Performance of an Inflatable Dam During Extreme Events

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ABSTRACT

A Fabridam* placed across Mitchell Creek in Edgecombe and Pitt Counties, N. C. to increase the stream water level depth during drought and provide for flood control during excessive rainfall was observed for three years. One year received below normal rainfall, the next was an extreme drought year during the growing season, and the third year received above normal precipitation. To evaluate the effects of stream water level control during extreme events and to evaluate stream water level control on the water table levels and irrigation water pumped during droughts, measurements of flow past the Fabridam were used.

Although there were several extreme rainfall events, the flow depth over the Fabridam never exceeded the two automatic control settings. However, it was necessary on several occasions, due to high water table levels, to lower the automatic stream water level settings to facilitate field drainage. Stream water level control can be effectively utilized to store water underground for crop use, and controlling the stream water level had no adverse effects on downstream flow during a drought.

INTRODUCTION

There are about 3.4 million ha of drained sandy loam and organic soils in the South Atlantic Coastal Plain (Wenberg and Gerald, 1982). It is estimated by Soil Conservation Service personnel that there are an additional 1.5 million ha of these soils from Virginia to New Jersey. In the Mid-Atlantic Coastal Plain, soils that flood often must be drained to protect property and crops; however, sandy soils drained too deeply will develop drought stress unless rain occurs within 4 to 7 days (Doty et al., 1975).

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The research is the composite cooperative effort of agencies from USDA-ARS and SCS; the North Carolina Agricultural Research Service, North Carolina State University; the Edgecombe County Drainage District #2; and local farmers and landowners.

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TABLE 1. IRRIGATION WATER PUMPED, AND HECTARES OF SURFACE IRRIGATION FOR 1980-85

Year	System used* CP	VG	CDSI	Avg. yearly irrigation applied	Area covered/ surface irrigation	Irrig. water pumped from Mitchell Creek
	No.			mm†	ha	m³†
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	3	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

Flooding occurred periodically before a ditch drainage system was installed in 1967 on Mitchell Creek in Edgecombe and Pitt Counties, North Carolina. After the ditch drainage system was installed, water table levels within the watershed dropped as much as 2.5 m below the surface near the streams, affecting crop yields up to 400 m away from the creek (Doty et al., 1982). As a result, farmers began using center pivots and volume guns to alleviate the drought stresses to their crops. Domestic well points had to be lowered. During periods of drought, little water was available to be pumped from Mitchell Creek for irrigation, only enough to partially supply two center pivots and 2 volume guns (Table 1).

Research was begun in 1979 to assess the need for stream water level control (Doty et al., 1982). That research showed that the water table was lowered to as much as 2.5 m below the soil surface near the Creek. In April 1982, a water inflatable dam (Fabridam) was installed across Mitchell Creek (Doty et al., 1984b). One question that was unanswered was how well the Fabridam would function during extreme events of flooding and drought.

The Fabridam (Fig. 1) was designed to (a) allow flood waters to pass in the same manner as in the original ditch drainage system, (b) control the stream water level in Mitchell Creek to raise the water table levels in the field, thereby, reducing drainage to the creek, and (c) conserve water by raising the water table and storing water underground for crop use instead of allowing it to flow downstream into the rivers and to the Atlantic Ocean. This paper describes the performance of the Fabridam and its effect on upstream and downstream water levels, amount of irrigation water supplied, and water table elevations in adjacent fields during extreme events of excessive rainfall and drought. Rainfall for an extreme event is a single event of more than 50 mm or a period of rains with one event greater than 50 mm. For our purposes, a drought is a period of time with no flow over the Fabridam.

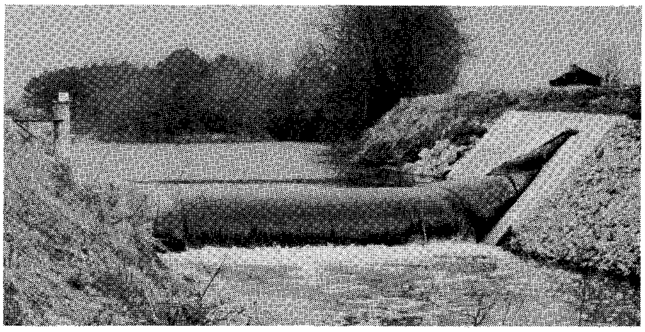

Fig. 1—The Fabridam on Mitchell Creek, N. C.

MATERIALS AND METHODS

The 2.7-m high Fabridam structure (Fig. 1) was installed across Mitchell Creek, Pitt County, NC, about midway of the 3.5-km channel section in the study area and put into operation in April 1982 (Doty et al., 1984a, 1984b). The Fabridam is a water-inflatable structure made of 2-ply nylon rubber-coated fabric bolted to a concrete pad formed to the shape of the stream channel. The stream crosssection is 5.8 m wide at the bottom of the creek and 12.5 m wide at bank height. The dam is inflated through pipes in the concrete pad from the water tower located about 8.3 m above the stream bottom. The water tower is kept full by a pump. Automatic monitors are used to control the water level between 9.3 m (pad bottom) and 11.9 m above mean sea level (MSL). The Fabridam deflates through pipes in the concrete pad to downstream which allows flood to pass.

The Fabridam operates in the following manner. Control levels are set on the dam for various seasons of the year and can be changed at any time if the weather warrants. For example, in order to obtain the maximum storage of water underground in the summer, the water surface elevation of the stream would be set at a maximum of 11.75 m above MSL, leaving about 0.7 m freeboard to the top of the stream bank. When rainfall causes the upstream water level to rise 0.15 m, the Fabridam begins to deflate, but will still control the upstream water level between 11.75 and 11.9 m above MSL. If the stream level continues to rise to 11.93 m (0.18 m rise), another valve opens, and the Fabridam deflates faster but will still maintain the upstream water level between 11.75 and 11.93 m above MSL. If the upstream water level continues to rise to about 11.96 m (0.21 m rise), a 0.203-m dia. syphon will deflate the Fabridam at a rate of about 0.06 m/min to a preset stream water elevation of about 10.35 m above MSL. When the upstream water level is lowered to this point, the syphon is broken, and the Fabridam is automatically inflated to the original setting of 11.75 m above MSL. When extended rainfall periods cause extreme high water tables in the area, it is necessary to manually lower the dam control setting to keep the water table more than 0.6 m below the soil surface.

The flow over the Fabridam was calibrated in situ. A water stage recorder was placed in the sensing line to the Fabridam. The crest height of the dam was determined in relation to water level (pressure) inside the Fabridam. Side slopes and crest widths were determined for various crest heights. A relationship for the radius of the dam surface in contact with the water was developed with information on the shape of the dam and the crest height obtained from the designers, Fabridam engineers, N. M. Imbertson and Associates, Burbank, California. A relationship was determined for the average width of flow (AWF) in relation to crest height. The depth of flow was determined by the difference in the recorded stream water level upstream from the Fabridam and the recorded crest height of the dam. A relationship which utilized the discharge coefficient (DC), the flow depth over the dam (H), and the radius of the dam (R) at any crest height was developed. The instantaneous flow over the Fabridam was calculated from the cylindrical crested weir formula (M. G. Bos, ed. 1976) rewritten in the form of equation [1].

$$q_t = a(H/R)^b\ 2/3\ (2/3g)^{0.5}(AWF)H^{1.5} \quad \ldots\ldots\ldots [1]$$

where

q_t = the rate of flow over the dam at any time t.
a,b = numerical coefficients (a = 12.984, b = 0.879) determined for the dam in situ.
H = depth of flow over the dam at time t.
R = radius of dam surface at time t.
g = acceleration of gravity.
AWF = average width of flow at time t.

The $q_{t1} + q_{t2} + \ldots + q_{tn}$ were then summed according to time to obtain daily, monthly, and yearly flows.

Selected storm events were used to depict the operation of the Fabridam. Data were used from the stream gage recorders on Mitchell Creek above and below the Fabridam. Data on water table elevations were obtained from stage recorders in the field.

RESULTS AND DISCUSSION

Weather conditions were variable during the three-year study. Growing season rainfall by months for the three-year period is shown in Table 2. Compared to the mean for 30 years of data from Wilson, NC, the growing season rainfall (April through September) was below normal in 1982 and 1983 and above normal in 1984. Although the Fabridam was installed in April 1982, the recording equipment on the Fabridam was not completed until early August. For the three-year period, the Fabridam was set at a low elevation during the first winter [Calendar Day (CD) 278, 1982]. The Fabridam was operated during the winters of 1983 and 1984 at a higher elevation to reduce nitrate losses through drainage.

TABLE 2. MONTHLY GROWING SEASON RAINFALL AND DAILY MAXIMUM EVENTS ON THE PROJECT SITE AND THE 30-YEAR NORMAL RAINFALL FOR WILSON, N.C., ABOUT 30 MILES AWAY

	Rainfall			30-Year	Daily maximum events		
Month	1982	1983	1984	average	1982	1983	1984
	mm						
April	94	59	84	83	44	20	25
May	24	104	184	96	24	38	64
June	90	58	30	106	30	25	14
July	78	59	260	151	50	20†	50*
August	119	79	101	135	80*	70†	32
September	95	135	123	105	43	71†	74
Total	500	494	782	676			

*Extreme drainage event discussed in this study.
†Extreme drought event discussed in this study.

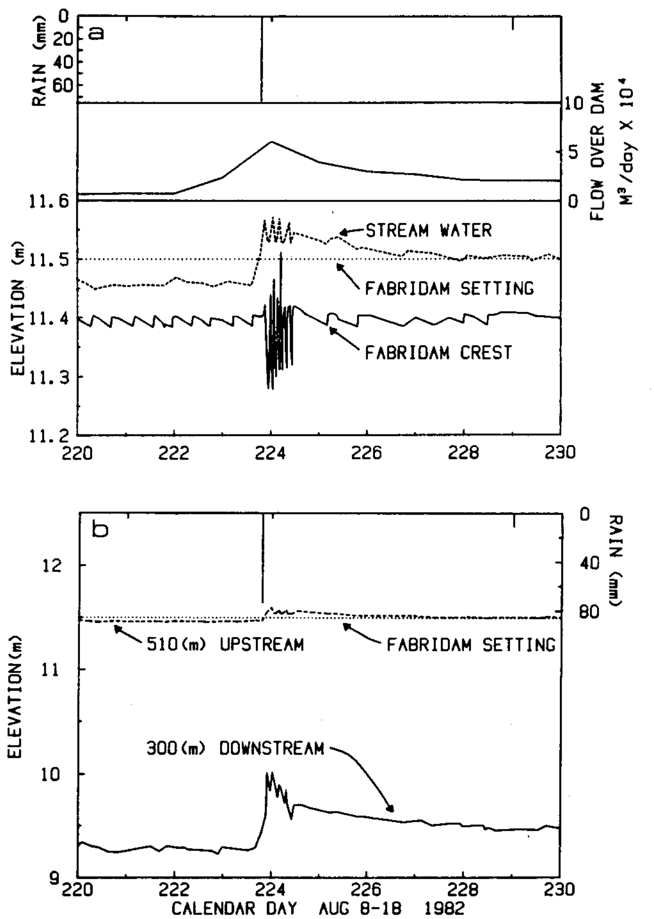

Fig. 2—Performance of the Fabridam during a single, storm event. (a) Rainfall, stream flow rates, stream water levels, Fabridam settings, Fabridam crest elevations. (b) Stream water level elevations at 510 m upstream and 300 m downstream from the Fabridam with Fabridam settings.

Water Table Control During High Rainfall Events

The Fabridam operated automatically during more than 50 storms in 1982, 1983 and 1984; in addition, more than 20 manual operations were needed. One of the automatic operations during an extreme event is shown in Fig. 2. About 80 mm of rainfall (CD 223) caused the Fabridam to fluctuate about 10 times on Calendar Days 223 and 224. The stream water level rose about 0.1 m during the period after the rain, but remained within $\pm$ 0.06 m of the control setting of 11.5 m above MSL which is within the specifications for the Fabridam (Fig. 2a). Fluctuations of the dam crest height before the rainfall event were caused by the sun heating up the fabric which in turn changes the internal pressure in the dam. Stream water levels 510 m upstream and 300 m downstream from the dam are shown in Fig. 2b. The stream water level 510 m upstream remained very close to the 11.5 m above MSL for which the control level was set. At 300 m downstream from the Fabridam, the flow increase over the dam (Fig. 2a) caused a 0.75-m rise in the stream water elevation.

Changes in elevation settings for control of the Fabridam during a relatively wet year, 1984, are shown in Table 3. Extreme rainfall events occurred on CD 45, 151, 195, and 258 in 1984. The Fabridam setting had to be lowered for each of these events, except CD 45, and in this case, the dam was already set at a lower elevation.

TABLE 3. ELEVATION SETTINGS FOR CONTROL OF THE FABRIDAM DURING CALENDAR YEAR 1984

Date (CD)*	Elevation	Reason for change
	----m----	
Winter setting	10.4	Nitrate control
Jan 3 (3)	9.4	Bridge maintenance
Jan 28 (28)	10.4	Nitrate control
Feb 21 (52)	10.8	Water storage
Apr 27 (118)	11.3	Water storage
May 28 (149)	11.7	Water storage
May 30 (151)	11.1	Heavy rain
Jun 6 (158)	11.7	Water storage
Jul 16 (198)	10.8	Heavy rain
Aug 6 (219)	11.7	Water storage
Aug 10 (223)	11.4	Heavy rain
Aug 13 (226)	11.7	Water storage
Sep 11 (255)	11.0	Hurricane Diana
Sep 17 (261)	11.3	Water storage and nitrate control
Dec 11 (346)	11.3	Nitrate control

*CD = Calendar day

The Fabridam setting was also lowered on CD 223 because of several smaller events. Several smaller events occurred after the extreme event on CD 195, and for that reason, this period of time will be discussed.

The Fabridam adequately controlled the stream flow over a 6-day period around CD 195 in 1984 when 113 mm of rain occurred from five events (Fig. 3a). The automatic controls were efficient in controlling the upstream water level throughout the period. However,

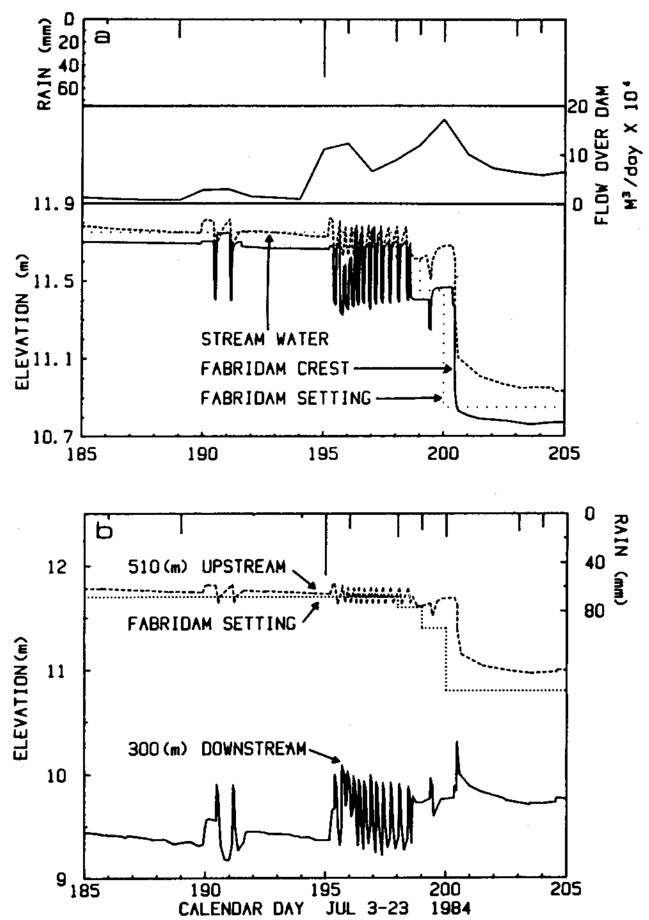

Fig. 3—Performance of the Fabridam during several rainfall events. (a) Rainfall, stream flow rates, stream water levels, Fabridam settings, Fabridam crest elevations. (b) Stream water level elevations at 510 m upstream and 300 m downstream from the Fabridam with Fabridam settings.

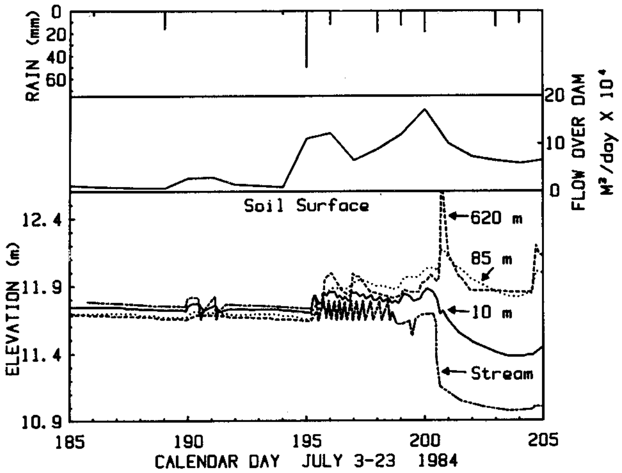

Fig. 4—Rainfall, flow rate over the Fabridam, and soil-water table elevations at various distances away from Mitchell Creek and 510 m upstream from the Fabridam.

about CD 200, the Fabridam setting had to be lowered to provide drainage in adjacent fields. Water levels in Mitchell Creek, about 510 m upstream and 300 m downstream for this period (Fig. 3b), show water level fluctuations caused by rainfall and the Fabridam control of the upstream water level. The Fabridam controlled the upstream water level within design specifications. The downstream level fluctuated more than the upstream level due to the increased flow over the Fabridam. This additional flow is shown in Fig. 3a.

Water tables in the field during the period were controlled at about 1 m from soil surface until a 50-mm rain on CD 195 in 1984 (Fig. 4). After the 50-mm rain and four additional rains, water tables rose and came to the soil surface at 620 m away from and perpendicular to the stream. From CD 186 to the 50 mm rainfall on CD 195, the water table gradient sloped from the stream to a point 620 m away (Fig. 4). After the 50-mm rain on CD 195, this gradient changed so that drainage flowed toward the stream, but the slope was not steep enough to provide sufficient drainage to keep the field water table from rising. On CDs 198, 199, and 201, stream water levels were lowered, and within a two-day period, water tables in the field dropped to around 0.9 m below the soil surface. However, because of a 1 or 2-day delay in lowering the stream water level, the water table at 620 m rose to the surface for a short period. After two days, there was a drainage gradient at 620 m to 85 m from the stream. As shown in Fig. 4, this gradient increased at points closer to the stream.

The fact that the control elevation on the Fabridam had to be manually changed 13 times during 1984 (Table 3) and the automatic controls began operating soon after rainfall began (Figs. 2, 3) shows that control structures on main channels or creeks should be easily operated and automatically controlled. A system involving the removal or addition of stop logs or boards would require time and labor for each change. Without the removal or addition of the boards, crops could be damaged or water lost from storage.

There were several extreme rainfall events during the three years; however, the flow depth over the dam never exceeded the two automatic control settings, i.e., the syphon never completely lowered the dam. It was necessary on several occasions to lower the automatic controls for stream water level due to extremely wet field conditions. This shows that to provide control of water table levels in the fields adjacent to a stream such as Mitchell Creek and to control stream flow during heavy rainfall periods, the control structure should be automatic and easily lowered or raised at times of intense or prolonged rainfall. A control structure can range from a Fabridam-type structure to a flashboard riser with automatic controls attached. Automatic controls should be considered in the design of stream water level control structures to provide for flood protection during heavy rainfall periods even on a small stream.

Water Table Control During Drought

The stream drainage system completed in 1967 reduced the water table levels in the fields but caused increases in drought stresses to crops in adjacent fields. Farmers began using center pivots and volume guns to alleviate the drought to their crops. The water pumped from Mitchell Creek could only supply water for two center pivots and two volume guns in 1980. These systems covered only 79 ha of crops, mainly corn and tobacco. However, installation of the Fabridam to supply stream water and underground storage of water in the shallow underground aquifer has changed the farmers' outlooks. Irrigation systems have continually increased from 1980 to 1985 (Table 1). In 1983, 3.7 times more water was pumped from Mitchell Creek for irrigation than in 1980 with 2.6 times more area irrigated. In 1985, 8 center pivots, 3 volume guns, and a controlled-drainage/subirrigation system were fully operated on water pumped from Mitchell Creek (Table 1).

During a 64-day period in 1983, CD 194 to 258, little or no water flowed over the Fabridam because of a lack of rainfall and irrigation pumping (Fig. 5). The lowest elevation of the stream during this drought was about 10.7m above MSL. Before CD 235, 308,640 m^3 of irrigation water was pumped from Mitchell Creek causing the water level to drop about 0.8 m. A 70-mm rain on CD 235 relieved the drought, but did not refill the soil profile. Another 71 mm rain occurred on CD 256 refilling the depleted soil water storage and causing stream flow over the Fabridam at a normal elevation of 11.5 m above MSL. Through CD 256, 342,878 m^3 of irrigation water were pumped from the Mitchell Creek system for supplemental irrigation.

Stream water levels 510 m upstream and 300 m downstream from the dam are shown (Fig. 5b). Although the upstream water level dropped 0.8 m from CD 190 to CD 235, the downstream water level rose slightly at 300 m below the dam. The rising downstream water level without flow over the Fabridam can be explained by water table changes and groundwater flow. When the stream water level (Fig. 3a) was lowered about a meter, the water table level also dropped (Fig. 4). This caused a gradient change (the head on groundwater flow in the Darcy equation) from 60 m upstream from the Fabridam to about 305 m downstream. Before the stream water level was lowered (CD 200, Fig. 4), the gradient (not shown) was about 1.5 m over 365 m or .004 m/m. Four days later (CD 204, Fig. 4) the gradient was about 1.2 m over 365 m or 0.003 m/m. The drop in the water table

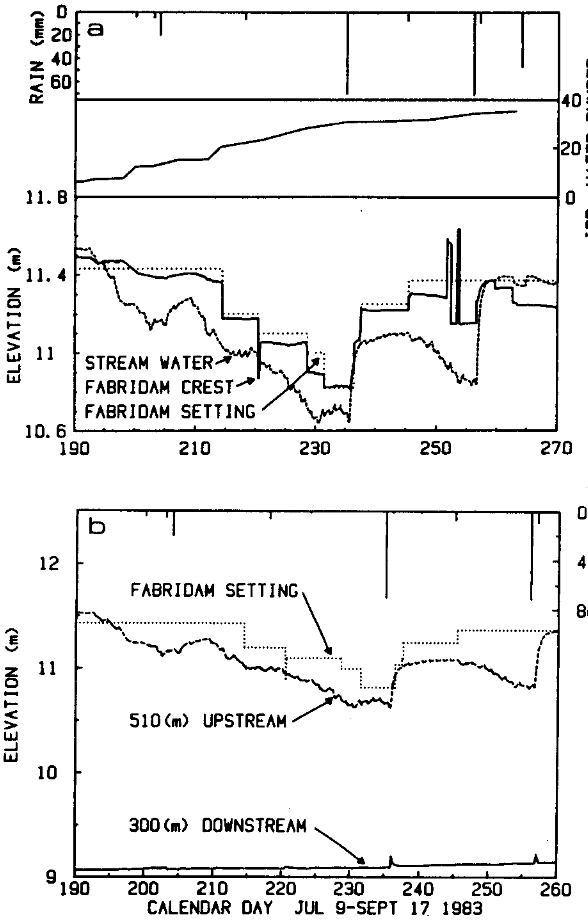

Fig. 5—Performance of the Fabridam when there was high water use with no flow over the Fabridam. (a) Rainfall, rate or irrigation pumped from the stream, with stream water level, Fabridam-crest height and Fabridam-setting elevations. (b) Stream water level elevations at 510 m upstream and 300 m downstream from the Fabridam with Fabridam settings.

level from CD 200 to 204 (Fig. 4) also changed the area of flow per unit width by about 0.5 m. These changes can cause as much as a 25% drop in flow rate. The reverse of this happened during the drought period in 1983. High stream water levels (Fig. 5b) and associated high field water tables caused increased groundwater seepage to the lower stream water levels downstream which maintained base flow in the stream without flow over the Fabridam. Therefore, if water was being pumped from Mitchell Creek below the Fabridam (in this case, there was none), the same amount of downstream water would be available as would have been available without stream water level control. Stream water level control helped to store 352,840 m^3 of water that was pumped for irrigation, and additional water was available for crop consumption to increase nonirrigated crop yields. Water was stored as shallow groundwater, thus preventing it from flowing down Mitchell Creek into the Tar River and to the ocean.

For the full-growing season which ended CD 283, a total of 352,840 m^3 of water was pumped for supplemental irrigation. However, this pumping did not exhaust the underground storage (Fig. 6). Water cannot be pumped from Mitchell Creek below the stream bottom and water stored in the soil cannot flow into Mitchell Creek without a gradient. Therefore, any water storage below the lower dotted line on Fig. 6 is assumed

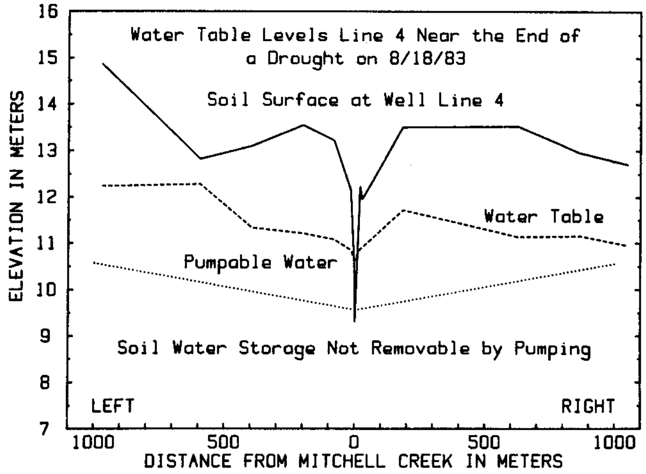

Fig. 6—Soil water storage below the surface at the end of a drought. A cross-section 510 m upstream from the Fabridam.

to not be available for pumping and of little value for crop use. It is 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.

Water table elevations at 15, 80, and 595 m perpendicular from Mitchell Creek, stream water levels and average soil surface elevations about MSL are shown in Fig. 7. Stream water levels and water table levels at 15 m from the creek dropped more rapidly than the water table level at 80 m from the creek. At 595 m from the creek there was little drop in the water table level during the first 45 days of the drought period. During this time, 308,640 m^3 of water was pumped from Mitchell Creek, but water was still available for pumping. The 70-mm rain on CD 235 caused a 0.6-m rise in the water table at 595 m from the creek, but only a 0.15-m rise at 15 m from the creek. However, as water table levels were being equalized the water table at 595 m continued dropping while the water table at 15 m continued to rise for about 10 days. At this time, soil reserve was recharged from rainfall and was available for pumping instead of flowing downstream. Two rains, 70 and 71 mm, on CD 235 and 256 brought water tables and stream water levels back to normal and water began flowing over the dam for the

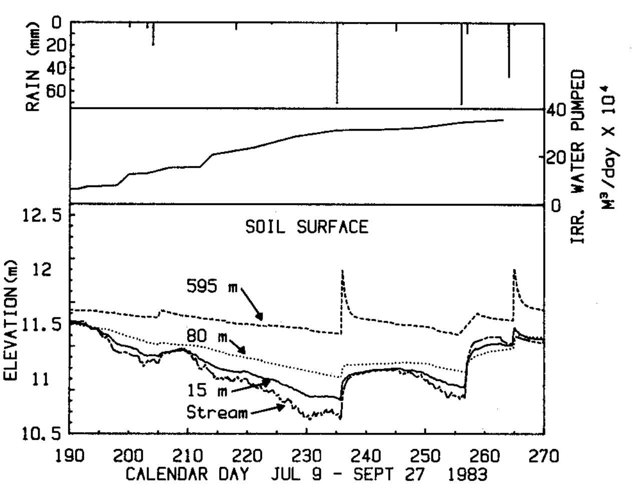

Fig. 7—Effect of rainfall and irrigation pumped from Mitchell Creek on the stream and water table levels at various distances from the stream. The soil surface is about 12.6 m above MSL.

first time in 64 days.

The Fabridam provided stream water level control which stored water for crop use and irrigation pumping during drought periods. The three-year average corn yields were increased by 20% on nonirrigated fields and by 75% on the irrigated fields compared to yields from below the structure that received no stream water level control or irrigation (Doty et al., 1984c). They also reported a net return to management and Fabridam maintenance of $137/ha.

Problems Occurring with Fabridam Operations

The Fabridam is an excellent structure to control the stream water level, and most of the time its control systems worked well. However, several problems occurred with the electronic switches and valve controls. On CD 318 in 1983, an electronic valve stuck in the open position causing the dam to inflate. The technician was called by a local farmer and replaced the switch controlling the valve on CD 319.

On another occasion, in 1984, the Fabridam was lowered to allow drainage in the farmer's fields on CD 150, then was reset to 11.7 m above MSL on CD 157. On CD 159, the electric circuits malfunctioned and without rain the Fabridam crest height and stream water level began to fluctuate. A bad switch was determined to be the cause. When the part was replaced, the Fabridam returned to normal operation.

SUMMARY AND CONCLUSIONS

A Fabridam placed across Mitchell Creek in Pitt County, N.C. to increase the stream water level depth during drought and to provide for flood control during excessive rainfall was observed for three years. Below normal rainfall occurred the first year, an extreme drought occurred during the growing season of the second year, and above normal rainfall occurred the third year. Calibrations were made to measure the flow past the Fabridam. This discharge data, rainfall, stream water levels, and field water table level were used to evaluate the effectiveness of stream water level control during extreme events of high rainfall and droughts.

Although there were several extreme rainfall events, the flow depth over the Fabridam never exceeded the two automatic control settings, i.e., the syphon did not operate which would have lowered the dam completely. However, it was necessary on several occasions, due to high water table levels, to lower the automatic stream water level settings to facilitate field drainage. Stream water level control structure should be automatic and should be easily adjusted so that stream water levels can be varied at times of excess rainfall and drought.

Stream water level control furnished irrigation water for 8 center pivot systems, three volume guns, and one controlled-drainage/subirrigation system in 1985. In 1983, more than 352,000 m^3 of water were pumped from Mitchell Creek, and there was more than 10 times this amount left in storage at the end of the growing season. Stream water level control will store water underground for crop use. Without stream water level control, water would have flowed down Mitchell Creek to the Tar River and to the ocean.

Controlling the stream water level had no adverse effects on downstream flow during a drought. The controlled water table levels above the Fabridam gave an increased hydraulic gradient to lateral seepage around the structure; therefore, the base flow in Mitchell Creek did not decrease during drought.

The Fabridam can be effectively utilized to control stream water levels. However, electronic switches and control valves are subject to malfunction. Frequent maintenance and inspection of the structure should be conducted. The controls should be flushed once a month and all motors and pumps lubricated.

Stream water level control or water table management should be considered on all future water resource projects. The technology currently available should permit the automatic control of stream water levels that reduce the risk of loss of property and crops and also provide increased irrigation water and agronomic returns.

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