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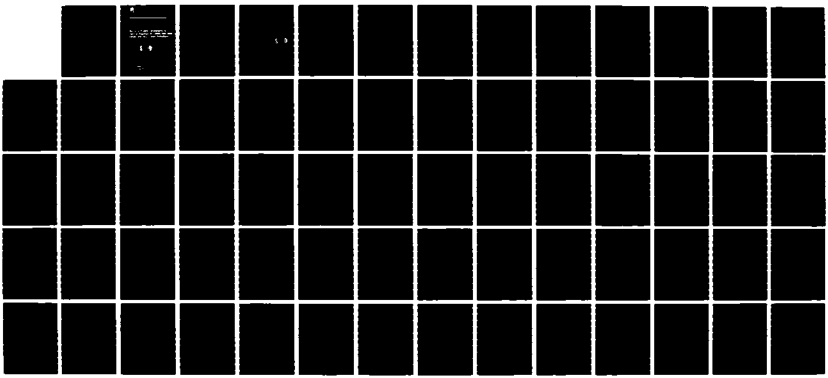

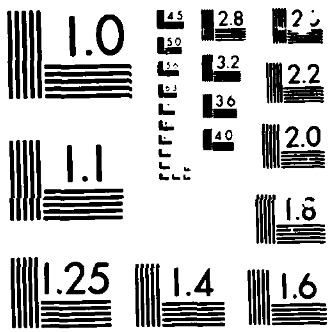
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Effects of Project Operations on Thermal Regimes of Center Hill, Dale Hollow, and Wolf Creek Tailwaters

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Effects of Project Operations on Thermal Regimes of Center Hill, Dale Hollow, and Wolf Creek Tailwaters

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INTRODUCTION

The Center Hill, Dale Hollow, and Wolf Creek projects are three of a number of reservoir projects operated by the Nashville District, U.S. Army Corps of Engineers (CE). All three of these dams were built for the purposes of flood control and power generation. Later, recreational interests were included as well. Recreational sites include both the reservoir and the tailwater where sport fishing has recently flourished.

Presently, the wildlife management agencies of Tennessee and Kentucky maintain the Center Hill Tailwater (Caney Fork River), Dale Hollow Tailwater (Obey River), and the Wolf Creek Tailwater (Cumberland River) with a constant supply of fish with its put-and-take rainbow (Salmo giardneri) and brown (Salmo trutta) trout fisheries programs. Cold water, which is a primary requirement for these fish species, is provided by power generation releases from the dams. The CE have been trying to maintain this cold water ecosystem by employing minimum flow criteria. This criteria requires at least one unit in operation for at least 1 hour during any 48 hour period for the Center Hill and Dale Hollow projects. The criteria is in effect from 1 June through 15 September at Dale Hollow and from 1 June through 30 November at Center Hill. There is no minimum flow criteria for the Wolf Creek project. This had been the only alternative since present methods for determining the quantity and timing of reservoir releases to maintain the tailwater ecosystem for trout fisheries are inadequate (Walburg, et al, 1983) and not well documented. The CE, over the years, have been facing certain problems with their existing minimum flow criteria namely, overheating of the stream beyond trout tolerability during the hot summer months when generation had been kept low for an extended period. Also, such extended low flow periods followed by a sudden flash of cold water release from the dam have been found to cause temperature shocks which may be lethal to fish.

To better understand and quantify the effects of reservoir releases on the tailwater environment and to hopefully find a solution/remedy to the problem, the CE entered into a contract with the Water Center at Tennessee Tech University. The resulting research program was designed to collect field temperature data and analyze the effectiveness of the minimum flow criteria as part of the study. The study began with a literature review and temperature monitoring of the tailwaters was included in the study.

PURPOSE AND OBJECTIVES

The objectives of this research were to obtain field data on stream temperatures and discharge quantities from the dam. Then these data were to be analyzed to determine the following:

1) Warming rates and travel times for the three tailwaters.
2) Temperature differences (stratification) between the surface and bottom of pools in the stream.
3) Impacts of local tributaries (warm water) on the tailwater.

In addition to the above, the data were also to be analyzed to evaluate the effectiveness of the existing minimum flow criteria in maintaining temperatures suitable for a viable cold water stream ecosystem and/or limiting habitat.

MATERIALS AND METHODS

To accomplish the objectives, a plan of study was outlined and carried out. The plan was categorized into several phases which included equipment rental and set up, field data collection, laboratory and field quality control and assurance respectively, recovery and storage of data, the analysis of data, and preparation of the final report. Prior to any work, some review of literature was conducted to obtain a better understanding of the work to be performed and the results that could be expected. The literature review also led to some knowledge of the temperature tolerances of the rainbow and brown trout.

Equipment

Field data were collected primarily by means of portable temperature recorders. The CE provided five Hydrolab temperature recorders and a decoder (DMU) for use with them. These recorders are essentially mini-computers that read and store surrounding temperature values at a preset time interval. For the study, fifteen minute intervals were used since they were the smallest permissable interval. These recorders are battery operated and the internal components can be very tightly sealed to avoid any leakage. They are floatable units and therefore needed some kind of weight to hold them in place. These recorders had to be tested and set up properly before each use in the field.

In addition to these Hydrolab recorders, the Water Center at Tech rented three more Ryan (Model J) strip chart type recorders from the Ryan Instrument Corporation. Unlike the Hydrolab recorders, these Ryan units took surrounding temperature readings continuously, marking them onto a 90-day strip chart. The Ryan units also had a good seal and were floatable. Therefore, these Ryan units had to be tied to some kind of weight before they were sunk. These recorders are often called the Peabody Ryan units.

In addition to the eight recorders (five Hydrolabs and three Ryans) a Steel (old Ryan) Ryan temperature recorder was used as well. This unit had the smallest physical size and the casing was made of stainless steel. It takes continuous temperature readings in (°F) unlike the others, and marks them on a 90-day strip chart. The steel casing gave this unit some weight.

Table 1 gives some physical characteristics of the three kinds of units used in the survey. The temperature ranges and expected errors are also shown.

Table 1. Physical Description and Other Pertinent Information on the Hydrolab, Peabody Ryan, and Steel Ryan

Hydrolab Unit	Peabody Ryan	Steel Ryan
Life - 2 to 3 weeks continuous	Life - 90 to 180 days	Life - 30 days
Recording Interval - (15,30,60 minutes)	Range - 5 to 45°C	Range - 0 to 120°F
Needs - decoder (12V, 1.5A) gell cell and 8 alkaline batteries and a computer hook up	Needs - Strip charts and batteries	Needs - Strip charts and winding
Size/weight - D=4", ht. 12", 5 lbs	Features - on/off switch battery tester, transparent casing	Features - heavy steel casing
Accuracy - good at medium temperatures, good for elapsed time, 30 minute response time	Size/weight - D<5" ht. 10", 2.5 lbs	Size/weight - D=3", ht-8", wt-8 lbs
	Accuracy - the greater of ±5% elapsed time or ±1 hour, good at all temperatures, quick (15 minute response time)	Accuracy - not as good for small intervals with respect to time, response time about 1 hr, good temperature accuracy
	Temperature - ±2% scale	

Besides the temperature recorders, the other pieces of equipment that were used during the study were the Hydrolab Surveyor unit, mercury thermometers, a lightweight and medium sized 14 foot boat with a 15 or 35 hp motor, and the necessary safety equipment for the boat. A number of concrete blocks (hollow) were also used during the survey for sinking the recorders and enabling them to remain in place under the force of flow currents. The Hydrolab Surveyor unit is a very sophisticated piece of equipment consisting of a surface unit and a submersible unit. It gives instantaneous measurements of six water quality parameters, namely, the temperature, DO, pH, conductivity, ORP, salinity, and depth of the water above the submersible unit. The surface unit gives the readings with the flip of a switch. The unit has to be calibrated before each use to avoid errors. The Surveyor unit uses a 12V, 20 amp-hour portable battery for the power source. The Hydrolab Surveyor unit and mercury thermometers were used in the study for the purpose of quality control and assurance work. The boat was used to get to station locations when they were not accessible by a motor vehicle or by foot.

Field Work

The field work for the study generally included continuous temperature monitoring at specific sites downstream from the dam, instantaneous measurements of temperature, DO, pH, conductivity, and ORP of discharge from the dam, continuous temperature monitoring of a tributary to investigate its effect on the main river, continuous monitoring of temperature at deep pools in the Obey and Caney Fork Rivers to investigate the stratification of the pools. Details of the field work performed are described separately for each river study. All stations were located on topographic maps prior to any field work.

Center Hill Tailwaters: Survey No. 1 - The work outlined to be performed in the Center Hill tailwater (Caney Fork River) began on the 7 June 1985. After careful calibration, the nine temperature recorders were taken to the sites and put in place at eight stations in the Caney Fork River downstream from the dam, and one recorder in the Smith Fork Creek. Before each trip (especially the first and last during the survey) it had to be ascertained that enough time had elapsed after generation for the large portion of the water to be drained out of the river. This made it easier to wade through the water carrying a recorder tied to two concrete blocks.

Besides, it also gave some assurance that the stage would not get too much lower, and that the recorder would always be submerged. In spite of much care, there were still a couple of instances where the stage had fallen so low that the recorders became exposed to direct air and sunlight causing the recorded temperature to rise very high.

The purpose of the recorders that were placed along the Caney Fork River downstream from the dam was to provide continuous temperature data of the river water until 22 June. Approximately two weeks of study was thought to be sufficient to give representative data. The continuous temperature and discharge data obtained from the CE for the same period were used to determine the time of travel, warming rates, and the effectiveness of the existing minimum flow criteria in maintaining the low temperatures necessary for the trout fishery.

The one recorder placed in the Smith Fork Creek was intended to give continuous temperature data of that warm water creek. The purpose of this temperature monitoring was to study the impact of the local tributary (the Smith Fork Creek) on the Caney Fork River. Of course, temperature data from two of the other eight monitoring stations in the Caney Fork River at CFRM 16.7 and at CFRM 15.0 (upstream and downstream from the mouth of the Smith Fork at CFRM 15.9) stations were also used in the local tributary impact study. Unfortunately, the recorders at stations CFRM 16.7 and CFRM 3.3 malfunctioned and this survey had to be redone to accomplish all the objectives.

As a part of the study, the CE made an effort to stop discharge from the dam for a period of at least one whole day while the recorders were in operation in the field. The purpose of this effort was to study the effect of heat from the sun on the water remaining in the river during the shut-off. These temperatures were found to rise dramatically when the hot summer sun was coupled with low river flows during the study period.

In addition to the continuous monitoring of temperature, instantaneous measurements of temperature, DO, pH, conductivity, and the ORP reading of the discharge from the dam were also taken periodically. Before taking instantaneous readings, it was ascertained that generation had been in progress for at least a half an hour, so that the data would be representative of the discharge water and not that of the water that had been in the river. To do this instantaneous survey, the Hydrolab Surveyor unit was used. The mercury thermometer was also used in some instances to double-check the units. The instantaneous reading of temperature, DO, pH, conductivity, and ORP were taken at two specific locations.

1) The boat ramp on the left bank downstream from the dam approximately 200 yards from the power house.

2) At the weir on the right bank of the Caney Fork River and approximately 50 yards from the dam.

The purpose of this part of the survey was to periodically monitor the quality of the discharge from the dam and the weir.

<u>Center Hill Tailwaters: Survey No. 2</u> - To complete the proposed work on the Center Hill tailwaters (Caney Fork River), which was not fully accomplished due to recorder failures in June, a second survey was carried out from 4 September 1985 until 20 September 1985. To investigate the impact of the local warm water tributary (Smith Fork Creek) on the Caney Fork River, three recorders were put in place at CFRM 16.7 (upstream from the mouth of the Smith Fork Creek), CFRM 15.0 (downstream from the mouth of the Smith Fork Creek), and a third recorder in Smith Fork Creek at approximately 1.5 miles from the confluence of the creek. All recorders were secured in the same way as before and put in place (hidden away). All

stations were accessed with a motor vehicle or by foot and usually a combination of both.

In addition to the local tributary impact study, a deep pool stratification study had been planned as well. To accomplish this objective, two recorders were placed at the deep pool spot at CFRM 16.7. One recorder that was already there for the tributary impact study served to provide temperature data for the surface of the pool. The temperature data for the bottom of the pool (approximately 10 feet in depth) were obtained by sinking a recorder, tied to two concrete blocks, into the pool. The blocks were tied to a cable and secured to a tree along the bank. There were not any access points there and therefore, a small lightweight boat had to be used. Besides these four recorders, two more recorders were also placed at CFRM 26.3 and CFRM 8.3 to monitor temperature fluctuations of the Caney Fork River due to discharge from the dam and heating from the sun. All recorders were recovered on 20 September 1985 and the field work was then complete.

Dale Hollow Tailwaters - The work outlined to be performed on the Dale Hollow tailwater (Obey River) began on the morning of 18 July 1985. Five temperature recorders were placed at four different locations along the Obey River downstream from the dam. All recorders were secured to concrete blocks similar to the Center Hill tailwater survey, and were to serve the same purpose. It was also ascertained that field work began only after a long period of no generation, so that the stations were shallow and accessible. All of the temperature recorders were put in place from the 15 hp boat. There were very few access points along the river except for the two ramps at ORM 6.7 and ORM 1.5. The boat was launched at ORM 6.7. Four of these recorders were used to produce continuous temperature data of the water in the Obey River throughout the period of study, i.e. from 18 July to 2 August. These temperature data, and the discharge data obtained from the CE were used to evaluate minimum flow criteria in maintaining suitable temperatures for the trout fishery.

In addition to these four recorders, a fifth recorder was placed at the same location as the fourth one, but in the bottom of a pool approximately 10 feet deep at the Celina water treatment plant intake (ORM 1.0). This last recorder was secured with a cable to a pipe running along-side of the intake station. The pool was found using an electronic depth finder. The purpose of this part of the Dale Hollow survey was to study the stratification (if any) of the water at this deep pool. The stratification was expected to occur after an extended no discharge period.

The CE also made an effort to stop the hydro discharges for at least one whole day during the field survey period. The purpose of this effort was to study the rate of warming in the river during no-generation periods.

Here again, instantaneous measurements of the dam discharge were taken. The parameters measured were temperature, DO, pH, conductivity, and ORP. These data were taken for the same purpose as during the Center Hill tailwaters survey and the data were taken periodically. The locations where these instantaneous readings were taken were:

1) The boat ramp at the right bank of the Obey River at approximately 500 yards from the dam.

2) Effluent from the Dale Hollow trout hatchery.

The purpose was to monitor the quality of the discharge from the dam and the trout hatchery effluent. All data from the recorders were recovered and recorded on a diskette and then merged into a masterfile for analysis on the VAX computer.

Wolf Creek Tailwaters - The survey on the Wolf Creek (Cumberland River) tailwater was performed from 6 August until 23 August 1985. Since the Cumberland River is large and deep it was easier to navigate with a 35 hp boat. All three recorders were placed in the river from the boat. Each one of these recorders was tied to a concrete block and thus it was quite heavy. In addition to the three sets of data, a fourth set for the station at location CRM 393.7 was obtained from the Turkey Neck Bend monitoring station operated by the Kentucky Department of Environmental Protection. At Burkesville, where the river was very deep, the concrete blocks were tied with a cable to a tree on the bank, and then sunk in the water. This enabled easy recovery of the recorder. During recovery of the recorders on 23 August, the water level had risen so high at CRM 459.4 station that the blocks had to be fished out with an iron hook and a rope. The dam discharge data were obtained from the CE at Nashville. All recorders were recovered and the temperature data from the recorders were stored in the computer. The purpose of this survey on the Wolf Creek tailwater was to investigate the temperature rise during the no discharge periods, calculate the times of travel and warming rates, and determine the suitability of these temperatures for the trout fishery.

Retrieval and Storage of Data - Data were retrieved from the Hydrolab temperature recorders with the use of a decoder (DMU) that the CE had provided, and the data were transferred directly onto a diskette using the Rainbow 100 microcomputer. One file was created for each station. The files were later sent to the VAX 11/785 and merged appropriately into a large master file to be used for graphical plotting and data analysis.

Data from the Ryan units which were plotted on strip charts, were retrieved manually and entered into the computer. These data files were also merged appropriately to form large masterfiles. All the master files were stored in the TTU computer, the VAX 11/785 for further analysis.

Quality Control Program - Prior to use in the field, all the temperature recorders were tested for quality control in the lab. All the recorders were set up and first placed in the 0°C room for a period of one week. To double-check, two mercury thermometers (with their calibration already tested with steam and ice) were placed alongside, and temperature readings recorded daily from the thermometer. Accurate time was kept as well. At the end of the one week period, the recorders were opened and data were retrieved. Then recorders were placed in the 21°C room for another week and the same procedure was repeated.

From the observation of temperature data from recorders versus the thermometer readings at the same time of the day, no substantial differences were noticed. At the lower 0°C temperatures, all recorders showed a slight deviation of about ±0.6°C from the 0°C, but this deviation was not thought to be a threat to the study and no corrections made. This deviation could be due to the low conductivity and poor response of metals at low-freezing temperatures. At the 21°C room on the other hand, the deviations from the 21°C mark were very minor and did not pose a threat at all. Only one unit (Hydrolab) often showed a slight deviation of +0.5°C, but again a +0.5°C temperature difference was not taken to be a problem. The Peabody Ryan units also showed better and quicker response to temperature changes. The Ryan units also kept good time. Overall, from laboratory studies, it was concluded that all the recorders were functioning satisfactorily. For double-checking purposes, quality control work was also performed before and after each survey, in the 21°C room. Field quality assurance work is described later.

Methods of Analysis - A major part of the analysis was done by means of graphical observations pertinent to the study. All graphics are included in the chapter on results along with an explanation of the observations made. All numerical computations were done with the aid of data printouts, aside from the use of graphs. These graphs that were plotted by the DISSPLA software program, by Issco, were expanded two times to help in the graphical observations. The DISSPLA program is in the mainframe computer, the VAX 11/785.

LITERATURE REVIEW

Introduction

The purpose of the literature review was to determine the current state temperature standards for Tennessee and Kentucky troutwaters, assess current criteria and findings for coldwater and coolwater fish likely to be found in the three tailwaters, and assess the problems which may be related to temperature shocks.

Temperature Standards

The Caney Fork and Obey River tailwaters are within the State of Tennessee. Chapter 1200-4-3 of the Rules of the Tennessee Department of Health and Environment state the following standards:

a) DO - The dissolved oxygen of recognized trout streams shall not be less than 6.0 mg/l.

b) pH - The pH value shall lie within the range of 6.5 - 8.5 and shall not fluctuate more than 1.0 unit over a period of 24 hours.

c) Temperature - The temperature of recognized trout waters shall not exceed 20°C and the maximum rate of change shall not exceed 2°C per hour.

The reach of the Cumberland River tailwater covered by this report is within the State of Kentucky. Kentucky has a coldwater fishery use classification which requires temperatures to be maintained below 20°C and DO above 6.0 mg/l on a daily average with an instantaneous low of 5.0 mg/l. Chlorine should not exceed 2 μg/l. In addition, the Department of Fish and Wildlife requires pH between 6.5 and 8.2, turbidity less than 10 NTU, specific conductivity less than 1,000 μmho/cm, and salinity less than 4 ppt.

Rainbow Trout Criteria

Optimal rainbow trout (*Salmo giardneri*) riverine habitat is characterized by clear, cold water; a silt-free rocky substrate in riffle run areas; an approximately 1:1 pool-to-riffle ratio, with areas of slow, deep water; well-vegetated stream banks; abundant instream cover; and relatively stable water flow, temperature regimes, and stream banks (Raleigh and Duff, 1980).

Cover for adult trout consists of areas of obscured stream bottom in water having a velocity of ≥15 cm/sec (Wesche, 1980). Wesche (1980) reported that, in larger streams, the abundance of trout ≥15 cm in length increased with increasing water depths; most trout were at depths of at least 15 cm.

The upper and lower incipient lethal temperatures for adult rainbow trout are 25°C and 0°C, respectively (Black, 1953; Lagler, 1956). Zero growth rate occurred at 23°C for rainbow trout in the laboratory (Hokanon, et al, 1977). Changes in the natural growth rate of rainbow trout are detrimental to their development and survival. Therefore, 25°C should be considered the upper limit suitable for rainbow trout and then only for a short period of time. Adult stream rainbow trout select temperatures between 12.0°C and 19.3°C (Garside and Tait, 1958). Dickson and Kramer

(1971) reported that the greatest scope of rainbow trout activity occurred at 15°C and 20°C when tested at 5°C temperature intervals. Therefore, the optimal temperature range for rainbow trout is assumed to be 12°C to 18°C (Raleigh, et al, 1984). Where pool requirements are concerned, it was reported that the best stream is one which had at least 30% of the area covered by 1st-class pools which are actually large and deep pools sufficient to provide a low velocity nesting area for several adult trout (Raleigh, et al, 1984).

A two year study carried out by Walburg, et al (1983) reported a number of findings. On the Barren and Green Rivers in Kentucky, which receives cold water releases from flood control dams (Barren and Green Reservoirs in south-central Kentucky), it was found that low water temperatures necessary for trout ($\leq$21°C) were, at best, only marginally maintained. Tailwater temperatures immediately below the dams exceeded 21°C during most of the summer. Maintenance of low water temperatures appeared possible under normal circumstances in the Green River Reservoir tailwater but not in the Barren River Reservoir tailwater. Summer water temperatures in both the tailwaters increased downstream as a result of solar warming. However, the cold water discharge in Barren and Green tailwaters provided conditions suitable for a put-and-take rainbow trout fishery.

Walburg, et al (1983) also summarized that the primary perturbations affecting the biota in the tailwaters of the hydropower projects were periodic water level changes, flow fluctuation and the generally low water temperatures. The cold, fluctuating releases near the dam appeared to limit both macroinvertebrate and fish fauna to organisms that were able to survive in these specialized environments. Downstream, increased numbers were noted among species associated with more natural stream communities.

It was also found that trout stocked in tailwaters of hydropower and flood control projects with cold water releases, moved little and generally congregated near where they were released. The decrease in number, or absence, of trout farther downstream was largely related to the rapid summer warming of water in all tailwaters. There was no clear relationship between tailwater fish catch and reservoir discharge volumes.

Hewitt, in his book, reported that water temperatures have the greatest effect on trout life and the range they can stand is not very wide. He reported that trout will live in water at 0°C, but their metabolism is very slow and they are not active, so they acquire very little food at this temperature. Digestion of food seemed very slow at these low temperatures. Food was actually found in the trout's stomach decayed rather than digested, when heavy feeding occurred at these low temperatures. The most rapid digestion of food was found to occur at 19°C. Above this temperature, trout ate less and ceased to eat at about 21°C. This shows that digestion is best at temperatures ranging from 9°C to 19°C and these are the temperatures where trout were almost always found in the stream.

Brown Trout Criteria

Greenberg stated that differences in water temperature along a stream reach make it possible for two species of trout to exist in the same stream, with one being confined to the cool upper waters, and the other to the warmer downstream reaches. Brown trout water should never exceed 21°C, while rainbow can withstand a temperature of 24°C. These are not mean temperatures, either daily or monthly, but individual maximums on hot days. According to Embody (1922) the lethal temperature for rainbow trout is about 30°C and slightly lower for brown trout.

Shirvel, et al, 1983, did a study to quantify the water depth, water velocity, and substrate used by adult brown trout (Salmo trutta) for feeding and spawning in rivers. It was found that the brown trout (mean fork length of 42 cm) preferred a depth of 65.0 cm, a mean velocity of 39.4 cm/sec, and a substrate size of 14.0 mm. Velocity appeared to be the most important factor determining position choice but ranking of factors may vary with the type of activity. Brown trout chose positions with optimum combinations of depth and velocity instead of positioning with more preferred values of either factor alone.

Temperature Increases and Their Effects

From studies done on coho salmon (Oncorhynchus kisutch) and rainbow trout (Salmo giardneri) by Hughes, et al (1978) in an aquarium, it was found that temperature elevation of 3.4°C to 7.8°C above ambient levels of a small natural stream generally increased metabolic rate and maintenance ration levels and reduced the growth rates of these species. Only at the highest ration levels were the growth rates of fish held at higher temperatures nearly equal to those of the controls. Persistent temperature elevation of 3-4°C over ambient levels reduced survival, number, biomasses, and production rates of the salmonids in the model stream.

A study was designed (Lee, et al, 1980) to indicate through laboratory experiments, the thermal limits of natural waters suitable for restocking native trout. The critical thermal maximum (CTM) was determined for five trout species and found to be remarkably similar. For acclimation temperatures of 10°C, the mean species CTM's differed only by 0.7°C at most. Under fluctuating temperature regimes, lethal temperatures were lower because the fish were subjected to elevated temperatures for longer periods of time.

Enzyme activities of rainbow trout versus rise in temperature were investigated (Sauer, et al, 1977). The species had previously been adapted to temperatures of 3,5,6,8,12,15,17,19,21.5 and 23°C. It was found that most of the enzyme activity increased with the rise in temperature.

Temperature Shocks

Resistance to abrupt and gradual cold shock was determined in bioassays with rainbow trout (*Salmo gairdneri*) and others acclimated to higher temperatures at 5°C increments (Becker, et al, 1977). Test criteria were median tolerance limits (TLm) for 96-hour exposures after abrupt cold shock, and 50% loss of equilibrium (LE50) for decline rates of 18,15,10,5 and 1°C/hour during gradual cold shock. Cold resistance was found to depend on original acclimation temperatures (AT) and varied among species under both test conditions. Rainbow trout at 20°C, 15°C, and 10°C acclimation temperature encountered abrupt exposures down to 3.3, 1.5 and 0.5°C respectivaly at 50% mortality in 96 hours. These values (TLm) were found to be slightly above LE50 values. It was also detected that instantaneous temperature changes falling in the zone of thermal resistance of any species can result in significant mortality. They also reported that the duration of exposure, as well as the cold shock temperature, combine to influence mortality in field situations.

Coutant (1977), through his research at Oak Ridge National Laboratory, found a number of interesting facts about cold water fish. Tolerance limits, also known as lethal threshold or incipient lethal temperatures, where 50% mortality of the test group at some interval (usually 4 days to 1 week) were taken as representative end points. Coutant found that for a 20°C acclimation temperature, the lower lethal threshold is 4°C and the upper lethal temperature is 27°C; for 14°C acclimation temperature the lower lethal temperature is 2°C and an upper lethal temperature is 26°C. He also reported that upon introduction to water with a temperature near the lower tolerance limit, a test fish may exhibit a short period of hyper-activity, which is immediately followed by slowed movements and sinking to the bottom. A period of low responsiveness is followed by loss of body equilibrium in which the fish usually rolls on its back or side. A "cold coma" ensues, in which the fish is alive and the gill covers beat faintly. If the cold temperature continues and the temperature is below the tolerance limit, the cold coma is ended by cessation of all gill-cover movements, which is an indication of death. The rate of temperature decrease has been shown to have some effect on the survival of fish, even when the rate is more rapid than that needed for complete acclimation (Coutant, et al, 1975). Speakman, et al (1971), showed that cooling a test group of bluegills from 30°C to 10°C at 0.6°C/hour caused 90% mortality, whereas cooling at 0.25°C/hour caused only 10% mortality. Coutant also found that the upper avoidance and final preferendum temperture for rainbow trout is about 19°C and 13°C to 16°C.

The lethal limits are largely determined as a TLm^{96} median tolerance limit, over time (Welch, et al, 1980). Thus, they designate a constant exposure temperature, usually interpolated, at which 50% of the test fish survive for 96 hours. If the temperature is fluctuated daily, slightly higher maximums can be tolerated for short periods if temperature is lowered below the level for longer periods. Welch, et al (1980), defined "the scope of activity" as the temperature range at which fish can feed, swim, and avoid predators at an optimum rate. They found that for brook trout, the scope for activity (as determined by respiration rate) occurs at a temperature range (19°C) much less than the lethal limit of 25°C. Brown trout are generally considered more tolerant of higher temperatures than brook trout (Breet, 1956). This may be an important reason why brown trout often tend to dominate in apparently marginal waters. "Preferred temperature" or the temperature willingly selected by a species under experimental conditions, is the temperature that most approximates the temperature that allows the maximum scope for growth and activity. It was noted that the preferred temperature for brook trout is 14-16°C. They also stated that the temperature rise above ambient should not exceed 2.8°C in streams. The maximum temperature at any time should not exceed 20-21°C.

Hahn (1977), reported that temperature affected the population density of rainbow trout. As many fish remained in fluctuating as in constant mean (13.5°C) temperatures; twice as many fish remained in fluctuating temperatures as in constant 18.5°C temperatures; and twice as many fish remained in constant 8.5°C as in fluctuating temperatures.

Rainbow trout reared at 10°C, placed in 1°C water for periods of 2,4,6,8 and 10 hours, and then placed in 15°C water for 4 days did not exhibit any mortality. Test fish reared at 10°C, placed in 1°C water for the above five exposure periods, and then placed in a final water temperature of 20°C for 4 days, did not die (Bidgood, 1980). These observations illustrate the short-term tolerances of rainbow trout to temperature shock.

Temperatures selected and avoided by 13 fish species, evaluated at decreasing increments of 3°C from 30°C to 6°C, declined as the acclimation temperature decreased from summer to winter. As acclimation levels declined, the difference between these two temperatures increased for trout above and below the 13°C level of acclimation. Rainbow and brook trout selected the lowest temperatures (Cherry, et al, 1975).

Application to the Three Study Streams

The fisheries management of the three tailwaters studied is selective for rainbow and brown trout. Rainbow trout are stocked extensively in t:e Caney Fork and Obey Rivers. Brown trout are only stocked when available as surplus from rearing stations. Kentucky stocks mostly rainbow trout in the Cumberland River but will occasionally add brown trout to the river below Wolf Creek Dam.

Rainbow trout appear to prefer water temperatures in the 13 to 16°C range. They will avoid temperatures above 19°C and the upper and lower lethal limits are 25 to 27°C and 0°C. No growth occurs at 23°C. The lethal temperature shock temperatures are related to acclimation temperatures. Rainbow trout acclimated at 20°, 15°, and 10°C experienced 50% mortality at 3.3°, 1.4°, and 0.5°C respectively.

Brown trout should have water slightly cooler than rainbow trout and 21°C is considered an upper satisfactory limit for their growth. No temperature shock data were found for brown trout.

CENTER HILL TAILWATER STUDIES

Survey Number 1

General Description - Temperature studies were conducted on the Caney Fork River between Center Hill Dam (CFRM 26.6) and the U.S. 70 bridge (CFRM 3.3) during 7-22 June 1985. The river reach studied is shown by Figure 1. Nine temperature recorders were placed at CFRM 26.3, 24.0, 20.7, 16.7, 15.0, 11.7, 8.3, and 3.3 and in Smith Fork Creek near the TN 141 bridge on 7 June. All recorders were removed on 22 June. Seven of the nine recorders worked well, but the recorder at CFRM 16.7 experienced battery failure and the recorder at CFRM 3.3 leaked and the water ruined the instrument.

Location and Description of Stations - Initially temperature recorders were put in place at the following sites: CFRM 26.3, 24.0, 20.7, 16.7, 15.0, 11.7, 8.3, and 3.3 and the Smith Fork Creek. But, two recorders malfunctioned at CFRM 3.3 and 16.7 and therefore the survey had to be redone. Figure 1 shows stations where data were recovered. Table 2 gives a description of the stations involved.

Table 2. Description of Survey Stations for the Caney Fork River Survey No. 1

Station Name	Description
CFRM 26.3	Boat ramp at left bank and approximately 0.3 miles downstream of Center Hill Dam. Unit was at a depth of 4 feet and approximately 10 feet from the left bank.
CFRM 24.0	A distance approximately 2.5 miles from the dam, at right side of small island/gravel bar 3 feet deep and approximately 15 feet from the left bank.
CFRM 20.7	The I-40W rest area. Unit was placed at a depth of 3 feet and about 14 feet from the left bank.
CFRM 15.0	Downstream from mouth of Smith Fork Creek, under the most downstream I-40 bridge. The depth of the unit equaled about 3.5 feet and about 8 feet from the right bank.
CFRM 11.7	Below mouth of Hickman Creek. The depth equaled approximately 6 feet and placed at about 12 feet from the left bank.
CFRM 8.3	At Carthage water treatment plant intake. Depth equaled about 2.5 feet and approximately 10 feet from the left bank.
Smith Fork Creek	Approximately 1.5 miles from mouth of the creek. Unit was placed under a tree root at an approximate depth of 3 feet and 3 feet from the right bank.

All references are made to the banks looking downstream.

Data Presentation - Figure 2 shows the temperature record compiled from the survey except for the Smith Fork Creek data. The survey covered 18.3 miles of the river for a period of 16 days and two weekends. Releases during the study ranged from 0 - 7100 cfs with a mean of 707 dsf over the survey period, and two significant periods of zero release were included.

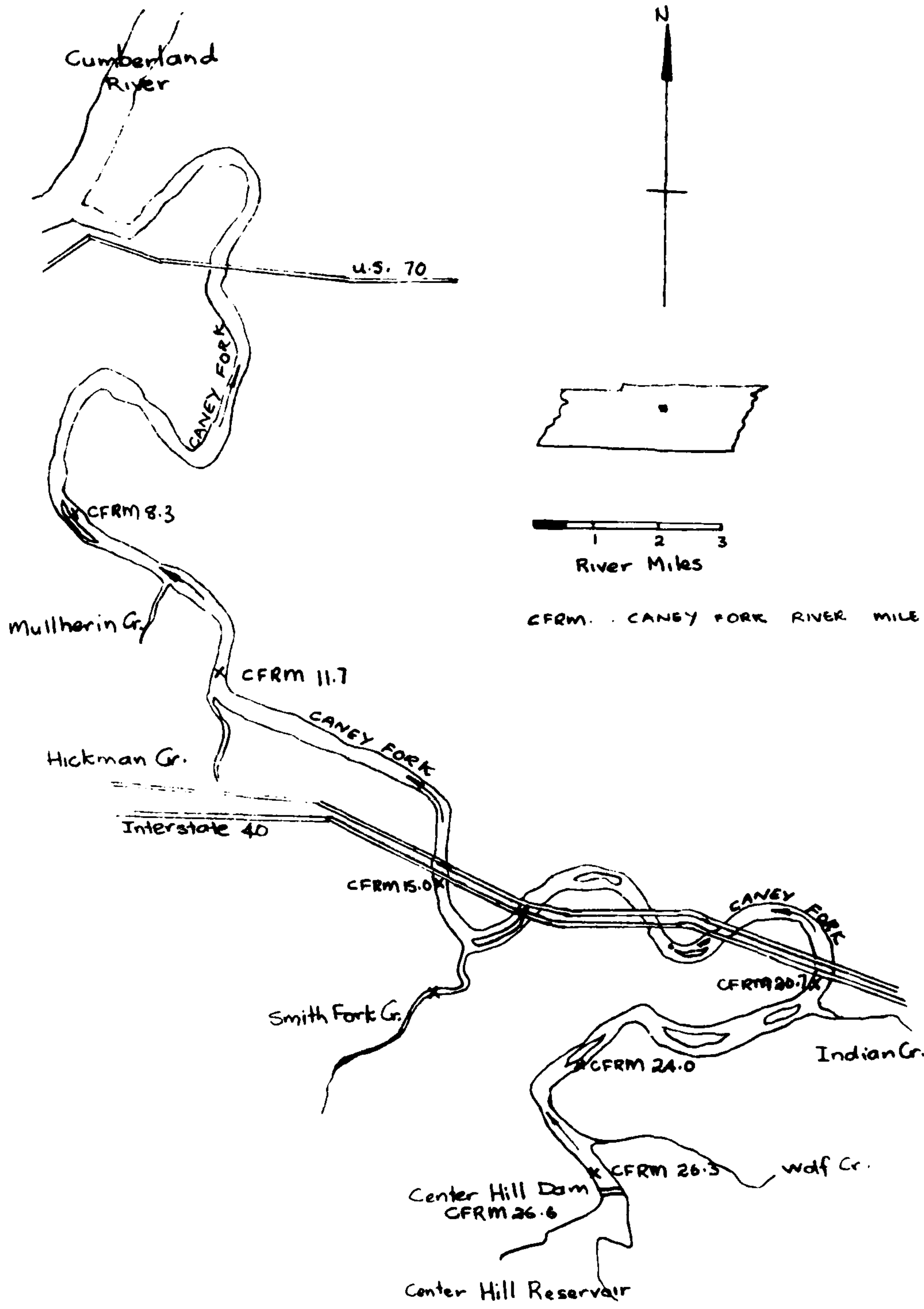
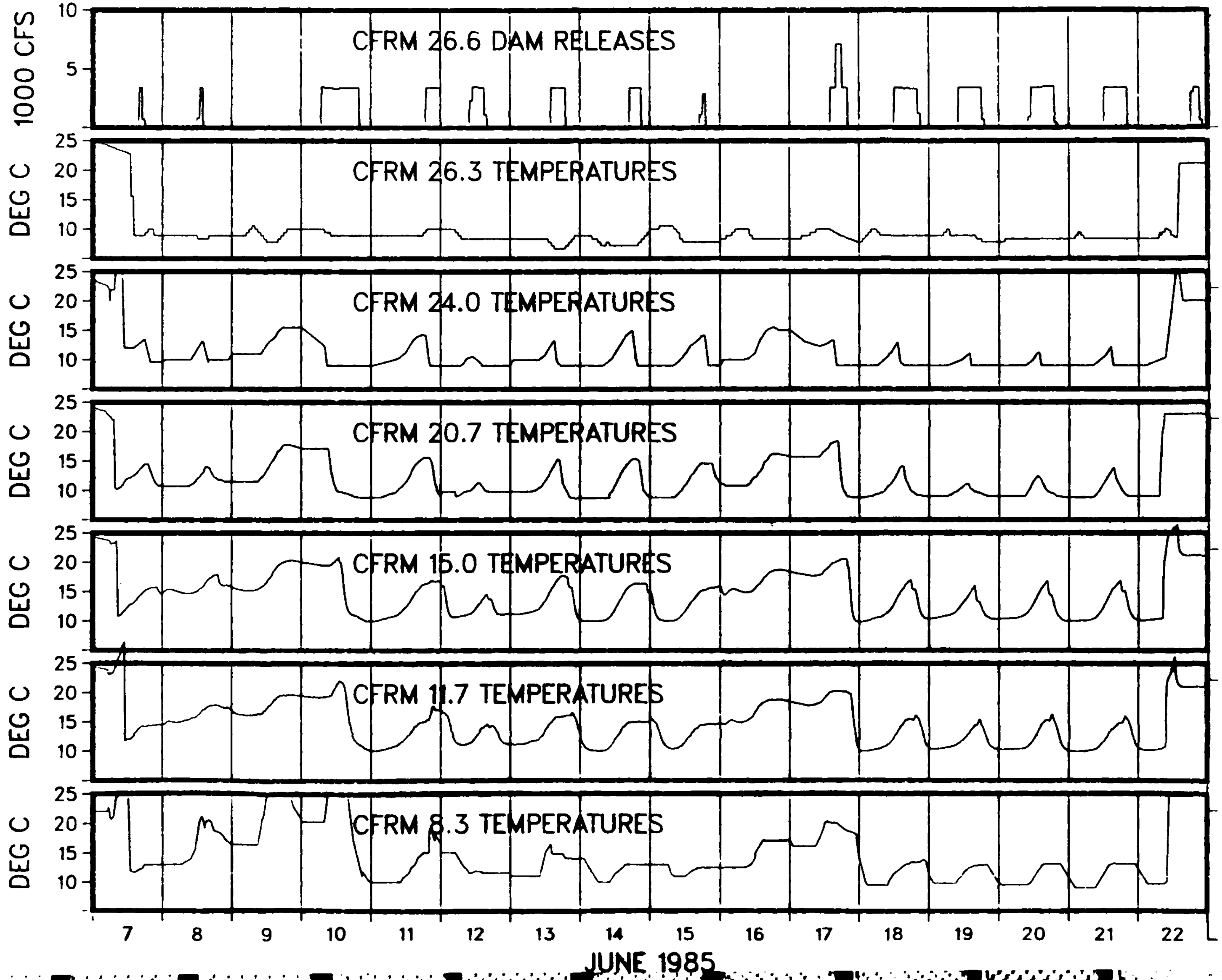


Figure 1

Caney Fork River and Its Tributaries Below Center Hill Reservoir Showing Locations of Sampling Stations (#1)

FIGURE 2

CENTER HILL TAILWATER TEMPERATURES



Time-of-Travel Estimations - Two time-of-travel assessments were computed from the data by calculating the time from the onset of generation until the temperature at the downstream location dropped to the base temperature. The results are shown in Table 3.

Table 3. Time-of-Travel Estimation for the Caney Fork River Below Center Hill Dam

CFRM	Time-of-Travel[1] (hours)	Time-of-Travel[2] (hours)
26.6	0.0	0.0
26.3	1.12	0.57
24.0	2.26	2.26
20.7	5.64	5.10
15.0	16.4	9.60
11.7	18.1	11.90
8.3	17.5	12.40

[1]June 10, Q=3330 cfs
[2]June 17, Q=3330 cfs stepped up to 7000 cfs

Obviously, time-of-travel is a function of flow, and also depends upon the amount of water in the stream channel from previous periods of generation. However, the peaking flows travel downstream at high velocities and this implies that short periods of generation can be used to keep cold water flowing down the stream channel.

Pertinent Observations - Stream temperatures exceeded 15°C below mile 24.0 and exceeded 20°C below mile 15 when generation was delayed about 40 hours. These higher temperatures occurred on 9 and 10 June and 17 and 18 June after 41 and 43 hours of no generation. Shorter periods of no generation on 11, 13, 14, and 15 June resulted in more moderate increases in temperature. It appears that 4 hours of generation per day at 3300 cfs keeps temperatures below 20°C throughout the entire reach as shown on 7, 8 and 15 June.

Temperature shocks of up to 11°C in 3 hours were recorded after the resumption of generation following 40 hours or more of no generation.

It is apparent, then, that long periods of non-generation (40 hours or more) permit heating of the water above 20°C and increase the magnitude of temperature shocks when generation resumes.

Quality Control - As part of the quality control program, the temperature recorders were usually placed in a constant temperature room (21.0°C) prior to and after each field investigation. This procedure was intended to measure the performance of the units right before and after field work, which may have been indicative of their performance in the field.

Data from the first four hours of the first day, and the last four hours of the last day of field investigations are shown in Table 4. The first four hours reflect temperature readings in an office where the units were kept prior to the field work. The mean, sample standard deviation and the grand mean are shown in Table 4. It can be observed that the mean temperature of each unit is within 1.0°C of the grand mean of 23.9°C. Therefore, based on the criteria of accepting temperature readings within 1.0°C of the grand mean, for practical purposes, the first four hour readings did not require correction. The last four hour temperature readings also did not show any individual mean deviations of greater than 1.0°C from the grand mean of 20.8°C and thus did not require any correction. But, the individual mean of the second-to-last column appears to be exaclty 1.0°C lower than the grand mean of the other six columns. Even so, no corrections were made since such a disagreement did not appear in the first four hour readings (prior to the use of the recorders).

Quality Assurance Measures - The laboratory analysis of all recorders had shown that they were all accurate and precise within 1°C. However, it was desired to check the performance of the units while in place in the river and therefore several surveys were initiated during the recording

Table 4

Quality Control Data Prior to and After
Center Hill Tailwater Investigations

(All temperatures listed in '°C')

Elapsed Time (hrs)	Flow (cfs)	Elevation (feet)	CFRM 26.3	CRFM 24.0	CFRM 20.7	CFRM 15.0	CFRM 11.7	CFRM 8.3	S. Fork Creek
0.25	0.00	475.43	25.00	23.80	24.00	24.30	24.40	23.50	24.40
0.50	0.00	475.43	25.00	23.70	24.00	24.30	24.40	23.50	24.30
0.75	0.00	475.43	25.00	23.60	24.00	24.30	24.30	23.50	24.30
1.00	0.00	475.43	25.00	23.50	24.00	24.20	24.30	23.50	24.30
1.25	0.00	475.43	24.83	23.40	23.90	24.20	24.30	23.40	24.20
1.50	0.00	475.43	23.83	23.30	23.80	24.20	24.30	23.20	24.20
1.75	0.00	475.43	24.83	23.30	23.90	24.10	24.20	23.20	24.20
2.00	0.00	475.43	24.83	23.30	23.80	24.10	24.20	23.10	24.10
2.25	0.00	475.15	24.67	23.30	23.80	24.10	24.20	23.00	24.10
2.50	0.00	475.15	24.67	23.20	23.70	24.00	24.20	23.00	24.10
2.75	0.00	475.15	24.67	23.20	23.60	24.00	24.10	23.00	24.10
3.00	0.00	475.15	24.67	23.20	23.70	24.00	24.10	23.00	24.00
3.25	0.00	475.15	24.44	23.10	23.60	24.00	24.10	22.90	24.00
3.50	0.00	475.15	24.44	23.10	23.50	23.90	24.00	22.90	24.00
3.75	0.00	475.15	24.44	23.10	23.60	23.90	24.00	22.90	24.00
4.00	0.00	475.15	24.44	23.10	23.50	23.90	24.00	22.80	23.90
Mean ($\bar{x}$)			24.74	23.33	23.76	24.09	24.19	23.16	24.14
Sample Standard Deviation (σ n-1)			0.2132	0.2206	0.1807	0.1436	0.1340	0.2555	0.1408

Grand Mean = 23.9

Table 4 Continued

380.25	3400.0	480.76	21.11	20.50	20.90	21.10	21.10	20.00	21.20
380.50	3400.0	480.76	21.11	20.50	20.90	21.10	21.00	20.00	21.10
380.75	3400.0	480.76	21.11	20.50	20.90	21.20	21.10	20.00	21.10
381.00	3400.0	480.76	21.11	20.50	20.90	21.20	21.00	20.00	21.10
381.25	600.0	477.46	21.11	20.50	20.90	21.10	21.00	20.00	21.10
381.50	600.0	477.46	21.11	20.50	20.90	21.20	21.00	20.00	21.10
381.75	600.0	477.46	21.11	20.50	20.90	21.10	21.00	20.00	21.10
382.00	600.0	477.46	21.11	20.50	20.90	21.10	21.10	20.00	21.10
382.25	0.0	476.26	21.11	20.50	20.90	21.10	21.00	20.00	21.10
382.50	0.0	476.26	21.11	20.50	20.90	21.10	21.10	20.00	21.10
382.75	0.0	476.26	21.11	20.50	20.90	21.20	21.00	20.00	21.10
383.00	0.0	476.26	21.11	20.50	20.90	21.10	21.10	20.00	21.10
383.25	0.0	475.56	21.11	20.50	20.90	21.20	21.10	20.00	21.20
383.50	0.0	475.56	21.11	20.50	20.90	21.10	21.00	20.00	21.10
383.75	0.0	475.56	21.11	20.50	20.90	21.20	21.00	20.00	21.20
384.00	0.0	475.56	21.11	20.50	20.90	21.20	0.00	20.00	21.10
Mean ($\bar{x}$)			21.11	20.50	20.90	21.14	21.04	20.00	21.12
Sample Standard Deviation (σn-1)			0.00	0.00	0.00	0.0512	0.0507	0.00	0.0403

Grand Mean = 20.8
Mean of G = 21.0

period wherein hand-held mercury thermometers were placed in the stream near the recorders and the instantaneous temperatures recorded. These instantaneous measurements were compared to the records as a measure of quality assurance.

Table 5 shows the quality assurance data for the first Caney Fork survey. These data were very disturbing, especially at station 26.3 where the old stainless steel Ryan recorder was placed. The QA data for June 9, 17, and 20 were indicative of poor performance from this unit. A study of the data record generated by this unit showed that this unit did not operate very well. It was slow to adjust to new temperatures, stuck on certain temperatures, and recorded temperatures too low to be realistic. Therefore, this unit (old SS Ryan) was not used thereafter and its data set cannot be considered completely reliable.

There were a few other problems with the QA data which we felt were due to not measuring temperature right at the instrument. In subsequent surveys, every effort was made to measure temperatures very near the recorders to and be very close on time of measurement.

In general, Table 5 showed that the recorders agreed to the QA data to within 1°C on an average basis. Therefore, no changes were made to any of the recorded data sets prior to plotting.

Survey Number 2

General Description - The second Caney Fork River survey was conducted during 4 - 20 September 1985 between Center Hill Dam (CFRM 26.6) and the Carthage water treatment plant (CFRM 8.3). Seven recorders were placed at CFRM 26.3, 16.7, 15.0, 8.3, one at the bottom of the deep pool at 16.7, and one in Smith Fork Creek. The station at CFRM 3.3 was eliminated because

Table 5. Observed/Recorded Temperatures During the First Caney Fork Survey, 7-22 June 1985

Station	6/7	6/9	6/13	6/17	6/20	6/22	Average
26.3	8.0/8.9	14.0/7.8	8.2/6.7	15.0/10.0	10.2/8.3	9.8/9.4	10.9/8.5
24.0	11.0/12.0	16.6/14.6	11.0/12.0	17.2/13.1	11.0/9.5	10.5/10.2	12.9/11.9
20.7	9.0/10.5	19.9/17.2	13.5/10.8	*	9.2/9.	10.0/9.0	12.4/11.3
15.0	10.2/10.8	*	12.5/13.0	*	10.8/11.2	9.8/10.4	10.8/11.4
11.7	11.2/11.7	20.0/19.6	14.1/14.6	*	11.5/11.5	10.5/10.9	13.5/13.7
8.3	13.0/12.0	21.1/25.0	15.0/16.4	*	12.0/10.6	11.2/10.0	14.5/14.8

it was obviously in backwater of Old Hickory Lake. The purposes of the second study were to assess thermal stratification in a deep pool, assess the impact of Smith Fork Creek, and partially repeat the previous survey under differing flow and meteorological variables. Recorders were put in the stream on 4 September and removed on 20 September. All seven recorders were recovered and worked well during the survey.

Location and Description of Stations - Recorders were placed at CFRM 26.3, 16.7, 15.0, 8.3, and in the Smith Fork Creek. This survey was done mainly to study the impact of Smith Fork Creek on the Caney Fork River temperatures, and the stratification of a deep pool. All temperature recorders functioned well and all data were recovered this time. The station locations are shown in Figure 3. Table 6 gives a description of the location of the stations.

Table 6. Description of Survey Stations for the Caney Fork River Survey No. 2

Station Name	Description
CFRM 26.3	Boat ramp at left bank and approximately 0.3 miles downstream. Unit was placed 4 feet deep and approximately 10 feet from the left bank.
CFRM 16.7	Upstream from the mouth of Smith Fork Creek approximately 0.8 miles, close to the I-40 bridge. The depth of the unit equaled 2.5 feet and was placed at about 3 feet from the left bank.
CFRM 16.7	At bottom of deep pool, approximately 10 feet deep and 9 feet from the right bank.
CFRM 15.0	Downstream from the mouth of Smith Fork Creek, under the most downstream I-40 bridge. The depth equaled 3.5 feet and was placed approximately 8 feet from the right bank.
CFRM 8.3	Close to Carthage water treatment plant. The depth of the unit equaled approximately 3 feet and 8 feet from the left bank.
Smith Fork Creek	At approximately 1.5 miles from the mouth of the creek. The unit was at a 3 foot depth and 3 feet from the right bank.

Figure 3

Caney Fork River and Its Tributaries Below Center Hill Reservoir Showing Locaitons of Sampling Stations (#2)

All depths were taken at low flows and references to the river banks are made looking downstream.

Data Presentation - Figure 4 shows the temperature record compiled from the survey except for the Smith Fork Creek survey. The data cover 18.3 miles of tailwater for a period of 17 days including two weekends. Flows ranged from 0 - 12,400 cfs with a mean of 1,524 dsf over the survey period.

Time-of-Travel Estimations - Two time-of-travel assessments were computed from the data by calculating the time from the onset of generation until the temperature at the downstream location dropped to the base temperature. The results are shown by Table 7. The results of Tables 3 and 7

Table 7. Time-of-Travel Estimation for the Caney Fork River Below Center Hill Dam

CFRM	Time-of-Travel (hrs)[1]	Time-of-Travel (hrs)[2]
26.6	0.0	0.0
26.3	*	1.13
16.7	8.47	11.30
15.0	9.04	11.30
8.3	13.60	18.10

[1]September 10, Q=3380 cfs
[2]September 16, Q=3380 cfs

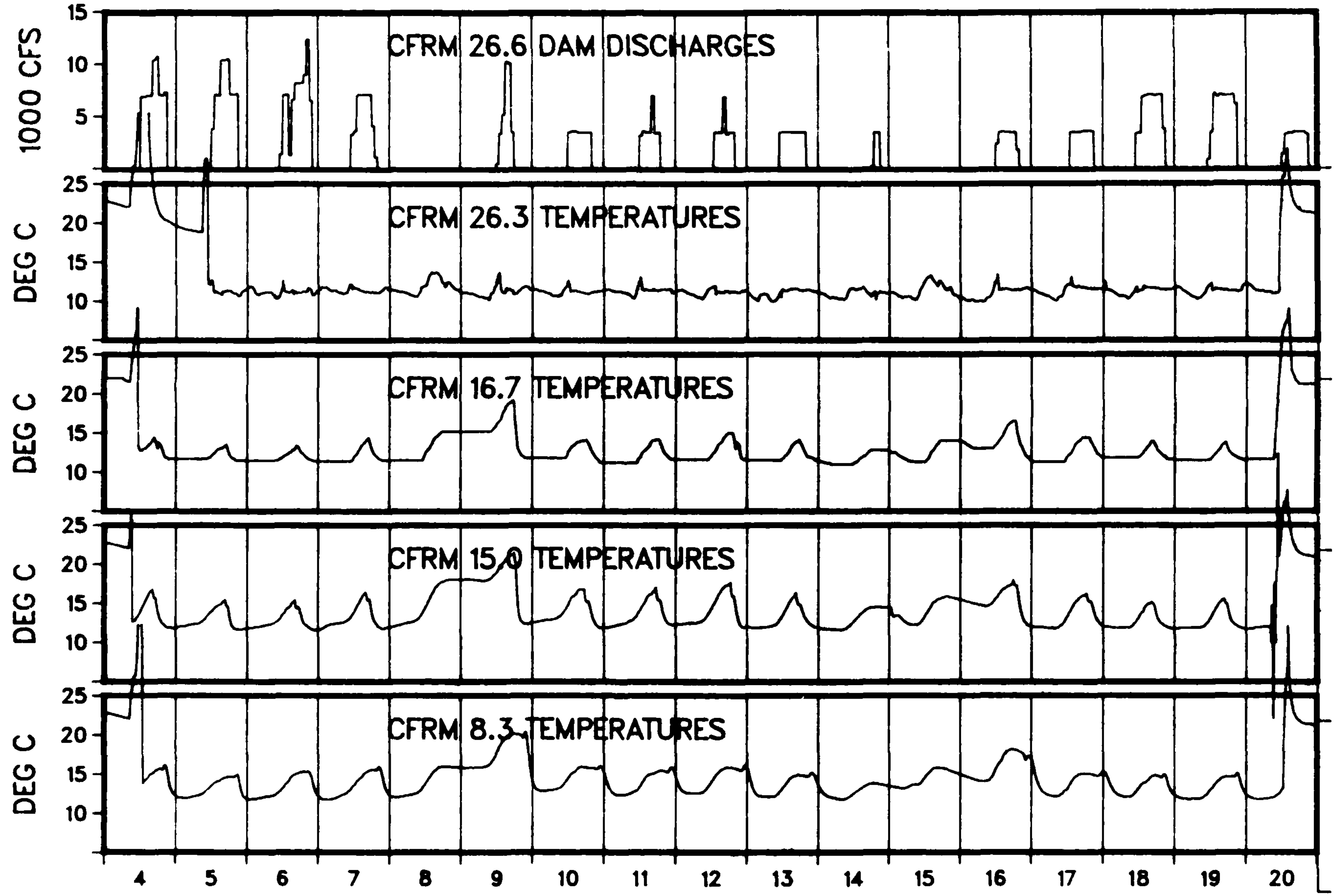
show the apparent variation in time-of-travel at a flow of about 3350 cfs as shown below. The variation due to the method and system is fairly substantial.

Station	Time-of-Travel at 3350 cfs (hrs)
26.3	1.12, 1.13
15.0	16.4, 9.04, 11.3
8.3	17.5, 13.6, 18.1

Pertinent Observations - Stream temperatures exceeded 15°C below mile 16.7 and exceeded 20°C below mile 15.0 following 37 hours of no generation

FIGURE 4

CENTER HILL TAILWATER TEMPERATURES



on 7, 8, and 9 September. Temperatures were slightly lower after a 48 hour period of no generation during 14, 15, and 16 September. Maximum air temperatures were 91°F on the 8th and and 73°F on the 15th. Obviously, the cooler temperatures slowed heating on the 15th just prior to the 43 hour period of no generation.

Effect of the Smith Fork Creek Tributary - Recorders located in the Caney Fork River at miles 16.7 and 15.0 plus a recorder in the Smith Fork Creek showed that some warming of the river is caused by the inflow of the Smith Fork Creek. Figure 5 shows the temperature record for these three stations. Peak heights were compared on a daily basis between CFRM 16.7 and 15.0 and peak temperatures were always warmer below Smith Fork Creek. Increases ranged from 1.3 to 2.9°C with a mean increase of 2.2°C and a standard deviation of 0.46°C. The warming of the Caney Fork River by Smith Fork Creek was slight but noticeable under normal runoff conditions. A similar analysis of the June data (Figure 2) between miles 20.7 and 15.0 showed increases ranging from 1.3 to 5.0°C with a mean peak temperature increase of 2.8°C and a standard deviation of 1.2°C. Of course, part of this increase is due to warming in the 5.7 mile distance between stations. The impact of Smith Fork Creek following a storm event was an objective, but storms did not occur during the 32 days covered by these surveys. Thus, the objective was not met.

Deep Pool Stratification Study - Two recorders were placed at CFRM 16.7 to see if stratification by temperature occurs in deep pools in the Caney Fork River. This pool was the deepest spot located along the study reach and was 10 feet deep at low-flow (no generation) conditions. The recorders produced the conditions shown by Figure 6. There appeared to be about 1.3°C difference between the surface water and the bottom water

FIGURE 5

CENTER HILL TAILWATER STUDY

INFLUENCE OF SMITH FORK CREEK

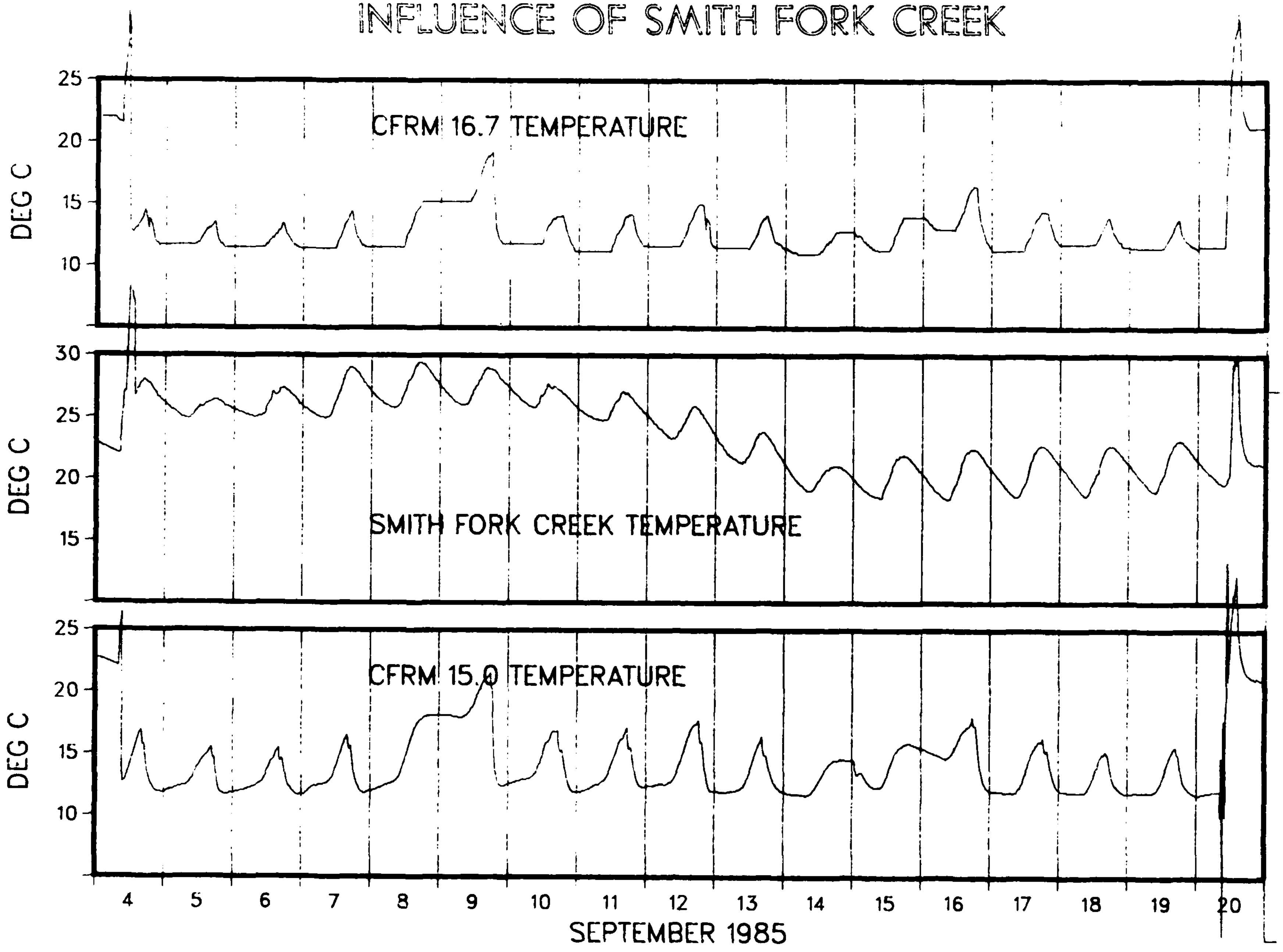
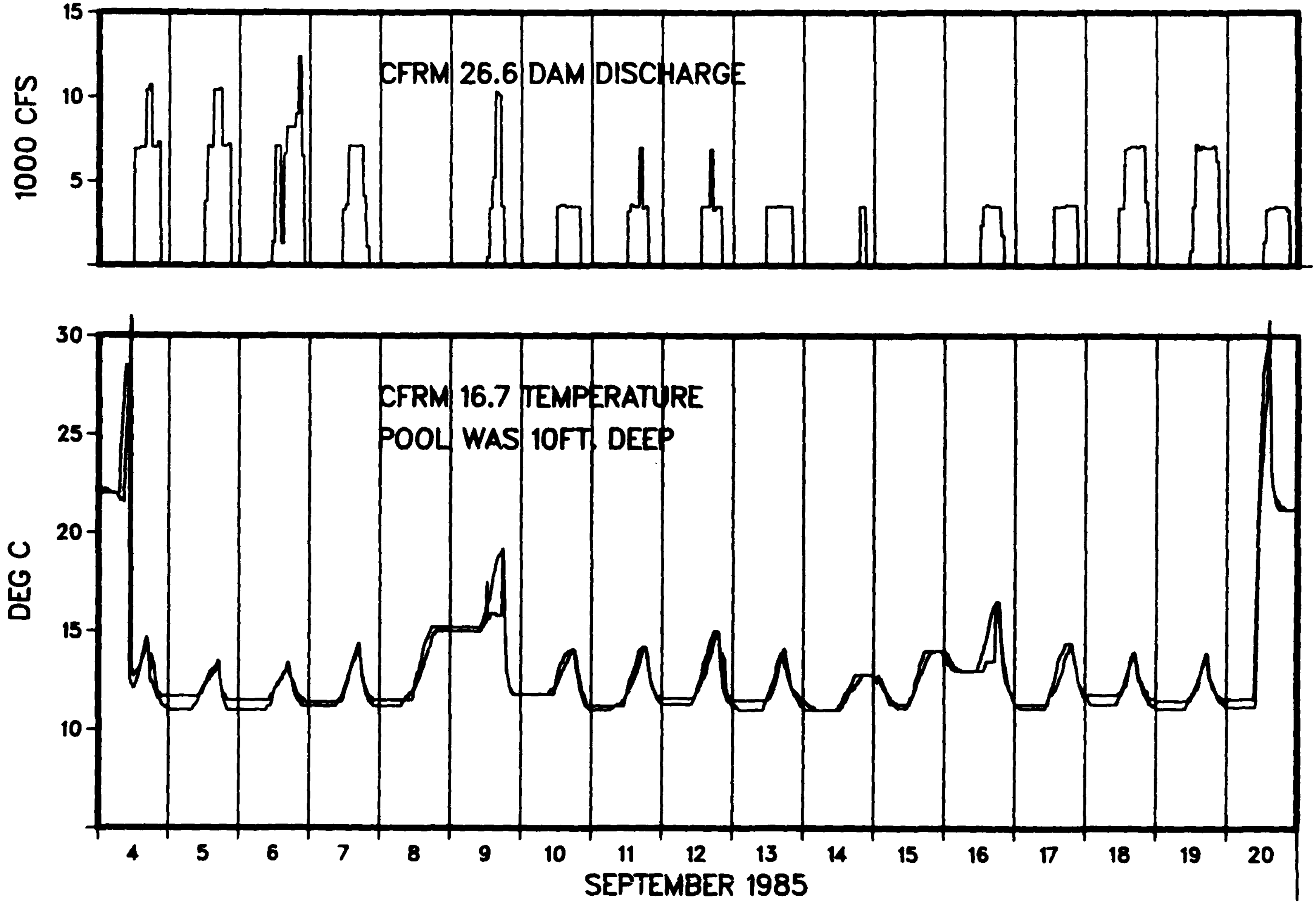


FIGURE 6

CENTER HILL TAILWATER TEMPERATURES
STRATIFICATION STUDY



at this location at base-line temperatures. Power releases caused the temperatures to converge more closely. However, the quality control data show that the bottom recorder was exactly 1.0°C low at the start and remained 1°C low at the end. Thus, on the average there was no stratification evident in this pool except just after the 40 hours of non-generation on Spetmeber 9, 1986. The pool did stratify with differences up to 3.2°C. The surface temperature peaked at 19.2°C.

Quality Control - Table 8 shows the quality control data from this survey. The grand mean was calculated to be 22.3°C for the first four hours. By comparing individual means with this grand mean, the third mean value from the left (21.0°C) appeared to be off by 1.3°C, and is therefore not within acceptable limits. All other mean values fall within the acceptable range. Then, observations of the mean values from the last four hours following the survey also show the same kind of deviation of the third column's mean value from the grand mean of 21.05 but to a smaller extent (0.85°C). Other mean values appear to be alright. Since the discrepancy appears both prior to and after field investigations, it is assumed that the same approximate deviation also occurred in the field and thus, a 1.0°C increase was imposed on all values throughout the third temperature column, in order to meet with the criteria limit. Also a side by side comparison of temperature columns two and three showed a need for this correction. Since these were a part of the stratification study, it was important to make this correction.

Quality Assessment Measures - Quality assessment was evaluated by periodic measurments with a hand-held mercury thermometer near the recorders during the survey period. Table 9 shows this data. These data are all in good agreement and show that with more care in obtaining the observed field data, the units are shown to perform very well.

Table 8

Quality Control Data Prior to and After Center Hill Tailwater Investigations (#2)

(All temperatures listed in '°C')

Elapsed Time (hrs)	Flow (cfs)	Elevation (feet)	CFRM 26.3	CFRM 16.7 Surface	CFRM 16.7 Bottom	S. Fork Creek	CFRM 15.0	CFRM 8.3
0.75	0.00	475.97	22.90	22.30	21.00	22.90	22.80	22.80
0.50	0.00	475.97	22.80	22.30	21.00	22.80	22.70	22.80
0.75	0.00	475.97	22.80	22.30	21.00	22.80	22.70	22.80
1.00	0.00	475.97	22.80	22.30	21.00	22.80	22.70	22.80
1.25	0.00	475.50	22.70	22.20	21.00	22.80	22.70	22.80
1.50	0.00	475.50	22.70	22.10	21.00	22.70	22.70	22.80
1.75	0.00	475.50	22.70	22.20	21.00	22.70	22.70	22.80
2.00	0.00	475.50	22.70	22.20	21.00	22.70	22.70	22.70
2.25	0.00	475.26	22.60	22.20	21.00	22.60	22.60	22.70
2.50	0.00	475.26	22.60	22.20	21.00	22.60	22.60	22.70
2.75	0.00	475.26	22.60	22.20	21.00	22.60	22.60	22.70
3.00	0.00	475.26	22.60	22.20	21.00	22.60	22.60	22.60
3.25	0.00	475.26	22.50	22.10	21.00	22.60	22.60	22.60
3.50	0.00	475.26	22.50	22.10	21.00	22.50	22.50	22.60
3.75	0.00	475.26	22.50	22.10	21.00	22.50	22.50	22.60
4.00	0.00	475.26	22.50	22.10	21.00	22.50	22.50	22.50
Mean ($\bar{x}$)			22.66	22.20	21.00	22.67	22.64	22.71
Sample Standard Deviation (σ_{n-1})			0.1263	0.0730	0.00	0.1250	0.0885	0.0998

Grand Mean = 22.3

Table 8 Continued

404.25	3300.00	480.85	21.30	21.20	20.20	21.30	21.10	21.40
404.50	3300.00	480.85	21.30	21.20	20.20	21.30	21.10	21.40
404.75	3300.00	480.85	21.30	21.20	20.20	21.20	21.10	21.40
405.00	3300.00	480.85	21.40	21.20	20.20	21.30	21.20	21.40
405.25	0.00	477.54	21.30	21.20	20.20	21.30	21.10	21.40
405.50	0.00	477.54	21.30	21.20	20.20	21.30	21.10	21.40
405.75	0.00	477.54	21.30	21.20	20.20	21.30	21.10	21.40
406.00	0.00	477.54	21.20	21.20	20.20	21.30	21.00	21.40
406.25	0.00	476.44	21.20	21.20	20.20	21.20	21.00	21.30
406.50	0.00	476.44	21.20	21.20	20.20	21.20	21.00	21.30
406.75	0.00	476.44	21.20	21.20	20.20	21.20	21.00	21.30
407.00	0.00	476.44	21.20	21.20	20.20	21.20	21.00	21.30
407.25	0.00	475.74	21.20	21.20	20.20	21.20	21.00	21.30
407.50	0.00	475.74	21.20	21.20	20.20	21.20	21.00	21.30
407.75	0.00	475.74	21.20	21.20	20.20	21.20	21.00	21.30
408.00	0.00	475.74	21.30	21.20	20.20	21.20	21.00	21.30
Mean ($\bar{x}$)			21.27	21.20	20.20	21.24	21.05	21.35
Sample Standard Deviation (σ n-1)			0.0629	0.00	0.00	0.0507	0.0632	0.0516

Grand Mean = 21.05

Table 9. Observed/Recorded Temperatures During the Second Caney Fork Survey, September 4-20, 1985

Station	9/4	9/12	9/20	Average
26.3	12.0/11.3	11.7/11.2	11.0/11.1	11.6/11.2
16.7 (shallow)	12.3/13.2	14.0/12.3	11.2/11.6	12.5/12.4
15.0	12.5/12.7	12.5/13.3	10.5/10.3	11.8/12.1
SFC	26.2/26.7	24.0/24.1	20.5/20.3	23.6/23.7
16.7 (deep)	12.4/12.0	*	*	12.4/12.0

DALE HOLLOW TAILWATER STUDIES

Location of Study

The Obey River exits Dale Hollow Dam at mile 7.2 and flows past Celina, Tennessee, to the confluence with the Cumberland River at CRM 380.9. A map of this reach of the Obey River is shown by Figure 7.

Description of Stations

Five temperature recorders were placed in the Obey River at ORM 6.7, 4.0, 2.2, 1.0 (surface), and 1.0 (10 feet deep). The recorders were positioned to best record the temperature regime of the river and to observe the effect of stratification at ORM 1.0. The recorders were put in place on 18 July and removed on 2 August, 1985. All recorders worked well and all were recovered. The survey period covered two weekends, one period of no generation for 38 hours, and two periods of heavy rainfall and runoff. A description of the stations is given by Table 10.

Table 10. Description of Survey Stations for the Dale Hollow Tailwater Study

Station Name	Description
ORM 6.7	Between boat ramp near dam and mouth of Dry Branch at an approximate depth of 3 feet during low flow and 15 feet from either bank.
ORM 4.0	Midway between mouth of Dry Branch and bridge past an island. Unit was placed about 2 feet from the left bank and at a 4 foot depth.

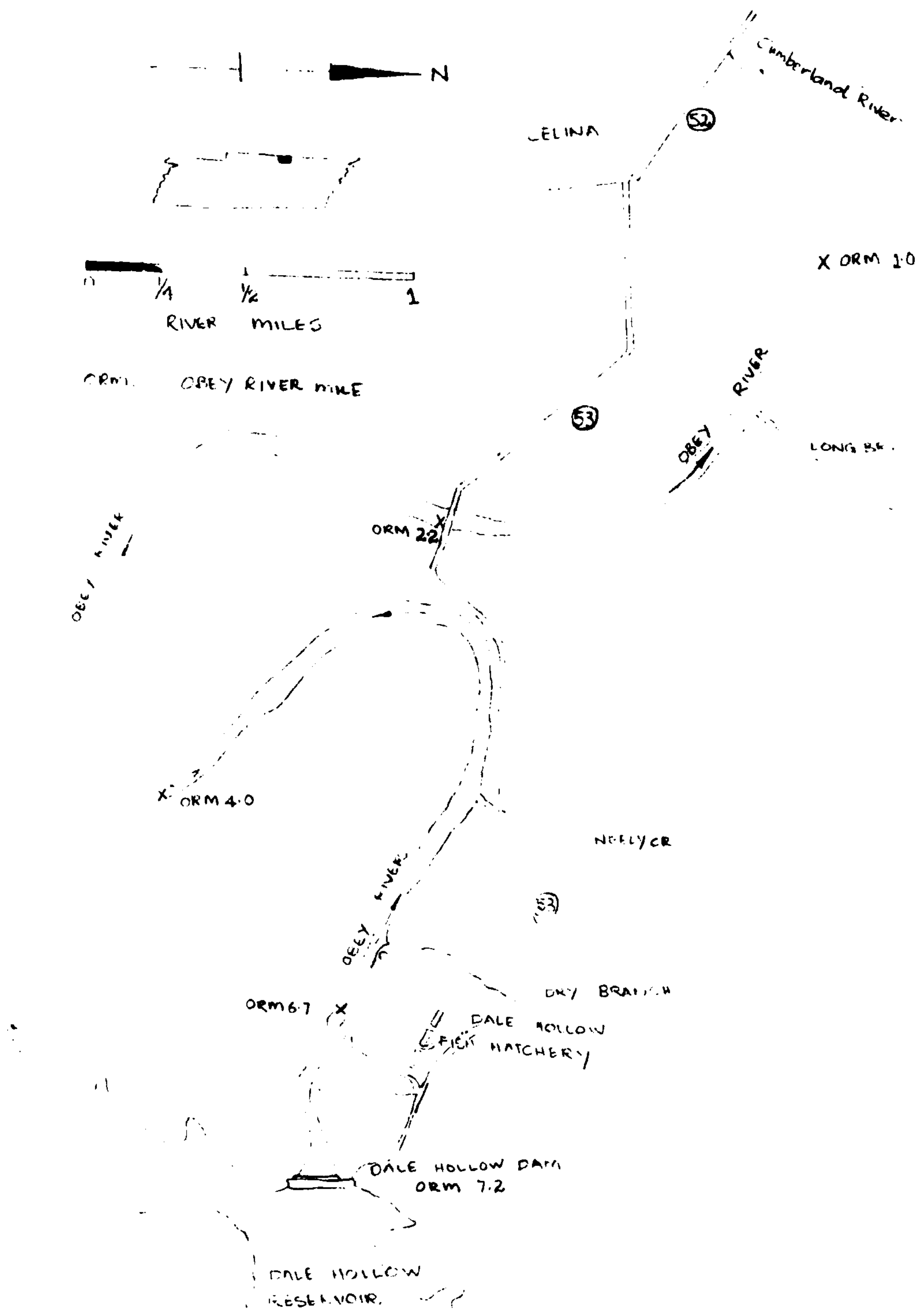


Figure 7

Obey River and Its Tributaries Below Dale Hollow Reservoir Showing Locations of Sampling Stations

ORM 2.2	Under the bridge at a depth of 4 feet and 4 feet from the right bank.
ORM 1.0	Celina water treatment plant intake, surface of pool. Unit was placed at a depth of 2.5 feet and about 2 feet from the left bank.
ORM 1.0	Bottom of pool at Celina water treatment plant intake. The depth of the unit equaled approximately 10 to 12 feet and was placed about 10 feet from the left bank.

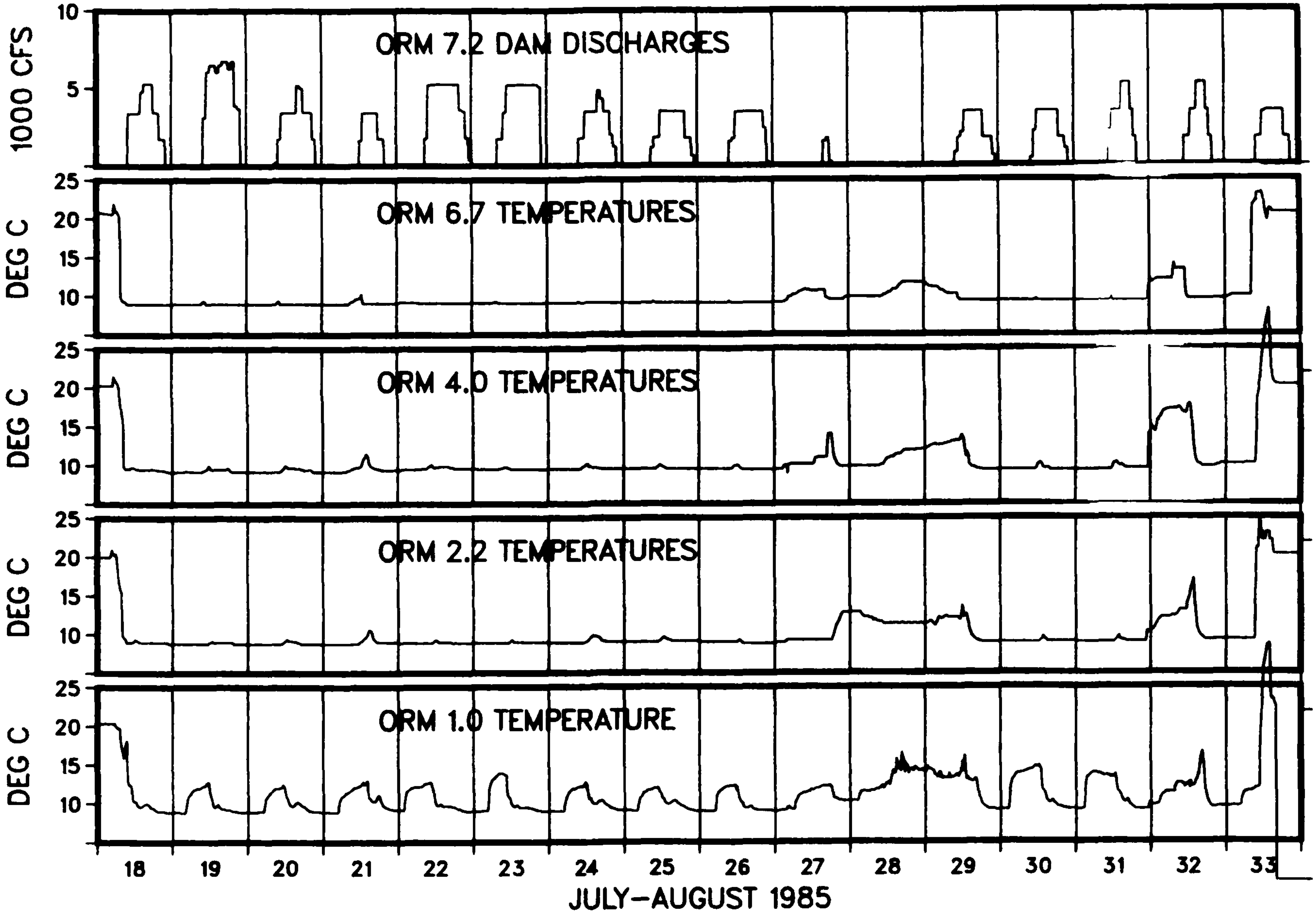
All references to depth were made during low flow periods and river banks were referenced looking downstream.

Data Presentation

The temperature record compiled from the survey is shown by Figure 8. Releases during the study were numerous and frequent ranging from 17 - 6737 cfs with a mean value of 1517 dsf over the survey period. In general releases up to about 7000 cfs occurred for 10 to 14 hours per day. This release schedule caused temperatures at all stations to remain below 15°C from 18-27 July. On 27 July, a period of no generation for 38 hours began. Between 27 and 29 July, the stream temperatures rose a little at all stations. No temperatures exceeded 15°C except at ORM 1.0 on the surface. Meteorological data showed maximum air temperatures of 80, 85, and 86°F on 27, 28 and 29 July. On 27 July, heavy rainfall of 3.25 inches was followed by 0.45 inches on the 28th. These high rainfalls caused the Obey River to become quite muddy on 28 July. On 1 August, the Celina station recorded 4.30 inches of rain which raised the river temperature above 15°C at ORM 4.0 and 2.2 by local runoff. Generation on that morning pushed this warm rainfall out of the Obey River to the Cumberland. Some temperature shock was noted at this time.

FIGURE 8

DALE HOLLOW TAILWATER TEMPERATURES



Time-of-Travel Estimations

Figure 8 allowed the time-of-travel to be estimated between the dam and ORM 4.0 and 2.2. The time-of-travel between ORM 7.2 and 4.0 was estimated at 7.8 hours and that for the reach between miles 7.2 and 2.2 was 8.2 hours. Thus, water moves through the reach below the dam at a fairly rapid rate. These time-of-travel values were determined on 29 July at a flow of 3400 cfs.

Deep Pool Stratification Study

Two recorders were placed at ORM 1.0 to evaluate the degree of stratification at that location. Figure 9 shows the record obtained. This location experienced stratification which might be expected this close to the Cumberland River. The difference between these two recorders (10 feet in depth) when placed in the stream (18 July to 2 August) ranged from 1.8 to 5.8°C with a mean difference of 3.7°C and a standard deviation of 1.1°C. At this wide, deep portion of the river, the cold water of the Obey River underflows a wedge of warmer water. Generation causes the warm overflow wedge to be flushed out of the Obey River and results in converging temperatures.

Quality Control

From the first four hour part of Table 11 the individual means of all the columns appear to be within 1.0°C of the grand mean of 20.7°C. But, the mean values of the last two columns appear to be 1.0°C higher when compared to the grand mean value of only the first three columns and the average mercury thermometer reading of 20.3°C. Since this is not within the acceptable limit and no further data were available to prove otherwise, the temperature values of the last two columns were reduced by 1.0°C throughout. The last four hour part of the table did not show any great deviations

FIGURE 9

DALE HOLLOW TAILWATER TEMPERATURES

STRATIFICATION STUDY

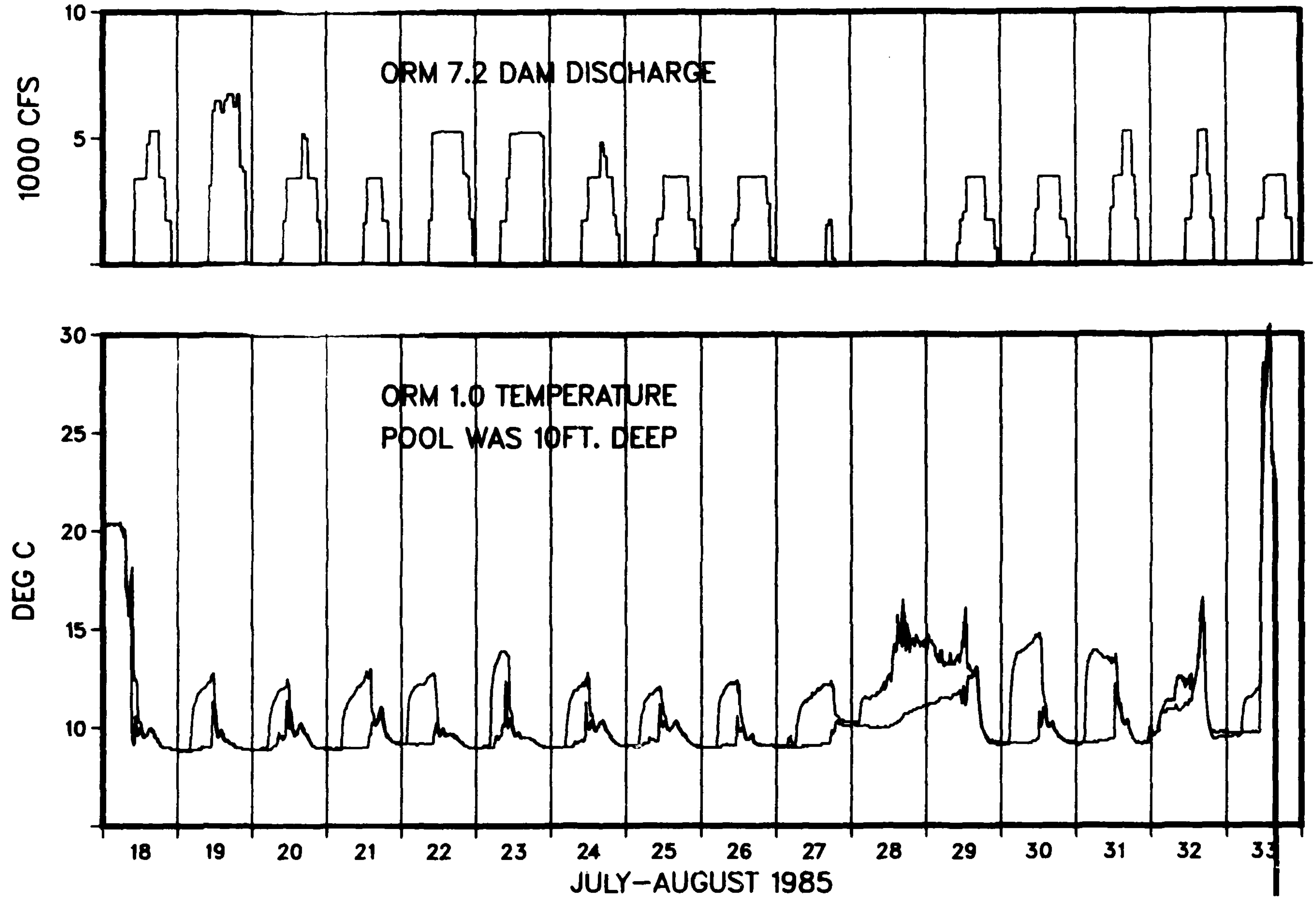


Table 11

Quality Control Data Prior to and after Dale Hollow Tailwater Investigations

(All temperatures listed in '°C')

Elapsed Time (hrs)	Flow (cfs)	Elevation (feet)	ORM 6.7	ORM 4.0	ORM 2.2	ORM 1.0 Surface	ORM 1.0 Bottom
0.25	17.00	506.40	20.80	20.30	20.00	21.30	21.30
0.50	17.00	506.40	20.80	20.30	20.00	21.30	21.40
0.75	17.00	506.40	20.80	20.30	20.00	21.30	21.40
1.00	17.00	506.40	20.80	20.30	20.00	21.30	21.30
1.25	17.00	506.40	20.80	20.30	20.00	21.30	21.30
1.50	17.00	506.40	20.80	20.30	20.00	21.30	21.40
1.75	17.00	506.40	20.80	20.30	20.00	21.30	21.40
2.00	17.00	506.40	20.70	20.30	20.00	21.30	21.40
2.25	17.00	506.40	20.70	20.30	20.00	21.40	21.40
2.50	17.00	506.40	20.70	20.30	20.00	21.40	21.40
2.75	17.00	506.40	20.70	20.30	20.00	21.40	21.40
3.00	17.00	506.40	20.70	20.30	20.00	21.40	21.40
3.25	17.00	506.40	20.70	20.30	20.00	21.30	21.40
3.50	17.00	506.40	20.60	20.30	20.00	21.30	21.40
3.75	17.00	506.40	20.60	20.30	20.00	21.30	21.40
4.00	17.00	506.40	20.60	20.30	20.00	21.40	21.40
Mean ($\bar{x}$)			20.72	20.30	20.00	21.34	21.38
Sample Standard Deviation ($\sigma n-1$)			0.0775	0.00	0.00	0.0500	0.0403

Grand Mean 20.7
Mean of 3 = 20.3

Table 11 Continued

380.25	1767.00	511.60	21.60	20.20	20.20	*	*
380.50	1767.00	511.60	21.60	20.20	20.20		
380.75	1767.00	511.60	21.60	20.20	20.20		
381.00	1767.00	511.60	21.00	20.20	20.20		
381.25	17.00	508.30	21.00	20.20	20.20		
381.50	17.00	508.30	21.00	20.20	20.20		
381.75	17.00	508.30	21.00	20.20	20.20		
382.00	17.00	508.30	21.00	20.20	20.20		
382.25	17.00	507.80	21.00	20.20	20.20		
382.50	17.00	507.80	21.00	20.20	20.20		
382.75	17.00	507.80	21.00	20.20	20.20		
383.00	17.00	507.80	21.00	20.20	20.20		
383.25	17.00	506.90	21.00	20.20	20.20		
383.50	17.00	506.90	21.00	20.20	20.20		
383.75	17.00	506.90	21.00	20.20	20.20		
384.00	17.00	506.90	21.00	20.20	20.20		
Mean ($\bar{x}$)			21.00	20.20	20.20		
Sample Standard Deviation ($\sigma n-1$)			0.00	0.00	0.00		

Grand Mean = 20.3

Mercury thermometer readings during this period were 20.20, 20.30 and 20.50.

*QC data omitted.

from the grand mean of 20.3°C and thus, did not require any correction. Quality control data were omitted for the last two columns of the second half of the table because the data were retrieved from the units right after the field investigation, which did not allow for the capture of any qualtiy control data.

Quality Assessment

Quality assurance was assessed by four surveys using hand-held mercury thermometers at the positions of the recorders on 18, 24, 28 July and on 2 August. The data are shown by Table 12. These data are in good agreement and show that the units performed well.

Table 12. Observed/Recorded Temperatures During the Obey River Survey, 18 July to 2 August, 1985

Station	7/18	7/24	7/28*	8/2	Average**
6.7	9.2/10.0	10.2/9.1	14.0/10.4	11.0/9.9	10.1/9.7
4.0	(9.2/9.8;10.0/9.7)	10.4/9.5	16.0/11.6	11.8/11.2	10.4/10.1
2.2	(9.5/9.6;9.8/9.0)	10.5/8.9	18.0/11.4	11.0/9.2	10.2/9.2
1.0	13.3/13.9	13.2/13.3	20.0/20.0	13.6/13.1	15.0/15.1
1.0(deep)	10.0/10.8				10.0/10.8

*Muddy runoff of rain water, obvious stratification at almost all stations.
**Omitting the 7/28 data.

LAKE CUMBERLAND TAILWATER STUDIES

Location of Study

The study area began at Wolf Creek Dam (CRM 460.9) and continued downstream to the Turkey Neck Bend Water Quality Monitoring Station at CRM 393.7, a distance of 67.2 miles. Three temperature recorders were placed at CRM 459.4, 44.8, and 427.0 and the monitoring data at CRM 393.7 were used. The recorders were put into service on 6 August and recovered on 23 August 1985. The stations are listed in Table 13 and shown by Figure 10.

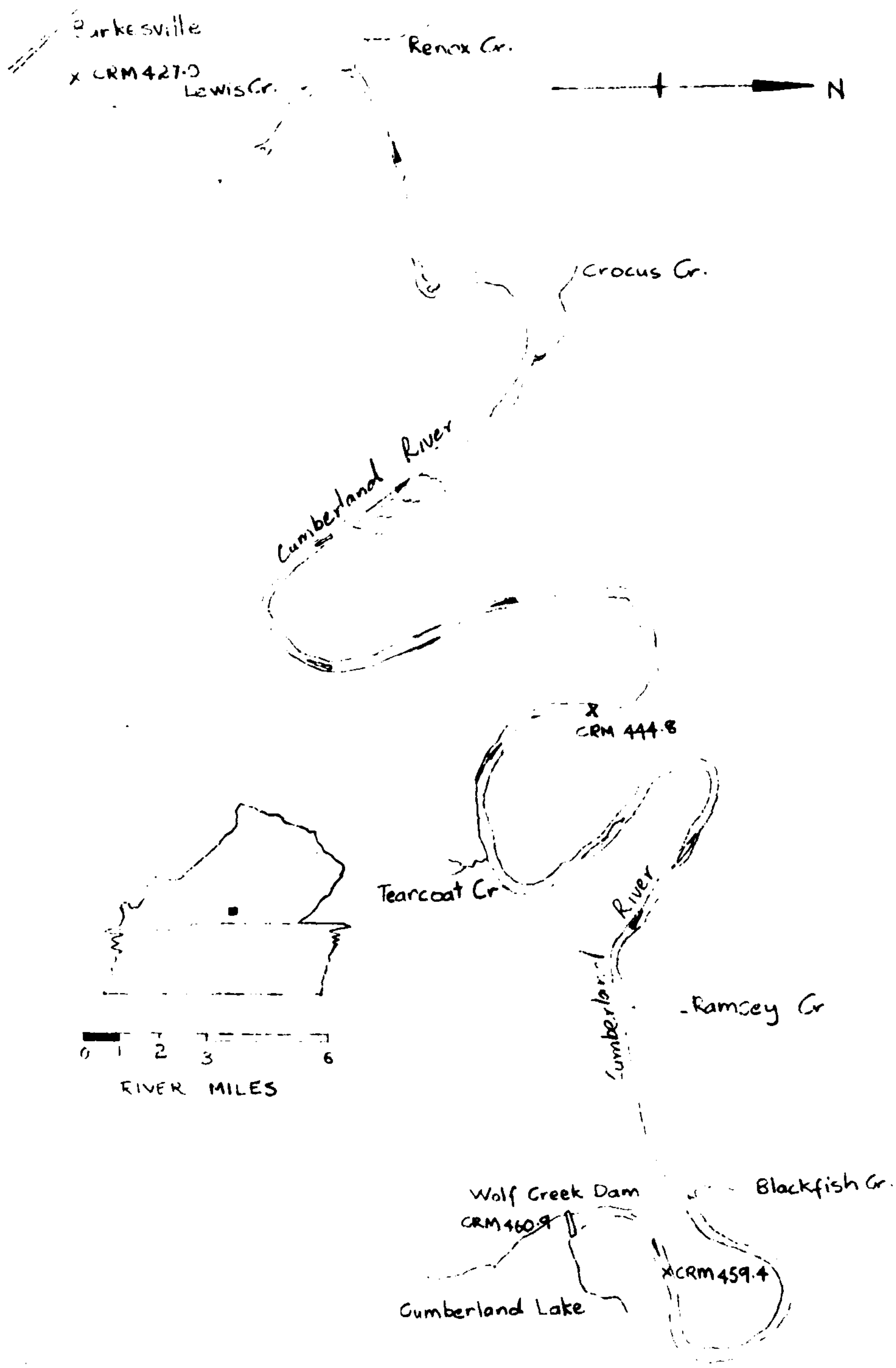


Figure 10

Cumberland River and Its Tributaries Below Wolf Creek Dam Showing Locations of Sampling Stations

Table 13. Description of Survey Stations for the Wolf Creek Tailwater Survey

Station Name	Description
CRM 459.4	Rowena stream gage. The depth of the unit equaled approximately 6 feet and was placed 10 feet from the left bank.
CRM 444.8	Winfrey's Ferry crossing. The unit was placed at a depth of 4-5 feet and at a depth of 10-11 feet from the right bank.
CRM 427.0	Burkesville boat ramp. The unit was placed at a depth of about 8 feet and about 10 feet from the right bank.
CRM 393.7	Turkey Neck Bend Monitor

References to all units' depths are made during low flow periods and river banks are referenced looking downstream.

Data Presentation

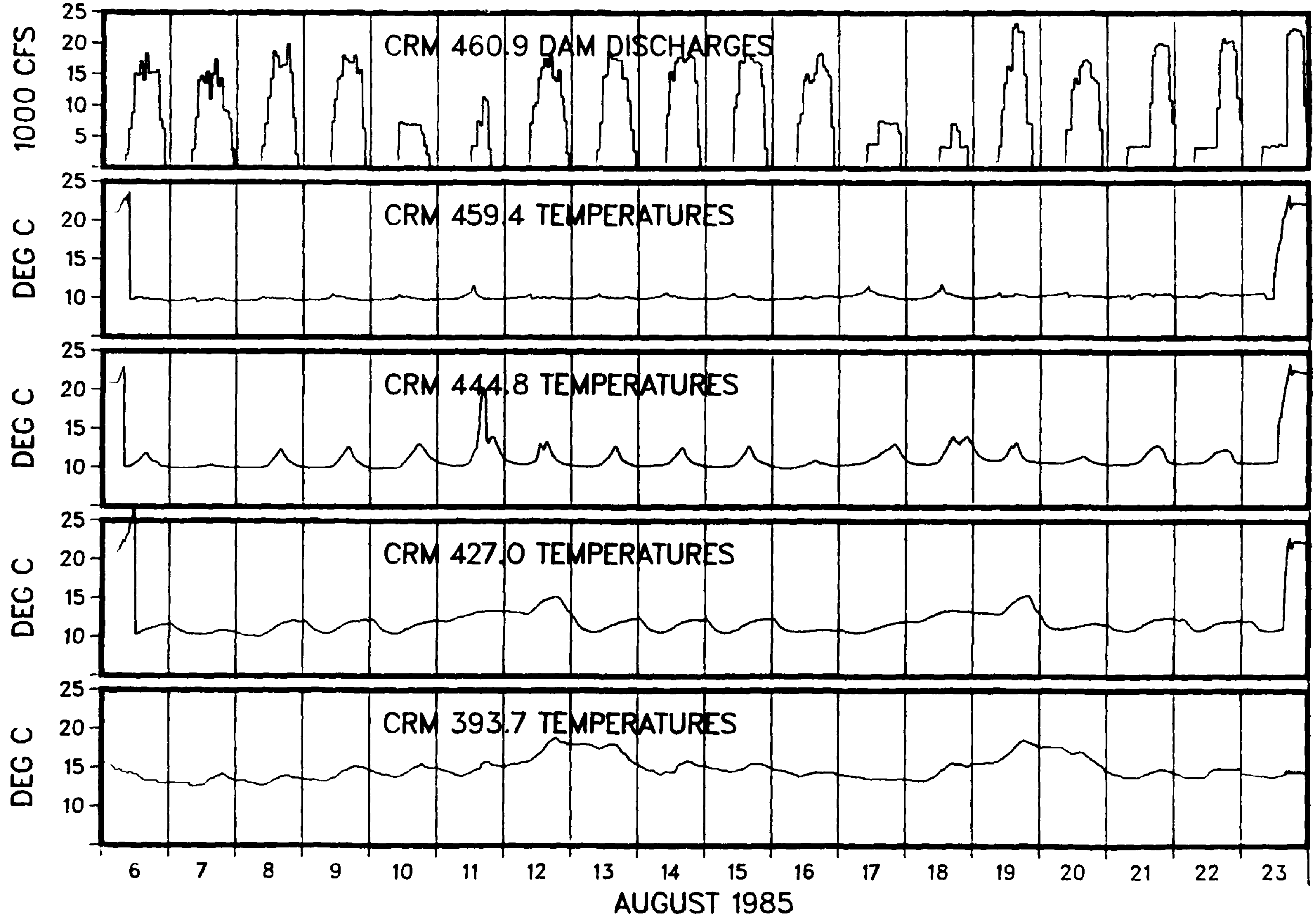
The temperature record developed from the survey is shown by Figure 11. Outflows during the 18 day survey period ranged from 20 - 23,280 cfs with a mean value of 6214 dsf over the survey period. Most days showed 10 or more hours of generation at between 15 and 20 thousand cfs. There were two days of lower-rate generation on 17 and 18 August but no days of zero generation. This generation schedule kept temperatures below 15°C down to CRM 427.0 and below 20°C to CRM 393.7. One short period of temperature increase on 11 August at CRM 444.8 was attributed to the recorder getting partially out of the water for a short period of time.

Time-of-Travel Estimations

It was only possible to estimate the time-of-travel between the dam and CRM 444.8, a distance of 16.1 miles. Four estimates of this time-of-travel were made for the dates of 13, 14, 15, and 18 August. The times

FIGURE 11

WOLF CREEK TAILWATER TEMPERATURES



were 14.3 hours at 16,400 cfs, 14.0 hours at 17,400 cfs, 12.3 hours at 18,200 cfs, and 16.3 hours at 7,300 cfs. As noted for the other projects, these power waves move rapidly downstream. The temperature peaks and valleys below CRM 444.8 became so rounded that no realistic travel times could be calculated.

Quality Control

The first half of Table 14 shows a grand mean of 21.0°C and the individual means of each of the three columns appear to be within the acceptable criteria of 1.0°C from the grand mean. The second half of the same table also shows such an agreement with respect to its grand mean of 22.3°C; therefore, no correction is made to any of these readings.

Quality Assurance

Quality of the data was assessed by three surveys using a hand-held mercury thermometer on 6, 12, and 23 August. The quality assessment data are shown by Table 15. The table shows that all of the recorders worked well during the survey.

Table 15. Observed/Recorded Temperatures During the Cumberland River Survey, 6-23 August 1985

Station	8/6	8/12	8/23	Average
459.4	9.9/9.9	*	10.0/10.1	10.0/10.0
444.8	10.1/10.3	13.7/13.1	10.7/11.0	11.5/11.5
427.0	10.4/10.4	16.5/15.2	11.5/11.2	12.8/12.3

*No data available.

CONCLUSIONS

Caney Fork River

During the June and September surveys the Caney Fork River below Center Hill Dam maintained temperatures below 20°C except on hot, clear days which

Table 14

Quality Control Data Prior to and after Wolf Creek Tailwater Investigations

(All temperatures listed in '°C')

Elapsed Time (hrs)	Flow (cfs)	Elevation (feet)	CRM 459.4	CRM 444.8	CRM 427.0
0.25	20.00	546.38	21.10	21.00	21.00
0.50	20.00	546.38	21.10	21.00	21.00
0.75	20.00	546.38	21.10	21.00	21.00
1.00	20.00	546.38	21.10	21.00	21.00
1.25	20.00	545.48	21.10	21.00	21.00
1.50	20.00	545.48	21.10	21.00	21.00
1.75	20.00	545.48	21.10	21.00	21.00
2.00	20.00	545.48	21.10	20.90	21.00
2.25	20.00	544.69	21.00	20.90	21.00
2.50	20.00	544.69	21.00	20.90	21.00
2.75	20.00	544.69	21.00	20.90	21.00
3.00	20.00	544.69	21.00	20.90	21.00
3.25	20.00	544.09	21.00	20.90	21.00
3.50	20.00	544.09	21.00	20.90	21.00
3.75	20.00	544.09	21.00	20.90	21.90
4.00	20.00	544.09	21.00	20.90	20.90
Mean ($\bar{x}$)			21.05	20.94	20.99
Sample Standard Deviation (n-1)			0.0516	0.0512	0.0342

Grand Mean = 21.0

Table 14 Continued

428.00	22270.00	557.46	22.30	22.50	22.40
428.25	22270.00	557.42	22.30	22.40	22.40
428.50	22130.00	557.42	22.30	22.40	22.40
428.75	22130.00	557.42	22.30	22.40	22.40
429.00	22130.00	557.42	22.30	22.40	22.40
429.25	21290.00	557.40	22.30	22.40	22.40
429.50	21290.00	557.40	22.20	22.40	22.30
429.75	21290.00	557.40	22.20	22.40	22.30
429.75	21290.00	557.40	22.20	22.40	22.30
430.00	21290.00	557.40	22.20	22.40	22.30
430.25	10160.00	554.40	22.20	22.30	22.30
430.50	10160.00	554.50	22.20	22.30	22.30
430.75	10160.00	554.40	22.20	22.30	22.30
431.00	10160.00	554.40	22.20	22.30	22.30
431.25	3340.00	552.19	22.20	22.30	22.30
431.50	3340.00	552.19	22.20	22.30	22.20
431.75	3340.00	552.19	22.10	22.30	22.20
432.00	3340.00	552.19	0.00	22.20	22.20
Mean ($\bar{x}$)			22.23	22.35	22.32
Sample Standard Deviation (n-1)			0.0602	0.0717	0.0728

Grand Mean = 22.3

coincided with periods of no generation extending to 40 hours. Then, temperatures rose above 20°C until generation was resumed. Temperature shocks of up to 11°C in 3 hours (temperature drop) were observed. The current minimum flow criteria (one unit for one hour in every 48 hours) will not maintain the Caney Fork River below 20°C, which allows the temperature "cold-shock" following generation to be more severe. Under the outflow temperatures and meteorological conditions experienced during the survey, it appears daily generation with one unit for 4 hours would keep stream temperatures below 15°C and eliminate most temperature shock potential. The inflow of warm water from Smith Fork Creek warmed the Caney Fork 2-3°C at low-flow periods. Power waves move rapidly downstream and the reach from mile 26.6 to 8.3 has a time-of-travel of 18 hours with one turbine generating a flow of about 3300 cfs. Visual observations show that water is retained in the stream channel during periods of no generation.

Obey River

During the July-August survey, the Obey River below Dale Hollow Dam maintained temperatures below 15°C throughout the 7.2 miles reach to the Cumberland River. Periods of up to 38 hours of zero generation did not result in temperatures rising to 20°C and temperature shocks were thus minimized. Local runoff from storm events were observed to warm the river between generation periods. Rises in the Cumberland River can cause water to flow upstream into the Obey River during the periods of no generation. The river becomes slightly stratified at ORM 1.0. Visual observations show that the river retains water fairly well during no-generation periods.

Cumberland River

During the August survey, the Cumberland River below Wolf Creek Dam maintained temperatures below 20°C for 67 miles. Relatively constant generation schedules result in a good flow of water at most times, but shoals are present at zero generation. The effects of extended periods of low-flow were not observed. Rapid water movement and short times-of-travel result from power waves.

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