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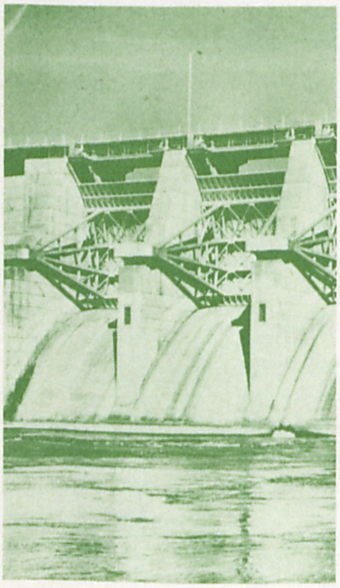

ENVIRONMENTAL LABORATORY

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WATER QUALITY STUDY OF PROPOSED REREGULATION DAM DOWNSTREAM OF WOLF CREEK DAM, CUMBERLAND RIVER, KENTUCKY

by

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Environmental Laboratory

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This report describes the application of an unsteady, one-dimensional water quality model to the Cumberland River below Wolf Creek Dam, Kentucky. A hydropower upgrade of Wolf Creek Dam and construction of a reregulation dam, located approximately 10 miles below Wolf Creek Dam, are under consideration. Simulations were conducted under unreregulated conditions and projected conditions following impoundment to provide information concerning the effect of the reregulation dam on water quality in the Cumberland River. Under the conditions

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simulated, the reregulation dam was predicted to have little impact on temporally averaged water temperatures or dissolved oxygen concentrations. Temporal variations in water temperatures were retarded under reregulation conditions.

PREFACE

This study was conducted by the Environmental Laboratory (EL) of the US Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., for the US Army Engineer District, Nashville (ORN). The project was authorized by Intra-Army Order for Reimbursable Services No. 85-0070 dated 2 April 1985 and amended 26 June 1985.

This report is an evaluation of simulated differences in water temperatures and dissolved oxygen concentrations in the Cumberland River, Kentucky, below Wolf Creek Dam, for projected conditions with and without a reregulation dam.

The study was conducted and the report prepared by Dr. James L. Martin of the Water Quality Modeling Group (WQMG), Ecosystem Research and Simulation Division (ERSD), EL, under the direct supervision of Mr. Mark S. Dortch, Chief, WQMG, and under the general supervision of Mr. Donald L. Robey, Chief, ERSD, and Dr. John Harrison, Chief, EL. Contributions and reviews by Dr. Stephen P. Schreiner, Ms. Sandra L. Bird, and Mr. Mark S. Dortch, WQMG, and Mr. Jack Brown, ORN, are gratefully acknowledged. This report was edited by Ms. Jamie W. Leach, Publications and Graphics Arts Division, WES.

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WATER QUALITY STUDY OF PROPOSED REREGULATION DAM DOWNSTREAM OF WOLF CREEK DAM, CUMBERLAND RIVER, KENTUCKY

PART I: INTRODUCTION

Background

Wolf Creek Dam, located at mile 460.9 on the Cumberland River in Kentucky, is currently operated for flood control and base load hydropower production. The project has a total hydropower capacity of 270 megawatts installed during construction of the project and an average annual energy output of 900 million kilowatt hours. The project was placed on line for power production between 1951 and 1952. To aid in meeting future power needs, an upgrade of the hydropower generating capacity at Wolf Creek Dam, Lake Cumberland, has been proposed. The proposed upgrade includes the addition of new units, refitting of existing units, and a change from base load generation to peaking operation. The feasibility of various structural and operational alternatives associated with the hydropower upgrade are currently under consideration.

The project currently releases an annual average flow of 10,800 cfs with a maximum hydropower capacity of 30,000 cfs. Revised operating plans under consideration include increasing the hydropower capacity to a maximum of 60,000 cfs during peaking periods. However, the existing seasonal operation pattern will be maintained to minimize changes on in-pool water level fluctuations. Construction of a reregulation (rereg) dam downstream from Wolf Creek is being considered to attenuate the power wave. The proposed rereg dam is presently sited about 10 miles below Wolf Creek Dam, at river mile 450.7.

The closing of Wolf Creek Dam to form Lake Cumberland resulted in substantial flow and water quality changes in the Cumberland River below the dam. Summertime releases from Wolf Creek Dam are substantially colder than preimpoundment temperatures due to the relatively deep location of the penstocks. The cold releases have changed the Cumberland River from a warm water stream to a cold water habitat and significantly changed the environmental conditions in the downstream waters. Temperatures in the outflows typically vary between 6 degrees C in the winter to a high of 15 degrees C in the early fall. Dissolved oxygen (DO) concentrations in project releases typically vary between 12 mg/l in March to a minimum of 5 mg/l in October (Nashvlle District, 1985). Iron and manganese concentrations are typically low and DO concentrations are satisfactory for maintenance of aquatic life.

The year-round availability of cold water has allowed the development of a valuable put-and-take trout fishery in this formerly warm water stream. Harvestable-size rainbow trout are stocked in the Wolf Creek tailwater by the Kentucky Department of Fish and Wildlife Resources.

An area of environmental concern is the effect of hydropower upgrade and rereg impoundment on water quality within the proposed rereg pool. Altered flow conditions within the rereg pool are expected to affect water temperatures and DO concentrations. Changes in water temperatures and DO could potentially impact aquatic habitat within and below the rereg pool.

Objective

The objective of this report is to predict water quality conditions in the Cumberland River within the reach impacted by the proposed rereg dam. Simulations were conducted under projected conditions with and without a rereg dam and were intended to provide information concerning the effect of the rereg dam on water quality of the Cumberland River. Due to the highly unsteady conditions resulting from peaking hydropower operations, this analysis required the use of an unsteady flow water quality model. The following sections of this report describe the model used, its application, and the conclusions of the study.

PART II: MODEL DESCRIPTION

A one-dimensional (1-D) riverine water quality model developed by Bedford et al. (1982) was selected for use in this study. The highly unsteady nature of flows in the system required application of an unsteady flow model. A cross-sectionally averaged, longitudinally 1-D model was considered appropriate for this application.

The Bedford model was selected for this application because of capabilities to simulate highly unsteady conditions, to include in-stream hydraulic structures (i.e., the rereg dam) and because of its mechanistic water quality algorithms. The Bedford code consists of two sub-models. The hydrodynamic code (referred to as RIV1H) simulates water movement within the modeled system. This code can stand alone and may be used to simulate river flows, water surface elevations (stage), depths, cross sectional areas, and top widths under unsteady conditions. The water quality model (referred to as RIV1Q) requires output from RIV1H to drive the transport algorithms for water quality simulations.

RIV1H Submodel

RIV1H is patterned after the National Weather Service Dambreak Model (Fread, 1978) using the four point implicit finite difference method. The advective term of the momentum equation is left in nonlinear form, thus a Newton-Raphson iteration is used to converge the solution at each time step. The model permits relatively unequal space and time steps. The model also allows simulation of branched river systems with multiple hydraulic control structures.

RIV1H requires river geometry descriptions and flow conditions to perform the hydrodynamic calculations. Describing river geometry requires prescribing the location of control structures, distances between nodes, stream bed elevations, cross sectional area versus depth equation coefficients, and Manning's coefficients. Flow conditions include initial flow rates and stages, lateral inflows or withdrawals, and boundary conditions. Boundary conditions may be provided in terms of flows, stages, or rating curves at control structures or boundaries.

Cross-sectional area and discharge are the dependent variables of the hydrodynamic equations. Once these variables are computed, stage, depth, and width can be determined. Time histories of all these variables can be output for each node of the river model. Additionally, all of these variables are used by RIV1Q to calculate dynamic changes in temperature and concentrations of water quality variables.

RIV1Q Submodel

After computing hydraulic conditions with RIV1H, RIV1Q is applied for water quality predictions. RIV1Q uses an explicit finite difference method to solve the constituent transport/reaction equations. A two point fourth order accurate scheme developed by Holly and Preissmann (1978) provides highly accurate advective transport during the solution of these equations.

RIV1Q was originally developed to simulate effects of wastewater or pollutant loadings on riverine systems. The model could originally simulate up to seven water quality variables: temperature, dissolved oxygen (DO), carbonaceous biochemical oxygen demand (CBOD), organic nitrogen, ammonia nitrogen, nitrate nitrogen, and phosphate (phosphorus), as well as a user-selected variable, e.g., conservative tracer. Additionally, the effects of phytoplankton and macrophyte growth and decay on nutrient balances and DO are included. Phytoplankton and macrophytes are assumed to be light limited only. Recent modifications to the code by the Water Quality Modeling Group at WES also allow simulation of dissolved iron, dissolved manganese, and coliform bacteria. A brief description of how each of these ten water quality variables is modeled is discussed below.

Temperature computations are generally modeled BY RIV1Q using a direct energy balance approach (Roesner et al., 1977). However, for this application, the code was modified allowing the equilibrium temperature approach (Edinger, Brady and Geyer, 1974) to be used. Equilibrium temperatures and coefficients of heat exchange had been previously computed by ORN from historical meteorological data for the 1948-1981 period of record. Typical conditions for the critical months of July through September were identified by ORN and used in thermal modeling of the Cumberland River below Wolf Creek Dam using simplified (steady-state) modeling techniques. The modification of

RIV1Q allowed these previously computed meteorological variables to be used in simulations and provided a greater degree of comparability between modeling studies. Computed temperatures are used to modify reaction rates for other water quality constituents.

Computation of DO concentrations is a primary focus of the model. Reaeration and photosynthesis are sources of oxygen, while organic matter decay, nitrification, plant respiration, and iron and manganese oxidation deplete DO. Reaeration in the river itself follows the Tsivoglou formulation (Tsivoglou and Wallace, 1972), and reaeration through the rereg dam is according to the empirical relationship developed by Wilhelms and Smith (1981).

Carbonaceous biochemical oxygen demand (CBOD) represents the amount of biodegradable organic matter present in terms of oxygen equivilants required for its complete decay. Oxygen or nitrate can serve as terminal electron acceptors for this process depending upon half saturation constants used and the concentrations of oxygen and nitrate present. The amount of oxygen or nitrate reduced decreases and increases, respectively, as the DO approaches zero. CBOD removal, which is a first-order process, does not occur in the absence of oxygen or nitrate.

Nitrogen in three forms occurs in the model-- organic nitrogen, ammonia nitrogen, and nitrate nitrogen. Organic nitrogen is a constituent of organic matter and the model converts organic nitrogen to ammonia through hydrolysis. Ammonia is derived from organic nitrogen and algal and macrophyte decay, all first-order processes.

Ammonia is lost from the system by nitrification and uptake by plants, also first order processes. Nitrate is formed from ammonia by nitrification and removed by plant uptake and denitrification under low DO conditions.

Phosphate phosphorus is removed from the system by algal and macrophyte uptake and released to the system by plant decay.

Dissolved iron and manganese may enter the system through releases or lateral inflows. When DO is greater than 1.0 mg/1, dissolved iron and manganese are oxidized (first-order process) and lost from the system.

Fecal coliform bacteria enter the system through lateral inflows which represent agricultural or urban runoff or wastewater return flows. Fecal coliforms do not reproduce in aerobic free state and their populations decay exponentially (first-order decay).

PART III: METHODS AND SIMULATION CONDITIONS

System Discretization

The model simulates the Cumberland River as a series of two (with rereg dam) or one (without rereg dam) segments which are bounded by a control structure at their upstream end (Wolf Creek Dam). Inflows are specified from Wolf Creek Dam, located at river mile 460.9. Flows are also specified for the proposed rereg dam, located at river mile 450.7. The final lower boundary condition at river mile 444.5 is defined by a rating curve. Each model segment is divided into a series of nodes where the river geometry (cross sectional area and bed elevation) and initial conditions are defined and at which the model makes predictions about hydrodynamic and water quality conditions. The cross sectional area at each node is described by the equation A = C1 * H + C2 * H ** C3, where A is the cross sectional area; H is the depth from the stream bed to the water surface; and the C's are user-defined coefficients. At any given node, lateral inflows and withdrawals can be defined, with the net input or withdrawal divided by the length of the reach between nodes (units of cubic feet per second-foot).

The cross sectional data for the segment impacted by the rereg dam were obtained through surveys conducted during 1985. The X,Y points obtained from these surveys were then used to obtain cross sectional areas at discrete elevations using the program GEDA (Hydrologic Engineering Center, 1981). The values of the C's used to compute cross sectional areas in the model were computed using nonlinear regression techniques. The number of nodes used in simulations varied from 24 without the rereg dam to 25 with the rereg dam. The nodes and values of C′s used to compute areas are provided in Table 1 with node 1 (river mile 460.9) being the site of Wolf Creek Dam. Node 20, the site of the rereg dam, was not utilized in simulations of unreregulated conditions.

A time step of 200 seconds was selected for all model simulations. With the explicit scheme of RIV1Q and the highly dynamic flow with large flow rates during power generation, this small time step was selected to ensure numerical stability.

Hydraulic Simulations

Hydraulic simulations of the reach impacted by the rereg structure were conducted by Mr. Don Getty, ORN, using a version of the Branched Implicit River Model (BIRM; Johnson, 1983), an unsteady hydraulic model. These simulations formed the basis for the hydraulic simulations with RIV1H. ORN provided channel geometries, initial flow and stage conditions at each node, Manning′s n values, inflows from Wolf Creek Dam (upstream boundary, river mile 460.9), and outflows from the rereg dam (river mile 450.7) for simulations with RIV1H. The initial conditions and Manning′s n values are provided in Table 1. The upstream boundary conditions were the same for simulations with and without a rereg dam. The downstream boundary, at river mile 444.5, was specified by a rating curve. The initial conditions were

Table 1. Input Data for RIV1H, With Rereg Dam

Node	River Mile	Initial Flow cfs	Initial Depth ft	Lateral Flow, cfs/ft	Bed Elevation ft,msl	C1	C2	C3	Manning's n
1	460.90	500.	7.67	0.	534.30	0.00000	60.638599	1.408000	0.03
2	460.00	500.	7.61	0.	534.30	0.00000	60.638599	1.408000	0.03
3	459.26	500.	7.39	0.03643	534.50	0.00000	68.808998	1.400000	0.03
4	458.74	600.	10.08	0.	531.80	0.00000	51.362202	1.475180	0.03
5	458.12	600.	7.54	0.	534.30	0.00000	54.972401	1.442340	0.03
6	457.40	599.	2.93	0.05769	538.80	0.00000	52.513000	1.258770	0.03
7	457.16	675.	8.55	0.	533.20	0.00000	22.042801	1.790260	0.03
8	456.40	675.	6.85	0.	534.50	0.00000	119.658997	1.300690	0.03
9	455.90	675.	6.20	0.01776	535.10	166.753006	1.426200	2.434520	0.03
10	455.10	750.	6.01	0.	535.20	9.963000	165.373993	1.205240	0.03
11	454.70	750.	6.42	0.	534.70	0.000000	61.693199	1.533900	0.03
12	454.48	750.	4.95	0.03643	536.10	215.182999	0.722000	2.569910	0.03
13	453.70	900.	5.11	0.	535.60	0.000000	109.501999	1.340260	0.03

Table 1. Input Data for RIV1H, With Rereg Dam
(Completed)

Node	River Mile	Initial Flow cfs	Initial Depth ft	Lateral Flow, cfs/ft	Bed Elevation ft,msl	C1	C2	C3	Manning's n
14	453.18	900.	5.88	0.03381	534.60	0.000000	126.236000	1.295250	0.03
15	452.76	975.	6.21	0.02152	534.20	0.000000	139.466003	1.257880	0.03
16	452.10	1050.	10.48	0.	529.90	139.121994	11.086200	1.733150	0.03
17	451.70	1050.	9.36	0.	531.00	0.000000	128.514999	1.247330	0.03
18	451.20	1050.	9.03	0.	531.30	105.446999	8.486900	2.051860	0.03
19	450.95	1050.	7.51	0.	532.80	100.617996	83.238197	1.322310	0.03
20*	450.72	1050.	7.51	0.	532.80	100.617996	83.238197	1.322310	0.03
21	450.70	1050.	7.51	0.	532.80	0.000000	42.990501	1.495380	0.03
22	450.26	1050.	6.13	0.	527.80	0.000000	42.990501	1.661910	0.03
23	448.20	1050.	4.64	0.	527.50	119.067001	17.871099	1.427650	0.03
24	446.80	1050.	3.59	0.	527.00	72.454002	41.958500	1.277000	0.03
25	444.5	1051.	8.47	0.	521.00	0.000000	107.084999	1.277000	0.03

* Site of rereg dam

modified for some simulations as discussed below. A number of nodes with identical geometries used in BIRM simulations were combined for RIV1H simulations, resulting in fewer total nodes.

Hydraulic simulations were conducted for three conditions representing projected operating schedules over a typical week during July. Simulations were conducted with and without lateral inflows for the first two conditions. The third condition represented a week of operation without weekend power generation. In all simulations, the minimum specified low flow from Wolf Creek Dam was 500 cfs. This low flow was utilized in simulations with BIRM, and subsequently RIV1H, to maintain numerical stability. Zero flows, or flows which would result in zero depths at any point in the reach, can not be simulated with either model. This necessitated the selection of a low flow condition which insured numerical stability. However, Wolf Creek Dam does not have the capability of generating at flows of less than about 2500 cfs, and seepage and leakage during non-generation are considerably less than 500 cfs. Worst water quality conditions would be expected to occur under zero flow conditions rather than the minimum specified low flow of 500 cfs.

Under the first condition, BIRM hydraulic simulations included a total of seven tributaries in addition to the main branch to allow simulation of tributary storage, with inflows from tributaries varying from 75 to 100 cfs, totaling 550 cfs. Tributary storage was not considered in RIV1H simulations. Tributary flows were specified as lateral inflows (Table 1). Instantaneous discharges from Wolf Creek Dam varied from 500 to 48000 cfs, with flows of 500, 12000, 30000, and

48000 cfs being incremented stepwise over a five hour power generation cycle on weekdays. The mean daily outflows varied from 5896 cfs during the week to 4146 cfs on Saturday and 2438 cfs on Sunday. The rereg dam was operated to release the daily volume of the Wolf Creek outflow at a constant rate. Outflows from the rereg dam were 1050 cfs for the first approximately 12 hours of simulation, afterwhich they remained at a constant 6200 cfs. Hydraulic simulations were conducted for a period of 7.63 days, extending from Wednesday through a weekend operation to the following Wednesday. The simulations were intended to reflect variations due to a typical July operating schedule. Simulations were conducted for conditions both with and without a rereg dam.

The second condition for hydraulic simulations is identical to those above except lateral inflows were not included in simulations. Conversations with Mr. Jack Brown, ORN, indicated that the 550 cfs represented a high flow event for tributary flows. To prevent tributary flows from artifically biasing study results, they were removed from subsequent simulations. To obtain the outflows from the rereg dam under conditions without tributary flows, discharges predicted by BIRM simulations were decremented by 550 cfs. Initial conditions were obtained by simulating a period of constant inflows and outflows of 500 cfs with RIV1H until a steady state water surface elevation was obtained. The final conditions were then used as the initial conditions for subsequent simulations.

The third condition for hydraulic simulations represented a week of operation including low flow conditions during the weekend. As the worst conditions, with respect to water quality, would be expected to occur following a prolonged period of low flows, inflows from Wolf Creek Dam were held steady at 500 cfs over the weekend. The week of operation extended from a Monday to the following Monday, for a total of 7.58 days of simulation. Mean daily outflows from Wolf Creek Dam varied from 7146 cfs during the week to 500 cfs during the weekend. Instantaneous discharges varied from 500 to 54000 cfs, with flows of 500, 18000, 36000, and 54000 cfs being incremented stepwise over a five hour power generation cycle on weekdays. Discharges from the rereg dam specified by BIRM simulations varied from 7500 cfs during weekdays to 5500 cfs during the weekend. Tributary inflows were included in BIRM hydraulic simulations. Tributary inflows were not utilized in RIV1H simulations, for reasons discussed above, and discharges from the rereg dam predicted by the BIRM model were decremented by 550 cfs. For the two previous simulations, hydropower generation occurred during the weekend.

Water Quality Simulations

Upon completion of hydraulic simulations with RIV1H, water quality simulations were conducted to identify spatial and temporal variations in water temperatures and DO under projected conditions with and without a rereg dam.

Hydraulic simulations were conducted using a specified operating schedule for July. This period was suitable for estimating highest expected temperature conditions in the impacted reach. However, DO concentrations in releases from Wolf Creek Dam are generally lowest in September and October. Water quality simulations were conducted for September assuming that the July operating schedule applied.

Simulations of water temperature were based upon monthly average equilibrium temperatures and coefficients of heat exchange as provided by ORN (Table 2).

Water quality simulations required specification of water temperatures and constituent concentrations for flows from Wolf Creek Dam. Concentrations of CBOD, organic nitrogen, ammonia-nitrogen, nitrate-nitrogen, dissolved manganese, and dissolved iron were taken from data supplied by ORN and generally represent average observed outflow values over the period of 1970-1983 (Table 3). These values were assumed to remain constant with flow and for the July and September simulations to allow assessment of the relative impact of the rereg dam on DO depletions. Their decay or oxidation rates were based upon previous model applications (Table 3). The effects of photosynthesis and plant respiration were not included in water quality simulations, since no data were avaiable for estimating their effects. Wind driven aeration was also not included in simulations, since wind speed data were not available. Therefore, predicted dissolved oxygen concentrations may be somewhat lower than those that may actually occur under the conditions simulated.

Table 2. Heat exchange coefficients.

	July	September
Equilibrium Temperature (degrees C)	30.1	25.3
Coefficient of Heat Exchange (Watts per square meter per degrees C)	29.0	22.9

Table 3: Values of water quality variables in releases from Wolf Creek Dam.

	Concentration mg/l	Decay/Oxidation Rate per day
Carbonaceous B.O.D.	2.0	0.15
Organic Nitrogen	0.3	0.50
Ammonia-Nitrogen	0.05	0.50
Nitrate-Nitrogen	0.40	--
Dissolved Iron	0.08	1.0
Dissolved Manganese	0.02	0.50

The water temperatures and dissolved oxygen concentrations of releases from Wolf Creek Dam, the upstream boundary, were varied with flow and between the July and September simulations. Water temperatures and DO were determined through selective withdrawal simulations conducted by Mr. Jack Brown, ORN, using typical profiles for July and September and outflow magnitudes used in hydraulic simulations. The water temperatures and constituent concentrations of discharges from Wolf Creek Dam, as used in simulations, are provided in Table 4.

Initial conditions are also required for each water quality constituent at each modeled node. These initial conditions were determined by simulating water quality variables over the week, and then using the final conditions as the initial conditions for subsequent simulations.

Water quality simulations were conducted under four sets of conditions:

<u>Condition 1</u>

For this condition, lateral inflows were included in simulations. The lateral inflows, totaling 550 cfs, represent higher tributary flows than would ordinarily be expected to occur. These high tributary inflows were used in BIRM simulations to provide a conservative maximum estimate of water surface elevations.

Table 4: Water temperatures and dissolved oxygen concentrations of releases from Wolf Creek Dam.

Flow cfs	JULY Water Temperature degrees C	JULY Dissolved Oxygen mg/l	SEPTEMBER Water Temperature degrees C	SEPTEMBER Dissolved Oxygen mg/l
500	11.8	8.1	14.5	6.3
12000	11.8	8.1	14.5	6.3
18000	12.1	8.1	14.6	6.3
24000	12.0	8.1	14.8	6.3
30000	12.5	8.1	15.0	6.4
36000	12.6	8.1	15.5	6.4
48000	12.8	8.1	15.6	6.4
54000	12.9	8.1	15.6	6.4

Water temperatures only were simulated under this condition. Simulations were conducted for both July and September using data from Tables 2 and 3. The July release temperature from Wolf Creek Dam was held constant at 11.2 degrees C, while September releases were held at 14.2 degrees C. Water temperatures of lateral inflows were set equal to those of Wolf Creek Dam releases, as recommended by ORN.

Condition 2

Lateral inflows were not included under this condition. Rereg outflows provided through BIRM simulations were decremented by 550 cfs to compensate for the reduced total inflow. Simulations were conducted for July and September for both DO and water temperature using results of hydraulic simulations and data from Tables 2-4.

Condition 3

Previous simulations assumed that the equilibrium temperature and coefficient of heat exchange (Table 2) were constant over the period of simulation. However, large diel variations in equilibrium temperature are known to occur. Studies were also conducted to examine the relative differences in DO and water temperature, with and without the rereg dam, under unsteady meteorological conditions.

Edinger, Brady and Geyer (1974) indicated that the equilibrium temperature at any time of a day can be approximated by:

$$E = Ea + Hs/2K \sin [6.2832/W (T-To)]$$

where E is the equilibrium temperature (degrees C) at time T, Ea is the daily average equilibrium temperature, Hs is the solar noon maximum solar radiation (Watts per square meter), K is the coefficient of heat exchange (Watts per square meter per degree C), W is the cycle frequency, and To is the time at the start of the sine wave.

Troxler and Thackston (1977), in studies on the Cumberland River, indicated that Hs for July was near 946 Watts per square meter (300 BTU per square foot per hour). Given the average conditions (Table 2) and assuming that maximum equilibrium temperatures occur near 2:00 P.M., the above expression was then modified to yield:

$$E = 30.1 + 16.3 \sin [6.2832/24 \ (T-8.)]$$

where T is the time (hours). This expression was used to calculate equilibrium temperatures at each time step over the week of simulation. Water temperatures and DO were computed for July only using results of hydraulic simulations and the data provided in Tables 2-4.

Condition 4

Under conditions 1-3, peaking operations occurred over the weekend with instantaneous inflows from Wolf Creek Dam reaching 30,000 cfs on Saturday and 24,000 cfs on Sunday. Simulations were also conducted to evaluate the effect of low flow conditions over the weekend. Simulations were conducted over a 7.58 day period extending from a Monday to the following Monday for both July and September using the results of hydraulic simulations with low weekend flows and the data provided in Tables 2-4. Inflows from Wolf Creek Dam, the upstream boundary, for this simulation were higher during the week than those of previous conditions. Inflows from Wolf Creek Dam over the weekend were held constant at 500 cfs. As indicated previously, this low flow was specified to ensure numerical stability in simulations with BIRM and RIV1H and is considered greater than the actual flow expected during non-generation.

PART IV: RESULTS AND DISCUSSION

Hydraulic Simulations

Hydraulic simulations were conducted using boundary and geometric conditions provided by ORN. Simulations were conducted for a typical July beginning on a Wednesday and extending for 7.63 days for the first two hydraulic conditions and extending for 7.58 days beginning on a Monday for the third. No actual stage/discharges were available, therefore no rigorous attempt at model calibration could be attempted. Comparisons were made with results of hydraulic simulations conducted by ORN, and discrepancies in both predicted water surface elevations and predicted water volumes were noted. The precise cause of these discrepancies are not, as yet, known. However, the differences are not expected to appreciably affect the results of this study. The study does allow examination of relative differences in hydraulic and water quality conditions both with and without a rereg dam.

Hydraulic simulations conducted with lateral inflows totaling 550 cfs were conducted for conditions with and without the rereg structure. Both discharge and water surface elevations under these conditions are provided in Figures 1-3 for river miles 460.9 (Wolf Creek Dam), 455.10, and 450.95 (located immediately above the present site of the proposed rereg structure). The peak discharges from Wolf Creek Dam (Figure 1) during power operation varied from 48,000 cfs during weekdays, 30,000 cfs on Saturday, and 24,000 cfs on Sunday. The operating schedule involved five hours of increased flows, with 1

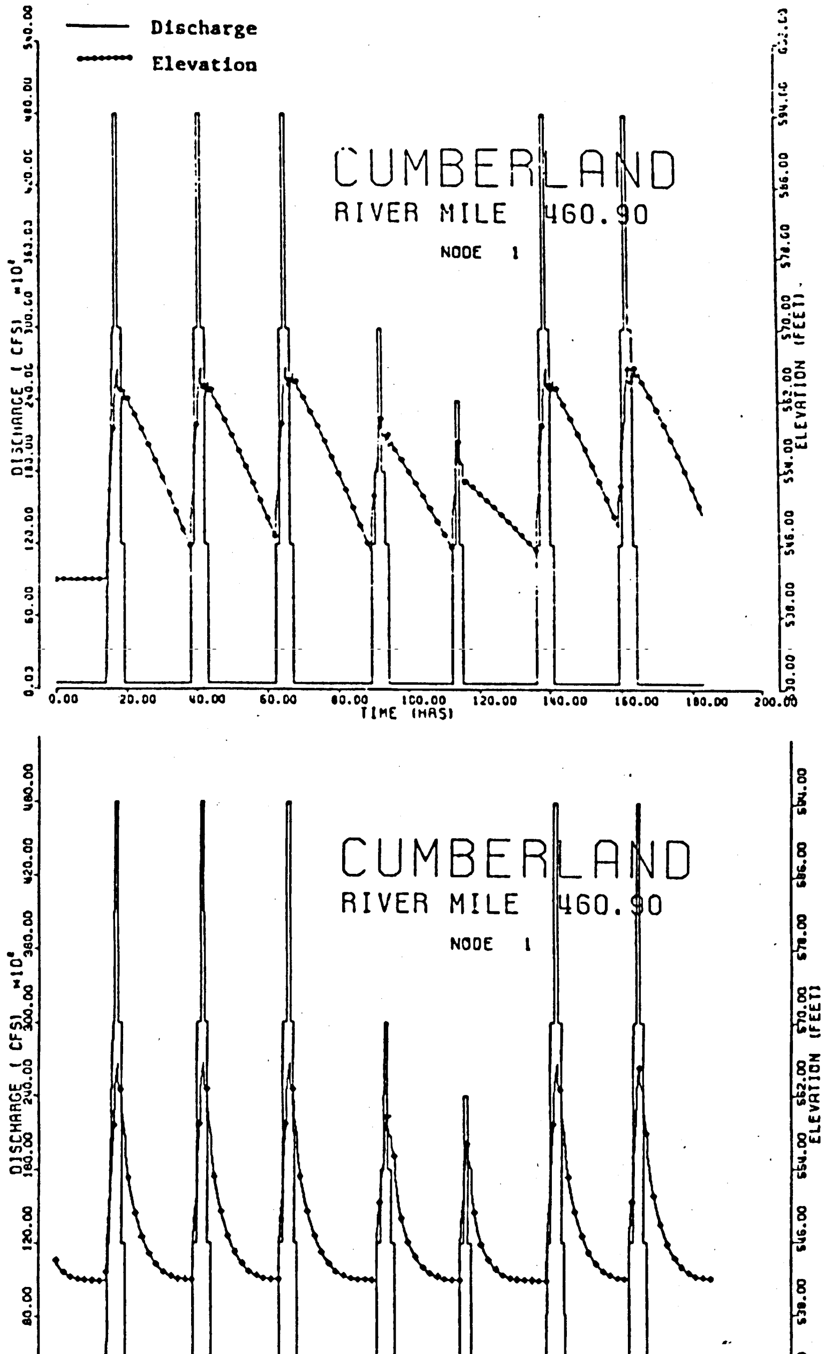


Figure 1. Variations in water surface elevations and discharges in the Cumberland River at river mile 460.9, the upstream boundary, for conditions with (Top) and without (Bottom) a rereg dam and with lateral inflows

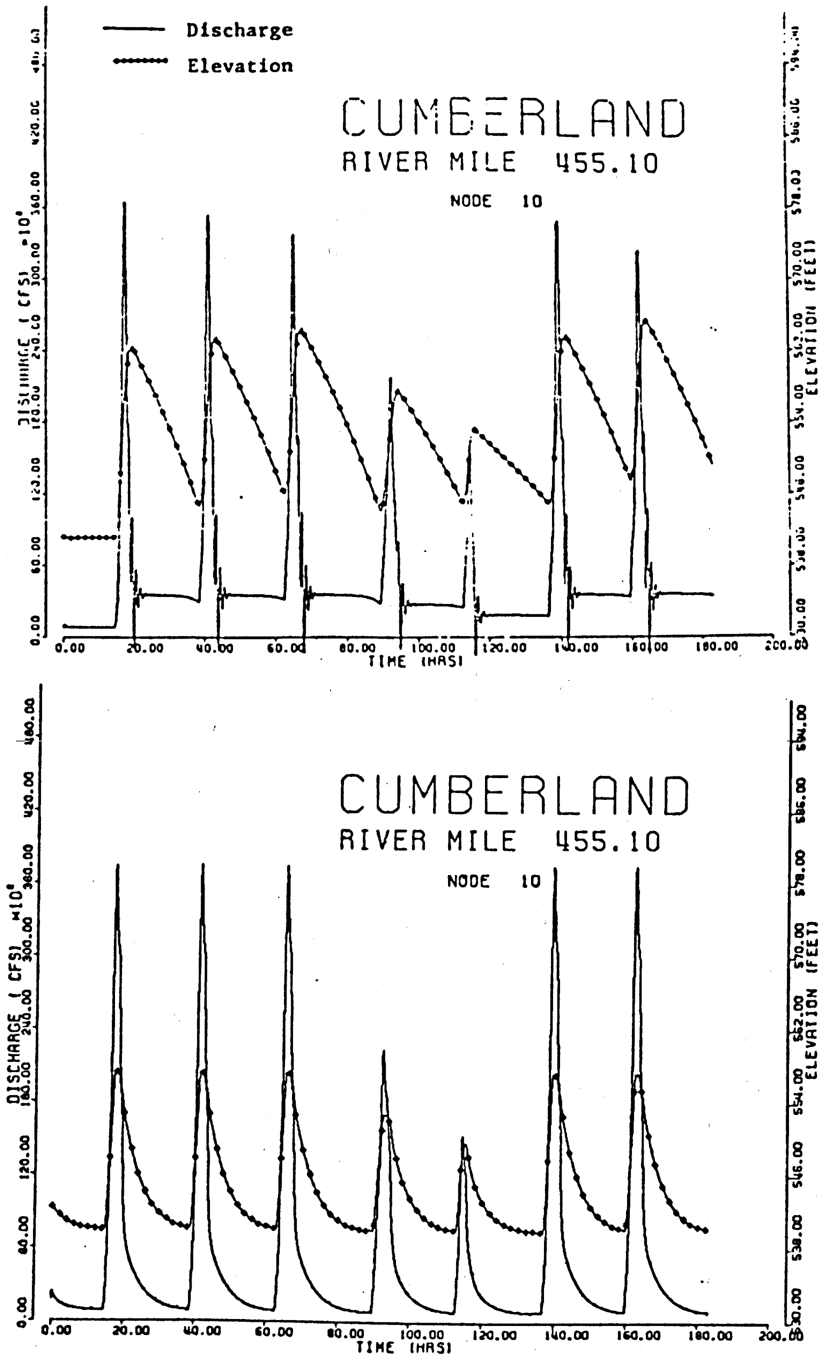


Figure 2. Variations in water surface elevations and discharges in the Cumberland River at river mile 455.1 (rereg dam at river mile 450.7), for conditions with (Top) and without (Bottom) a rereg dam and with lateral inflows

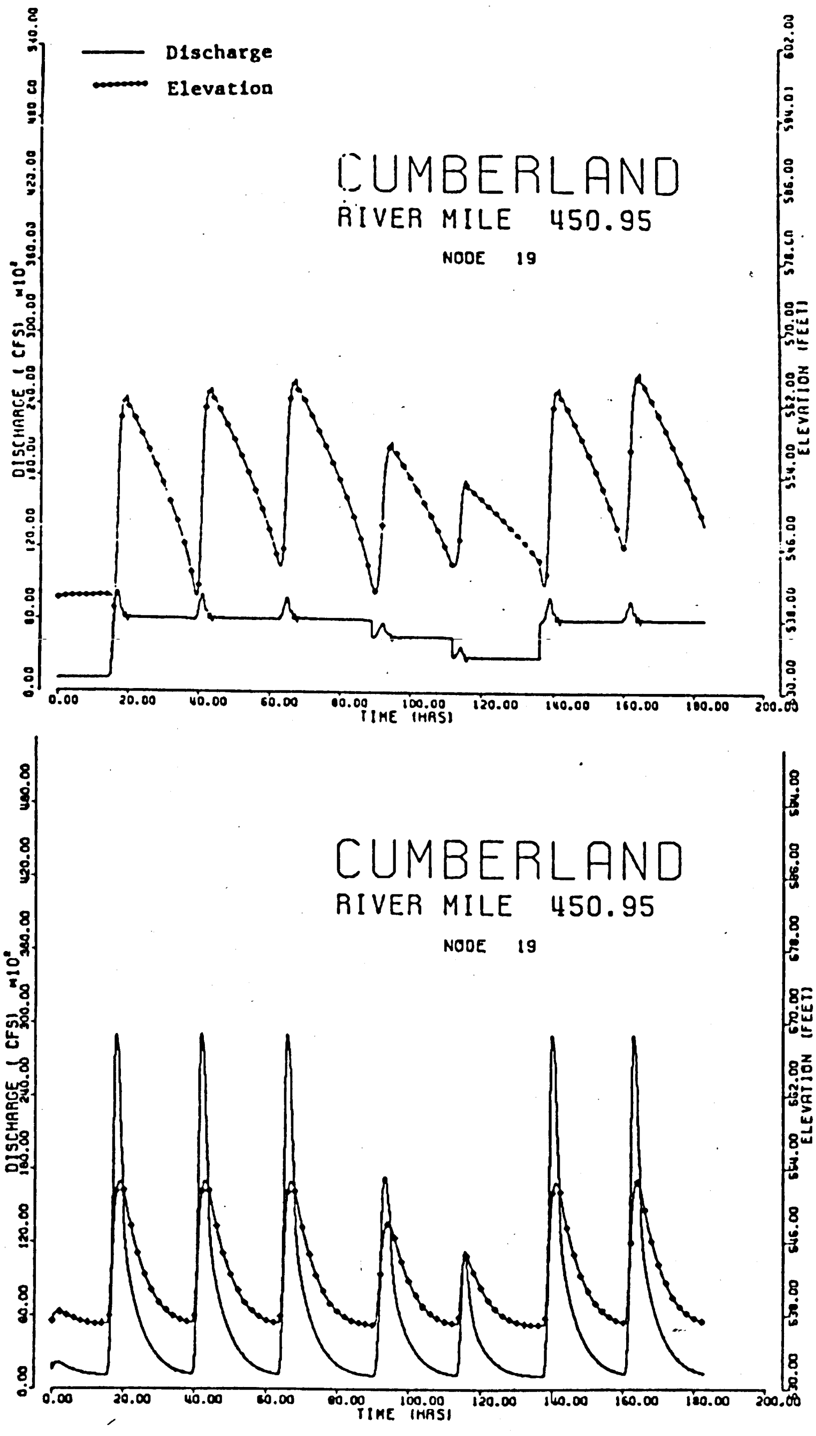


Figure 3. Variations in water surface elevations and discharges in the Cumberland River at river mile 450.95 (rereg dam at river mile 450.7) for conditions with (Top) and without (Bottom) a rereg dam and with lateral inflows

hour at each stepwise increase, and one hour at the peak flows for all days except Sunday. Sunday's operation schedule was three hours in duration. Discharges at all other, non-generating, times were held constant at 500 cfs. This low flow was selected to ensure numerical stability in hydraulic simulations. Discharges from the rereg pool varied from 1050 cfs for the first approximately 13 hours of simulation, and thereafter remained at 6200 cfs (weekdays), 5500 cfs (Saturday), or 4000 cfs (Sunday, Figure 3). Average retention time of the rereg pool was 0.6 days for the 7.63 days of simulation. Average volume was 6180 acre-feet.

As would be expected, the predicted discharges both with and without the rereg structure became attenuated downstream of the upstream boundary (Figures 1-3). A greater degree of attenuation was observed under the rereg condition due to the influence of the control structure. Flow reversals were also noted within the rereg pool following peak flows, as is evident in Figure 2. The peaking hydrograph remained relatively sharp, with peak flows occurring over a short time period, for both conditions with and without a rereg structure.

Peak water surface elevations also became attenuated downstream for the case without the rereg structure, with peak water surface elevations during weekdays varying from approximately 565 feet at river mile 460.9 (Figure 1) to 553 feet at river mile 450.95 (Figure 3). Variations in water surface elevations over a weekday averaged nearly 21 feet at river mile 460.9 and approximately 15 feet at river mile 450.95. Water surface elevations decreased in an approximately exponential manner following peaks for conditions without the rereg dam. For conditions with the rereg dam, peak water surface elevations were similar to those without the rereg dam. However, the peak elevation did not become appreciably attenuated downstream, and water level variations were nearly equal at all nodes. Decreases in water surface elevations following peaks were nearly linear and occurred at a much slower rate with the rereg structure than without, as would be expected (Figures 1-3).

Simulations were also conducted without lateral inflows and with the discharges from the rereg dam decremented by 550 cfs to account for the reduced total inflow. ~~Simulations were conducted for~~ conditions with and without the rereg dam. All other conditions remained the same. The results of these simulations were similar to those described above, with the exception that predicted flows and water surface elevations were slightly lower (Figures 4-6).

The third condition for hydraulic simulations included a July operating schedule extending over 7.58 days from a Monday through the following Monday. Flows at each of the steps during power generation were 6000 cfs higher than previous simulations, reaching a peak of 54000 cfs during the weekdays (Figure 7). No generation occurred during the weekend. Discharges from Wolf Creek Dam were maintained at 500 cfs during non-generation periods and tributary inflows were not included in simulations. Simulations conducted under this condition necessitated use of a lower Manning's n for the rereg case (0.025) than that used in previous simulations (0.03). This Manning's n was required in order to maintain numerical stability in the region of the

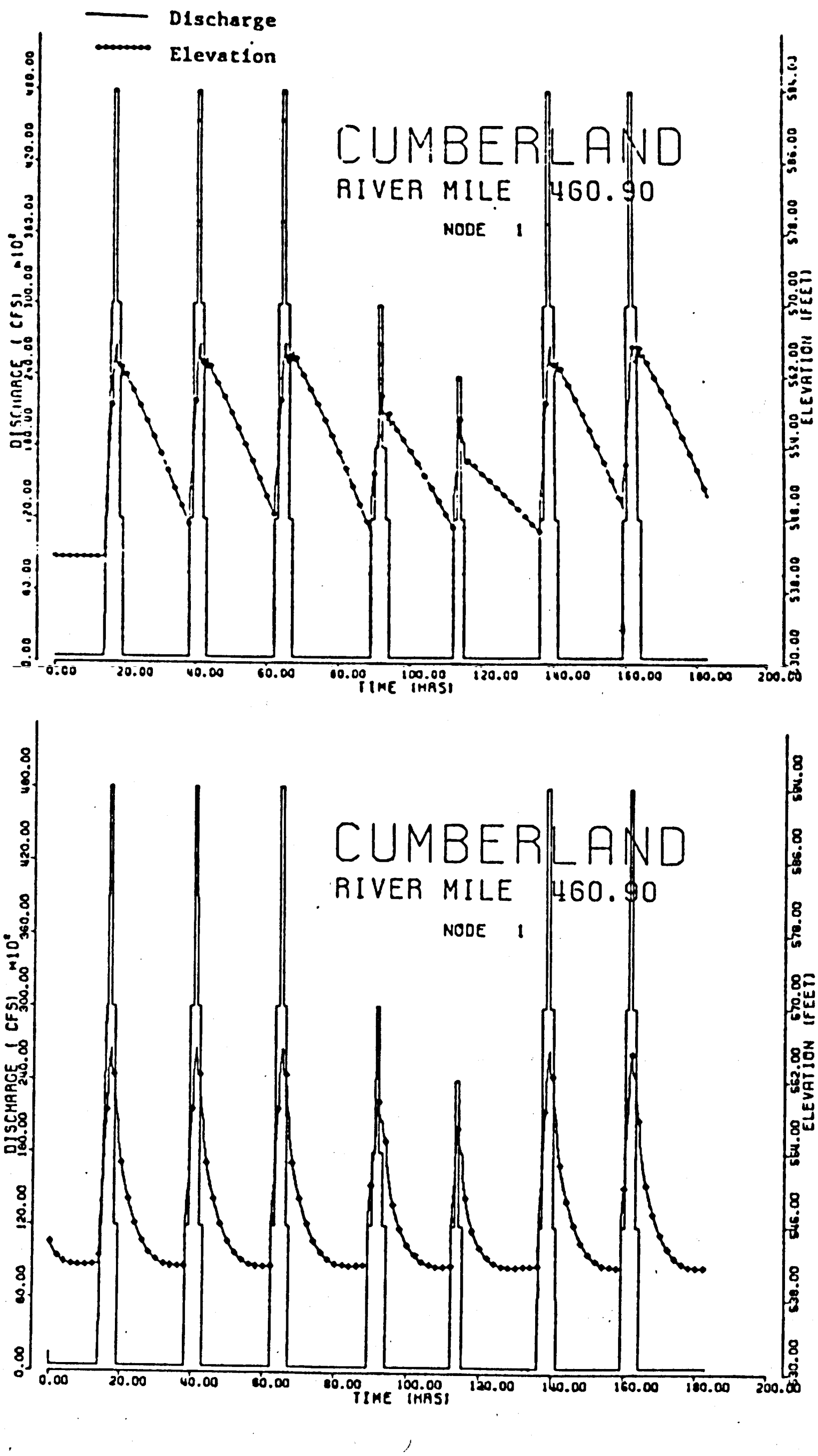


Figure 4. Variations in water surface elevations and discharges in the Cumberland River at river mile 460.9, the upstream boundary, for conditions with (Top) and without (Bottom) a rereg dam and without lateral inflows

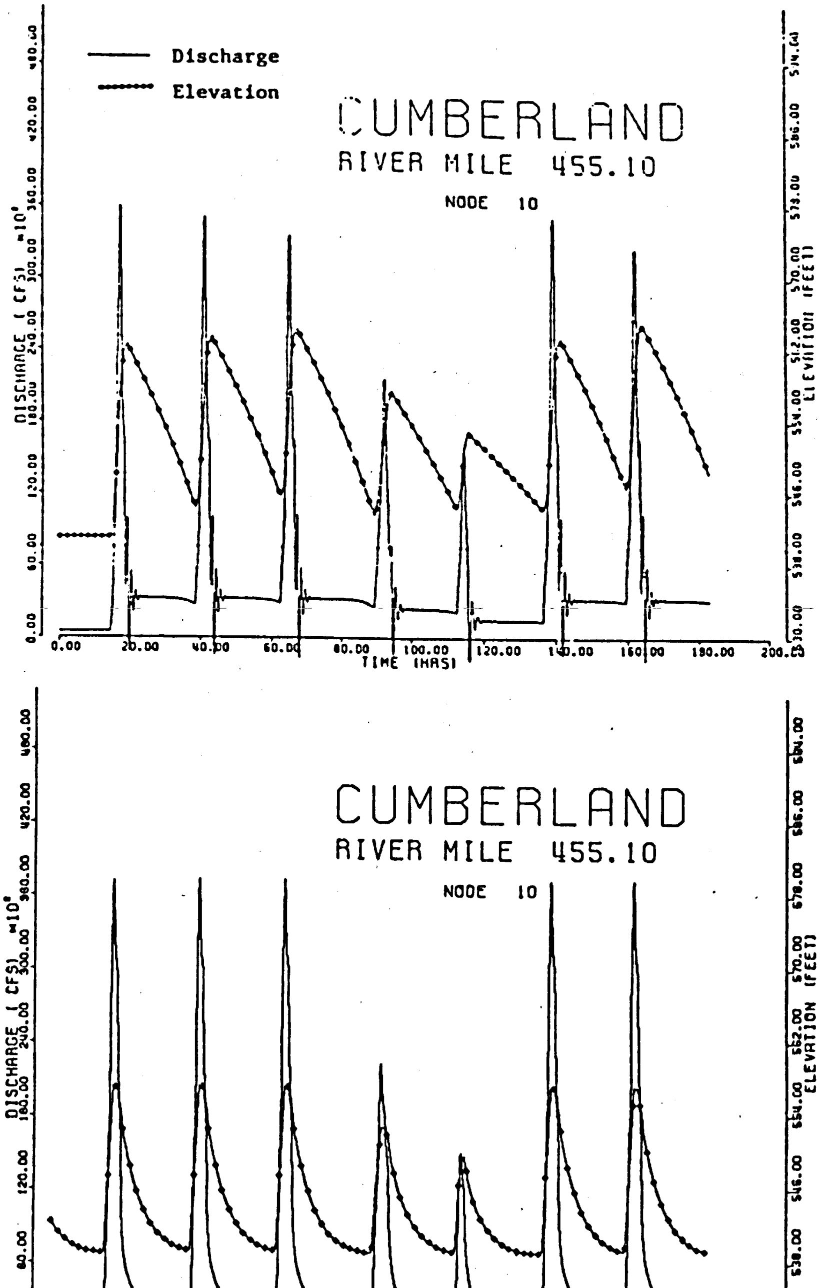


Figure 5. Variations in water surface elevations and discharges in the Cumberland River at river mile 455.1 (rereg dam at river mile 450.7) for conditions with (Top) and without (Bottom) a rereg dam and without lateral inflows

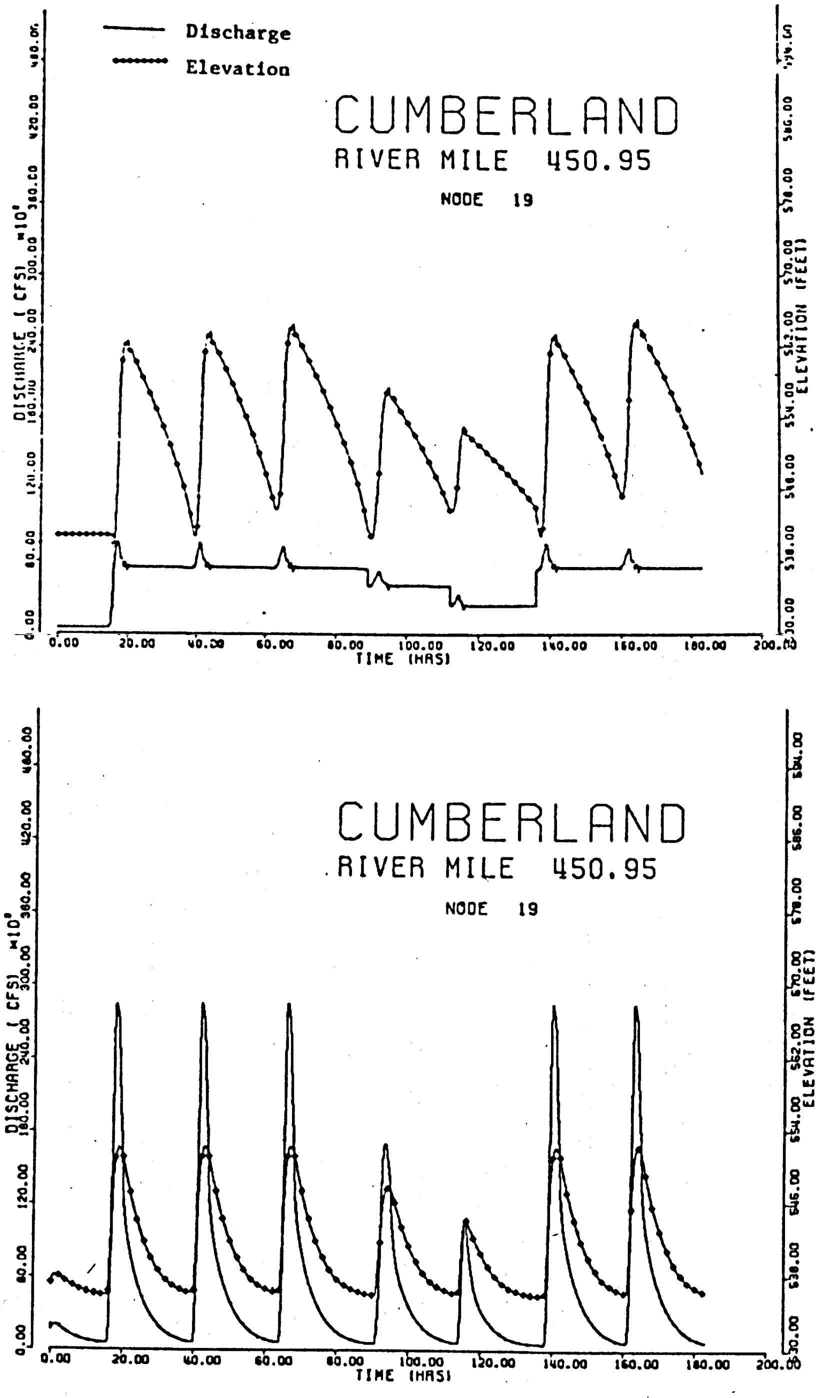


Figure 6. Variations in water surface elevations and discharges in the Cumberland River at river mile 450.95 (rereg dam at river mile 450.7) for conditions with (Top) and without (Bottom) a rereg dam and without lateral inflows

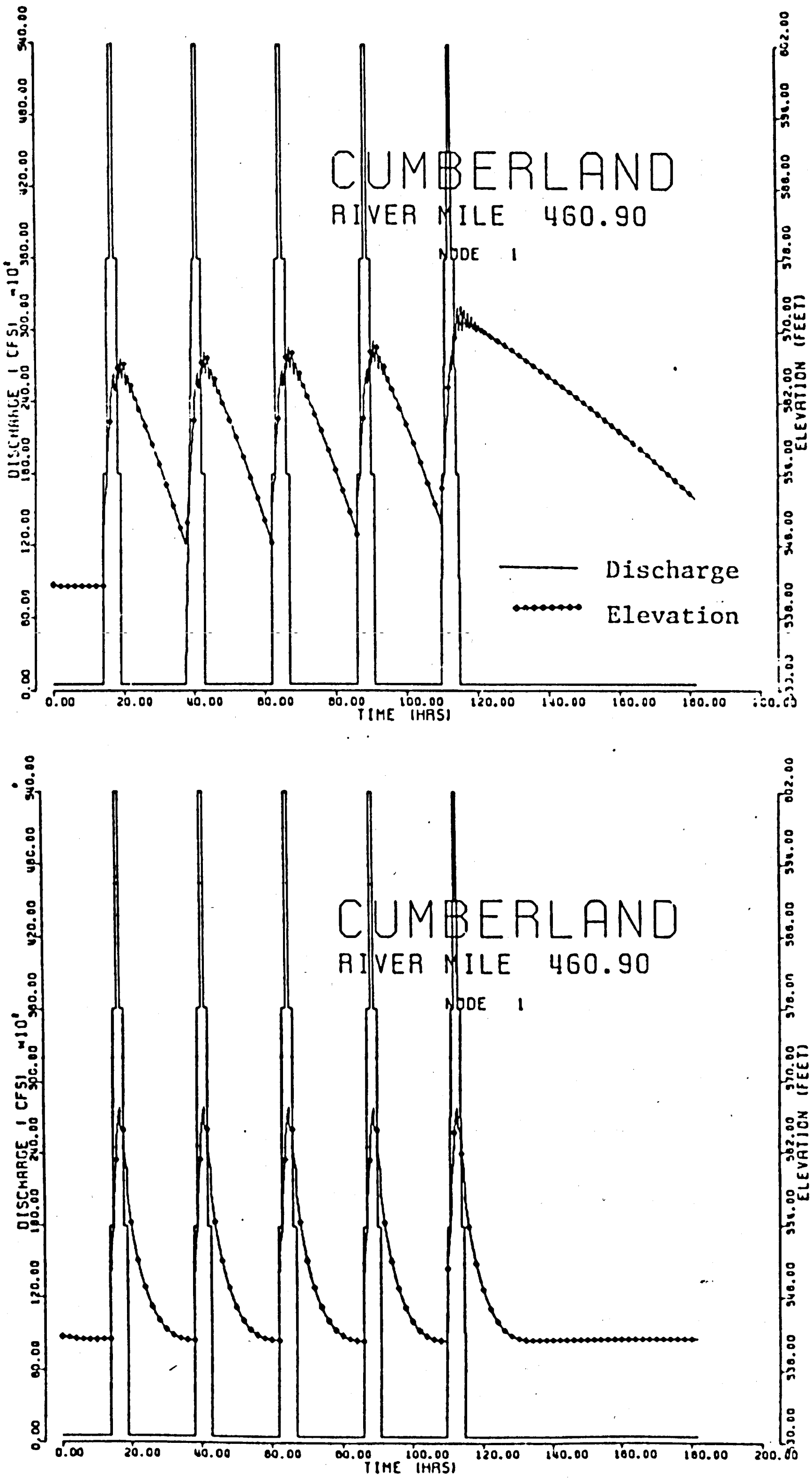


Figure 7. Variations in water surface elevations and discharges in the Cumberland River at river mile 460.9, the upstream boundary, for conditions with (Top) and without (Bottom) a rereg dam and with low weekend flows

rereg dam when lateral inflows were not included in simulations and resulted in less bottom friction for the reach. The original value of 0.03 was retained for simulations without the rereg dam. Results of these simulations were similar to those described above during weekdays. Differences were noted in peak flows, due to the increased discharges from Wolf Creek Dam. Differences were also noted in predicted flows during low flow periods. Predicted low flows tended to be less for this condition than predicted for other conditions. On Friday of the week of simulation, the water surface elevation for the rereg condition was increased above that of previous days reflecting water stored to be released over the weekend and was then decreased linearly over the weekend, as depicted by water surface elevations at river miles 450.10 and 455.95 (Figures 8,9). The flow patterns were also similar to previous simulations at the upstream and downstream boundaries during weekdays. However, for the rereg condition positive (downstream) flows and flow reversals were predicted to alternate in a near harmonic manner following the peak flows (Figure 8). The amplitude of the harmonic oscillations became more pronounced as the week progressed, becoming greatest on Friday. Similar oscillations were noted in previous simulations, but were much less pronounced (Figures 2,5). Greater oscillations during this condition may be due to the higher overall flows during power generation at Wolf Creek Dam and the lower Manning's n used in simulations. Some flow reversals and oscillations would normally be expected in a rereg pool following peak flows. It is not known whether the degree of the predicted oscillations is reasonable or results from insufficient damping. However examination of water quality simulations indicated that these

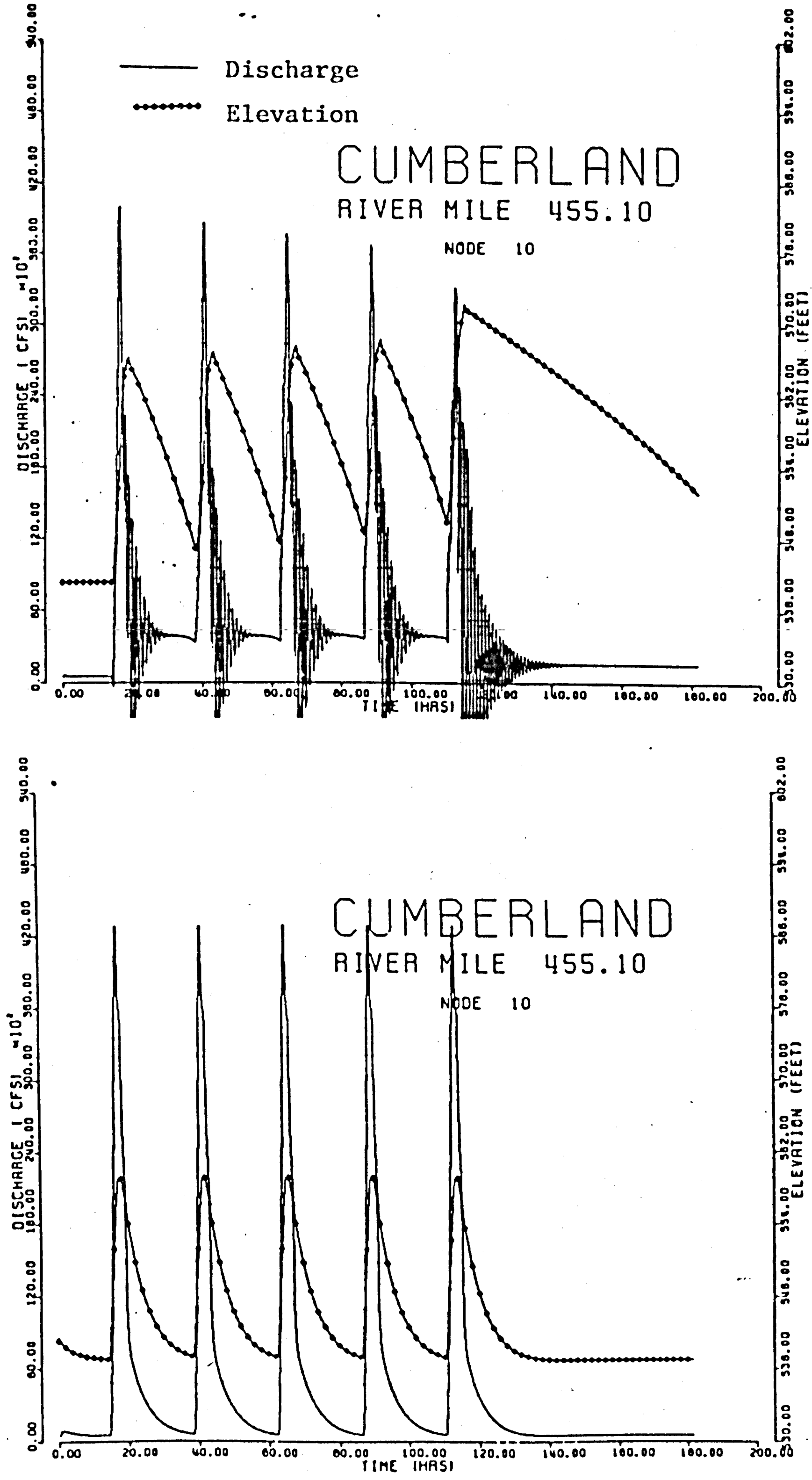
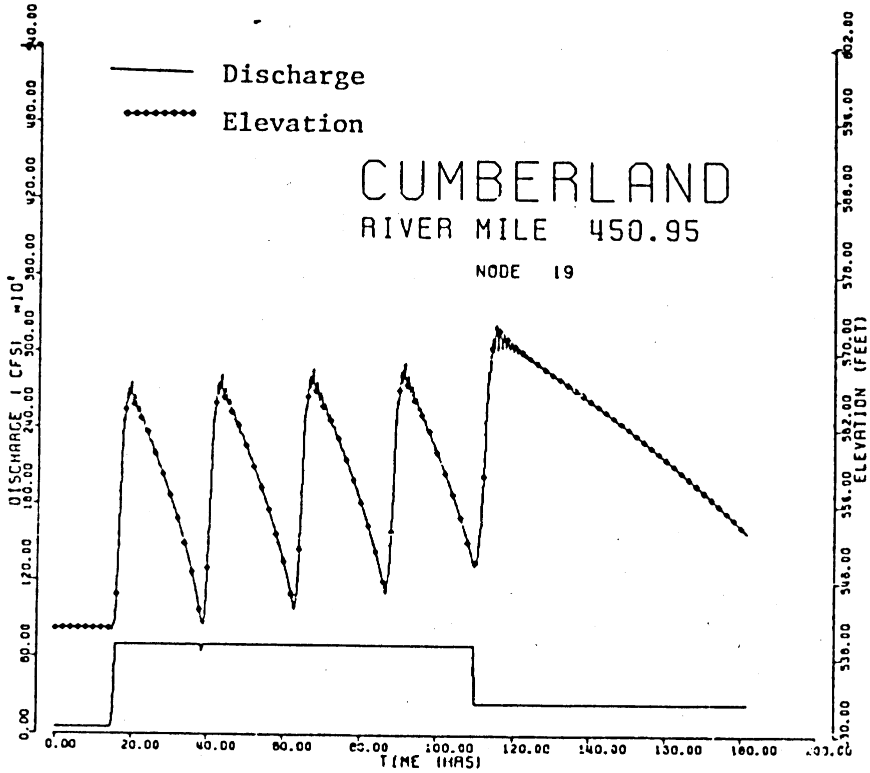


Figure 8. Variations in water surface elevations and discharges in the Cumberland River at river mile 455.1 (rereg dam at river mile 450.7) for conditions with (Top) and without (Bottom) a rereg dam and with low weekend flows



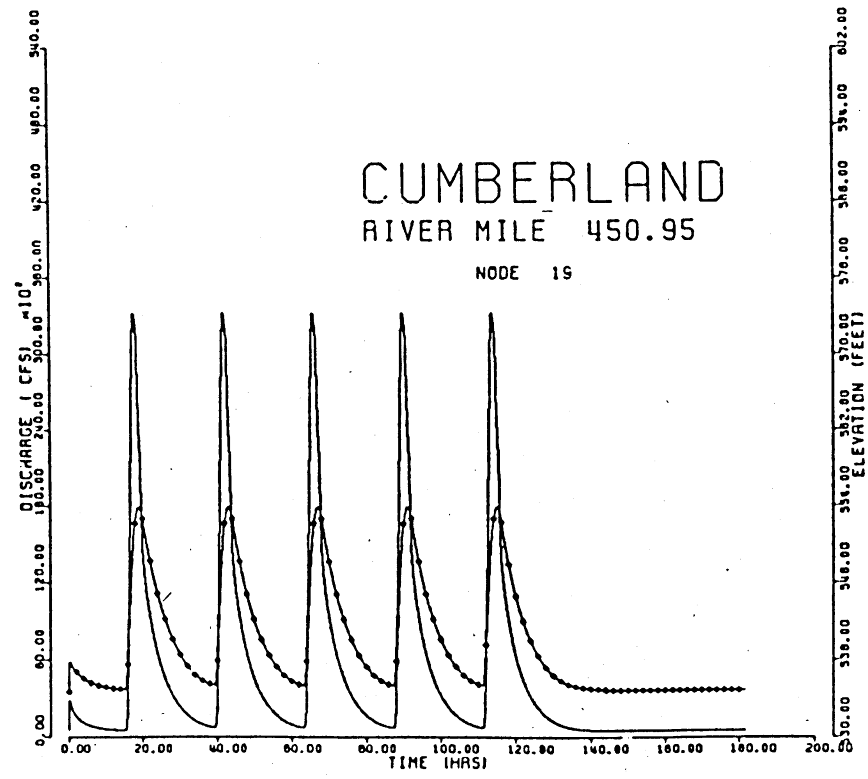


Figure 9. Variations in water surface elevations and discharges in the Cumberland River at river mile 450.95 (rereg dam at river mile 450.7) for conditions with (Top) and without (Bottom) a rereg dam and with low weekend flows

oscillations did not produce similar fluctuations, or unreasonable predictions in temperatures or dissolved oxygen concentrations.

Water Quality Simulations

Water quality simulations were conducted to determine spatial and temporal variations in temperature and DO concentrations for conditions with and without the rereg pool. Four conditions were chosen for simulations, as described previously (see Water Quality Simulations in Methods and Simulation Conditions).

Condition 1

A constant inflow water temperature for July of 11.2 degrees C was specified for this condition. Lateral inflows were included in hydraulic simulations, and steady meteorological data were utilized (Table 2).

Simulations under this condition indicated that temporal variations would be expected at each node due to warming in the reach during non-generation followed by the influx of colder waters during power generation. Predictions also indicated that temporal temperature variations were less, and rates of temperature changes generally slower, with a rereg pool than without. At river mile 450.95, diel temperature variations averaged near 3.6 degrees C without the rereg dam and 1.8 degrees C with the rereg dam (Figure 10). Variations were less upstream of the rereg dam, as demonstrated by temperature variations at river mile 455.10 (Figure 10). Water

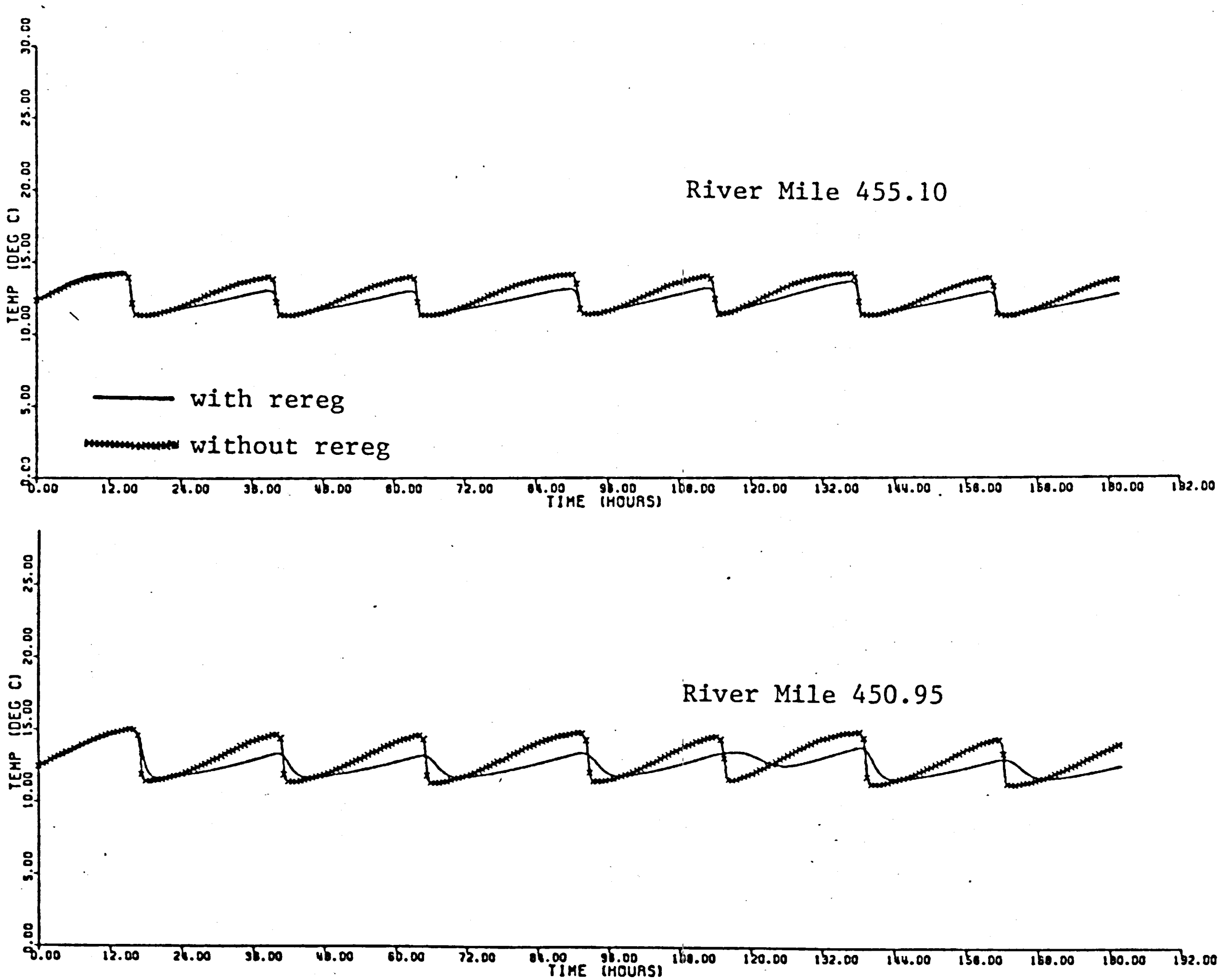


Figure 10. Variations in water temperatures during July under conditions with and without a rereg dam at river miles 455.10 and 450.95 of the Cumberland River for condition 1 (rereg dam at river mile 450.7)

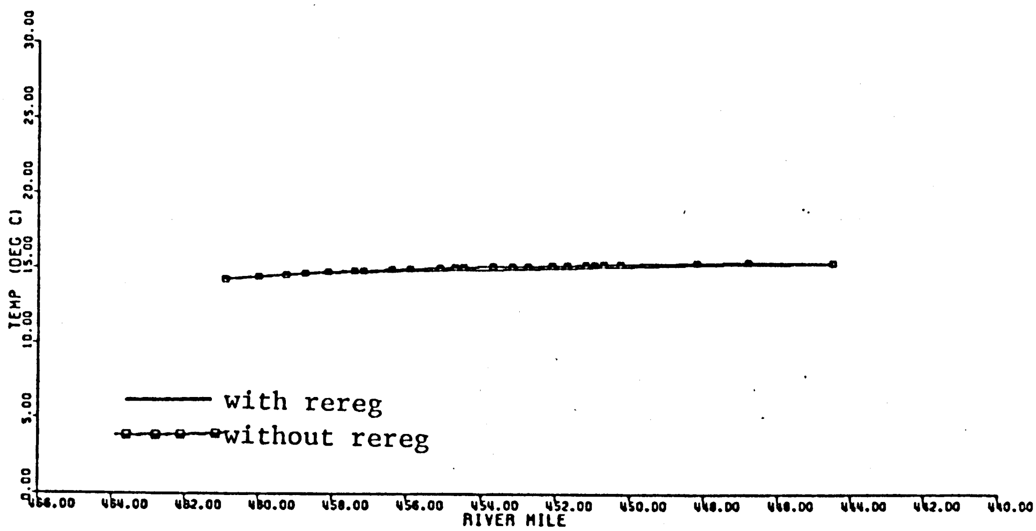
temperatures averaged over the 7.63 days of simulation increased downstream, reaching a peak of 13.5 degrees C at river mile 444.5 (Figure 11), for an average warming of 2.3 degrees C over the entire study reach. Very little difference was observed in average water temperature predictions over the impacted reach between simulations conducted with and without the rereg structure.

Water temperature simulations were also conducted for September using a constant inflow temperature (14.2 degrees C) and steady meteorological data (Table 2). Relatively little change was observed in predicted water temperatures with time at a given station (Figure 12) ~~and a less than 1 degree change noted in the~~ averaged water temperatures for the week over the study reach (Figure 11) both with or without the rereg structure.

Condition 2

Water temperature and DO simulations were conducted for conditions excluding lateral inflows, with meteorological conditions as specified in Table 2, water quality constituents as specified in Table 3, and water temperatures and DO concentrations varying with discharges from Wolf Creek Dam (Table 4). Simulations were conducted for July and September both with and without the rereg dam.

July simulations indicated that with varying inflow temperatures, predicted diel variations in water temperatures changed only slightly from predictions under Condition 1 for the rereg case (Figure 13). Diel variations for the nonreregulated case increased by nearly 2 degrees C from Condition 1, averaging nearly 6 degrees C at river mile



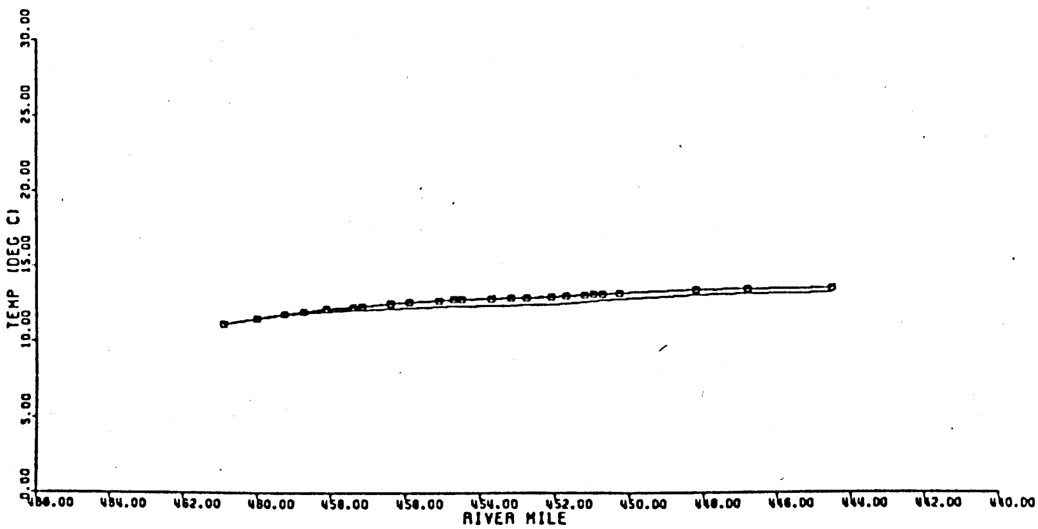


Figure 11. Average variations in water temperature over a 7.63 day period during July (Bottom) and September (Top) for conditions with and without a rereg dam for condition 1 (rereg dam at river mile 450.7)

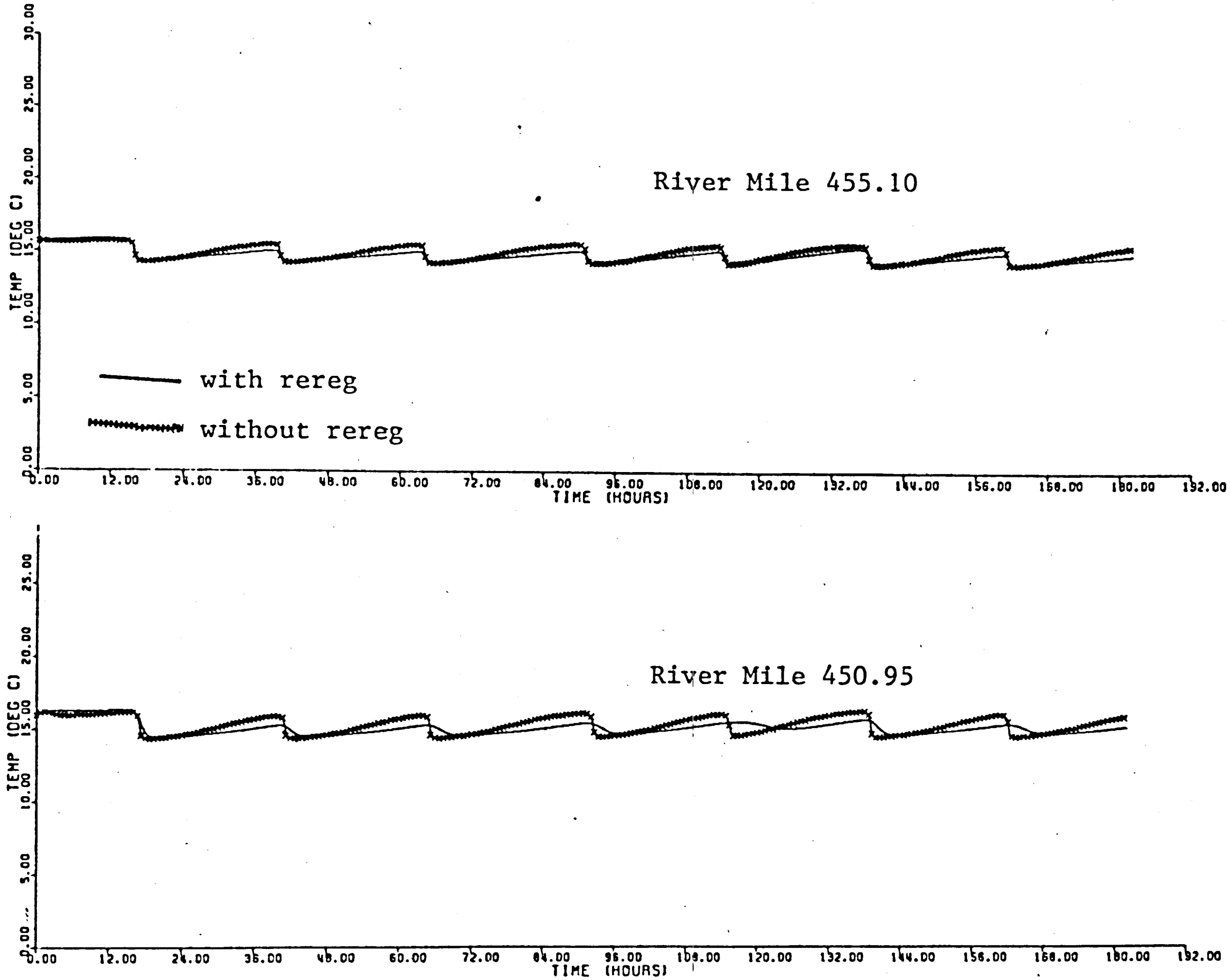


Figure 12. Variations in water temperatures during September under conditions with and without a rereg dam at river miles 455.10 and 450.95 of the Cumberland River for condition 1 (rereg dam at river mile 450.7)

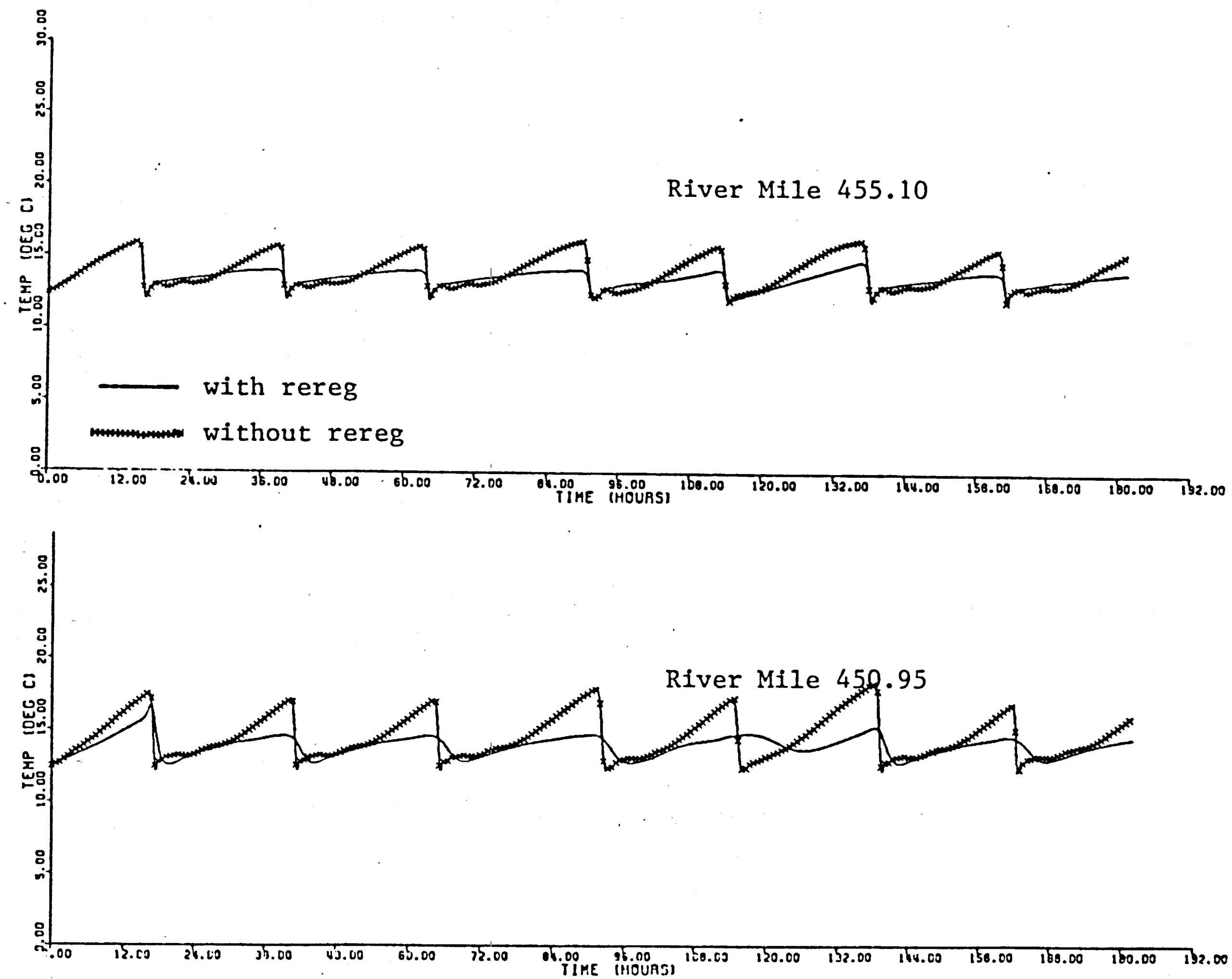


Figure 13. Variations in water temperatures during July under conditions with and without a rereg dam at river miles 455.10 and 450.95 of the Cumberland River for condition 2 (rereg dam at river mile 450.7)

450.95 (Figure 13). Due to the higher average inflow temperatures, the water temperatures averaged over the week at each node were somewhat higher than predictions under Condition 1, varying from near 12.0 degrees C at river mile 460.9 to near 14.6 degrees C at river mile 444.5; however, little difference was observed between average temperatures for conditions with and without the rereg structure (Figure 14).

September simulations indicated that variations in water temperature with time at a particular node were less under rereg conditions than those without (Figure 15), and that the average temperature over the period of simulation remained relatively constant over the reach, averaging near 14.4 degrees C. As in July simulations, little difference was noted in average predicted water temperatures with or without the rereg structure (Figure 16).

July simulations indicated that DO variations over time at a given node increased with increasing distance below Wolf Creek Dam, as illustrated at river miles 455.1 and 450.95 (Figure 17). DO concentrations generally reached lower levels with the rereg dam, as would be expected due to the increased retention time, did not attain the peak concentrations as under unreregulated conditions, due to the lower stream reaeration, and exhibited less short-term variability. Predicted concentrations both with and without the rereg structure remained near or above 8 mg/l. Averaged conditions over the week indicated virtually no difference in DO within the rereg pool for conditions with and without the rereg structure, with concentrations increasing from near 8.1 at river mile 460.9 to near 8.4 mg/l at river

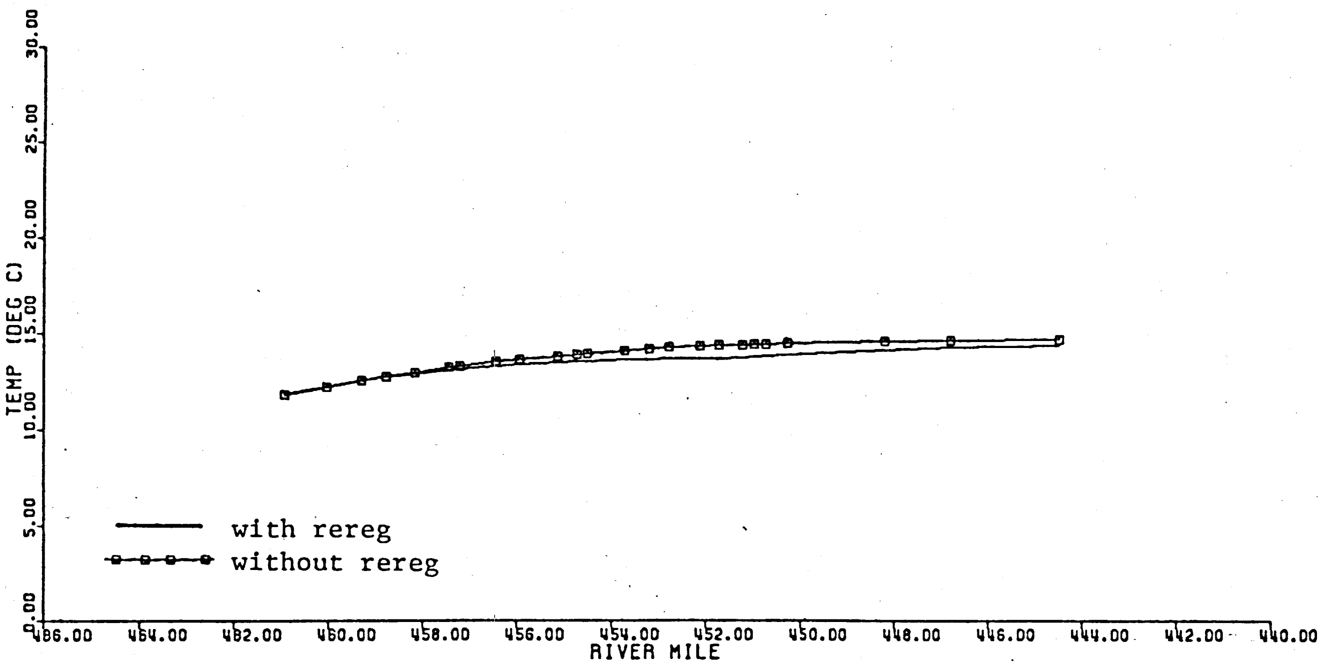


Figure 14. Average variations in water temperature over a 7.63 day period during July for conditions with and without a rereg dam for condition 2 (rereg dam at river mile 450.7)

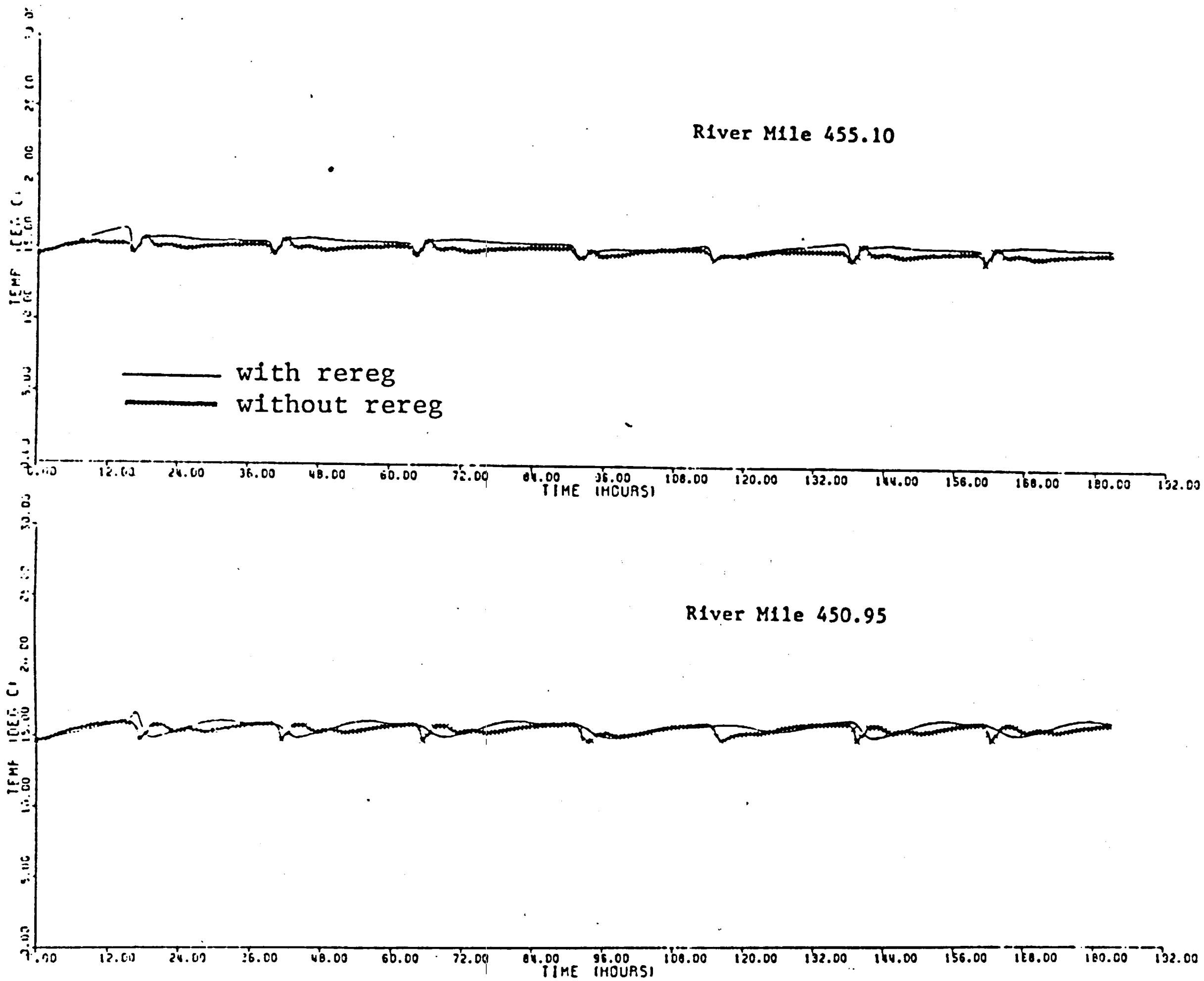


Figure 15. Variations in water temperatures during September under conditions with and without a rereg dam at river miles 455.10 and 450.95 of the Cumberland River for condition 2 (rereg dam at river mile 450.7)

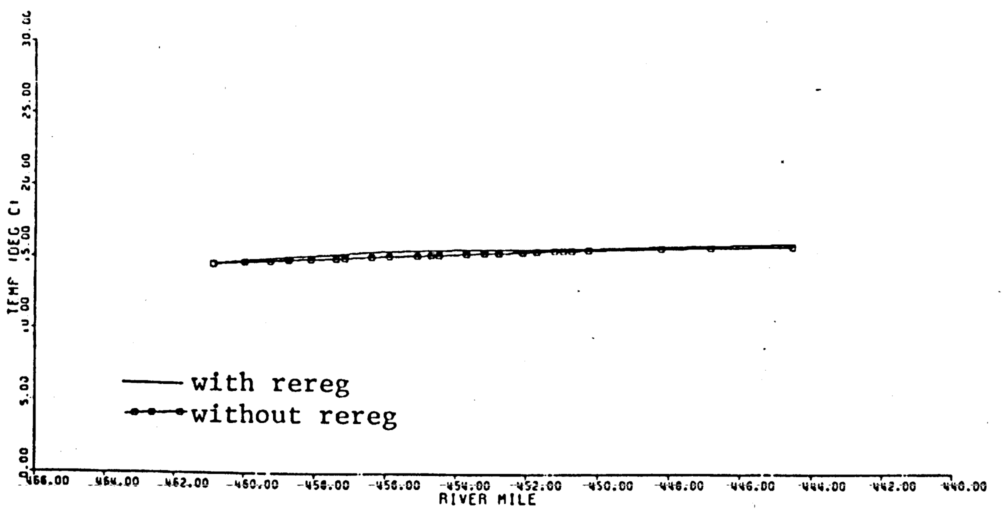


Figure 16. Average variations in water temperature over a 7.63 day period during September for conditions with and without a rereg dam for condition 2 (rereg dam at river mile 450.7)

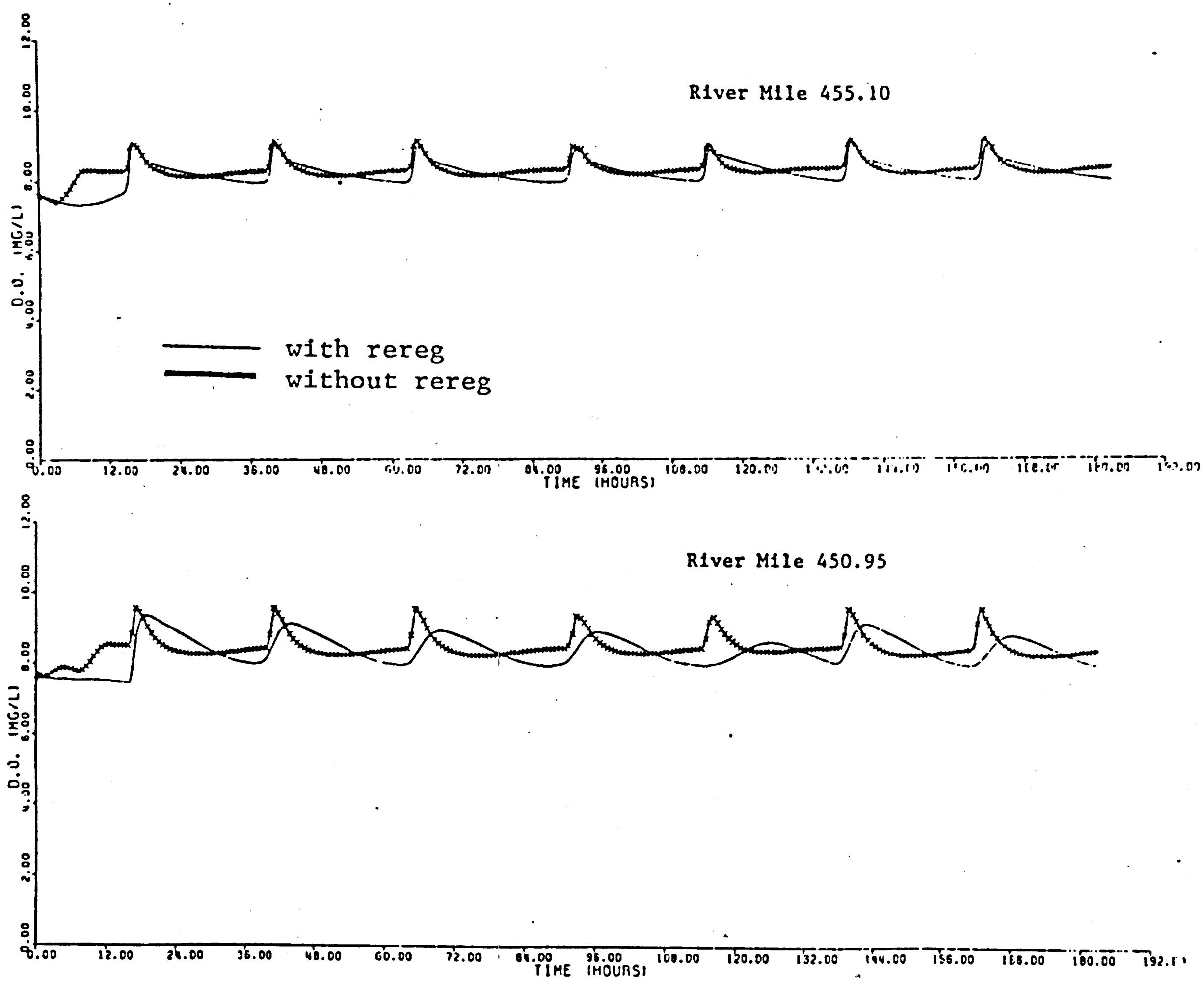


Figure 17. Variations in dissolved oxygen concentrations during July under conditions with and without a rereg dam at river miles 455.10 and 450.95 of the Cumberland River for condition 2 (rereg dam at river mile 450.7)

mile 450.70 (Figure 18). For simulations with the rereg dam, DO concentrations increased approximately 0.7 mg/l below the dam, due to structural reaeration, and remained higher for the remainder of the study reach (Figure 18).

September DO simulations indicated a greater degree of variability in concentrations at a given node (Figure 19) than occurred in July. This resulted primarily from the lower inflow concentrations (Table 4). Maximum DO variations were generally between 6 and 8 mg/l with the rereg structure, and between 6.5 and 8.5 mg/l without the rereg structure. Averaged conditions for the simulation period indicated that DO increased with distance from Wolf Creek Dam, from approximately 6.2 to 6.8 mg/l. Little difference was noted in average conditions with or without the rereg dam for river miles above 450.7. Below the rereg dam, DO concentrations increased by approximately 1.1 mg/l due to structural reaeration under rereg conditions and remained higher than non-rereg conditions for the remainder of the study reach (Figure 20).

Condition 3

Simulations were also conducted to estimate differences in diel variations in water temperatures and DO concentrations for July, both with and without the rereg structure, using methods to approximate unsteady meterological conditions. These simulations indicated that temporal variations in predicted water temperature at a given node did increase under unsteady meteorological conditions. Diel variations for simulations with the rereg structure generally did not change appreciably from conditions using steady meteorological data during

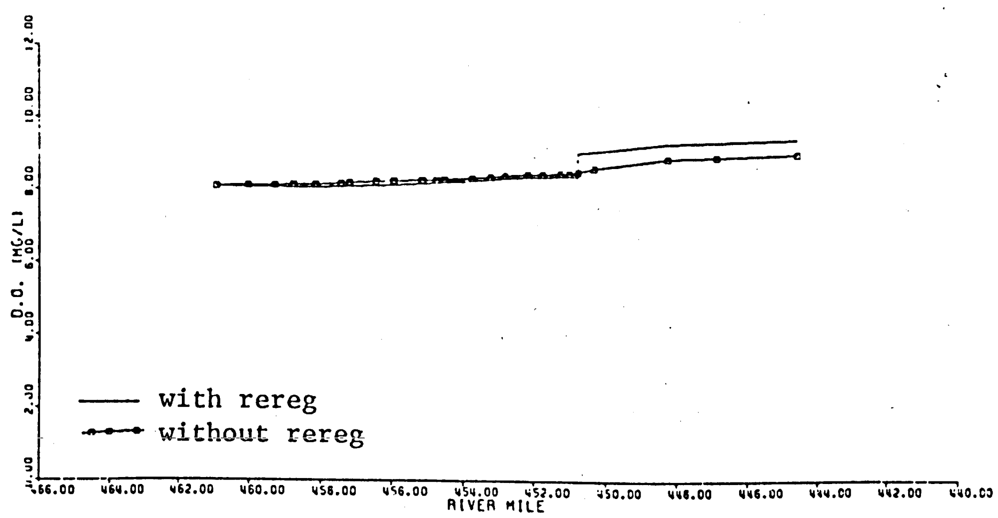


Figure 18. Average variations in dissolved oxygen concentrations over a 7.63 day period during July for conditions with and without a rereg dam for condition 2 (rereg dam at river mile 450.7)

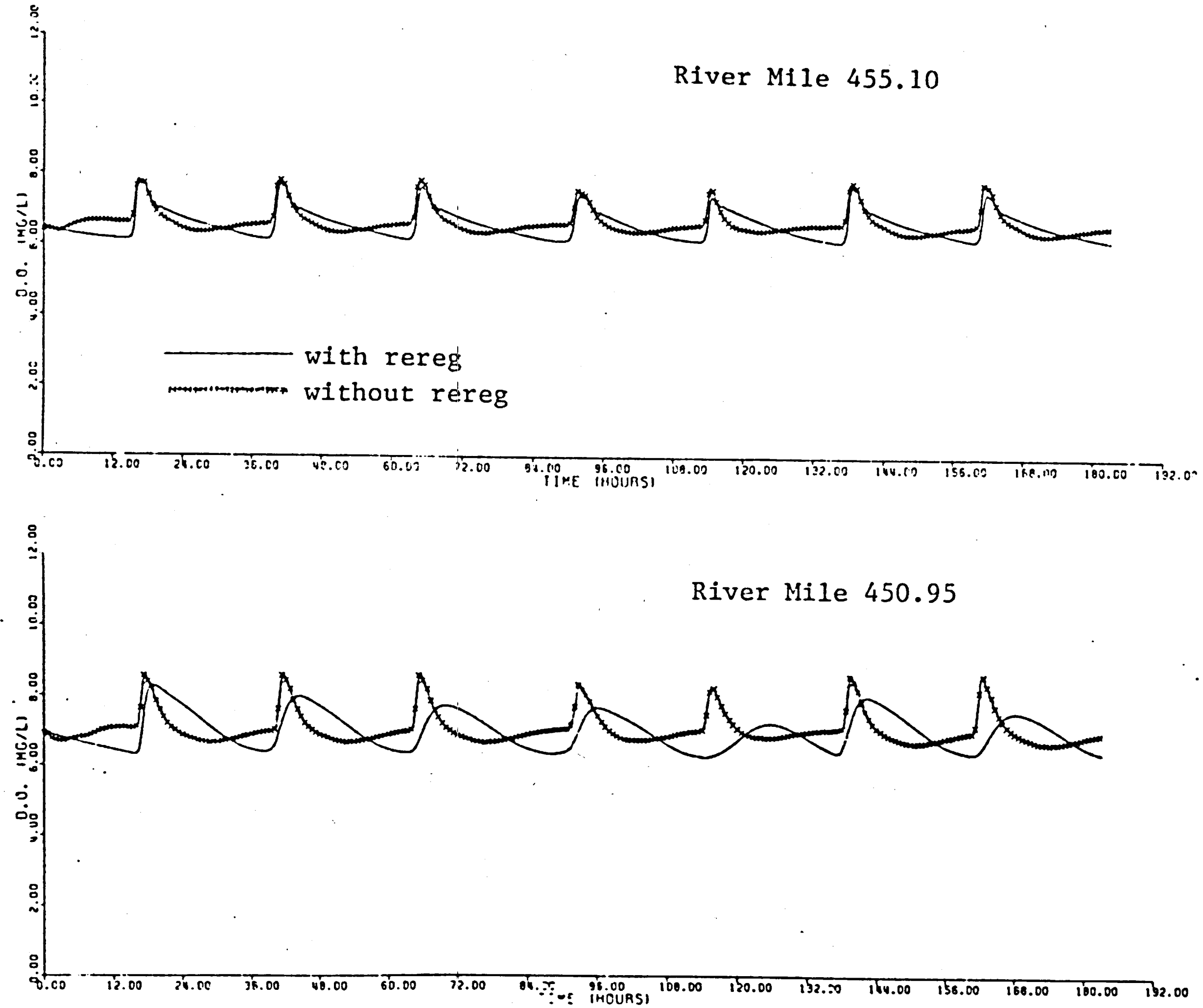


Figure 19. Variations in dissolved oxygen concentrations during September under conditions with and without a rereg dam at river miles 455.10 and 450.95 of the Cumberland River for condition 2 (rereg dam at river mile 450.7)

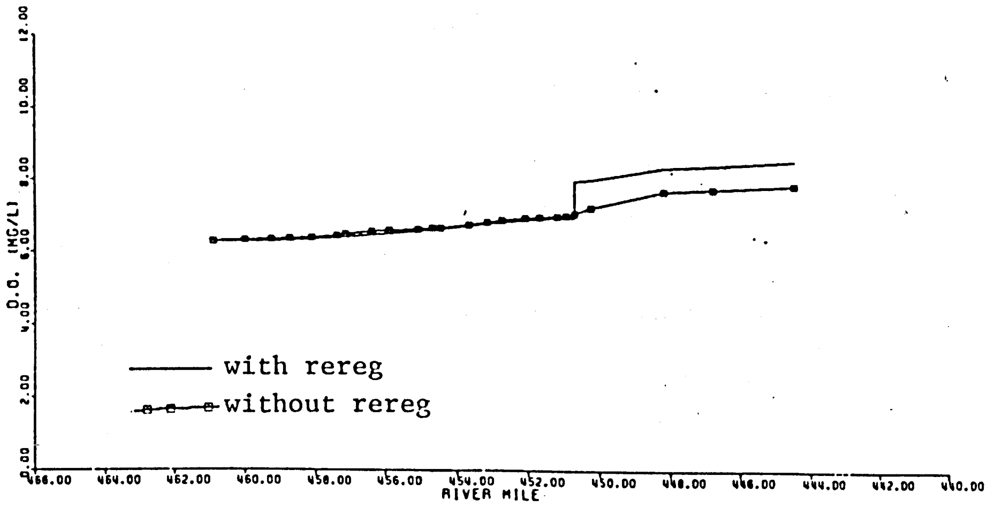


Figure 20. Average variations in dissolved oxygen concentrations over a 7.63 day period during September for conditions with and without a rereg dam for condition 2 (rereg dam at river mile 450.7)

the week and increased by less than 0.7 degrees C during the weekend. Temperature variations without the rereg structure generally increased by over 1.5 degrees C (Figure 21) for unsteady meteorological conditions as compared to predictions using steady meteorological conditions. No difference was observed in the average water temperature over the week (Figure 22) between steady and unsteady meteorological simulations, as would be expected with the sinusoidal nature of the imposed meteorological conditions. No appreciable differences were observed in predicted DO variations or average concentrations from Condition 2 due to the unsteady meterological conditions.

Condition 4

Simulations conducted under this condition were intended to determine the effect of a week of operation with low weekend discharges from Wolf Creek Dam on water quality in the Cumberland River.

Results of temperature simulations for July indicated that greater diel temperature variations occurred during weekdays under unreregulated conditions than occurred with the rereg dam, as was noted for previous conditions (Figure 23). Predicted diel variations for simulations with the rereg dam remained near 1.8 degrees C.

During the low flow period over the weekend, water temperatures for simulations without the rereg pool increased relatively rapidly to a temperature near 19 degrees C at river mile 450.95 and then remained relatively constant for the remainder of the simulation period (Figure

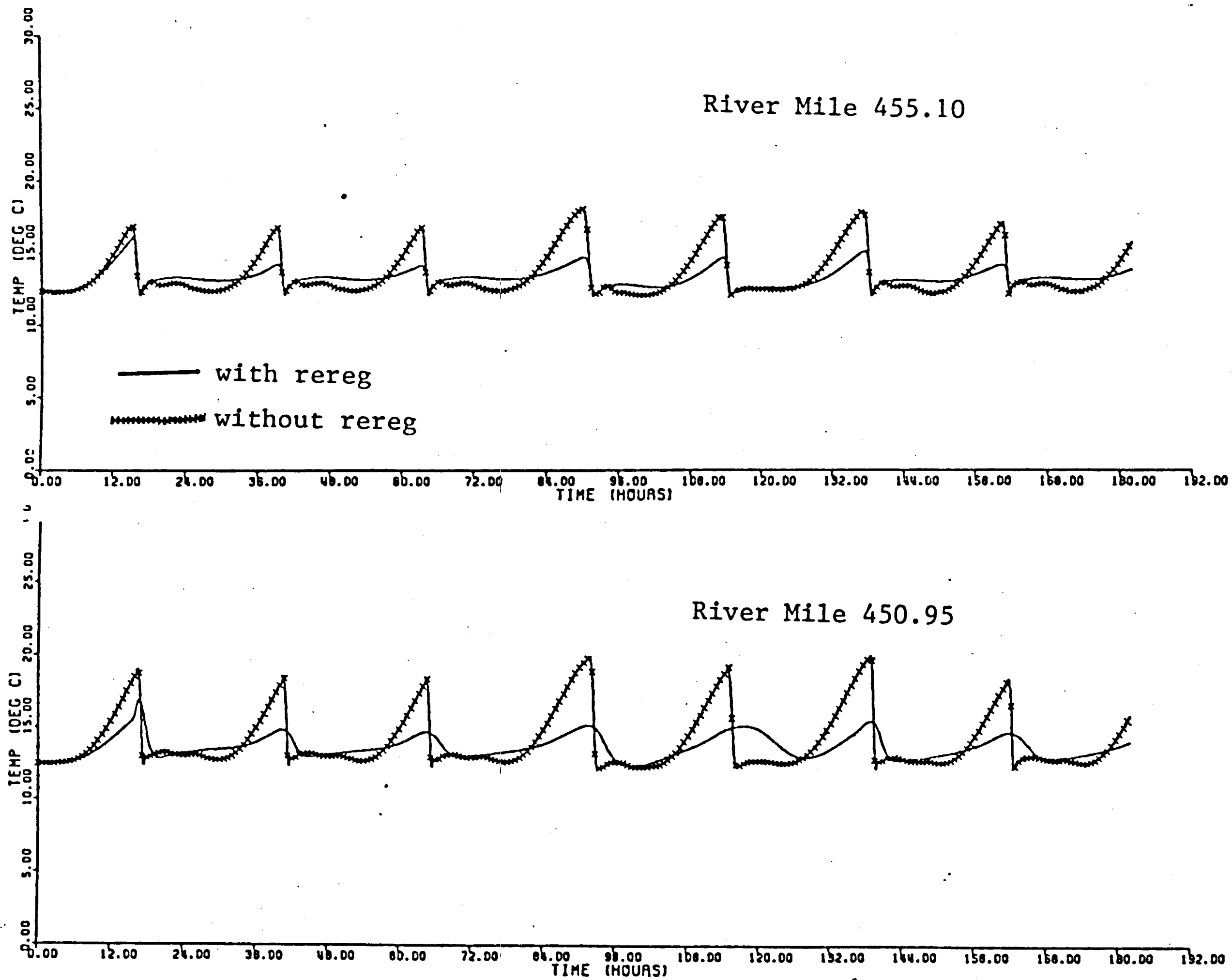


Figure 21. Variations in water temperatures during July under conditions with and without a rereg dam at river miles 455.10 and 450.95 of the Cumberland River for condition 3 (rereg dam at river mile 450.7)

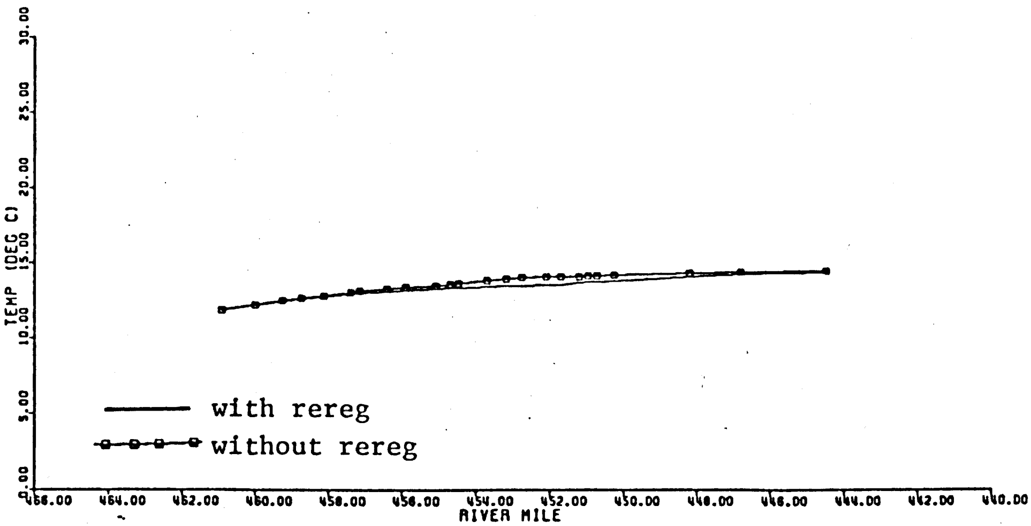


Figure 22. Average variations in water temperature over a 7.63 day period during July for conditions with and without a rereg dam for condition 3 (rereg dam at river mile 450.7)

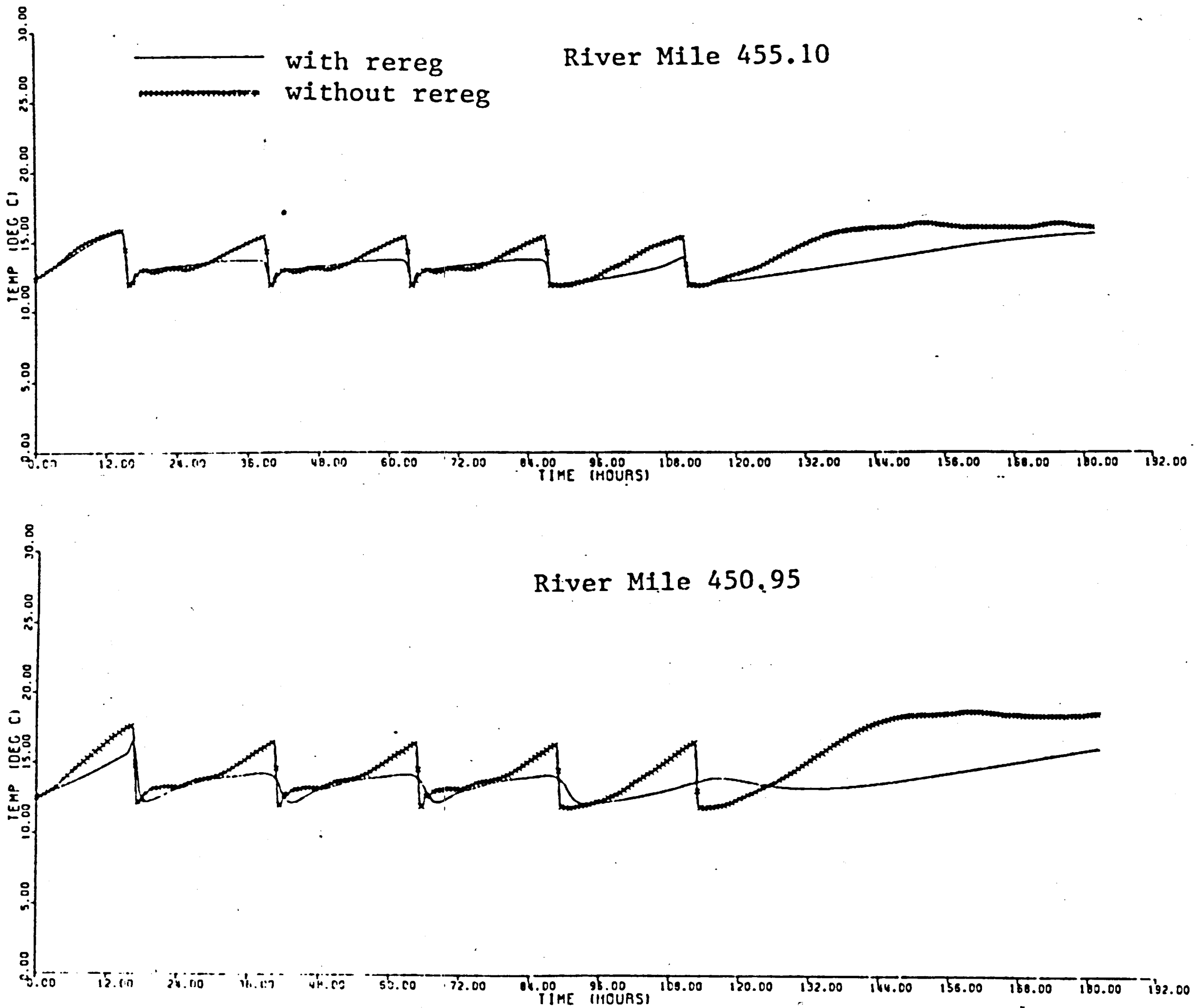


Figure 23. Variations in water temperatures during July under conditions with and without a rereg dam at river miles 455.10 and 450.95 of the Cumberland River for condition 4 (rereg dam at river mile 450.7)

23). Water temperatures for conditions with the rereg dam increased at a much slower rate during the low flow period, and attained a temperature of near 16.5 degrees C by the end of the simulation period at river mile 450.95. This trend for cooler predicted temperatures to occur in simulations with the rereg dam was also apparent in temperatures averaged over the week (Figure 24), where average temperatures were approximately 1.5 degrees cooler at the site of the rereg dam. Water temperatures of near 15.6 degrees C were predicted near the site of the proposed rereg dam.

Variations in predicted water temperatures for September were similar to those predicted under Condition 2 during weekdays. Water temperatures were slightly higher than in Condition 2 simulations due to the increased temperatures associated with the higher flows from Wolf Creek Dam (Table 4). Diel temperature variations under unreregulated conditions, of near 1.8 degrees C, were greater than under rereg conditions, which generally remained near 1.2 degrees C (Figure 25). During the weekend low flow period, predicted water temperatures increased relatively rapidly under conditions without the rereg dam until a temperature near 16.8 degrees C was obtained at river mile 450.95, after which water temperatures remained relatively constant. For the case with the rereg dam, water temperatures increased at a slower rate, with increases being nearly linear. At the end of the simulation period, predicted water temperatures with the rereg dam were about 16.8 degrees C, while without the rereg dam they were nearly 18 degrees C at river mile 450.95 (Figure 25). At river mile 444.5 water temperatures averaged over the 7.58 day period

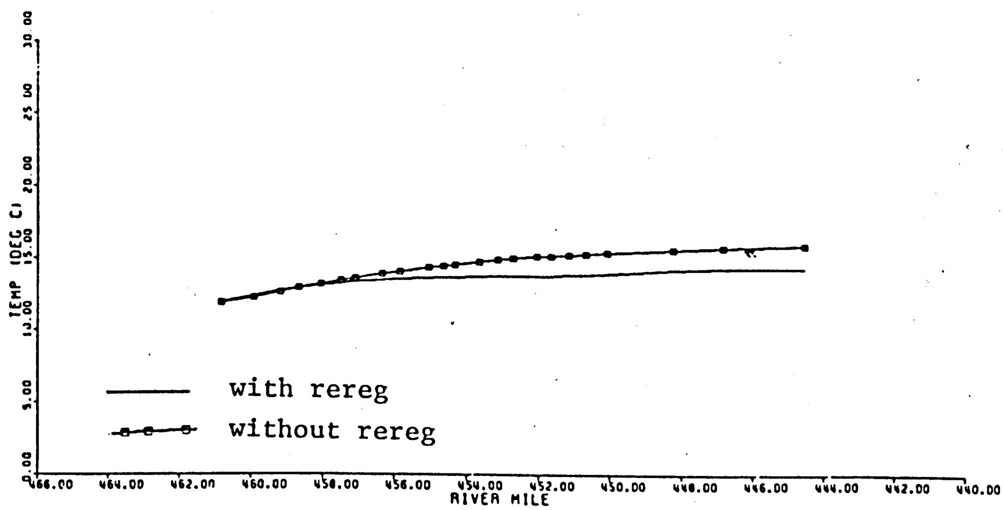


Figure 24. Average variations in water temperature over a 7.58 day period during July for conditions with and without a rereg dam for condition 4 (rereg dam at river mile 450.7)

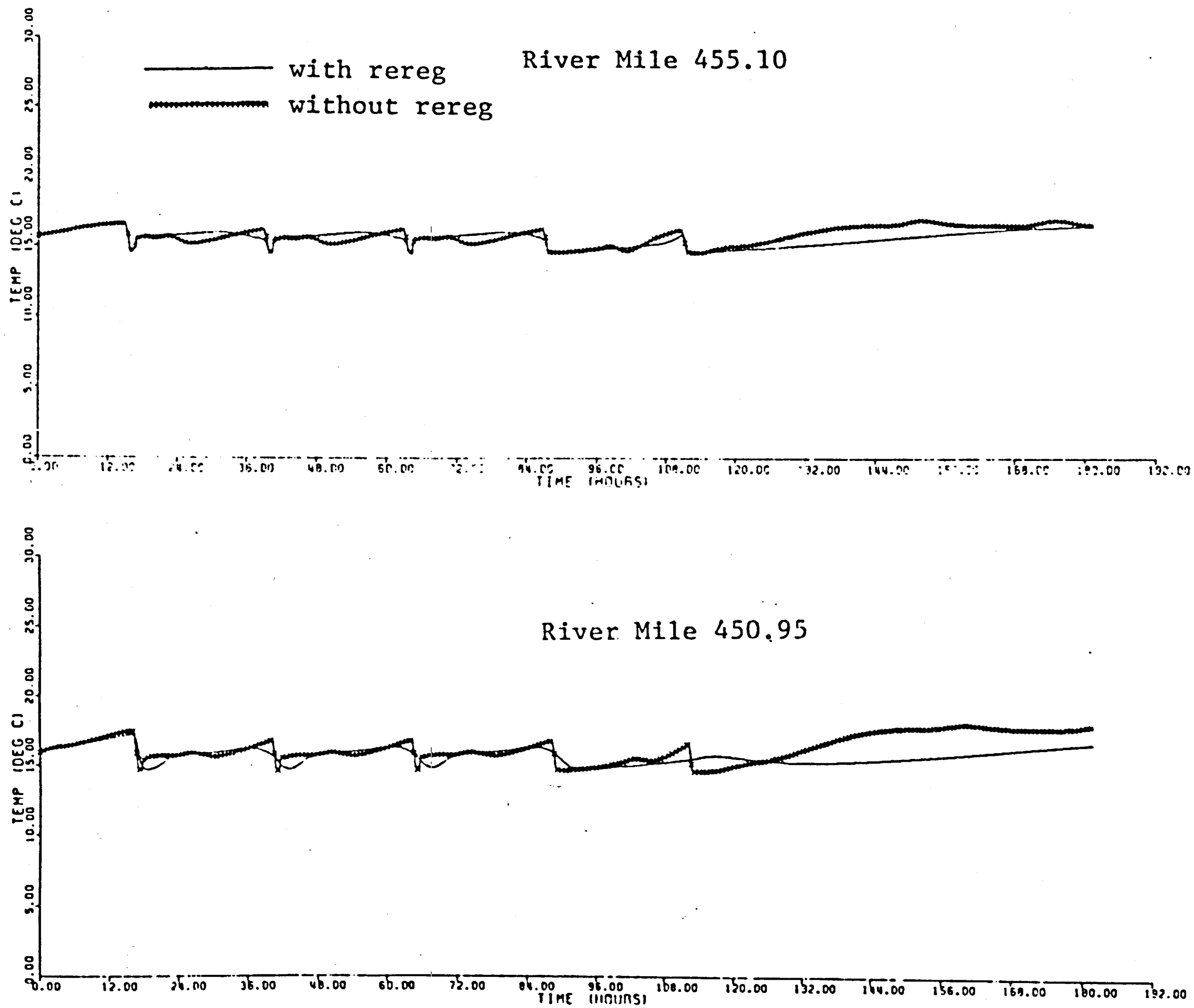


Figure 25. Variations in water temperatures during September under conditions with and without a rereg dam at river miles 455.10 and 450.95 of the Cumberland River for condition 4 (rereg dam at river mile 450.7)

indicated that without the rereg dam temperatures averaged approximately 1 degree C higher than those with the rereg dam, and approximately 0.6 degrees higher at the site of the rereg dam (River mile 450.70; Figure 26).

Predicted water temperatures at the end of the weekend low flow period for both July and September remained considerably less than the equilibrium temperatures (Table 2) under both unreregulated and reregulated conditions. The relatively low predicted temperatures are due, in part, to the minimum flow of 500 cfs used in simulations. As discussed earlier, this minimum low flow was used to ensure numerical stability and exceeds the low flows that would normally occur from Wolf Creek Dam during non-generation periods. Worst case conditions would be expected to occur under zero flows rather than the minimum flow used in simulations.

Variations in predicted DO concentrations during July for this condition were similar to those of Condition 2 during weekdays. Greater diel variations were noted in simulations without the rereg pool due to increased stream reaeration during high flow periods (Figure 27). During the weekend low flow event, DO concentrations remained relatively constant at about 8.2 mg/l at river mile 450.95 in simulations without the rereg dam, while DO concentrations steadily decreased in simulations with the rereg pool, with concentrations of about 7.3 mg/l occurring at the end of the simulation period at river mile 450.95 (Figure 27). The DO concentrations averaged over the simulation period were only slightly lower for simulations with the rereg dam, and were approximately 1.0 mg/l higher in downstream

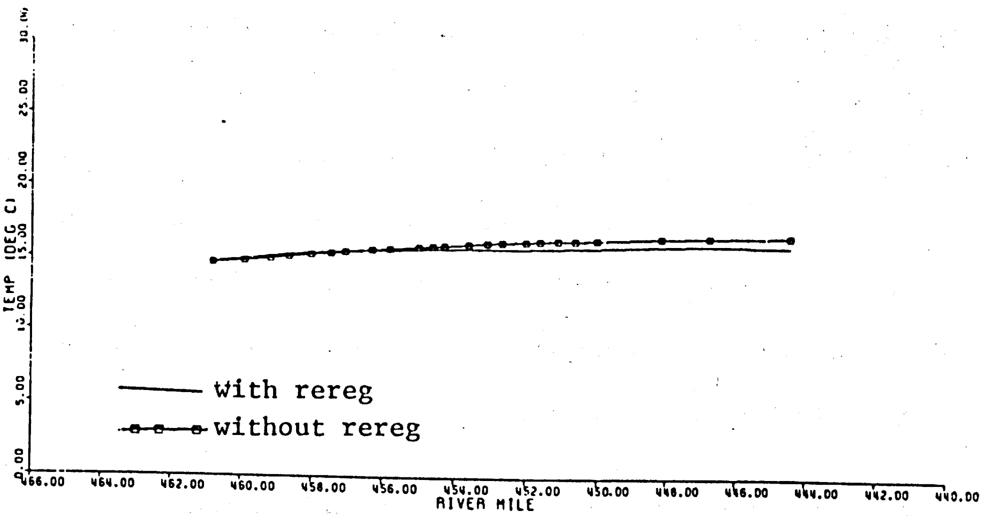


Figure 26. Average variations in water temperature over a 7.58 day period during September for conditions with and without a rereg dam for condition 4 (rereg dam at river mile 450.7)

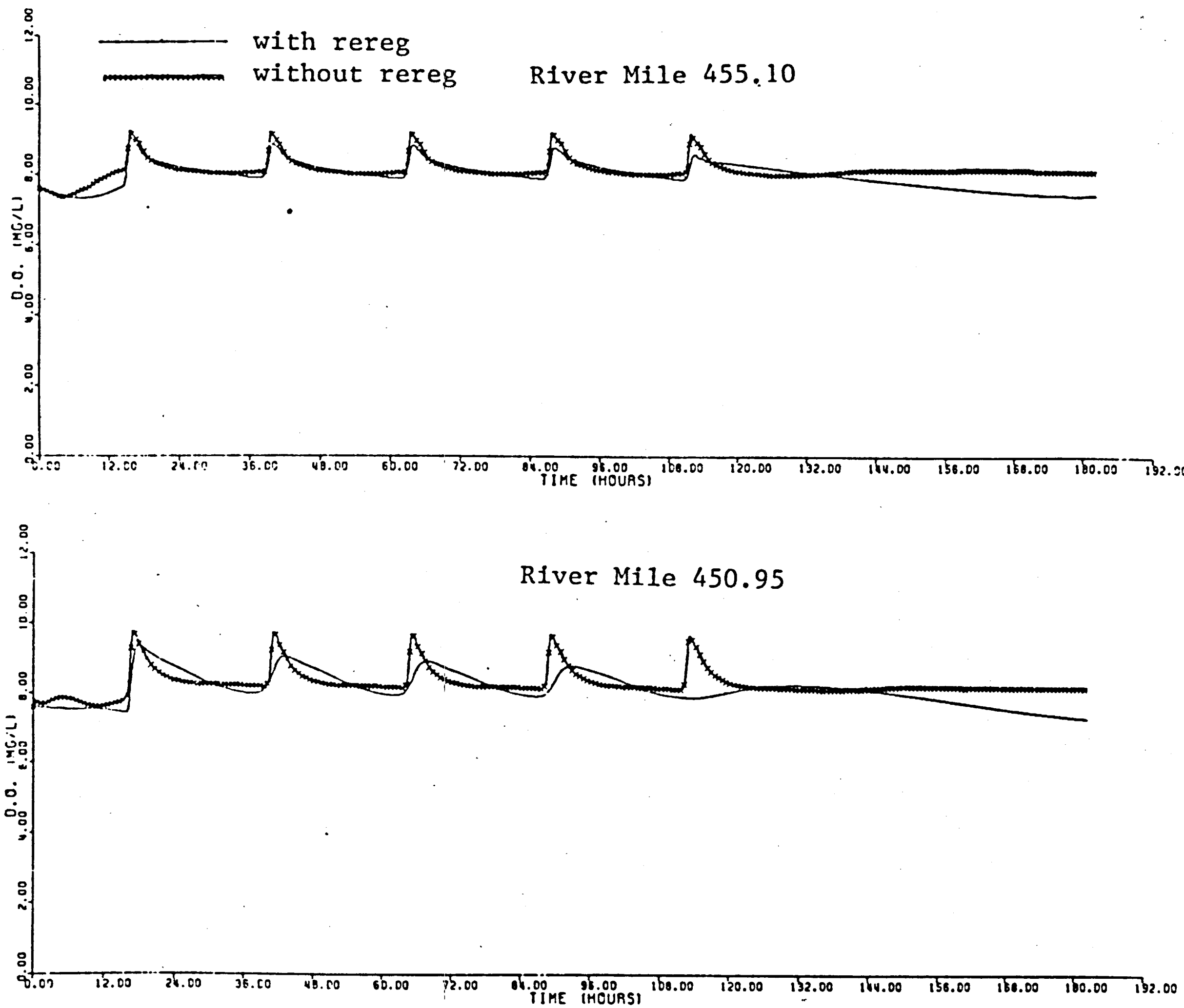


Figure 27. Variations in dissolved oxygen concentrations during July under conditions with and without a rereg dam at river miles 455.10 and 450.95 of the Cumberland River for condition 4 (rereg dam at river mile 450.7)

segments due to structural aeration (Figure 28).

Variations in predicted DO concentrations for September simulations were similar to those during July, although concentrations were consistently lower due to the lower inflow concentrations (Table 4). During the week, diel variations were greatest for the case without the rereg dam due to increased stream reaeration. During the weekend, DO concentrations were less for the rereg case due to the longer overall retention time, reaching a low of 5.7 mg/l at river mile 450.95 as compared with 6.5 mg/l without the rereg dam (Figure 29). DO concentrations averaged over the week were slightly higher without the rereg dam for river miles greater than 450.70 (Figure 30). Weekly averaged concentrations, both with and without the rereg dam, remained near or above 6.2 mg/l. An average gain due to structural reaeration of 1.6 mg/l DO was predicted for the rereg case, yielding concentrations of near 8.5 mg/l below the rereg dam (Figure 30).

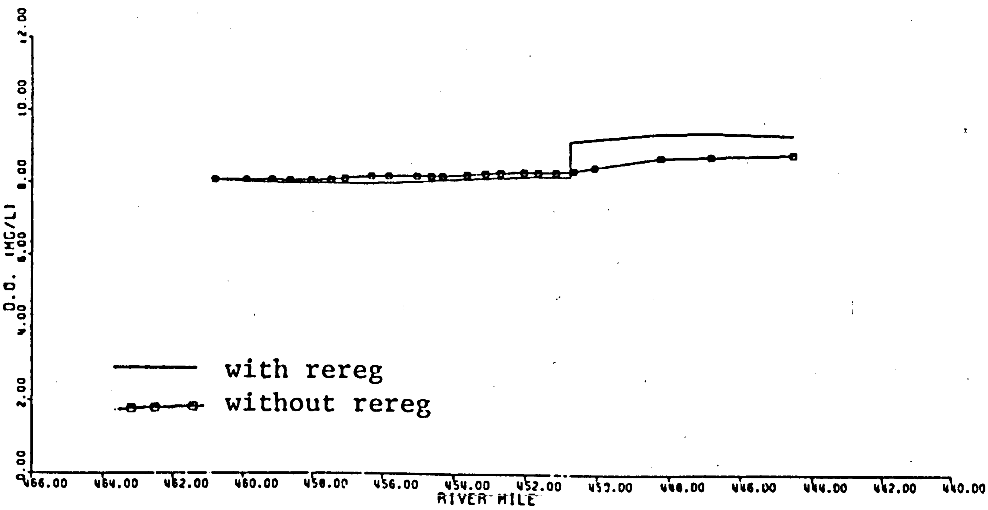


Figure 28. Average variations in dissolved oxygen concentrations over a 7.58 day period during July for conditions with and without a rereg dam for condition 4 (rereg dam at river mile 450.7)

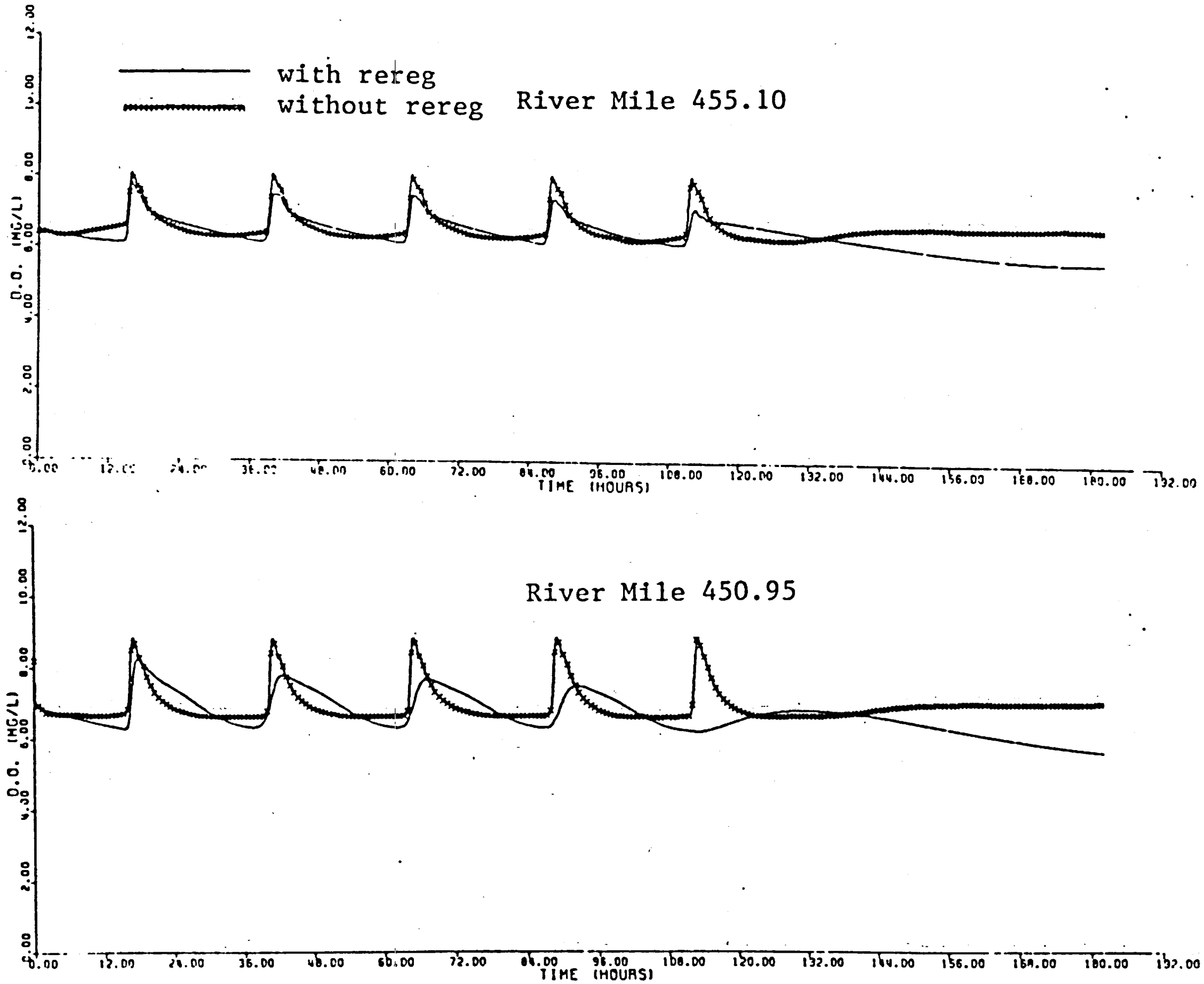


Figure 29. Variations in water dissolved oxygen concentrations during September under conditions with and without a rereg dam at river miles 455.10 and 450.95 of the Cumberland River for condition 4 (rereg dam at river mile 450.7)

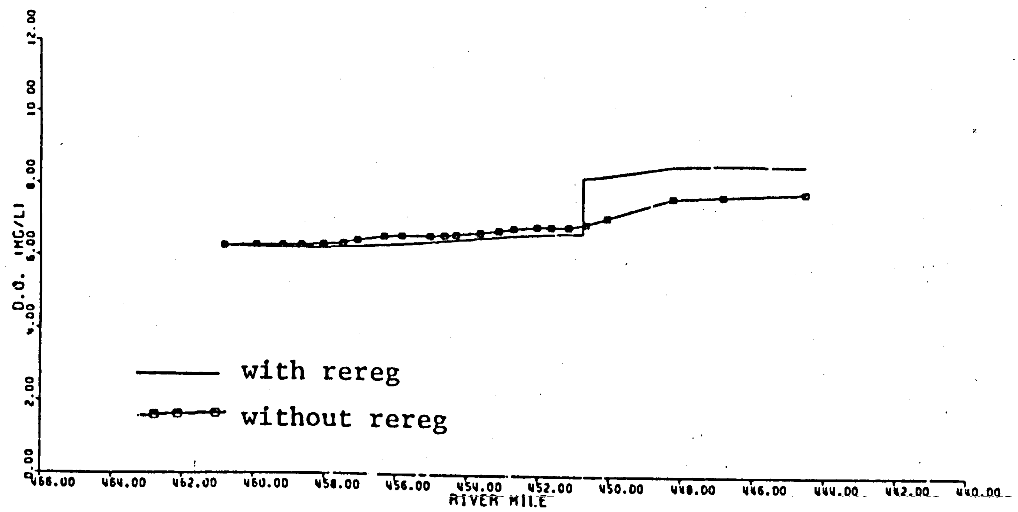


Figure 30. Average variations in dissolved oxygen concentrations over a 7.58 day period during September for conditions with and without a rereg dam for condition 4 (rereg dam at river mile 450.7)

PART V: SUMMARY AND CONCLUSIONS

Simulations were conducted using an unsteady hydrodynamic and water quality model developed by Bedford et al. (1982) to determine the effects of a proposed reregulation structure on dissolved oxygen (DO) and water temperature variations in the Cumberland River below Wolf Creek Dam. Hydraulic simulations were conducted for a projected July operating schedule supplied by ORN for conditions with and without a rereg dam. Water quality simulations were conducted for conditions with and without the rereg structure for both July and September. September simulations were included because of the generally lower DO in releases from Wolf Creek Dam during that month. The July operating schedule was assumed to be applicable to the September simulations. Boundary condition data for water quality simulations, including inflow temperatures and DO concentrations and meterological conditions, were supplied by ORN. No field data were available for complete model calibration and verification. Therefore, the results of this study are only intended to provide information on the relative differences in water quality under projected conditions with and without the rereg structure.

Simulations of water temperature indicated that maximum variations occurred in July. Simulations conducted with constant inflow temperatures, inflow temperatures varying with flow as determined by selective withdrawal studies, steady meteorological conditions, or time varying meteorological conditions resulted in differing degrees of diel variations at given nodes. For simulations without the rereg structure, maximum diel variations in predicted water temperatures of over 4 degrees C were noted near the site of the proposed rereg dam. Diel variations were generally less under conditions with the rereg dam than without due to the increased water volume retarding rates of warming and cooling. During simulations with low flow conditions occurring over a weekend, considerably more warming was predicted to occur for conditions without the rereg dam than with the rereg dam. This is also attributed to the retarding action for heating due to increased water volume in the rereg pool. This retardation, or attenuation, of diel variations and variations under low flow conditions can potentially benefit the system by decreasing thermal shock to aquatic organisms due to rapid changes in water temperatures in the rereg pool and releases.

Predicted water temperatures, averaged over the 7.63 days of simulation, increased by slightly less than 2.0 degrees C in July for the reach between Wolf Creek Dam (river mile 460.9) and the present site of the proposed rereg dam (river mile 450.70) for simulations both with and without the rereg structure. In September, this average increase is less than 1 degree C. Simulations indicated that little difference occurred in average water temperatures for conditions with and without the rereg structure for conditions with peaking flows. For low flow periods, water temperatures tended to be warmer for conditions without a rereg structure.

Troxler and Thackston (1977), in studies of heat transfer in the Cumberland River below Wolf Creek Dam, indicated that due to fog formation and the micrometeorology of the area, predictions of water temperatures using meteorological data taken from Nashville could result in an overestimation of water temperatures in the Cumberland River. As the meteorological conditions used in this study were computed from Nashville data, the predicted water temperatures may be higher than those which would actually occur under the conditions simulated.

The predicted DO concentrations in July generally remained near 8.0 mg/l for both conditions with and without the rereg dam. Greatest variations in DO predictions occurred during September, as expected. DO concentrations for September generally remained near 6.0 mg/l for simulations with power generation during a portion of the day. For simulations with low flows during the weekend, DO concentrations decreased to near 5.7 mg/l by the end of the simulation period. As with water temperatures, temporal variations in DO were greatest for conditions without the rereg structure. The minimum DO concentrations were generally lower for the condition with the rereg structure, due to its longer retention time allowing additional decomposition of oxygen consuming materials and less reaeration. The maximum DO concentrations were generally greatest under the condition without the rereg structure due to increased stream reaeration.

As with water temperatures, little difference was noted in the DO concentrations averaged over the week between simulations with or without the rereg dam between river miles 460.9 (the upstream boundary) and river mile 450.70 (the site of the proposed rereg structure). However, for conditions with the rereg structure, DO concentrations were predicted to increase due to structural reaeration by about 1.0 mg/l and remain higher from below the rereg dam (river mile 450.70) to the end of the study reach (river mile 444.5).

The concentrations of materials that exert a demand on DO were taken from average values in releases from Wolf Creek Dam over the period of record. Therefore, the results of the DO simulations conducted in this study do not represent the worst conditions that may occur, and were intended only to allow a comparison of conditions that may occur with or without the proposed rereg dam.

The results of this study indicate that, under the conditions simulated, the proposed rereg dam may have little impact on average water temperatures or DO concentrations in the study reach extending from river mile 460.9 to 450.70. While average conditions are similar, simulations indicated that the rereg dam attenuates diel variations in water temperatures and results in slower rates of warming during low flow periods. Dissolved oxygen concentrations below the rereg structure were predicted to increase by about 1.0 mg/l due to structural reaeration. These predicted impacts due to the rereg structure are not considered detrimental, and may instead have beneficial effects on the aquatic habitat within and below the proposed rereg pool. The rereg structure also allows maintenance of steady flows in downstream segments. Martin, Curtis, and Nestler (1985) indicated that such reduction of flow variations may have a beneficial impact on downstream fisheries.

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