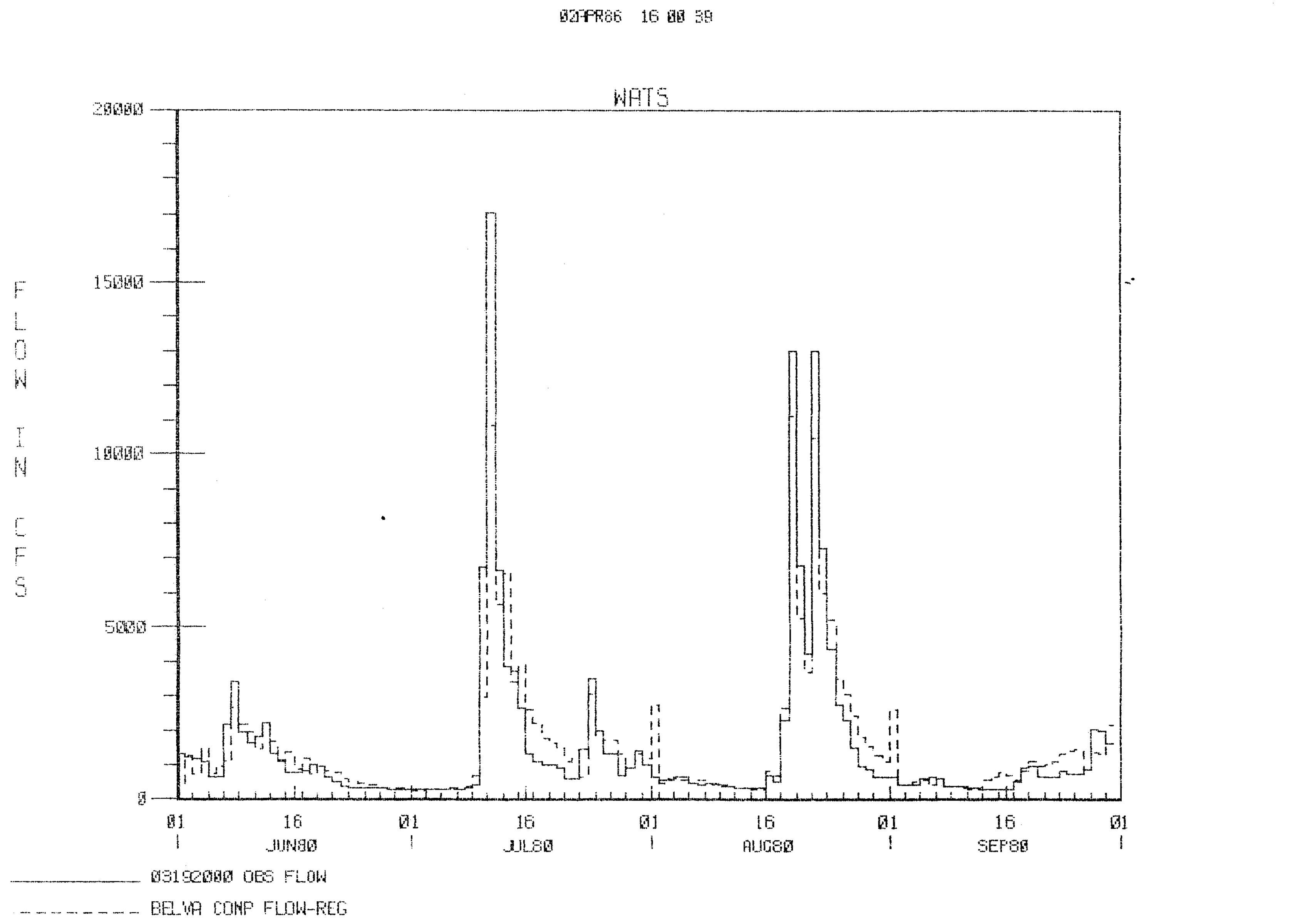
16
AUG79
01
16
SEP79
01
03192000 OBS FLOW
BELVA COMP FLOW-REG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0
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AUG80
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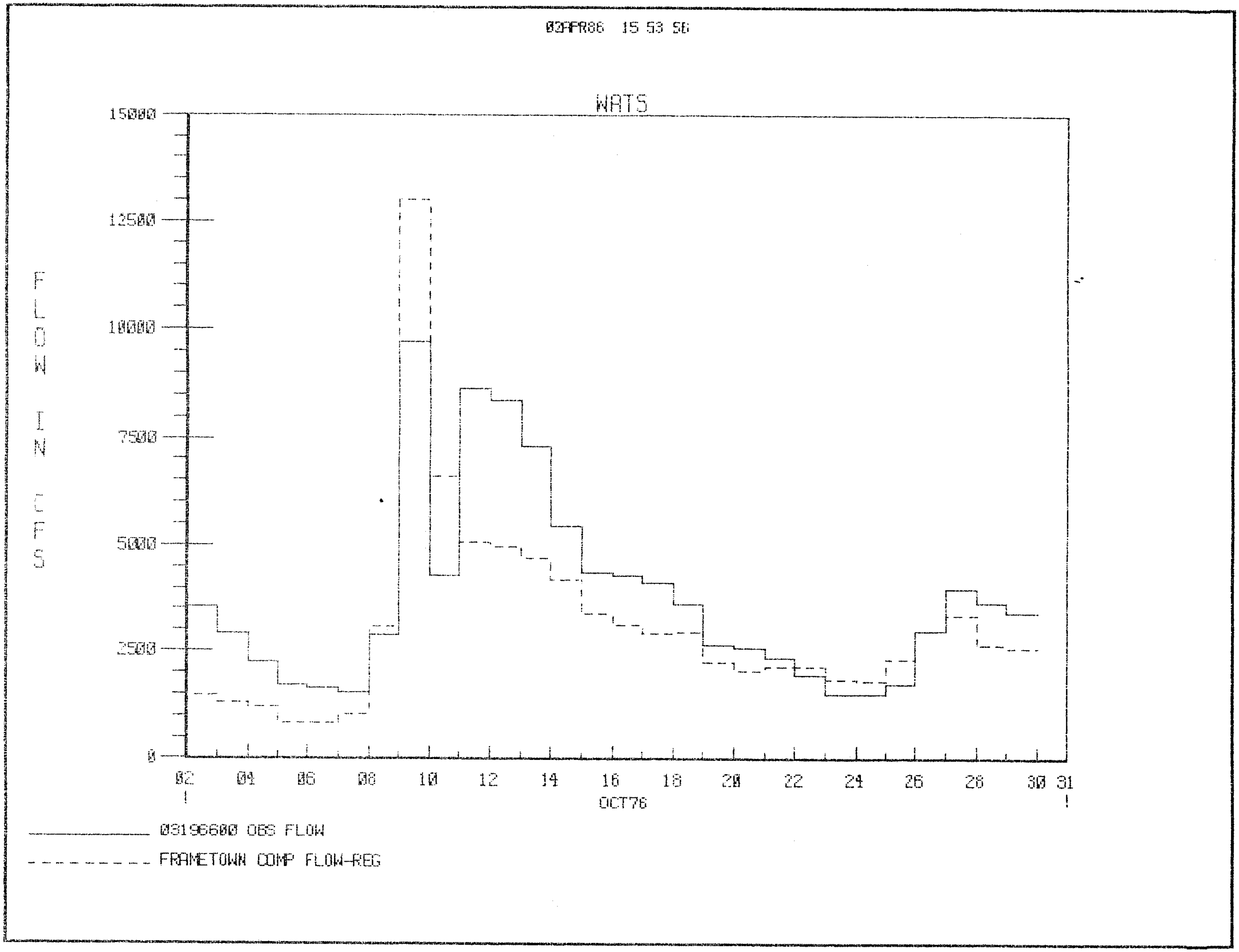
SEP80
01
03192000 OBS FLOW
BELVA COMP FLOW-REG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12
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03196600 OBS FLOW
FRAMETOWN COMP FLOW-REG

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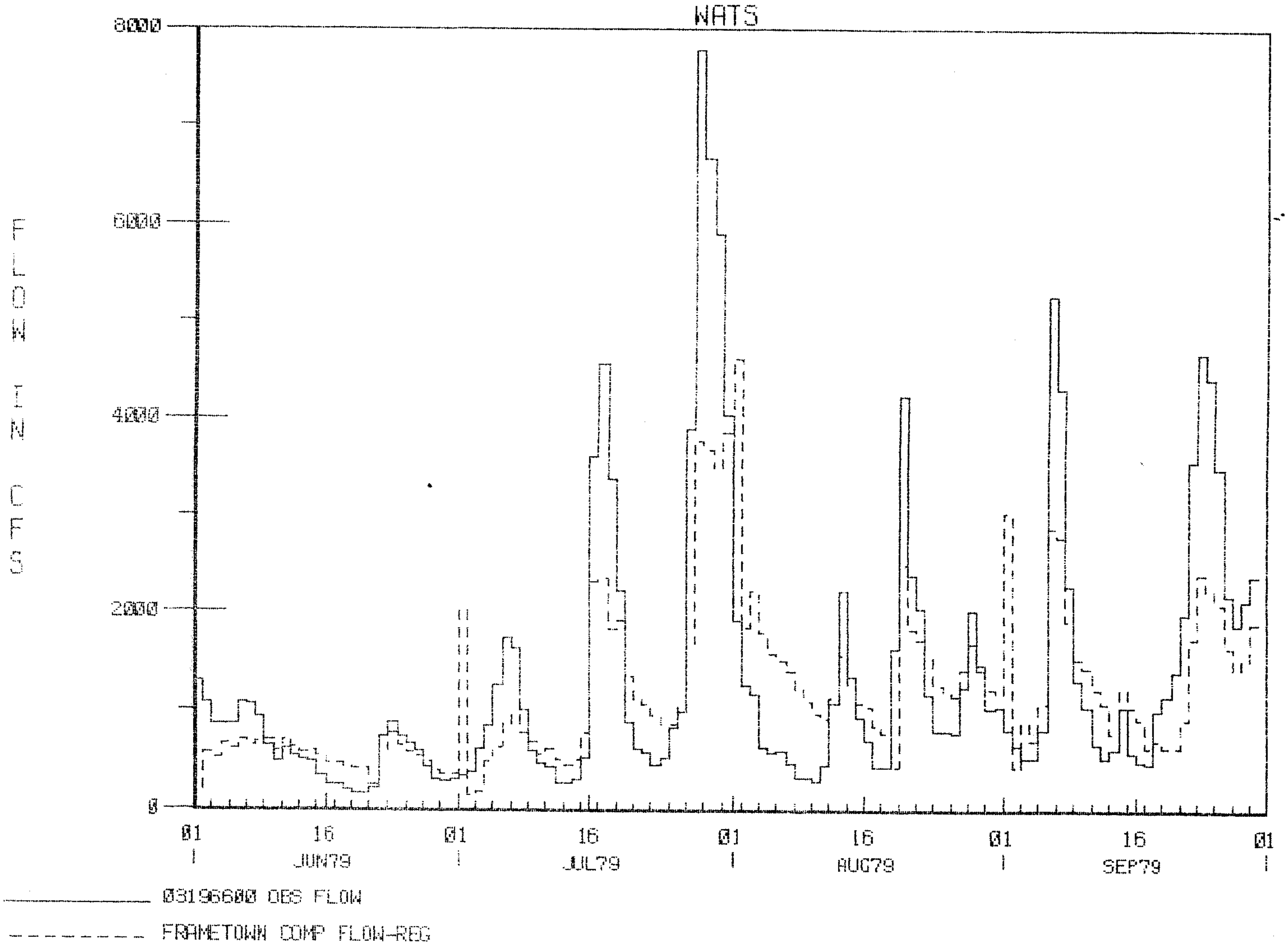

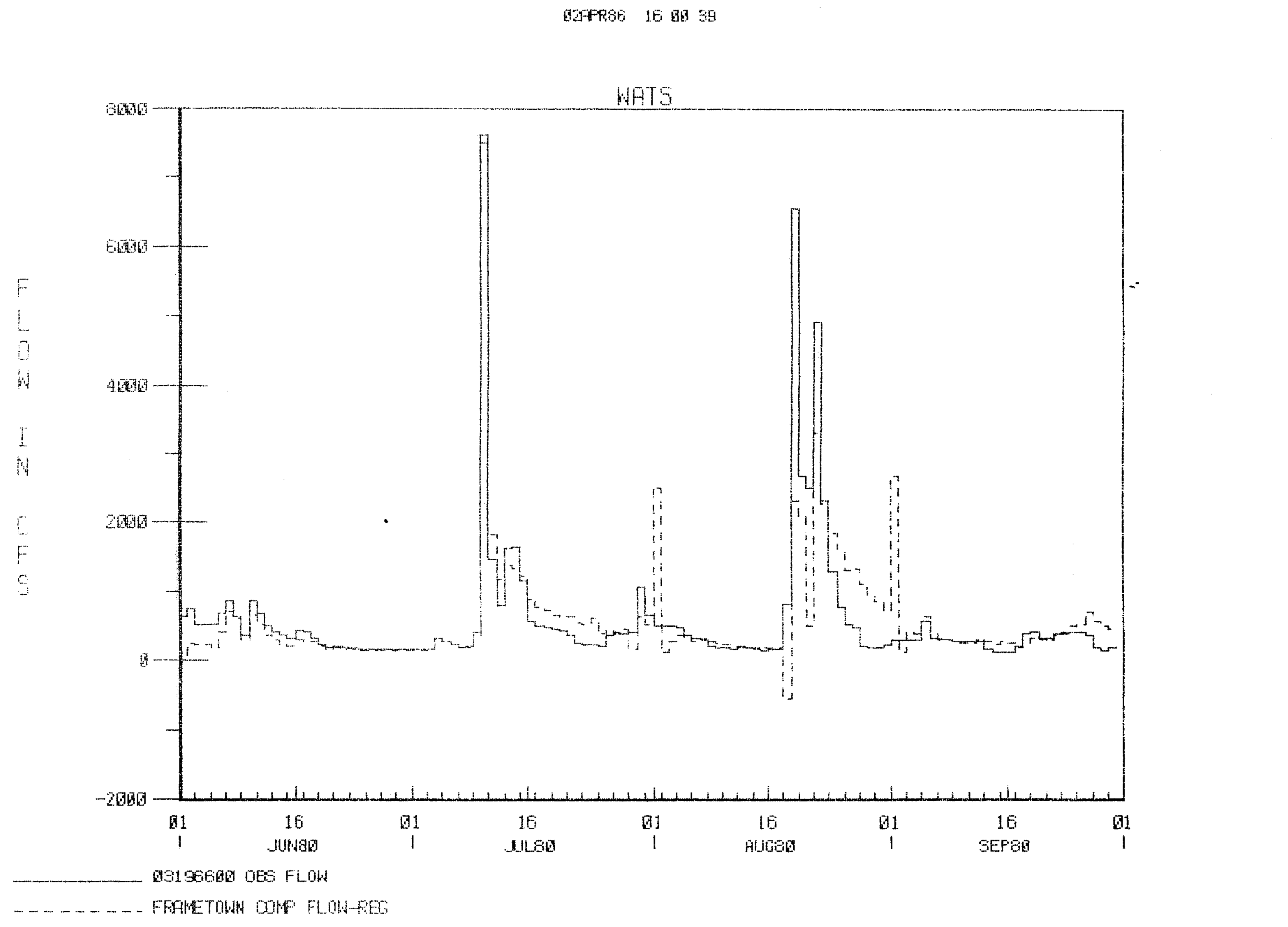
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SEP80
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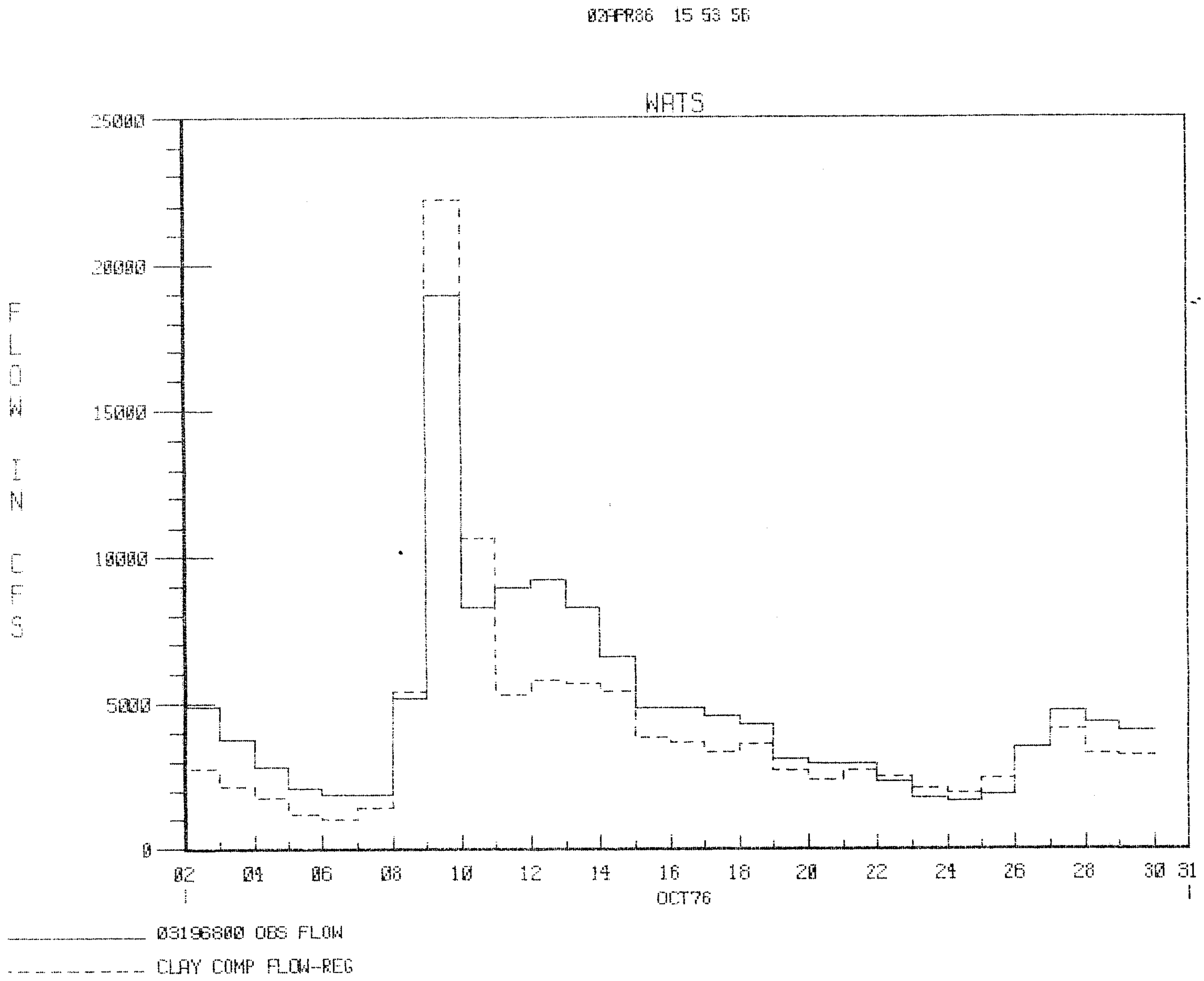
FRAMETOWN COMP FLOW-REG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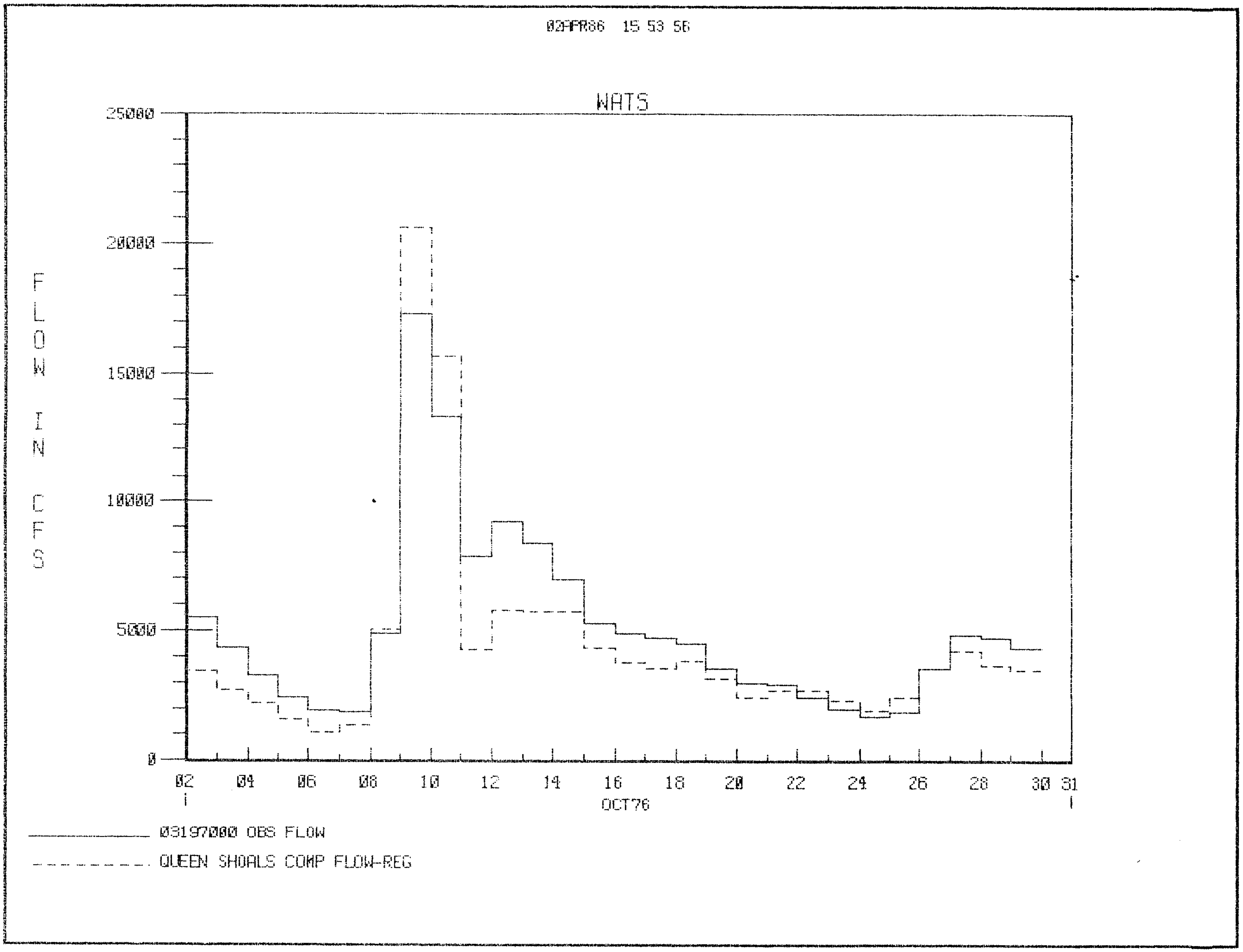
CLAY COMP FLOW-REG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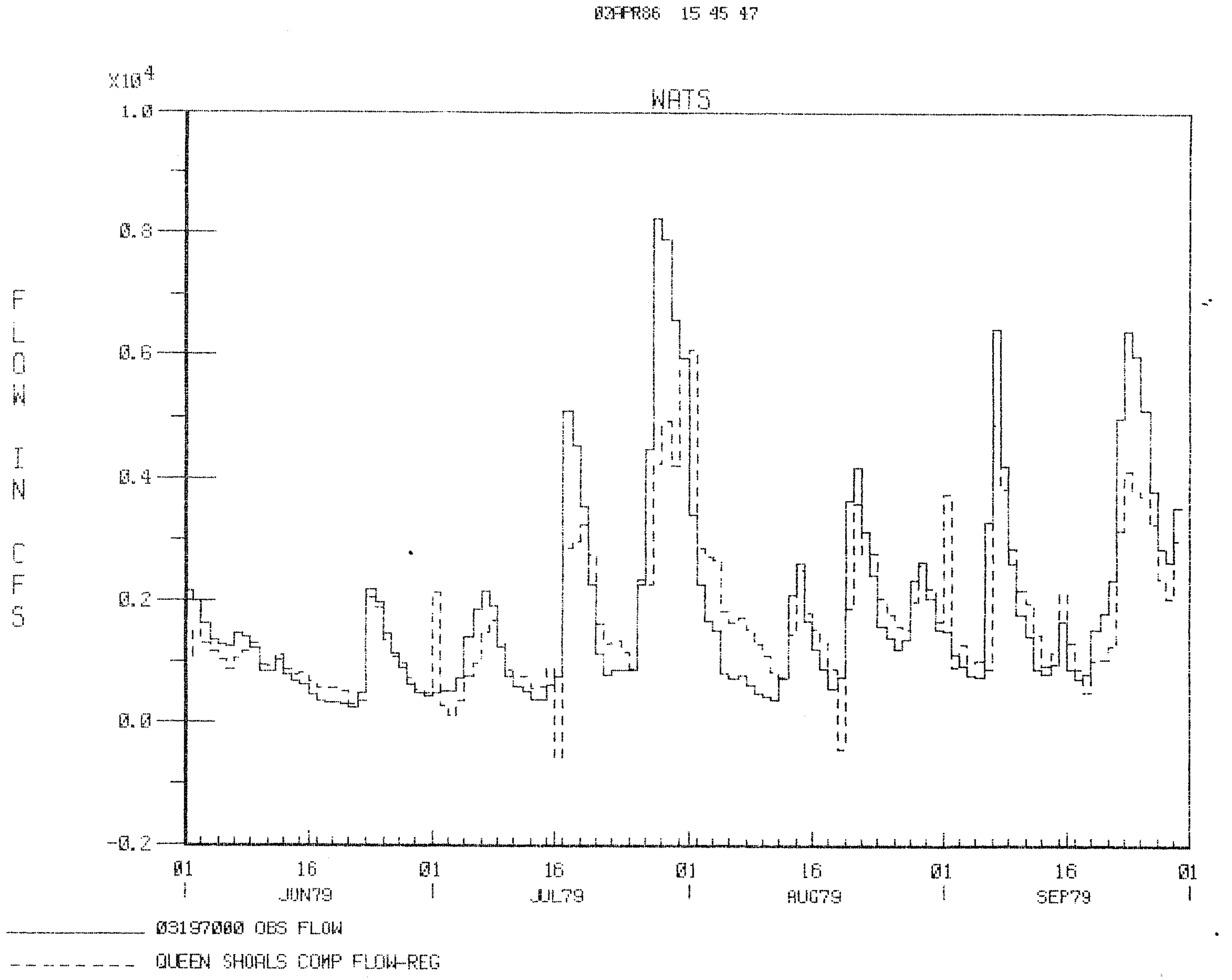
QUEEN SHOALS COMP FLOW-REG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X10^4
1.0
0.8
0.6
0.4
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0.0
-0.2
FLOW IN CFS
01
16
JUN79
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AUG79
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SEP79
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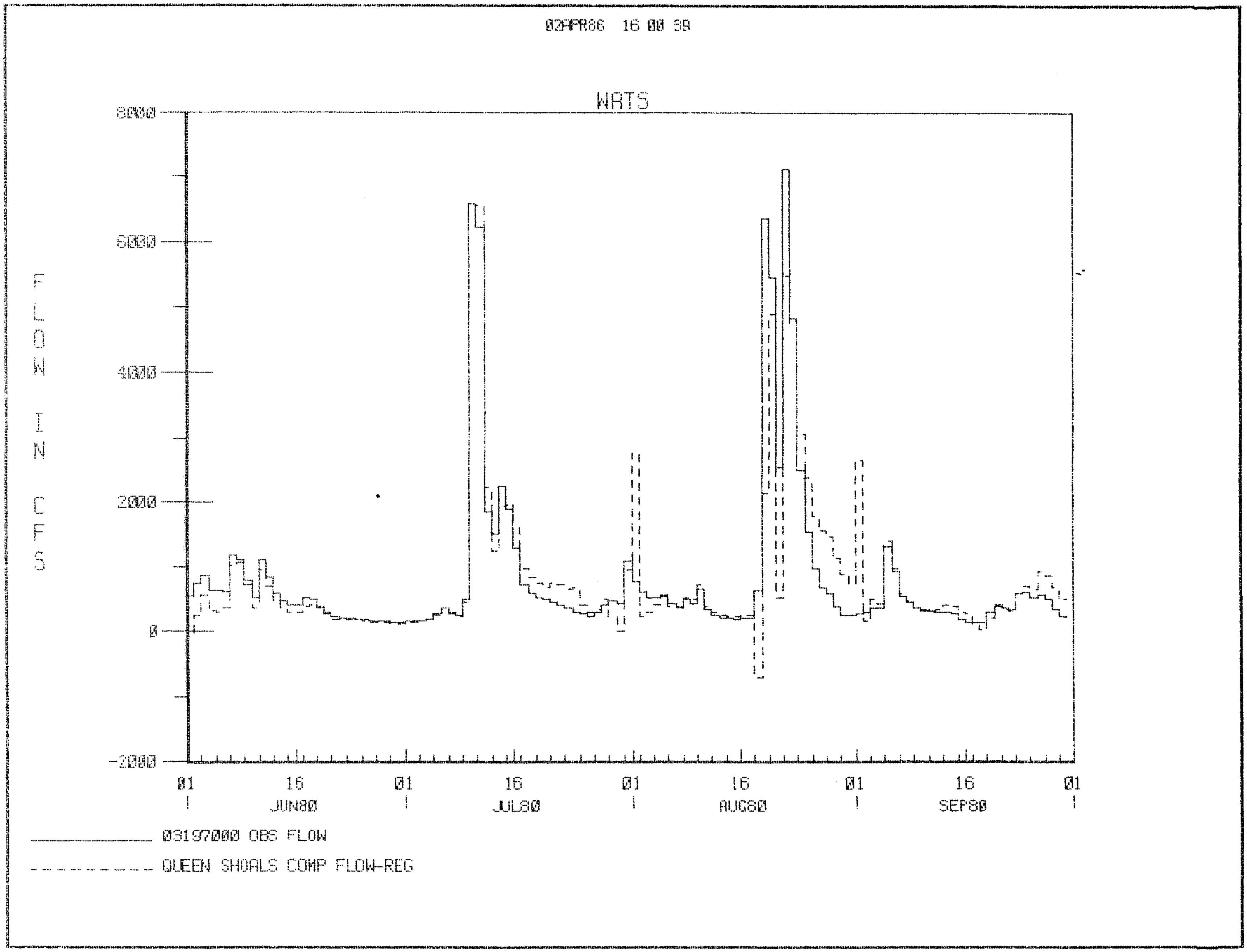
03197000 OBS FLOW
QUEEN SHOALS COMP FLOW-REG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4000
2000
0
-2000
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JUN80
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AUG80
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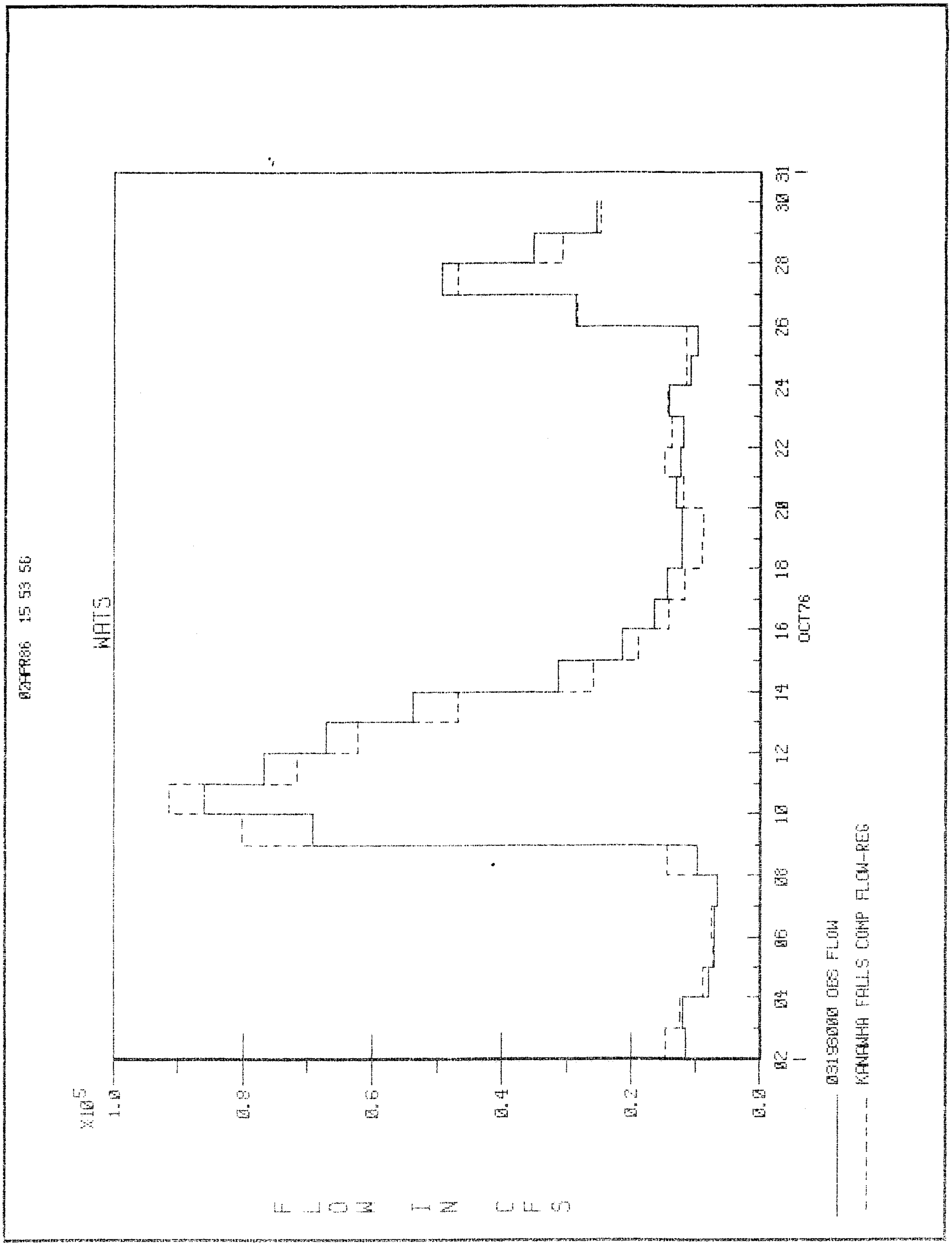
SEP80
01
03197000 OBS FLOW
QUEEN SHOALS COMP FLOW-REG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0.6
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0.2
0.0
FLOW IN CFS
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04
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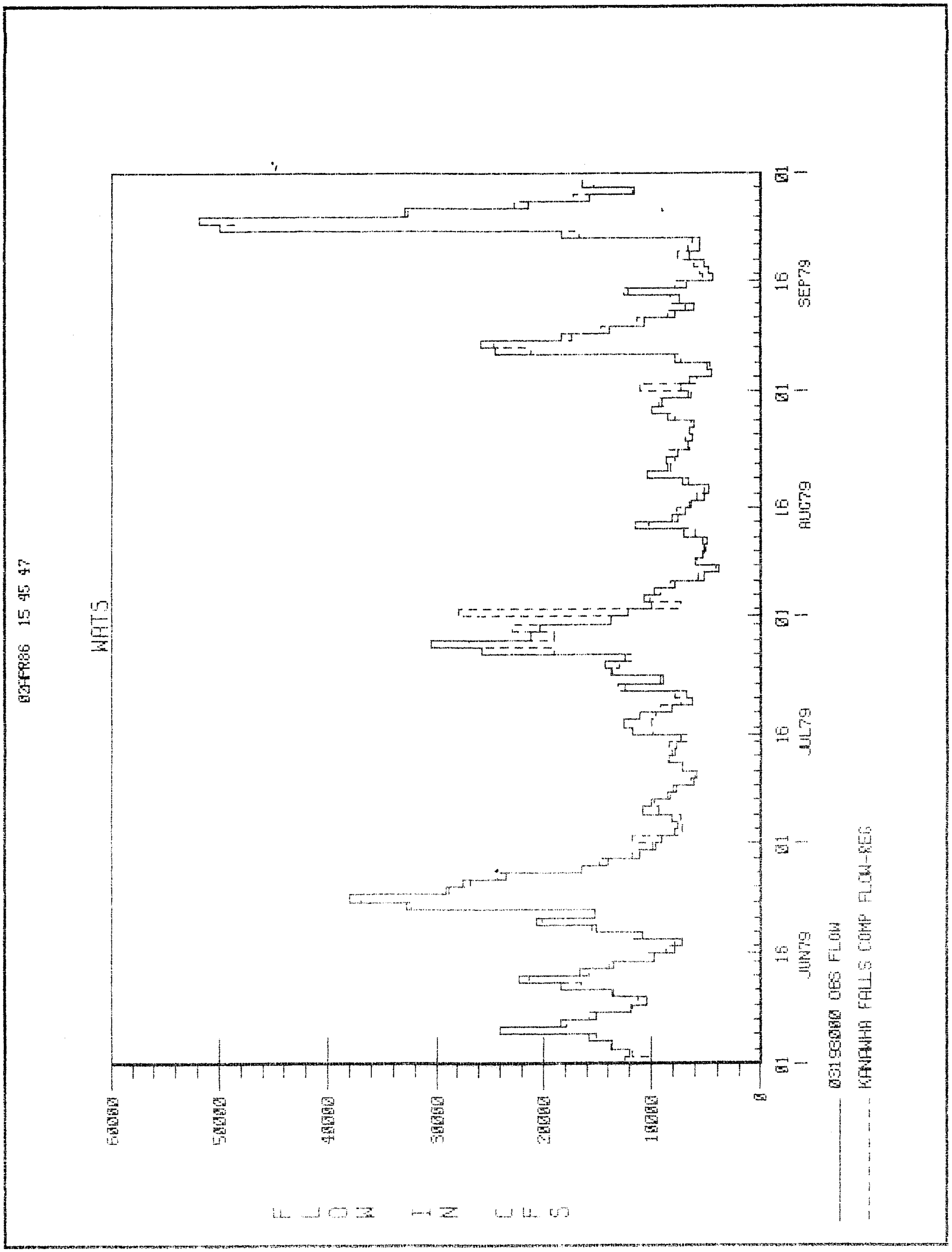
OCT76
03193000 OBS FLOW
KANAWHA FALLS COMP FLOW-REG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JUL79
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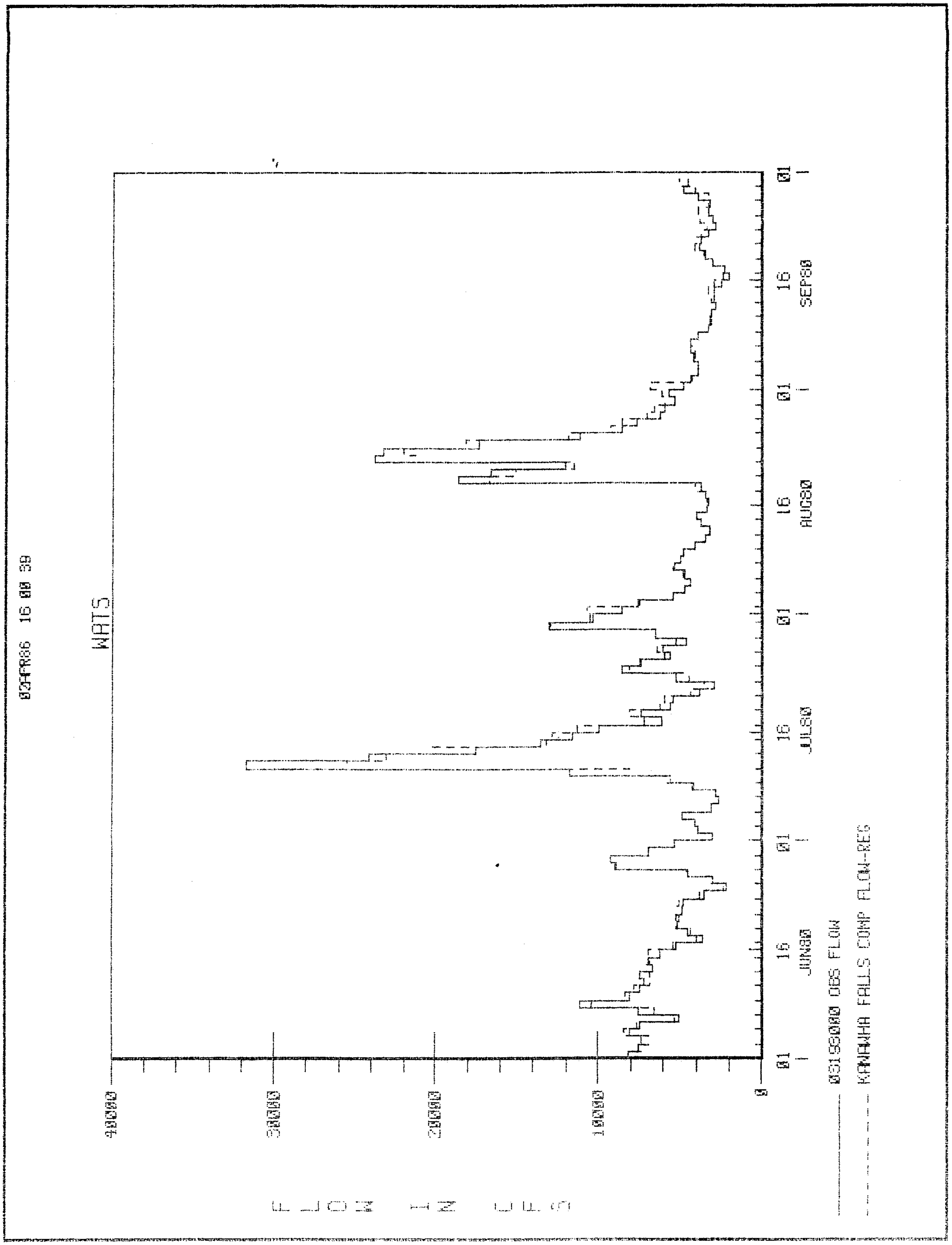
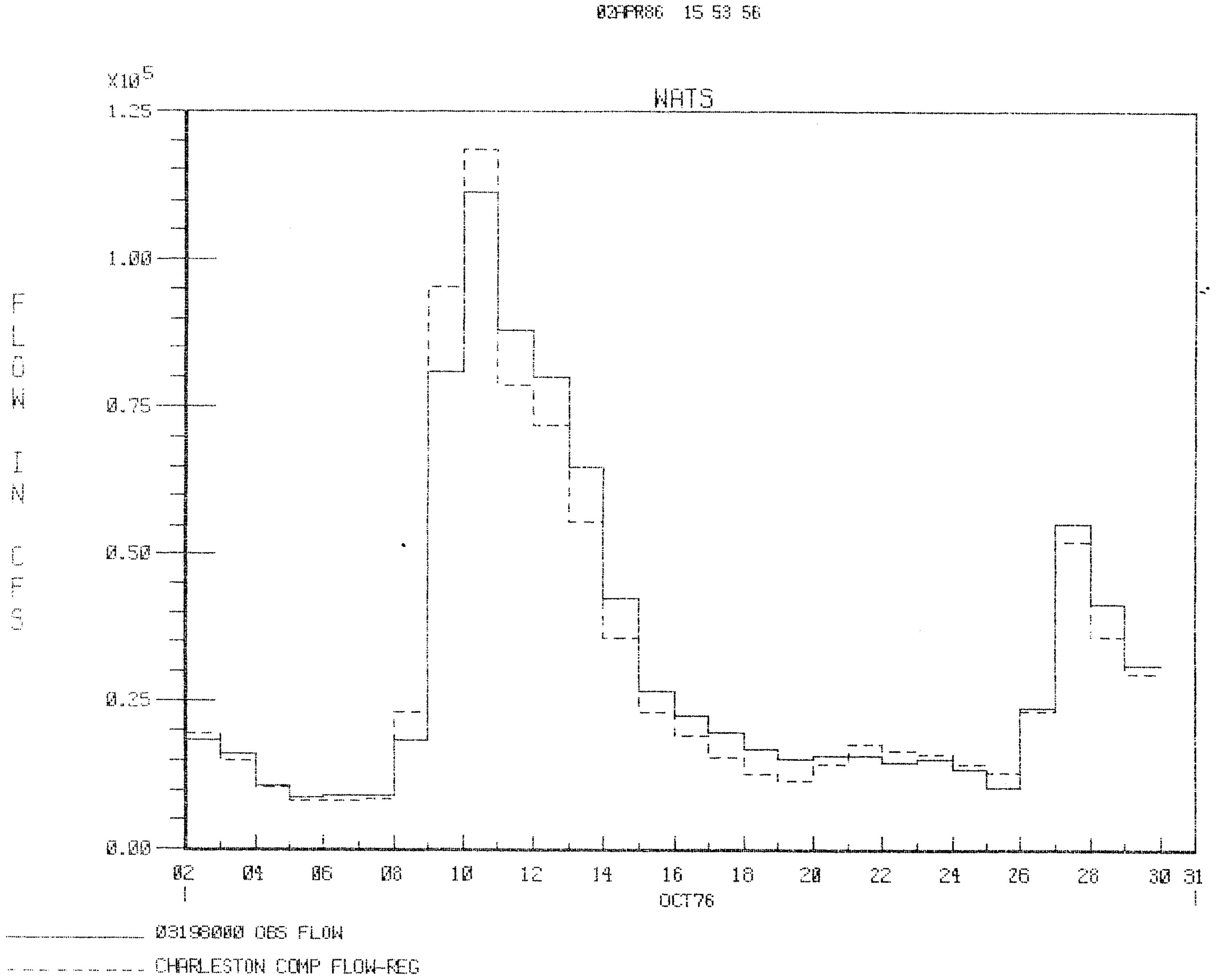
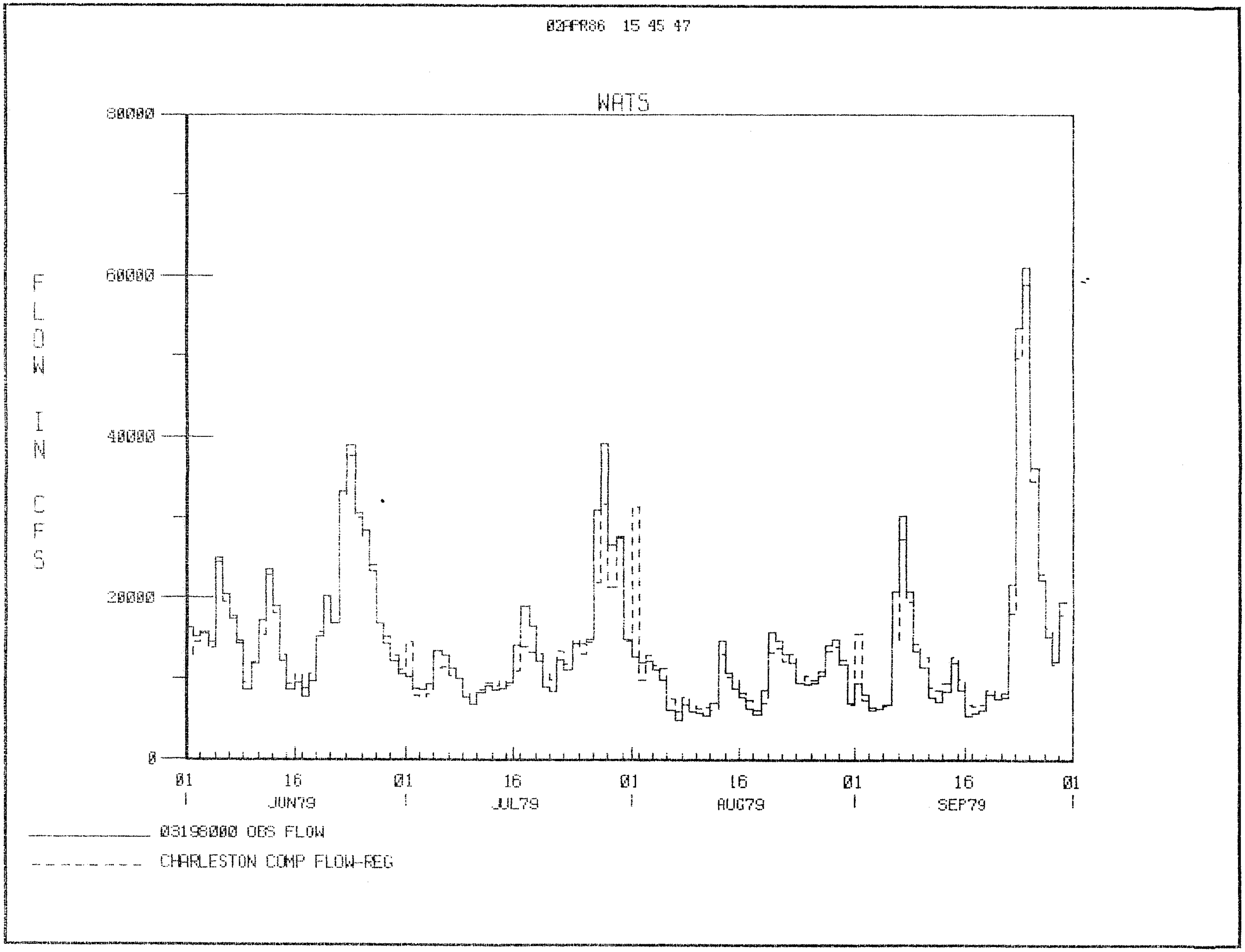
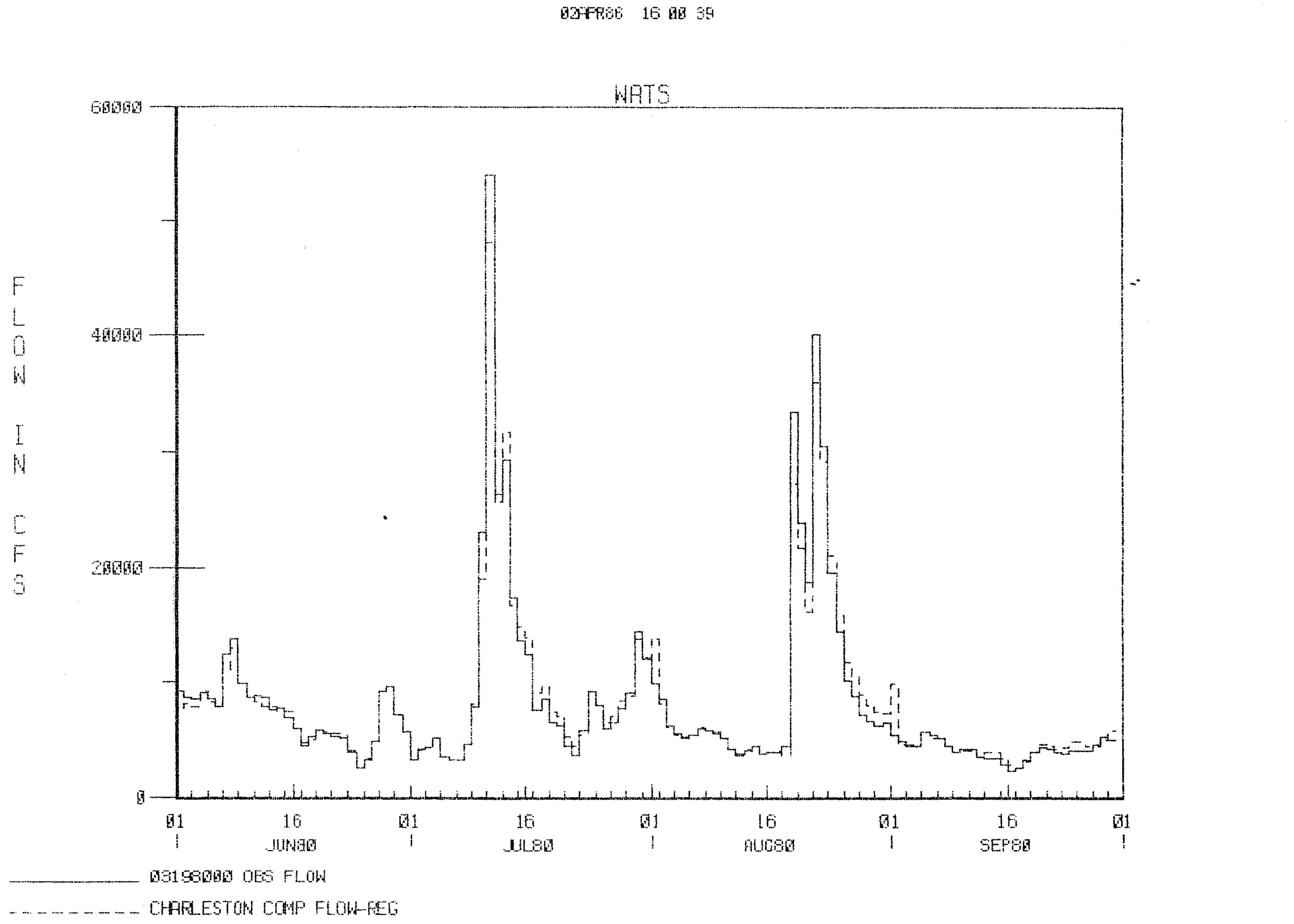
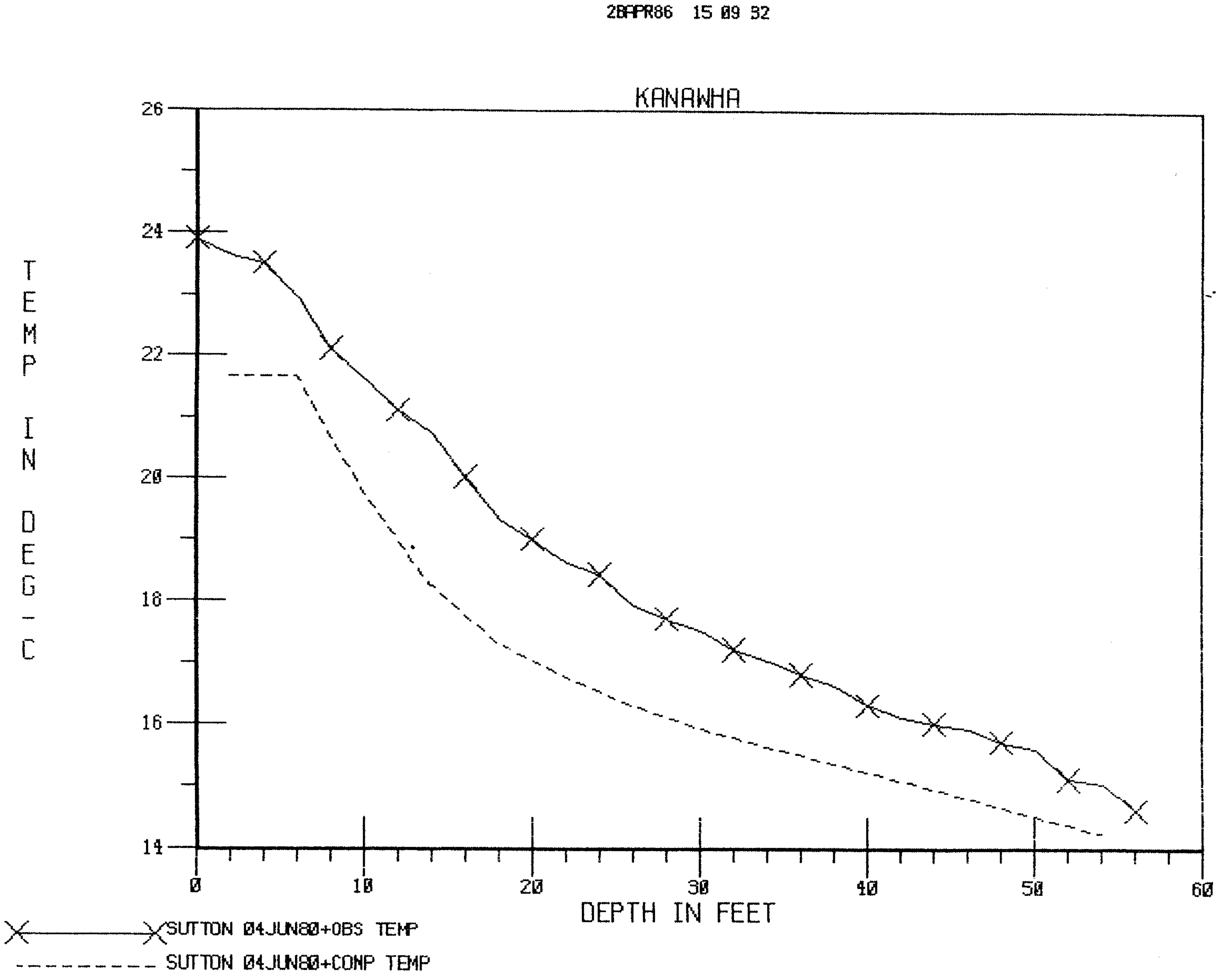
SEP79
01
03198000 OBS FLOW
KANAWHA FALLS COMP FLOW-REG

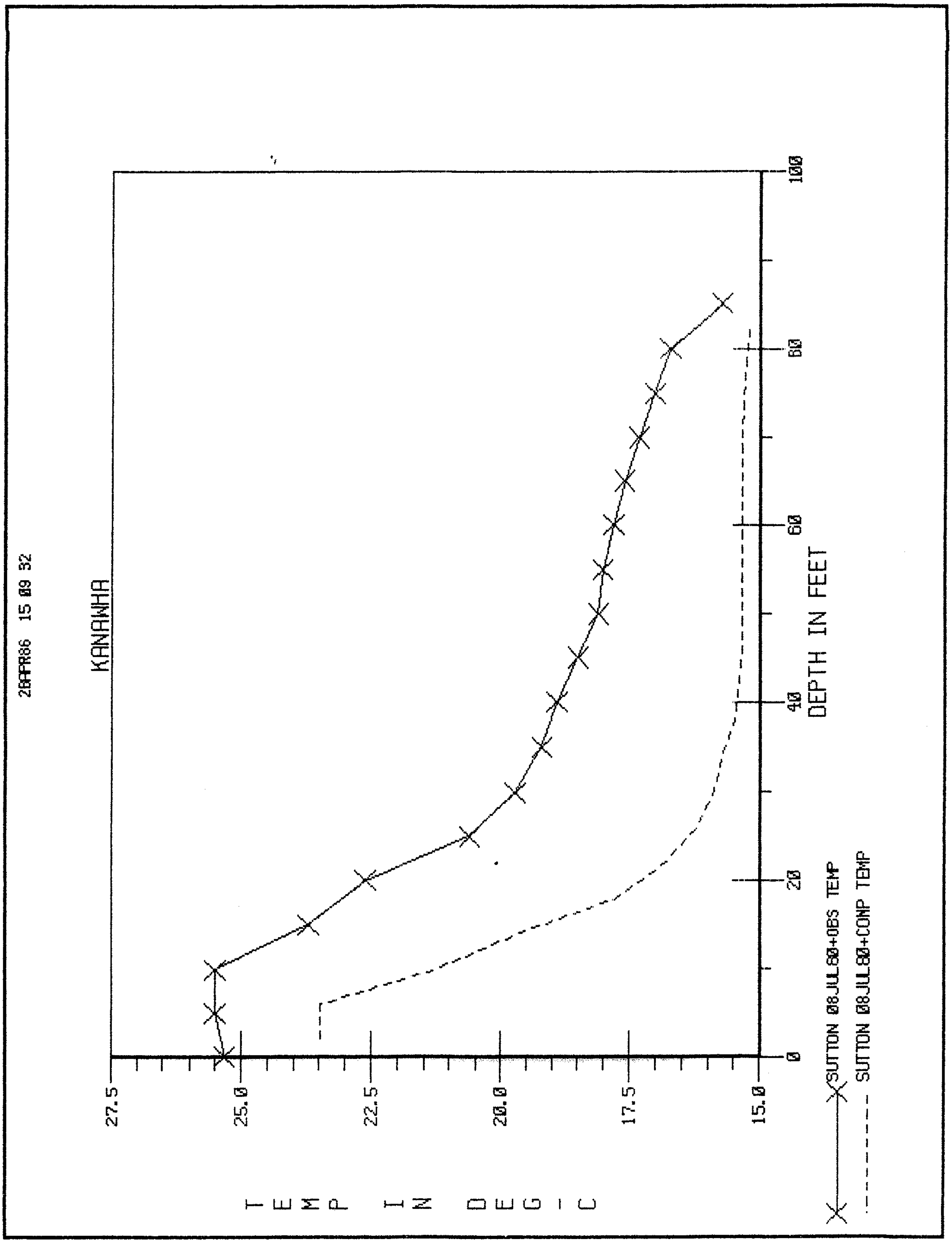

03APR86 16 00 39
WATS
FLOW IN CFS
40000
30000
20000
10000
0
01
16
JUN80
01
16
JUL80
01
16
AUG80
01
16
SEP80
01
03193000 OBS FLOW
KANAWHA FALLS COMP FLOW-REG

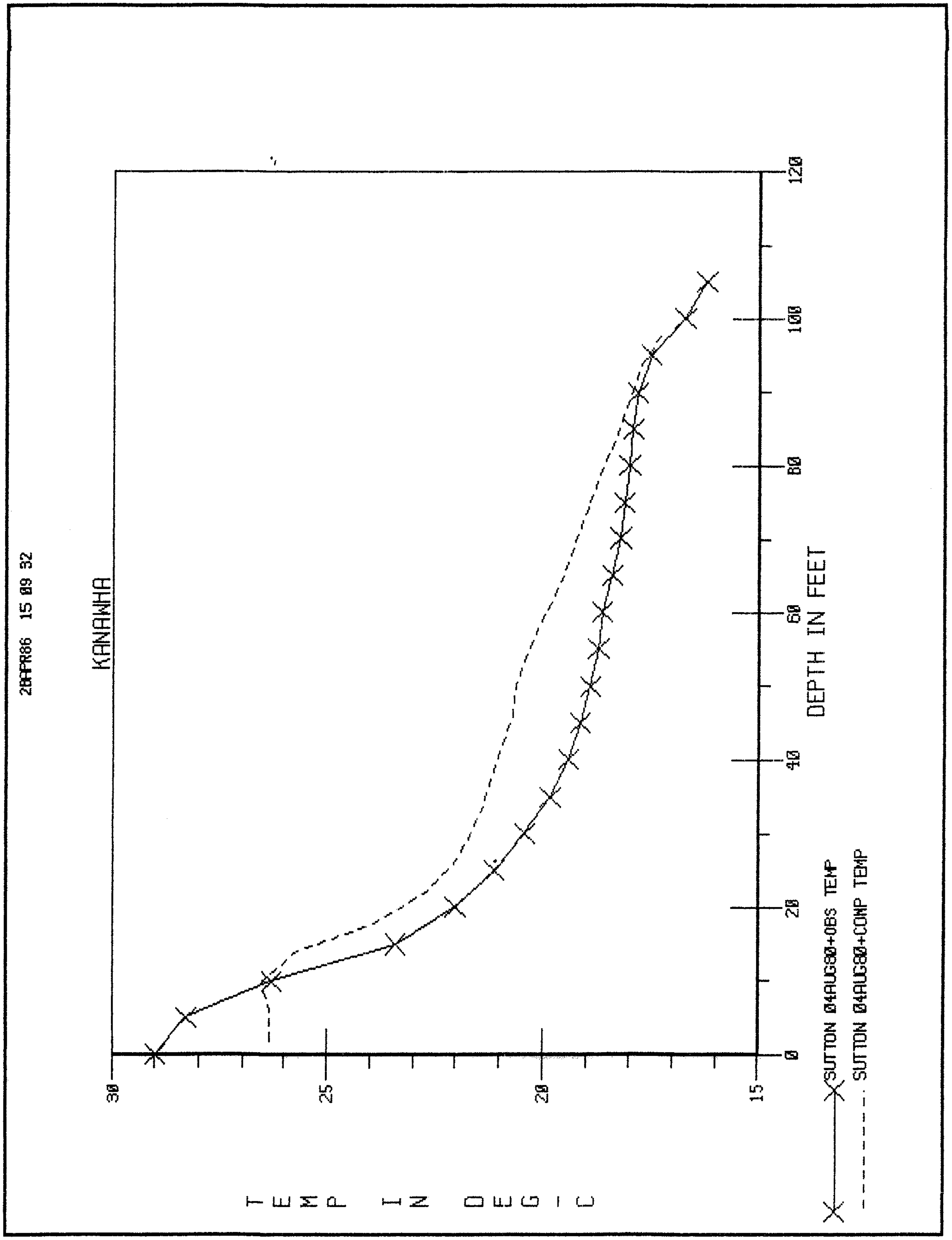

02APR86 15 53 56
WATS
X10^5
1.25
1.00
0.75
0.50
0.25
0.00
FLOW IN CFS
02
04
06
08
10
12
14
16
18
20
22
24
26
28
30
31
OCT76
03198000 OBS FLOW
CHARLESTON COMP FLOW-REG

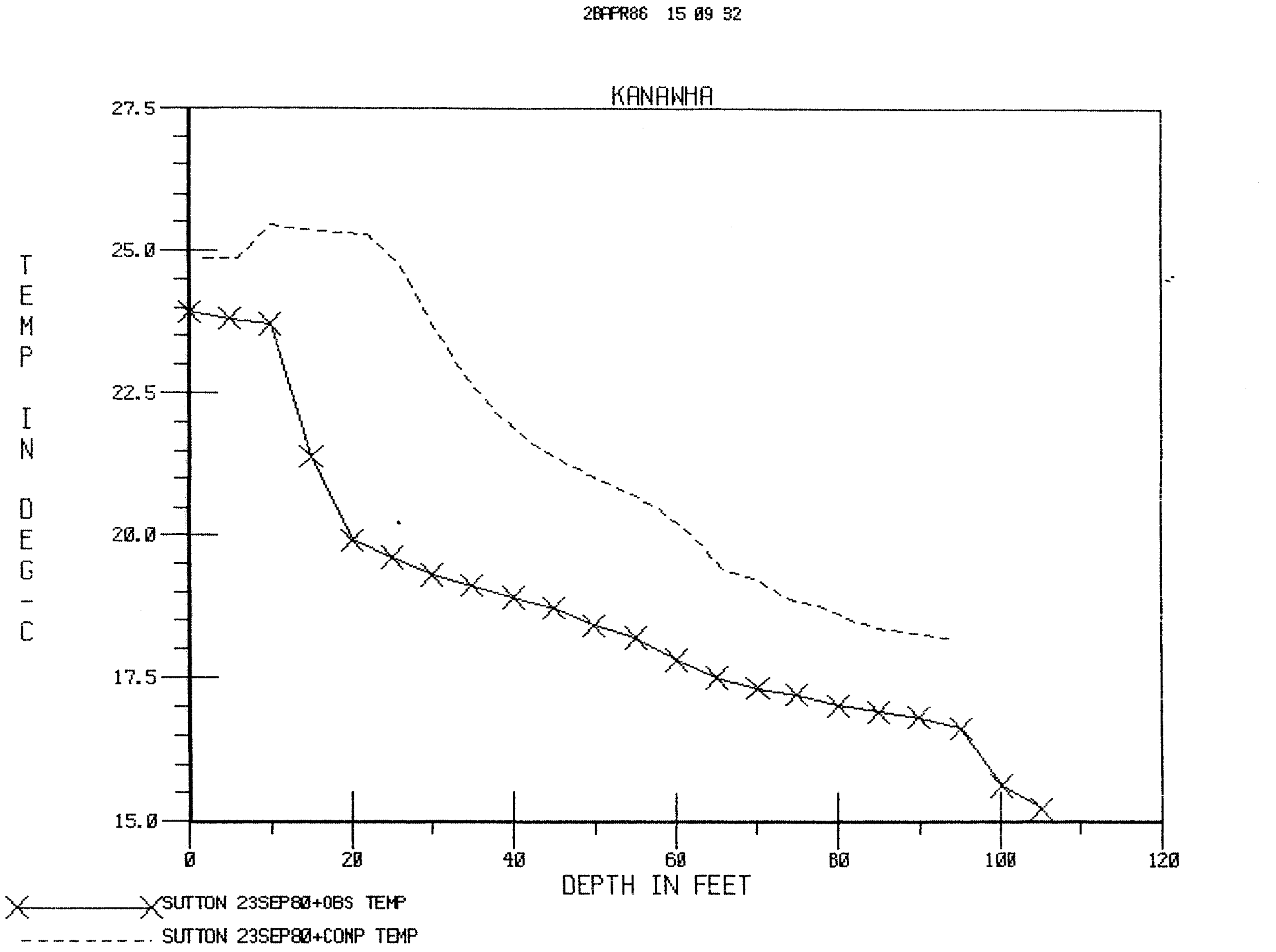

02APR86 15 45 47
WATS
FLOW IN CFS
80000
60000
40000
20000
0
01
16
JUN79
01
16
JUL79
01
16
AUG79
01
16
SEP79
01
03198000 OBS FLOW
CHARLESTON COMP FLOW-REG

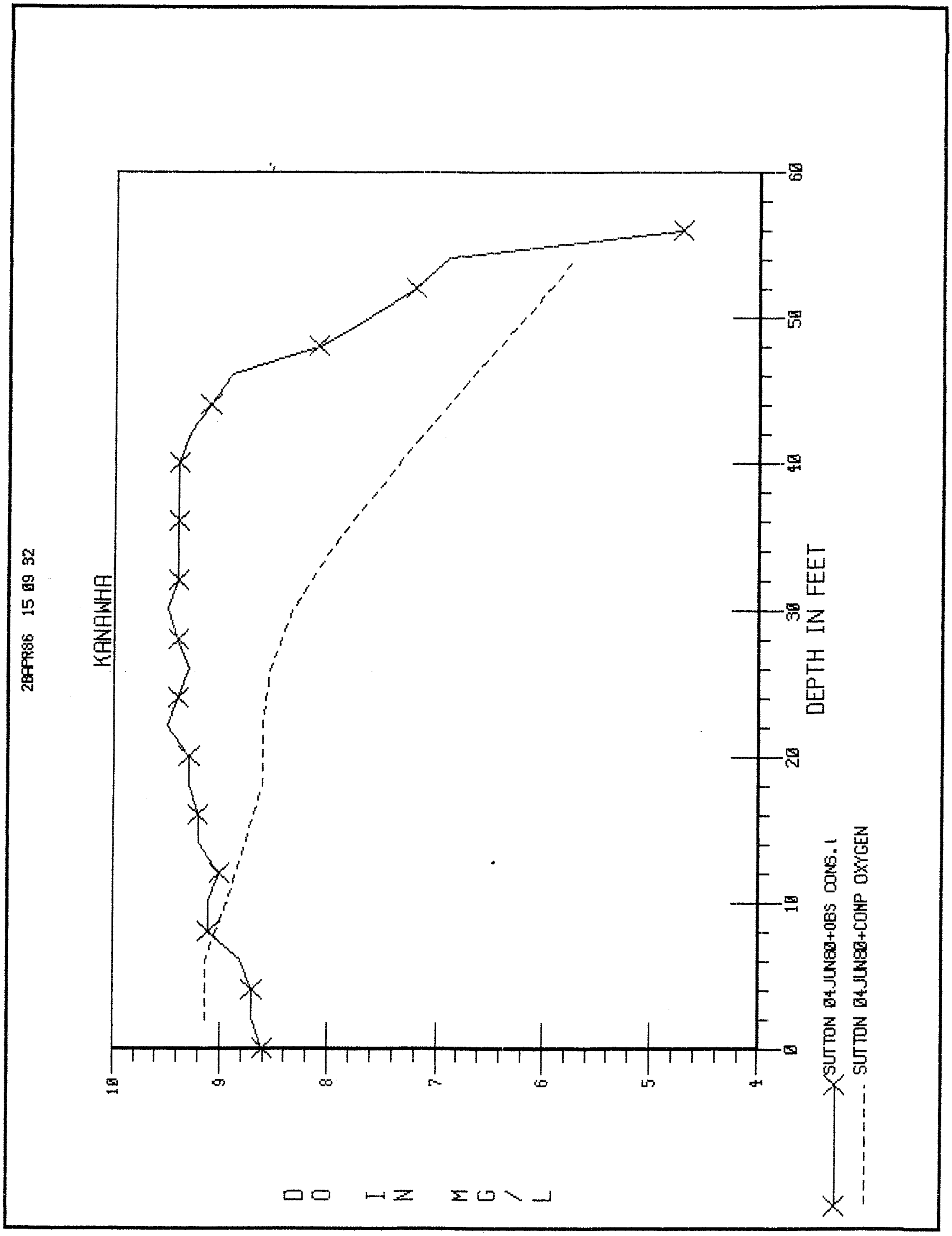

03APR86 16 00 39
WRTS
FLOW IN CFS
60000
40000
20000
0
01
16
JUN80
01
16
JUL80
01
16
AUG80
01
16
SEP80
01
03198000 OBS FLOW
CHARLESTON COMP FLOW-REG

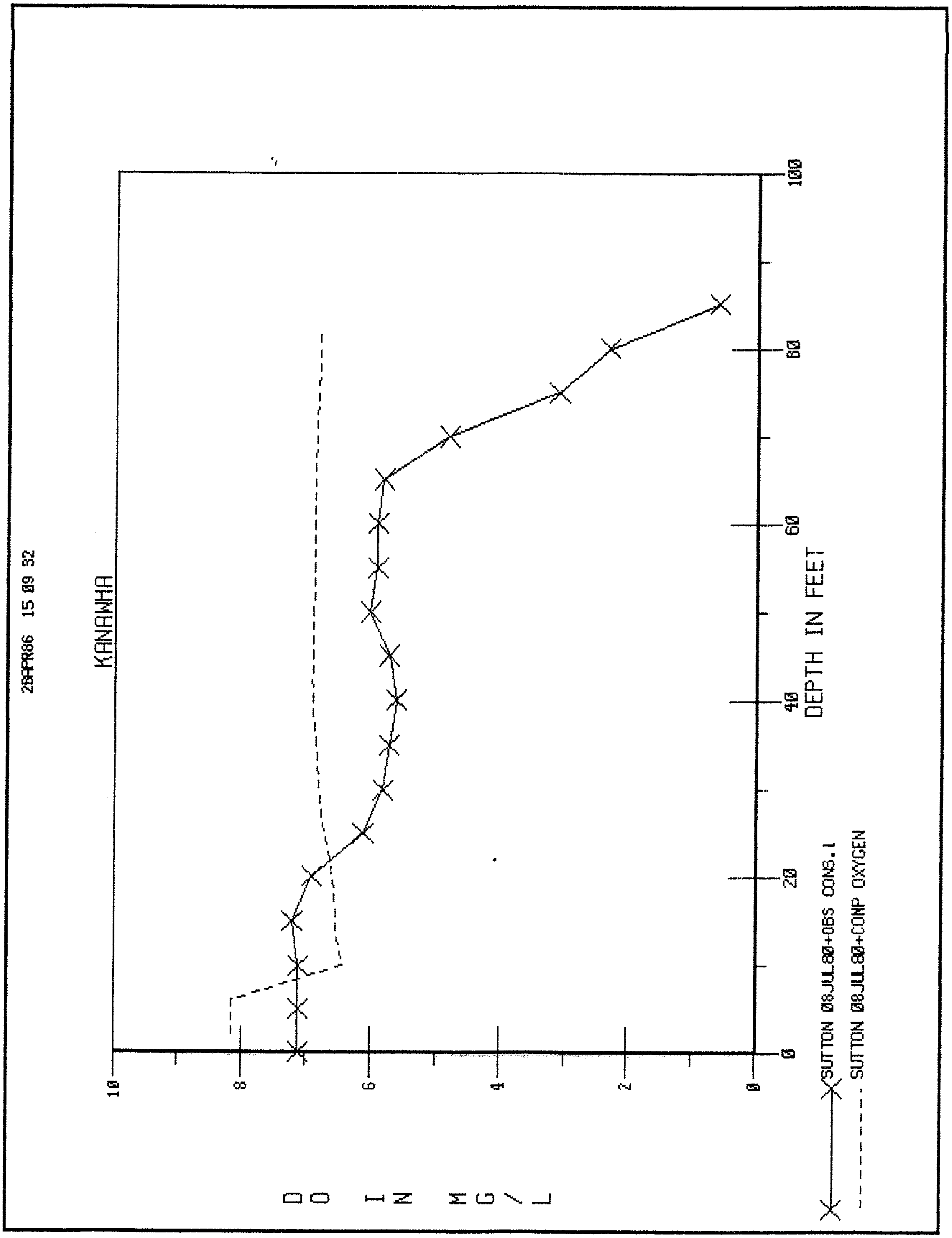

28APR86 15 09 32
KANAWHA
TEMP IN DEG-C
26
24
22
20
18
16
14
0
10
20
30
40
50
60
DEPTH IN FEET
SUTTON 04JUN80+OBS TEMP
SUTTON 04JUN80+COMP TEMP

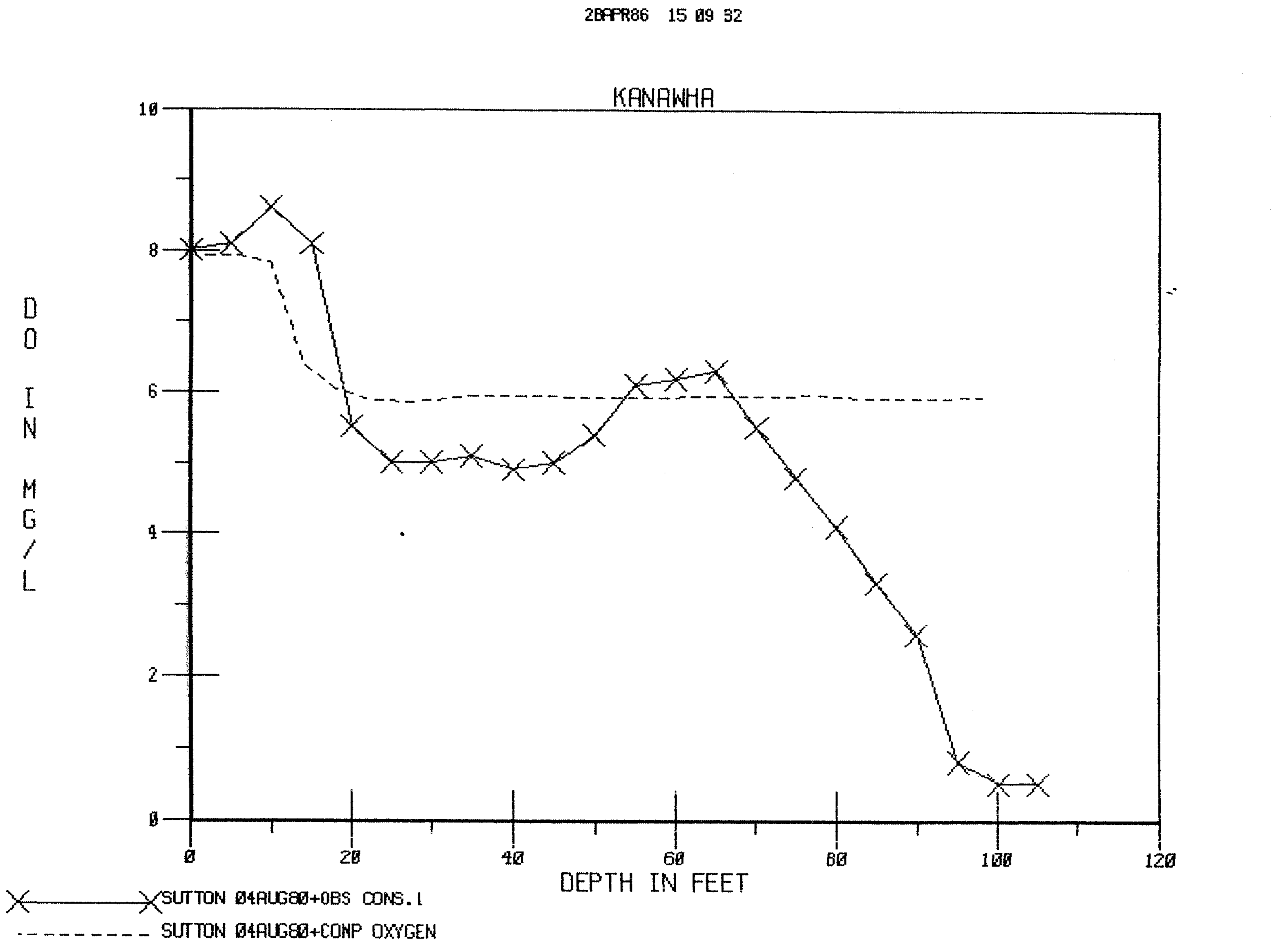

28APR86 15 09 32
KANAWHA
TEMP IN DEG-C
27.5
25.0
22.5
20.0
17.5
15.0
0
20
40
60
80
100
DEPTH IN FEET
SUTTON 08JUL80+OBS TEMP
SUTTON 08JUL80+COMP TEMP

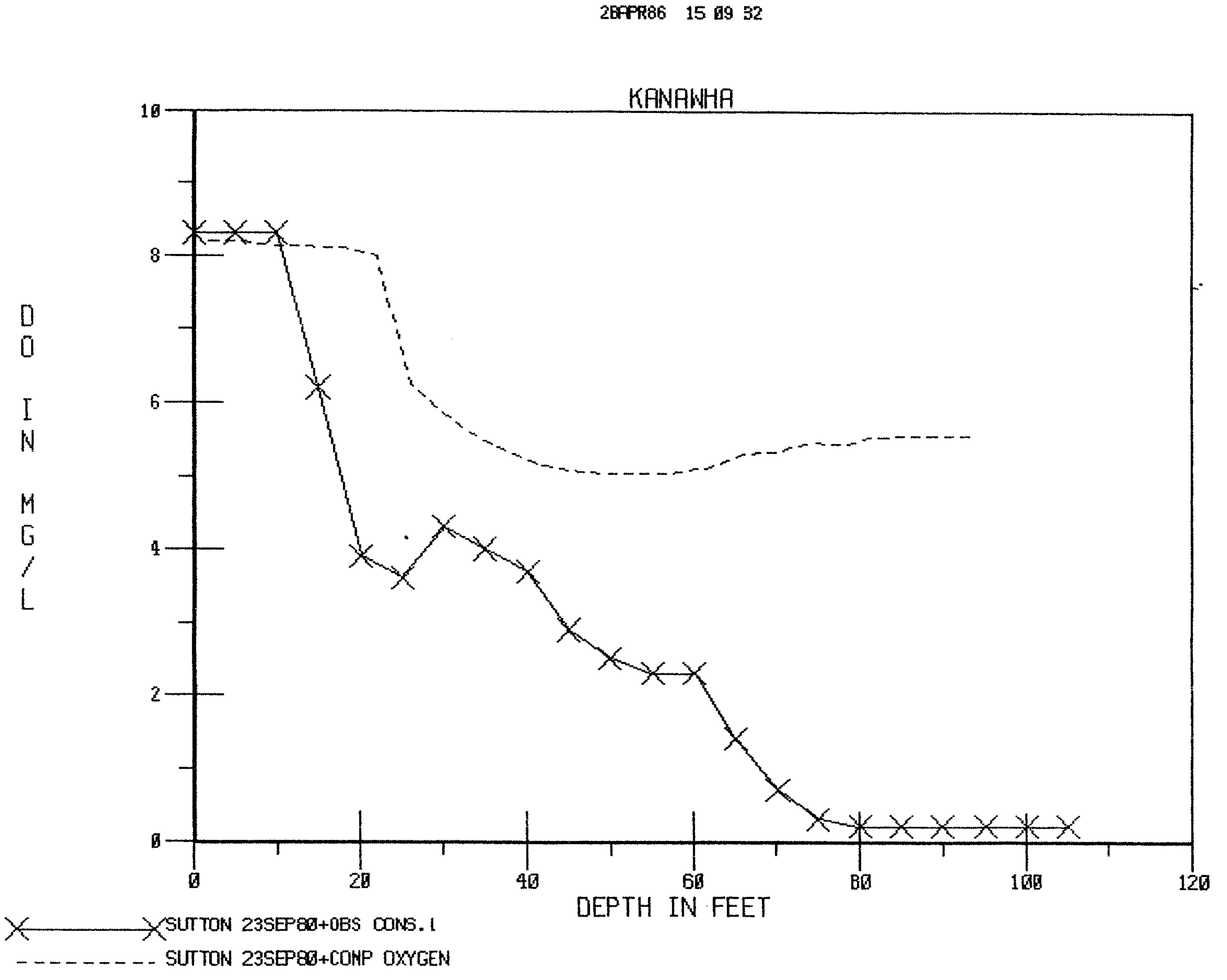

28APR86 15 09 32
KANAWHA
TEMP IN DEG-C
30
25
20
15
DEPTH IN FEET
0
20
40
60
80
100
120
SUTTON 04AUG80+OBS TEMP
SUTTON 04AUG80+COMP TEMP

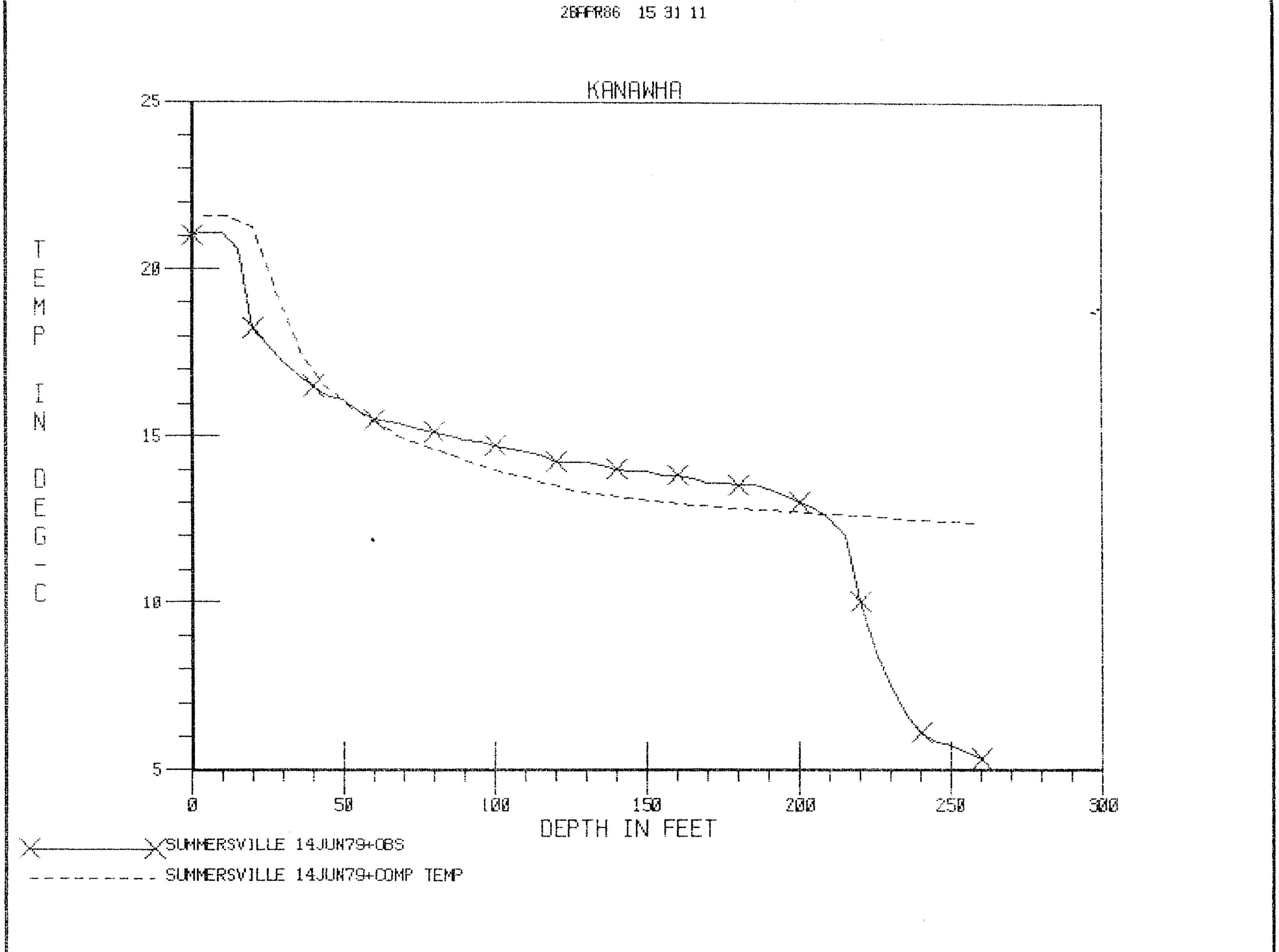

28APR86 15 09 32
KANAWHA
TEMP IN DEG-C
27.5
25.0
22.5
20.0
17.5
15.0
0
20
40
60
80
100
120
DEPTH IN FEET
SUTTON 23SEP80+OBS TEMP
SUTTON 23SEP80+COMP TEMP

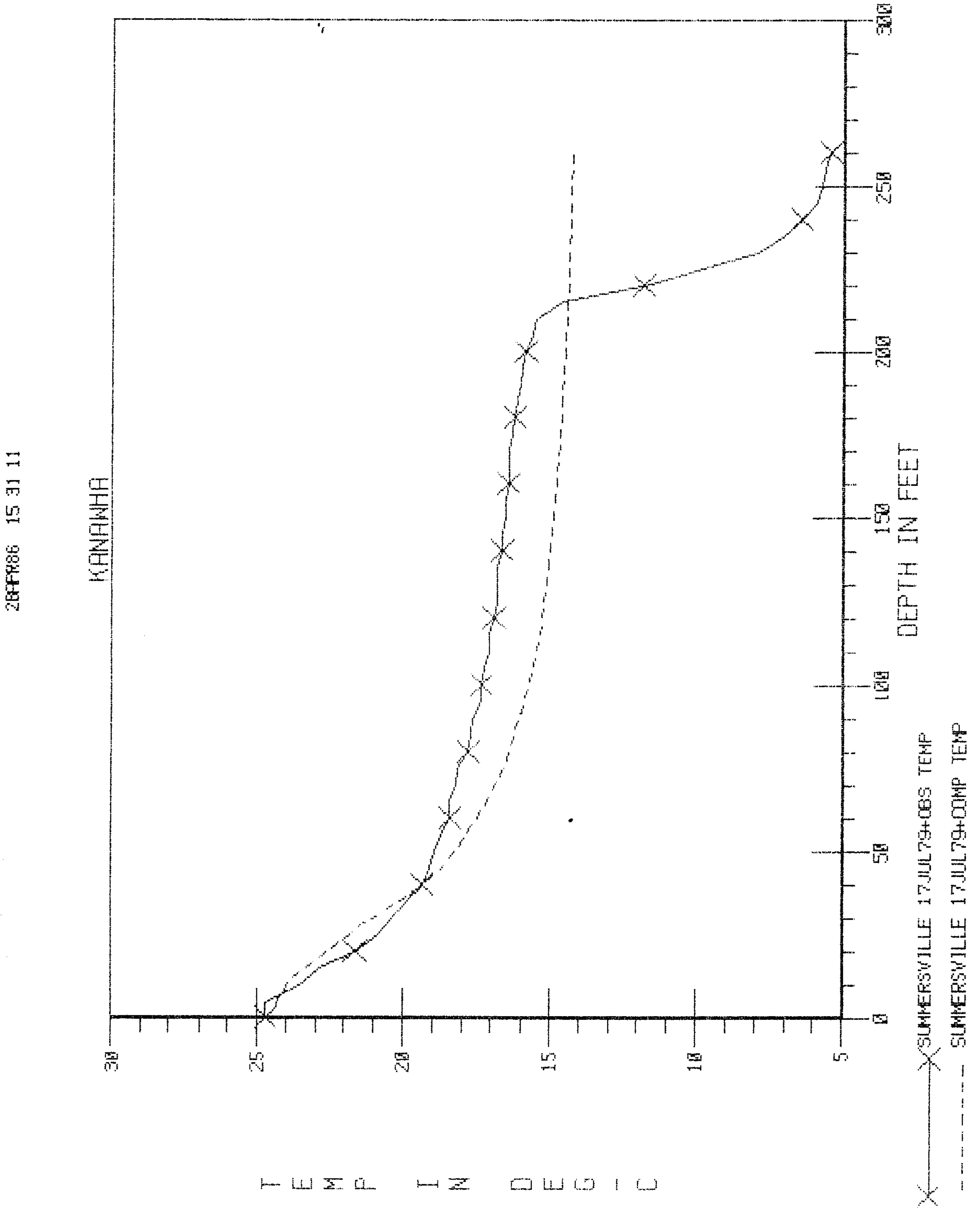

28APR86 15 09 32
KANAWHA
DO IN MG/L
DEPTH IN FEET
10
9
8
7
6
5
4
0
10
20
30
40
50
60
SUTTON 04JUN80+OBS CONS.1
SUTTON 04JUN80+COMP OXYGEN

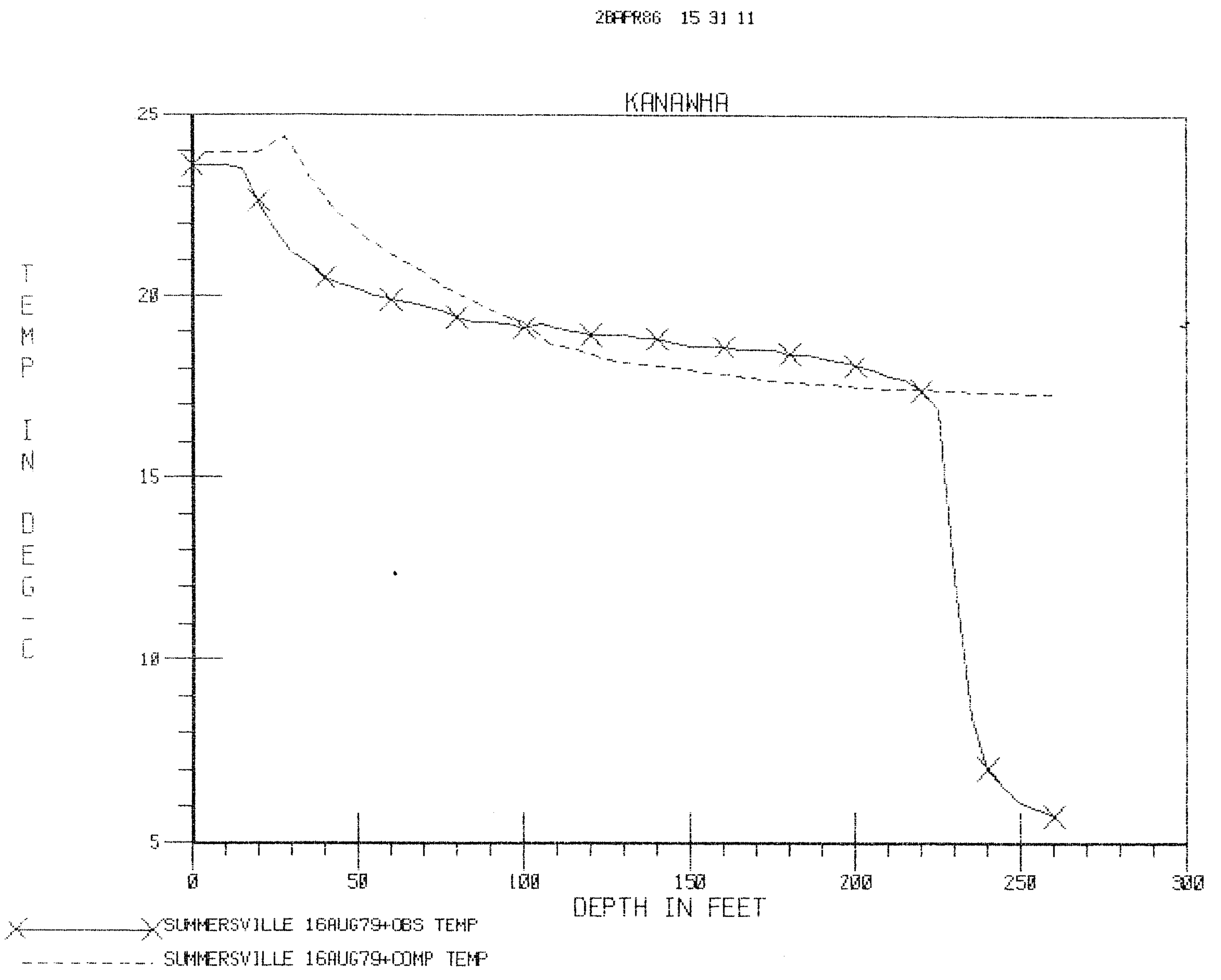

28APR86 15 09 32
KANAWHA
DEPTH IN FEET
0
20
40
60
80
100
DO IN MG/L
0
2
4
6
8
10
SUTTON 08JUL80+OBS CONS.1
SUTTON 08JUL80+COMP OXYGEN

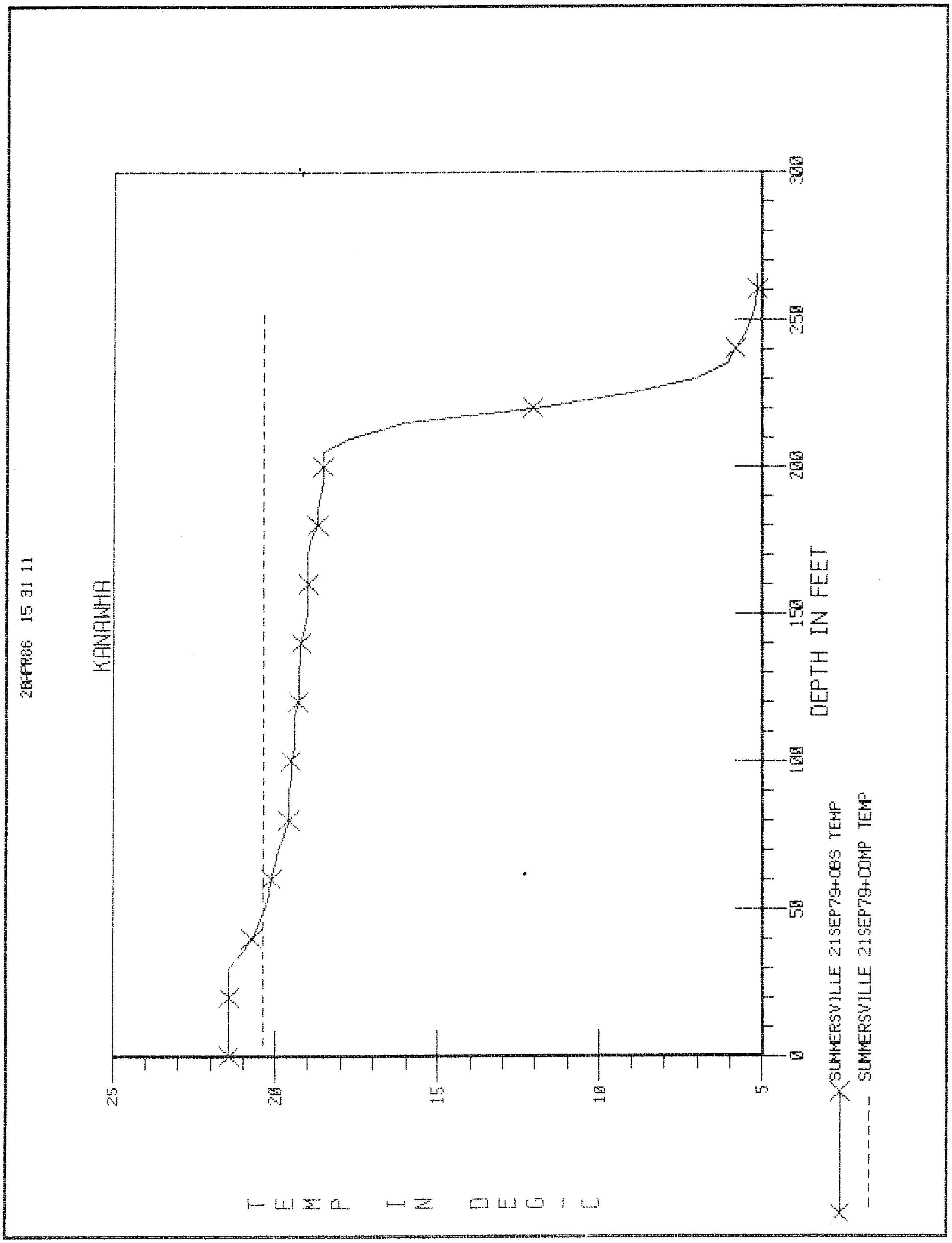

28APR86 15 09 52
KANAWHA
D O IN MG/L
10
8
6
4
2
0
0
20
40
60
80
100
120
DEPTH IN FEET
SUTTON 04AUG80+OBS CONS.1
SUTTON 04AUG80+CONP OXYGEN

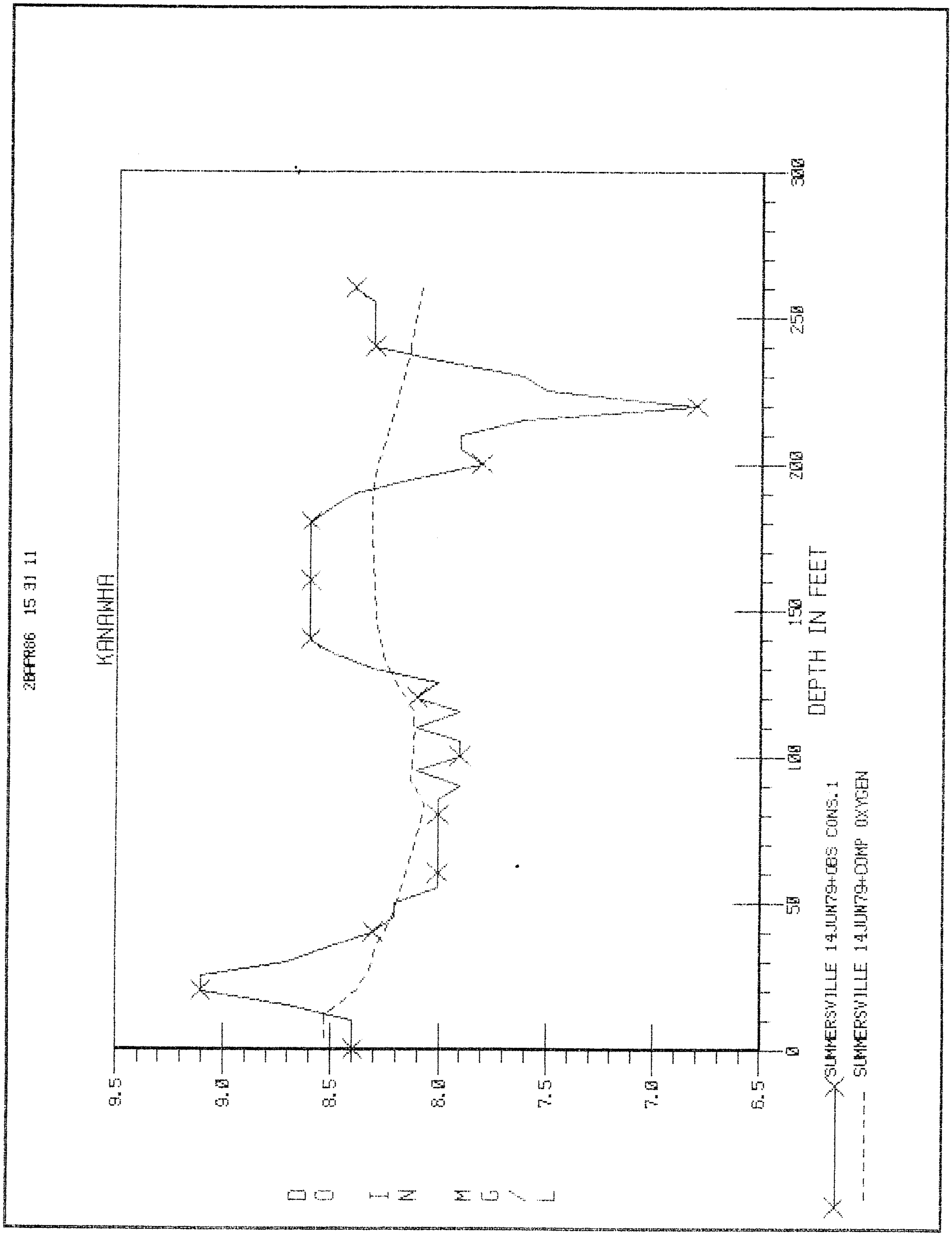

28APR86 15 09 32
KANAWHA
DO IN MG/L
10
8
6
4
2
0
0
20
40
60
80
100
120
DEPTH IN FEET
SUTTON 23SEP80+OBS CONS.l
SUTTON 23SEP80+CONP OXYGEN

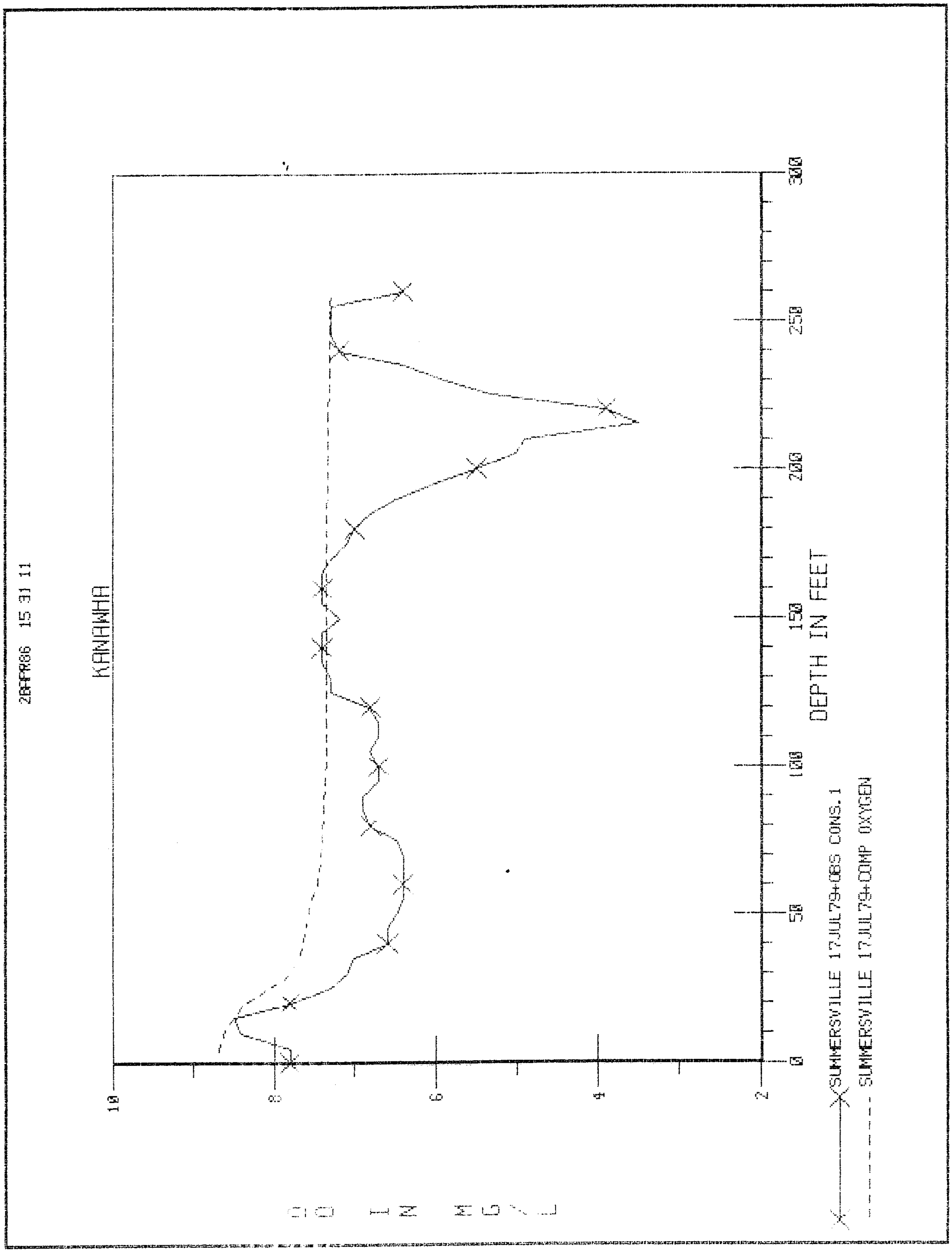

28APR86 15 31 11
KANAWHA
TEMP IN DEG-C
25
20
15
10
5
0
50
100
150
200
250
300
DEPTH IN FEET
SUMMERSVILLE 14JUN79+OBS
SUMMERSVILLE 14JUN79+COMP TEMP

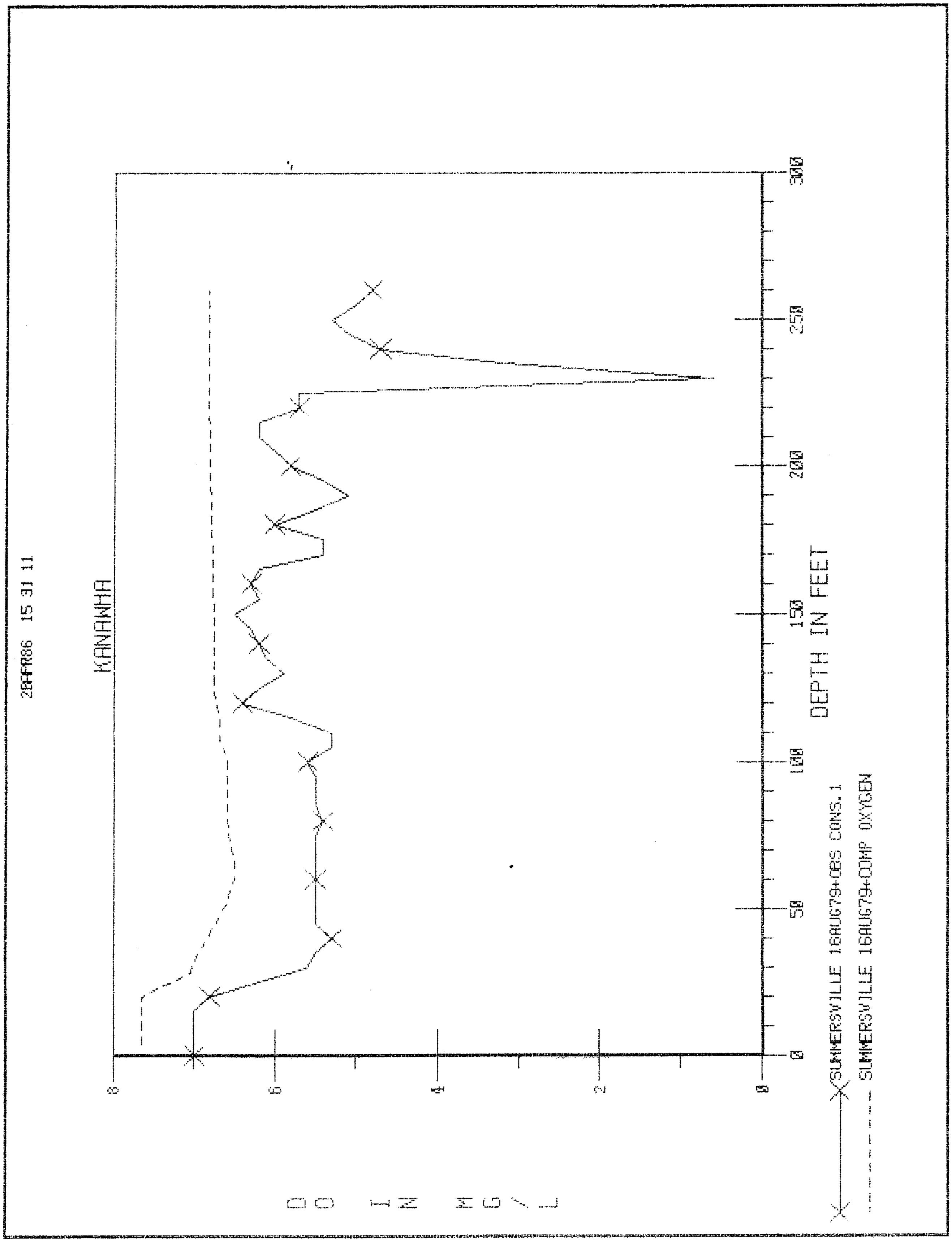

28APR86 15 31 11
KANAWHA
TEMP IN DEG C
30
25
20
15
10
5
DEPTH IN FEET
0
50
100
150
200
250
300
SUMMERSVILLE 17JUL79+OBS TEMP
SUMMERSVILLE 17JUL79+COMP TEMP

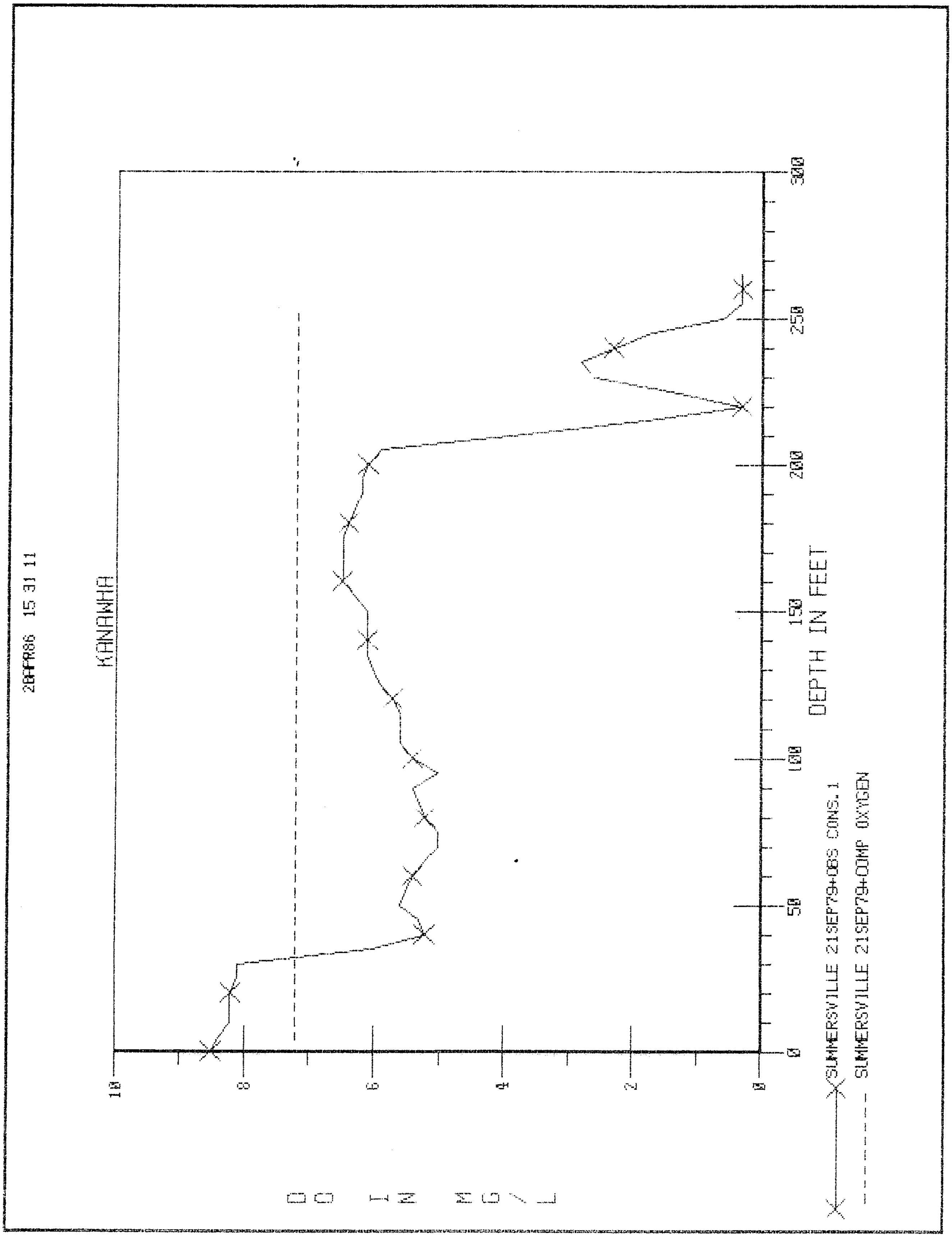

28APR86 15 31 11
KANAWHA
TEMP IN DEG C
25
20
15
10
5
0
50
100
150
200
250
300
DEPTH IN FEET
SUMMERSVILLE 16AUG79+OBS TEMP
SUMMERSVILLE 16AUG79+COMP TEMP

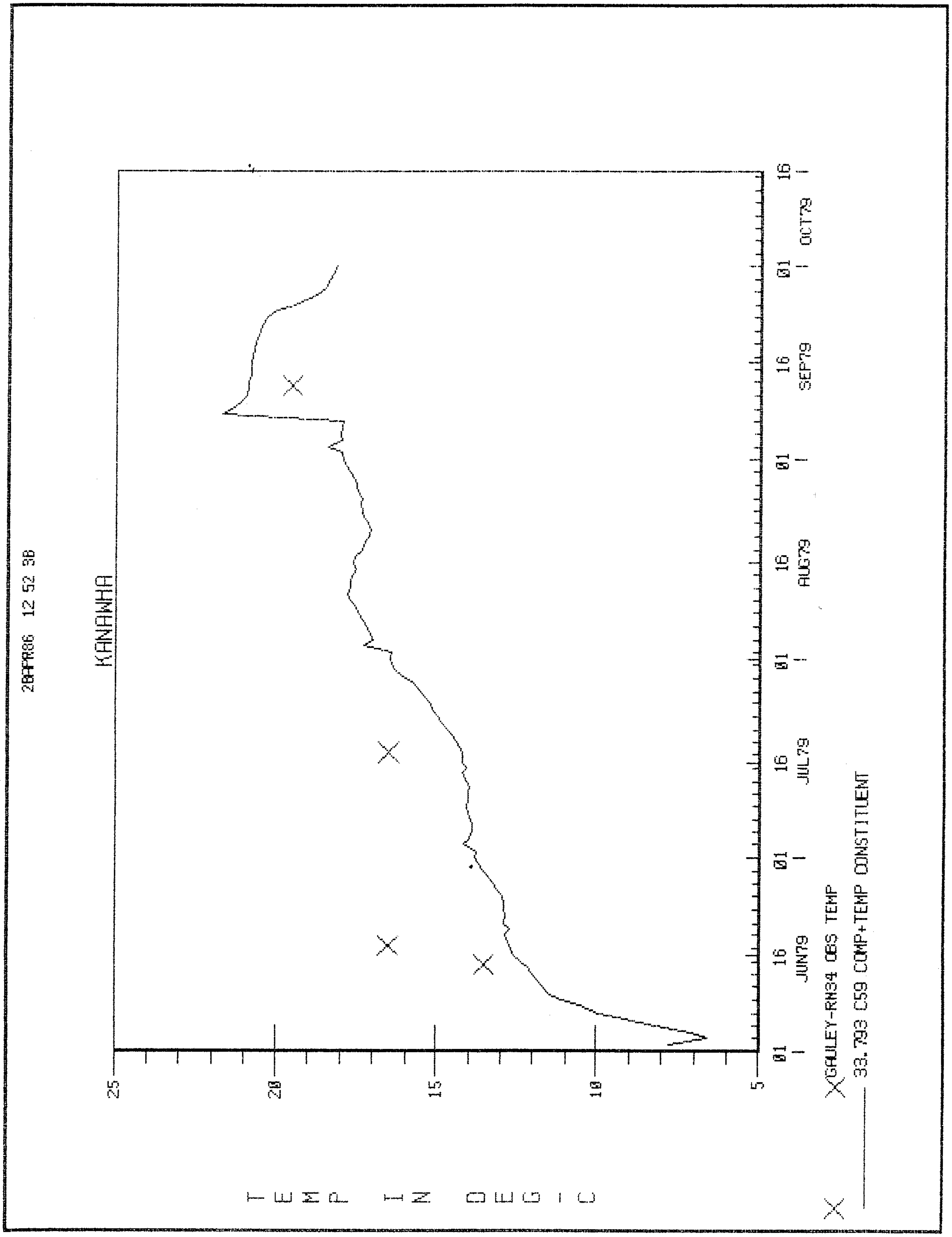

20APR86 15 31 11
KANAWHA
TEMP IN DEG-C
25
20
15
10
5
DEPTH IN FEET
0
50
100
150
200
250
300
SUMMERSVILLE 21SEP79+OBS TEMP
SUMMERSVILLE 21SEP79+COMP TEMP

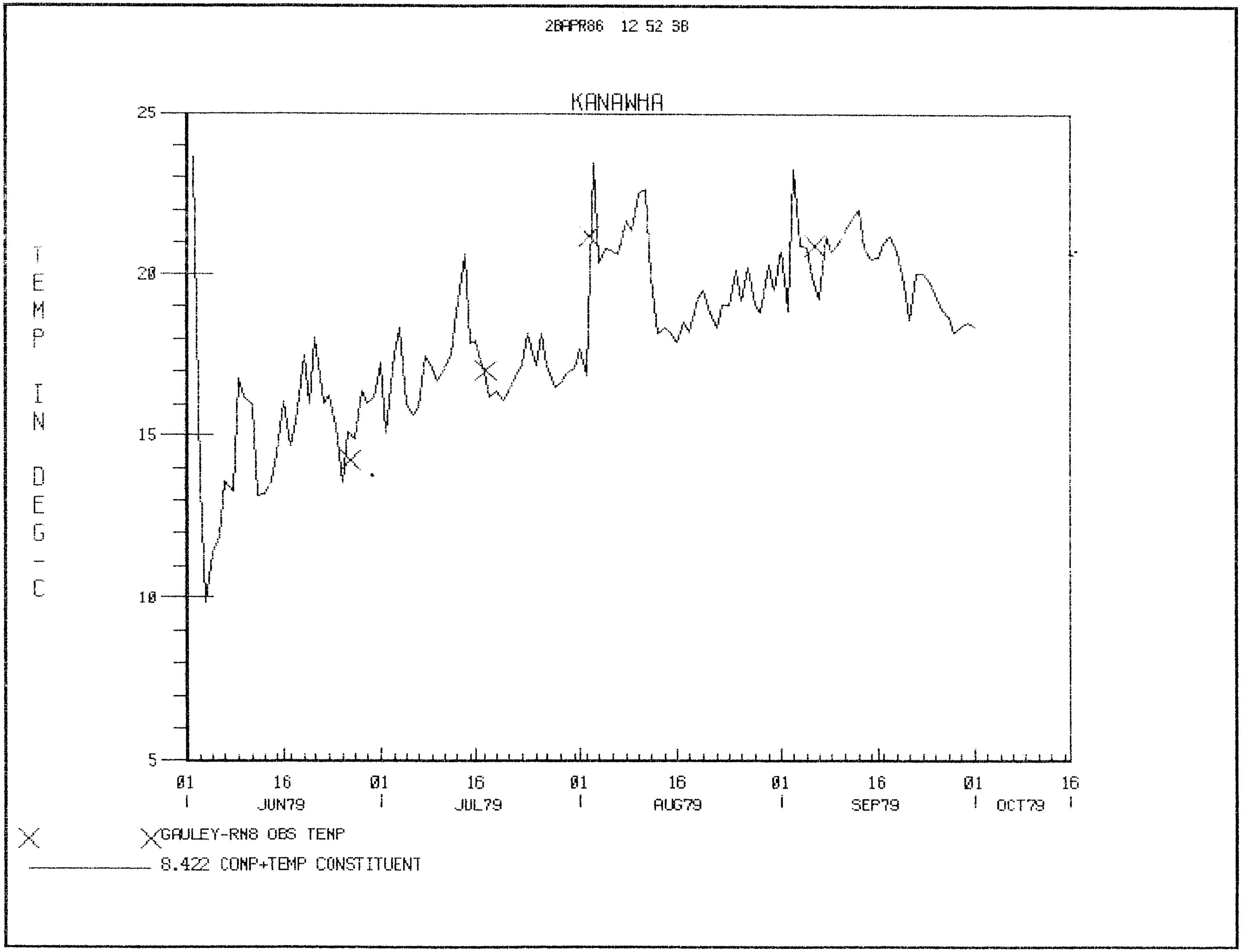

26APR86 15 31 11
KANAWHA
DO IN MG/L
9.5
9.0
8.5
8.0
7.5
7.0
6.5
0
50
100
150
200
250
300
DEPTH IN FEET
SUMMERSVILLE 14JUN79+OBS CONS.1
SUMMERSVILLE 14JUN79+COMP OXYGEN

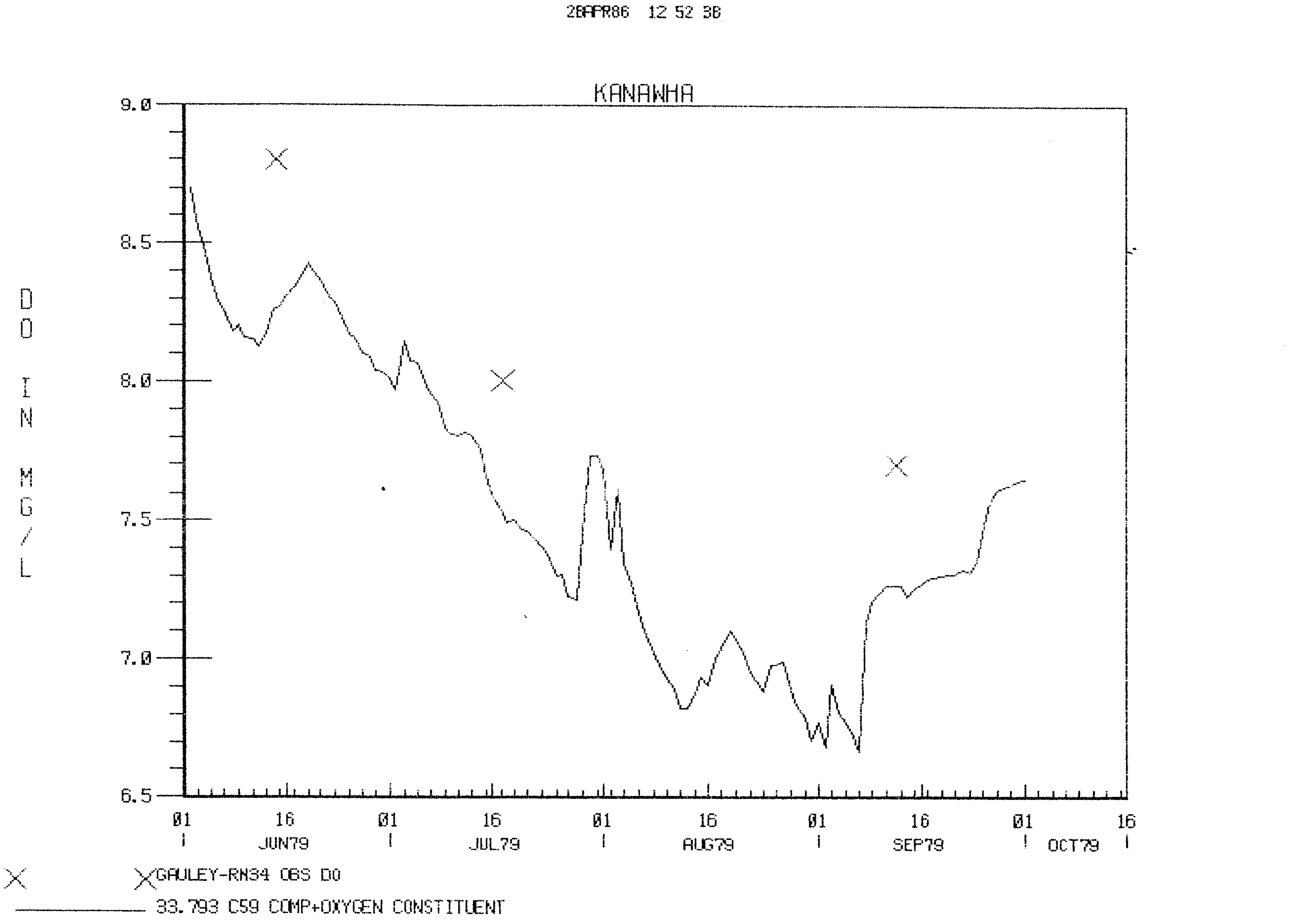

28APR86 15 31 11
KANAWHA
DO IN MG/L
10
8
6
4
2
0
50
100
150
200
250
300
DEPTH IN FEET
SUMMERSVILLE 17JUL79+OBS CONS.1
SUMMERSVILLE 17JUL79+COMP OXYGEN

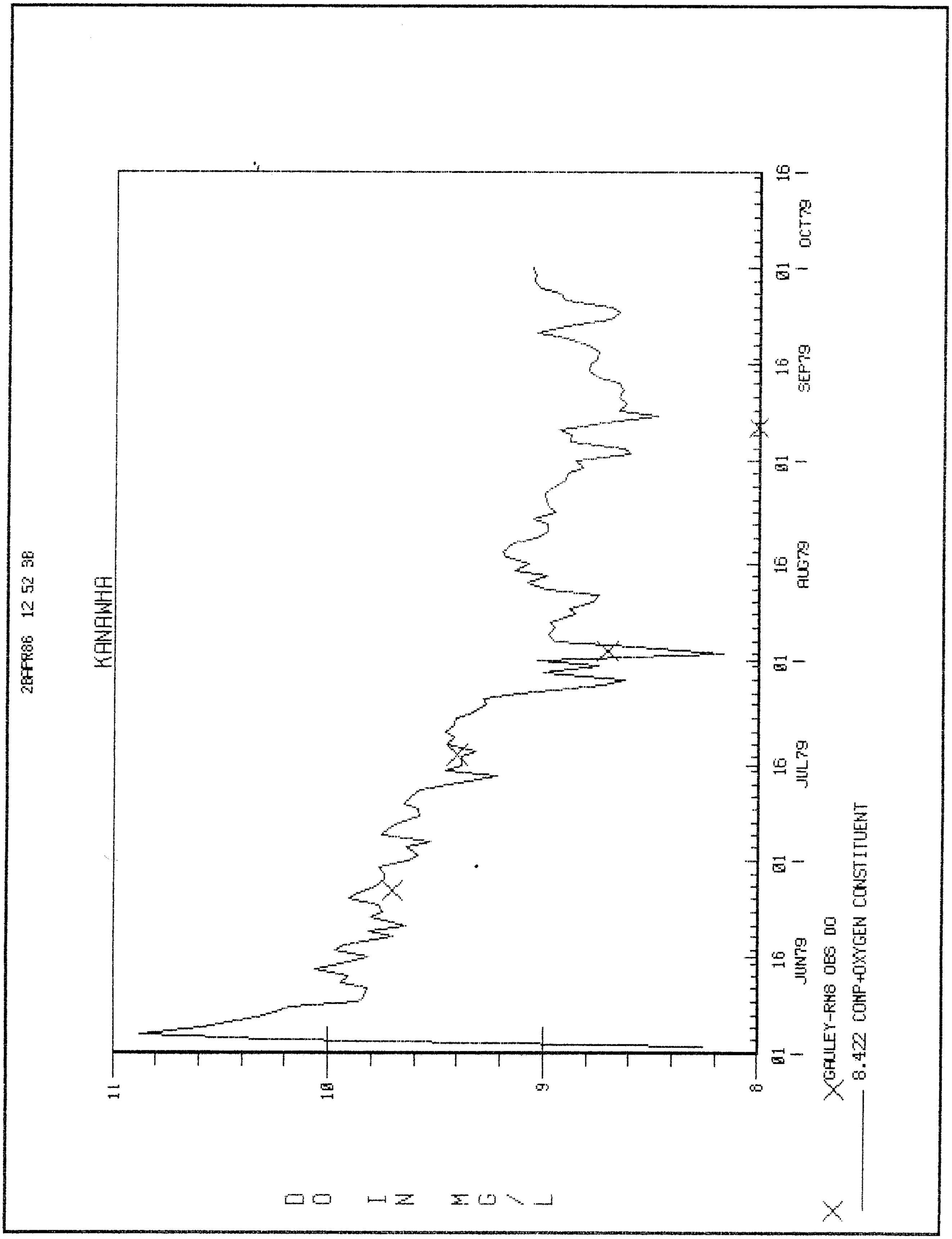

28MAR86 15 31 11
KANAWHA
DO IN MG/L
8
6
4
2
0
0
50
100
150
200
250
300
DEPTH IN FEET
SUMMERSVILLE 16AUG79+OBS CONS.1
SUMMERSVILLE 16AUG79+COMP OXYGEN

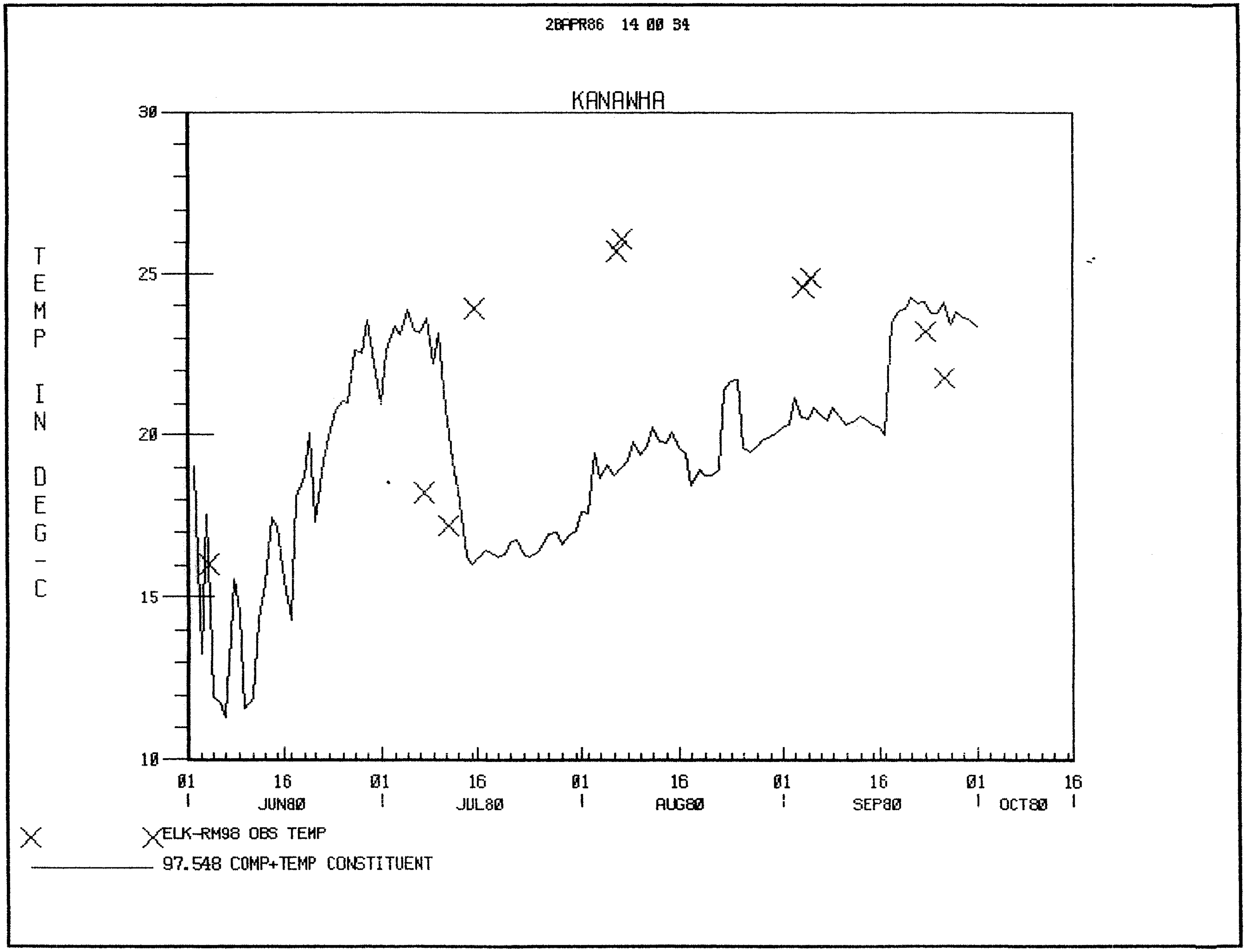

20APR86 15 31 11
KANAWHA
DO IN MG/L
10
8
6
4
2
0
0
50
100
150
200
250
300
DEPTH IN FEET
SUMMERSVILLE 21SEP79+OBS CONS.1
SUMMERSVILLE 21SEP79+COMP OXYGEN

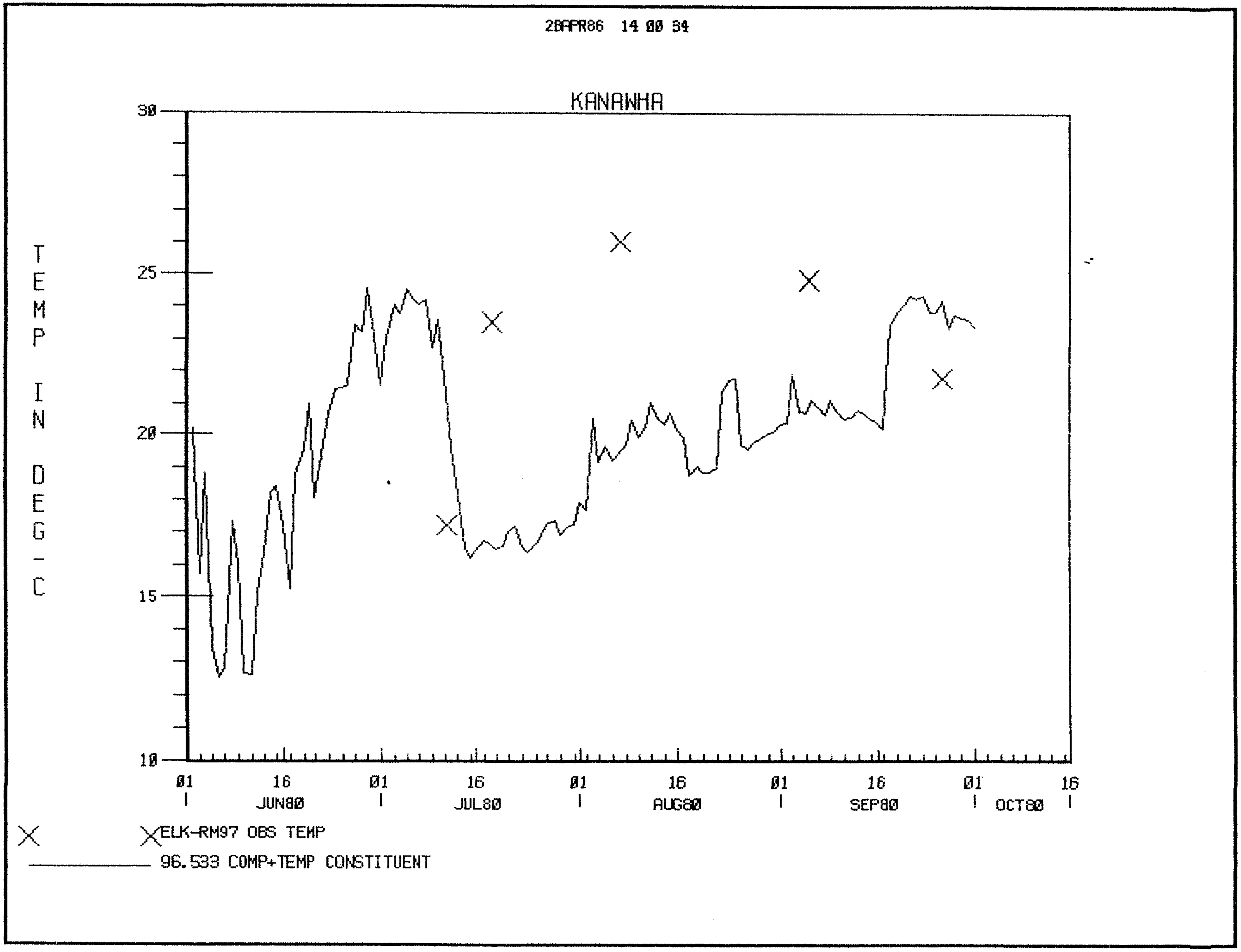

20APR86 12 52 38
KANAWHA
TEMP IN DEG-C
25
20
15
10
5
01
16
JUN79
01
16
JUL79
01
16
AUG79
01
16
SEP79
01
16
OCT79
X GAULEY-RN34 OBS TEMP
33.793 C59 COMP+TEMP CONSTITUENT

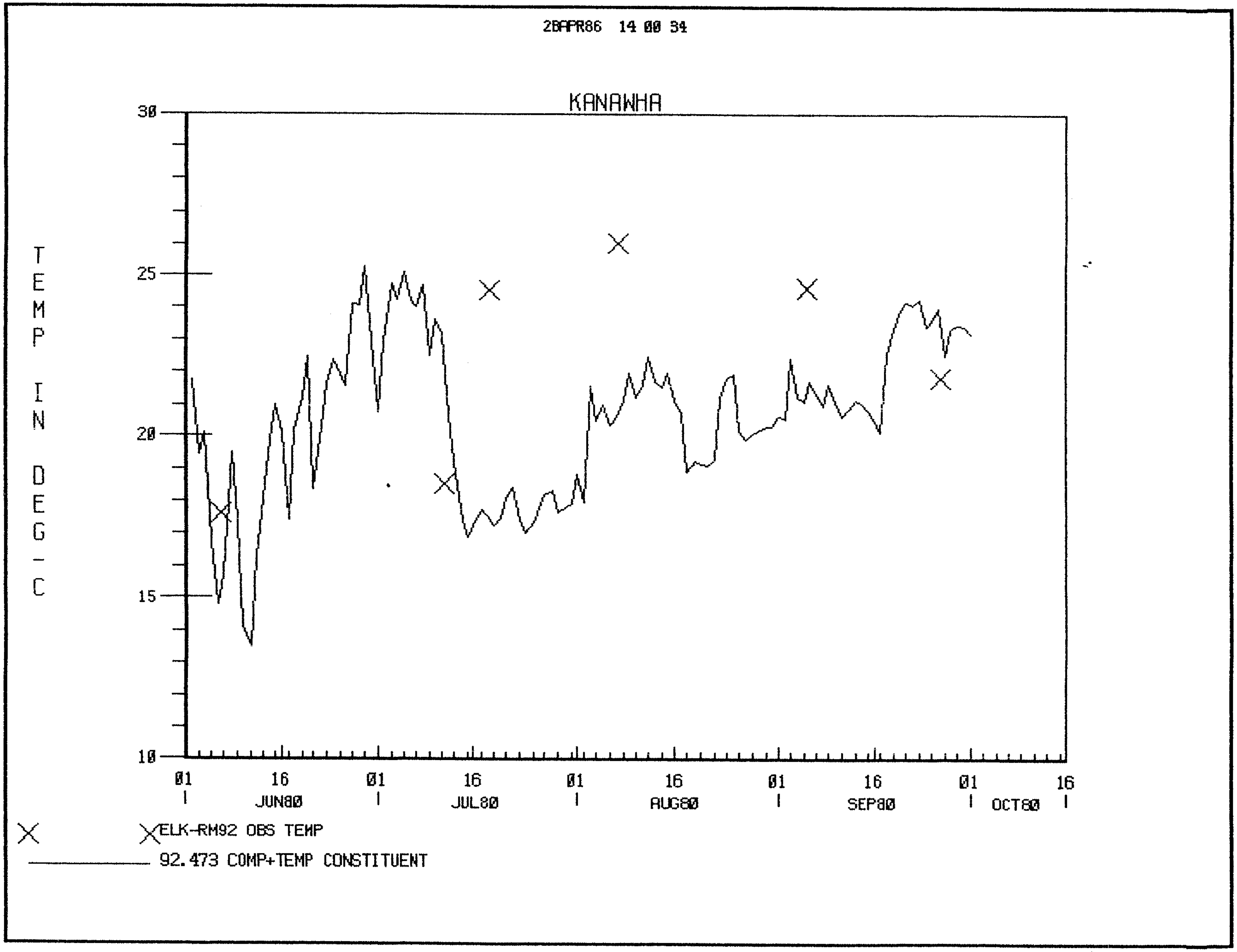

28APR86 12 52 38
KANAWHA
TEMP IN DEG-C
25
20
15
10
5
01
16
JUN79
01
16
JUL79
01
16
AUG79
01
16
SEP79
01
OCT79
16
GAULEY-RN8 OBS TEMP
8.422 COMP+TEMP CONSTITUENT

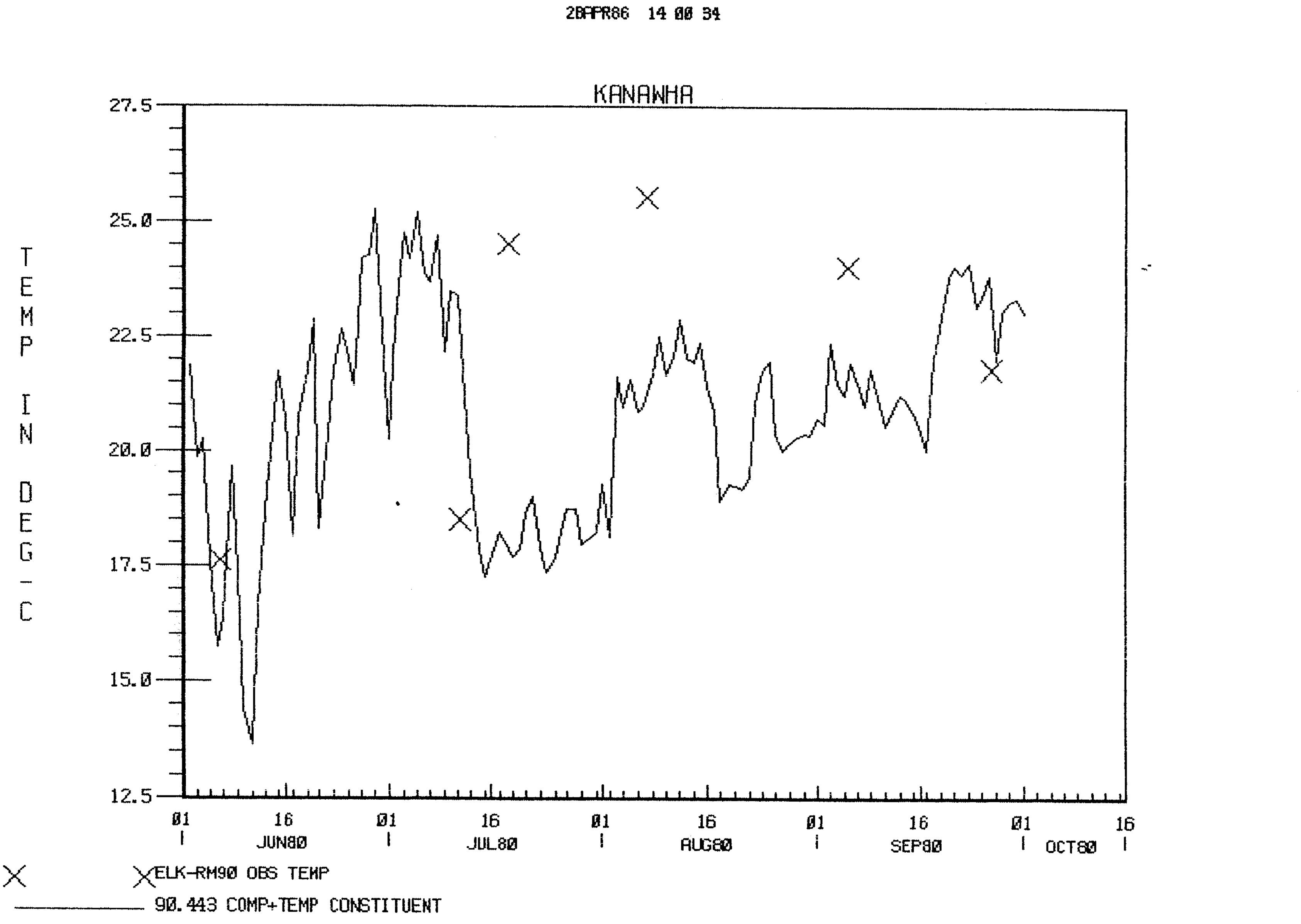

28APR86 12 52 38
KANAWHA
DO IN MG/L
9.0
8.5
8.0
7.5
7.0
6.5
01
16
JUN79
01
16
JUL79
01
16
AUG79
01
16
SEP79
01
OCT79
16
GAULEY-RN34 OBS DO
33.793 C59 COMP+OXYGEN CONSTITUENT

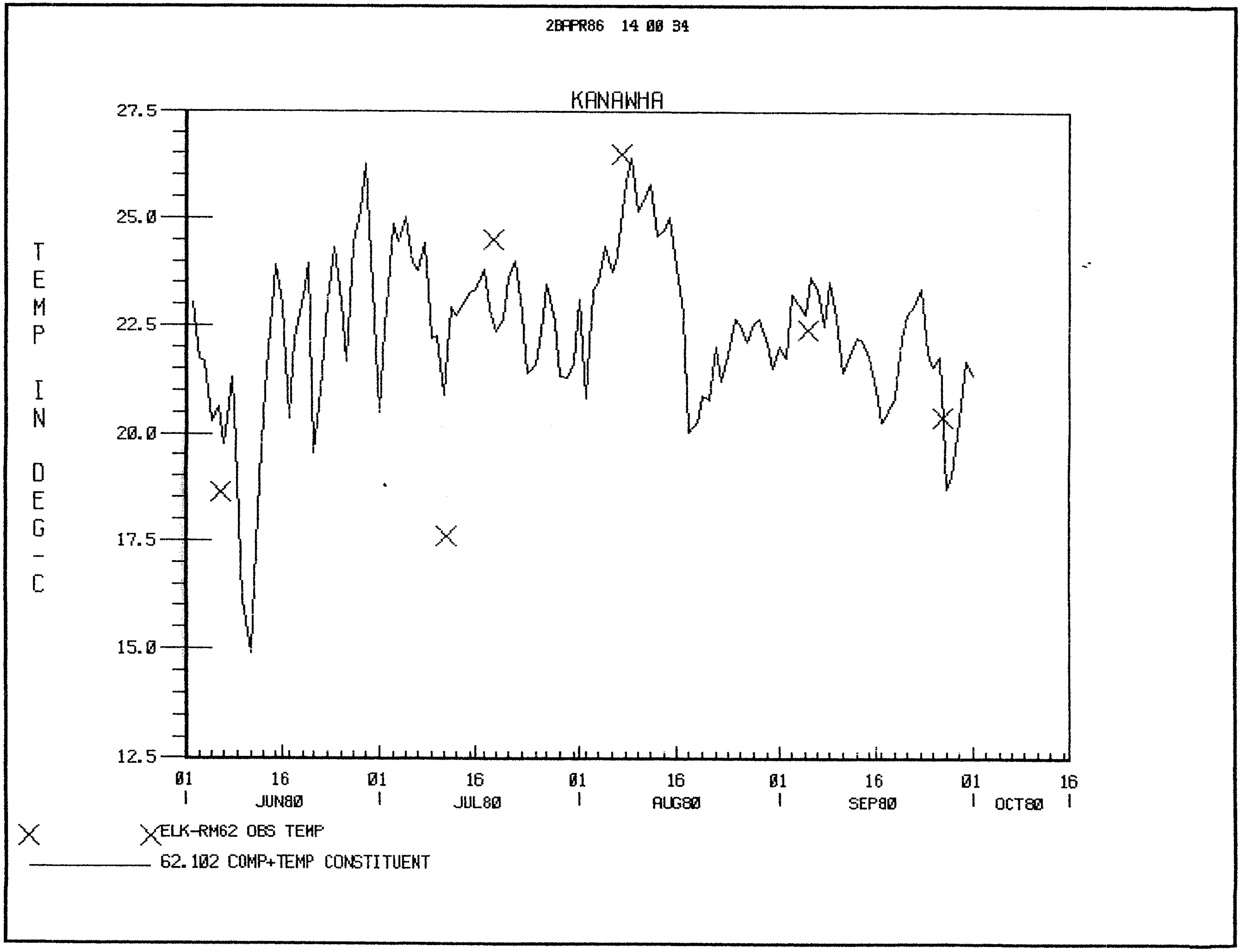

28APR86 12 52 38
KANAWHA
DO IN MG/L
11
10
9
8
01
16
JUN79
01
16
JUL79
01
16
AUG79
01
16
SEP79
01
OCT79
16
GAULEY-RN8 OBS DO
8.422 COMP+OXYGEN CONSTITUENT

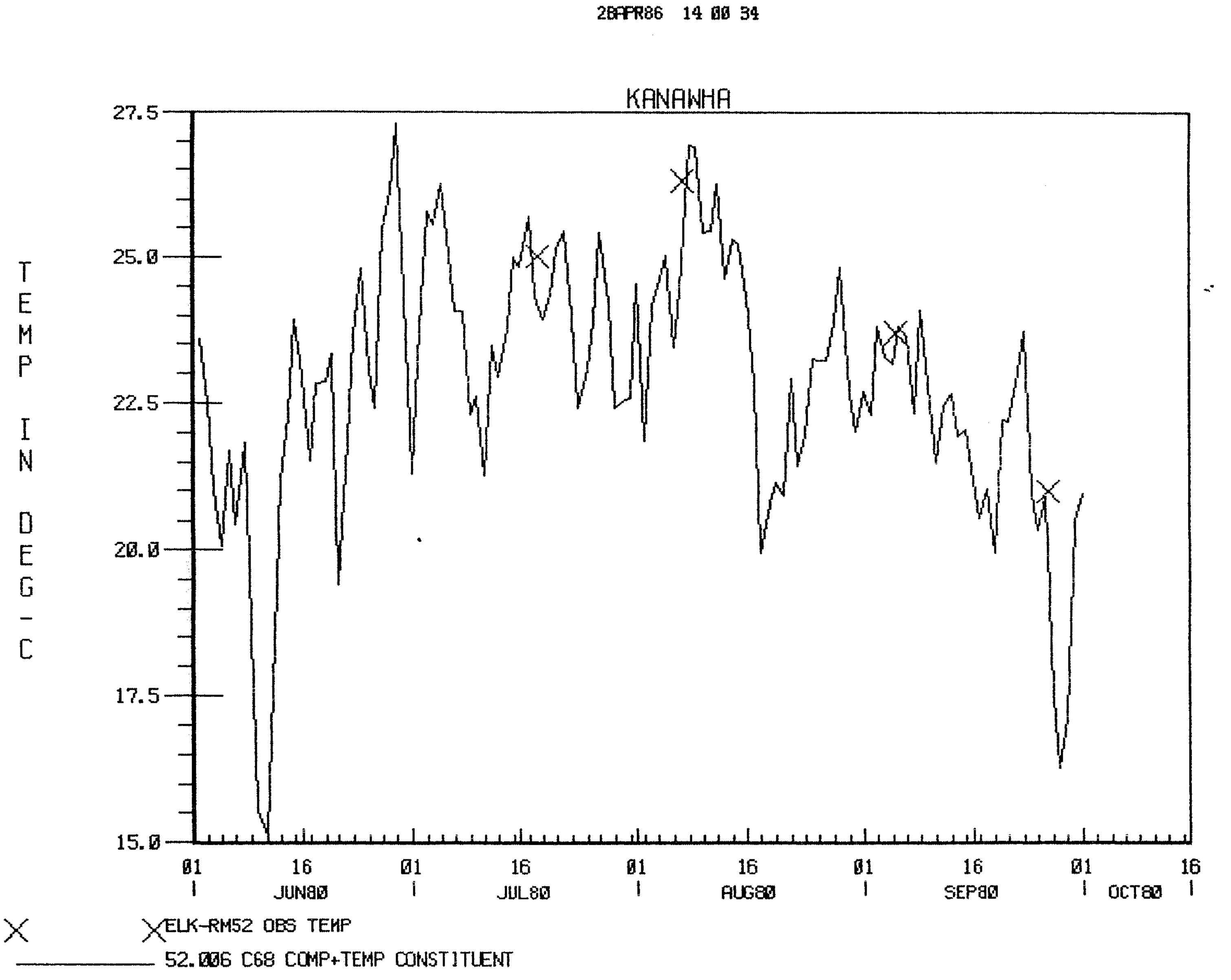

28APR86 14 00 34
KANAWHA
TEMP IN DEG-C
30
25
20
15
10
01
16
JUN80
01
16
JUL80
01
16
AUG80
01
16
SEP80
01
OCT80
16
ELK-RM98 OBS TEMP
97.548 COMP+TEMP CONSTITUENT

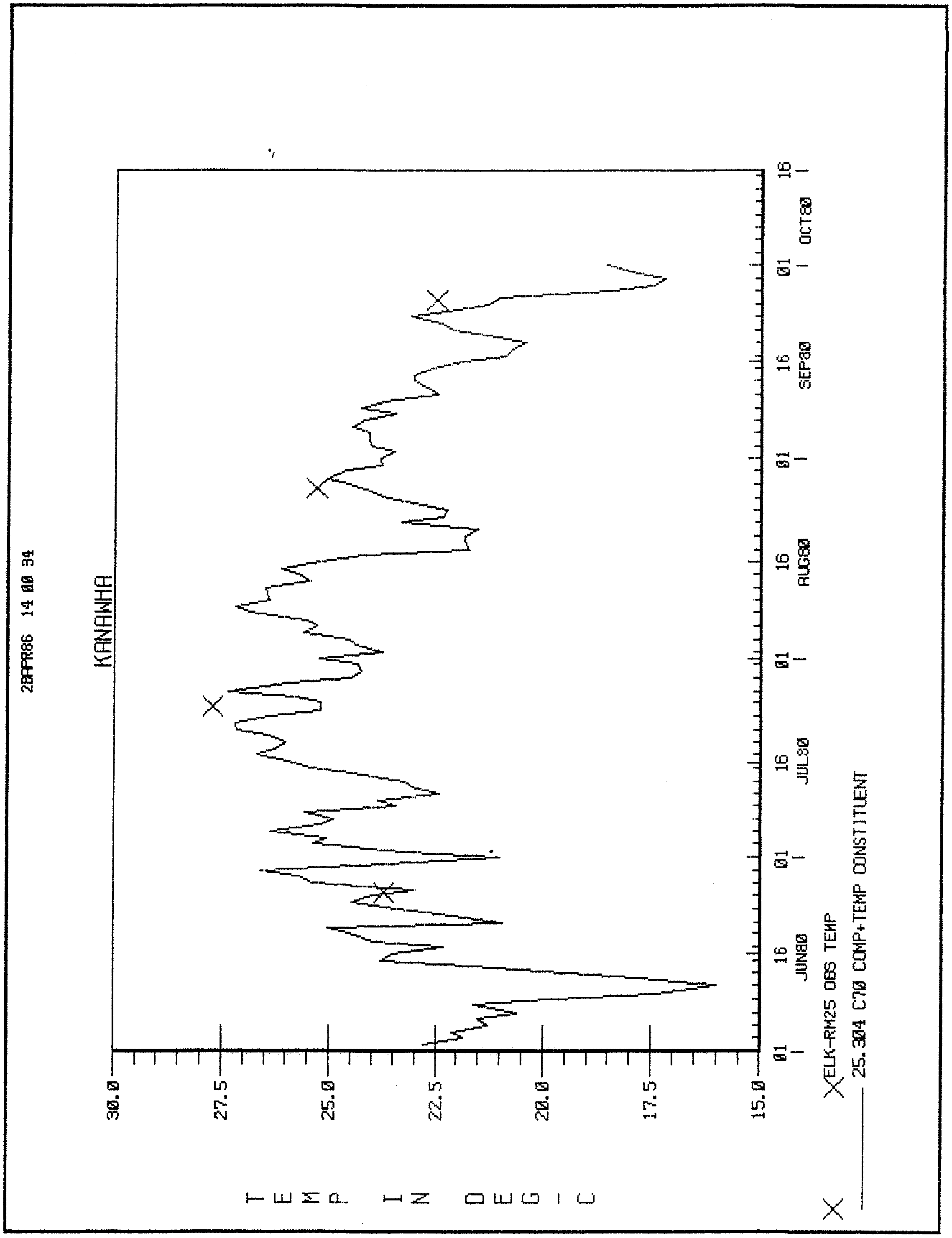

28APR86 14 00 54
KANAWHA
TEMP IN DEG-C
30
25
20
15
10
01
16
JUN80
01
16
JUL80
01
16
AUG80
01
16
SEP80
01
OCT80
16
ELK-RM97 OBS TEMP
96.533 COMP+TEMP CONSTITUENT

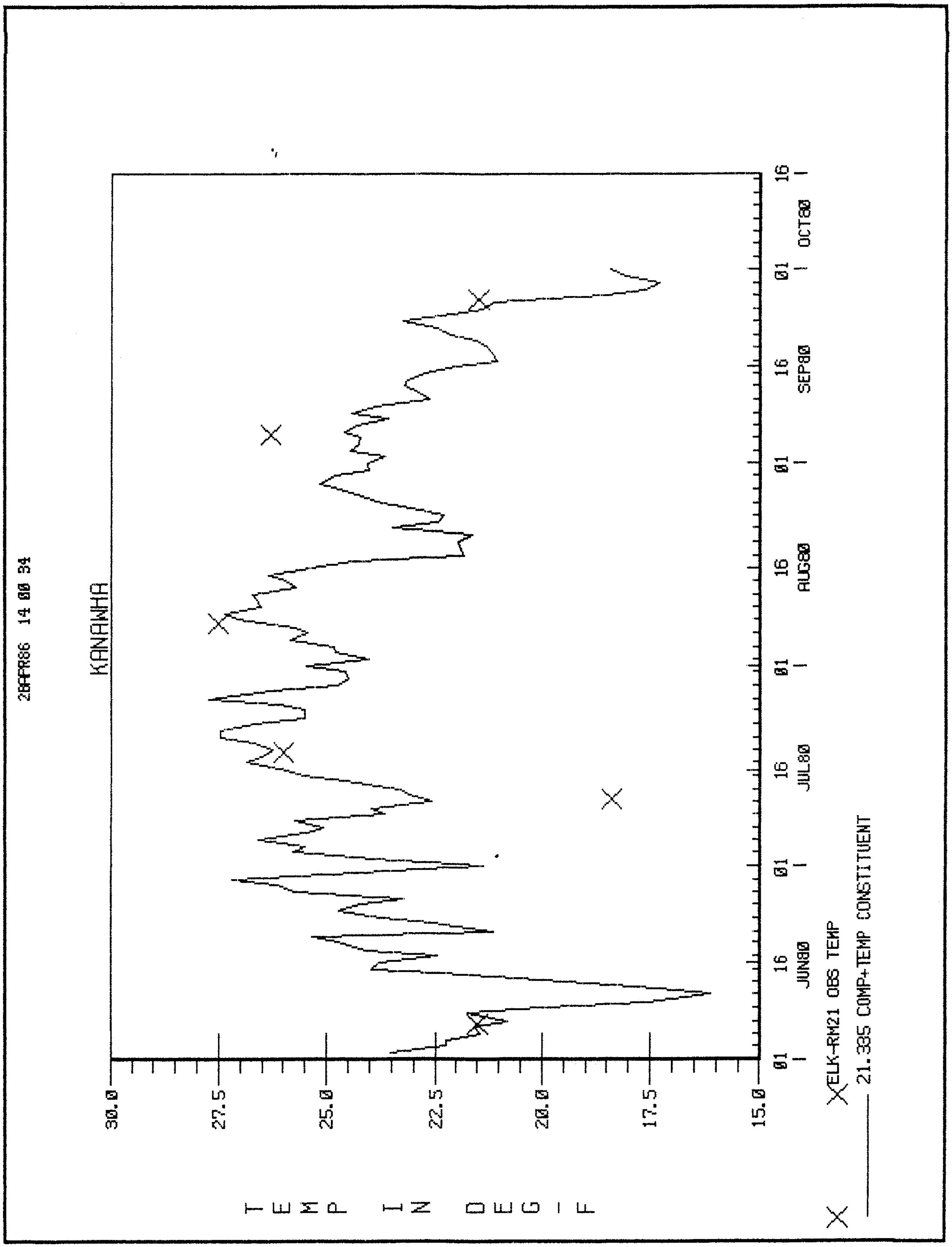

28APR86 14 00 34
KANAWHA
TEMP IN DEG-C
30
25
20
15
10
01
16
JUN80
01
16
JUL80
01
16
AUG80
01
16
SEP80
01
16
OCT80
ELK-RM92 OBS TEMP
92.473 COMP+TEMP CONSTITUENT

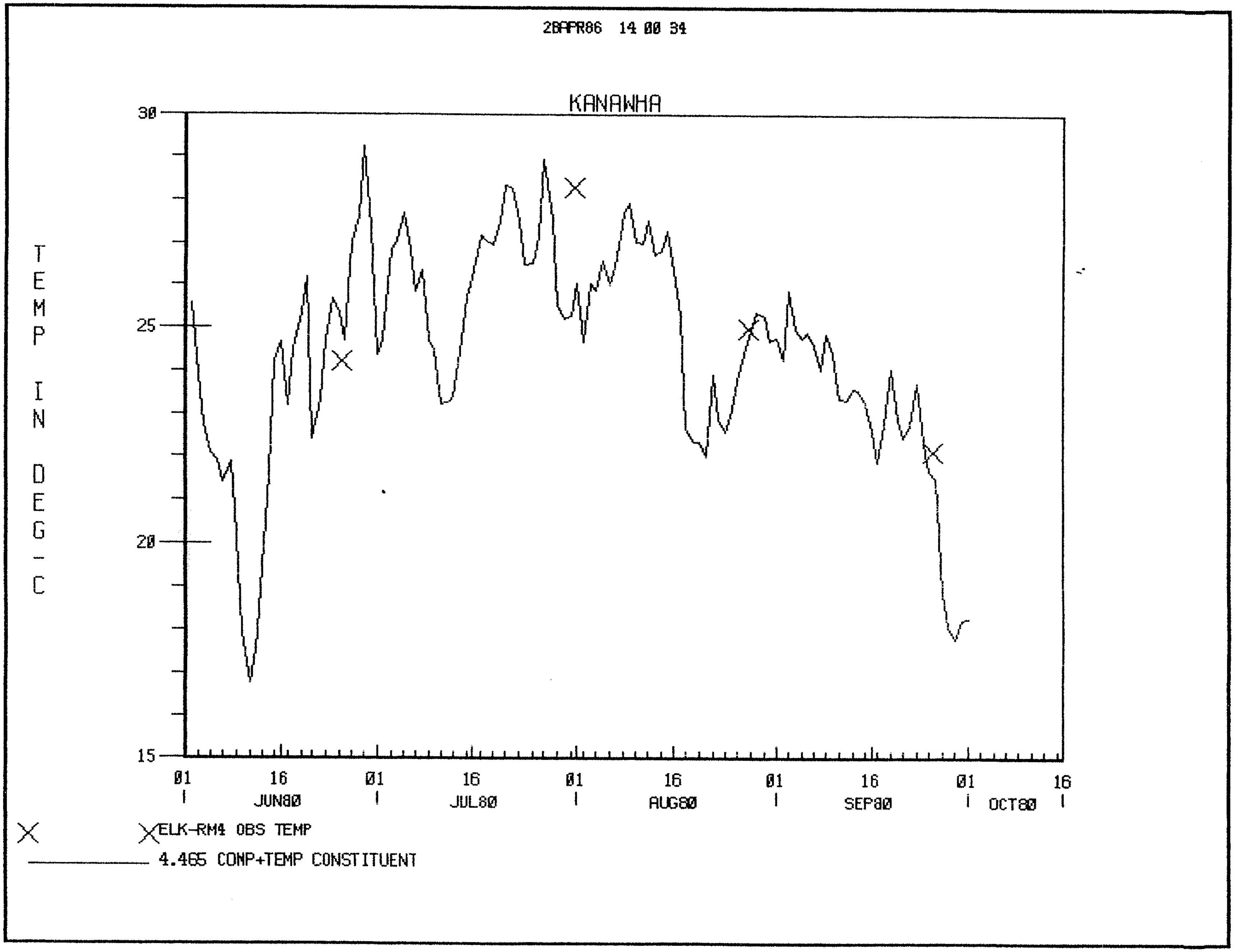

28APR86 14 00 34
KANAWHA
TEMP IN DEG-C
27.5
25.0
22.5
20.0
17.5
15.0
12.5
01
16
JUN80
01
16
JUL80
01
16
AUG80
01
16
SEP80
01
OCT80
16
ELK-RM90 OBS TEMP
90.443 COMP+TEMP CONSTITUENT

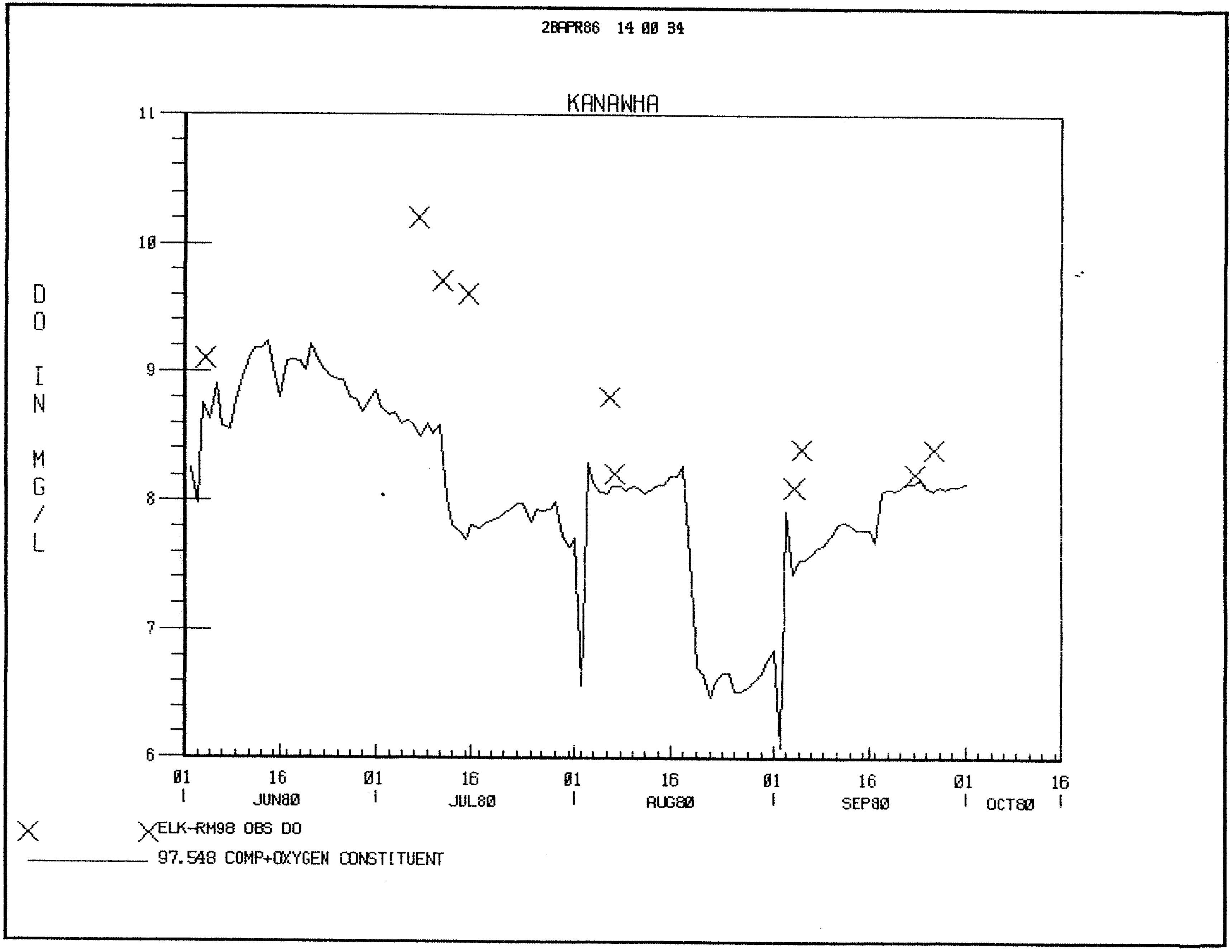

28APR86 14 00 34
KANAWHA
TEMP IN DEG-C
27.5
25.0
22.5
20.0
17.5
15.0
12.5
01
16
JUN80
01
16
JUL80
01
16
AUG80
01
16
SEP80
01
OCT80
16
ELK-RM62 OBS TEMP
62.102 COMP+TEMP CONSTITUENT

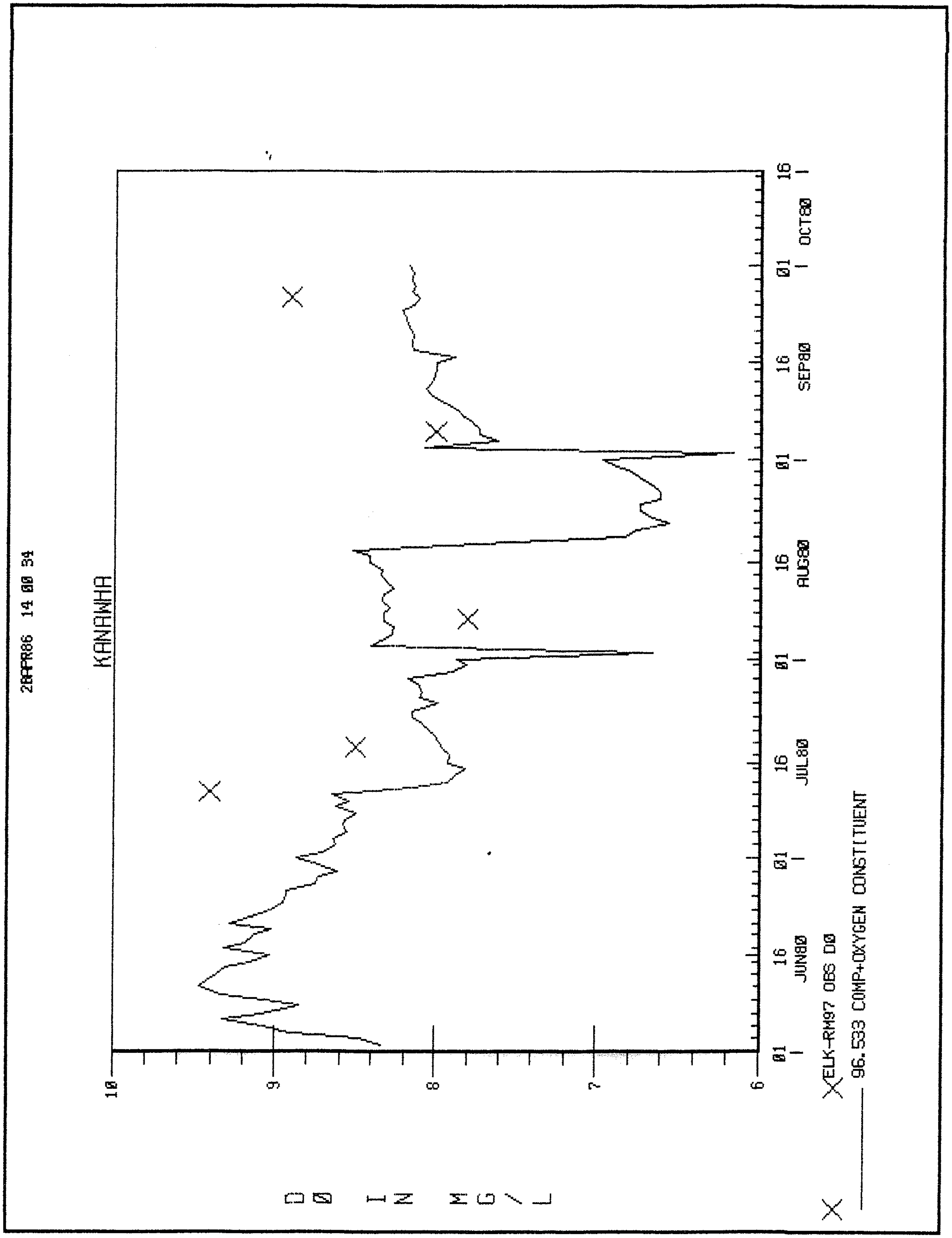

28APR86 14 00 34
KANAWHA
TEMP IN DEG-C
27.5
25.0
22.5
20.0
17.5
15.0
01
16
JUN80
01
16
JUL80
01
16
AUG80
01
16
SEP80
01
OCT80
16
ELK-RM52 OBS TEMP
52.006 C68 COMP+TEMP CONSTITUENT

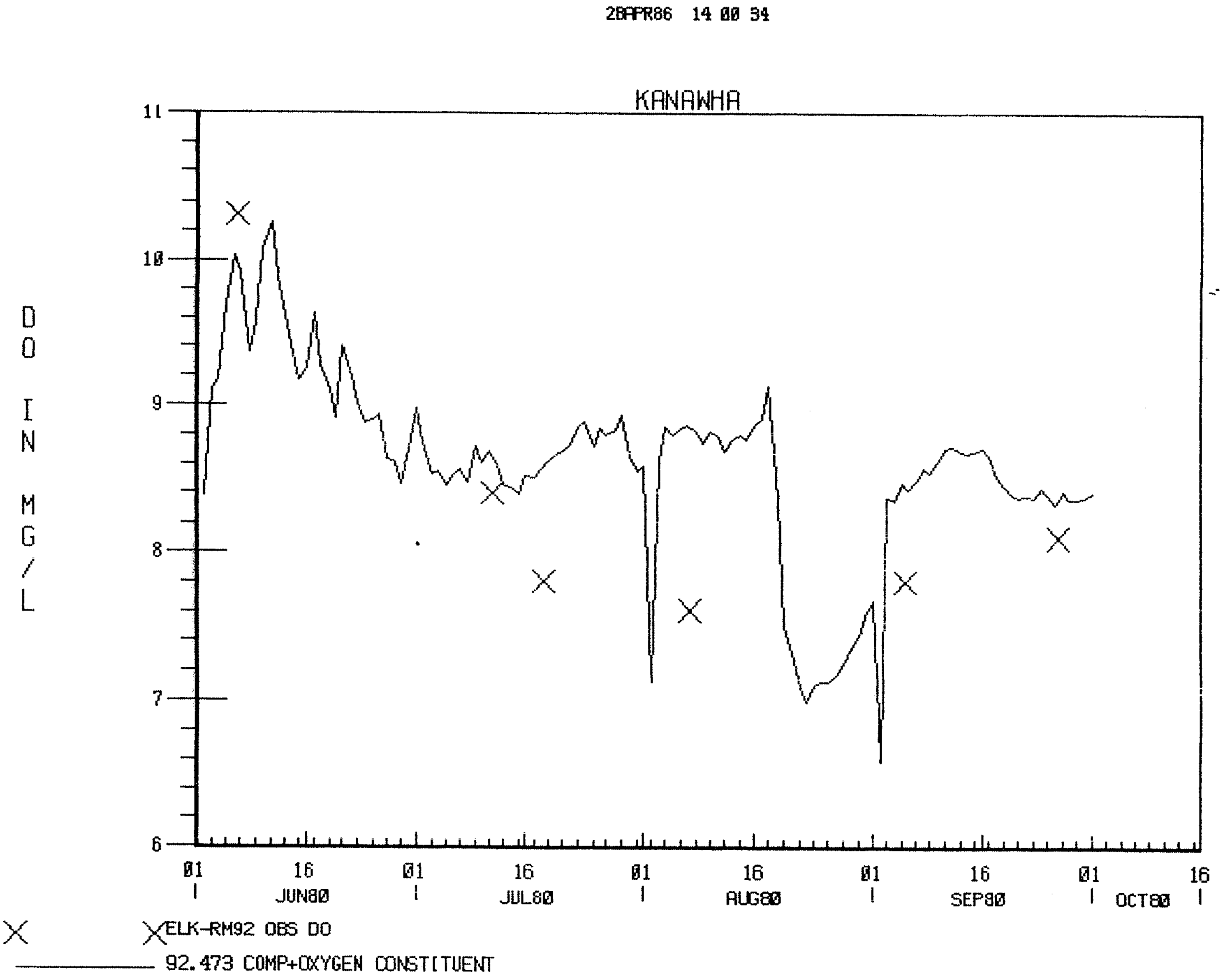

28APR86 14 00 34
KANAWHA
TEMP IN DEG-C
30.0
27.5
25.0
22.5
20.0
17.5
15.0
01
16
JUN80
01
16
JUL80
01
16
AUG80
01
16
SEP80
01
16
OCT80
ELK-RM25 OBS TEMP
25.304 C70 COMP+TEMP CONSTITUENT

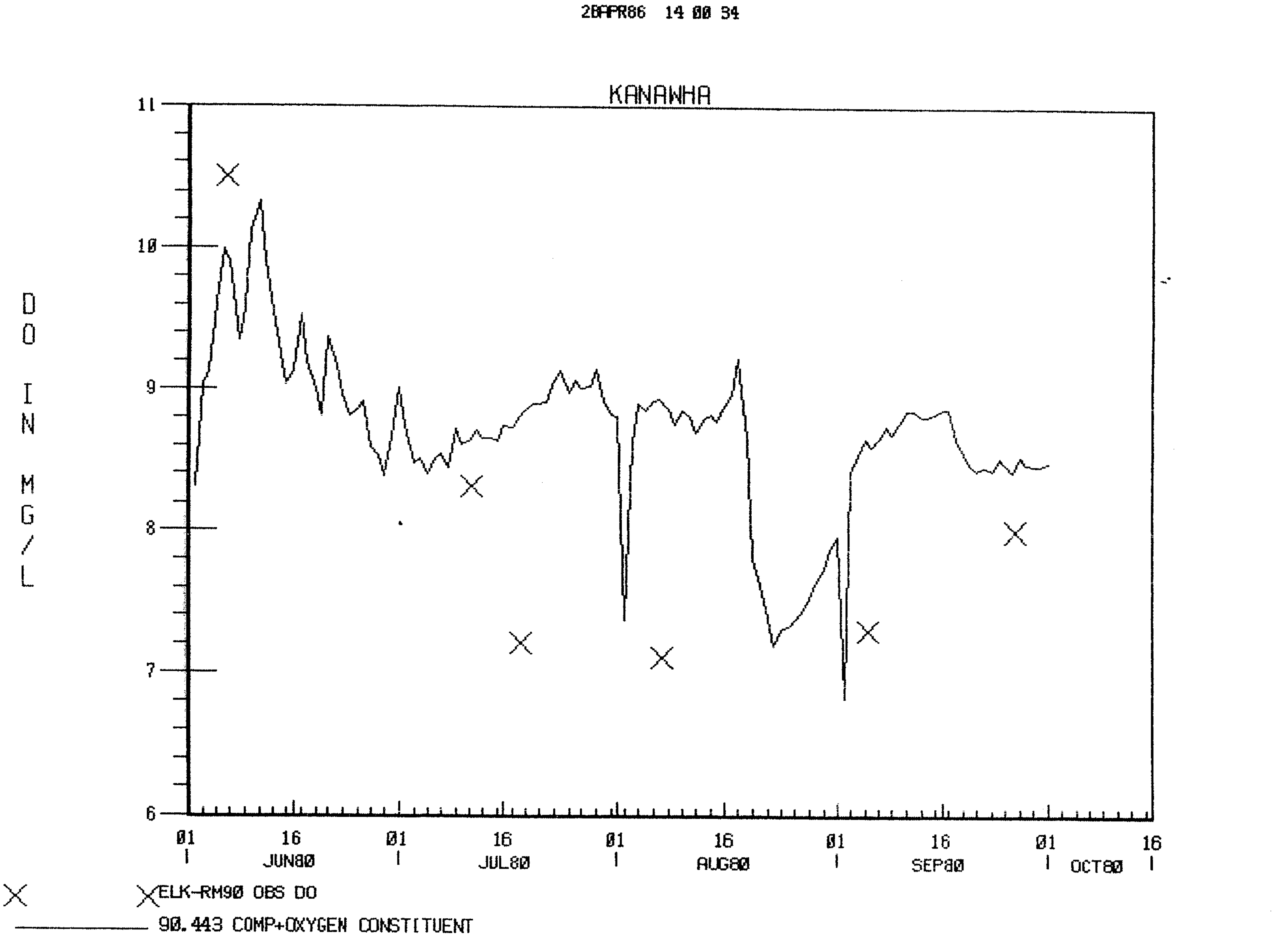

28APR86 14 00 34
KANAWHA
TEMP IN DEG-F
30.0
27.5
25.0
22.5
20.0
17.5
15.0
01
16
JUN80
01
16
JUL80
01
16
AUG80
01
16
SEP80
01
16
OCT80
01
16
ELK-RM21 OBS TEMP
21.335 COMP+TEMP CONSTITUENT

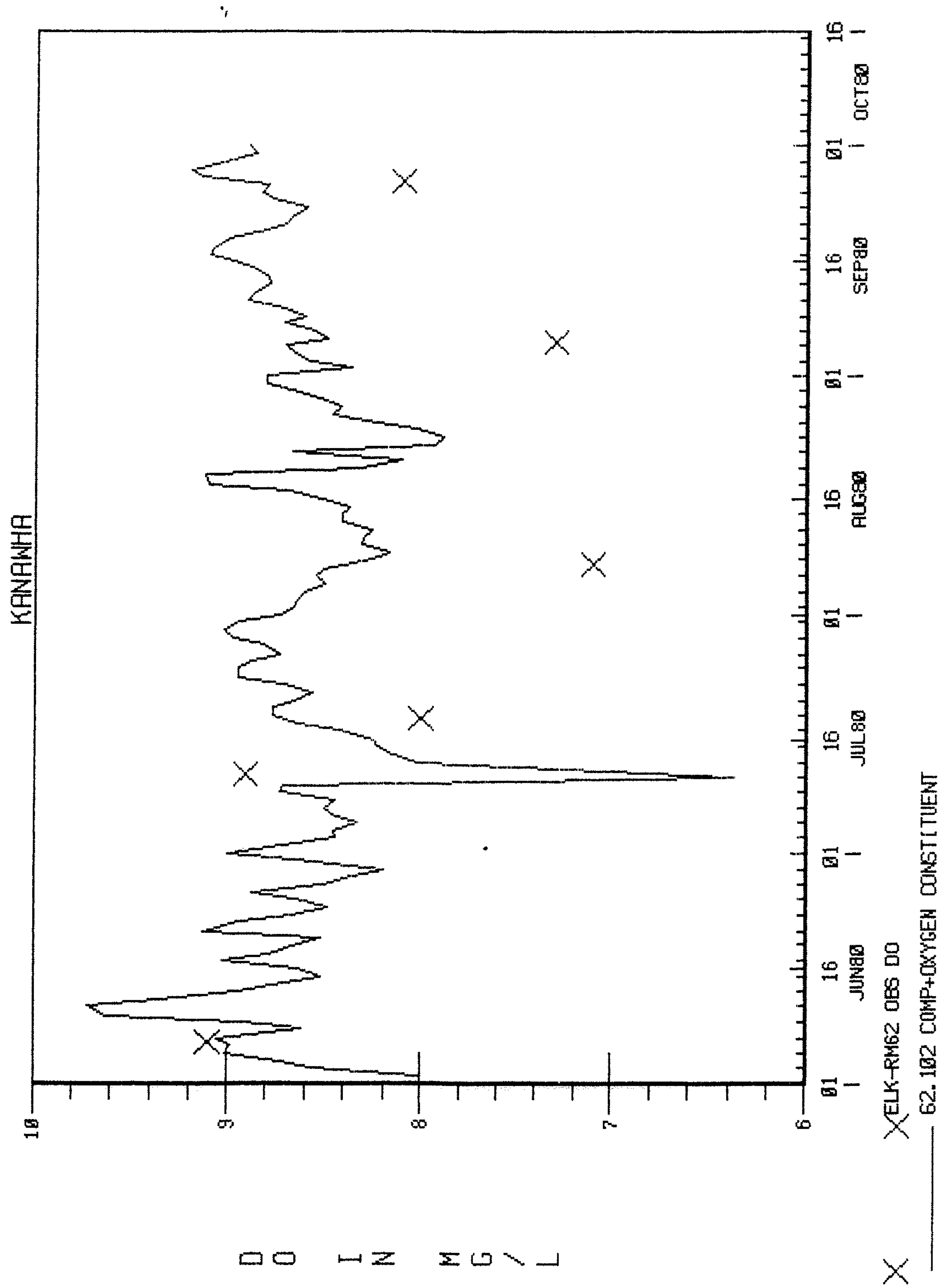

28APR86 14 00 34
KANAWHA
TEMP IN DEG-C
30
25
20
15
01
16
JUN80
01
16
JUL80
01
16
AUG80
01
16
SEP80
01
OCT80
16
ELK-RM4 OBS TEMP
4.465 COMP+TEMP CONSTITUENT

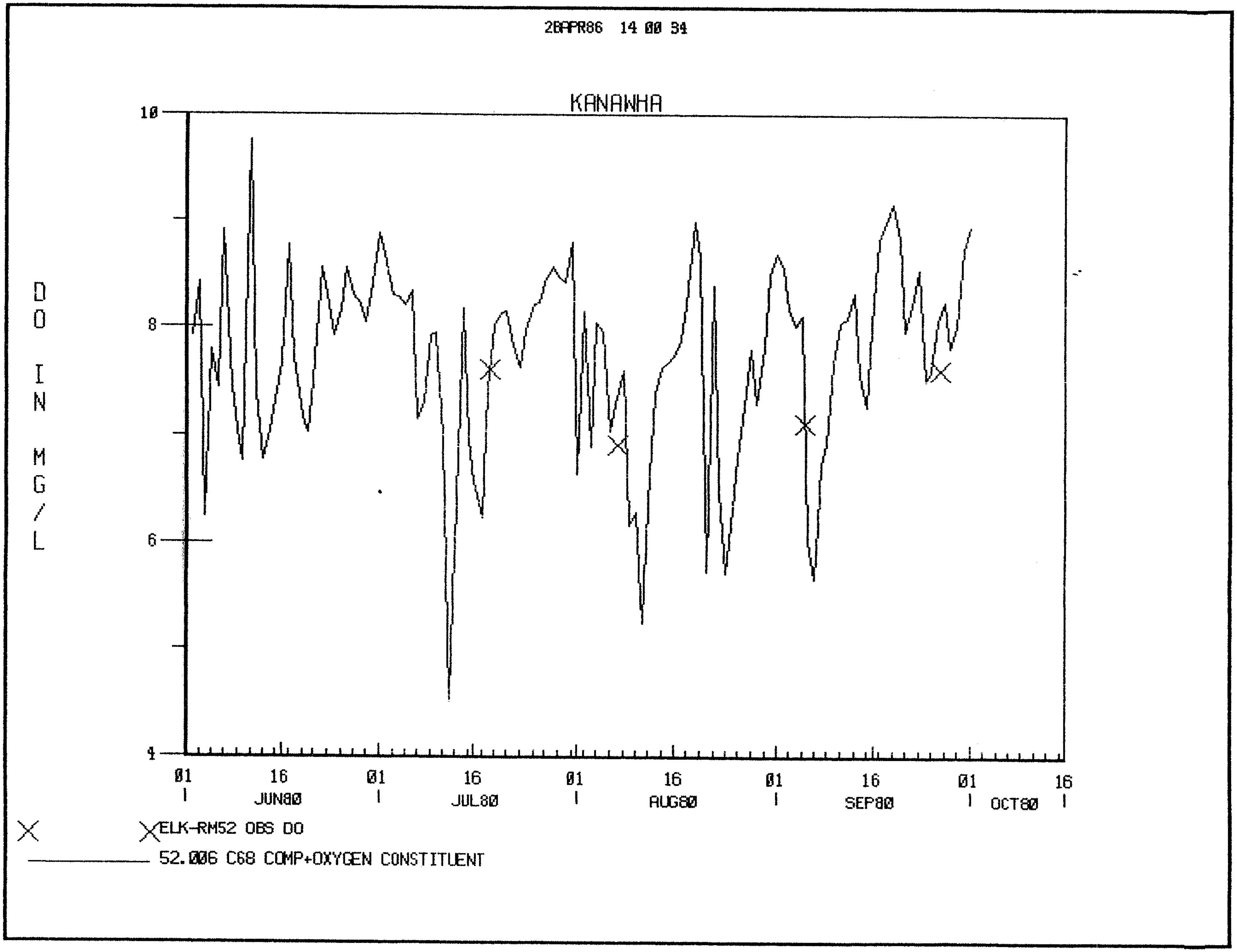

28APR86 14 00 34
KANAWHA
DO IN MG/L
11
10
9
8
7
6
01
16
JUN80
01
16
JUL80
01
16
AUG80
01
16
SEP80
01
OCT80
16
ELK-RM98 OBS DO
97.548 COMP+OXYGEN CONSTITUENT

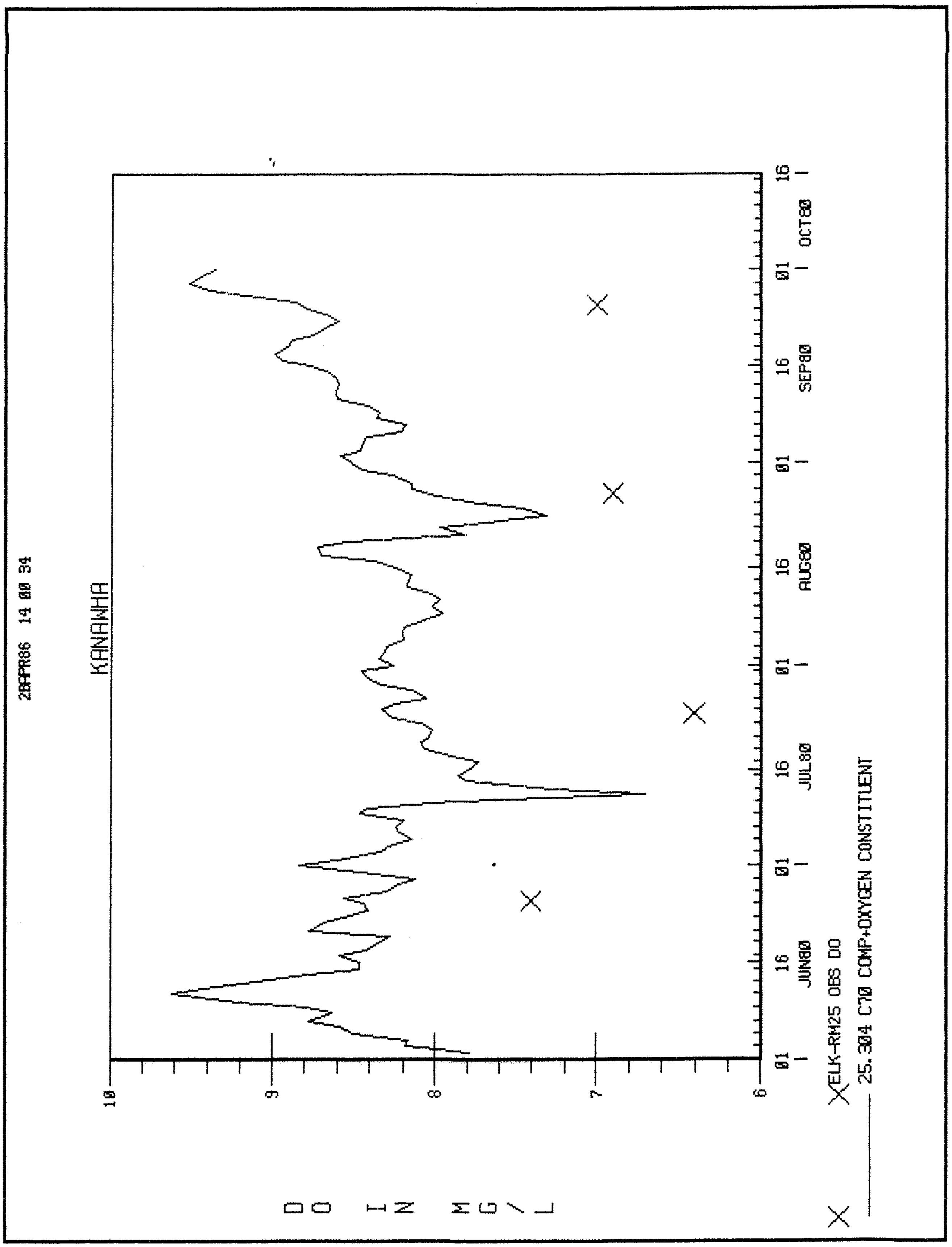

28APR86 14 00 34
KANAWHA
D0 IN MG/L
10
9
8
7
6
01 JUN80 16
01 JUL80 16
01 AUG80 16
01 SEP80 16
01 OCT80 16
ELK-RM97 OBS D0
96.533 COMP+OXYGEN CONSTITUENT

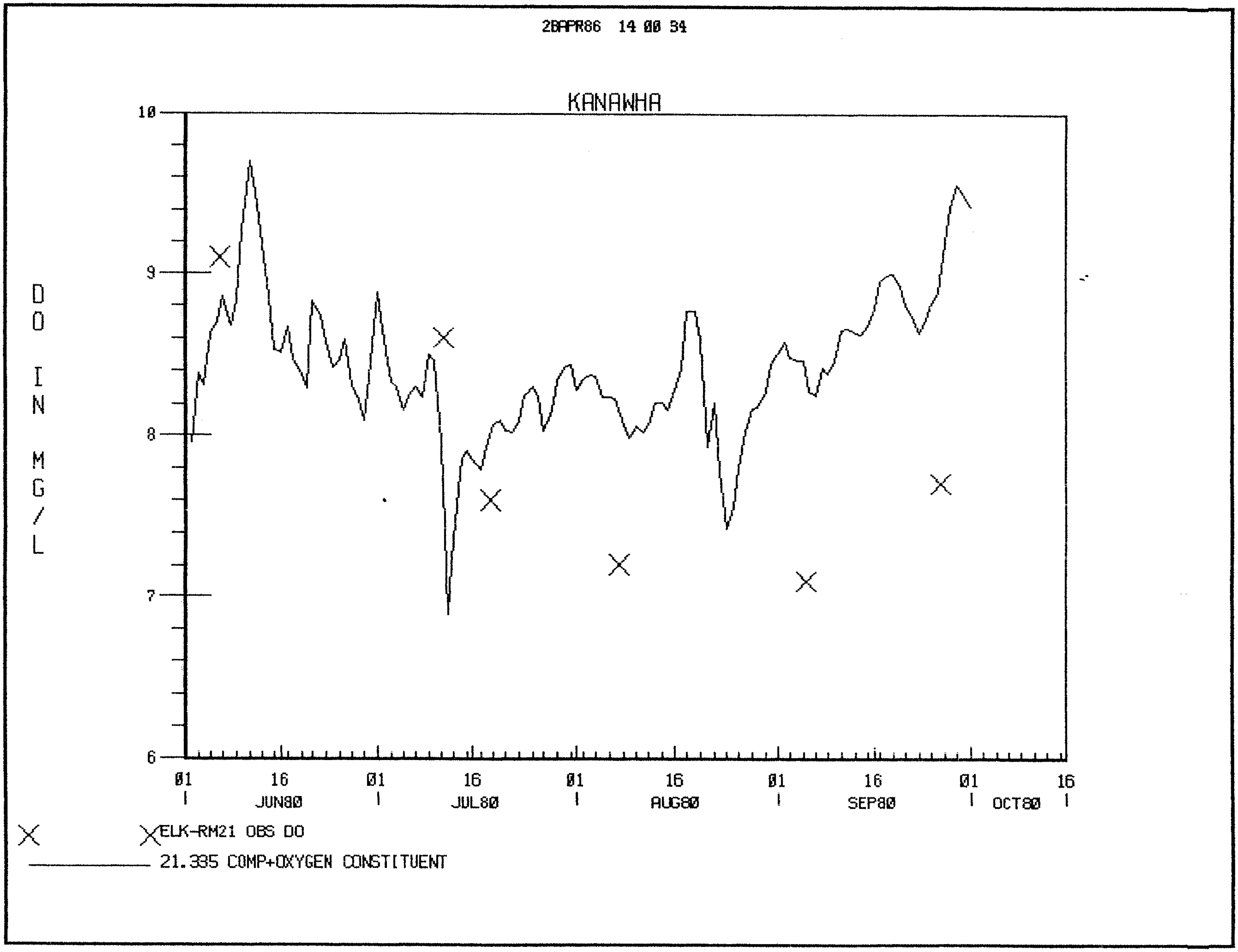

28APR86 14 00 34
KANAWHA
DO IN MG/L
11
10
9
8
7
6
01
16
JUN80
01
16
JUL80
01
16
AUG80
01
16
SEP80
01
OCT80
16
ELK-RM92 OBS DO
92.473 COMP+OXYGEN CONSTITUENT

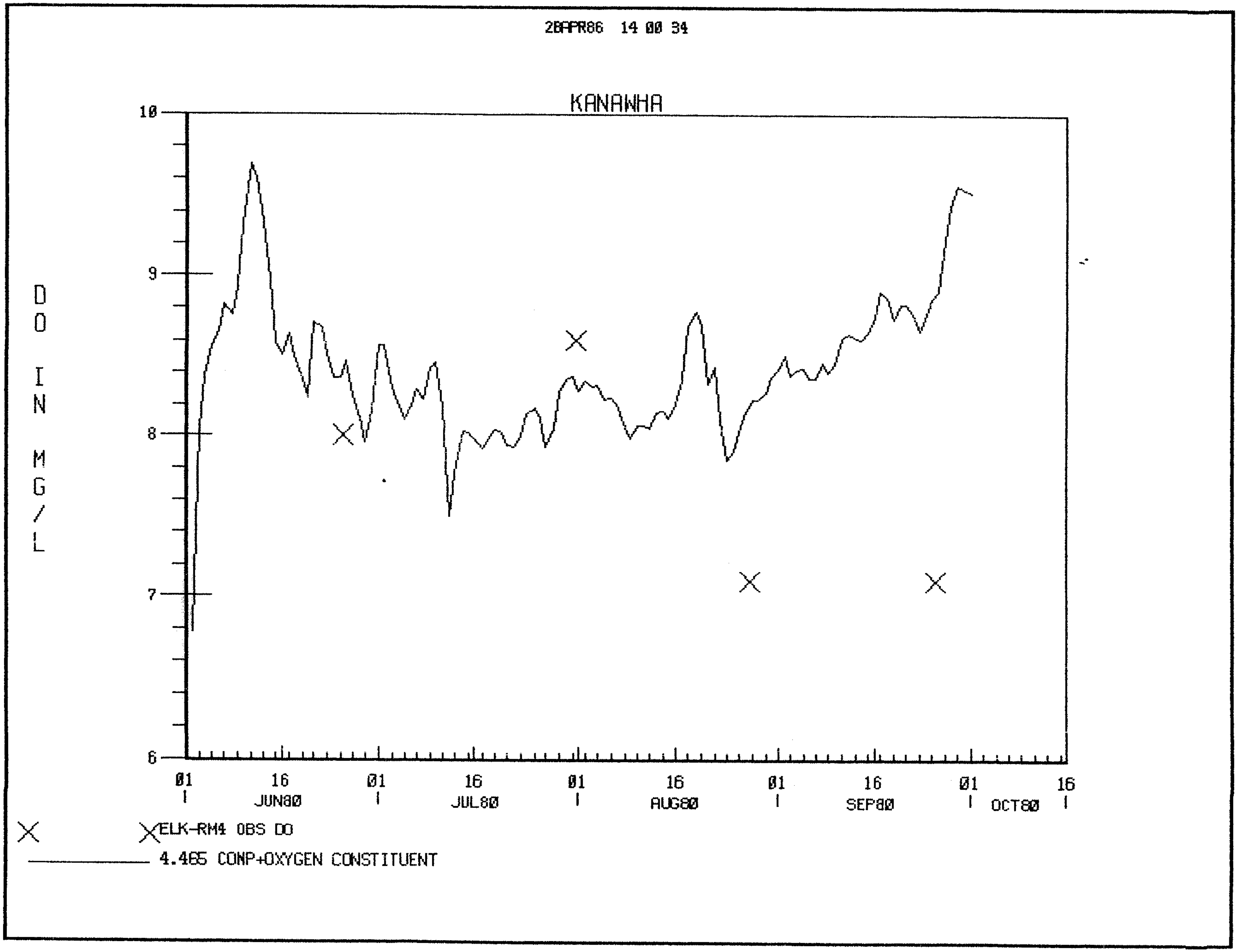

28APR86 14 00 34
KANAWHA
DO IN MG/L
11
10
9
8
7
6
01
16
JUN80
01
16
JUL80
01
16
AUG80
01
16
SEP80
01
OCT80
16
ELK-RM90 OBS DO
90.443 COMP+OXYGEN CONSTITUENT

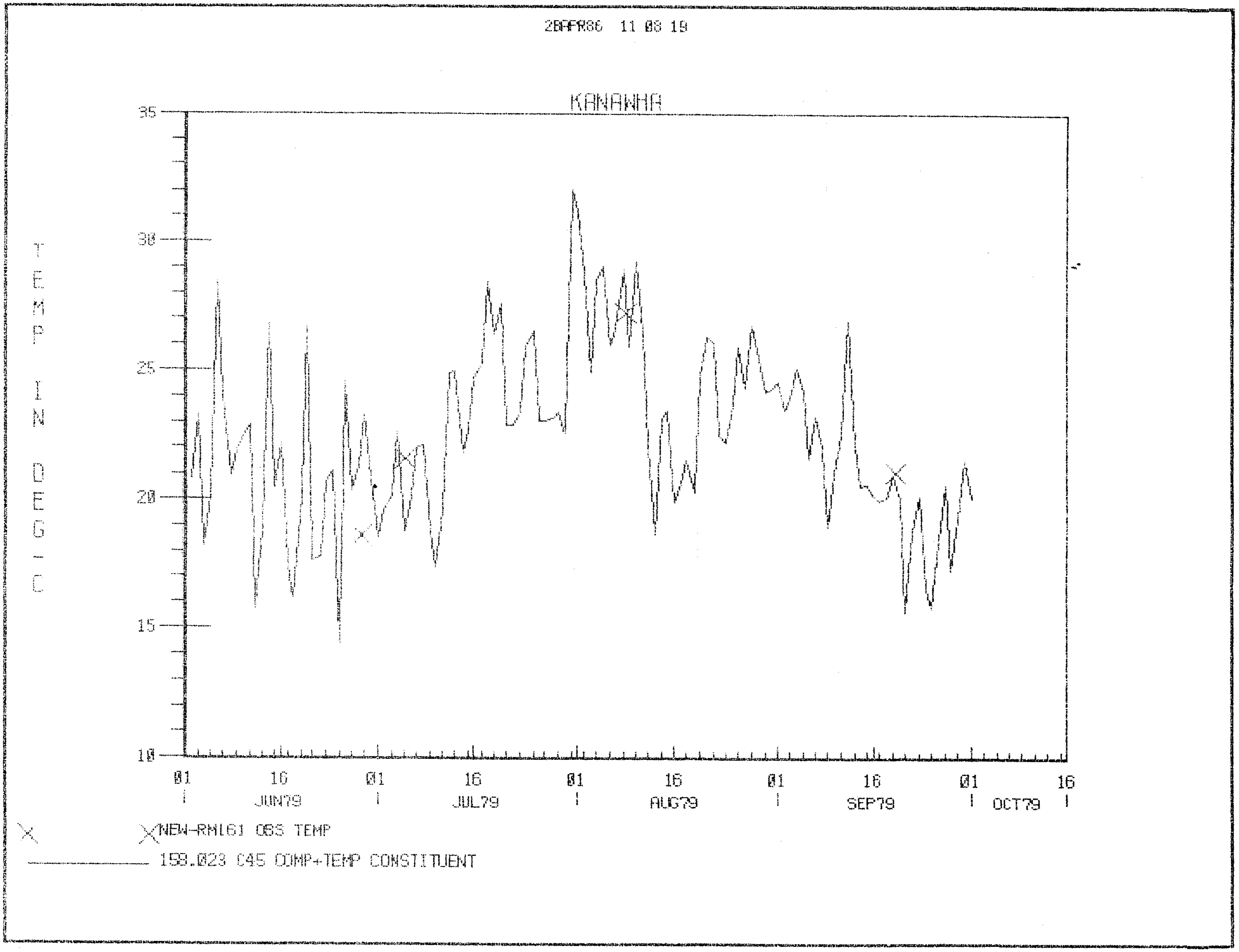

28APR86 14 00 34
KANAWHA
DO IN MG/L
10
9
8
7
6
01
JUN80 16
01
JUL80 16
01
AUG80 16
01
SEP80 16
01
OCT80
16
ELK-RM62 OBS DO
62.102 COMP+OXYGEN CONSTITUENT

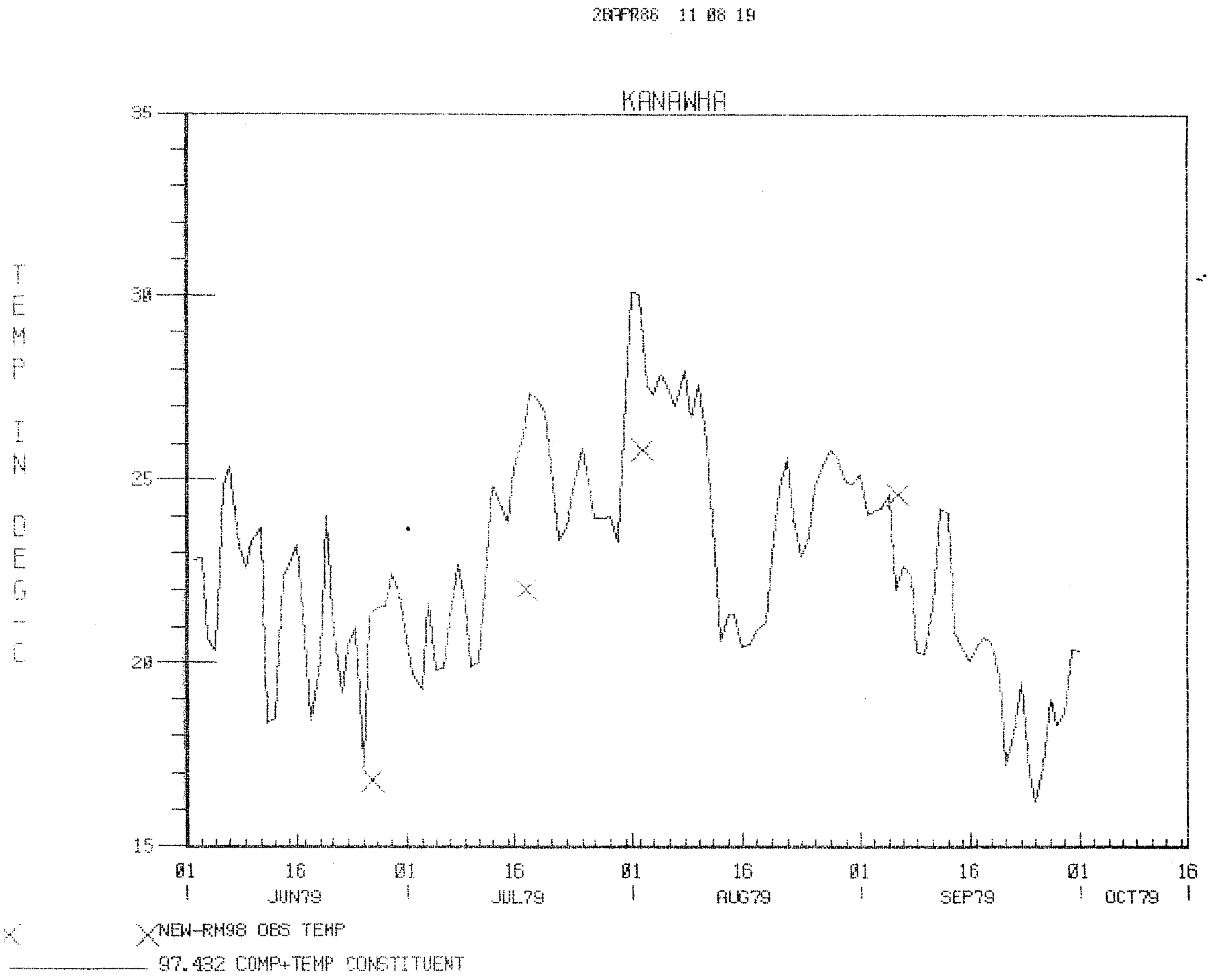

28APR86 14 00 34
KANAWHA
DO IN MG/L
10
8
6
4
01
16
JUN80
01
16
JUL80
01
16
AUG80
01
16
SEP80
01
OCT80
16
ELK-RM52 OBS DO
52.006 C68 COMP+OXYGEN CONSTITUENT

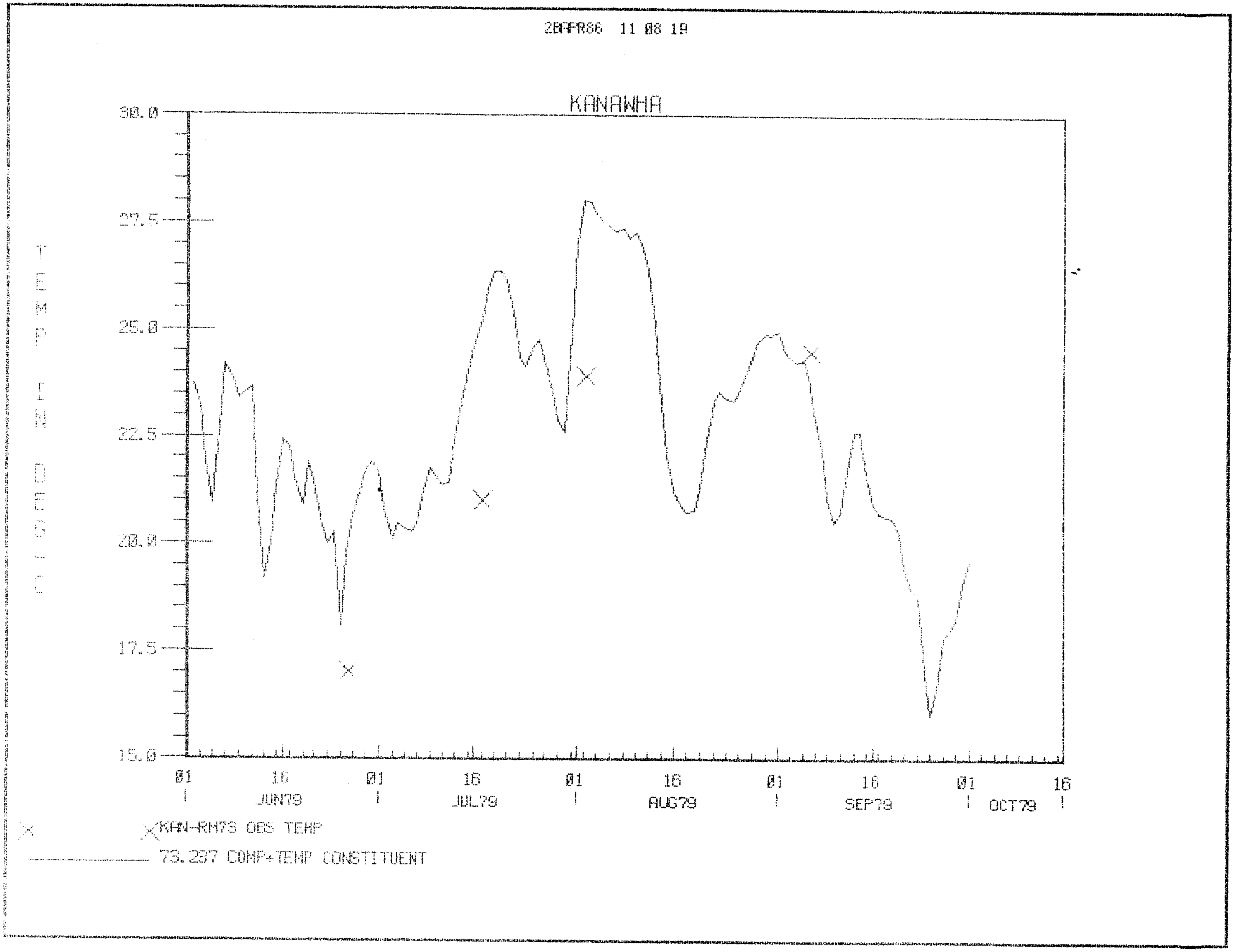

28APR86 14 00 34
KANAWHA
DO IN MG/L
10
9
8
7
6
01
16
JUN80
01
16
JUL80
01
16
AUG80
01
16
SEP80
01
16
OCT80
ELK-RM25 OBS DO
25.304 C70 COMP+OXYGEN CONSTITUENT

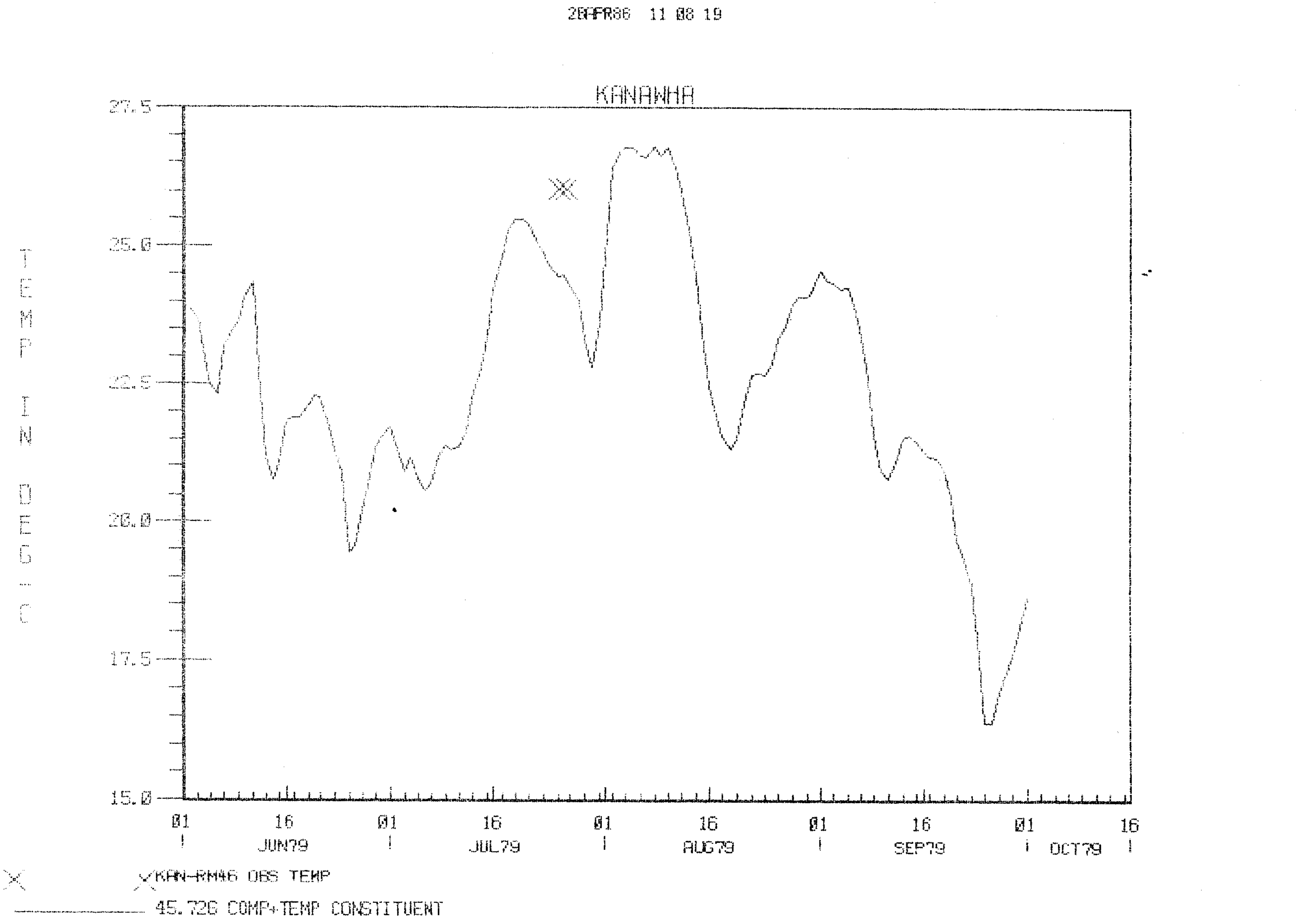

28APR86 14 00 34
KANAWHA
DO IN MG/L
10
9
8
7
6
01
16
JUN80
01
16
JUL80
01
16
AUG80
01
16
SEP80
01
OCT80
16
ELK-RM21 OBS DO
21.335 COMP+OXYGEN CONSTITUENT

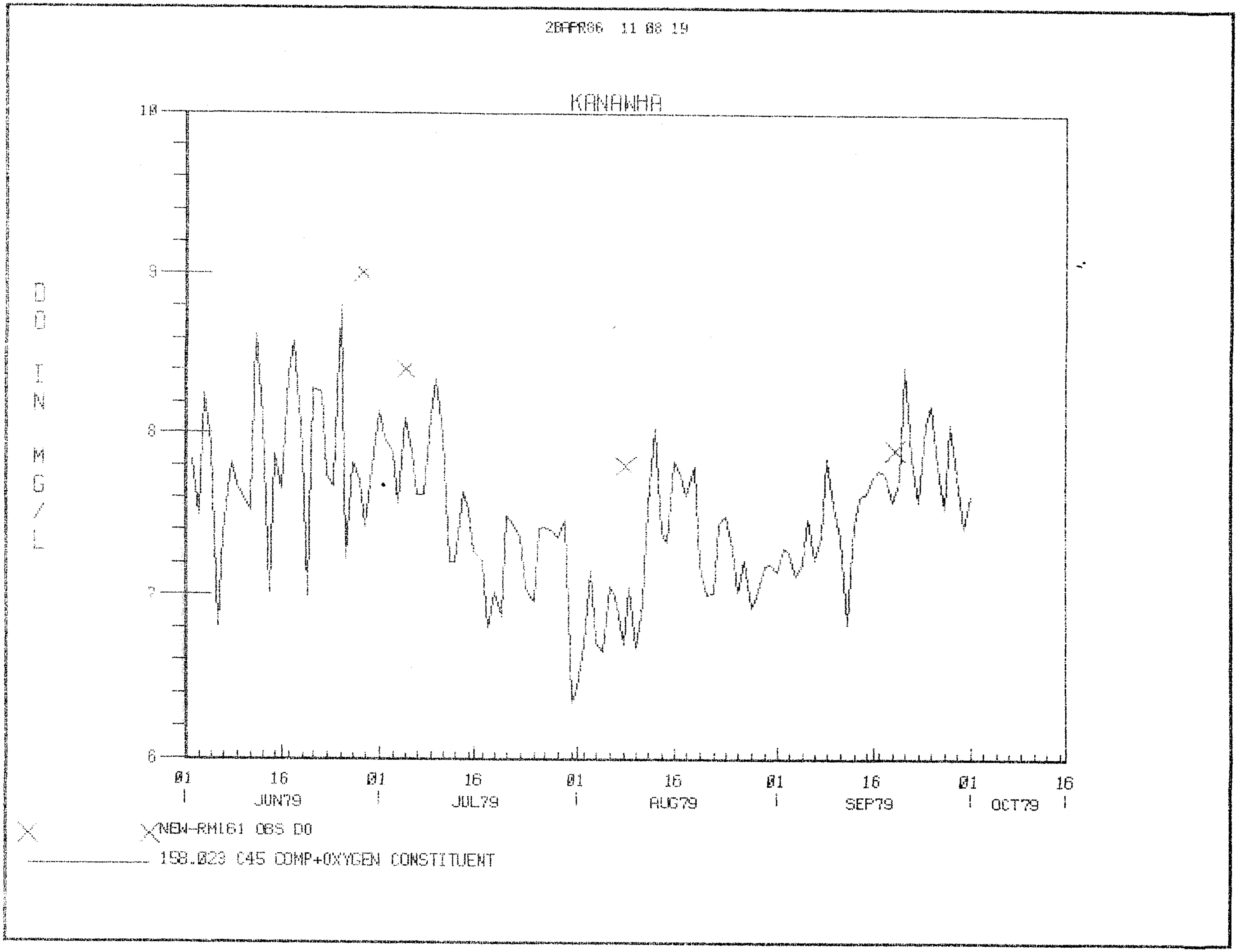

28APR86 14 00 34
KANAWHA
DO IN MG/L
10
9
8
7
6
01
16
JUN80
01
16
JUL80
01
16
AUG80
01
16
SEP80
01
OCT80
16
ELK-RM4 OBS DO
4.465 CONP+OXYGEN CONSTITUENT

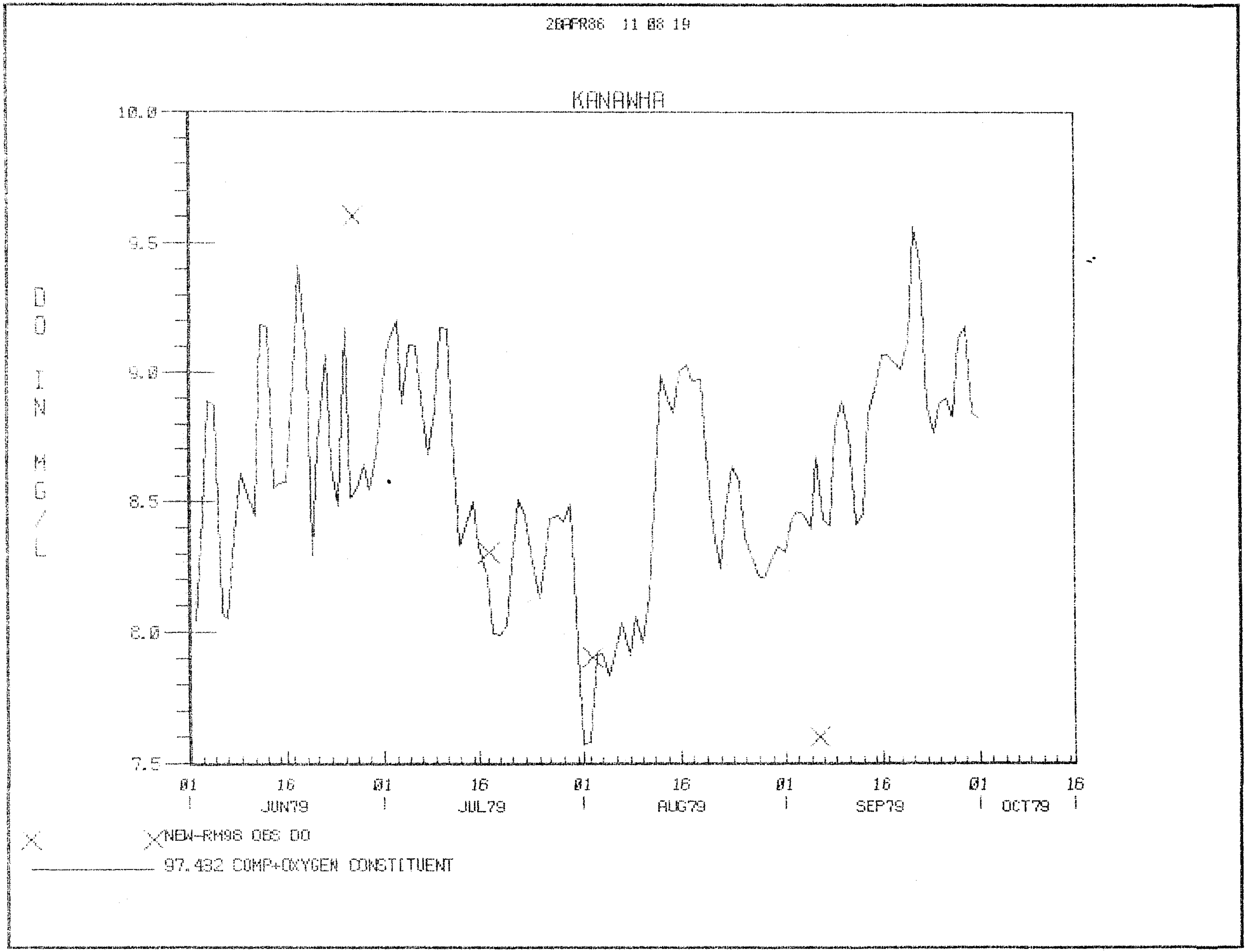

28APR86 11 08 19
KANAWHA
TEMP IN DEG-C
35
30
25
20
15
10
01
16
01
16
01
16
01
16
01
16
JUN79
JUL79
AUG79
SEP79
OCT79
NEW-RM(61 OBS TEMP
158.023 C45 COMP+TEMP CONSTITUENT

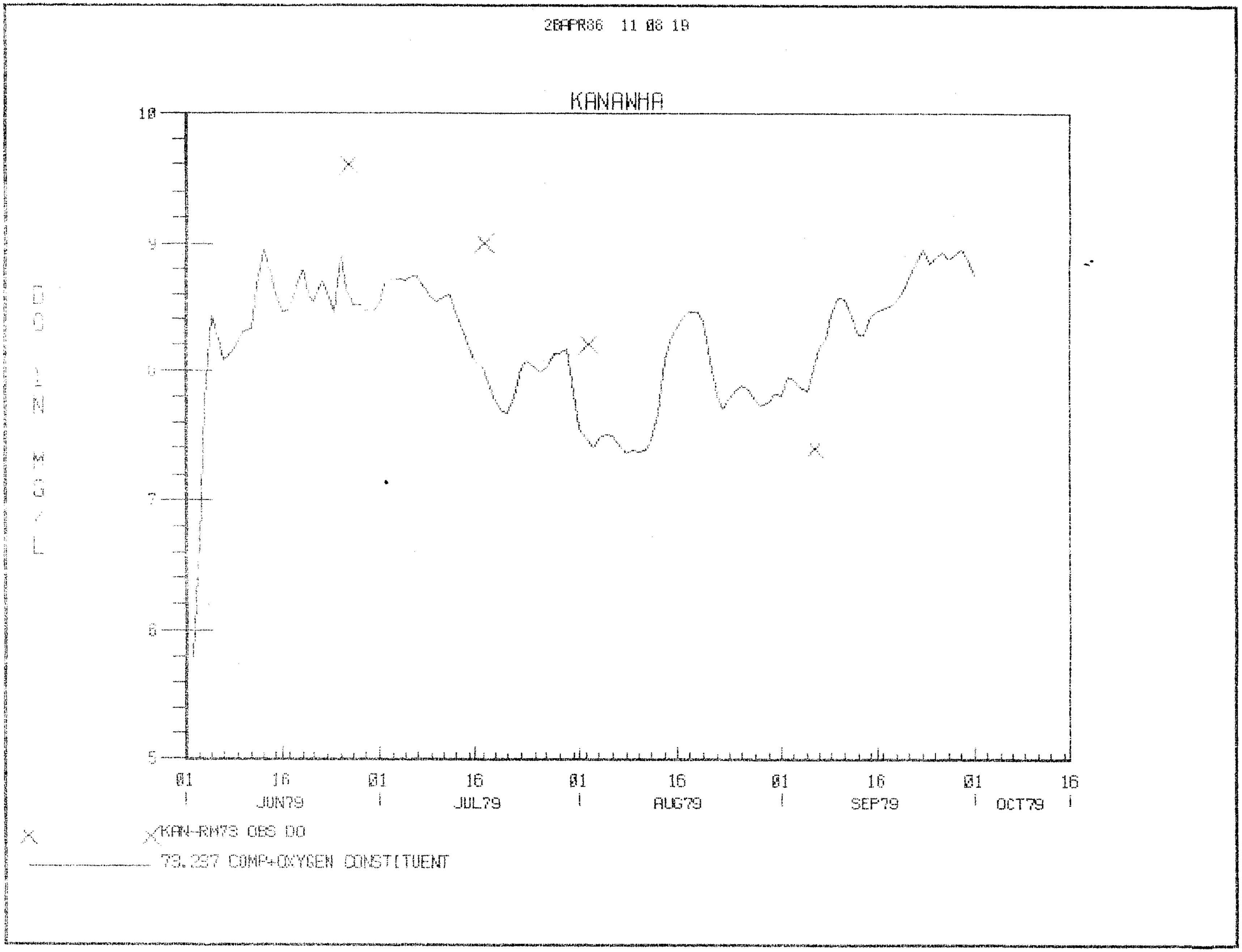

20APR86 11 08 19
KANAWHA
TEMP IN DEG-C
35
30
25
20
15
01
16
JUN79
01
16
JUL79
01
16
AUG79
01
16
SEP79
01
OCT79
16
NEW-RM98 OBS TEMP
97.432 COMP+TEMP CONSTITUENT

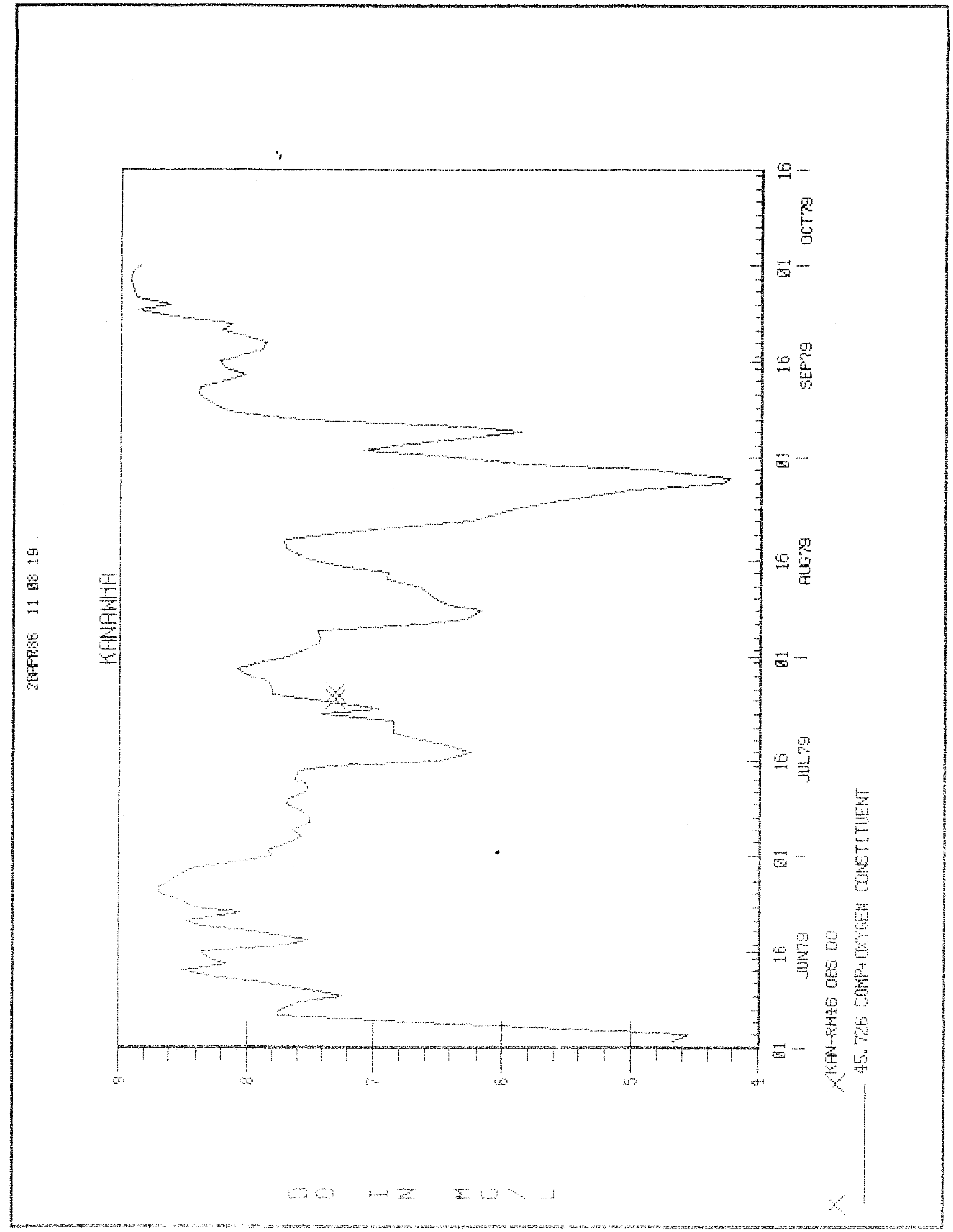

20APR86 11 08 19
KANAWHA
TEMP IN DEG C
30.0
27.5
25.0
22.5
20.0
17.5
15.0
01
16
JUN79
01
16
JUL79
01
16
AUG79
01
16
SEP79
01
OCT79
16
KAN-RM73 OBS TEMP
73.237 COMP+TEMP CONSTITUENT


20APR86 11 08 19
KANAWHA
TEMP IN DEG C
27.5
25.0
22.5
20.0
17.5
15.0
01
16
JUN79
01
16
JUL79
01
16
AUG79
01
16
SEP79
01
OCT79
16
KAN-RM46 OBS TEMP
45.726 COMP-TEMP CONSTITUENT


28APR86 11 08 19
KANAWHA
DO IN MG/L
10
9
8
7
6
01
16
JUN79
01
16
JUL79
01
16
AUG79
01
16
SEP79
01
OCT79
16
NEW-RM161 OBS DO
158.023 C45 COMP+OXYGEN CONSTITUENT


28APR86 11 08 19
KANAWHA
DO IN MG/L
10.0
9.5
9.0
8.5
8.0
7.5
01
16
JUN79
01
16
JUL79
01
16
AUG79
01
16
SEP79
01
OCT79
16
NEW-RM98 OBS DO
97.482 COMP+OXYGEN CONSTITUENT


28APR86 11 08 19
KANAWHA
DO IN MG/L
10
9
8
7
6
5
01
16
JUN79
01
16
JUL79
01
16
AUG79
01
16
SEP79
01
OCT79
16
KAN-RM73 OBS DO
73.297 COMP+OXYGEN CONSTITUENT


20FEB86 11 08 19
KANAWHA
DO IN MG/L
9
8
7
6
5
4
01
16
JUN79
01
16
JUL79
01
16
AUG79
01
16
SEP79
01
OCT79
16
X KAN-RM46 OBS DO
45.726 COMP-OXYGEN CONSTITUENT

APPENDIX D

UTILITY PROGRAM PROCEDURES

APPENDIX D

Utility Program Procedures

GEDA EXECUTION PROCEDURE

1. Obtain HEC-2 type cross-sectional data files either from past studies or if in graphical form convert to a magnetic file using a utility program and a graphics tablet (available from HEC but is currently not in a generalized, documented form).

2. Prepare input file as shown in GEDA Users Manual [HEC, 1981]. The bulk of the input file will be the HEC-2 type cross-sectional data but be careful to edit the HEC-2 data card types, according to the guidance in the GEDA manual.

3. To execute GEDA, type:

```
GEDAX INPUT=filename.IN OUTPUT=filename.OUT PUNCH=filename.PU
   (Note: if necessary for space use $MO  PS=500)
```

4. The "filename.PU" from GEDA needs some editing before it is ready to merge with HEC-5Q input. The following steps must be performed:

(a) change the record identification from A3 to S3 in columns 1 and 2.

(b) The second field of numbers should be deleted.

(c) The first field of numbers should be changed to river mile identification if the HEC-2 type input used identification not related to river mile. This step can be accomplished easily by a utility program. The first section number should be the most upstream cross-section river mile. Each cross-section river mile thereafter should be reduced by the element length (or the reach length divided by the number of elements in the GEDA run). The last cross-section number should be exactly the river mile of the downstream end of the reach.

(d) Control point numbers should be inserted into field 1, making the cross-section numbers move to field 2, etc. Each cross-section will have either its own control point number or the number of the next downstream control point on the first record of each section.

(e) If stage control (i.e., use of a rating curve) in HEC-5Q is important at any given cross-section, field 8 of the S3 record should contain the flow rate corresponding to the elevation in field 3. If this field is blank, normal depth is assumed unless a flat surface projected upstream from a downstream section using stage control provides a larger depth.

5. All of the tasks in Step 4 can be easily accomplished by use of a utility routine (available from HEC but is currently not in a generalized, documented form).

WEATHER EXECUTION PROCEDURE

1. Physically load magnetic tape onto mainframe tape drive.

2. Type on terminal:

```
RS 14=TAPE  WAIT
BLOCK
TAPE TO DISK
Account Number*filename.IN  80  80  12
(Wait for delay while tape is being read)
$EOF
FR 14
```

3. "Filename.IN" now contains all the years of data that were on the original magnetic tape. Edit "filename.IN" to include only those years of interest (this step is optional to save computer time). Add a header record as shown in the WEATHER Users Manual [HEC, 1986].

4. To execute WEATHER, type:

```
*SAUF77.W WEATHR
$VU.BR WEATH, PR PX OW OD
LIB HECN*HECLIB  *LIBERY
BEGIN
WEATH INPUT=filename.IN OUTFILE=filename.OUT
```

5. Proceed to HEATX procedure with "filename.OUT".

HEATX EXECUTION PROCEDURE

1. Prepare input file as shown in "Thermal Simulation of Lakes" Users Manual [U.S. Army, 1977].

"Filename.OUT" from WEATHER provides card types 8-11 in the proper format. Edit "filename.OUT" to include card types 1-7. Rename file "filename.IN".

2. To execute HEATX, type:

```
HEATX INPUT=filename.IN OUTPUT=filename.OUT PUNCH=filename.PU
```

3. The punch file is input to HEC-5Q. Merge "filename.PU" into the HEC-5Q input file.