Water table control for water resource projects on sandy soils

C. W. Doty, J. E. Parsons, A. W. Badr, A. Nassehzadeh-Tabrizi, and R. W. Skaggs

ABSTRACT: Some 800 ha (2,000 acres) of land near Tarboro, North Carolina, are under study to assess water table management effects on water savings and crop yields. Stream water levels are controlled by a fabric dam built across Mitchell Creek. The stream's water level was increased about 2.0 m (6.6 feet) upstream, increasing upstream field water tables about 1.0 meter (3.3 feet) near the stream with no appreciable increase 620 meters (2,037 feet) away from the stream. Soil water storage was increased above the dam. Computer simulation showed that in 1982, without water level control, only 7% of the area could be irrigated with water pumped from Mitchell Creek. With stream water level control 50% of the area could be irrigated. Crop yields in 1982 increased 20% and 16% for corn and soybeans, respectively, in areas with water table control. Future planning of water resource projects must take into account water management as well as drainage and flood control.

THE humid region of the United States includes 15 to 25 million ha (37-62 million acres) of drained farmland. Design and evaluation of watershed-scale water management systems is important in such regions, particularly in the southern Coastal Plains.

With recent improvements in drainage outlets, land that once was marginally drained can now be farmed. Natural streams were deepened, widened, and straightened, providing adequate flood control during high rainfall periods. Such improvements, while indeed providing drainage to prevent flooding, often add to the problem of short-term summer drought due to overdrainage. The South Atlantic Coastal Plains of North and South Carolina, Georgia, Florida, and Alabama include about 3.4 million ha (8.4 million acres) of sandy, sandy loam, and organic soils (9). Another 1.5 million ha (3.7 million acres) of such soils occur in Virginia, Maryland, Delaware, and New Jersey. The water-holding capacity of sandy soils is generally less than 3 cm per 30 cm (1.2 inches/foot) of soil—only enough to supply crops for 4 to 7 days.

Artificial drainage is necessary for trafficability in the spring and fall and for protection of crop roots from excessive soil water during wet periods. With good drainage, for example, with tile drains spaced about 20 m (65.6 feet) apart, long-term average corn yields on a Rains soil were about 80% of the maximum or potential yield (7). With poor drainage, drain spacings of 100-150 m (328-492 feet), the average relative yield was only 48%. This emphasizes the need for good drainage in Coastal Plain soils.

Flood protection is essential in many low-lying Coastal Plain areas where water resource projects are under development. For example, the Conetoe Drainage District in North Carolina drains 26,000 ha (64,200 acres) of land. Several thousand hectares of cropland that were flooded several times each year are now protected. To drain and provide flood control in low areas, however, required channels more than 2.5 m (8 feet) deep. Flooding is no longer a problem. But drought and low water table levels are problems, and more farmers are investing in irrigation systems each year.

Herein we explore the effects of stream water level control on water tables and crop yields in the Conetoe Drainage District.

Background and methods

The water management study area is a 4-km (2.5-mile) section along Mitchell Creek (Figure 1). The 800-ha (2,000-acre) area is flat to gently rolling with a maximum elevation difference of 1.5 m (5 feet). Nine soil series—Altavista, Augusta, Cape Fear, Conetoe, Portsmouth, Roanoke, State, Tarboro, and Wahee—were mapped and rechecked for each yield sample site by Soil Conservation Service personnel. Soils are poorly to somewhat excessively drained; formed in sandy, alluvial, and marine sediments; and underlain by a coarse, sandy aquifer about 1.5 to 2.4 m (5-8 feet) below the surface. The coarse sand is underlain by a layer of blue consistent clay ranging in depth from 4 to 8 m (13-26 feet) below the surface.

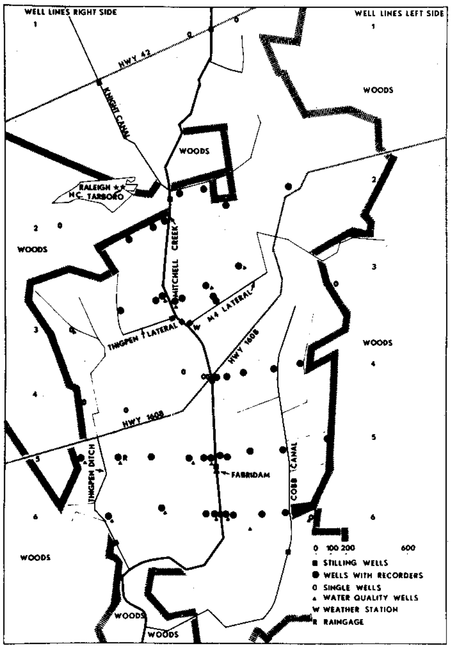

Figure 1. Layout of the study area and instrument locations on Mitchell Creek.

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A Fabridam[1] (*3*) was installed in 1982 across Mitchell Creek about midway along the study area (Figure 2) to control stream water level elevations. The Fabridam is a water-inflatable structure made of 2-ply nylon rubber-coated fabric bolted to a concrete pad in the shape of the stream channel. It is 2.74 m (9 feet) high, 5.79 m (19 feet) wide at the bottom of the creek, and 12.5 m (41 feet) wide at bank height. The dam is inflated through pipes in the concrete pad from a water tower located about 8.3 m (27 feet) above the stream bottom. Automatic monitors control the water level from 9.3 m (30.5 feet) (slab bottom) to 11.89 m (39 feet) above mean sea level (MSL). The Fabridam deflates rapidly through pipes in the concrete to allow floods to pass.

We installed six lines of water table observation wells, 5.5 m (18 feet) deep, perpendicular to and on each side of the creek. Well locations ranged from 10 to 970 m (30 to 3,200 feet) from the channel (Figure 1).

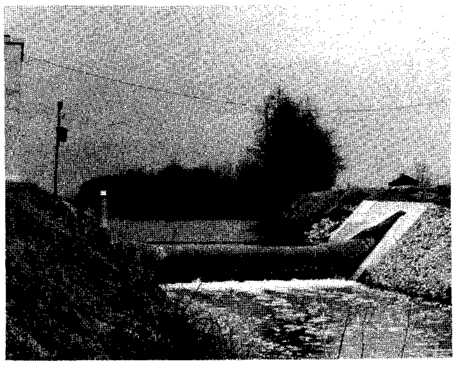

Figure 2. The Fabridam, a patented structure by N.M. Imbertson and Associates, Inc., Burbank, California, designed to Agricultural Research Service specification and put into operation across Mitchell Creek on April 2, 1982.

Twelve stream gaging sites were equipped with stage recorders. Hydraulic conductivity was measured randomly over an area with the auger hole method (*6*) and with the open-end pipe test method (*8*).

We sampled corn yields by hand from two replications [6 rows, 2 m (6.6 feet) long] near the water table observation wells (Figure 1). Yields are averages of samples taken over the area where crops were grown. Yields for 1981 were averaged for the entire area. In 1982 we divided the area into sections above (control) and below (no control) the dam, with irrigated and nonirrigated fields in both areas.

Results and discussion

Rainfall in 1981 (Figure 3) was lower than normal; 1982 was about normal. After day 220 in both years (Figure 3), rainfall increased; however, less rain fell from day 260 to day 310 in 1981 than in 1982.

In 1981 there was as much as a 1.75-m (5.75-foot) difference in the soil water table near the stream and at 610 m (2,000 feet) from the creek. The water surface elevation in the soil continuously rose in 1981 with no control from 9.75 m (32 feet) at the stream to 11.5 m (37.7 feet) at 610 m. In 1982 water tables were nearly flat to the 610-m distance, but still drained toward Mitchell Creek (Figure 3). Water table levels near the stream in well line 4 (Figure 1) were 2 m higher in the summer of 1982 than in the summer of 1981.

When the Fabridam was lowered on day 280 in 1982, water surface elevations in the stream and in the soil fell to relatively near 1981 levels. The creek's water level dropped in less than a day (Figure 3). But

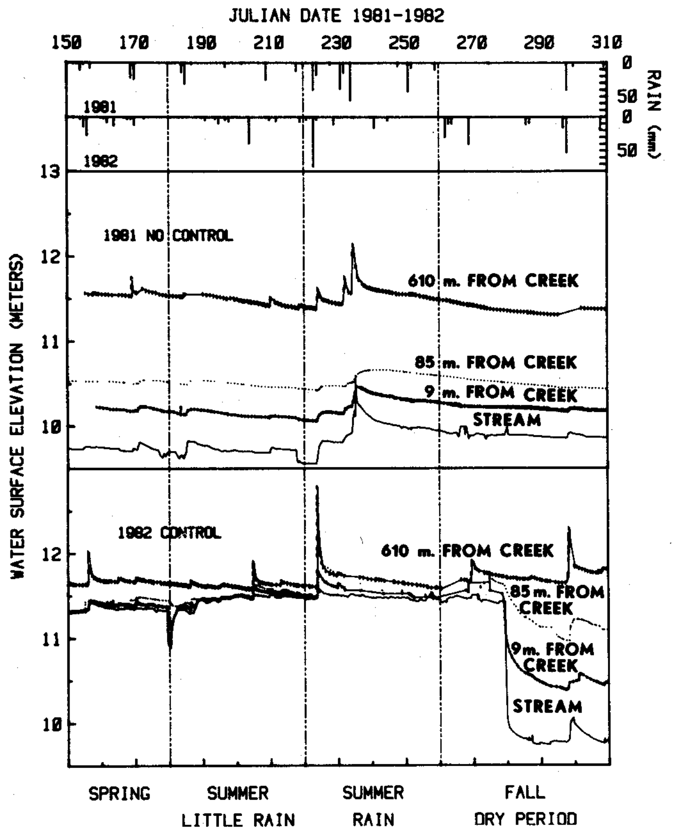

Figure 3. Relationship of rainfall and water table elevations at various distances from Mitchell Creek with no water level control in 1981 and with water level control in 1982.

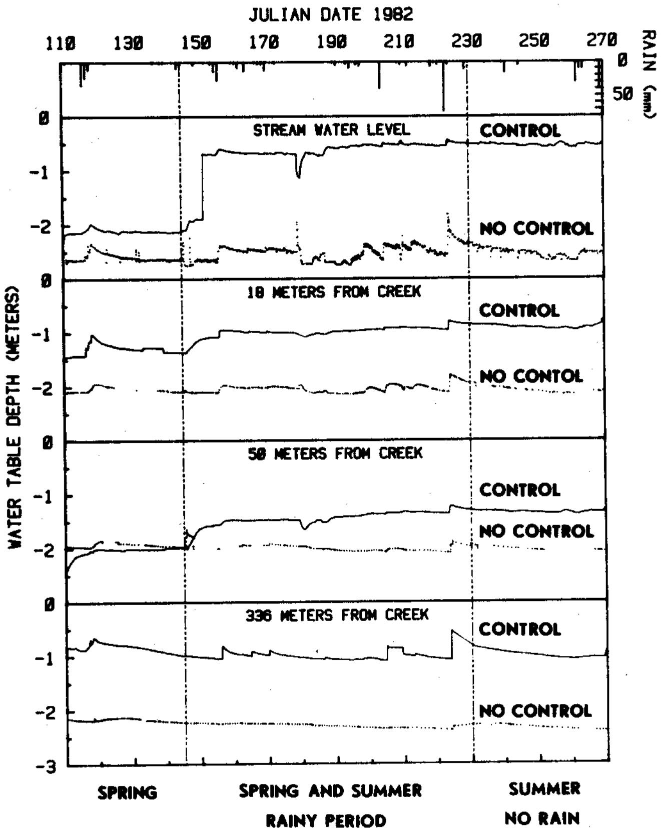

Figure 4. Relationship of water table depths from the soil surface for various distances from Mitchell Creek with and without stream water level control for 1982.

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[1] Mention of trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture or the North Carolina Agricultural Research Service and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

the rate at which the soil water dropped was progressively slower with distance away from the creek. At 610 m the water surface dropped in the soil at about the same rate as in 1981, indicating that stream water level control had little effect on the water table levels at that distance from the stream.

Rainfall affected groundwater surfaces differently at various distances from the stream (Figure 3). Generally, the increase in the soil water surface did not differ after rains with stream control by the dam in 1982 than without controls in 1981. The Fabridam controlled the stream water level, allowing it to increase only 0.15 m (0.5 foot). Stream water level control satisfactorily regulated the water table in the fields during periods of high rainfall.

Figure 4 shows water table depths versus time at distances from the stream for the spring and summer of 1982. We compared water table depths along well line 4, the control, to those along well line 6, no control (Figure 1). Before the stream water level was raised to the maximum, the stream water level above the Fabridam was controlled about 0.5 m (1.6 feet) closer to the soil surface than the downstream level. The stream water level was raised to 11.43 m (37.5 feet) above MSL on day 150. A difference of about 2 m in water table depths at the stream was maintained throughout the rest of the year.

At 18 m (59 feet) from the stream, there was a difference of 0.75 m (2.5 feet) in water table depths between the control and no control sections in the spring. Prior to increasing the stream water level, there was little difference in water table depths 50 m (164 feet) from the stream. On day 150 the stream water level was raised to about 2.0 m above the uncontrolled level. The water table depth in the control section was 1.0 m (3.3 feet) and 0.5 m (1.6 feet) closer to the surface than that in the no-control section at 18 m (59 feet) and 50 m (164 feet) from the stream, respectively. At 336 m from the stream, there was little difference in the water table depths between the control and no-control sections before and after the stream water level was raised. Stream water level control did not affect the water table depth in the fields after large rains. Therefore, stream water level control did not cause adverse effects on the water table within the root zone in this study.

Figure 5 shows the three-dimensional relationship of the water table surface for an area adjacent to Mitchell Creek on July 10, 1982. This area (Figure 1) is bounded by Mitchell Creek on the left and woods on the right, from well line 6 through well line 3 up Mitchell Creek. The Fabridam is about 305 m (1,000 feet) upstream from 0 (well line 6). Below the Fabridam, the water table surface elevation near Mitchell Creek was about 9 m (29.5 feet) above MSL. It increased to about 11 m (36.1 feet) at 621 m (2,037 feet) from the stream. Gradients in the water table surface in the channel direction near the Fabridam indicated soil water flowed around the dam to the low stream elevation below the dam. The water table surface was essentially controlled in a flat condition above the Fabridam over the 65-ha (160-acre) area and 1,045 m (3,428 feet) upstream from the dam (Figure 5). Controlling the stream water level successfully regulated the water surface in the soil adjacent to Mitchell Creek.

Soil water storage and irrigation. Hydraulic conductivity data showed that soils in the Mitchell Creek area are highly permeable. Surface soil permeability ranged from 0.17 to 1.52 m/day (0.28 to 2.49 inches/hr). Permeability of underlying sandy layers ranged from 1 to 99 m/day (1.6 to 162 inches/hr), but the blue clay layer under these sands was essentially impermeable. Our study showed that water moved freely in these soils. Badr (*1*) used the effective lateral hydraulic conductivity for each soil type in the study area in a simulation to determine the changes in soil water storage between Mitchell Creek and Cobb Canal, which are 620 m (2,034 feet) apart (Figure 1). Those results showed that stream water level control in 1982 increased stored water in the soil profile about 16 cm (6.3 inches). Evapotranspiration estimates also showed increases of about 2.7 cm (1.1 inches). Badr calculated that there was about 35,000 m^3 (341 acre-inches) of water stored in the stream channels above the Fabridam.

Badr also showed that the drainage rate of water stored in the soil profile into Mitchell Creek was at least 0.1 cm/day (.08 inch/day) per unit length of channel in 1982 (*1*). Such a water removal rate from the stream can be maintained without depleting the water stored in the stream. This removal rate dropped to about .035 cm/-day (.01 inch/day) with no controls.

From the simulation data, we predicted the percentage of the area that could be covered by irrigation (Table 1). Assuming the crop evapotranspiration rate is 0.5 cm/day (0.2 inch/day) and that irrigation would be required every 5 days, only 7% of the area could be irrigated with the water pumped from Mitchell Creek with no control. However, with the stream water level controlled by the Fabridam, 20% of the area could be irrigated with

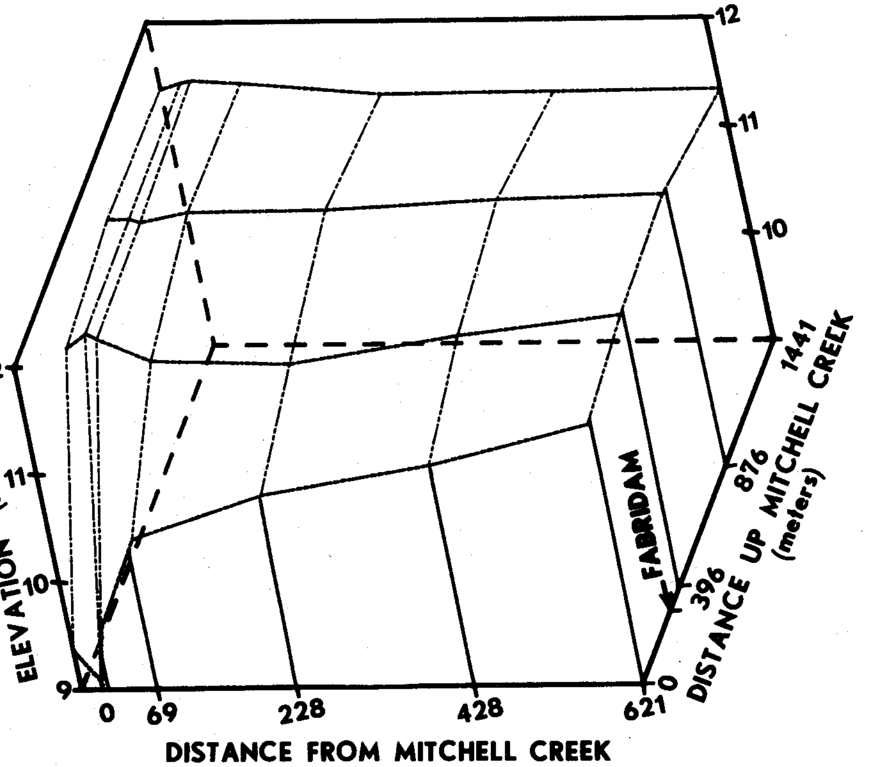

Figure 5. Three-dimensional relationship of water table surface from 305 m (1,000 feet) below the stream level control structure to 1,136 m (3,726 feet) above the structure and to 621 m (2,036 feet) away from Mitchell Creek, July 10, 1982.

water pumped from Mitchell Creek. These data indicate that with stream water level control 2.5 cm (1.0 inch) of water can be pumped from the stream and applied to 32 ha (80 acres) each day. With an irrigation return frequency of 13 days, 416 ha (1,027 acres) could be irrigated. This increased water storage is critically important for irrigation. Thus, future water resource project planning should consider water management as well as drainage and flood control.

Crop yields. Table 2 shows crop yields under four management systems in 1981 and 1982. With no irrigation, the areas with and without stream water level control produced 8.32 and 6.93 t/ha of corn (133 and 110 bushels/acre), respectively. This was a 20% increase but not significant (P.05 level). The increase is about the same as the increase due to irrigation in the no-control fields. However, corn yields increased 24% on fields with stream water level control on which 6.3 cm (2.5 inches) of irrigation water was applied. Stream water level control supplied water for an excellent crop. But the addition of irrigation water at the right time increased yields to 10.33 t/ha (165 bushels/acre), a significant 49% increase over the nonirrigated, no-control fields (Table 2).

Soybean yields (Table 2) showed a similar trend. Fields under stream water level control produced 2.07 t/ha (31 bushels/acre) of soybeans, 16% more than no-control fields. Application of 5 cm (2 inches) of irrigation water increased soybean yields to 2.40 t/ha (36 bushels/acre).

Yields related to water use. Badr's simulations (*1*) showed that evapotranspiration increased 2.7 cm (1.06 inches) during the corn growing season in the stream water level control area—averaged over the entire 1,200-m (3,936-foot) transect. Evapotranspiration would have been considerably more with water level control if Bahr had considered an increase from only the first 400 m (1,312 feet) from Mitchell Creek. Increased crop yields reflected the increased evapotranspiration where the stream water level was controlled. Crop water use was estimated based on an average production function for corn of 0.21 t/ha/cm (8.4 bushels/acre-inch) of water applied over the growing season (*2, 4, 5*). A 1.39 t/ha (22 bushel/acre) increase in corn yield in fields with stream water level control (Table 2) would have required 6.6 cm (2.6 inches) of additional water. This is only 2.4 times Badr's simulated value based on the entire transect (*1*). The yield increase due to irrigation in the noncontrolled fields was 1.36 t/ha (21.5 bushels/acre)—a water requirement of 6.5 cm (2.6 inches), compared to the 6.3 cm (2.5 inches) actually applied.

Table 1. Use of water stored in the soil profile under control and no-control stream water level conditions, based on 1982 rainfall.*

Condition	Drainage Rate to Stream	Irrigation Per Application	Return Frequency by Percent of Area to be Irrigated				
			100	50	35	20	7
	cm/day		days				
No control	0.035	2.5	71	36	25	14	5
Control	0.10	2.5	25	13	9	5	-

*Does not include streamflow or channel storage.

Table 2. Crop yields from four water management systems, 1981 and 1982.

Stream Water Level	Yields (t/ha)			
	1981		1982	
	Nonirrigated	Irrigated	Nonirrigated	Irrigated
Corn grain*				
Control	-	-	8.32 ab†	10.33 a
No control	6.47	10.67	6.93 b	8.29 ab
Soybeans‡				
Control	-	-	2.07 ab	2.40 a
No control	2.08	-	1.78 b	-

*Replications ranged from 8 to 26.

†1982 yields by crop followed by the same letter are not significantly different at the 5% level.

‡Replications ranged from 10 to 26.

Table 3. Rainfall, crop water requirements, and water supply for the 1982 corn crop in four water management areas.

Stream Water Level	Yearly Rainfall	Irrigated Water	Increase from Stream Level Control*	Total Water Applied†	Total Water Required‡
	cm				
Control					
Nonirrigated	34.06	-	6.62	40.68	39.62
Irrigated	34.06	6.3	9.50	49.86	49.17
No control					
Nonirrigated	34.06	-	-	34.06	33.00
Irrigated	34.06	6.3	-	40.36	39.47

*Based on increased corn yield.

†Total water applied = rainfall + irrigation + increase.

‡Based on total corn yields from system and 0.21 t/ha of corn grain at 15% moisture/cm of water used and the yields produced.

In fields under stream water level control, 6.3 cm (2.5 inches) of irrigation water increased yields 2.01 t/ha (31.7 bushels/acre), a water requirement of 9.5 cm (3.7 inches). The yield increases for stream water control under irrigated conditions was 2.04 t/ha (32.2 bushels/acre), a water requirement of 9.7 cm (3.8 inches). Based on these data, therefore, stream water level control reduced the drainage gradient and supplied at least 9.5 cm (3.7 inches) more water than noncontrolled water levels under irrigated conditions and about 6.6 cm (2.6 inches) more under nonirrigated conditions in 1982.

The water balance (Table 3) based on these results comes within 1.06 cm (0.42 inch) of balancing, indicating that the procedure is practical. We attributed the additional increase in water on the controlled, irrigated fields to the fact that the more water applied to the surface, the more efficient stream water level control becomes because less water percolates to the water table and flows into Mitchell Creek. This would be true until the water table rose so close to the surface that drainage would be needed.

Applications and benefits

Stream water level control will benefit most water resource projects, especially in irrigated areas where water levels in deep wells are dropping due to excessive pumping, for example, the Texas Plains, Nebraska, and the Southeast Coastal Plain. The greatest potential for solving such water shortages is to increase use of shallow groundwater that is recharged annually by rainfall. Controlling the streamflow and storing the water underground for later use accomplishes that task, thus, conserving water that would flow downstream into the rivers and finally into the ocean.

Watershed-scale, controlled drainage projects can conserve water without sacrificing the original objectives of the water resource projects. We estimate the Fabridam reported here can store enough water to irrigate 416 ha (1,027 acres) with water stored on either side of a 4-km (2.5-mile) section of Mitchell Creek, about 100 ha/km (410 acres/mile) of stream channel. In the total Conetoe Drainage District, there are 152 km (95 miles) of channels on 26,000 ha (64,200 acres). Using this network of channels, about 15,000 ha (37,000 acres) or 58% of the district could be irrigated. Results show that 50% of the area could be irrigated with a 13-day return frequency (Table 1). Therefore, stream water level control should not only benefit the nonirrigated areas by increasing yields, but should conserve water.

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