EFFECT OF LOW HEAD IMPOUNDMENTS ON AMBIENT TROUT STREAM TEMPERATURES

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ABSTRACT

Data from five northeast Georgia trout streams revealed significant alteration of ambient temperatures by impoundments. A 7.3 ha impoundment releasing water at 3.9 m warmed Anderson Creek a mean 2.2 C during August 1973 and reduced diurnal temperature variation by two-thirds. Surface-release impoundments on Bean Creek and Chickamauga Creek warmed ambient temperatures a mean 4.2 C and 3.8 C, respectively, during the summer of 1974. Diurnal fluctuations were increased in these two streams. A 21 ha surface release impoundment on Smith Creek warmed ambient stream temperatures a mean 3.6 C during the summer of 1973 in spite of efforts to release water through the drain valve at 18 m below the surface. A multi-level release structure on Taylor Creek designed to closely duplicate ambient mean daily temperatures was not properly adjusted and elevated temperatures a mean 4.3 C during a three month period.

The highly dendritic drainage pattern and the narrow valleys of the northeast Georgia mountains provide countless sites suitable for the construction of small impoundments. Many trout streams in this area have been impounded by private developers, and by the USDA Soil Conservation Service under Public Law 566.

Many proposed federally-funded impoundments have not been built because of a Georgia water quality regulation enacted in 1967. This regulation specifies no elevation or depression of natural stream temperatures in waters designated as trout water by the State Game and Fish Commission, now the Department of Natural Resources. Official criteria for designation of trout waters were established in 1971. Designated waters are cold enough to support trout on a year-round basis, either maintained by natural reproduction or by periodic stockings.

Most dams built on trout streams have a top water overflow. However, since the temperature regulation and trout water designation took effect, the construction of PL 566 structures on trout waters has been curtailed and those under construction at the time of enactment were required to incorporate a deep water release.

Little work has been done to monitor the effects of impoundments on trout stream temperatures in Georgia. Although the effects of low-head impoundments on ambient stream temperatures are broadly recognized, concrete data are needed for protection of the trout resource.

Schumacher (1969) found that a 1.7 ha Georgia impoundment with a release point 3 m below the surface warmed the discharge water by an average of 1.7 C over a four year period. During one 10-day period in July and August 1966, this structure maintained outflow temperatures above 20.5 C for a total of 122 hr, while inflow temperatures reached a maximum of 18.4 C.

The Soil Conservation Service recently began using thermal modeling to predict temperatures downstream from proposed impoundments. A model of a proposed structure on the Etowah River, Georgia, predicted stream temperatures would average 1.1± 1.8 C (67% confidence limits) higher below the designed impoundment (Drummond and Roby, 1974). This model indicated that a structure outlet can be designed so that mean daily release temperatures will closely approximate mean daily inflow temperatures. However, the statistical variation is too broad to ensure adequate protection for trout survival when confidence limits are applied to the predicted temperature curve. In addition, the use of mean temperatures without the consideration of the changes in diurnal variation is of little value when assessing the potential effects on the aquatic community.

Much of Georgia's trout waters reach or exceed optimum temperature levels for growth and other metabolic functions during the hotter months. For this reason, the problem of regulating temperature elevation through impoundments is especially significant. This study monitored summer temperatures of trout streams affected by impoundments of different outlet design to determine the extent of alteration of the ambient thermal regime.

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METHODS

The study area is located in the subdued mountains of the Southeastern Blue Ridge Escarpment. The topography of this region is rugged. Most slopes of the higher elevations range from 20 to 80% with a highly dissected dendrictic drainage pattern.

Streamflow depends heavily on seepage and varies with the rainfall. Rainfall (annual mean—68 inches) is normally heaviest in the winter and spring, but storms may bring long rainy periods at any time. Lowest flow conditions usually occur between June and November.

The area includes the southernmost extension of the natural range of the brook trout (*Salvelinus fontinalis*), as well as the southernmost area of the Blue Ridge Mountains where introductions of the brown trout (*Salmo trutta*) and the rainbow trout (*Salmo gairdneri*) have produced self-sustaining populations. These species are mainly limited to headwater streams where water temperatures remain cold and competition from other fish species is minimal.

Remote recording thermographs (Weather Measure Model 601) were used to monitor water temperatures above and below selected impoundments. Data were collected during the summer months on two streams in 1973 and three streams in 1974. Water temperature probes were housed in plastic pipe secured on the stream bottom. Daily maximum and minimum temperatures were tabulated for each thermograph site. Mean daily values were calculated by averaging instantaneous temperatures at 3 hr intervals. More detailed descriptions of the streams that were monitored during this study appear below and in Table 1.

Anderson Creek

Anderson Creek heads from several small intermittent streams near the Blue Ridge divide at about 774 m elevation near the Gilmer-Pickens County line in north central Georgia. From its headwaters it flows northwest 15.8 km where it is impounded by a PL 566 flood control structure. Mean gradient of the stream above the impoundment is 16.1 m/km, flowing through forested watershed in its headwaters, then through an agricultural area where it receives light to moderate shading.

From the impoundment, Anderson Creek flows about 1.9 km where it joins Tickanetley Creek at an elevation of 500 m. Mean gradient of Anderson Creek below the impoundment is 6.3 m/km, where it again flows through agricultural land and is shaded by a narrow belt of trees along most of its length.

Three thermographs were installed on Anderson Creek in 1973; immediately above the lake (Station 1), immediately below the dam (Station 2), and the third about 1.9 km downstream from the dam near the stream mouth (Station 3).

Smith Creek

Smith Creek heads at an elevation of 975 meters near the Blue Ridge crest in White County and flows south through heavily wooded National Forest land. Approximately 7.9 km from the source, it flows into Unicoi Lake. Mean gradient of the stream above Unicoi

Table 1. Design statistics and temperature data on five low head impoundments monitored on Georgia trout waters.

	Stream				
	Anderson	*Smith*	*Bean*	*Chickamauga*	*Taylor*
Point of Impoundment Base Flow (m^3/s)	1.0	0.6	0.4	0.4	0.4
Permanent Pool Elevation (m)	525	494	425	450	680
Permanent Pool Surface Area (ha)	7.3	21.0	6.5	7.3	6.3
Permanent Pool Storage Capacity ($m^3 \times 10^6$)	0.25	1.28	0.12	0.13	0.38
Maximum Depth (m)	5.8	18.0	4.6	3.7	16.7
Release Depth (m)	3.9	[1]	0	0	[2]
Maximum Instantaneous Inflow Temperature (C)	20.0	20.6	19.4	19.4[3]	20.5[4]
Maximum Instantaneous Outflow Temperature (C)	21.1	23.9	27.2	26.7	24.4
Inflow Maximum Mean Daily (C)	18.9	19.4	18.3	18.8[3]	18.6[4]
Outflow Maximum Mean Daily (C)	21.1	23.0	24.4	24.2	24.1
Mean Inflow Diurnal Variation (C)	2.0	1.4	1.6	0.7[3]	1.4[4]
Mean Outflow Diurnal Variation (C)	0.6	1.6	2.8	2.8	1.4
Maximum Daily Thermal Loading (outflow mean daily—inflow mean daily)	3.2	5.8	6.9	5.8[3]	5.6[4]
Maximum Mean Monthly Thermal Increase (C)	2.2	4.0	5.1	4.7	4.5
Degree-Hours Outflow at or Above 21.1 C (%)[5]	2.4	64.3	34.0	47.1	42.7

[1] Release mixture adjusted by varying discharge of deep release outlet valve.
[2] Multi-depth release with five release points.
[3] Inflow data missing for 31 Jul-26 Aug.
[4] Inflow data missing for 18-24 Aug.
[5] % hr for 92 day period 14 Jun-14 Sep.

Lake is 61.6 m/km. Release water normally flows over a concrete spillway, but during this study water was released through the drain pipe. This was done by adjusting the outlet valve according to the inflow. Below Unicoi Lake, Smith Creek flows 3.4 km where it joins the Chattahoochee River at elevation 439 m. This section of the stream flows through old fields and woodland and is exposed to light solar radiation.

Three thermographs were placed on Smith Creek; about 60 m above the lake (Station 1), about 30 m below the outlet (Station 2), and about 2.1 km below the second (Station 3).

Bean Creek

Bean Creek is a small stream located in northern White County. It flows southeast for a distance of 6.3 km to its junction with Sautee Creek, a tributary of the Chattahoochee River. Bean Creek heads at 500 m elevation and has a mean gradient of 19 m/km upstream of the monitored PL 566 impoundment located about 3.0 km from the stream source. Water is released from the surface.

Temperatures were recorded during the summer of 1974 by thermographs placed immediately above (Station 1) and below (Station 2) the structure.

Chickamauga Creek

Chickamauga Creek heads at about 536 m elevation in the northern edge of White County and flows south into Sautee Creek, a Chattahoochee River tributary. A PL 566 dam is located about 2.8 km from the stream source. Water released through the dam is drawn from the lake surface. Before flowing into the lake, Chickamauga Creek is joined by Snake Branch, a tributary of about equal size. This tributary heads at about 707 m elevation and has a mean gradient of 95.0 m/km. Snake Branch flows through a small impoundment before reaching Chickamauga Creek. About half of both watersheds are in forest cover with moderate stream shading in the remaining. Temperature data were collected during the summer of 1974 at locations immediately upstream (Station 1) and downstream (Station 2) from the lake.

Taylor Creek

Taylor Creek, a tributary of the Little Tennessee River, heads at 835 m elevation and flows through dense forest to the lake site. Mean gradient above the lake is 95.6 m/km. Greasy Creek, a tributary about half the size of Taylor Creek, also flows into the lake site. Base discharge of the combined flow was estimated at 0.4 m^3/s during the sample period.

A PL 566 flood control structure was under construction on Taylor Creek on Black Rock Mountain State Park during most of 1974. Construction was completed and the lake began filling during October 1974. Water can be released from any combination of five different levels by adjusting valves on the outlet tower. The structure was designed in this manner so that release temperatures would closely conform to inflow temperatures.

Two thermographs recorded stream temperatures immediately above the lake site (Station 1) and near the stream mouth (Station 3) about 1.6 km downstream from the dam site during and after construction. A third thermograph was installed just below the dam before construction was completed (Station 2).

RESULTS

Anderson Creek

Stream temperatures above and below the deep water release structure on Anderson Creek were monitored from 14 June to 30 October 1973. Data are plotted in Fig. 1 through 21 September after which there was little difference among temperatures at the three sites. The mean temperatures immediately below the structure outlet were almost invariably higher than inflow temperatures during the period illustrated.

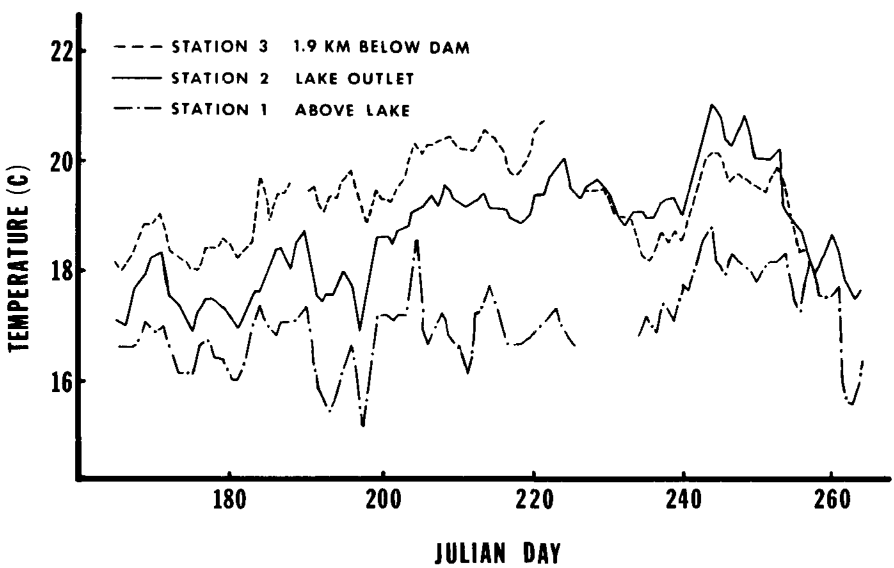

Figure 1. Mean daily water temperatures in Anderson Creek, Georgia, 1973.

Mean daily outflow temperatures were as much as 3.2 C greater than inflow temperatures and averaged 2.2 C higher during August, the month of greatest difference between the means at the two stations. The highest recorded mean daily inflow temperature was 18.9 C on 1 September, while the highest mean daily of the outflow was 21.1 C on the same date.

Records from Station 3 showed further warning downstream from the lake during most of the monitored period. The stream section between Station 2 and 3 warmed an average of 2.0 C daily during the period 14 June to 9 August. Cooling occurred in this section during the period 21 August to 10 September, when the temperature decreased an average of 1.1 C daily.

Daily temperature range above the impoundment averaged 2.0 C during the sample period. Diurnal variation at this location was least during August, averaging 1.6 C. Immediately below the impoundment at Station 2, mean daily range was 0.6 C throughout the period and averaged only 0.5 C during August and September. At Station 3, 1.9 km below the impoundment, mean diurnal fluctuation increased to 1.0 C for the study period.

Smith Creek

Temperatures were monitored at three sites on Smith Creek from 8 June to 14 September 1973. Mean daily outflow temperatures were as much as 5.8 C warmer than inflow means, and averaged 3.6 C warmer during the monitored period (Fig. 2). Temperature differences between these two stations were slightly greater during June, when the mean monthly temperature was 4.0 C warmer below the dam.

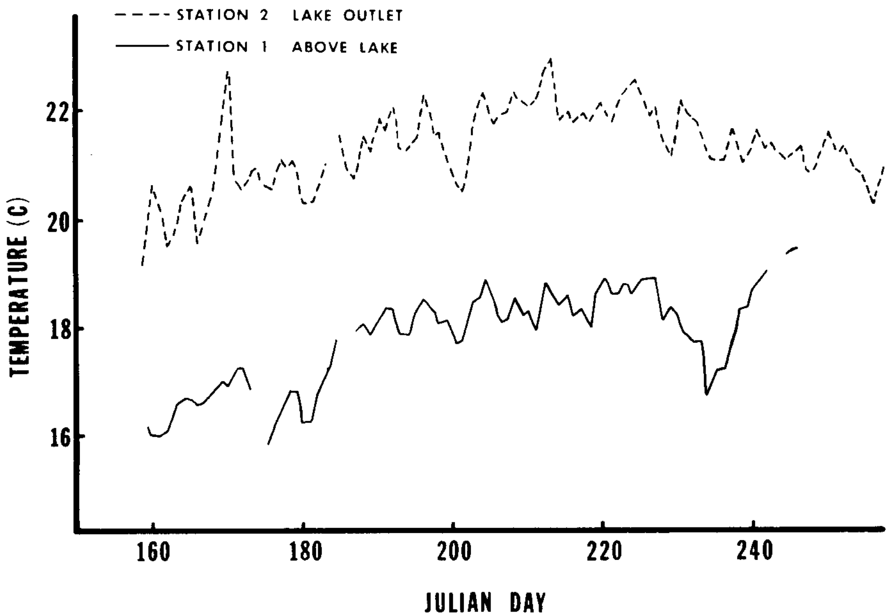

Figure 2. Mean daily water temperatures in Smith Creek, Georgia, 1973.

Records from Station 3, located 2.1 km below the dam, showed a mean decrease of 0.6 C below outfall temperatures.

Daily inflow range averaged 1.4 C during the study period. Mean diurnal variation was only slightly greater below the impoundment, averaging 1.6 C and 1.8 C at Station 2 and 3, respectively. Minimum mean diurnal fluctuations occurred during August at all three stations. Maximum diurnal fluctuations occurred during June at Stations 2 and 3 and were 7.2 C and 6.1 C respectively. Maximum diurnal variation above the impoundment was 2.2 C and occurred during each month of the study.

Bean Creek

Stream temperatures above and below the impoundment were monitored from 12 June to 26 September 1974 (Fig. 3). Mean daily temperatures above the impoundment at Station 1 showed little variation from 3 July to 3 September. Highest recorded mean daily temperature at this station was 18.3 C on 2 September. Maximum observed temperature was 19.4 C, occurring on 30 July and 3 August.

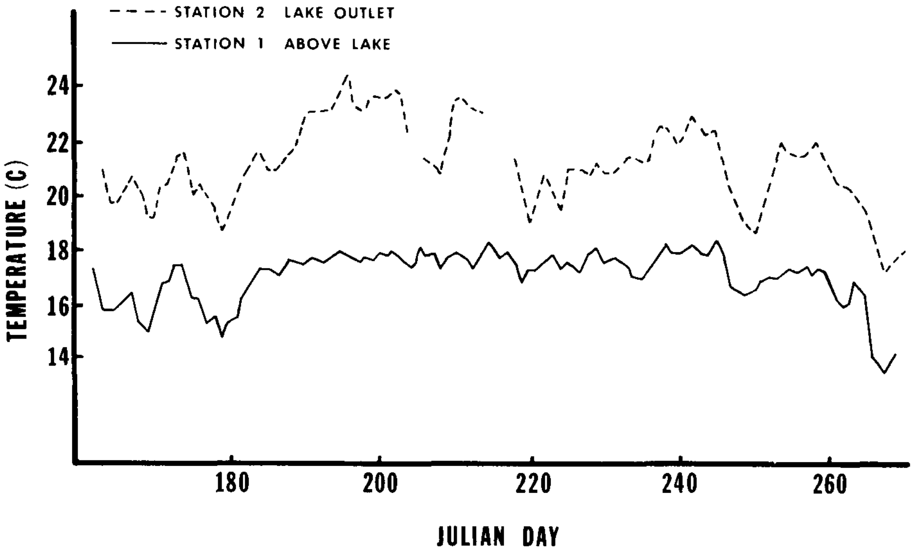

Figure 3. Mean daily water temperatures in Bean Creek, Georgia, 1974.

Stream temperature varied considerably below the impoundment. Mean daily temperatures at Station 2 averaged 4.2 C higher than at Station 1 throughout the sample period. The warming effect of the impoundment was greatest during July when the mean monthly temperature was 5.1 C higher at the lower station. A high of 27.2 C was observed at the lower station on 15 and 30 July. The maximum mean daily of 24.4 C occurred on 15 July.

Daily range averaged 1.6 C at Station 1 and was greatest during June, when temperatures varied as much as 3.9 C during a single day. Diurnal variation averaged 2.8 C at the lower station and was greatest during July, when daily highs exceeded lows by as much as 5.6 C.

Chickamauga Creek

Temperature was recorded at two sites on Chickamauga Creek from 12 June to 30 September 1974. Mean daily temperatures at both stations (Fig. 4) closely paralleled those observed on nearby Bean Creek. Highest recorded temperature above the impoundment at Station 1 on Chickamauga Creek was 19.4 C on 24 July, while the maximum mean daily was 18.8 C on 30 August. Greatest daily range at Station 1 (2.2 C) occurred on 30 September and averaged only 0.7 C during the sample period. Most of the Station 1 data for August was lost due to thermograph malfunctions.

Below the impoundment temperatures averaged 3.8 C higher than at Station 1 during the entire period. Greatest observed differences between the two stations occurred during

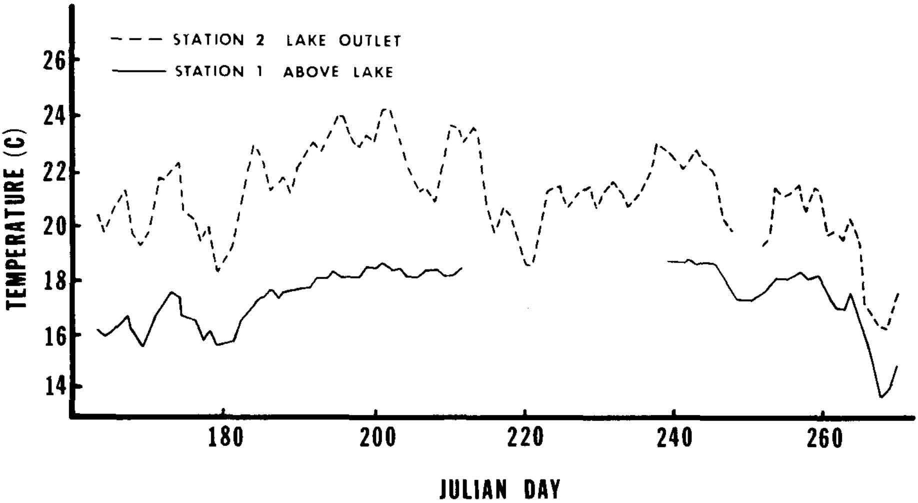

Figure 4. Mean daily water temperatures in Chickamauga Creek, Georgia, 1974.

July, when water was warmed an average of 4.7 C daily through the impoundment. Highest temperature recorded at Station 2 was 26.7 C on 21 and 29 July, and highest mean daily was 24.2 C on 21 July. Mean monthly temperature below the impoundment during July was 22.6 C. Mean daily range at Station 2 was 2.8 C and maximum daily range was 5.6 C during July and September.

Taylor Creek

Stream temperatures were monitored on Taylor Creek from 1 March 1974 to 30 September 1975. The multiple-outlet structure was completed and began filling on 11 October 1974. Filling of the pool was accomplished by adjusting the bottom outlet to release about half the existing volume of stream flow. It is apparent from subsequent temperature data and from conversations with the superintendent of Black Rock Mountain State Park that no further adjustments to the structure were made until August 1975. Upon filling of the lake during the winter of 1974-75, about half of the normal flow of Taylor Creek was released from the lake surface. This method of release resulted in a mean increase through the impoundment of 4.3 C daily during the period 1 May through 31 July 1975 (Fig. 5). During the same period in 1974, during construction but before impoundment, mean increase between Stations 1 and 3 was 2.4 C.

Air temperature records (Fig. 6) revealed consistently higher temperatures throughout most of the summer of 1975 as compared to 1974. The highest mean weekly recorded during 1974 was 21.2 C, occurring during the third week of July. The highest mean weekly in 1975 was 23.7 C, also during the third week of July.

The temperature increase between Stations 1 and 3 in 1975, as compared to 1974 when the stream cover was removed, was probably affected to some extent by the hot dry summer weather conditions as well as by the thermal characteristics of the newly impounded lake. However, the inflow temperature was also warmer in 1975. Thus, the greater temperature differential between Stations 1 and 3 in 1975 was caused mainly by the increasing effect of the impounded water on the ambient stream temperatures.

DISCUSSION

Deep Release

The deep water outlet on the Anderson Creek impoundment elevated mean daily summer stream temperatures as much as 3.2 C. The maximum mean daily stream

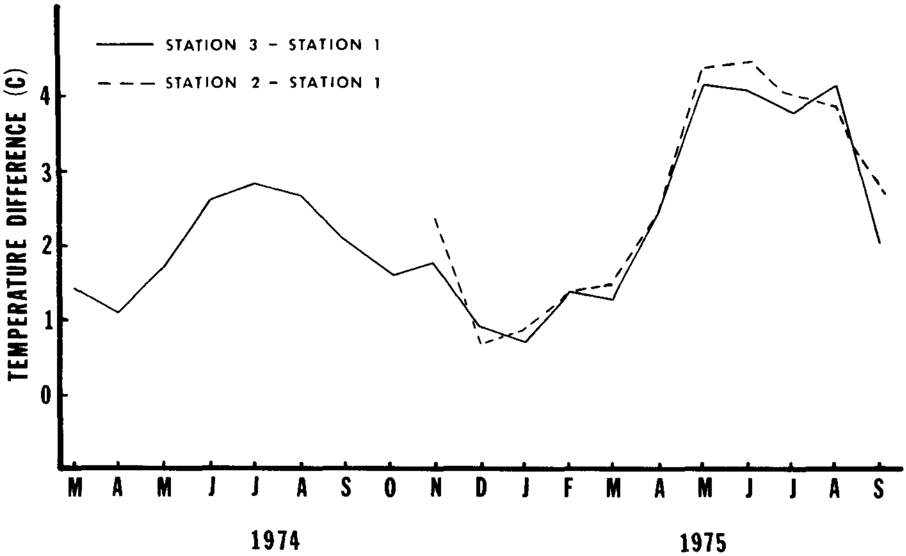

Figure 5. Differences in mean monthly water temperatures between Stations 1 and 2 and between Stations 1 and 3 on Taylor Creek.

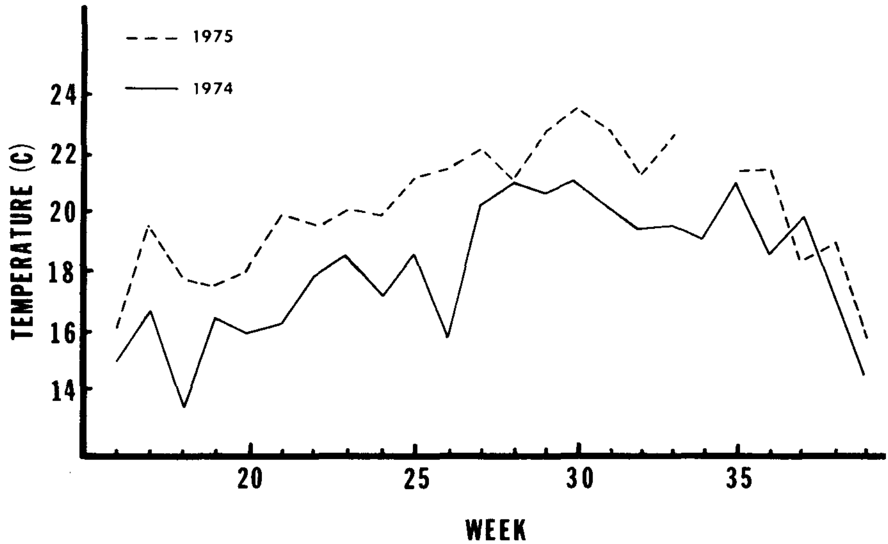

Figure 6. Mean weekly air temperatures below the Taylor Creek impoundment.

temperature above the impoundment stayed within the optimum temperature range for growth reported for brown trout (Brown, 1946), and was only slightly above the optimum range for rainbow trout (Hokansen and Kleiner, 1973). The warmer temperatures below the impoundment remained well above optimum for several weeks at a time. It is apparent from this study that this impoundment would have to have a considerably greater storage capacity to prevent downstream warming. Diurnal temperature variation was nearly eliminated below the structure.

The attempt to maintain the ambient stream temperature regime by releasing water through the drainage valve on the Smith Creek impoundment was unsuccessful. A significant portion of the outlet flow apparently came from the lake surface, as temperatures below the dam were much higher. The range of diurnal variation was not significantly altered by the Smith Creek impoundment.

Surface Outlets

The surface-release impoundments on Bean and Chickamauga Creeks had marked effects on the temperature regimes of these two streams. Stream sections below each of these impoundments are unsuitable for trout due to the warmed release water. Temperature changes through these impoundments are greatest during the long days of early summer when maximum solar radiation occurs. Diurnal temperature variation was greatly increased by these surface-release impoundments.

Multiple Outlets

Since no effort was made to adjust the release from the Taylor Creek impoundment, no evaluation could be made of the efficacy of the multiple outlet structure in duplicating inflow temperatures. However, certain conclusions can be drawn concerning the use of a multiple outlet design. It is of no value to construct such an outlet unless detailed arrangements are made to use it. It would probably take one person working full time to adjust outflows to duplicate mean daily inflow temperatures, if in fact it could be accomplished. The temperature regime of the stream would still be affected with the alteration of the normal diurnal temperature curve.

Stream Temperature Recovery

Brown, Swank, and Rothacher (1971) indicate that shading is a key factor in stream temperature control, but that shaded reaches downstream cannot be relied upon to cool heated streams. Data from both Smith and Anderson Creeks support these contentions.

The continued warming trend in early summer between Stations 2 and 3 on Anderson Creek is apparently due to direct solar radiation. This stream has moderate bank shading, but being fairly wide, it is subject to considerable solar radiation when the sun is near its zenith. In late summer, as the days get shorter and the sun is lower in the sky, this stream section shows some recovery. This suggests that the critical period of warming on a large stream with only bank shading is in early summer when days are longest, rather than later when ambient stream temperatures are highest.

The slight cooling in the lower portion of Smith Creek may be due to stream shading, the influence of small springs, or both. Shading was certainly a factor in allowing downstream cooling, if not a direct cause.

The marked temperature increase between the two thermographs on Taylor Creek during impoundment construction must be attributed to loss of shading in the construction area. A 0.4 km section of stream was stripped of all shade during the initial phase of construction.

Impact on Trout Resources

Each impoundment evaluated significantly altered the ambient temperature regime to the point that the streams below the impoundments are no longer suitable for trout management. Smith Creek above Unicoi Lake on Unicoi State Park has been managed for years for high density use with frequent stockings of catchable trout. The 3.4 km section below the impoundment has habitat conditions and access patterns suitable for an intensive trout management program. However, the altered thermal regime eliminates the option of even put-and-take trout management.

Population sampling subsequent to temperature monitoring revealed a self-sustaining rainbow trout population in Bean Creek above the impoundment. The section of stream below this impoundment is also unsuitable for trout because of the altered thermal regime.

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