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STREAM WATER LEVEL CONTROL AFFECTS IRRIGATION WATER SUPPLY AND QUALITY

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SUMMARY: A collapsible fabric dam that controls water levels of both a stream and its adjacent groundwater table may help overcome seasonal droughts in agricultural fields of mid-Atlantic states. Raising the channel water levels reduced subsurface drainage and had beneficial effects on stream water quality. Water pumped from the controlled stream supplied eight center-pivots, four volume guns, and one subirrigation system.

KEYWORDS: Water, nutrients, drought, drainage, Fabridam, control, stream water levels.

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INTRODUCTION

The weather and soil conditions in the Southeastern Coastal Plains require the application of irrigation water to normalize crop yields to provide the farmer with a stable income. Although the average annual rainfall usually exceeds the evaporative demands, the erratic rainfall and low-water-holding-capacity soils cause an estimated number of drought days, expected 2 out of 10 years, of 3-5 days in April, 11-20 days in May, 16-19 days in June, 7-15 days in July, 6-14 days in August, and 9-14 days in September (van Bavel and Verlinden, 1956).

In the past ten years, irrigated land has increased from 216,500 ha to 759,200 ha in the South Atlantic Coastal Plains (Irrig. J., 1985). Water sources for irrigation are usually deep groundwater supplies, however, these sources are declining, and withdrawals from deep groundwater aquifers are exceeding recharge. In North Carolina, water levels in the Yorktown, Castle Hayne, and Cretacens Aquifers have dropped 3 m, 24 m, and 30 m, respectively, since 1965. In South Carolina, water levels in the Black Creek and Middendorf aquifers have dropped 9 m since 1965 (U.S. Geological Survey, 1985). This situation indicates the need for a new water source for irrigation.

Water quality is becoming an important issue because of vast amounts of groundwater contamination. "The widespread use of chemical products, coupled with the disposal of large volumes of waste materials, poses the potential for widely distributed groundwater contamination. Groundwater is the subsurface transporting agent for dissolved chemicals including contaminants." (National Research Council, 1984). On agricultural lands, the reduction of nutrients in the groundwater flowing into streams and the resulting nutrients in stream flows increase the quality of the downstream flow and reduce the need for the farmer to apply more nutrients to supply plant food. "Surface runoff carries more sediments, pesticides, and phosphorus than subsurface flows. But the higher proportion of subsurface flow is accompanied by a greater loss of nitrate-nitrogen and generally a greater loss of total N." (Gilliam et al., 1986). A reduction of NO_3-N was reported by controlling the drainage in tile drainage systems. The reduction due to drainage control in the total amount of NO_3-N loss through tile lines may result from a decrease in the amount of water passing through the tile lines and without reduction in NO_3-N concentration, or increased denitrification may result in a lower nitrate concentration. A reduction in NO_3-N and a slight reduction in total P was also noted on a watershed-scale project with stream water level control (SWLC). Three factors were believed to cause the decrease in NO_3 concentrations in the stream draining the watershed: (1) an increase in denitrification toward the outer edge of drainage area influenced by SWLC, (2) further denitrification as the water flows from the fields into the stream channel, (3) the denitrification which takes place in the stream channel itself (Gilliam et al., 1986). There was an inconsistent effect of SWLC in the watershed on P concentrations, since most of the water enters the channel by subsurface flow which contains little phosphorus.

Since irrigation water supply and quality are important, the purpose of this paper is to show that SWLC potentially increases the irrigation water supply and its quality in the Coastal Plains of the Southeast.

PROJECT DESCRIPTION AND METHODS

The project was a portion of the Conetoe Drainage Project, the Mitchell Creek Watershed in Pitt and Edgecombe Counties, N.C. The study area was located on a 4-km (2.5 mile) section along Mitchell Creek. The area, about 1330 ha, is flat-to-gently rolling with no more than a 1.5 m difference in elevation. Soils are poorly-to-somewhat excessively drained, formed in sandy fluvial and marine sediments. Further description is given by Doty et al. (1984, 1985).

Six lines of water table observations wells were installed perpendicular to the Creek on each side. Well locations ranged from 10 to 970 m from the channel. Average daily water table elevations were obtained from digitized recorder charts. A bank of water quality sampling wells was located next to 17 observation wells. Each bank consisted of a separate well for sampling each 1.0-, 2.5-, 3.5-, and 6.0-m depths. Samples were collected monthly, placed in a freezer, and transported frozen to the laboratory for nutrient analysis.

Twelve stream gaging sites were equipped with stage recorders, seven on Mitchell Creek, three on intersecting channels, and two on channels paralleling Mitchell Creek. Average daily stream water levels were obtained from digitized stage recorder charts. Water quality samples were collected weekly from the stream flow at each stage recorder, placed in a freezer, and transported frozen to the laboratory for nutrient analysis

Two years of data (1980-81) were obtained from the area with Mitchell Creek flowing unrestricted. A Fabridam[1] (Doty et al., 1984b), a water-inflatable structure made of 2-ply nylon rubber-coated fabric bolted to a concrete pad in the shape of the stream channel, was installed and made operational 2 April 1982. Four years, 1982-85, of data were collected from the area with the Fabridam automatically controlling the stream water level at various stages. For further description of the Fabridam and its operation, see Doty et al. (1984a, 1984b, 1986).

Corn yields were calculated from hand-harvested samples collected from two replications (6 rows, 2 m long) near the observation wells. Farmers had planted and managed the area in corn. The 800-ha area was divided into three treatment areas: (1) The stream water level control treatment area (with SWLC) which extended from the Fabridam to about 2,700 m upstream; and two additional treatment areas, but without SWLC, (2) below the Fabridam, and (3) above the stream water level control treatment area or at a distance greater than 3005 m above the Fabridam. Corn yield samples were collected from sprinkler-irrigated and rainfed fields in each of these three treatment areas. Yield data were tabulated and statistical analysis made by the Duncan's multiple range test and the T test (LSD) on the Statistical Analysis System (SAS).

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[1] The Fabridam is a patented structure, designed from ARS-SCS specifications by N.M. Imbertson & Assoc., Inc., Burbank, CA. Mention of trademark or vendor does not constitute a guarantee or warranty of the product by USDA and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

Irrigation water was measured with water meters placed on the various irrigation systems in the 1330-ha area. Water-meters readings were recorded weekly.

Nutrient concentrations were determined in the laboratory. Average stream water levels on the day nutrient concentrations were sampled were merged in the computer. Plots of the stream water levels and water table elevations were obtained from the merged data sets of nutrient concentrations and stream water level.

RESULTS AND DISCUSSION

Results for the period, 1980-1985, are reported in this report. Annual rainfall for 1980, 1981, 1982, 1983, 1984, and 1985 through August 15 was 933, 764, 1021, 1060, 1130, and 674 mm, respectively. The 30-year mean annual rainfall at Wilson, N.C. located about 50 km away, is 1199 mm. The corn-growing seasonal rainfall amounts, April through August, were 321, 452, 400, 349, 645, and 473 mm for 1980, 1981, 1982, 1983, 1984, and 1985, respectively. These corn-growing season rainfall amounts compare to the 30-year average of 571 mm. The driest growing season after installation of the Fabridam was 1983 with 349 mm of rainfall, 222 mm below the average, and the wettest growing season was 1984 with 645 mm of rainfall, 74 mm above the average.

Increased Water Supplies

Increased supplies of irrigation water resulted in an increase in the number of irrigation systems brought into use. In 1980, only 2 center pivots and 2 volume guns, irrigating 79 ha, were used in the 800-ha area affected by the Fabridam. In 1985, the number had increased to 8 center pivots, 4 volume guns, and 1 controlled-drainage/subirrigation system, irrigating 327 ha, or about 41% of the area (Table 1). These systems all pumped water from Mitchell Creek or its tributaries. Irrigation water was available throughout the growing season. The least amount of water available for irrigation pumping was at the end of a low rainfall period, 21 May to 22 August 1983. On 18 August 1983, "it was estimated that more than 4,000,000 m^3 of stored water was left in the soil profile, more than 10 times the amount of water pumped in 1983" (352,840 m^3) (Doty et al., 1986).

The farmers had pumped 308,640 m^3 through 22 August 1983. Using a computer model (Parsons, 1986), it was determined that at the end of a 19-day drought period on 22 August 1983, 488,000 m^3 (more than 1.5 times the amount of water pumped) of water was still available for irrigation pumping. The amount of water available for pumping from Mitchell Creek for irrigation with and without the Fabridam, after a 19-day drought in a dry year, 1983, and after a 19-day drought in a wet year, 1984, is shown in Figure 1. These data were simulated using the Water Resource Conservation Model (WATRCOM) (Parsons, 1986). Figure 1 shows that in 1983 more than 2.5 times more water was available for pumping with the Fabridam than without it. In 1984, after a 19-day drought, more than 1.5 times more water was available with the Fabridam than without.

Farmers increased their pumped volume more than 1.8 times from 1981 to 1983. They pumped 175 mm of water in 1983, the driest year of the study. At this rate, they could irrigate 450 ha (56%) of land in the area. They are now irrigating 327 ha or 41% of the land in the area. Although very little data were obtained during the 1986 drought, farmers produced excellent crops with irrigation although the water level above the Fabridam in Mitchell Creek was lowered more than 1 m.

The distribution of the water storage is shown in Figure 2. This represents a section about 800 m upstream from the Fabridam on the left side of Mitchell Creek looking downstream. More water is stored next to the stream than at 425 m from the stream. This means that the stream water level was raised allowing no flow out and that drainage toward the stream was slowed. Therefore, the water stored in the soil profile is a result of reduced drainage to the stream.

Crop Yields

Corn yields for the 4-year average, 1982-85, are shown in Table 2. Under rainfed conditions, SWLC significantly increased yields by 33% over those without SWLC. Sprinkler irrigation with SWLC produces significantly the highest yield, 10,452 kg/ha. There was no significant difference between rainfed with SWLC and sprinkler irrigated above the control area, although there was an 878 kg/ha difference in yield.

Corn yields for the driest growing season, 1983, and the wettest growing season, 1984, are shown in Table 2. These results show that during a wet year, 1984, corn yield for sprinkler irrigation with SWLC was not significantly different from that for irrigated with SWLC. Under rainfed conditions, yields with SWLC were not significantly different from below-structure yields without SWLC. In the driest year, SWLC did not furnish enough water, and sprinkler-irrigated yields without SWLC were significantly greater. Under rainfed condition without SWLC, below structure yields were significantly different from the yields above the control area -- less in the driest year and greater during the wettest year. This indicates that some water may have been furnished by SWLC above the control area in the driest year.

Water Quality

The stream water level at the Fabridam site and the NO_3-N concentrations in mg/L from 15 January 1980 to 15 July 1985 are given in Figure 3. SWLC did not exist until 2 April 1982, when the Fabridam was installed. Before SWLC, NO_3-N concentrations were low at the beginning (July 1980), increased over the winter (January 1981), and became low again in the summer (July 1981). Stream water levels remained relatively constant during 1980 and 1981.

After the Fabridam was installed and the stream water level was raised, the NO_3-N concentration began to decrease. The lowest concentrations were found to be 0.62 mg/L on 19 September 1982; 0.22 mg/L on 19 July 1983; 0.98 mg/L on 10 July 1984; and 0.20 mg/L on 5 August 1985. The NO_3-N concentrations decreased each time the stream water level was raised by SWLC. This decrease occurred even in the winter (15 January 1985) when the stream water level was maintained above 10.5 m elevation. This indicates that SWLC can decrease NO_3-N concentrations in stream flows.

A comparison of the NO_3-N concentration at the Fabridam with SWLC and 3005 m upstream without SWLC is shown in Figure 4. Before the Fabridam was installed, the NO_3-N concentrations were, in general, higher at the Fabridam than at 3005 m upstream. But after the Fabridam was installed, the NO_3-N concentrations at the Fabridam were less than those 3005 m upstream and were lower by 1 to 5 mg/L during the times of control. This indicates that although high NO_3-N concentrations were entering the SWLC area, they were reduced considerably by the time the water passed over the Fabridam. Stream flow measurements were made, but the calculations are not complete. Our first estimates indicate that the NO_3-N in the stream was reduced by about 25% with SWLC.

The NO_3-N concentration in the water table 2.5 m below the surface between 15 August 1980 and 15 August 1985 is shown in Figure 5. The NO_3-N concentrations before the dam was installed were lower in the control area above the dam site than in the no control area below the dam site. Above the dam site, the water table was at depths greater than 2.5 m most of the time, which accounts for the lack of data from November 1980 to February 1982. During the periods of control, after the Fabridam was installed, NO_3-N concentrations in the water table at 18 m from the creek were considerably less with SWLC than without it. However, this reduction during periods of control was not as pronounced at other distances from the Creek (Figure 6). For example, there was little change in the concentration at 885 m from the Creek until February 1984, the beginning of the wettest year, when the rains came and the concentrations began to rise.

Average NO_3-N concentrations before the Fabridam was installed increased from about 2 mg/L to 3.5 m as the stream water level elevation increased from 9.5 to 10.5 m. The average NO_3-N concentration after the Fabridam was installed, 2 April 1983, is shown in Figure 7. As the stream water level increased from 9.50 to 10.00 m, concentrations increased only slightly. But, as the stream water level elevations increased from 10.00 to 11.75 m, the average NO_3-N concentration decreased from about 4 mg/L to about 2 mg/L. This decrease of 2 mg/L in NO_3-N concentrations will improve the water quality downstream.

There are four factors believed to cause the decrease in NO_3-N concentrations in the stream flow: (1) an increase in denitrification throughout the drainage area influenced by the decreased depth to the water table with SWLC (This was especially true near the Creek where the water table was raised most.), (2) increased nitrogen uptake by the crops as shown by increased yields, (3) further denitrification as the subsurface water flowed from the fields into the stream channel, and (4) denitrification which takes place in the stream channel itself.

Normally, there is more phosphorus in the surface runoff than in subsurface flows. High water table levels with SWLC could have increased runoff and caused more phosphorus in the stream flow at the Fabridam, but there was little runoff from the area and little change in phosphorus concentrations throughout the measurement period (Figure 8). Concentrations of potassium in mg/L are also shown in Figure 8. Highest concentrations of potassium occurred in October 1980 and 1981 without SWLC. The lowest concentrations of potassium occurred during the summer months throughout the sampling period, both before and after the Fabridam. Concentrations of potassium during the summer months were about the same with and without SWLC. However, during the peak potassium concentration periods of October to January, potassium concentrations were considerably less after the Fabridam was installed. The stream water level was at a higher elevation most of the time during the winter months after the Fabridam was installed. Overall, potassium concentrations were less after the Fabridam was installed, especially during the wettest year, 1984.

SUMMARY AND CONCLUSIONS

Irrigation water supply and water quality were studied from 1980 to 1985 in a 1330-ha area along Mitchell Creek in Edgecombe and Pitt Counties, North Carolina. In 1980 and 1981, measurements were made with Mitchell Creek flowing unrestricted. During the period, 1982 through 1985, the area was studied with a Fabridam placed in Mitchell Creek to provide stream water level control.

In 1980 before the Fabridam was installed, farmers were using 2-center pivots and 2-volume guns, irrigating 79 ha. In 1985, after the Fabridam was installed, farmers were using 8 center pivots, 4 volume guns, and 1 controlled-drainage/subirrigation system, irrigating 327 ha. It was estimated that more than 1.5 times the maximum water pumped for irrigation remained in storage, a potential supply sufficient to irrigate 56% of the land area affected by the Fabridam or about 450 ha.

Stream water level control provides underground storage of water for irrigation supply and at the same time provides increased yield of nonirrigated crops through water table control. The four-year average corn yields with SWLC were 33% higher than those without SWLC in nonirrigated fields. Corn yields in the irrigated fields with SWLC were 71% higher than those in nonirrigated fields without SWLC.

The water quality in the stream flow was improved by SWLC. NO_3-N concentrations were reduced. Although it was expected that P and K concentrations might increase with the high water tables, P concentrations changed very little, and K concentrations were lower during the winter months after SWLC.

Stream water level control should be used in the future to increase the supply of irrigation water, which will relieve the strain now being placed on deep groundwater aquifers, to maximize yields, and to improve the quality of water in the stream flow.

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TABLE 1

Irrigation water pumped and hectares of surface watering, 1980-85

Year	#System Used* CP	VG	CDSI	Avg. Yearly Irrig. Appl.	Area Covered/ Surface Watering	Irrig. Water Pumped from Mitchell Creek
				mm*	ha	m^3**
1980	2	2	-	122	79	96,234
1981	2	3	-	159	118	187,970
1982	5	3	-	80	142	114,280
1983	6	4	1	175	210	352,840
1984	6	3	1	2	285	6,530
1985	8	4	1	82	327	261,284

* CP = center pivot; VG = volume guns; CDSI = controlled-drainage/subirrigation system

** Water applied to the 8-ha CDSI system was not measured

TABLE 2

Corn yield from six water table management systems

Water table management	1983 Dry - 175 mm of irrigation	1984 Wet - 2.0 mm of irrigation	1982-85 4-year average
NO SWLC*			
Rainfed			
Below structure	3,193 d	7,853 b	6,115 c**
Above control area	5,435 c	5,385 c	5,497 c
Mean	4,314	6,619	5,806
Sprinkler irrig. Above control area	7,844 b	9,536 a	8,627 b
WITH SWLC			
Rainfed	5,402 c	7,173 b	7,749 b
Sprinkler irrig.	9,959 a	10,466 a	10,452 a

* SWLC = stream water level control

** Yields followed by the same letter in the same column are not significantly different at the 5% level for the DMRT test or LSD.

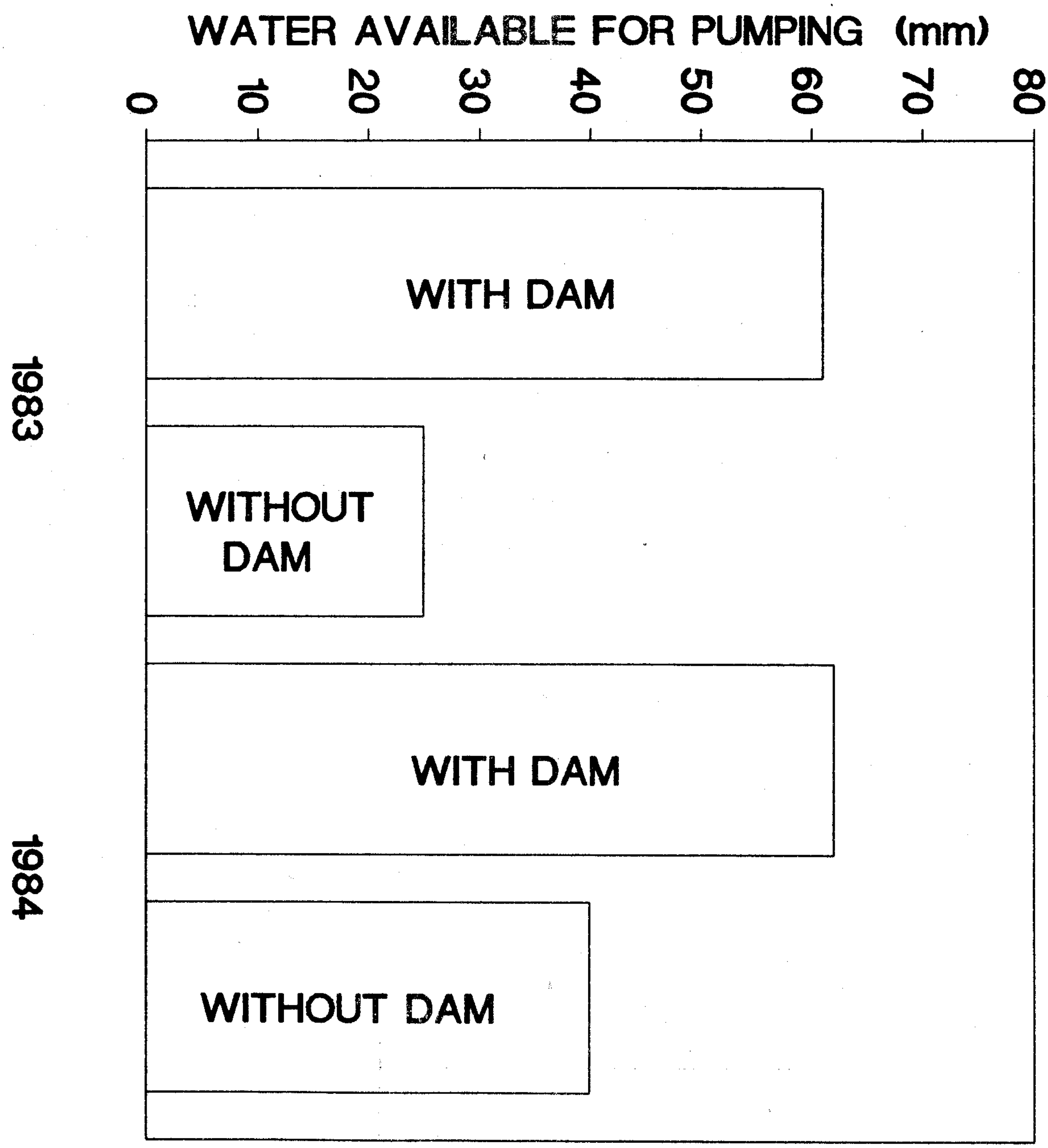

Figure 1. A computer model prediction of water available for pumping to irrigate the entire 800-ha area of the watershed during a 19-day drought period in 1983 and a 19-day drought period in 1984, with and without the Fabridam.

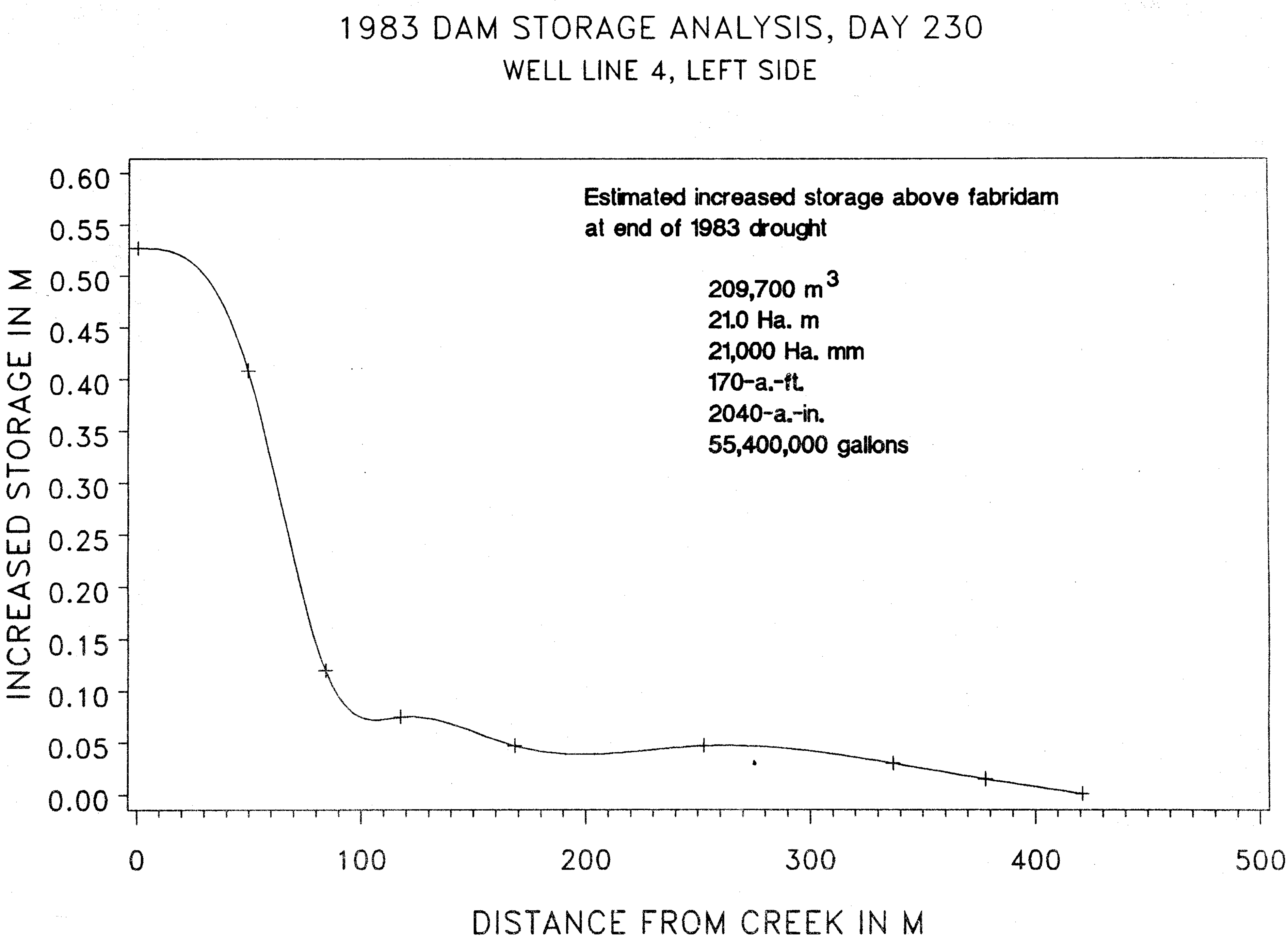

Figure 2. Computer model simulation of the distribution of water storage in relation to the distance from the Creek on 18 Aug 83, the end of the 1983 drought.

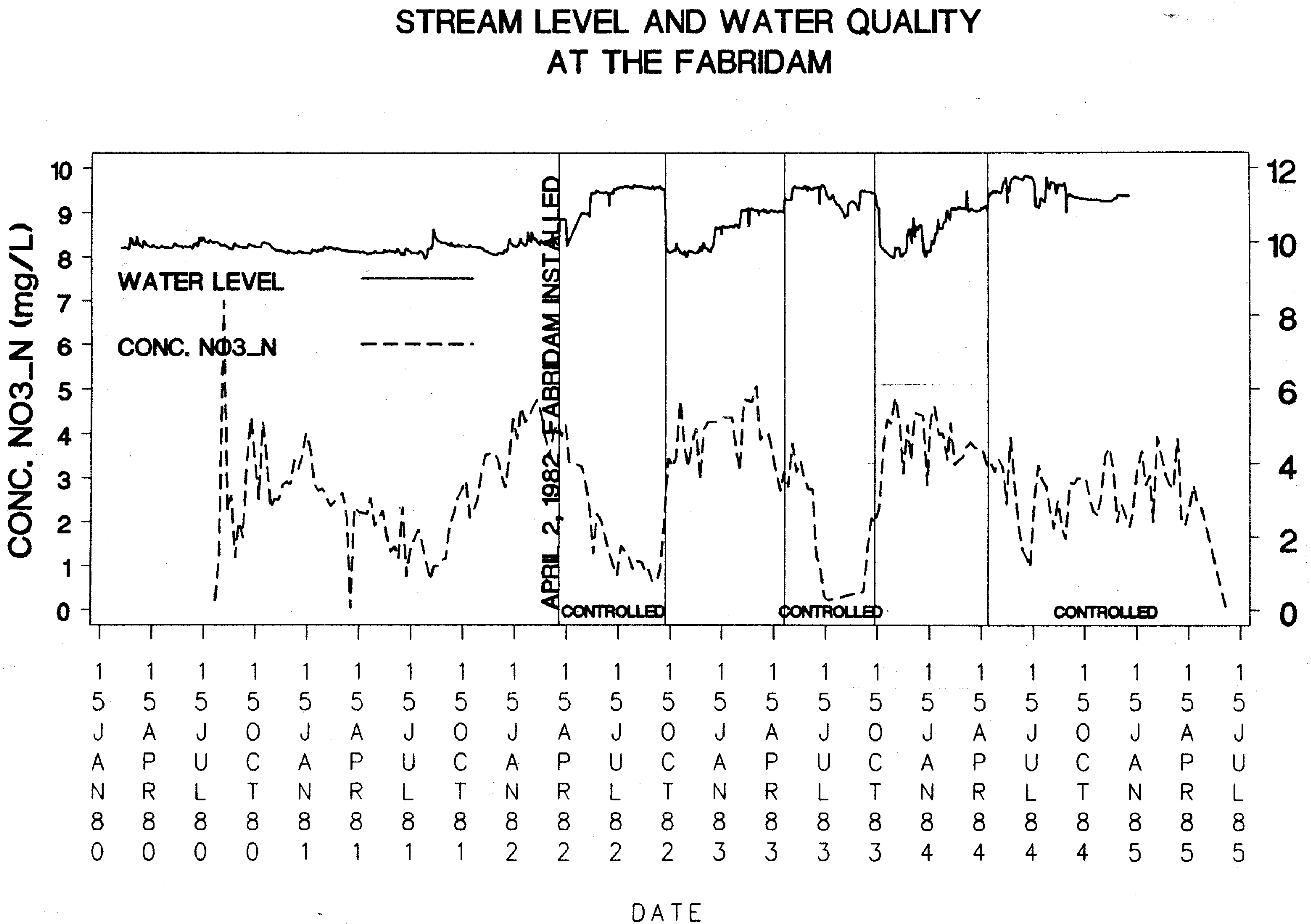

Figure 3. NO_3-N concentrations and stream water level elevations at the Fabridam site from 15 Jan 80 to 15 Jul 85 showing the various periods of SWLC.

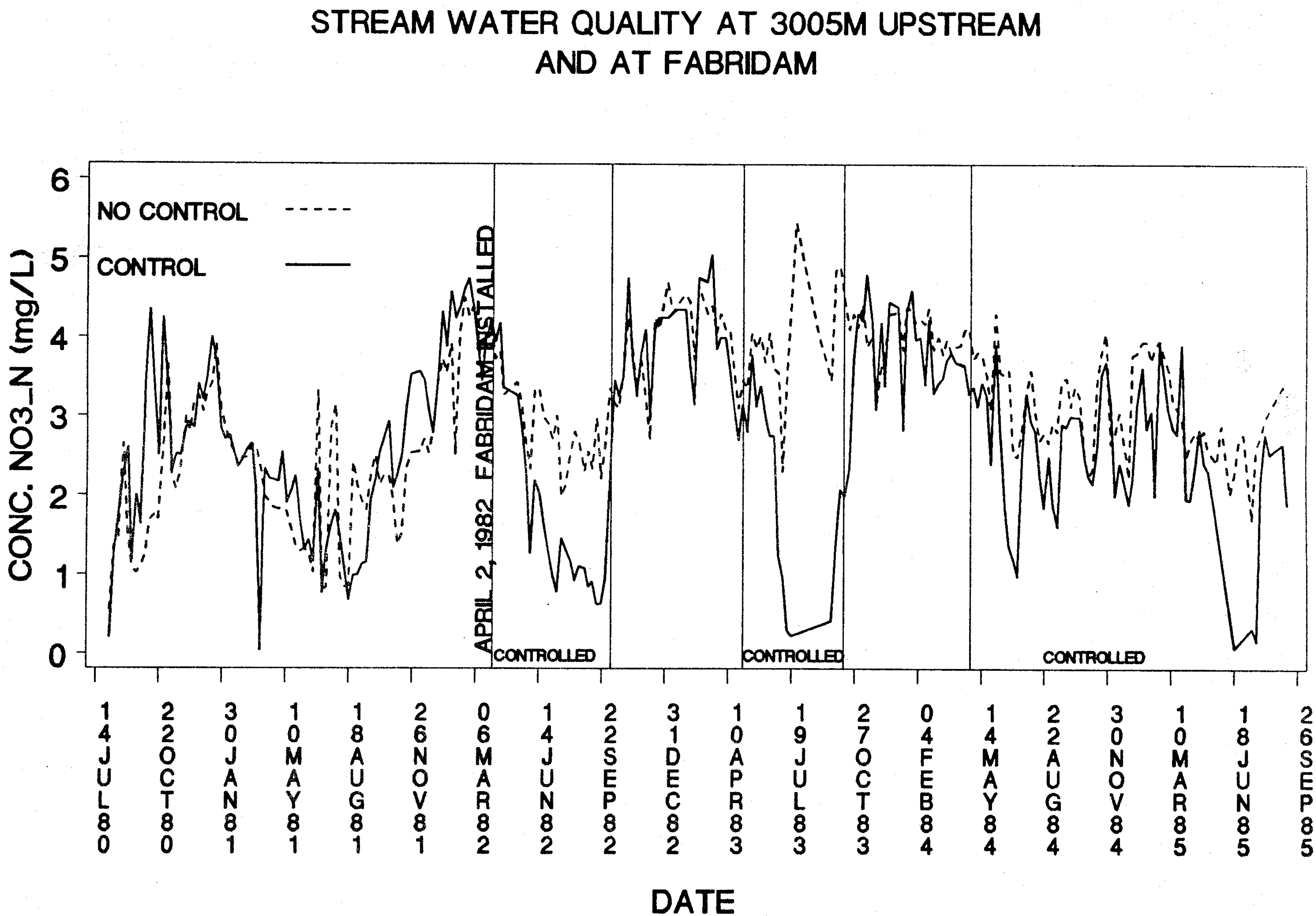

Figure 4. Comparison of NO_3-N concentrations at the Fabridam with SWLC and 3300 m upstream without SWLC.

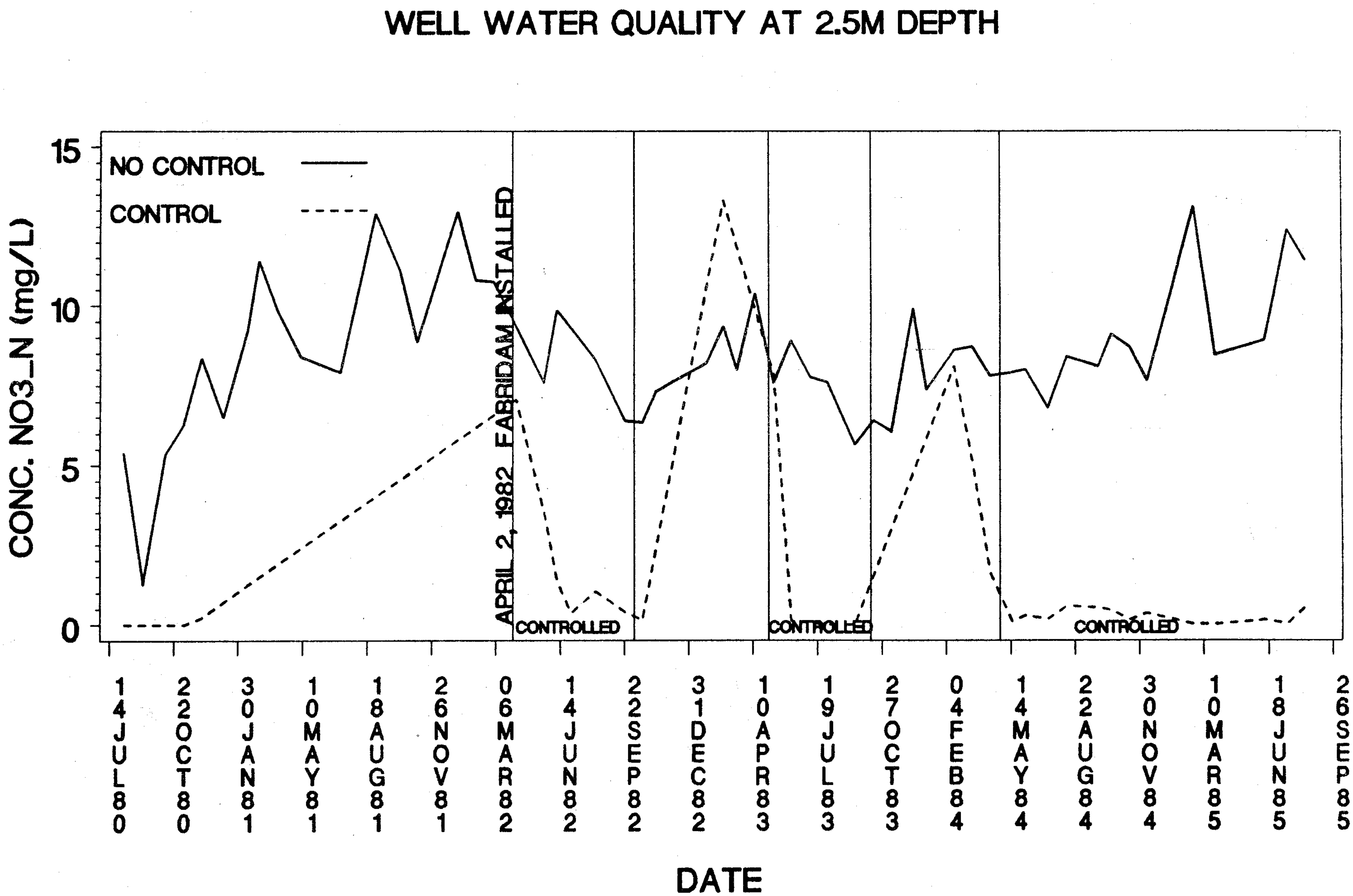

Figure 5. NO_3-N concentrations in the groundwater table 2.5 m below the surface from 15 Aug 80 to 15 Aug 85 from the SWLC (control) and without SWLC (no control) areas.

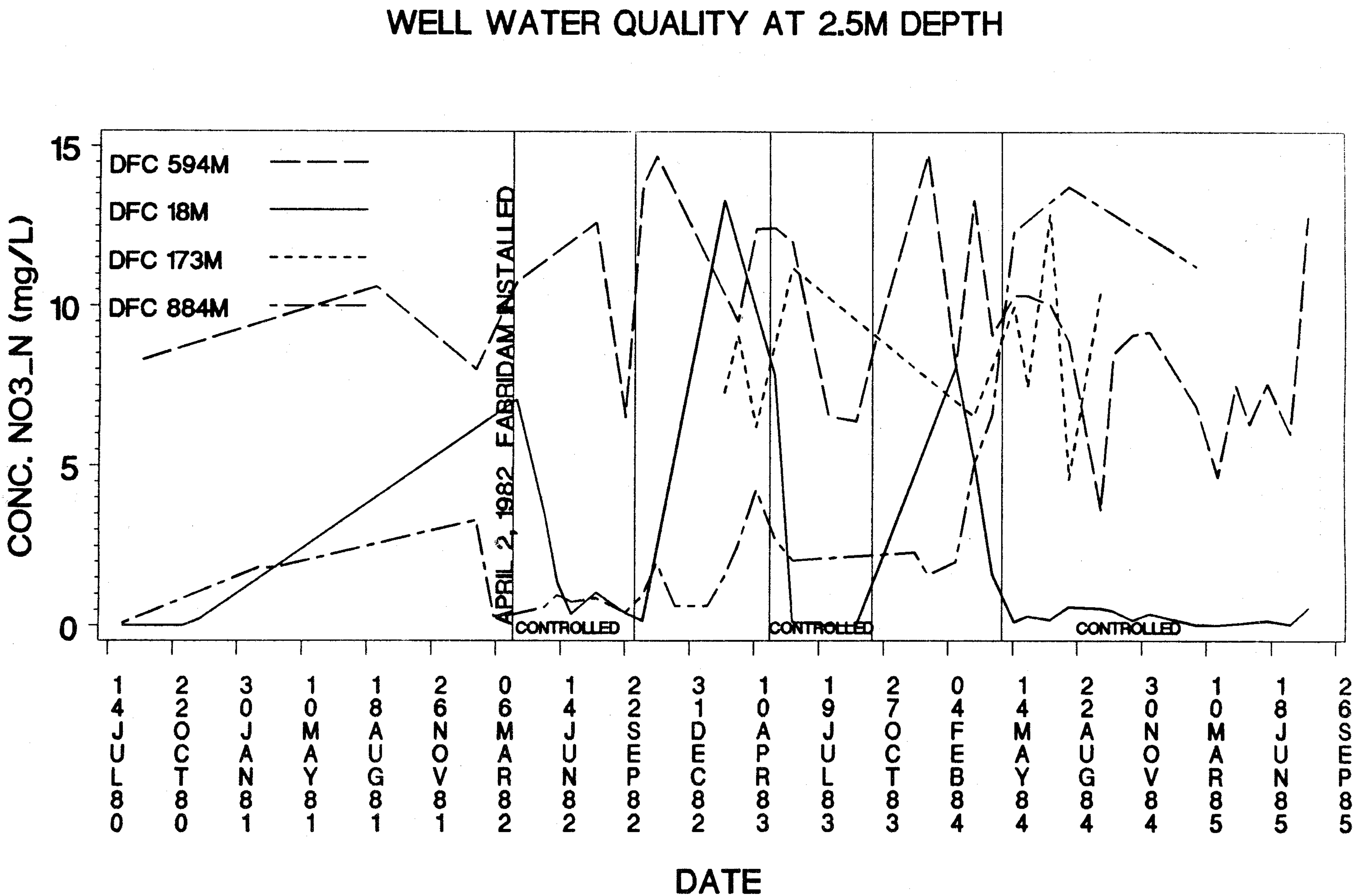

Figure 6. NO_3-N concentrations at various distances from the stream channel in the SWLC area.

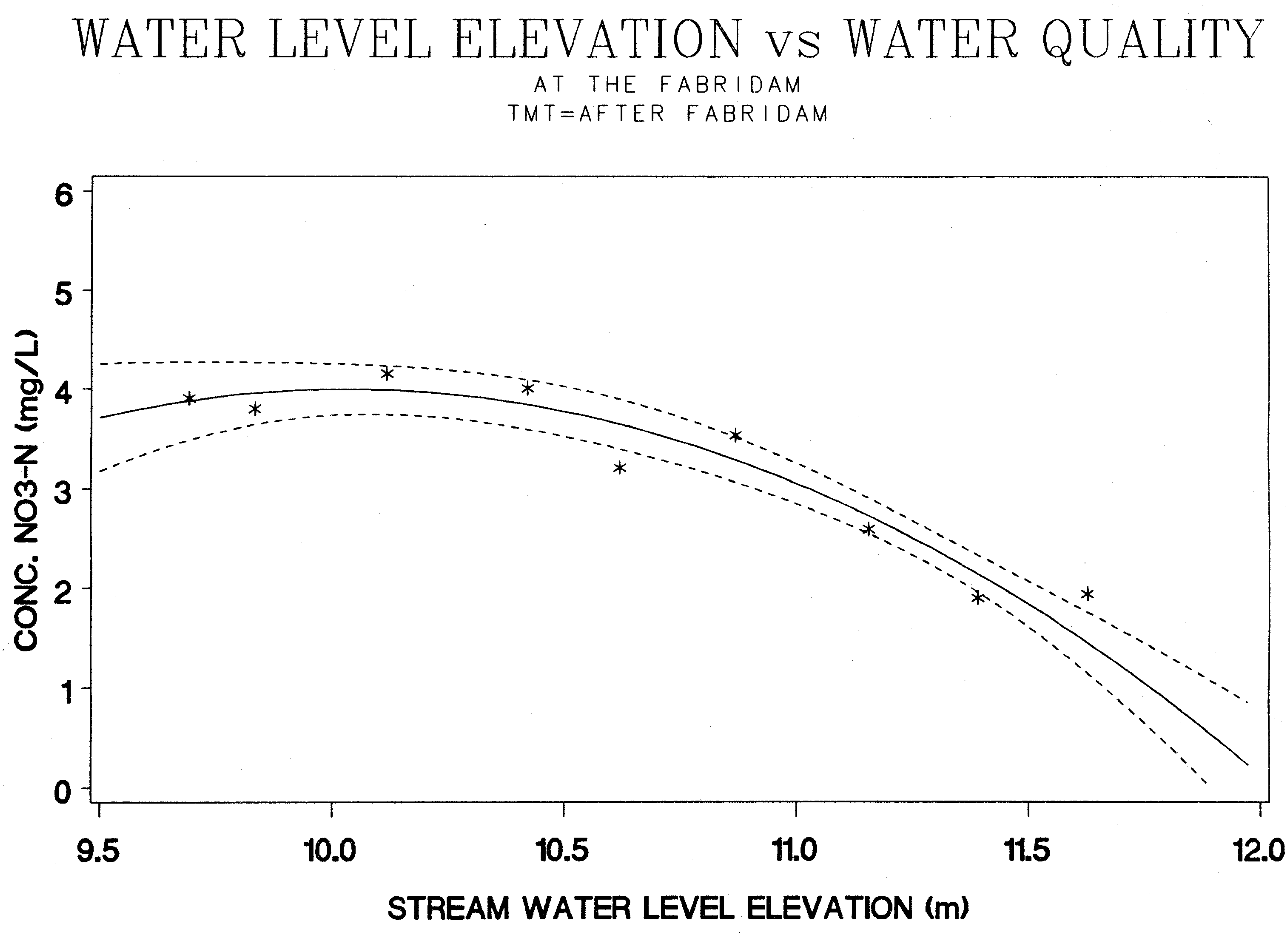

Figure 7. Average NO_3-N concentrations vs. stream water level elevation after the Fabridam was installed.

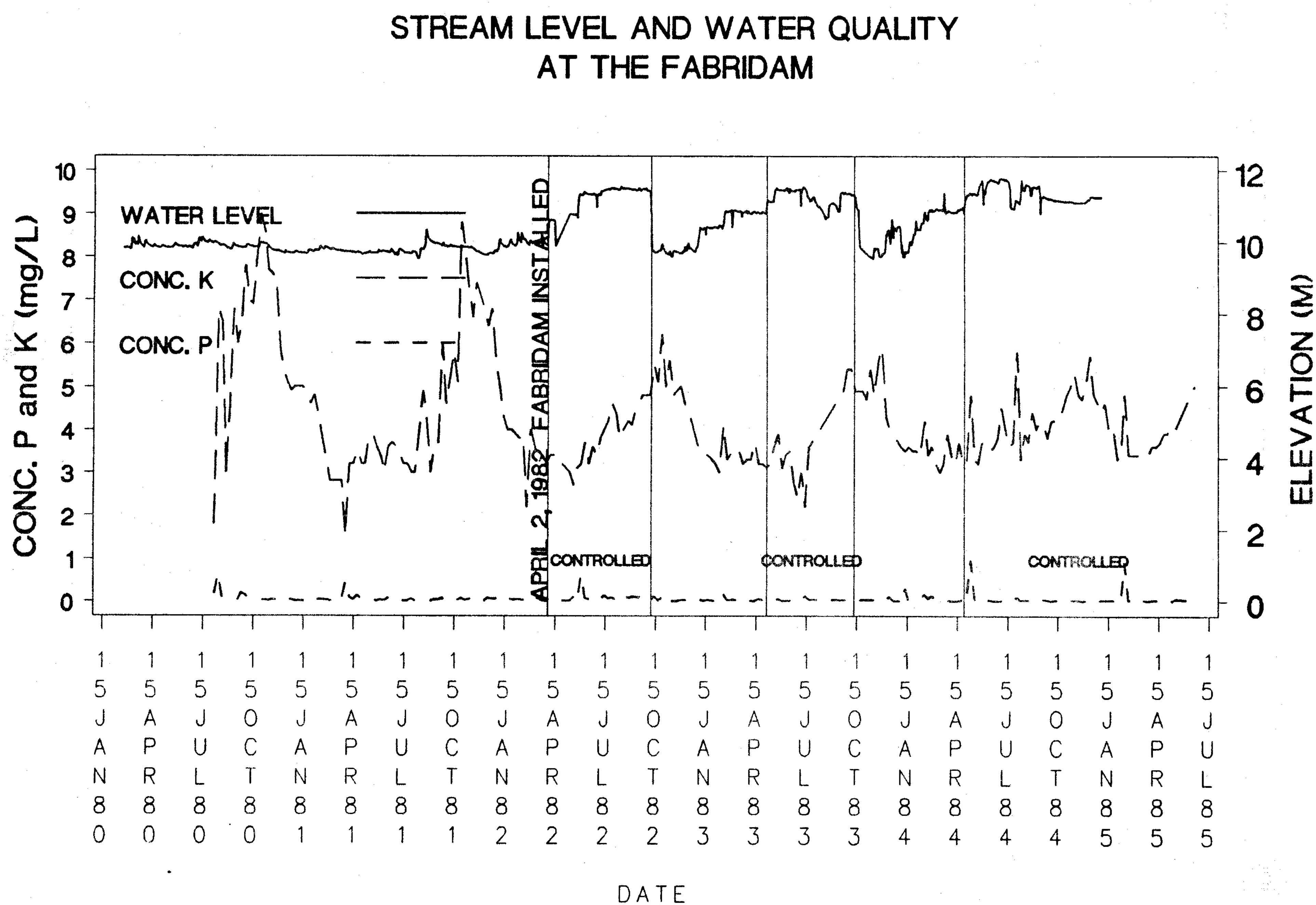

Figure 8. Concentrations of P and K mg/L in relation to stream water level elevation 15 Jan 80 to 15 Jul 85.