THE EFFECTS OF COLD WATER DISCHARGE ON A DOWNSTREAM RESERVOIR'S TEMPERATURE AND OXYGEN LEVELS [1]

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ABSTRACT

Data are presented on the effects cold water discharge from Hartwell Dam has on a twenty-mile stretch of river between Hartwell and Clark Hill Reservoirs and its influence on the temperature and oxygen concentrations beneath the thermocline in the lower lake.

This study revealed that oxygen concentration increased from 0.7 ppm to between 3.2 and 6.7 ppm when the sub-60 degree F. water was taken from a 105-foot depth in Hartwell Lake and discharged into the tailrace during generation periods. This water further increased its oxygen content as it became agitated while moving over shoal areas between the two reservoirs even though the water temperature sometimes reached 80 degrees F. for short periods of time when the river was low following generation shutdown.

Monthly temperature and oxygen collections taken from eight stations between the headwater and dam of the 70,000-surface-acre Clark Hill Reservoir indicated that the entire lake was capable of supporting trout through the month of April. However, this area was reduced to approximately 25% of the total lake surface and 15% of its volume by mid-September. It was also learned that the cold oxygenated water was stratified between two cold low oxygen-bearing layers in the deeper areas nearest the dam and that the suitable trout water (temperatures below 70 degrees F. and containing at least 3.0 ppm oxygen) extended laterally at the same depth but did not contain sufficient oxygen in the larger bays and tributaries after July.

INTRODUCTION

Clark Hill Reservoir and Dam is located on the Savannah River in the Piedmont section of Georgia, twenty-two miles upstream from Augusta, Georgia. This reservoir was constructed by the U. S. Corps of Engineers during the years 1946 to 1954 as a multi-purpose flood control and power reservoir. Clark Hill is thirty-nine miles long, has 1,200 miles of shoreline and contains 70,000 acres at power pool level. Maximum flood storage is 78,500 surface acres or 2,900,000 acre feet.

Hartwell Reservoir is also located on the Savannah River approximately thirty-six miles upstream from the headwater of Clark Hill Reservoir. Construction of Hartwell Reservoir (by the U. S. Corps of Engineers) was completed in April, 1962, when generation and discharge first occurred. This reservoir, like Clark Hill, is also a multi-purpose flood control and power reservoir. There are 962 miles of shoreline surrounding Hartwell Reservoir which contains 55,950 surface acres at power pool level. Maximum flood storage is 61,350 surface acres.

DISCUSSION

Hartwell Reservoir is fed by the Tugaloo and Seneca Rivers, both of which rise in the mountain section of Georgia and South Carolina. During generation periods, the cold layer of water in the lower strata of the reservoir is drawn into five 24-foot diameter penstocks located 105 feet below the surface. A survey conducted by U. S. Fish and Wildlife Service personnel during the summer and fall of 1964 indicated that the water cold enough to support trout contained oxygen concentrations not exceeding 0.7 ppm. This low water quality resulted in the

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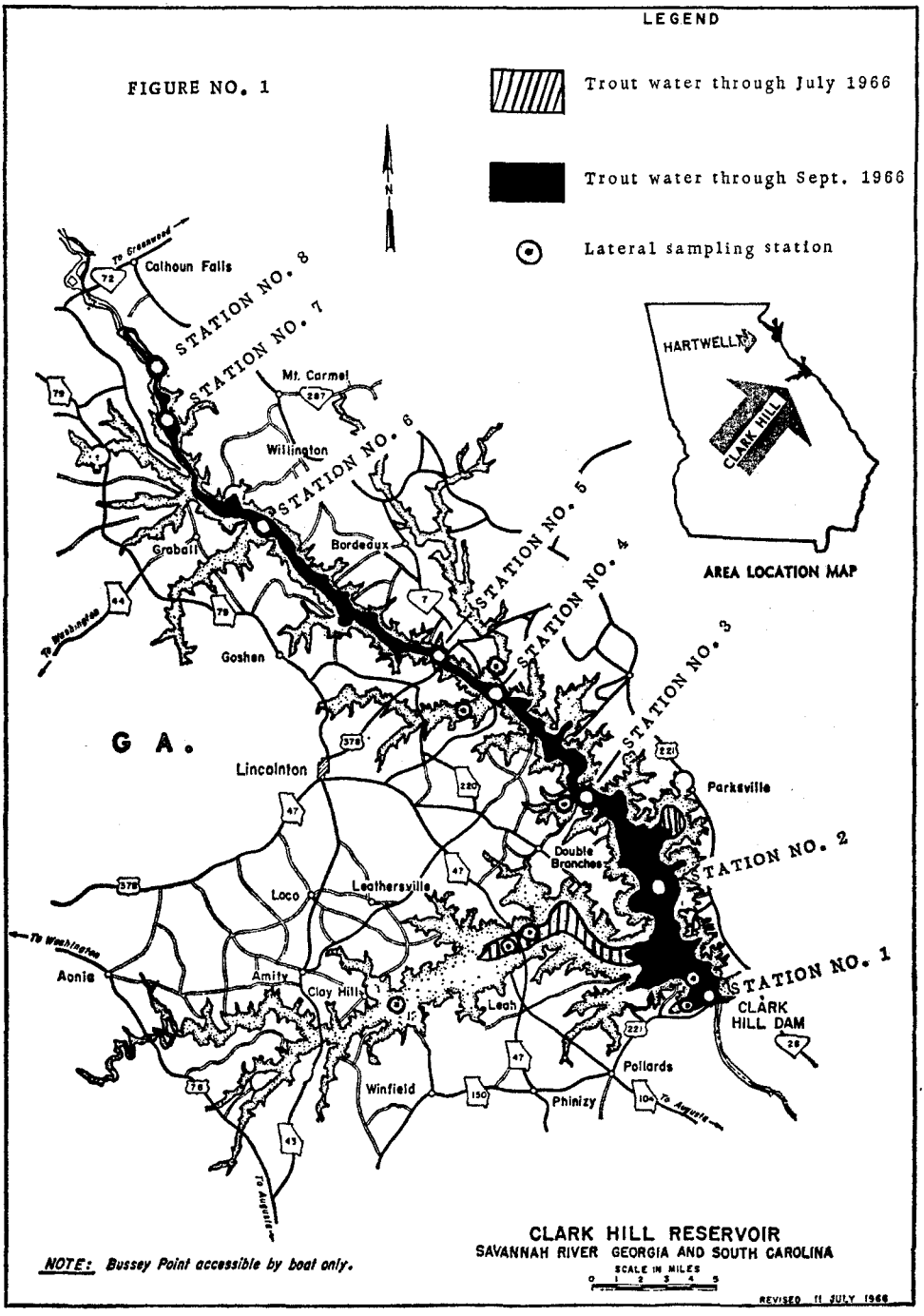
above agency not recommending the stocking of trout in Hartwell Reservoir at that time. It is this cold (60 degree F. or lower) low oxygen content water that is drawn into Hartwell Dam's penstocks at a 105-foot depth and released into the raceway during generation. This cold water is discharged into the tailrace and flows thirty-six miles down the Savannah River into the headwater of Clark Hill Reservoir. Studies made by the U. S. Corps of Engineers in the summer and fall of 1963 found the oxygen content to be between 3.2 and 6.7 ppm in the tailrace immediately behind Hartwell Dam. The South Carolina Wildlife Resources Department confirmed these findings and, therefore, made experimental stockings of 35,000 rainbow and brook trout in 1963 and an additional 5,000 rainbow and brook trout during 1965. The thirty-six mile section of river between the two reservoirs contains extensive shoal areas which increase the oxygen content and decrease carbon dioxide concentration before it enters Clark Hill in approximately eighteen hours after release. Maximum release at Hartwell Dam occurs week days from 11:00 a.m. to 12:00 p.m. Generation is stopped when the penstocks are closed every Friday night between 8:00 p.m. and 11:00 p.m. A very slight flow was maintained, barely enough to keep the river shoals from going dry, during this shut-down period. Water is released again and generation resumed each Monday between 6:00 a.m. and 8:00 a.m. Since July, 1966, the Corps of Engineers increased week-end flow rates at Hartwell Dam in order to help maintain a tail water trout fishery. However, recent temperature data collected in July, 1966, reveals that water temperatures may still increase to a high of 80 degrees F. for a few hours during the latter part of the week-end low flow period. Analysis of data collected fifteen miles downstream from Hartwell Dam indicates that temperatures ranged from 73 degrees F. to 59 degrees F. during week days. In contrast, during week-end low flow periods, water temperatures were found to range from 80 degrees F. to 56 degrees F. Since this temperature data was collected approximately eighteen inches from the stream bottom, it is obvious that during summer low flow periods, trout may not remain in this section of the Savannah River. However, since this condition exists for only a short period of time, it does not appear to endanger the trout fishery. In the past, warm water fish moved upstream from the headwater of Clark Hill during periods of low flow and associated higher water temperatures in the summer. When normal flow is resumed, Monday afternoon, light fish kills have been observed in the river section presumably resulting from the sudden change in water temperature.

It was apparent that cold water discharged from Hartwell Dam was possibly causing a gradual build-up of a layer of cold oxygenated water in Clark Hill Reservoir. To determine if this was true, past limnological data were reviewed and additional sampling stations were set up in the flooded Savannah River channel of Clark Hill. (See Figure 1.) Data were collected at these stations once each month from April through September, 1966. To determine if cold water extended into the flooded tributary arms of the lake, temperature and oxygen data were also collected at strategic lateral stations during July and August, 1966.

Both the U. S. Corps of Engineers and the South Carolina Wildlife Resources Department have collected temperature and oxygen data in the Savannah River from below Hartwell Dam downstream twenty miles toward the headwater of Clark Hill Reservoir. Both agencies set up sampling stations in the same general areas from Hartwell Dam at five-mile intervals downstream twenty miles to the head of an area known as Trotter's Shoals. Analysis of the data collected indicates that the cold low oxygen bearing water drawn into the penstocks at Hartwell Reservoir accumulates oxygen passing through the turbines. The Corps of Engineers' records for summer and fall 1963, as previously mentioned, show that directly below Hartwell Dam (Station No. 1) the oxygen concentration ranged from 3.2 ppm to 6.7 parts per million. Water temperatures during this same period did not rise above 67 degrees F. (range 53 degrees F. - 67 degrees F.). In general, discharge water tended to become oxygenated as it moved down river.


LEGEND
FIGURE NO. 1
Trout water through July 1966
Trout water through Sept. 1966
Lateral sampling station
N
STATION NO. 8
STATION NO. 7
STATION NO. 6
STATION NO. 5
STATION NO. 4
STATION NO. 3
STATION NO. 2
STATION NO. 1
Calhoun Falls
Mt. Carmel
Willington
Graball
Bordeaux
Goshen
Lincolnton
Parksville
Double Branches
Leathersville
Loco
Amity
Clay Hill
Leah
Aonis
Pollards
Phinizy
Winfield
CLARK HILL DAM
HARTWELL
CLARK HILL
AREA LOCATION MAP
G A.
NOTE: Bussey Point accessible by boat only.
CLARK HILL RESERVOIR
SAVANNAH RIVER GEORGIA AND SOUTH CAROLINA
SCALE IN MILES
0 1 2 3 4 5
REVISED 11 JULY 1966

Further analysis of the Corps of Engineers' records for 1964 and 1965 from Station 4 (15 miles downstream) and Station 5 (20 miles downstream) collected during week-ends (Saturday, Sunday and Monday) when discharge from Hartwell Dam was low or stopped, revealed that water temperatures sometimes ranged above 70 degrees F. during the period May through September. Water temperatures at these two downstream stations ranged from 50 degrees F. to 75 degrees F. during the summer of 1965. Temperatures above 70 degrees F. usually occurred approximately 12:00 p.m. on Mondays after the week-end shut-down period. The Georgia Game and Fish Commission and the South Carolina Wildlife Resources Department therefore requested the Corps of Engineers to make week-end water releases sufficient to sustain a trout fishery for twenty miles downstream from Hartwell Dam. Cooperation from the Corps of Engineers and the Southeastern Power Administration was received in this matter. However, it was apparent that week-end discharges were still not sufficient to prevent water temperatures in the lower portion of this twenty-mile study area from rising above 70 degrees F. at times. Therefore, the discharge was increased from 100 Day Second Feet to at least 645 Day Second Feet on Saturdays starting July 1, 1966.[2]

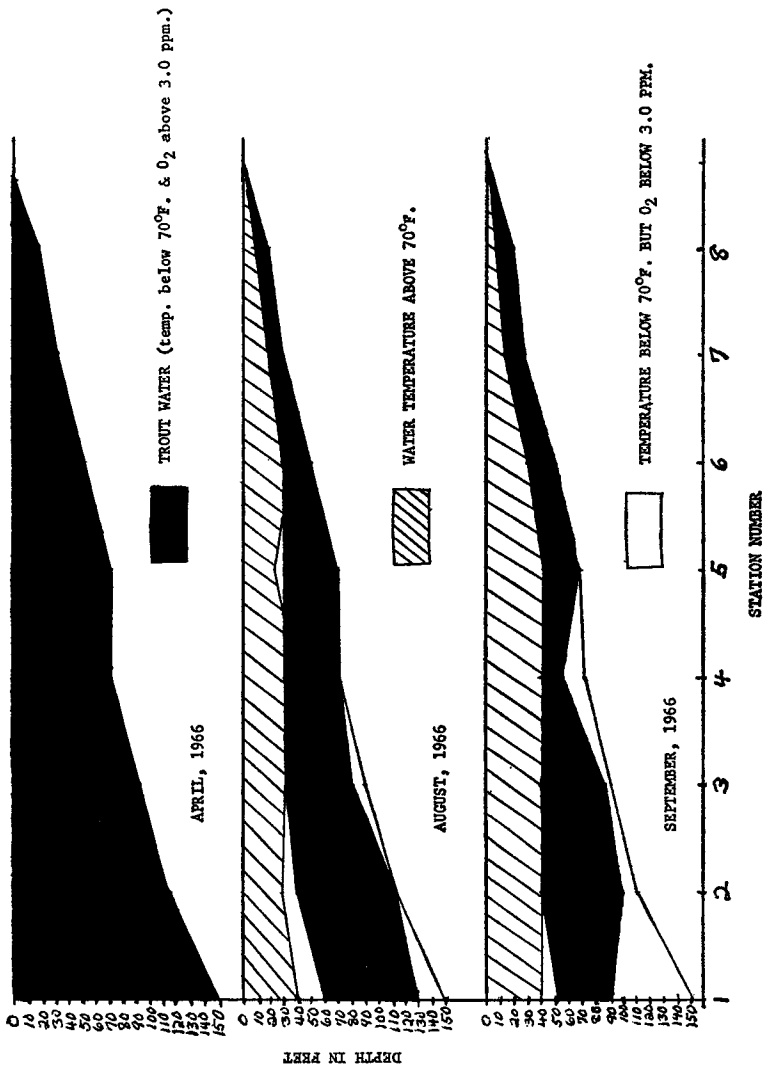
As the cold highly oxygenated water discharged from Hartwell Dam enters the headwater of Clark Hill Reservoir, it produces thermal stratification of unusually high oxygen content. To determine the extent of this oxygen-bearing layer of cold water in Clark Hill and investigate any possibilities of developing a two-story fishery, the Georgia Game and Fish Commission selected eight limnological sampling stations in the Savannah River channel of this reservoir. Monthly, from April through September, temperatures were recorded at five-foot intervals while dissolved oxygen determinations were made at the surface and every ten feet thereafter. In addition, samples were also collected at lateral stations (during July and August, 1966) located in bay areas and tributary arms of the lake to determine the extent cold water extended laterally at a given depth. See Figure No. 1.

Station No. 1 was located 500 feet in front of Clark Hill Dam. See Figure 1. During the hot weather months of July, August and September, 1966, water temperatures ranged from 94 degrees F. at the surface to 55 degrees F. on the bottom at a 150-foot depth. Oxygen concentrations ranged from 8.0 ppm to 0.1 parts per million. During July, a 105-foot vertical section of water was present suitable for trout, i.e., water having a temperature of 70 degrees F. or less and oxygen concentration of 3.0 ppm or more. By mid September, this vertical section of trout habitat was reduced to a forty-foot area located between 50 feet below the surface and sixty feet above the bottom. See Figure 2. Analysis of limnological data collected July, 1959 before operation of Hartwell Dam shows temperature ranges from 88 degrees F. to 65 degrees F. at Station No. 1. Oxygen concentrations also ranged from 4.7 ppm to 0.4 ppm during that period. Since 70-degree F. water was first present at the 70-foot level and oxygen concentrations ranged from 1.4 ppm at 70 feet to 0.4 ppm at the bottom, trout habitat was not present at that time. Recent investigations made at Station No. 1 and adjacent lateral stations during August, 1966 revealed that suitable temperatures and oxygen concentrations for trout survival were not present until a depth of 60 feet was reached. See Figure No. 1.

Little River (location: Georgia) is the largest flooded tributary arm of Clark Hill Reservoir encompassing approximately 35% of the total surface acreage of the lake. The mouth of Little River enters the main body of Clark Hill approximately two miles from Station No. 1. To determine what extent cold water present in the main body of the lake was extending into this main tributary, data were also collected at lateral stations in this region. It was found that cold water backed up from the mouth of Little River for approximately six miles upstream. At this point during July, 1966, 70-degree F. water temperatures were first present 30 feet below the surface and 50 feet of trout water was

[2] A Day Second Foot is the average cubic feet per second discharged during a twenty-four-hour period.

FIGURE 2
VERTICAL PROFILE OF TEMPERATURE AND OXYGEN LEVELS
WITH RESPECT TO TROUT HABITAT IN CLARK HILL
RESERVOIR DURING APRIL - SEPTEMBER, 1966



available in this area. However, by August this cold water layer became oxygen depleted. Therefore, Little River cannot be considered suitable trout habitat during late summer and early fall. See Figure 1.

Station No. 2 had a maximum depth of 110 feet and was located six miles upstream from Clark Hill Dam. At this station, from July through September, a temperature range from 86 degrees F. to 56 degrees F. was present and oxygen concentrations ranged from 8.3 ppm to 2.8 parts per million. In July, a 75-foot section of trout water was found at this station. By August, this vertical section was reduced to 70 feet, and in September it had receded to a 60-foot area located between forty feet below the surface and ten feet above the bottom.

The location of Station No. 3 was nine miles upstream from Clark Hill Dam containing ninety feet of water. During July, August and September, 1966 at Station No. 3, temperatures ranged from 87 degrees F. to 58 degrees F. at this location. Oxygen concentrations ranged from 10.0 ppm to 0.9 parts per million. In July, 1966, 65 feet of trout

habitat was present. However, in August, 1966, this cold water layer was reduced to forty feet. By September, 1966, it built up again to an area of fifty feet located forty feet below the surface and extending to the bottom. Data collected at a lateral station during August in the vicinity of Station No. 3 (Shiver Creek Bay—see Figure 1) revealed that suitable temperature and oxygen concentrations for trout survival were first present at a depth of forty feet. It was noted that at the forty-foot level, temperatures (66 degrees F.) and oxygen concentrations (4.3 ppm) at this lateral station were the same as those concentrations previously recorded at the forty-foot level for Station No. 3.

Station No. 4, having a maximum depth of 70 feet, was located fifteen miles upstream from Clark Hill Dam. At this station (during June, August and September, 1966), water temperatures ranged from 89 degrees F. to 58 degrees F. Oxygen concentrations ranged from 9.4 ppm to 2.5 parts per million. During June and August, 1966, a 40-foot section of trout habitat was present at this location. However, by September only fifteen feet of water suitable for trout was found. Samples were also collected at two lateral stations in this area located approximately one mile upstream from the mouth of Soap Creek and approximately one mile upstream from the mouth of Little River (South Carolina). See Figure 1. This was done to determine what extent trout habitat extended into these two flooded tributary arms of Clark Hill. It was found that in both Soap Creek and Little River (South Carolina) below 30 feet from the surface during August, 1966, there was insufficient oxygen present to support fish. In addition, temperatures below 70 degrees F. were not found until a depth of 40 feet below the surface was reached. It was obvious that trout could not survive in either of these tributary arms of Clark Hill during late summer and early fall.

Station No. 5, having a depth of 70 feet, was located sixteen miles upstream from Clark Hill Dam. From April through September, 1966, temperatures ranged from a high of 88 degrees F. to a low of 50 degrees F. Oxygen concentrations during this same period ranged from 10.1 ppm to 2.2 parts per million. A 70-foot area of trout habitat was present at this station during April, 1966. In July, 1966, this 70-foot area was reduced to 35 feet. However, during September, 1966 this 35-foot section of trout water receded further to an area of thirty feet. Analysis of previous data collected during July, 1958, prior to the construction of Hartwell Dam, revealed that only a ten-foot vertical area of trout habitat was present at that time. It is noted that this small vertical area extended from the bottom upward for ten feet and that within this area the oxygen concentration was only 3.2 parts per million which is very near the lower limits of the desirable level.

Station No. 6 was located twenty-six miles upstream from Clark Hill Dam and measured fifty feet in depth. Temperatures ranged, April through September, 1966, from 96 degrees F. to 52 degrees F. at this location. Oxygen concentrations were found to range from 10.0 ppm to 4.5 ppm during this same period. In April, 1966, a 50-foot section of trout habitat was evident. During July, 1966, this vertical area was reduced to twenty feet. Investigations made in September, 1966, revealed that trout habitat was still confined to the lower twenty feet. Data collected on August, 1961, prior to the operation of Hartwell Dam reveals that although oxygen concentrations were fairly high (8.1 ppm), suitable water temperatures for trout were not present at that time in this location. In contrast, during August, 1966, a twenty-foot vertical area of trout water was found.

The location of Station No. 7 was thirty-two miles upstream from Clark Hill Dam and two miles downstream from the head of the backwater. This station had a maximum depth of 35 feet. In this area, from April through September, 1966, water temperatures ranged from 93 degrees F. to 51 degrees F. Oxygen concentrations ranged from 10.5 ppm to 5.5 ppm during the same period. In the spring (April, 1966) a 30-foot vertical area of trout habitat was present at this station. In July, 1966, during a period when water was not being released from Hartwell Dam, this 30-foot area was reduced to only five feet. How-

ever, the following September, during a period of normal flow, the vertical area of trout habitat increased to 25 feet at this station, indicating that trout habitat in upper areas of the Reservoir are greatly influenced by Hartwell Dam's discharge schedule. Prior to the operation of Hartwell Dam, data collected at this station during August, 1961, indicated that a fifteen-foot vertical area of marginal trout water was present. The data collected during August, 1966, indicates a fifteen-foot vertical section of trout water is still present and of high quality. It is noted that in August, 1961, within the trout water zone, the average water temperature was higher (69.5 degrees F.) and the average oxygen concentration was lower (7.2 ppm) than in August, 1966. Whereas in August, 1966, the average water temperature was 59.7 degrees F. and the oxygen concentration averaged 8.8 parts per million.

Station No. 8 was located at the headwaters of Clark Hill approximately thirty-four miles upstream from the dam in fifteen feet of water. This station, April through September, 1966, exhibited a temperature range from 88 degrees F. to 53 degrees F. Oxygen concentrations ranged from 11.5 ppm to 7.3 parts per million. This entire section was suitable trout habitat through May. However, in June, 1966, during a period when water was not being released at Hartwell Dam, suitable trout water was not present at this station. In July, 1966, only five vertical feet of trout water was evident, but by September this area was increased to ten feet. It is evident that the increased minimum week in flow from Hartwell Dam, initiated in July, 1966, has favorably influenced this section of the lake relative to suitable trout habitat. In August, 1961, before operation of Hartwell Dam, prior data collected indicated suitable water temperatures for trout were not present at Station No. 8. However, during August and September, 1966, all but the upper five feet were found to be suitable trout habitat.

CONCLUSIONS

From the data collected, the following conclusions may be made:

1. Cold water taken into the penstocks at Hartwell Dam increases in oxygen content as it passes through the turbines and flows thirty-six miles downstream into Clark Hill Reservoir in approximately eighteen hours.
2. Cold oxygenated water discharged from Hartwell Dam enters Clark Hill Reservoir and slides under the upper warm water stratum.
3. Sufficiently low temperatures and high oxygen concentrations are present in Clark Hill to support trout during the critical hot weather months in approximately 15% of the reservoir's total volume.
4. The trout habitat present in the lower strata of Clark Hill Reservoir is not restricted to the Savannah River channel but does not extend into the tributary arms of the lake after mid-summer.
5. Trout habitat tends to increase as the depth increases but does not always extend to the bottom in the deeper sections of Clark Hill Reservoir.

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