LAND APPLICATION OF SEWAGE EFFLUENT FOR MISSOURI WATER RESOURCES CONSERVATION AND POLLUTION CONTROL

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ABSTRACT

The overall objectives of this study are twofold: 1) to domonstrate the viability and effectiveness of land treatment system to renovate lagoon effluent quality in Missouri and elsewhere in the Midwest; and 2) to conduct a comprehensive and systematic study to develop pertinent design and operating parameters that can be successfully used by other communities in the region.

The report described herein represents the results that is necessary before further development can be initiated. These results are: 1) community background survey; 2) current and proposed waste management methods; and 3) existing surface and subsurface water qualities at application site. Emphasis of the discussion is placed on the technical data which have a direct bearing on the future evaluation of the water quality improvement as a result of land application.

I. INTRODUCTION

A lagoon waste treatment system is currently being used by the city of Cabool, Missouri. Its effluent is discharged into the Big Piney River. Although lagoons are commonly used by Missouri rural communities for sewage treatment, their effluents are normally not of sufficiently high quality to meet either Federal or State standards. The one in Cabool is no exception. Its effluent, due to high concentrations of suspended solids and other pollutants, has caused a considerable degradation of water quality in the Big Piney River, which serves as a source of water supply for many communities downstream. Therefore, there is an urgent need to solve this lagoon pollution problem.

It happens to be that next to the lagoon, there are 42 acres of alluvial soils along the Big Piney River. It appears that this soil can serve as a natural filter to purify the lagoon effluent. It has been estimated that about 10 ft. of the lagoon effluent can be applied to this alluvial land annually. Becuase of this unique situation, a research project was initiated in June, 1983 to sutdy such a land treatment system. The study was carried out by a research team at the University of Missouri-Rolla, and it was supported by the U. S. Department of the Interior, U. S. Geological Survey.

At the conception of this study, it has been recognized that a successful land treatment project requires detail planning and design of the treatment and applicaton facilities, in-depth assessment of the backgrond data of the application site, proper establishment of liquid application rates, and subsequent monitorings of the fate of pollutants applied to land areas.

Therefore, the entire Cabool land treatment project should be divided into the following four phases.

Phase I: Evaluation of the Background Data of the Application Site and the Big Piney River Prior to Land Application.

Phase II Evaluation of Pollutant Attenuation from Lagoon Effluent by Soil Percolation.

Phase III: Year-Round Assessment of the Cabool Sewage Lagoon Performance with Respect to the Removal of All Major Types of Pollutants Which are of Concern to Typical Land Application Projects.

Phase IV: Systematic Field Monitoring of the Land Treatment Performance During the Application Period.

II. OBJECTIVE AND SCOPE

The overall objectives of the Cabool land treatment project are twofold:

1. Demonstrate the viability and effectiveness of land treatment systems to renovate lagoon quality in Missouri and elsewhere in the Midwest.
2. Conduct a comprehensive and systematic study to develop pertinent design and operating parameters that can be successfully used by other communities in the region.

The specific objective of the Phase I study was to evaluate the background data of the application site and the Big Piney River, which is the receiving stream of the current lagoon effluent discharge. This information will provide a data base for future decision of the effluent application rate as well as for evaluations of the future water quality improvement as a result of land application.

The scope of this phase included the following work:

1. Community Background Survey
2. Current and Proposed Waste Management Methods
3. Surface and Subsurface Water Qualities At the Application Site

The research findings for each of the above items are described in detail in individual chapters. Emphasis of the discussion is placed on the technical data which have a direct bearing on the future evaluation of the water quality improvement as a result of land application.

III. COMMUNITY BACKGROUND SURVEY

A. Location

Cabool is a fourth class city located in the southwest part of Texas County at the intersections of several Federal and State Highways, including U.S. 60 and 63 and State Highways 181, AD, M and PP. Located 65 miles east of Springfield and 175 miles southwest of St. Louis, Cabool is approximately in the center of the Ozarks region. The city is served by a small airport and a Burlington Northern Railroad line which runs from Springfield, Missouri to Memphis, Tennessee.

B. Population

The city has experienced a steady population growth as evidenced by the 1970 and 1980 census populations of 1,848 and 2,090, respectively. The disaggregated population projections for Texas County and the immediate area indicate that the population will grow approximately 21% from 1980 to the year 2000. A higher population growth rate has been predicted by Russell and Axon, which projects a population of 3,594 in the year of 2000.

C. Land-Use and Drainage

The general land uses in Cabool include residential, commercial, industrial, public and semi-public. Commercial uses are mainly in the central business district and along Business Highway 60. Industry is located south of the railroad tracks and north of the central business district surrounded by residential use. The school complex is in the center of town.

Cabool lies on the southern edge of the Gasconade drainage district which flows northward. Highway 60 generally follows the ridge which divides major drainage districts across the South Central Ozark Region. All drainage of the developed area in Cabool flows into the Piney River south and east of the town. North of the developed area, the natural drainage flows northward before entering the Piney at a point northeast of Cabool.

E. Meteorology and Hydrology

Cabool lies in the Humid Continental warm summer climate classification (Thornthwaite) and near the Humid Subtropic to the south. Warm air from the south frequently meets cold air from the north creating cyclonic storms. The winters are cold and the summers are hot. However, by being near the boundary of the two climate classifications, the summers are not as hot as those to the south nor are the winters as severe as those to the north.

The greatest precipitation occurs during the spring and summer months, and less occurs during fall and winter, with winter precipitation being mostly snow and ice. The annual average precipitation is about 42 inches. Winds prevail from the west. They are seasonal and the greatest velocities occur in spring.

A summary of climatological data which are obtained from the nearest weather station located in Mountain Grove, Missouri are tabulated in Table 1.

F. Water Supply

The city's water supply comes from five deep aquifer wells which are owned and operated by the city. The water is of such a high quality that except for fluoridation, no treatment is required.

G. Surface Water

The surface water in the area consists of rivers and streams along with man-made ponds and lakes. Due to the topography and large amounts of rainfall, there are an abundance of these. The rivers and streams serve to drain surface runoff from rainfall. The ponds serve as water supply for farm animals and minor irrigation. Lakes are for flood control and all surface water classifications serve as recreation facilities.

Table 1. Temperature and Precipitation for Cabool as Obtained at Mountain Grove 2N Station (1971-1981)

Month	Temperature (^oC) Max.	Avg.	min.	Precipitation (in.) Snow	Rain
January	40.7	31.2	21.7	1.95	4.88
February	46.1	35.3	25.1	1.87	4.52
March	58.1	47.0	35.8	4.58	2.34
April	68.9	57.3	45.7	4.61	1.10
May	75.0	64.0	53.0	4.21	0.00
June	83.1	72.2	61.3	4.39	0.00
July	89.3	78.1	66.9	4.11	0.00
August	87.7	76.0	64.4	3.42	0.00
September	80.0	69.1	58.0	3.70	0.00
October	70.2	58.2	46.1	3.42	0.00
November	54.8	45.3	35.6	4.09	3.51
December	40.07	31.2	21.7	1.95	4.88

The Piney River is the main body of surface water in Cabool. It is a valuable natural resource which is being used for recreational purposes for Cabool and also serves as a source of water supply for other communities downstream.

IV. CURRENT AND PROPOSED WASTE MANAGEMENT METHODS

A. Existing Waste Disposal System

A considerable amount of sewer extensions and interceptor construction has taken place in the last several years in the City of Cabool. Currently there are very few, if any, residents who are not served by a sanitary sewer system. The city owns and operates two lift stations and an aerated lagoon with two submerged sand filters as a polishing device. The existing treatment system was completed in 1976 by modifying a group of single celled lagoons.

The existing waste treatment scheme consists of influent pumping, comminution, flow measurement, aerated lagoon and submerged sand filters. The system was designed for a flow of 370,000 gpd. The dual submerged sand filters have a total surface area of 1.7 acres (or 0.85 acres each) with a permissible loading rate of 5 gpd/ft^2. The flow rate was based upon a population projection of 2,300 for the year 1993 plus 140,000 gpd from a dairy industrial source. However, the present existing flows have already approached 1.1 MGD, or three times the original design flow. It is estimated that up to 900,000 gpd are being contributed by the dairy industry.

In addition to the problem of excess hydraulic loading, the submerged sand filters have also been found to be inadequate and non-effective in polishing the lagoon effluent. It has been estimated that, to make the submerged sand filters effective, the maximum rate should not exceed 1 gpd/ft^2. This means that the existing filters need to be expanded five times to provide a total surface of 8.5 acres. Besides all these problems, the submerged sand filters have a tendence of depleting dissolved oxygen in the lagoon effluent, thereby making the effluent unable to meet the DO and ammonia limitations. Presently the BOD load from the dairy industry has accounted for more than one half of the total plant BOD. However, the dairy industry has just completed a new pretreatment facility and once this is placed in service, the effluent characteristics should be similar to those of domestic sewage in terms of BOD and suspended solids concentrations.

B. Proposed New Waste Management System

Plans have been made to modify the existing waste disposal method so that water qualities in the Big Piney River can be significantly improved. It has been proposed to irrigate 400,000 gpd lagoon effluent (which is based on a population of 2,550 at year 2000 plus 140,000 gpd from the dairy industrial source) on a 42-acre alluvial plain. The dairy industry has committed itself to reduce its flow to no more than 140,000 gpd in the near future.

The lagoon effluent will be taken from an existing holding cell and applied at a rate of 10.67 ft/yr on the 42-acre site, which will be divided into multi-cell units. The method of application will be by flooding each individual basin with 3 inches of water each week. The elevation of the existing lagoon is high enough to allow irrigation to be accomplished by gravity flow. A forage crop will be grown and harvested several times each year. This application rate is tentatively set following consultation with the USDA Soil Conservation Service and also utilization of the design procedures outlined in an EPA publication of "Process Design Manual--Land Treatment of Municipal Wastewater." However, the exact future application rates will be decided based on the findings of this project. In order to maximize the performance of the existing lagoon system, more aerators will be provided in the first cell, and the final holding cells will also be expanded to provide a minimum of 65 days storage. The capacity of the influent pump station will be increased to 2.0 MGD.

C. Effluent Limitations

The existing lagoon effluent discharge is into the headwater of the Big Piney River. At the discharge point, the Big Piney has a total drainage area of approximately 12 square miles. It is at this point that the stream is considered permanently flowing. The current water uses of the Big Piney include agricultural, wildlife watering, canoeing, fishing and wholebody contact. Fourteen miles downstream of the discharge point, there is a public access area owned and operated by the Missouri Department of Conservation. One mile further down, there is a summer camp for children. The existing discharge permit has the following effluent limitations: 20 mg/l for BOD_5; 20 mg/l for TSS; 12 mg/l for total Kjeldahl nitrogen (TKN); and 200 counts/ 100 ml for fecal coliforms.

D. Geology

The bedrock which underlies the Cabool area consists of thick carbonate rocks (dolomite and limestone), representing several geologic formations. The soil overburden has a mixture of chert, gravel, and sandstone boulders. The soil has developed as residuum from chemical weathering of the carbonate bedrock.

Weathering of the thick carbonate formations is attested by the prominence of pinnacles, caves, springs, and isolated, massive bedrock bluff projections through a mantle of soil. Dry stream valleys and streams with low flow also characterize the area. Loss of all or part of the flow of many surface streams have been found, which often results in groundwater pollution.

Weathering processes have formed a variety of soil types, ranging from very stoney soils to soils with a predominant clay texture. An unusual red, nearly pure clay soil is found to be abundant in this area and it has a permeability as high as the more stoney soil types. A less abundant, but more typical-behaving clay soil is also found, which usually has a lower clay content and lower permeability.

Karst terrains are a very important special case of carbonate bedrock areas. Karst topography normally occupies upland areas of low relief, which generally lack well-defined surface streams. The sinkholes act as natural funnels for surface drainage. A well-developed karst topography indicates integrated underground drainage. Surface water from rainfall, sewage treatment plants, lagoons, septic tanks and landfill drainage could be funneled into underground karst area and then resurge in springs at a lower level or become a part of the groundwater supply. Sinkholes and regions of high internal drainage are widespread across southern and central Missouri. The Cabool area is a part of this karst region.

V. SURFACE AND SUBSURFACE WATER QUALITIES

The major reason for pursuing land treatment operation at Cabool is to improve water quality in the Big Piney River. In order to evaluate the impact of land treatment on the water qualities, it is necessary to establish the existing database. During the period from August 1983 through June 1984 an intensive water quality survey was conducted on a monthly basis at various stations along the Big Piney River near Cabool area. In addition, three groundwater stations were also set up and their water qualities were monitored periodically.

In the water quality survey, sample collections were made on a monthly basis to establish the seasonal variation. Some samples were taken after a significant rainfall so that the effect of storm runoff on the water quality can be assessed.

A. Sampling Stations for Surface Water

Eight sampling stations along the Big Piney River were established for this study. Four of them are located above the lagoon discharge point while the other four are located below so that the impact of the lagoon effluent discharge on the Big Piney River can be evaluated before and after land treatment. These sampling stations are shown in Figure 1, and their exact locations are described below:

* Station 1 - It is located above the first cell of the entire lagoon system. At the collection point, it is a big shallow impoundment, which is the head water of the Big Piney River.
* Station 2 - It is located 100 feet below Station 1. At the sampling point, the channel is very narrow, only about 4 ft wide.
* Station 3 - It is located about 0.2 mile downstream from Station 2.

* Station 4 - It is located 10 feet below the discharge of the lagoon seepage, or approximately 400 feet above the lagoon outfall.
* Station 5 - It is located right under the Highway 63 bridge, or approximately 300 feet downstream from the lagoon outfall.
* Station 6 - It is located approximately 1,300 feet downstream from the lagoon effluent discharge.
* Station 7 - It is located below a low water bridge near Cabool airport, or approximately 0.6 mile downstream from the lagoon outfall.
* Station 8 - It is located between Highway 63 and the railroad bridge, or about 1.8 miles downstream from the lagoon outfall.

B. Sampling Stations for Groundwater

In addition to the eight sampling stations along the Big Piney River, three groundwater sampling wells were also constructed at the proposed application site (Figure 1). These wells, identified as G-1, G-2, and G-3, were used to monitor the water quality as well as groundwater level fluctuations. Besides, seven more test pits were also used for groundwater observation. These pits (Figure 1) were constructed to measure the soil profile and other hydraulic parameters which will be evaluated in the future phases of study.

C. Water Quality Parameters and Methods

The water quality parameters which were evaluated in this study included pH, temperature, dissolved oxygen (DO), total suspended solids (TSS), chemical oxygen demand (COD), soluble chemical oxygen demand (SCOD), coliform concentrations (MPN/100ml), ammonia nitrogen (NH_3-N), total Kjeldahl nitrogen (TKN), and phosphorus (ortho-P and total-P). Other aspects of water quality such as color, odor were also observed from time to time. In addition, several

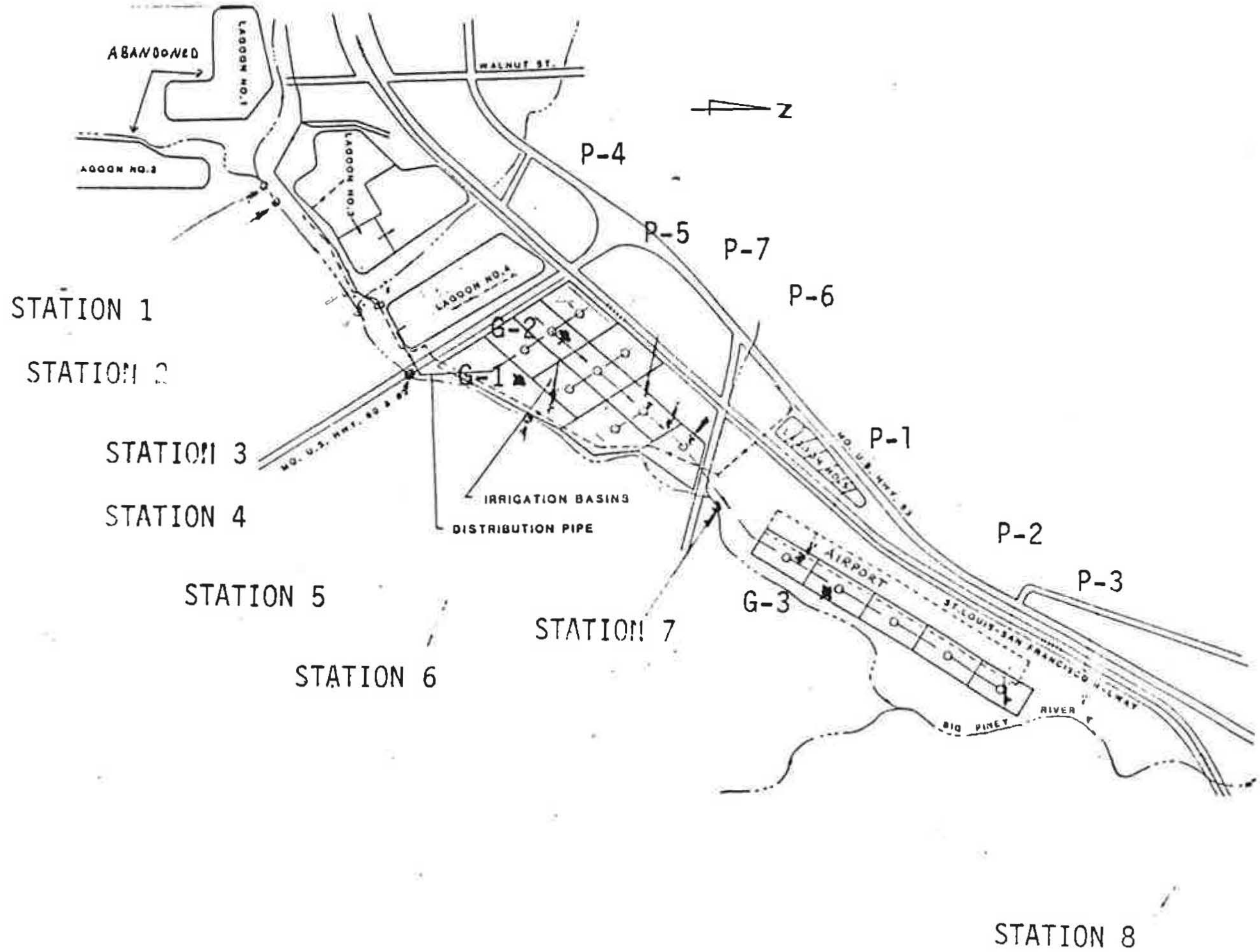

Figure 1. Locations of Surface and Subsurface Water Quality Sampling Stations

hydrological parameters such as flow rate, flow velocity, water depth and width were also measured at some selected stations. The determinations of pH, temperature, DO were made on-site while the measurement of TSS, COD, SCOD, MPN, nitrogen, and phosphorus were conducted at the Environmental Research Center, University of Missouri-Rolla. All analyses were made according to the procedures set forth in the Standard Methods.

D. Results and Discussion

D.1. Station 1:

The water quality data at Station 1 are listed in Table 2. The sampling location is a big shallow impoundment. During dry months, the channel width is about 20 ft and the average depth is 3 ft. There is a sluggish flow movement in the middle of the stream. About one third of water surface in the impoundment is covered with algal mats, which is probably caused by the nutrient enrichment from the fallen plant debris along one side of the river bank. There are many fish found in the water. The water temperature is up to 27^{o} C in the summer, but dropped to 10^{o} C in March. The DO concentration is high all year around (7.9 to 15 mg/l). The high DO concentration is mainly caused by the algal growth. The pH varies from 7.6 to 8.2. The variations of SS and COD with respect to time are illustrated in Figure 2. In general, the SS concentration stays around 10 mg/l while the COD level varies from 0 to 37 mg/l, with an average of about 15 mg/l. The high COD in August and September may be caused by the death of algae. One MPN analysis was made on October 21, 1983, which yielded a relatively high MPN index of 21,000/100 ml. Both the phosphorus and nitrogen concentrations are low at Station 1, indicating that there exists no man-made pollution at this point of the stream.

Table 2. Water Quality Data -- Station 1

Date	Temp (°C)	Flow (cfs)	DO (mg/l)	pH	TSS (mg/l)	COD (mg/l)	SCOD (mg/l)	BOD_5 (mg/l)	MPN (1000/100ml)	Ortho-P (mg/l)	Total-P (mg/l)	NH_3-N (mg/l)	TKN (mg/l)
8/7/83	-	-	-	-	-	-	-	-	-	-	-	-	-
8/23/83	27	-	8.6	8.2	6	30	27	-	-	-	-	-	-
9/7/83	24.5	-	8.2	8.2	17	37	28	-	-	-	-	-	-
9/21/83	15	-	11.8	8.2	8	0	0	-	-	-	-	-	-
10/21/83	-	-	-	8.0	8	13	6	-	21	-	-	-	-
1/24/84	-	-	-	-	-	-	-	-	-	-	-	-	-
3/15/84	10	-	8.5	7.6	14	24	-	-	-	0	0.04	0	0.2
4/19/84	17	-	15	8.0	2	8	-	-	-	0.02	0.31	0	1.3
5/15/84	13	-	7.9	7.7	8	20	-	-	-	-	-	-	-

Table 3. Water Quality Data -- Station 2

Date	Temp (°C)	Flow (cfs)	DO (mg/l)	pH	TSS (mg/l)	COD (mg/l)	SCOD (mg/l)	BOD_5 (mg/l)	MPN (1000/100ml)	Ortho-P (mg/l)	Total-P (mg/l)	NH_3-N (mg/l)	TKN (mg/l)
8/7/83	26	-	12.6	7.7	8	15	0	-	-	-	-	-	-
8/23/83	23	1.0	5.1	7.7	5	10	9	-	-	-	-	-	-
9/7/83	23	8.4	6.2	7.7	17	9	9	-	-	-	-	-	-
9/21/83	16.5	1.0	5.7	7.7	4	0	0	-	-	-	-	-	-
10/21/83	-	12.3	-	-	-	-	-	-	-	-	-	-	-
1/24/84	4	3.0	11.7	7.5	2	16	-	10	0	-	-	-	-
3/15/84	10	11.2	8.6	7.5	6	12	-	-	-	-	-	-	-
4/19/84	15	15.0	10.4	7.9	8	11	-	-	-	0.03	0.09	0	0.1
5/15/84	13	7.5	4.8	7.0	14	12	-	-	-	0.01	0.04	0	0.2

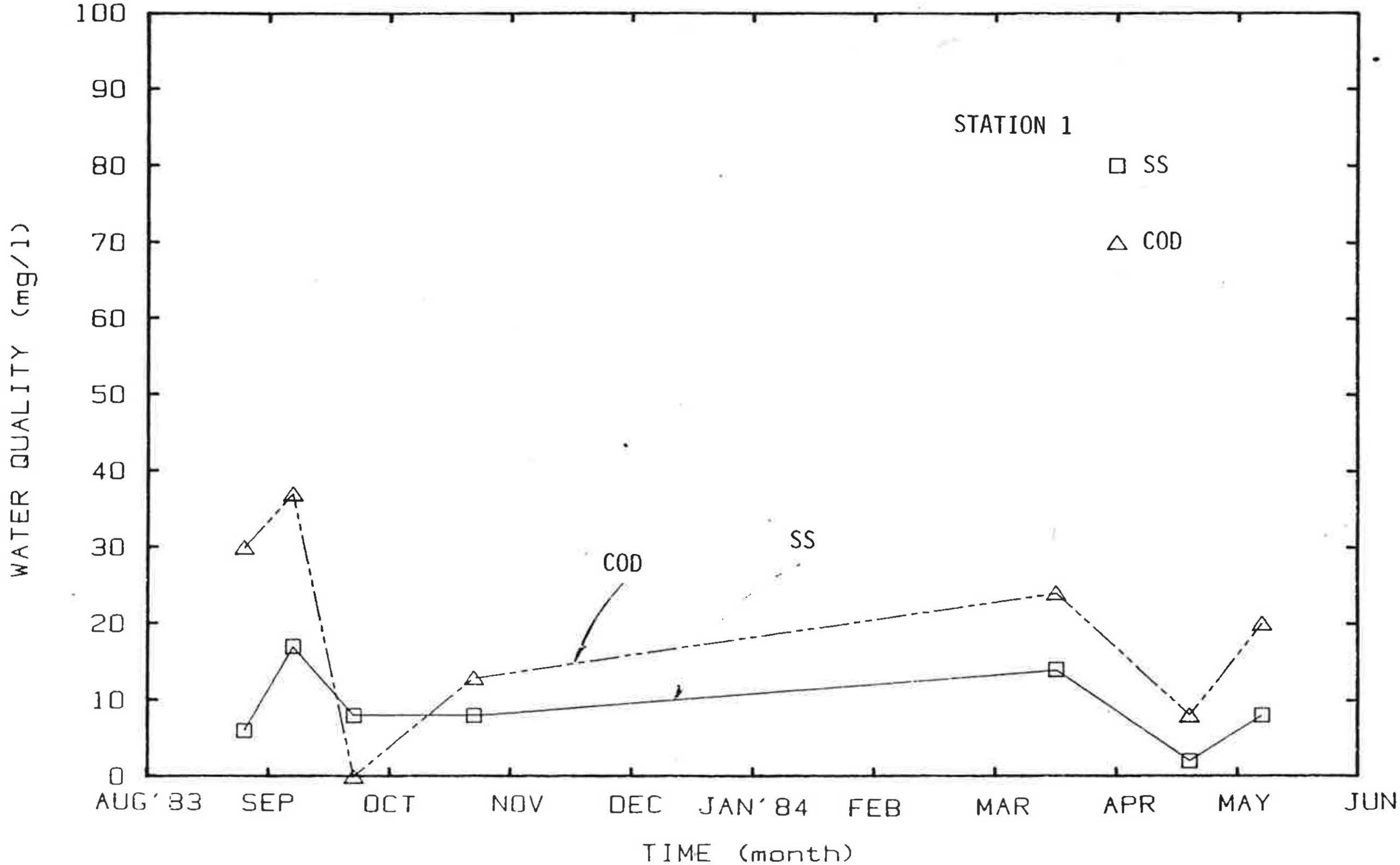

FIGURE 2. WATER QUALITY DATA FOR STATION 1

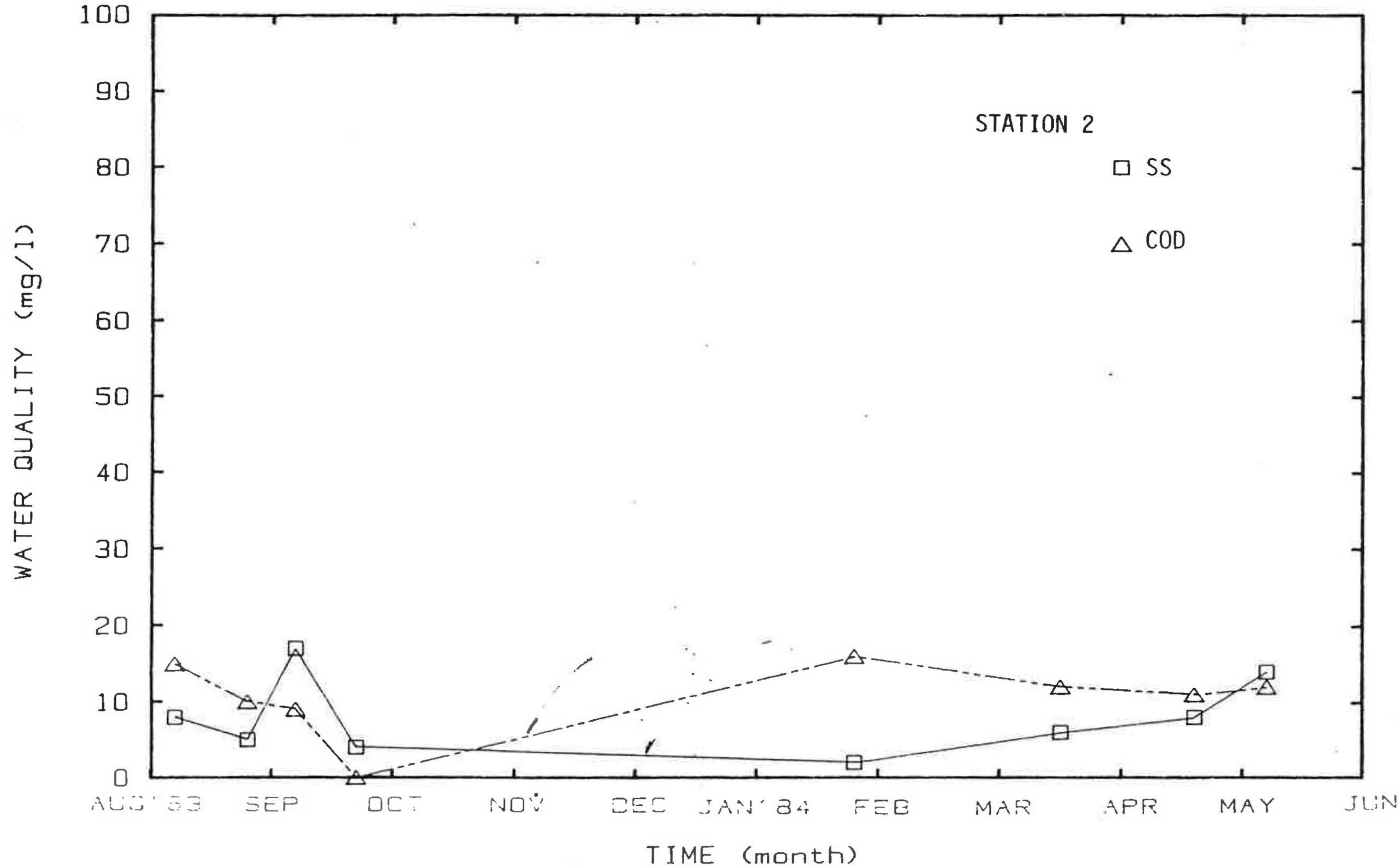

FIGURE 3. WATER QUALITY DATA FOR STATION 2

D.2. Station 2:

The water quality data for Station 2 are listed in Table 3. At this station, the stream channel is narrow, with a width between 4 and 6 ft. The water depth is under 1 ft. The flow rate during dry months is only about 1 cfs, but may go much higher after a significant rainfall. For example, the wet Spring of 1984 was able to increase the flow rate to 15.0 cfs. The water at this location is normally clear and the bottom rocks are clearly visible without algal growth. There are numerous minnows present in the water. The DO varies from 4.8 to 12.6 mg/l. All of these indicate that the stream water is not polluted at this point. The water temperature varies from 4 to 26^{0} C while the pH value is between 7.0 and 7.9. As shown in Figure 3, both the SS and COD concentrations are below 18 mg/l throughout the study period, which again indicates a good water quality at this station. A single measurement of both BOD and MPN was made on January 24, 1984 and the data indicated that the BOD_5 was only 10 mg/l while the MPN was zero. The phosphorus and nitrogen concentrations are also low. There is no NH_3-N detected, while the TKN varies from 0.1 to 0.2 mg/l. As for phosphorus, the ortho-P varies from 0.01 to 0.03 while the total-P varies from 0.04 to 0.09 mg/l.

D.3. Station 3:

This station is a large impoundment with a channel width of about 45 ft. and an average depth of 2.5 ft. The channel bottom is full of fine sediments and the water becomes turbid when there is a traffic crossing the river. Water moves very slowly at this point and there are also some algal mats found on the water surface. The water quality data are listed in Table 4.

The water temperature varies from 27^{0} C in August to 4.0^{0} C in January. The DO concentration is high throughout the study period, varying from 5.6

Table 4. Water Quality Data -- Station 3

Date	Temp (°C)	Flow (cfs)	DO (mg/l)	pH	TSS (mg/l)	COD (mg/l)	SCOD (mg/l)	BOD_5 (mg/l)	MPN (1000/100ml)	Ortho-P (mg/l)	Total-P (mg/l)	NH_3-N (mg/l)	TKN (mg/l)
8/7/83	27.0	-	8.5	7.7	40	47	0	-	-	-	-	-	-
8/23/83	26.0	-	6.1	7.6	42	40	36	-	-	-	-	-	-
9/7/83	24.5	-	5.6	7.5	40	37	28	-	-	-	-	-	-
9/21/83	14.0	-	10.8	7.9	6	9	9	-	-	-	-	-	-
10/21/83	-	-	-	7.5	54	6	6	-	15	-	-	-	-
1/24/84	4.0	-	12.2	7.5	4	28	16	-	-	-	-	-	-
3/15/84	10.0	-	9.2	7.7	6	12	-	-	-	0.02	0.06	0.0	0.1
4/19/84	15.0	-	13.0	8.0	8	8	-	-	-	0.02	0.08	0	0.2
5/15/84	13.0	-	7.5	7.7	16	20	-	-	-	-	-	-	-

Table 5. Water Quality Data -- Station 4

Date	Temp (°C)	Flow (cfs)	DO (mg/l)	pH	TSS (mg/l)	COD (mg/l)	SCOD (mg/l)	BOD_5 (mg/l)	MPN (1000/100ml)	Ortho-P (mg/l)	Total-P (mg/l)	NH_3-N (mg/l)	TKN (mg/l)
8/7/83	28.0	-	6.8	7.9	23	28	9	-	-	-	-	-	-
8/23/83	26.0	-	4.2	7.7	16	30	18	-	-	-	-	-	-
9/7/83	24.0	-	6.0	7.6	40	28	19	-	-	-	-	-	-
9/21/83	18.0	1.8	6.5	7.7	12	9	9	-	-	-	-	-	-
10/21/83	-	13.8	-	7.5	40	6	6	-	110	-	-	-	-
1/24/84	4.0	3.6	11.5	7.5	4	24	14	-	0.23	-	-	-	-
3/15/84	10.0	-	8.8	7.8	14	16	-	-	-	0.02	0.08	0	0.2
4/19/84	16.0	15.6	13.1	8.2	16	8	-	-	-	0.03	0.07	0	0.2
5/15/84	14.0	8.1	7.4	7.6	8	12	-	-	-	-	-	-	-

to 13.0 mg/l. The high DO concentrations are partly caused by the algal growth in the water. The pH is relatively constant, varying from 7.5 to 8.0, but the SS and COD concentrations fluctuate quite widely during the sampling period. As shown in Figure 4, the SS concentration was as high as 40 to 42 mg/l during August to early September, 1983, but dropped to only 6 mg/l in late September. After that, the SS concentration went up to 54 mg/l in late October before it dropped to much lower levels again in the first six months of 1984. The COD concentrations show a lesser degree of fluctuation, with an average value of about 20 mg/l. The extremely high SS concentration observed on October 21, 1983 was caused by a 9-inch rainfall one day prior to the sampling time.

Both phosphorus and nitrogen concentrations are low at Station 3. The total-P concentration is about 0.02 mg/l. The NH_3-N is not detectable while the TKN concentration varies from 0.1 to 0.2 mg/l. One MPN analysis was made on October 21, 1983, and the result indicated an MPN index of 15,000/100 ml. There is no explanation for such a high MPN concentration.

D.4. Station 4:

This station is located 10 ft below the inlet of the lagoon seepage water. During the dry period, the river channel at Station 4 is divided into two small streams. The channel bottom is almost completely covered with a sludge blanket. Heavy algal mats are found along the channel edges where the flow is sluggish. The color of water appears to be grayish, but there are still fishes swimming in the water. The water quality data are listed in Table 5.

The water temperature varies from 4^{o} C in January to 28^{o} C in August while the flow varies from 1.8 to 15.6 cfs. The DO concentration is also high, varying from 4.2 to 13.1 mg/l, but the pH is relatively constant, from 7.5 to 8.2. As shown in Figure 5, the SS concentration varies from

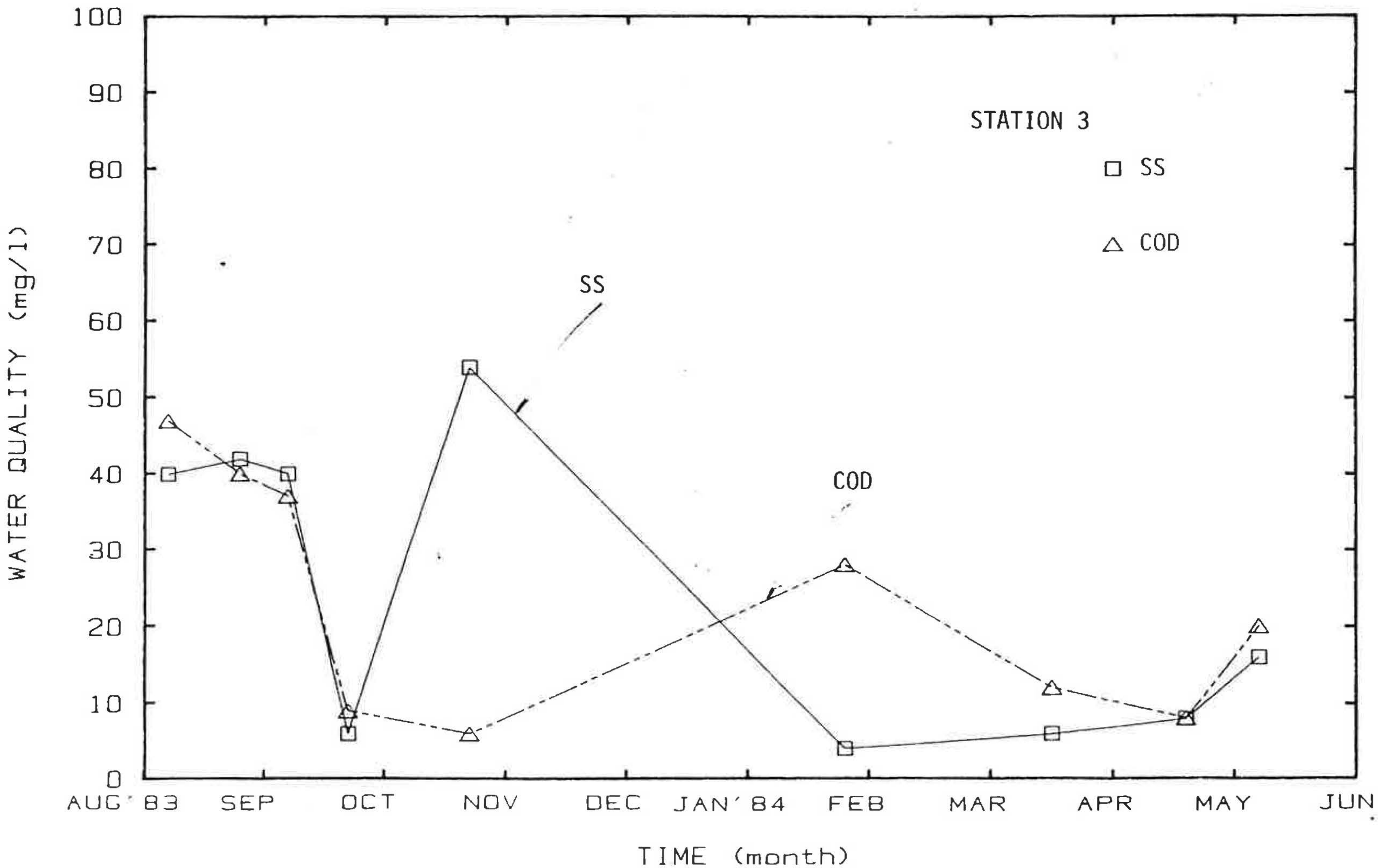

FIGURE 4. WATER QUALITY DATA FOR STATION 3

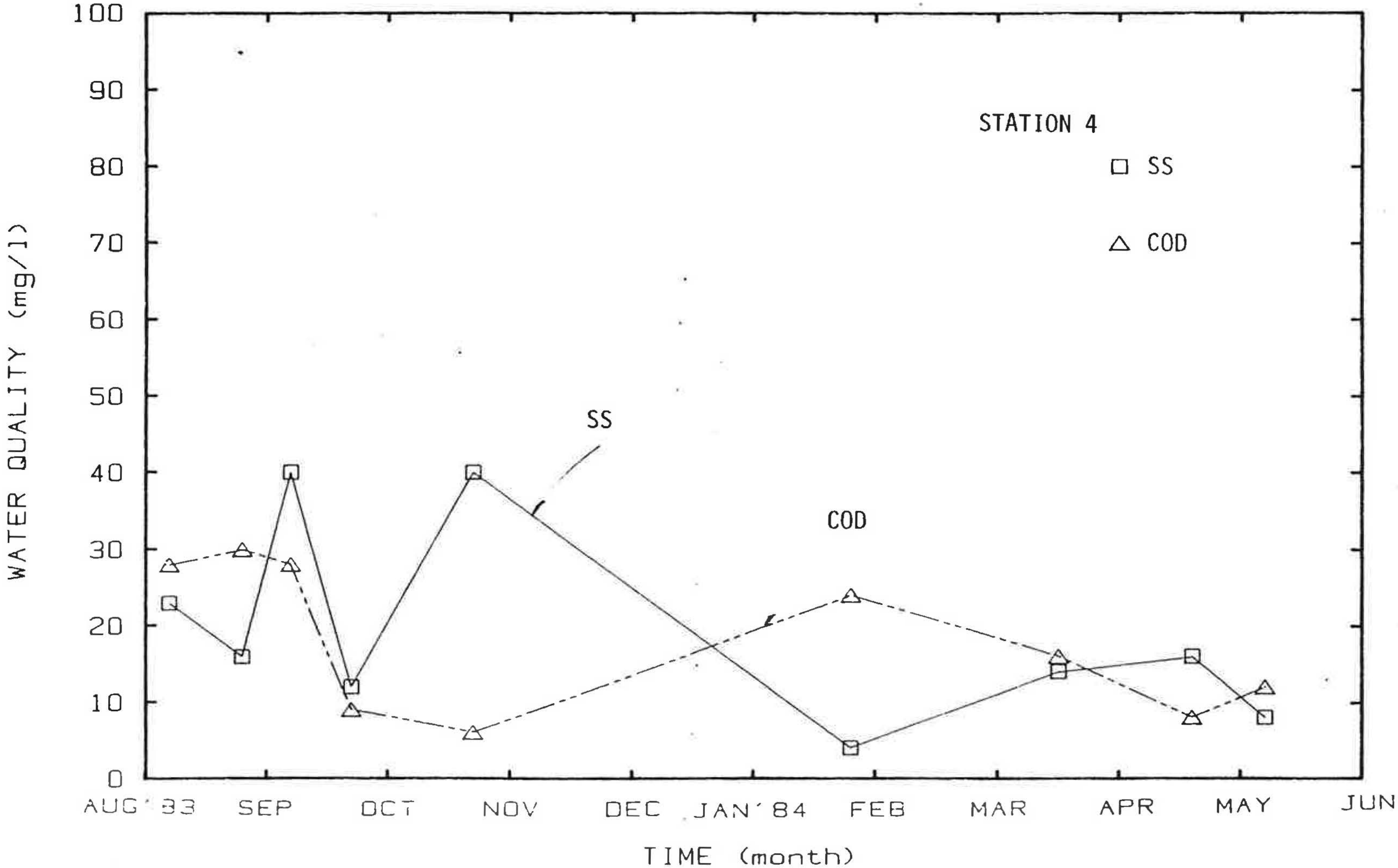

FIGURE 5. WATER QUALITY DATA FOR STATION 4

time to time over a range of 4 to 40 mg/l, while the COD value maintains within a smaller range, or from 6 to 30 mg/l. The average COD value is about 20 mg/l.

Two MPN analyses were made and the data were not consistent, from 230/100 ml on January 24, 1983, to 110,000/100 ml on October 21, 1984. The high MPN observed in October of 1983 was probably caused by the 9-inch rainfall before the water sample was taken, while the low MPN values observed in January of 1984 were mainly caused by the cold water temperature (4^{0} C). The phosphorus and nitrogen concentrations are low. The ortho-P concentration is between 0.07 and 0.08 mg/l. The NH_3-N concentration is not detectable while the TKN is 0.2 mg/l.

D.5. Station 5:

This station is located right underneath the crossing bridge of Highway 63 and the Big Piney River. The water is shallow and rocks are spread all over the channel. Heavy algal growths are observed on the channel bottom and on the rocks, and the stream bed has a visible layer of sludge, all of which are caused by the pollution from the lagoon effluent discharge. The water quality data of this station are listed in Table 6.

Water temperature generally varies from 4 to 28^{0} C while the DO varies from a low of 3.5 mg/l to a high of 12.7 mg/l. Apparently, the lagoon effluent has not affected the DO too much at this station during the daytime since algae are able to supply oxygen. The pH is fairly constant, varying from 7.5 to 8.1. One MPN analysis was made on October 21, 1983, which indicated a high MPN index of 75,000/100 ml. This MPN index is much higher than the average MPN index at the upstream stations because this is the first station located below the lagoon effluent discharge. The TKN is 0.2 to 0.3 mg/l and the NH_3-N is not detectable. The phosphorus concentration is much higher than those at the upstream stations, with a ortho-P being

Table 6. Water Quality Data -- Station 5

Date	Temp (°C)	Flow (cfs)	DO (mg/l)	pH	TSS (mg/l)	COD (mg/l)	SCOD (mg/l)	BOD_5 (mg/l)	MPN (1000/100ml)	Ortho-P (mg/l)	Total-P (mg/l)	NH_3-N (mg/l)	TKN (mg/l)
8/7/83	28.0	-	6.9	7.8	12	28	0	-	-	-	-	-	-
8/23/83	26.0	-	3.5	8.0	20	50	36	-	-	-	-	-	-
9/7/83	24.0	-	6.6	7.9	63	65	28	-	-	-	-	-	-
9/21/83	18.0	-	4.7	7.9	30	28	19	-	-	-	-	-	-
10/21/83	19.0	-	-	7.6	8	13	6	-	75	-	-	-	-
1/24/84	4.0	-	12.7	7.6	8	28	20	-	-	-	-	-	-
3/15/84	12.0	-	7.5	8.0	14	8	-	-	-	0.21	0.27	0	0.3
4/19/84	16.0	-	12.1	8.1	12	8	-	-	-	0.57	0.73	0	0.2
5/15/84	14.0	-	8.0	7.5	12	8	-	-	-	-	-	-	-

Table 7. Water Quality Data -- Station 6

Date	Temp (°C)	Flow (cfs)	DO (mg/l)	pH	TSS (mg/l)	COD (mg/l)	SCOD (mg/l)	BOD_5 (mg/l)	MPN (1000/100ml)	Ortho-P (mg/l)	Total-P (mg/l)	NH_3-N (mg/l)	TKN (mg/l)
8/7/83	27.0	-	9.5	8.0	14	28	9	-	-	-	-	-	-
8/23/83	25.0	-	2.1	8.1	40	70	36	-	-	-	-	-	-
9/7/83	23.0	-	7.1	7.6	37	37	19	-	-	-	-	-	-
9/21/83	16	-	4.5	7.8	10	9	9	-	-	-	-	-	-
10/21/83	18.0	-	-	7.6	12	19	6	-	21	-	-	-	-
1/24/84	2.5	-	13.2	7.6	18	32	20	-	-	-	-	-	-
3/15/84	12.0	-	8.3	8.1	52	20	-	-	-	0.19	0.24	0	0.2
4/19/84	17.0	-	11.0	8.0	22	11	-	-	-	0.43	0.43	0	0.3
5/15/84	14.0	-	7.9	7.5	20	16	-	-	-	-	-	-	-

between 0.21 and 0.57 mg/l and a total-P between 0.27 and 0.73 mg/l. Obviously, this station has received a substantial amount of phosphorus from the lagoon discharge. The SS and COD concentrations were high between August and October of 1983 as shown in Figure 6. Both the SS and COD reached a high concentration of around 65 mg/l in early September. However, after October, the SS and COD were rapidly reduced to around 20 mg/l or below.

D.6. Station 6:

This station has a channel width of about 40 ft and a depth of 2 ft. The water is turbid and dark green in color. Some spots are covered with algal mats from time to time. About one half of the channel bottom is covered with green aquatic weeds, which of course is a reflection of severe pollution existing at this station. The flow velocity is very sluggish during the dry period. The water quality data are listed in Table 7.

In general, the water temperature varies from 2.5 to 27^{o} C while the DO varies from 2.1 to 13.2 mg/l. The supersaturation of DO is mainly caused by the heavy growth of algae. The pH varies from 7.5 to 8.1. One coliform determination was made on October 21, 1983, which gave an MPN index of 21,000/100 ml. This coliform level is somewhat lower than the value of 75,000/100 ml observed at Station 5, which is an indication of the natural die-off of the coliform bacteria. Both the ortho-P and the total-P are still high (0.19 to 0.43 mg/l for ortho-P and 0.24 to 0.43 mg/l for total-P), indicating that the lagoon effluent still affects the nutrient concentrations at this station. The TKN varies from 0.2 to 0.3 mg/l, which is similar to those at other stations. The SS concentration was high on August 23, 1983 (40 mg/l), September 7, 1983 (37 mg/l), and March 15, 1984 (52 mg/l), but was much lower (not greater than 22 mg/l) on the other sampling dates (see Figure 7). The COD concentration has a similar variation pattern. For example, the COD value was as high as 70 mg/l on August 23,

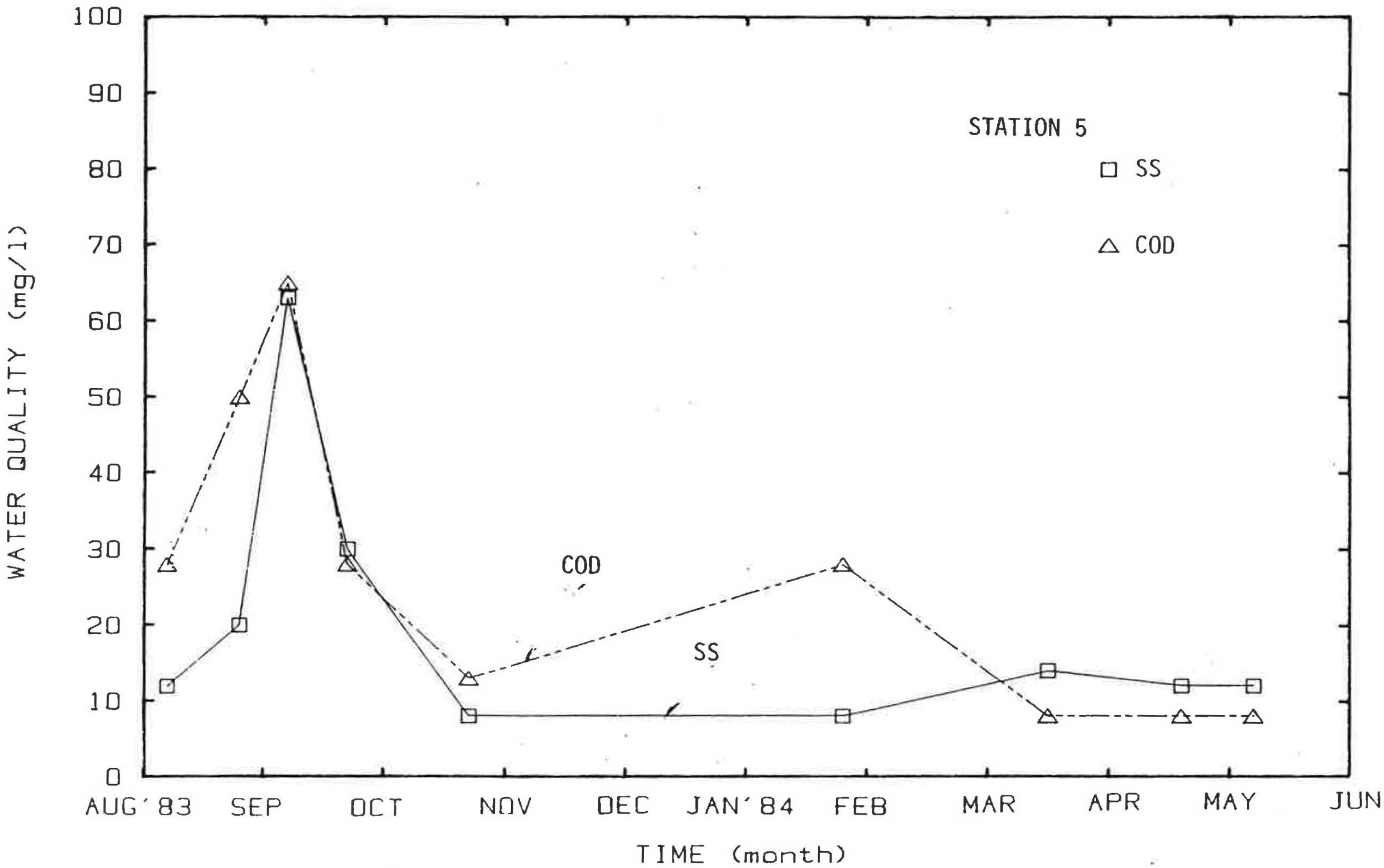

FIGURE 6. WATER QUALITY DATA FOR STATION 5

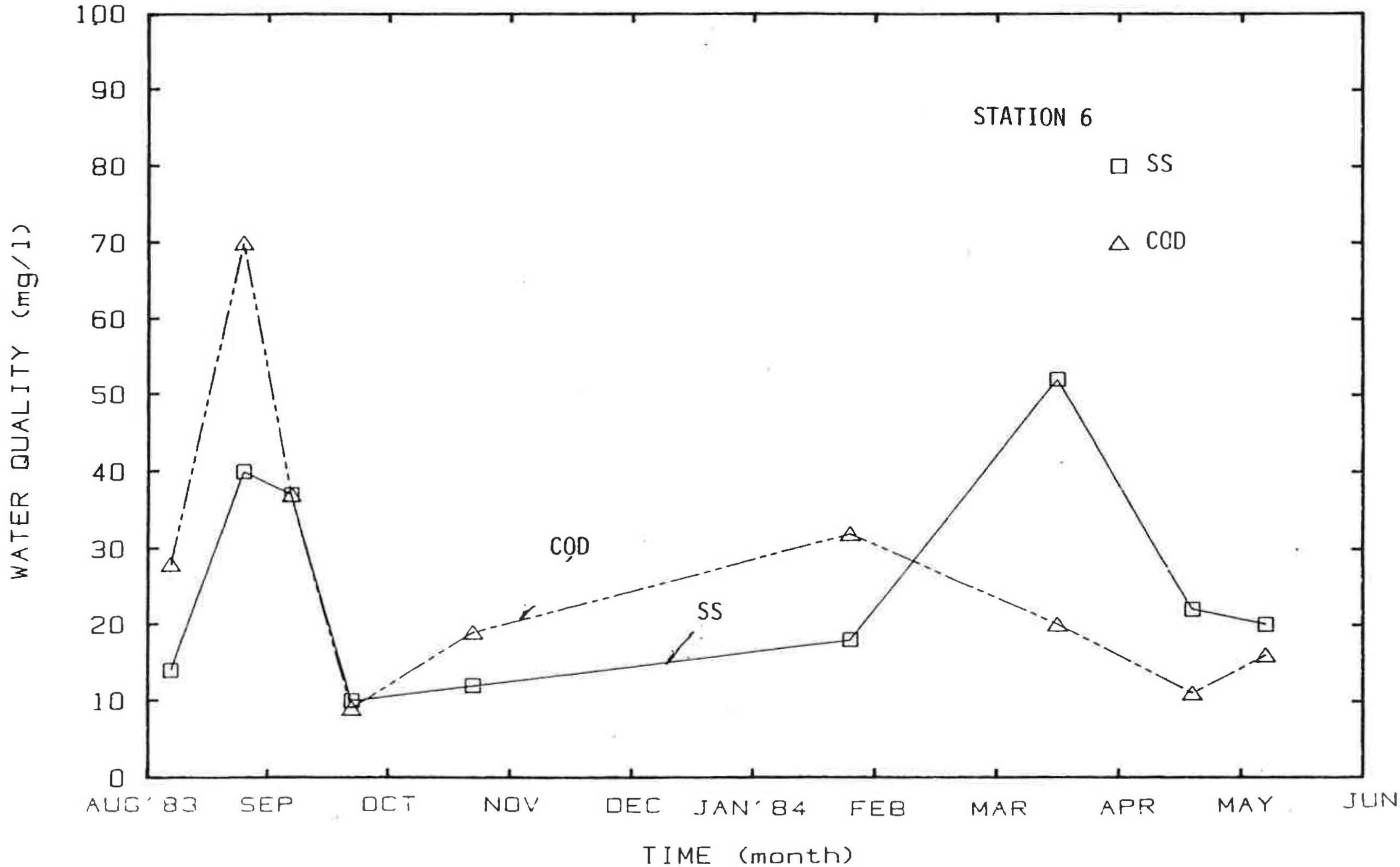

FIGURE 7. WATER QUALITY DATA FOR STATION 6

1983, but was reduced to only about 9 mg/l on September 21 of the same year.

D.7. Station 7:

This station is located below the low water bridge near the Cabool Airport. The river bed is wide, but the majority of which is covered with dry gravel and sand. During dry periods, the water is flowing along a narrow strip of the bank with a width of about 8 ft and the average depth is 1.5 ft. The average flow velocity is 8 ft/min and the flow rate is 1.6 cfs. But this may go up to as high as 18 cfs after a major rainfall. There are heavy algal growths at the stream bottom and on the rock surface. They appear to be quite slimy. However, there are no detached algal mats found on the water surface. The water quality data are summarized in Table 8.

The water temperature varies from 2 to 28^{o} C while the DO varies from 4.5 to 13.4 mg/l. Again, the high DO is caused by the presence of heavy algal growths. The pH is between 7.5 and 8.2. One MPN analysis was made on October 21, 1983, which showed a high MPN index of 110,000/100 ml. Both the ortho-P and total-P are still high (0.20 to 0.41 mg/l for ortho-P and 0.41 to 0.47 mg/l for total-P) at this station, which of course is a result of the lagoon effluent discharge. The TKN concentration is about 0.2 mg/l while the NH_3-N is not detectable. The SS concentration (as shown in Figure 8) is low and stays below 30 mg/l, but the COD concentration is relatively high (from 30 to 56 mg/l), particulary in the period from early August to early September.

D.8. Station 8:

This station is located between the Highway 63 bridge and the St. Louis San-Fransisco Railway Road Bridge. During dry periods, two-thirds of the river bed is dry with gravels. The width of the flowing stream is only 10 ft and the depth is approximately 0.5 ft. The water is clear and there are

Table 8. Water Quality Data -- Station 7

Date	Temp (^oC)	Flow (cfs)	DO (mg/l)	pH	TSS (mg/l)	COD (mg/l)	SCOD (mg/l)	BOD_5 (mg/l)	MPN (1000/100ml)	Ortho-P (mg/l)	Total-P (mg/l)	NH_3-N (mg/l)	TKN (mg/l)
8/7/83	28.0	-	6.1	7.8	16	38	9	-	-	-	-	-	-
8/23/83	26.0	1.6	4.6	7.9	16	30	27	-	-	-	-	-	-
9/7/83	23.0	12.6	5.2	7.5	27	56	28	-	-	-	-	-	-
9/21/83	16.5	1.8	4.5	7.8	4	19	19	-	-	-	-	-	-
10/21/83	18.0	14.0	6.3	7.8	18	13	13	-	110	-	-	-	-
1/24/84	2.0	4.3	10.2	7.6	8	28	20	-	-	-	-	-	-
3/15/84	14.0	11.6	10.8	8.2	16	12	-	-	-	0.20	0.47	0	0.2
4/19/84	14.5	18.0	13.4	8.2	4	11	-	-	-	0.41	0.41	0	0.2
5/15/84	14.0	11.2	9.4	7.5	18	4	-	-	-	-	-	-	-

Table 9. Water Quality Data -- Station 8

Date	Temp (^oC)	Flow (cfs)	DO (mg/l)	pH	TSS (mg/l)	COD (mg/l)	SCOD (mg/l)	BOD_5 (mg/l)	MPN (1000/100ml)	Ortho-P (mg/l)	Total-P (mg/l)	NH_3-N (mg/l)	TKN (mg/l)
8/7/83	31.0	0.8	7.8	8.1	24	20	9	-	-	-	-	-	-
8/23/83	28.0	1.0	6.9	8.0	9	30	27	-	-	-	-	-	-
9/7/83	27.0	11.5	8.8	7.9	30	19	9	-	-	-	-	-	-
9/21/83	19.0	2.5	10.2	8.1	4	9	9	-	-	-	-	-	-
10/21/83	-	18.4	-	7.7	8	13	6	-	110	-	-	-	-
1/24/84	1.5	-	14.5	7.8	10	16	16	-	0.09	-	-	-	-
3/15/84	15	25.7	7.5	8.3	6	20	-	-	-	0.10	0.15	0	0.2
4/19/84	15.0	37.5	12.1	8.1	6	8	-	-	-	0.17	0.34	0	0.2
5/15/84	14.0	22.9	9.2	7.6	12	12	-	-	-	-	-	-	-

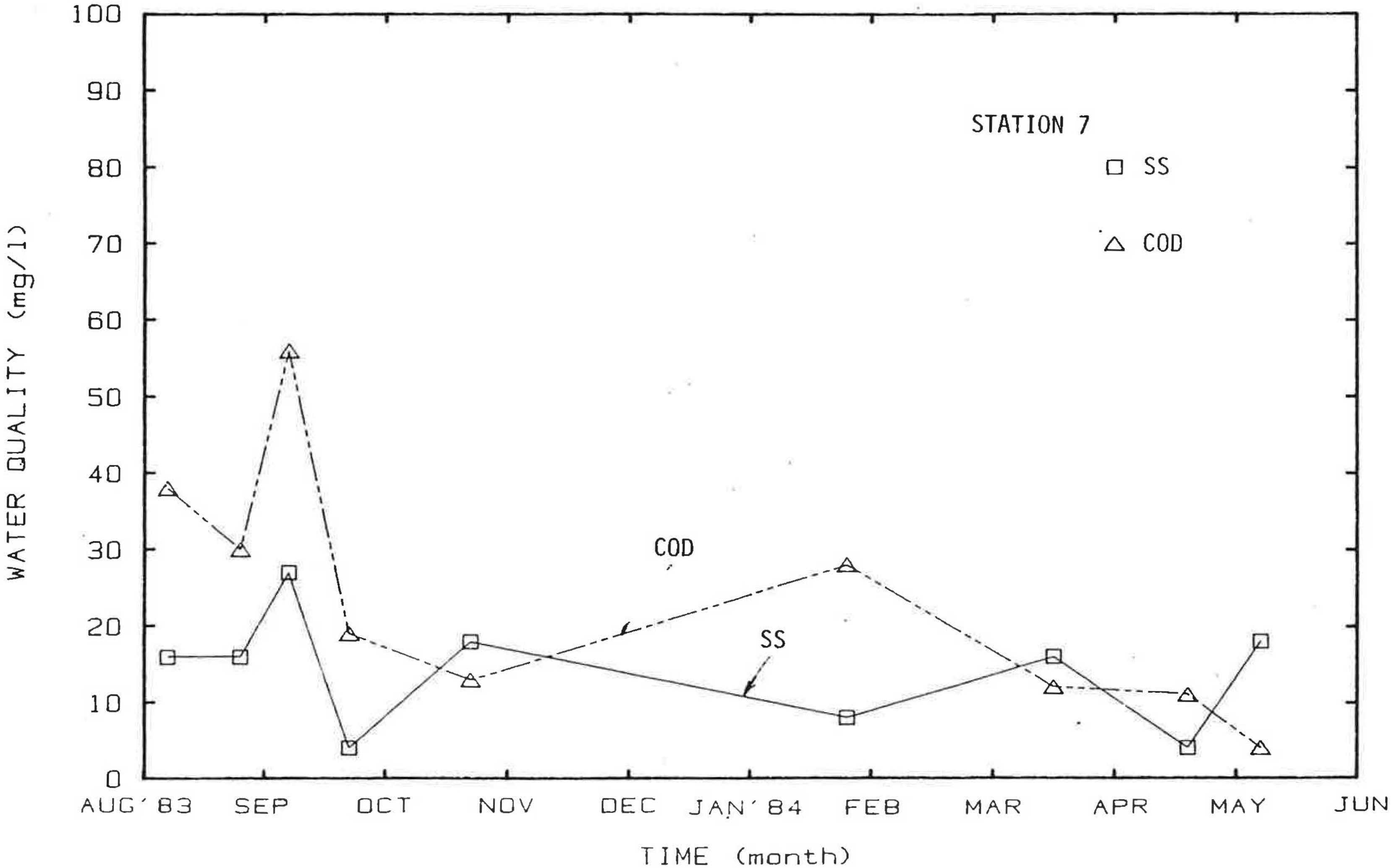

FIGURE 8. WATER QUALITY DATA FOR STATION 7

many minnows present. There are some algal mats along both sides of the banks. The water quality data at this station are listed in Table 9.

The water temperature varies from 1.5° C in January to 31° C in August while the flow varies from 0.8 cfs in August to 37.5 cfs in April. The DO concentration is high all year around (from 6.9 to 14.5 mg/l) and the pH varies from 7.6 to 8.1. Both the SS and COD concentrations are not greater than 30 mg/l(as shown in Figure 9). All of these indicate that much of the pollution from the lagoon effluent discharge has become stabilized through the natural purification process. However, the phosphorus concentration is still high, and so is the MPN index (110,000/100 ml) on some occasions, particularly after a major storm event, which increases the flow rate and allows the lagoon effluent discharge to reach Station 8 within a short period of time.

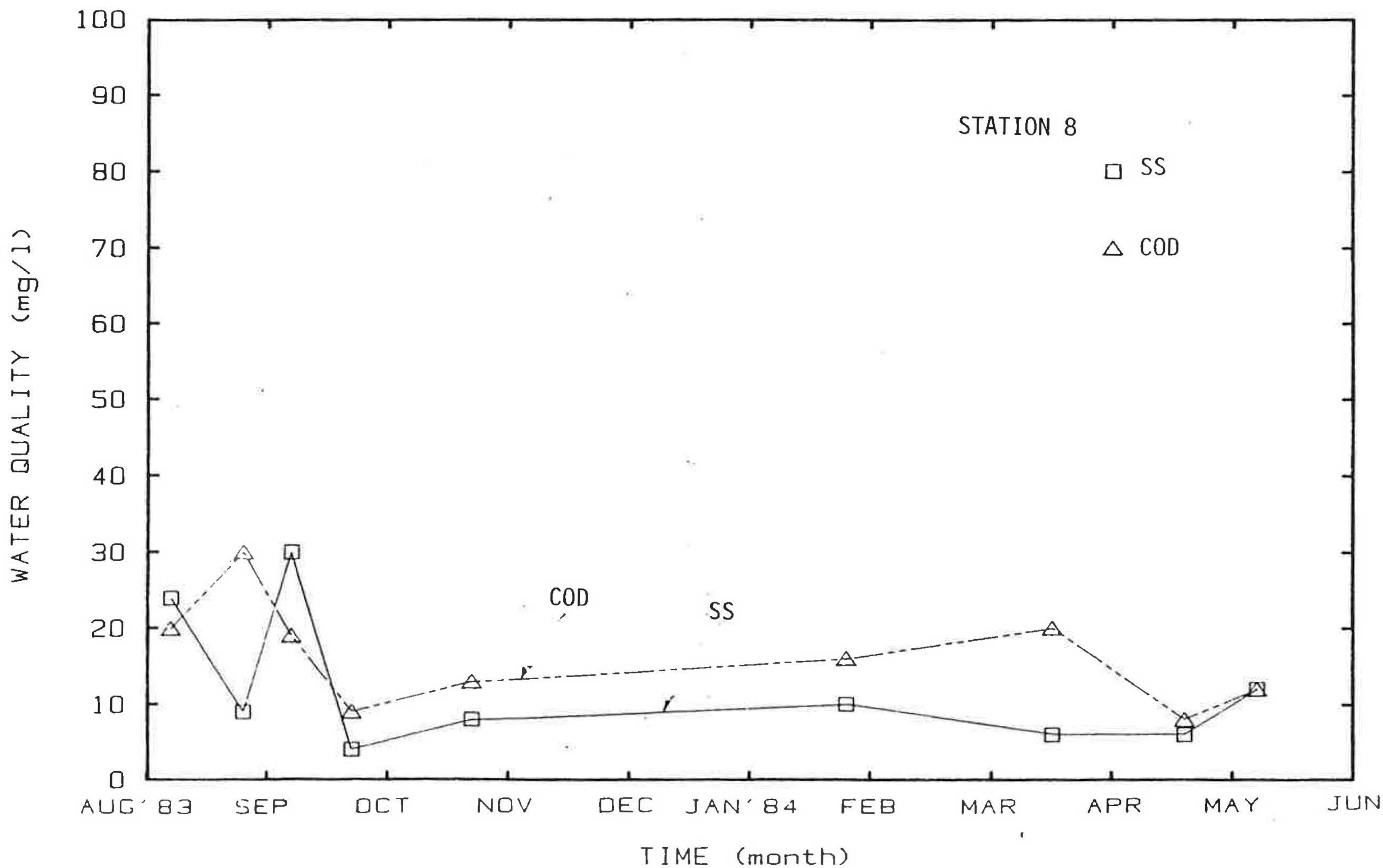

FIGURE 9. WATER QUALITY DATA FOR STATION 8

D.9. Station G-1:

The groundwater qualities observed at Station G-1 are listed in Table 10. The water temperature varies from 4.5 to 18.5^{o} C while the DO is generally much lower (between 0.7 and 7.6 mg/l) than those of surface water. The high DO concentrations, 7.6 mg/l observed on October 21, 1983, 5.0 mg/l on April 19, 1984 and 4.2 mg/l on May 15, 1984, were mainly caused by the rainfalls which occurred before the sampling dates. Otherwise, the DO should be below 3 mg/l. The groundwater maintains a constant pH between 6.8 and 7.2. The extremely high SS concentration between mid August and late September (see Figure 10) was mainly caused by a low groundwater level which results in the collection of some silts in the water sample. The COD concentrations were also high during this period. However, after this dry period, both the SS and COD concentrations were much reduced in the subsequent months. Two MPN analyses were made and the data analyses showed that the MPN index varied from zero to 15,000/100 ml. The high MPN value observed on October 21, 1983 was probably caused by an extensive subsoil percolation which resulted from a 9-inch rainfall before the sampling date. The nitrogen and phosphorus concentrations are generally much lower than those observed at the Big Piney River.

D.10. Station G-2:

The groundwater quality data observed at Station G-2 are listed in Table 11. The water temperature varies from 6 to 22^{o} C. The DO concentrations are generally low, varying from 0.9 to 3.7 mg/l. The pH is fairly constant with a low of 6.8 and a high of 7.3. The SS and COD concentrations have the same trend of variation as those observed at Station G-1, even though the SS levels are somewhat lower (212 to 1910 mg/l for Station G-2 as compared to 428 to 6470 mg/l for Station G-1) from mid August to late September (see Figure 11). The MPN index varied from a high of 46,000/100 ml on October 21,

Table 10. Groundwater Quality Data -- Station G-1

Date	Temp (^oC)	DO (mg/l)	pH	TSS (mg/l)	COD (mg/l)	SCOD (mg/l)	MPN (1000/100ml)	Ortho-P (mg/l)	Total-P (mg/l)	NH_3-N (mg/l)	TKN (mg/l)
8/7/83	-	-	7.0	428	160	9	-	-	-	-	-
8/23/83	-	-	7.2	2,565	100	27	-	-	-	-	-
9/7/83	21	1.4	7.0	6,470	112	84	-	-	-	-	-
9/21/83	19	0.7	7.1	2,970	84	28	-	-	-	-	-
10/21/83	18.5	7.6	7.5	40	19	19	15	-	-	-	-
1/24/84	4.5	1.0	7.1	145	32	13	0	-	-	-	-
3/15/84	-	2.6	7.1	42	4	-	-	0	0	0	0.3
4/19/84	13.5	5.0	7.2	96	15	-	-	0.02	0.53	0.5	1.9
5/15/84	13.0	4.2	6.8	110	8	-	-	-	-	-	-
11/7/83	-	-	6.9	26	8	-	-	-	-	-	-
11/15/83	-	-	6.8	26	6	-	-	-	-	-	-

Table 11. Groundwater Quality Data -- Station G-2

Date	Temp (^oC)	DO (mg/l)	pH	TSS (mg/l)	COD (mg/l)	SCOD (mg/l)	MPN (1000/100ml)	Ortho-P (mg/l)	Total-P (mg/l)	NH_3-N (mg/l)	TKN (mg/l)
8/83	-	-	7.0	212	188	28	-	-	-	-	-
8/23/83	-	-	7.3	535	130	62	-	-	-	-	-
9/7/83	22	1.0	6.8	1,773	28	19	-	-	-	-	-
9/21/83	20.5	0.9	6.8	1,910	75	28	-	-	-	-	-
10/21/83	20	3.7	7.0	80	26	13	46	-	-	-	-
1/24/84	6.0	1.8	7.0	155	56	13	0	-	-	-	-
3/15/84	-	2.1	7.0	80	32	-	-	0	0	1.0	1.2
4/19/84	14.0	2.2	6.9	98	23	-	-	0	3.0	1.3	2.0
5/15/84	14.0	2.2	6.9	100	24	-	-	-	-	-	-
11/7/83	-	-	7.1	100	65	-	-	-	-	-	-
11/15/83	-	-	6.7	215	27	-	-	-	-	-	-

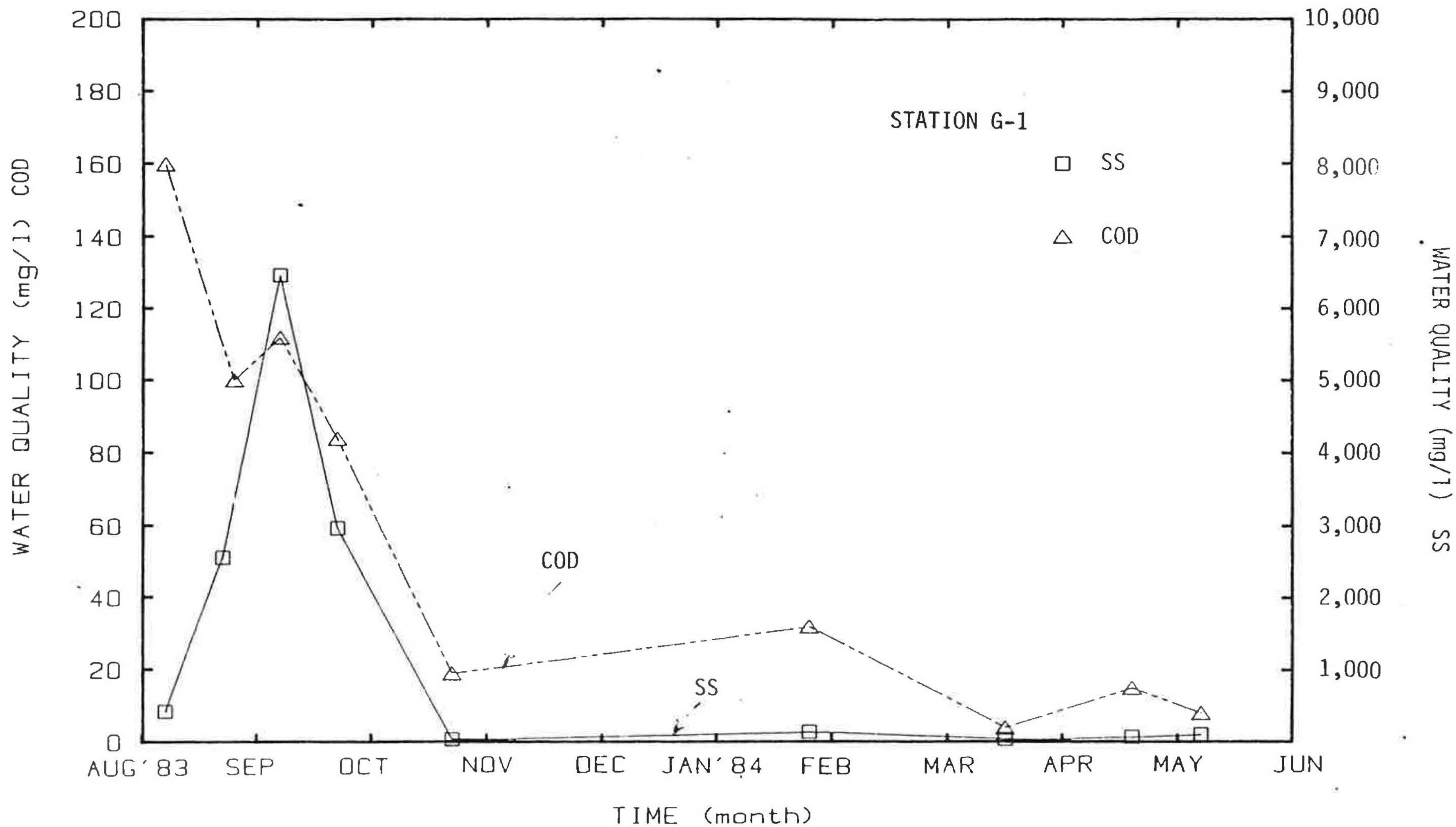

FIGURE 10. WATER QUALITY DATA FOR STATION G-1

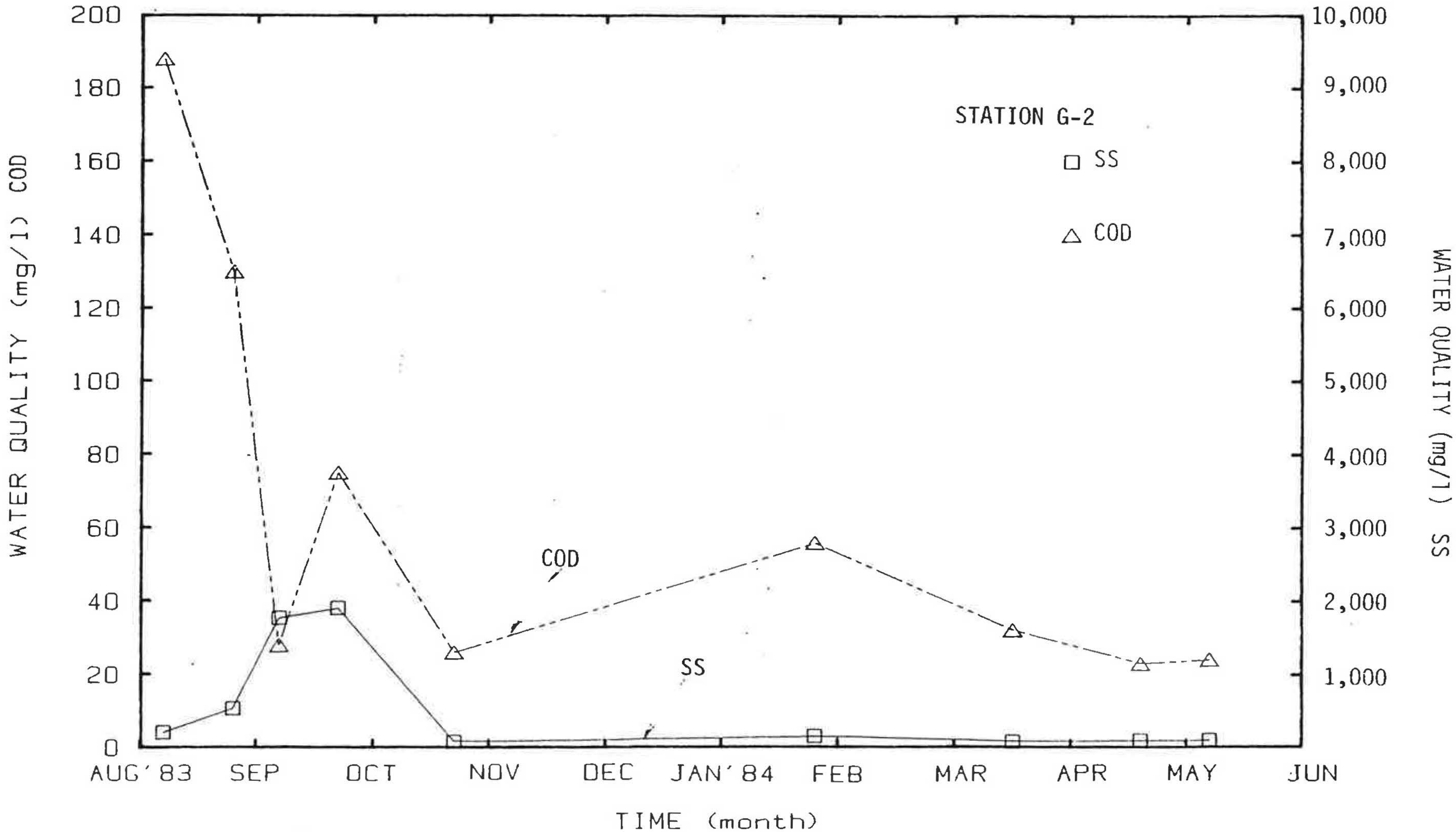

FIGURE 11. WATER QUALITY DATA FOR STATION G-2

1983 after a 9-inch rainfall to zero as observed on January 24, 1984. The nitrogen content is relatively high (1.0 to 1.3 mg/l for NH_3-N and 1.2 to 2.0 mg/l for TKN), but the phosphorus concentration is much the same as that of Station G-1, except for a high total-P of 3 mg/l which was observed on April 19, 1984.

D.11. Station G-3:

For this station, no proper groundwater samples were collected before October 21, 1983 because most of the collected samples consisted mainly of sands and silts, but little water. After the beginning of October rains, the groundwater level was raised and it became possible to collect some proper water samples. The DO varies from 0.5 to 4.0 mg/l while the pH is between 6.9 and 7.2 (see Table 12). High SS and COD concentrations were observed on January 24, 1984 (up to 5320 mg/l for SS and 104 mg/l for COD). After that date, the concentrations were significantly lower, from 50 to 126 mg/l for SS and 20 to 30 mg/l for COD (see Figure 12). A determination of MPN was made on January 24, 1984, which gave zero coliform concentration. The nitrogen concentrations are high (0.5 to 0.8 for NH_3-N and 1.1 to 1.3 mg/l for TKN) which are similar to those of the other two groundwater stations. The phosphorus concentration is generally low at this station.

D.12. Seven Test Pits:

Selected water quality parameters were also monitored at the seven test pits on three separate sampling occasions (October 28, November 7 and November 15, 1983). The results are shown in Table 13. The data are quite similar among the seven pits. There are also not much variations for the data observed at the three separate dates. The pH varies from 7.0 to 8.1. The SS concentration ranges from a low of 6 mg/l to a high of 62 mg/l while the COD concentration varies from 4 to 21 mg/l. Almost all the COD is soluble as can be seen from the data on October 28, 1983.

Table 12. Groundwater Quality Data -- Station G-3

Date	Temp (°C)	DO (mg/l)	pH	TSS (mg/l)	COD (mg/l)	SCOD (mg/l)	MPN (1000/100ml)	Ortho-P (mg/l)	Total-P (mg/l)	NH_3-N (mg/l)	TKN (mg/l)
10/21/83	-	-	7.0	887	-	-	-	-	-	-	-
1/24/83	7.0	0.5	7.2	5,320	104	23	0	-	-	-	-
3/15/84	-	2.6	7.0	67	20	-	-	0	0	0.5	1.1
4/19/84	14.5	4.0	7.2	126	30	-	-	0	0.61	0.8	1.3
5/15/84	13.0	2.3	6.9	50	20	-	-	-	-	-	-
11/7/83	-	-	7.1	225	48	-	-	-	-	-	-
11/15/83	-	-	7.0	120	80	-	-	-	-	-	-

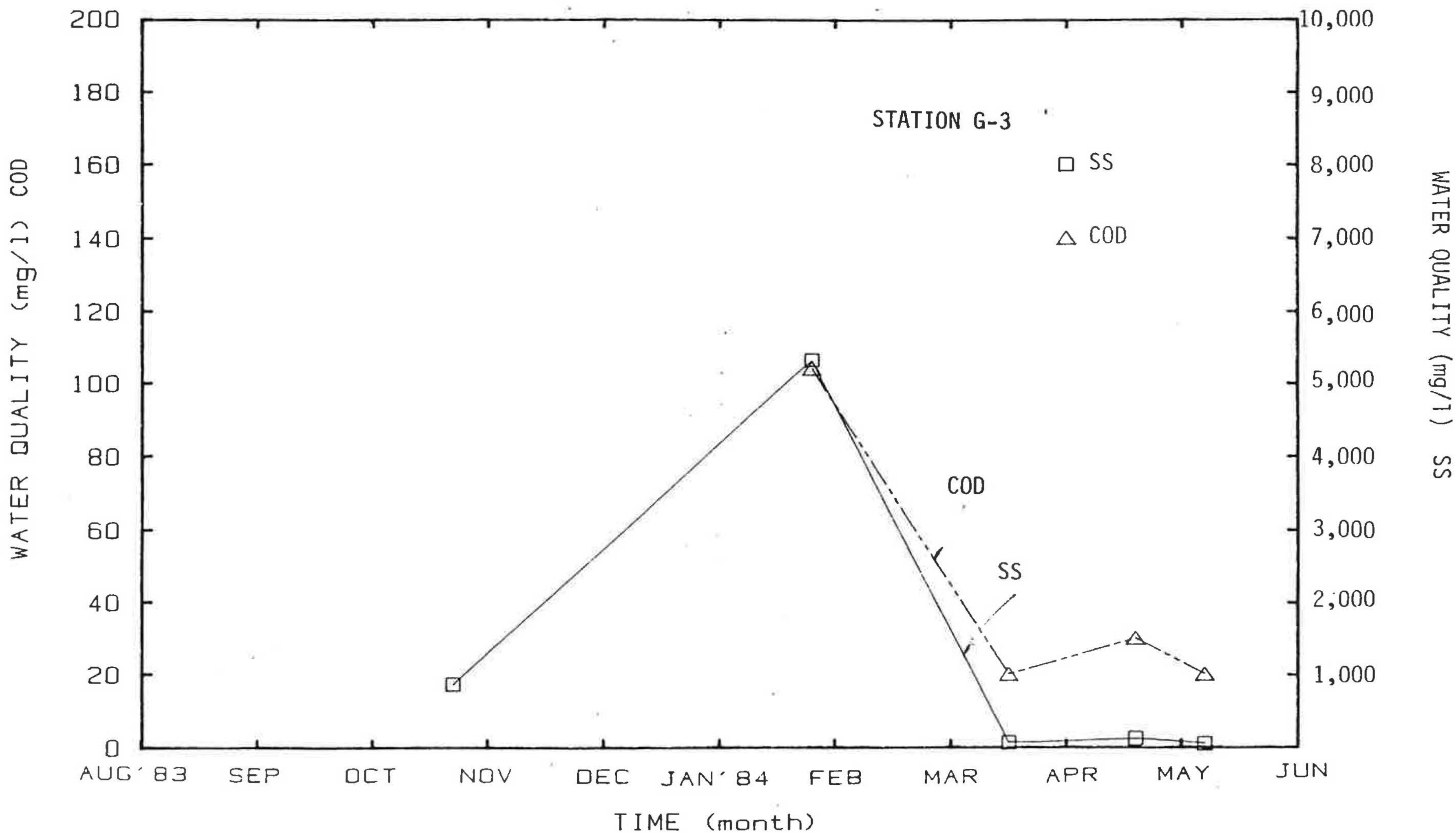

FIGURE 12. WATER QUALITY DATA FOR STATION G-3

Table 13. Water Quality Data of Seven Test Pits

Station	P-1			P-2			P-3			P-4		
Date	10/28/83	11/7/83	11/15/83	10/28/83	11/7/83	11/15/83	10/28/83	11/7/83	11/15/83	10/28/83	11/7/83	11/15/83
pH	7.4	7.1	7.5	7.3	7.2	-	7.3	7.0	-	-	-	7.6
SS (mg/l)	16	30	20	50	28	-	12	12	-	-	-	8
COD (mg/l)	6	17	11	19	13	-	6	4	-	-	-	4
Sol. COD (mg/l)	6	-	-	19	-	-	6	-	-	-	-	-

Table 13. Water Quality Data of Seven Test Pits (Cont'd)

Station	P-5			P-6			P-7		
Date	10/28/83	11/7/83	11/15/83	10/28/83	11/7/83	11/15/83	10/28/83	11/7/83	11/15/83
pH	7.0	7.1	7.4	7.2	7.1	7.4	7.2	7.3	8.1
SS (mg/l)	14	6	18	62	40	18	10	14	8
COD (mg/l)	6	4	15	19	11	4	19	6	21
Sol. COD (mg/l)	13	-	-	13	-	-	19	-	-

VI. SUMMARY

The general background data of the proposed land application site have been established in this study. Emphasis of the study has been placed on the evaluation of the existing qualities of surface and subsurface waters. From the one-year extensive monitoring of the stream water qualities at the eight sampling stations along the Big Piney River, it has been established that the present lagoon effluent at Cabool has caused a considerable degree of water quality degradation downstream of the application site. Major types of pollutants from the lagoon effluent discharge include organic matter (such as COD), suspended solids, inorganic nutrients (N and P) and coliform bacteria. These data will serve as a major baseline for future assessment of the water quality improvement as a result of land application.

Besides the study of surface water, groundwater qualities have also been evaluated. In general, the groundwater depth at the application site is very shallow, varying from four to seven feet. Its water qualities are highly dependent upon natural precipitation. During dry periods, water qualities appear to be superior to those of the wet-weather days. This is presumably caused by the rapid percolation of ground-surface pollutants into the subsurface water. In view of this observation, the future application rate of the lagoon effluent needs to be rigidly controlled to eliminate the migration of the pollutants to the groundwater.