THE EFFECTS OF TWO MULTIPURPOSE RESERVOIRS ON THE WATER TEMPERATURE OF THE MCKENZIE RIVER, OREGON

BY R. PEDER HANSEN

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 87-4175

Prepared in cooperation with the
U.S. ARMY CORPS OF ENGINEERS

Portland, Oregon
1988

DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, Secretary
U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

For additional information write to:

U.S. Geological Survey, WRD
847 N.E. 19th Ave., Suite 300
Portland, Oregon 97232

Copies of this report can be purchased from:

U.S. Geological Survey
Books and Open-File Reports Section
Federal Center, Building 810
Box 25425
Denver, Colorado 80225

CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

For use by those readers who prefer to use inch-pound units rather than metric units, the conversion factors for the terms used in this report are listed below.

Multiply SI units	By	To obtain inch-pound units
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
millimeter (mm)	0.03937	inch (in)
	Area	
square meter (m^2)	10.76	square foot (ft^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
hectare (ha)	2.471	acre
	Flow	
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
	Volume	
cubic meter (m^3)	0.0008107	acre-foot (acre-ft)
	Temperature	
degree Celsius (°C)	°F = 1.8(°C)+32 °C = 5.9(°F-32)	degree Fahrenheit (°F)
calorie (cal)	0.003968	British thermal unit (BTU)
	Pressure	
kilopascal	0.1450	pound per square inch
	Velocity	
meter per second (m/s)	2.237	mile per hour (mi/h)

Sea level: In this report "sea level: refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level of 1929."

THE EFFECTS OF TWO MULTIPURPOSE RESERVOIRS ON THE WATER TEMPERATURE OF THE MCKENZIE RIVER, OREGON

--

By R. Peder Hansen

--

ABSTRACT

A one dimensional, unsteady-state temperature model using the equilibrium-temperature approach (with air temperature used to estimate equilibrium temperature) is used to evaluate the effects of two Army Corps of Engineers dams and resulting reservoirs on the McKenzie River from Delta Park (River Kilometer 99.9) to Leaburg Dam (River Kilometer 62.4). Both Corps of Engineers projects are on tributaries to the McKenzie River and at present have only bottom-withdrawal capabilities. An effective top-width parameter, ETW, was introduced in model calibration to account for the high turbulence of the McKenzie River for much of the reach.

Extensive data were collected from May to October in 1983 and in 1984. Using these data, water temperatures were predicted to within 0.30 °C mean absolute deviation (MAD) at Finn Rock (at River Kilometer 87.2, 4.5 kilometers below the second tributary confluence) and near Vida (River Kilometer 76.8), and to within 0.40 °C at Leaburg Dam (River Kilometer 62.4). Since these data represent hydrologic and meteorologic conditions over a very short period, analyses were extended to include 3 additional historic years and an average-conditions year. The average-conditions-year values were obtained by using the mean daily values for the period of record at key stations. Accuracy was lost when simulating historic years, since the only meteorological data available were collected outside the basin and hence were less representative.

Simulation of historic data showed that Corps of Engineers projects have little or no effect on water temperatures of the McKenzie River near Vida (River Kilometer 76.8) from the end of November to the end of May. Projects have a cooling effect from the beginning of June to the first part of September and a warming effect from the middle of September to the end of November. Warming and cooling effects average just over 1 °C. There is little or no temperature effect during periods of flood control operation or reservoir filling. Cooling effects are due to conservation holding, when releases are cooler than inflows. Drafting of reservoirs in preparation for flood control causes a warming effect when heat stored in the upper water layers during conservation holding is released as reservoir water levels lower.

INTRODUCTION

Dams capable of releasing water from several levels with different temperatures can provide cooler or warmer water temperatures downstream at critical times of fish spawning, rearing, or migration. Federal projects on the Willamette River system do not have this selective withdrawal capability. Facilities to provide greater water-temperature control would be costly to construct. Evaluation of the feasibility of constructing multilevel water-withdrawal structures at Federal projects requires an accurate understanding of the temperature regime in the stream below a reservoir under present conditions and under planned withdrawal conditions. This study was done in cooperation with the Portland District of the Army Corps of Engineers (COE) and is a part of the Willamette System Temperature Control Study (WSTCS). An objective of WSTCS is to determine the feasibility of using selective withdrawal from Cougar and Blue River Lakes to control stream temperatures in the McKenzie River. Stream-temperature and atmospheric condition data were collected to calibrate a mathematical temperature model for the McKenzie River from Delta Park (River Kilometer [RKM] 99.9) to Leaburg Dam (RKM 62.4). The location of the study area is shown in figure 1.

Problem

Evaluation of the influence of upstream releases from a dam on downstream temperatures includes (1) the determination of how far downstream water temperatures will be affected (the point at which the differences between with-project and without-project water temperatures are negligible) and (2) the determination of the effects on daily maximum, minimum, and mean water temperature. This study was done to answer the following questions:

(1) How accurately can the U.S. Geological Survey temperature model predict stream temperatures of the McKenzie River?

(2) How accurately can the U.S. Geological Survey temperature model predict water temperatures using only data from long-term stations in the McKenzie River basin?

(3) How have the COE projects affected water temperature of the McKenzie River?

(4) Can significant (greater than model accuracy) downstream changes in water temperature be achieved by altering present release temperatures (simulating selective withdrawal), but maintaining present flow-operation schedules?

Objective

The objectives of this study were to (1) define existing water-temperature conditions in the McKenzie River and simulate them with a mathematical model using minimal meteorological data and (2) determine effects of COE projects on the water temperature of the McKenzie River. The objectives were addressed using data from permanent gaging stations, supplemented with additional data collected at temporary locations.

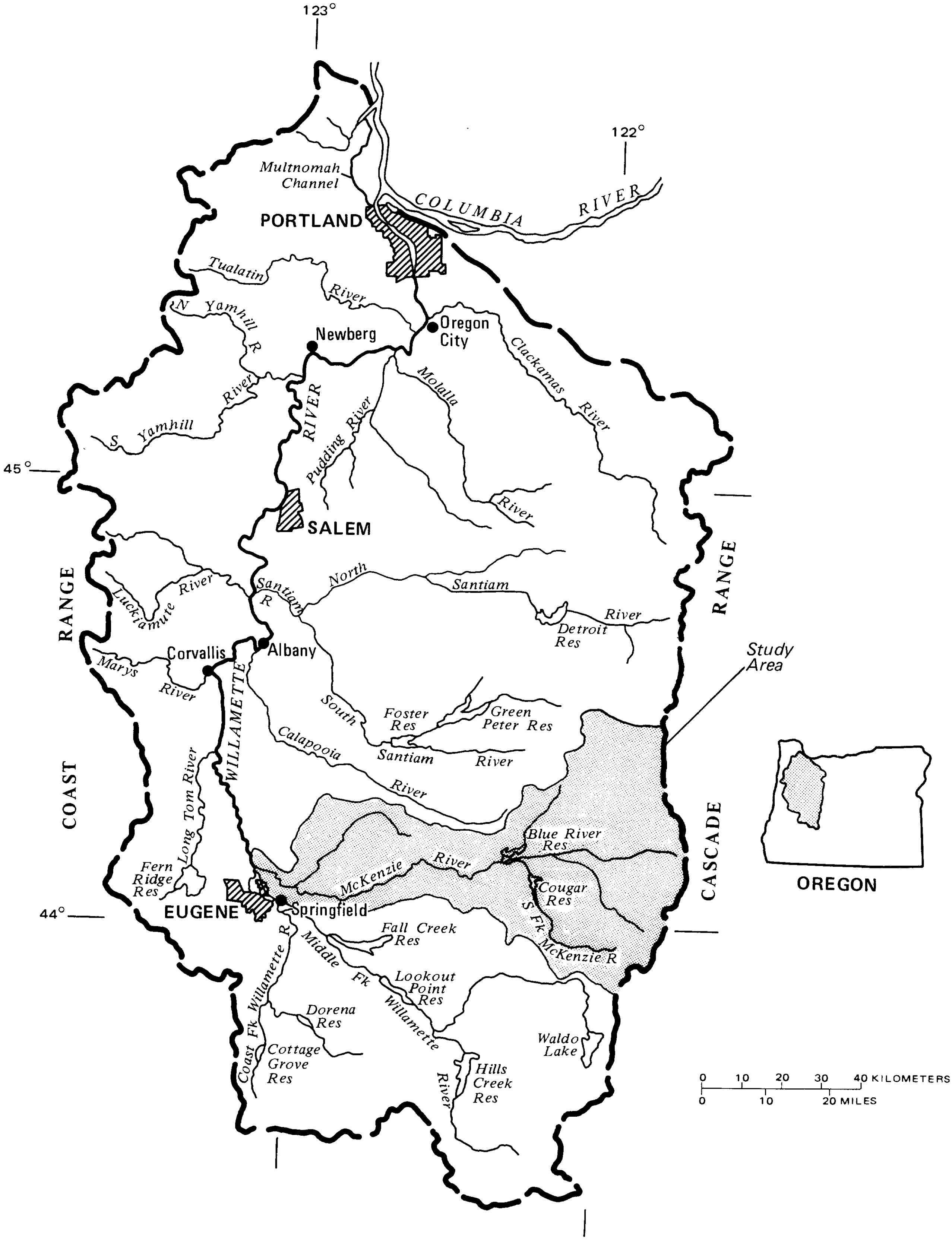

FIGURE 1.--Location map of the study area.

Approach

A temperature model as described by Jobson (1980a) was calibrated to run on 1-day time steps with data collected in the McKenzie River basin. This model has been shown to produce accurate results in a nearby river basin of similar character (Laenen and Hansen, 1985). The model was used with only windspeed and air temperature as meteorological inputs. Stream-width information was obtained from aerial photos and checked with field data. Stream cross-sectional areas were determined at selected locations from field measurements. Stream-velocity data were verified using a report by Harris (1968). Comparisons between simulated and observed water temperatures were made to determine model accuracy. Comparisons between simulations of water temperatures under with- and without-Federal project conditions were made to determine to what extent and how far downstream reservoirs affected the McKenzie River. Tributary temperatures from Blue River and South Fork McKenzie River were varied to simulate selective withdrawal.

PHYSICAL SETTING

Geography and Geology

The McKenzie River and its tributaries drain the western slopes of the Cascade Range from Three Fingered Jack to Irish Mountain (fig. 2). This basin occupies a drainage area of about 3,470 square kilometers. It extends westward from the Cascade Range to the confluence of the McKenzie River with the Willamette River near Eugene.

The McKenzie River basin is made up primarily of sedimentary, volcanic, and alluvial rock units. The oldest rocks consist of sandstone and siltstone and are exposed along the base of the Coburg Hills. Volcanic rocks form the Cascade Range and are divided into basalts and rhyolites. Alluvial deposits, made up principally of coarse volcanic sand and gravel, extend far up the McKenzie River valley. Porous lavas of the High Cascades store large quantities of precipitation and snowmelt and release the water gradually, thus sustaining relatively high stream flows during early summer months.

The Cascade Range gives the basin a mountainous character, with about 90 percent of the basin's area above the 300-meter contour and 70 percent above 600 meters. Elevations range from about 107 meters above mean sea level at the mouth of the McKenzie River to 3,156 meters at the summit of North Sister.

Climate

The McKenzie River basin has a temperate marine climate, characterized by relatively wet winters and dry summers. About 80 percent of the normal precipitation falls between October and May. Mean annual rainfall ranges from about 100-130 millimeters near Eugene to about 2,800 millimeters inches at the headwaters of Blue River. The normal annual air temperature at Mahlon-Sweet Airport in Eugene (the nearest first-order weather station) is 11.4 °C (degrees Celsius). Normal monthly temperatures range from 4.44 °C in January to 19.3 °C in July. Extremes range from -24.4 °C to 42 °C. The normal annual windspeed is 3.4 m/s (meters per second).

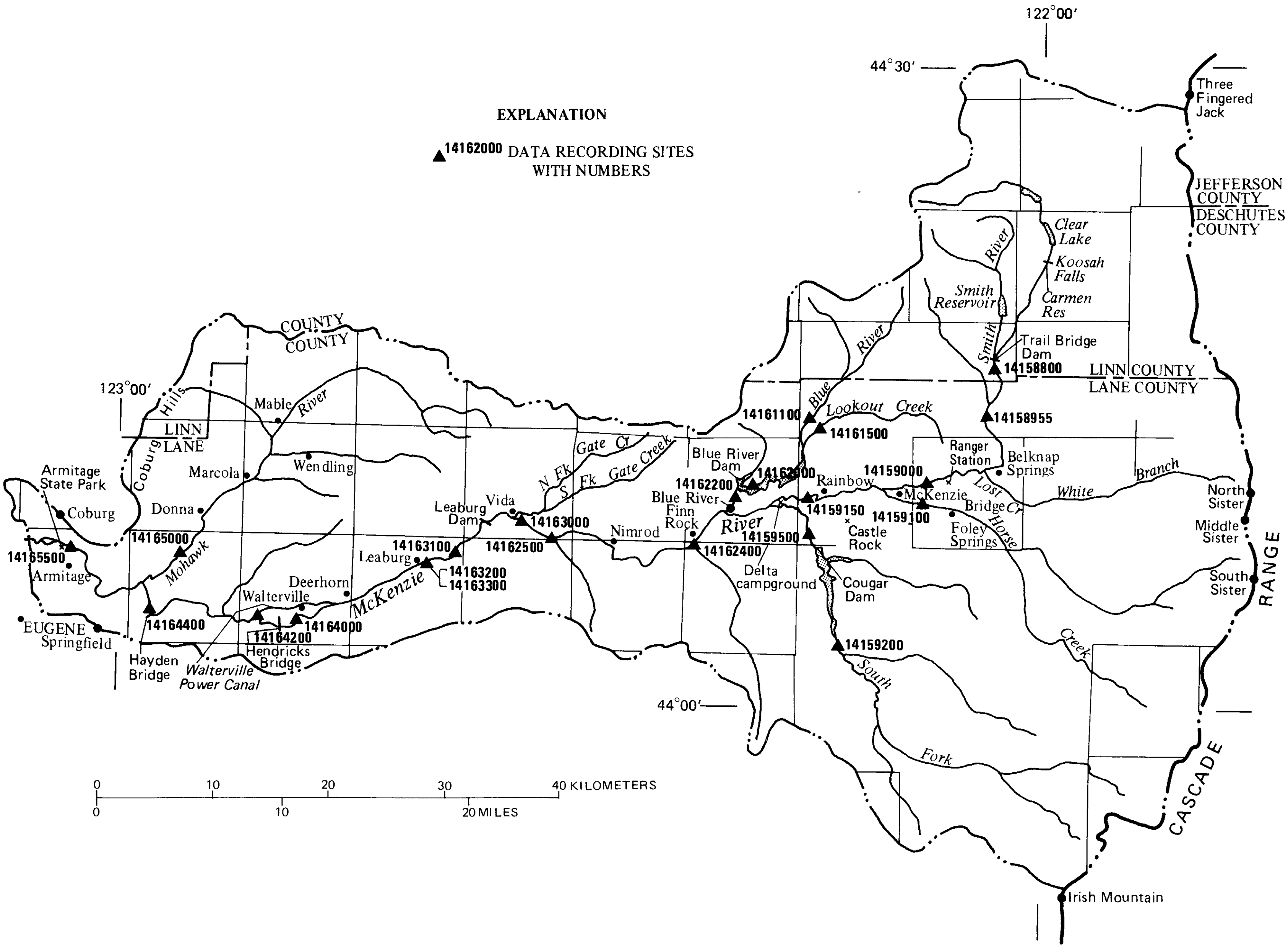

FIGURE 2.--Map of McKenzie River basin with data recorder sites.

Normal monthly windspeed ranges from 3.0 m/s in October to 3.8 m/s in March. The maximum windspeed of at least 1-minute duration was 28 m/s. Selected atmospheric statistics for Eugene are shown in table 1.

Table 1.--Selected meteorological normals, means and extremes for Eugene, Oregon

[Normals are for 1951-80; means and extremes are for 1942-84]

Month	Monthly recorded air temperatures (°C) Normal	Max	Min	Mean sky cover (tenths)	Normal precipitation (millimeters)	Wind speed (meter/s)
Jan.	4.4	19	-20	8.6	231.1	3.6
Feb.	6.4	22	-19	8.4	130.5	3.5
Mar.	7.7	25	-7	8.0	129.8	3.8
Apr.	9.8	30	-3	7.5	70.1	3.4
May	12.8	33	-2	6.8	50.0	3.3
June	16.2	38	0	6.3	31.5	3.3
July	19.3	41	4	3.9	6.9	3.6
Aug.	19.0	42	3	4.6	24.1	3.3
Sep.	16.7	38	0	5.0	36.8	3.3
Oct.	11.8	34	-7	7.1	88.1	3.0
Nov.	7.4	24	-11	8.4	173.2	3.2
Dec.	5.2	20	-24	8.9	215.6	3.4
Year	11.6	42	-24	7.0	1169.1	3.4

Description of the River

The McKenzie River has its origin at the outlet of Clear Lake in the Cascades. From Clear Lake, the river flows south about 24 km (kilometer) and then west for 121 km to its confluence with the Willamette River. The McKenzie River is diverted by Eugene Water and Electric Board (EWEB) below Koosah Falls (RKM 141.0) from Carmen Reservoir through a diversion tunnel to the Smith River and Smith Reservoir. EWEB uses the water to generate power as it passes from Carmen and Smith Reservoirs to Trail Bridge Reservoir, located at the natural confluence of the Smith and McKenzie Rivers. Trail Bridge Reservoir is used to attenuate daily fluctuations in streamflow caused by producing power to meet peak demands. Below Trail Bridge Dam (RKM 131.8), the McKenzie River flows to Belknap Hot Springs (RKM 120.1). The contribution of heat and flow from this spring is small compared to the total flow in the McKenzie River at that point.

Lost Creek (White Branch) joins the McKenzie River from the east at RKM 118.4. Its source is glaciers on North and Middle Sister volcanoes. A significant portion of the flow in Lost Creek is from springs draining porous lavas. These sources provide a nearly constant flow throughout much of the year, with water temperatures at or near the water temperature of the McKenzie River at the Lost Creek-McKenzie River confluence.

Horse Creek meets the McKenzie from the southeast at RKM 108.1. Horse Creek and its tributaries drain glaciers on South Sister and are similar to Lost Creek in their basin hydrology. Horse Creek drains 11 percent of the total basin area and contributes approximately 9 percent of the annual McKenzie River basin yield.

The McKenzie River combines with the South Fork McKenzie River at RKM 96.1. The South Fork McKenzie River has its origins in the High Cascades and is fed by snowmelt in the spring. Much of the snowmelt reaches the stream by way of porous lava beds, which tend to release water at a uniform rate and naturally sustain summer flows. South Fork McKenzie River drains 16 percent of the total basin area and contributes about 15 percent of the total McKenzie River basin annual yield. South Fork McKenzie River has been regulated since 1963 by Cougar Dam. Cougar Dam and the resultant Cougar Lake form one of two COE projects in the McKenzie Basin.

Blue River joins the McKenzie River from the north at RKM 91.7. A relatively large part of the annual yield of Blue River occurs in April and May from snowmelt. Lack of stream regulation by ground-water storage is evidenced by low base flow in late summer. Blue River drains 7 percent of the total basin area and contributes 8 percent of the total annual basin yield. Blue River has been regulated since 1969 by Blue River Dam. Blue River Dam and Blue River Lake make up the second of the two COE projects in the McKenzie Basin.

Gate Creek, entering from the north, has its confluence with the McKenzie River at RKM 66.6. Gate Creek contributes 4 percent of the total basin yield and drains 4 percent of the total basin area. Gate Creek receives relatively little snowmelt contribution and is typical of the lower McKenzie River streams, which deliver high winter and low summer flows to the McKenzie River.

EWEB diverts water at Leaburg Dam (RKM 62.4) into the Leaburg Power Canal for power generation. EWEB is required to leave a minimum of 14.2 m^3/s (cubic meters per second) for fish habitat in the McKenzie River below Leaburg Dam. The diverted flow is returned at RKM 53.4, but the traveltime through the power canal is faster then it would be down the river channel. EWEB diverts water again for power generation at RKM 45.9 and returns it to the river at RKM 33.6 (Walterville Power Canal). Minimum-flow requirements in the McKenzie River, after diversion into the Walterville Canal range, from 9.9 m^3/s for the period October-April, to 28.3 m^3/s in May (State Water Resources Board, 1961). Approximately 62.3 m^3/s are diverted at Leaburg Dam and 56.6 m^3/s are diverted near Walterville (Rick Junker, oral commun., September 1983). EWEB also diverts water (approximately 1.13 m^3/s) at Hayden Bridge (RKM 23.8) for use as a water supply for the city of Eugene.

Mohawk River, the last major tributary, joins the McKenzie River from the north at RKM 22.0. It rises from a lower elevation than the other tributaries and has no significant snowmelt contribution. It has a low baseflow during the late summer, because the Mohawk River basin contains less porous rocks than the basins in the McKenzie River headwaters. Mohawk River contributes 9 percent of the total annual basin yield, but drains 13 percent of the total basin area.

Reservoirs

The COE operates two Federal projects in the McKenzie River basin, Cougar and Blue River. The primary authorized purposes of these projects are flood control, irrigation, and downstream navigation improvement. Cougar Dam also has a 25,000-kilowatt generating capacity. Secondary purposes include low flow augmentation, pollution abatement, and recreation.

Cougar Lake was formed by the completion of Cougar Dam in 1963. Cougar Dam is a 138-meter high embankment dam located at RKM 7.2 on the South Fork McKenzie River about 74 km east of Eugene. Cougar Lake has a 2.55×10^8 m^3 (cubic meter) storage capacity and a 500 ha (hectare) surface area at full pool.

Blue River Dam, a 98-meter high embankment dam, was completed in 1969. It is located on Blue River about 77 km east of Eugene. Blue River Lake was formed by completion of Blue River Dam and by a 21-meter embankment dam about 6 km from the main dam (the second dam closes off a low saddle between the Blue River and McKenzie River drainages). The reservoir provides 1.02×10^8 m^3 of storage and has a surface area of 384 ha at full pool.

Completion of Cougar and Blue River Dams blocked upstream migration of salmon and steelhead beyond the dam sites. Upstream fish passage facilities were not constructed at either site. The loss of salmon and steelhead spawning grounds caused by the construction of Cougar and Blue River Dams has been compensated for by mitigation actions.

DATA NETWORK

Data used in this study included data from long-term stream gage and temperature-recording locations, from temporary recording sites, and from miscellaneous field measurements. The location of existing stream gages and temperature recorders plus temporary temperature and atmospheric-data recorders are shown in figure 2.

Long-term Stations

Long-term sites included Geological Survey stream-gaging stations on the McKenzie River at McKenzie Bridge (14159000) and near Vida (14162500), on the South Fork McKenzie River above Cougar Lake near Rainbow (14159200) and below Cougar Lake near Rainbow (14159500), on Blue River below Tidbits Creek near Blue River (14161100) and near Blue River (14162200), on Lookout Creek near Blue River (14161500), on Gate Creek at Vida (14163000) and on the Mohawk River near Springfield (14165000). Long-term stream-discharge and water-temperature data have been collected at each of the above sites, with the exception of 14163000 and 14165000, at which water-temperature data were collected only for the duration of this project (April to October, 1983-84). The period of record for each variable at each site is shown in table 2. Hourly air-temperature and windspeed data were available from the National Weather Service station at Mahlon-Sweet Airport in Eugene.

Table 2.--Period of record for each variable at long-term stations

[Q = discharge]

Station number	Location description	Para-meter	Sta-tistic	Period of record Begin	End
14158850	McKenzie River below Trail Bridge Dam	Temp	Max	1976 11	1985 09
		Temp	Min	1976 11	1985 09
		Temp	Mean	1977 10	1985 09
		Q	Mean	1960 10	Present
14159000	McKenzie River at McKenzie Bridge	Temp	Max	1976 11	1985 09
		Temp	Min	1976 11	1985 09
		Temp	Mean	1978 08	1985 09
		Q	Mean	1910 08	Present
14159100	Horse Creek nr McKenzie Bridge	Temp	Max	1963 01	1969 09
		Temp	Min	1963 01	1969 09
		Q	Mean	1962 10	1969 10
14159200	South Fork McKenzie River at Cougar Lake	Temp	Max	1957 11	Present
		Temp	Min	1957 11	Present
		Temp	Mean	1978 08	Present
		Q	Mean	1957 10	Present
14159500	South Fork McKenzie River nr Rainbow	Temp	Max	1955 07	Present
		Temp	Min	1955 07	Present
		Temp	Mean	1978 08	Present
		Q	Mean	1947 10	Present
14161100	Blue River below Tidbits Creek nr Blue River	Temp	Max	1963 09	Present
		Temp	Min	1963 09	Present
		Temp	Mean	1978 06	Present
		Q	Mean	1963 09	Present
14161500	Lookout Creek nr Blue River	Temp	Max	1950 08	1981 09
		Temp	Min	1950 08	1981 09
		Temp	Mean	1978 08	1981 09
		Q	Mean	1949 10	1955 09
		Q	Mean	1963 10	Present
14162000	Blue River nr Blue River	Temp	Max	1961 06	1964 09
		Temp	Min	1961 06	1964 09
		Q	Mean	1935 09	1964 12
14162200	Blue River at Blue River	Temp	Max	1966 08	Present
		Temp	Min	1966 08	Present
		Temp	Mean	1978 08	Present
		Q	Mean	1966 10	Present
14162500	McKenzie River nr Vida	Temp	Max	1961 06	1985 09
		Temp	Min	1961 06	1985 09
		Temp	Mean	1978 02	1985 09
		Q	Mean	1910 07	1911 03
		Q	Mean	1924 09	Present
14163000	Gate Creek nr Vida	Q	Mean	1951 10	1957 09
		Q	Mean	1966 10	Present
14165000	Mohawk River nr Springfield	Temp	Max	1963 10	1969 09
		Temp	Min	1963 10	1969 09
		Q	Mean	1935 10	1957 09
		Q	Mean	1963 10	Present
14165500	McKenzie River nr Coburg	Temp	Max	1963 10	1975 09
		Temp	Min	1963 10	1975 09
		Q	Mean	1944 10	1972 09

Additional Sites

Data were collected at several additional sites from April to October 1983-1984 (unless otherwise noted). Additional water-temperature data were collected by installing mini-monitor temperature units with thermistor probes and Leupold-Stevens[1] digital recorders in temporary shelters on the McKenzie River at Armitage Park near Coburg (14165500), at Hendricks Bridge near Walterville (14164000), at Leaburg (14163200; 1984 only), at Finn Rock (14162400), at Delta Campground near Rainbow (14159150), and above Belknap Springs (14158955; 1983 only). Water-temperature recording units of this type were also located on the EWEB Power Canal near Walterville (14164200), the EWEB Power Canal near Leaburg (14163300; 1984 only) and on Horse Creek near McKenzie Bridge (14159100). Data were recorded on paper tape at half-hour intervals and reduced to hourly averages.

Campbell CR-21 dataloggers with thermistor temperature probes and anemometers were used on the McKenzie River at Hayden Bridge near Springfield (14164400; 1984 only), at Leaburg Dam (14163100), and at the McKenzie Bridge Ranger Station near McKenzie Bridge. Only air-temperature and windspeed data were collected at the ranger station site. Air-temperature, water-temperature, and windspeed data were collected at the other two CR-21 datalogger sites. Additional meteorological data were collected at the Leaburg Dam site during July and August 1984. The data collected were for solar radiation, atmospheric radiation, relative humidity, and vapor pressure. All CR-21 data were collected at 1-minute intervals, reduced on site to hourly averages, and then recorded on cassette tape.

Field surveys

Field surveys were made to obtain top-width, cross-section, and water-temperature data. Top-width and cross-section surveys were made July 25 to 29 and August 5, 1983 in the reach from Finn Rock to Armitage Park. Water-temperature surveys were made August 22 to 24 and August 31 to September 2, 1983 in the reach from above Belknap Springs to the mouth of the McKenzie River. An additional float survey was made August 21-22, 1984, from Leaburg Dam to RKM 30.2 near Springfield.

During the water-temperature survey, an attempt was made to float with the stream current and record water temperatures at regular intervals. The object was to follow a water parcel and observe how it heated or cooled in response to tributary inflow, streambank canopy, streambed character (riffle or pool), and manmade alterations.

Water-temperature cross sections were made at selected locations to determine horizontal and vertical variations in temperature. These temperature cross sections appear in figure 3. The uniform temperature distribution shown in the cross sections indicate that a one-dimensional representation of water temperature is justified for the McKenzie River.

---

[1] The use of trade or product names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

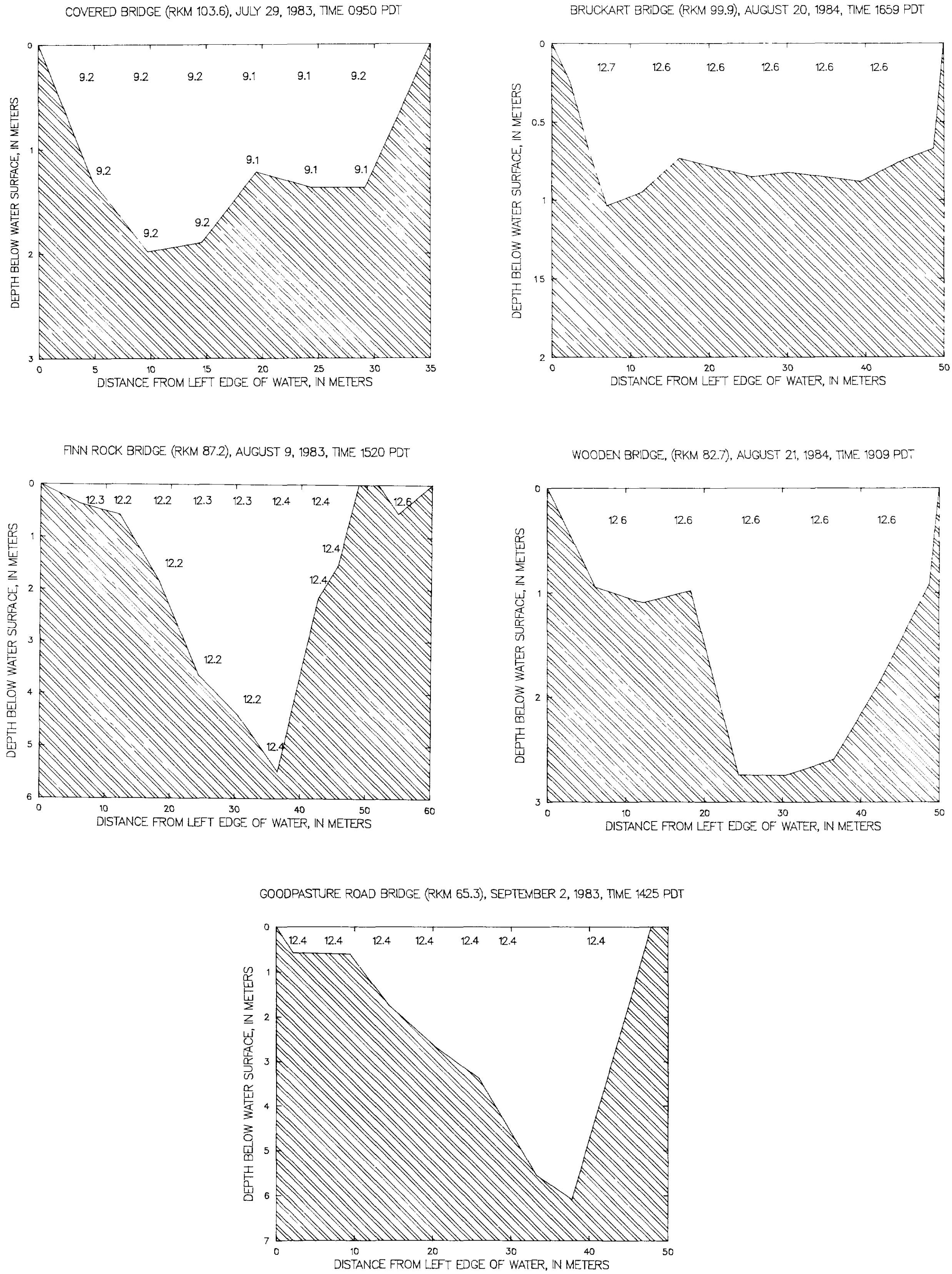

FIGURE 3.--Water-temperature cross sections at selected sites on the McKenzie River.

TEMPERATURE MODEL

Water temperature is an important water-quality variable because the rates of most chemical and biological reactions and the spawning and growth cycles of most fish are temperature-dependent. Mathematical modeling of water temperature has become a valuable tool for use in any study determining anthropogenic effects on natural basins. The method most widely used in water-temperature prediction utilizes some form of energy-budget analysis.

The temperature model used in this study was developed by Jobson (1980a). It simulates one-dimensional, unsteady temperature, in steady-state flow, using the Lagrangian or moving reference frame. In the Lagrangian framework, an individual fluid parcel is followed and those factors affecting temperature change are applied. The major sources and sinks of heat transfer to the stream are considered to be tributary inflow and heat exchange between air and water. Sources or sinks of heat considered negligible and hence not included in this study are precipitation, ground-water inflow, and bed conduction.

Convection-diffusion Equation

Applying the thermal continuity equation to a unit mass of fluid and integrating over the travel time, the convective-diffusion transport equation solved by the model is:

$$Tw = Tw0 + \int_0^t \frac{d\overline{u'Tw'}}{d\xi}\, dt' + \int_0^t \frac{HW}{A\, Cp\, \rho}\, dt' + \int_0^t \Phi\, dt', \qquad (1)$$

where

- Tw = water temperature of parcel at time t, in °C;
- $Tw0$ = initial water temperature of parcel, in °C;
- $\overline{u'Tw'}$ = average of the product of instantaneous velocity, in m/s, and water temperature, in °C;
- ξ = Lagrangian distance coordinate;
- H = net rate of heat exchange per unit area of air/water interface, in calories/cm^2/s;
- W = width, in meters;
- A = area, in m^2;
- Cp = specific heat of water (unitless);
- ρ = density of water (1 g/cm^3);
- Φ = additional heat source (or sink) term to account for tributary inflow; and
- t = time, in seconds.

This equation states that the temperature of a parcel is equal to its initial temperature plus any change due to dispersion, air/water interface heat exchange, and tributary inflow. This equation is especially useful because it allows the contribution of each heat-exchange process to be isolated.

Dispersion Term

Longitudinal dispersion is caused primarily by the difference in flow velocity between different points in the cross section. Assuming the temperature in each parcel is well mixed and the flow rate from parcel K to K+1 is DQ, the heat flux across a boundary can be computed using continuity considerations. The dispersion term can be written:

$$\int_0^t \frac{du'T'}{d\xi} = \frac{DQk\text{-}1\ \Delta t\ (Tk\text{-}1 - Tk) + DQk\ \Delta t\ (Tk\text{+}1 - Tk)}{V}, \qquad (2)$$

where

DQ = flow rate between parcels, in m^3/s;
V = parcel volume in m^3; and
Δt = time step.

Air/water Interface Heat Exchange

An equation for heat exchange across the air-water interface (Edinger and Geyer, 1965) can be written as:

$$H = (Hs + Ha - Hsr - Har) - (Hb \pm He \pm Hc), \qquad (3)$$

where

Hs = incoming short-wave (solar) radiation,
Ha = incoming long-wave (atmospheric) radiation,
Hsr = reflected solar radiation,
Har = reflected atmospheric radiation,
Hb = long-wave back radiation from the water surface,
Hc = conduction, and
He = evaporation.

The terms Hs, Ha, Hsr, and Har are independent of water temperature, while Hb, Hc, and He are water-temperature dependent. The temperature-independent terms can be measured directly using a pyranometer (short-wave radiation) and a pyrgeometer (long-wave radiation). Reflected components of each can be measured by inverting the above radiometers or can be estimated by using the procedure described by Jobson and Keefer (1979). The temperature-dependent terms can be calculated using physical laws and empirical relations.

The long-wave radiation emitted from the water surface can be computed using the Stefan-Boltzman law for blackbody radiation:

$$Hb = \epsilon\ \sigma\ (Tw + 273.16)^4, \qquad (4)$$

where

ϵ = emissivity of water = 0.97 (unitless),
σ = Stefan-Boltzman constant for blackbody radiation,
= $1.171 \times 10^{-7}\ cal/cm^2\ d\ K^4$,
Tw = water temperature in °C, and
273.16 = converts to the Kelvin temperature scale.

According to Jobson (1980a) the heat utilized by evaporation can be expressed as:

$$He = \rho\ L\ \psi\ (eo - ea), \tag{5}$$

where

- L = latent heat of vaporization = (595.9 - 0.545 Tw), in cal/g;
- ψ = empirical windspeed function = (α + N V), in cm/d kPa;
- eo = saturation vapor pressure of air at the water-surface temperature, in kPa; and
- ea = vapor pressure of the air above the water, in kPa.

From the thermal balance of an open channel, Jobson (1980b) found values for the empirical windspeed function of α = 3.02 mm/d kPa and N = 0.113 mm/d (m/s) kPa. The value of the saturation vapor pressure, eo, can be determined from the water temperature using the empirical equation (Jobson, 1980a):

$$eo = \exp\left[52.418 - \frac{6788.6}{(Tw + 273.16)} - 5.0016\ \ln(Tw + 273.16)\right]. \tag{6}$$

To calculate the conduction term, the Bowen ratio concept of identical eddy diffusivities of heat and mass is assumed. The conduction term (Jobson 1980a) can then be expressed as:

$$Hc = \gamma\ \rho\ L\ \psi\ (Tw - Ta), \tag{7}$$

where

- γ = the psychrometric constant (about 0.06 kPa/°C), and
- Ta = air temperature in °C.

To calculate the components of the air/water interface heat-exchange equation requires a significant amount of meteorological data (solar and atmospheric radiation plus reflected components of each, air temperature, windspeed, and air vapor pressure). However, complete long-term meteorological data needed for historic and extreme simulations are not normally available. Instrumentation required to collect all the meteorological data needed is expensive--both to purchase and to maintain. These costs--combined with the fact that the more variables one needs to adequately run a model, the smaller the complete data set seems to become--inspired the search for a simpler, less data-intensive approach.

Equilibrium-temperature Approach

From the energy-budget equations, an analytical solution for water temperature is seldom possible because of the nonlinearity of terms representing net heat flux at the air-water interface. The concept of an equilibrium temperature was developed to help linearize the net heat-flux equation. The equilibrium-temperature approach uses a simplified expression for the net surface exchange:

$$H = -K\ (Tw - Te), \tag{8}$$

where

- K = a positive surface exchange coefficient, and
- Te = the equilibrium temperature, in °C.

This equation gives the net heat exchange at the air/water interface as proportional to the difference between the water temperature and the equilibrium temperature. The equilibrium temperature is the temperature at which there is no net heat transfer across the air/water interface (H=0) and is the temperature toward which the water temperature will tend at any given time. If Te is greater than Tw, H is positive and the water is gaining heat. Conversely, if Te is less than Tw, H is negative and the water is losing heat.

To determine the surface exchange coefficient, equate equations (3) and (8), substitute for the various components, and then differentiate with respect to the water temperature. This procedure gives:

$$dH/dTw = -K = -4\epsilon\sigma(Tw + 273.16)^3 - \rho L\psi(\lambda + \gamma), \qquad (9)$$

where

λ = slope of the vapor pressure curve evaluated at the water temperature, in kPa/°C.

The slope can be accurately evaluated empirically (Jobson, 1980a) as:

$$\lambda = 1.1532 \times 10^{11} \frac{[\exp(-4271.1/(Tw + 242.63))]}{(Tw + 242.63)^2}. \qquad (10)$$

To complete the evaluation of the simplified expression for net surface exchange, the determination of a suitable equilibrium temperature is needed. Observations have shown that weekly or monthly average water and air temperatures relate well over time (Jobson, 1980a). On the basis of these observations, air temperature can be assumed to approximate equilibrium temperature, since that is the temperature the water will approach.

The net surface heat exchange can be estimated by using just two meteorological variables: windspeed (the sole meteorological variable needed to determine K, since all other components are constants or functions of water temperature) and air temperature (used to approximate equilibrium temperature). These two variables are relatively easy to obtain, greatly reduce the amount of data required, and help alleviate data handling problems.

Model segmentation

Jobson's model requires stream top-width and cross-sectional area at distinct grid points to define parcel characteristics. The model uses the average of consecutive grid points to define the parcel properties between those grid points. Grid points are also used to add tributary inflow or subtract diversion outflow. Inputs required for each time step are initial upstream water temperature, air temperature (or other estimate of equilibrium temperature), windspeed, and tributary-inflow temperatures. Initial model calibration assumed steady-state flow.

Top-widths were estimated from aerial photos by averaging widths measured every 600 meters along the stream length. These were checked with random field measurements. Cross-sectional areas were estimated from field measurements and travel-time estimates. Travel-time estimates were used to approximate cross-sectional area when discharge and distance traveled were also known (area = discharge/distance/travel time).

The original intent of this study was to model the McKenzie River from above the confluence with the South Fork McKenzie to Armitage Park near the mouth of the McKenzie River. It was soon realized, however, that the two EWEB power canals complicated the modeling effort and would require the use of a model with branching network capabilities to properly simulate water temperatures downstream from Leaburg Dam. The EWEB power canals affect the stream temperature (see fig. 4) by decreasing travel-time and lowering the top-width to depth ratio (thereby decreasing the surface area available for heat transfer). Even with proper modeling capabilities, separating the effects of these two EWEB facilities from the effects of COE projects may be difficult. Temperature data predating EWEB facilities (representing completely natural conditions) are virtually nonexistent. Temperature data predating COE projects, but collected after EWEB facilities were constructed, are similarly lacking. Separating the effects of EWEB and COE projects is possible, but requires a much more complex temperature analysis and modeling approach.

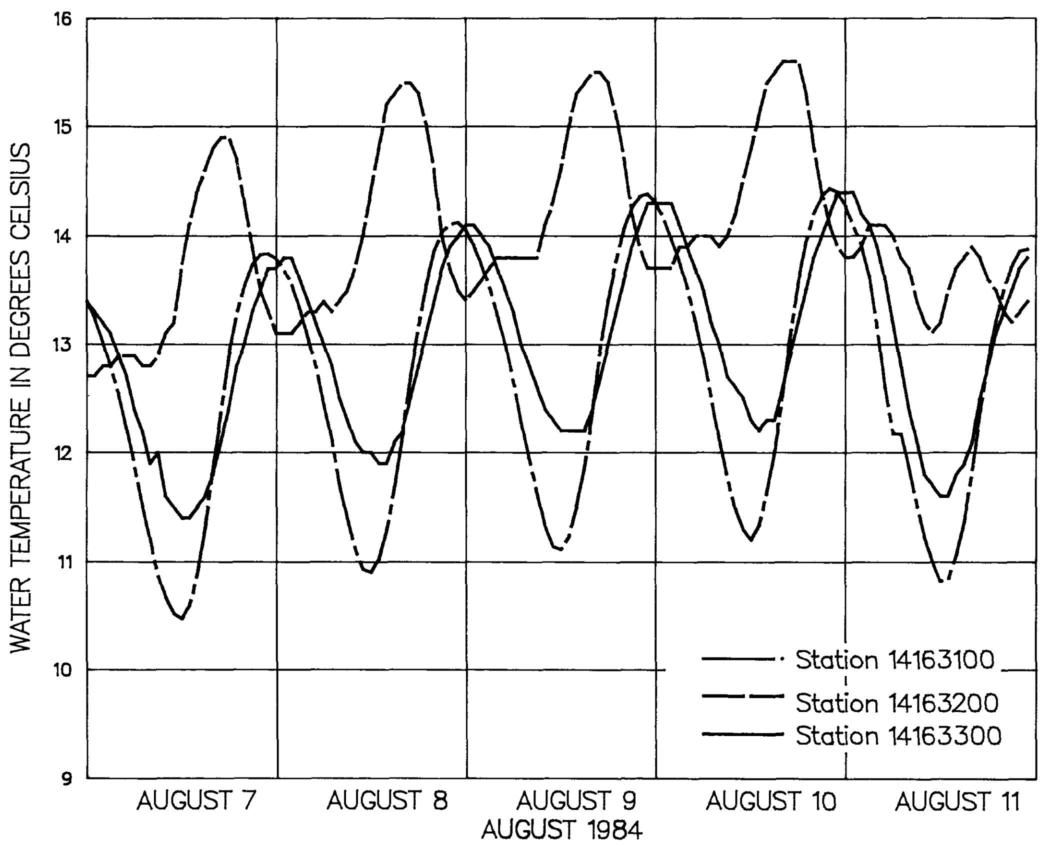

FIGURE 4.--Comparison of recorder water temperatures of the McKenzie River at Leaburg Dam just upstream of the canal diversion (14163100), the McKenzie River upstream of the canal return (14163200), and the Leaburg Power canal at the downstream end (14163300).

A temperature station was installed above Belknap Springs to determine if there were any significant effects from those hot springs. Preliminary modeling and data analysis showed no effects from the hot springs, and the station was discontinued after the first season.

Tributary temperatures were measured on Horse Creek to assess its influence on the McKenzie River. Water-temperature cross sections made at the covered bridge at Rainbow (RKM 103.6), 4.5 km downstream from the Horse Creek confluence, showed that water temperatures were well mixed by this point and that modeling could begin at Delta Park (RKM 99.9). Beginning simulation at Delta Park also eliminates the need to estimate the discharge from Horse Creek.

The section of the McKenzie River selected for analysis extends from Delta Park (RKM 99.9) to Leaburg Dam (RKM 62.4). This reach of river was delineated by 9 grid points (8 subreaches); see figure 5. The grid points are:

(1) Delta Park (RKM 99.9),
(2) Confluence with South Fork McKenzie (RKM 96.1),
(3) Confluence with Blue River (RKM 91.7),
(4) Finn Rock (RKM 87.2),
(5) Geological Survey gage near Vida (RKM 76.8),
(6) Confluence with Gate Creek (RKM 66.6),
(7) Upper end of Leaburg impoundment (RKM 65.3),
(8) Middle of Leaburg impoundment (RKM 63.9), and
(9) Leaburg Dam (RKM 62.4).

Table 3 shows the top-widths and cross-sectional areas used for each grid point.

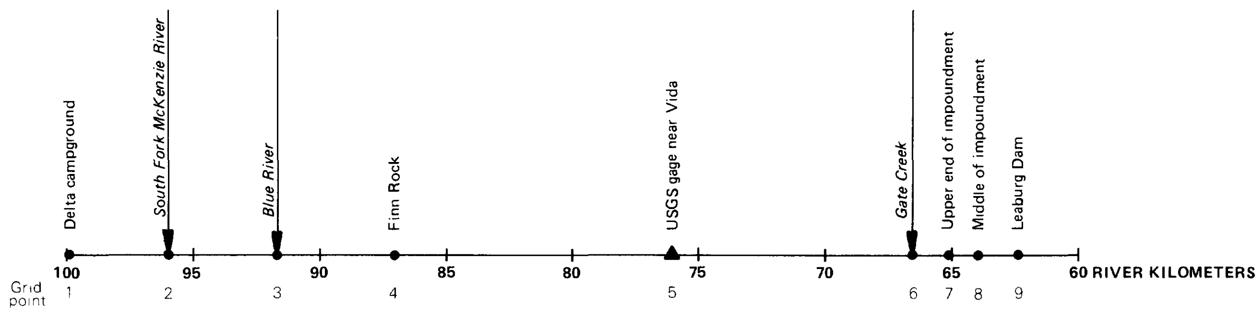

FIGURE 5.--Schematic diagram showing model segmentation.

Table 3.--Summary of grid-point characteristics used for the McKenzie River

Grid point	River kilometer	Area (m^2)	Top-width (m)
1	99.9	45	40
2	96.1	70	50
3	91.7	85	50
4	87.2	100	70
5	76.8	100	60
6	66.6	110	70
7	65.3	120	80
8	63.9	230	100
9	62.4	800	120

Calibration and Validation

Calibration and validation of the model were performed for a time-step length of 1 day. Air-temperature and windspeed data used were collected at Leaburg Dam (14163100). Since the model was used in steady-state discharge mode, the discharge used was the mean discharge for each period modeled. Upstream discharge was calculated by subtracting discharges at South Fork McKenzie River (14159500) and Blue River (14162200) from the discharge at the McKenzie River near Vida (14162500). This method of calculation assumes that South Fork McKenzie and Blue River are the only major tributaries in the reach between Delta Park and the Geological Survey gage near Vida or that, when other tributaries contribute significant discharges, their water temperatures do not differ significantly from the water temperatures in the McKenzie River.

Discharges and temperatures from the South Fork McKenzie River (14159500), Blue River (14162200) and Gate Creek (14163000) were used as tributary inputs. Blue River and Gate Creek gages are located within 2 km of the confluence, and inflow values of discharge and water temperature would be very close to the actual confluence values. The South Fork McKenzie River gage, however, is located 6.3 km upstream from the confluence. Data values from this gage should be slightly less than actual confluence values, since temperatures and discharges would likely increase before the actual confluence is met. When water is released from Cougar Lake at much warmer than normal temperatures, temperature values used would likely be higher than confluence values. Magnitudes of the differences are not known, but the existence of differences should be kept in mind.

Initial model runs (fig. 6) generally underestimated temperatures, and improvement was deemed necessary. First, an assumption was made that the estimate of heat entering the parcel at the air/water interface was not properly evaluated. Next, the initial water temperature, dispersion, and tributary inflow heat contributions were assumed to be accurate. The following three explanations were considered for underestimating heat input (assuming heat loss was not overestimated): (1) the reach modeled (Delta Campground RKM 99.9 to Leaburg Dam RKM 62.4) has many riffles, and an effective top-width, rather than the actual field measured top-width, needs to be used; (2) air temperature underestimated equilibrium temperature in this case; or (3) some combination of the two above conditions occurred. For whatever the reason, the heat coming into a parcel was underestimated or the heat leaving was overestimated.

When investigating the effects of COE projects on the diel fluctuation of water temperature in the McKenzie River, Hansen (1986) introduced a heat-exchange parameter (HEP) to account for the additional surface area of a stream effectively available because of a multitude of riffles. If the convection term in equation 1 (the third term on the right side) is multiplied by a factor greater than 1, the amount of heat coming into the system (or leaving, depending on the sign of H) is increased. Since both H (the net air/water interface heat-exchange term) and W (the width) are in the numerator of the convection term, the two can be treated together instead of separately. Finally, a factor less than 1 can be used if the modeling indicated that temperatures were being overpredicted (modeled temperatures were greater than observed temperatures). Calibration is then reduced to determining the HEP value needed to provide the best match of modeled versus observed data.

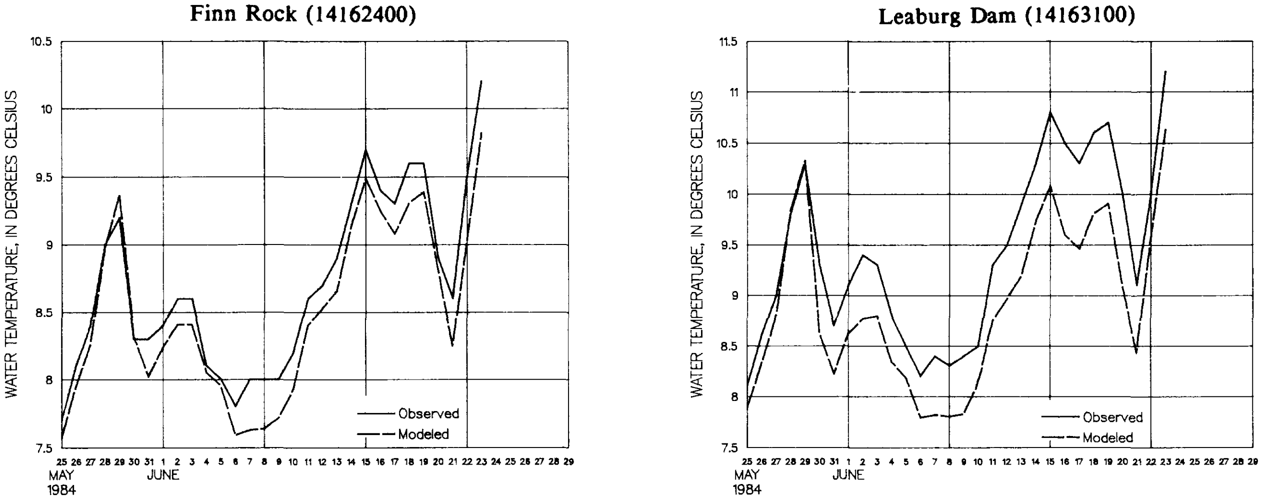

FIGURE 6.--Initial modeled water temperatures compared to observed water temperatures at selected sites on the McKenzie River.

The periods used for calibration were May 25 to June 23 and July 11 to September 30, 1984. The calibration was then verified by using the parameters determined and then modeling the 1983 periods (June 2 to July 8, August 8 to September 30, and October 1 to 31). These periods represent the occasions when data were available at all sites. Figures 7 and 8 show the calibration and validation data. The value of HEP used was 2.5 for June and 2.0 for July to October. The larger value seems to correspond with higher flows and thus with larger effective top-widths.

The modeled results at Finn Rock for the period October 1 to 31, 1983 were far below observed temperatures. A plausible explanation for this is that the recorded temperatures were probably modified by Blue River water entering the McKenzie River on the same side and 4.5 km upstream from Finn Rock recorder. COE project operations call for reservoir drafting during September and October to prepare for the flood-control season. Releases from Blue River averaged 3.60 m^3/s at 16.2 °C from October 1 to 15 and 13.5 m^3/s at 15.7 °C from October 16 to 31. These temperatures were about 5 °C higher than temperatures in the McKenzie River upstream of the confluence with Blue River. When a sufficient volume of water exists, these higher temperatures form a plume and impede complete mixing of waters by the time Finn Rock is reached. Recorded temperatures during the October period were of the Blue River plume and hence were not representative of the actual mean cross-sectional temperature. This condition resulted in abnormally large discrepancies between modeled results and observed results at Finn Rock during the October period.

Comparisons of modeled versus observed temperatures at RKM 76.8 (which is also on the right bank) for the period October 1 to 31, 1983, indicate that 15.0 km below the Blue River confluence, the river is well mixed and the assumption of a 1-dimensional model is again valid.

Before calibration, modeled results were consistently below observed data. After calibration, the relation between modeled results and observed data became more random. The calibration results indicate a better model fit and that, "on the average," there is no bias. Error can then be attributed more to random error than to model-process error.

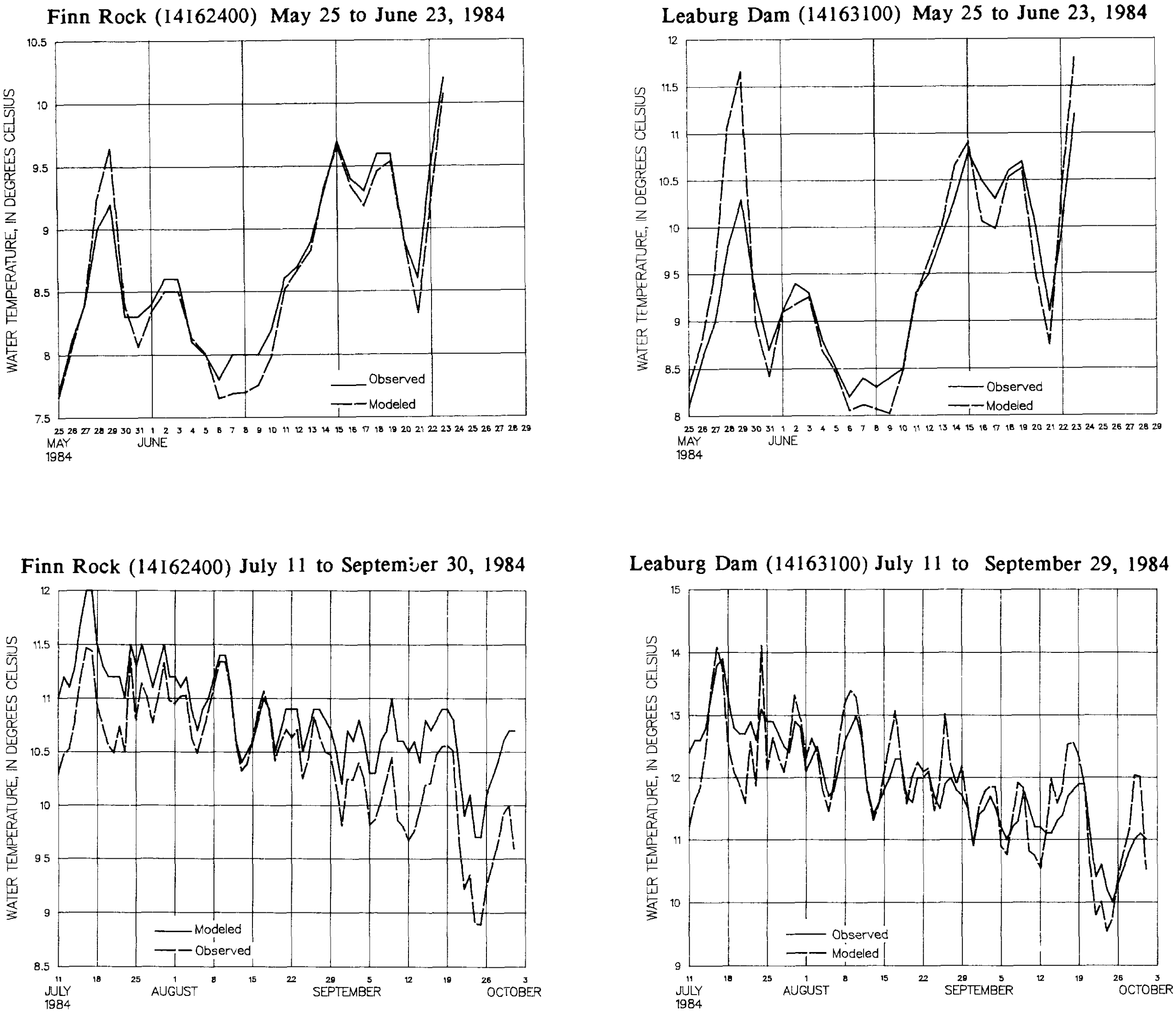

FIGURE 7.--Water-temperature model calibration results at selected sites on the McKenzie River.

Accuracy

Stream-temperature model accuracy is highly dependent on how well the equations used to estimate the energy exchanged between water and the surrounding media approximate the actual physical processes. But even the most complex mathematical expressions, representing every conceivable physical process, can yield misleading results if used with inaccurate data. Thus, accuracy of model results is a reflection of both process-modeling accuracy and input-data accuracy.

Accuracy of the model was measured using the mean absolute deviation of observed and simulated temperatures. The mean absolute deviation (MAD) is calculated by taking the absolute value of the difference between modeled temperatures and observed temperatures, totaling the absolute values, and dividing by the number of values compared.

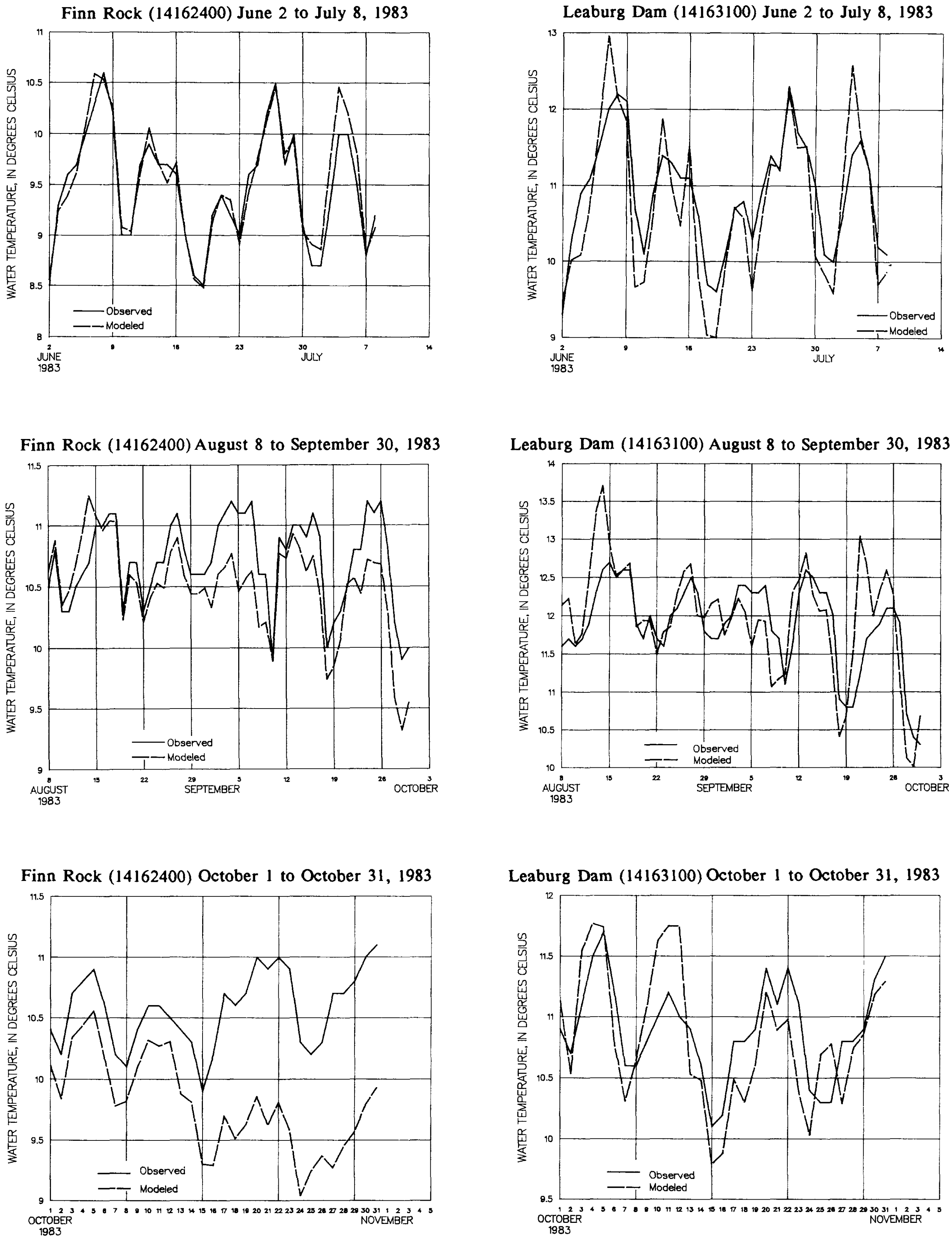

FIGURE 8.--Water-temperature model validation results at selected sites on the McKenzie River.

The MAD of observed and simulated temperatures for daily time steps was 0.27 °C at Finn Rock and 0.38 °C at Leaburg Dam. Finn Rock deviations do not include the period October 1 to 31, 1983, since recorded temperatures during that period were not representative of the cross-sectional mean (as previously mentioned). If this period were included, the MAD at Finn Rock would be 0.34 °C. This accuracy is considered quite good, since observed water temperatures published by the Geological Survey are considered accurate to within ± 0.5 °C.

Sensitivity

The model was analyzed for sensitivity by varying model inputs and comparing results, in order to evaluate which inputs cause the largest changes. It should be recognized, however, that this sensitivity analysis was done under a specific set of conditions; the results should be used as a measure of the relative sensitivity of the variables and not of the absolute values of variable sensitivity.

The period August 8 to September 30, 1983, selected for the 1-day time-step sensitivity analysis, is of sufficient length to overcome abnormal disturbances. This period also corresponds to the low-flow, warm-temperature extreme period, which is usually the most difficult to model and the period when sensitivity to the variables should be greatest (most heating, largest difference between air and water temperatures, least volume of water to be heated). The results of the sensitivity analysis are summarized in table 4.

Changes in air temperature had the greatest effect on downstream water temperature. A 5 °C change in daily mean air temperature produced a MAD water-temperature change of over 1.4 °C at Leaburg Dam. Air temperature is the model's principal measure of atmospheric heat input.

Table 4.--Summary of model-sensitivity analysis for selected variables for 1-day time steps at Leaburg Dam, August 8 to September 30, 1983

Variable	Change	Base value	Average resultant water temperature change °C	Percent
Air temperature	+5°C	Leaburg	+1.49	+12.4
	-5°C	daily mean	-1.42	-11.8
Windspeed	+2 m/s	Leaburg	+0.50	+4.2
	0 m/s	daily mean	-0.43	-3.6
Discharge	+50%	50.41 m^3/s	-0.78	-6.5
	-50%		+0.89	+7.4
Top-width	+50%	See	+0.64	+5.3
	-50%	table 3	-0.76	-6.3
Cross-section area	+50%	See	±0.07	±0.6
	-50%	table 3	±0.62	±5.2
Tributary inflow	double	S.F. =	±0.38	±3.2
	half	Blue =	±0.37	±3.1

Upstream discharge was the next most sensitive variable. Doubling or halving the discharge caused about 0.8 °C of water-temperature change at Leaburg Dam. Discharge gives the volume of water per unit time that must be heated or cooled. The larger the volume, the smaller the temperature increase for a given heat input and duration.

Stream top-width proved to be the third most sensitive variable. Increasing or decreasing the top-width by 50 percent causes a corresponding increase or decrease of about 0.7 °C at Leaburg Dam. Top-width is used in the model to determine surface area available for heat transfer.

The fourth most sensitive variable was windspeed. Increasing daily mean windspeed by 2 m/s or neglecting altogether (set = 0) changes water temperatures at Leaburg Dam by about 0.5 °C. Windspeed affects the rate of heat gain or loss due to conduction or evaporation. In Jobson's model, it is used in calculating the surface-exchange coefficient, K.

Doubling or halving South Fork McKenzie and Blue River tributary inflow changed temperatures at Leaburg Dam by about 0.4 °C. Both doubling and halving the discharge caused increases and decreases in the water temperature. These results occurred because during the period inflow-water temperatures were first warmer and then cooler than outflow temperatures. Doubling inflow of cooler or halving inflow of warmer stream temperatures caused a decrease in water temperatures downstream. Conversely, doubling inflow of warmer or halving inflow of cooler stream temperatures caused an increase in water temperature downstream.

Increasing cross-sectional area by 50 percent had very little effect (±0.07 °C MAD) on water temperatures at Leaburg Dam. Decreasing the cross-sectional area by 50 percent caused both increases and decreases in the downstream water temperature. The MAD was ± 0.62 °C. Increases in water temperature occurred during the first 19 days, when air (equilibrium) temperatures were largest and tributary inflow was colder than McKenzie River water temperatures. Decreases in water temperature occurred during the latter 35 days, when the conditions were converse.

Cross-sectional area determines the velocity, and hence the travel time, at a given discharge. It also determines the depth, since the top-width is kept constant and rectangular cross sections are assumed. The third term on the right side of equation 1 shows how changing the cross-sectional area affects water temperatures when the other variables are held constant.

ANALYSIS

The model has now been shown to be able, on the average, to replicate water temperatures of the study reach of the McKenzie River to within 0.4 °C. By altering input variables to the model, simulations of other conditions can be investigated and their departure from present conditions can be analyzed. Simulations of the water-temperature regime with and without COE projects were compared to determine their temperature effects on the McKenzie River. Simulations without the projects were made first for periods in 1983 and 1984, using data from both the long-term and the supplementary collection sites within the basin, and the results were compared to simulations with the projects in place.

Next, historic simulations for 1977, 1979, 1982, 1983, and 1984, using data collected only at the permanent stations, were made for those periods when data were present at all inflow and outflow sites. Finally, with- and without-project "average conditions" simulations were made, using mean daily values for the model inputs.

1983-84 With- and Without-project Simulations

The calibrated model was used to simulate the temperature regime in the McKenzie River if Cougar and Blue Lakes were removed. This simulation was done by using the inflow temperatures and discharges to the reservoirs, instead of the project outflow temperatures and discharges, as tributary inputs to the model. This approach does not take into account changes in flow or temperature for the reach from the stations above the reservoir to the stations below the projects. These reaches measure 10.5 km on the South Fork McKenzie River and 12.2 km on Blue River. The results represent minimum effects, since both tributary temperatures and flows would likely increase before the confluence with the McKenzie River was reached. Figure 9 shows with- versus without-project scenarios for those periods when adequate inflow data were available.

During the period May 25 to June 23, 1984, there was almost no difference between with- and without-project simulations (figs. 9a and 9b). The MAD was 0.17 °C at Finn Rock and 0.09 °C at Leaburg Dam. Both values are well within model accuracy. Since the MAD was below model accuracy, the conclusion was that there were no effects from COE projects on downstream temperatures during this period.

During the period June 2 to July 8, 1983, COE projects had a cooling effect on the McKenzie River (see figs. 9c and 9d). The MAD at Finn Rock was 0.51 °C; temperatures without COE projects were always warmer than with the projects. The MAD at Leaburg Dam was 0.73 °C. Again, temperatures without the projects were always warmer than those with the projects. Since the MADs at Finn Rock and Leaburg Dam both exceeded the model accuracy, COE projects were concluded to have a cooling effect on water temperatures of the McKenzie River during this period. This conclusion does not agree with the results for a similar period, given previously. The reason similar periods from different years show conflicting results is that the reservoir-inflow temperatures in 1983 were 3.6 to 4.3 °C warmer than the outflow temperatures, while in 1984 the reservoir-inflow temperatures were only 1.1 to 1.4 °C warmer. Reservoir-inflow discharge almost equaled outflow discharge in both years.

During the period July 11 to September 30, 1984, COE projects had both a warming and a cooling effect on the McKenzie River (figs. 9e and 9f). The projects had a cooling effect in the first part of the period and a warming effect in the last part. Cross-over from cooling to warming occurred in the beginning of September. The MAD at Finn Rock for the entire period was 0.72 °C and was 1.10 °C at Leaburg Dam. There was a cooling effect at Finn Rock on 61 of the 82 days of the period. The MAD for cooling alone was 0.78 °C. The MAD for the remaining 21 days when warming occurred was 0.56 °C. At Leaburg Dam, cooling occurred on 66 days and the MAD was 1.22 °C. Warming occurred on 16 days and the MAD was 0.61 °C.

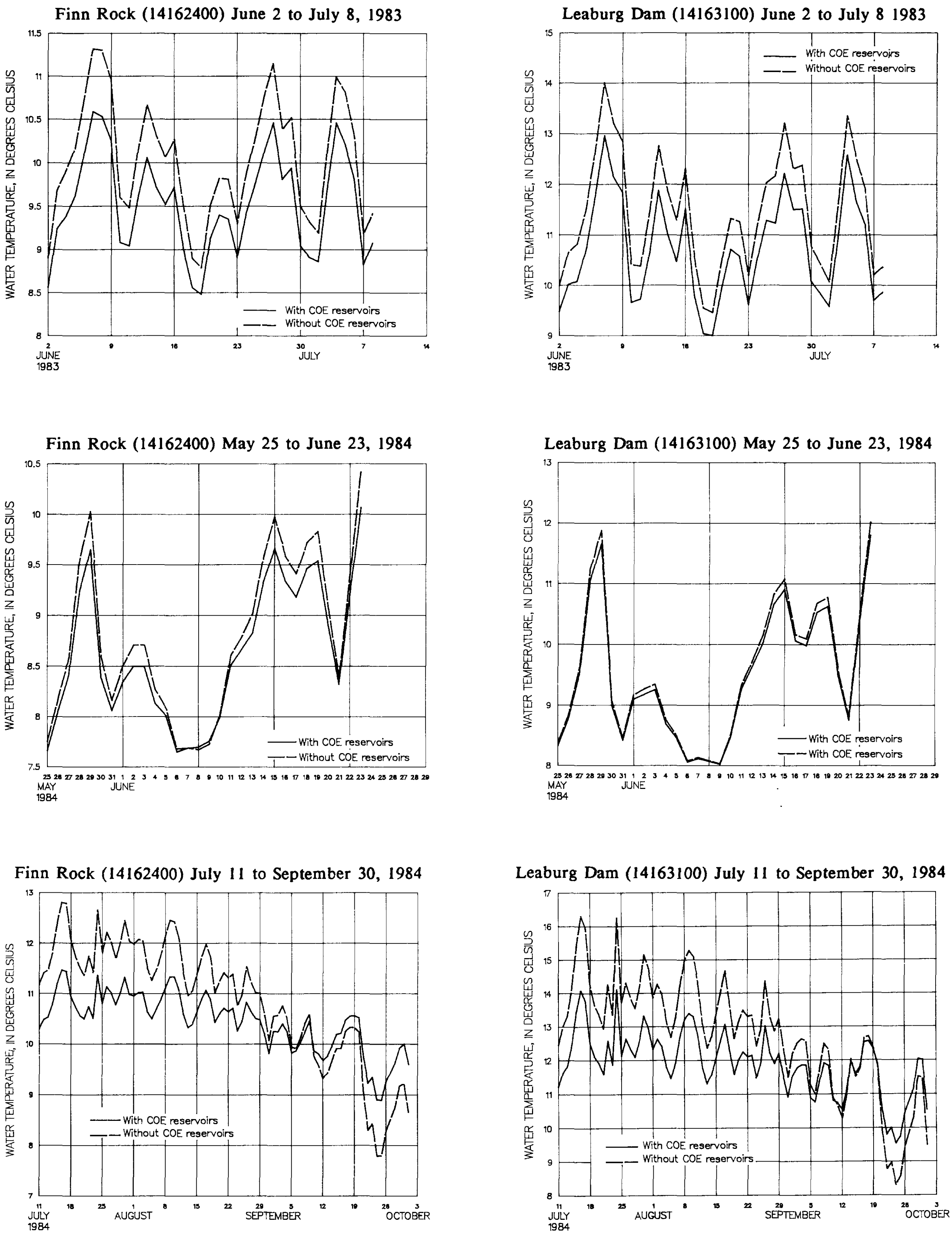

FIGURE 9.--Water-temperature simulations with, and without, U.S. Army Corps of Engineers reservoirs at selected sites on the McKenzie River.

The cooling and warming effects can be attributed to two phenomena. First, the inflow temperatures are warmer and cooler, respectively, than the outflow temperatures. Second, and probably more important, is the volume of water released at the lower or higher temperatures. Due to low-flow augmentation, the mean daily release from both reservoirs totaled 29.2 m^3/s, while the average total inflow to both reservoirs totaled 9.4 m^3/s. Thus, any deviation in the release temperature from the inflow temperature was compounded by a three-fold increase in volume at that temperature.

Historical With- and Without-project Simulations

Analyses to this point have been made with the aid of data collected at sites specifically set up for this study. The additional data gave only a very short record to work with and covered a limited range of hydrologic and meteorologic conditions. To extend the analyses to a wider range of conditions required the exclusive use of data from the permanent (long term) stations within the basin. Using only the permanent station data presented a problem, because no atmospheric data were available within the basin. In addition, water-temperature data on the McKenzie River were sparse, and recorders were less than ideally located. Fortunately, there are adequate water-temperature and discharge data for the South Fork McKenzie and Blue Rivers.

The shortage of water-temperature data on the McKenzie River and lack of atmospheric data from within the basin for input hinders efforts to extend the analyses to the historical data. Additional analyses were made using meteorological data from Eugene as atmospheric input and water temperatures for the McKenzie River at McKenzie Bridge (RKM 112.5, 14159000) as the upstream water-temperature value.

A direct comparison with the more complete data-collection network was made to determine accuracy loss due to less representative conditions (table 5). The model was not recalibrated for use with the historic data. Using data from permanent stations decreases accuracy at each site and the decrease in accuracy escalates with distance downstream.

To make historical simulations with a steady-state model requires dividing each data set into periods when the steady-state assumption is valid. Another approach is to convert to unsteady-discharge mode, in which periods of any length can be simulated. The latter option was chosen.

Jobson's model can be converted to unsteady flow by the addition of only a few extra lines of code in the program (Jobson, 1980a). However, a hydraulic model or subroutine must be used to provide hydraulic data (velocity, cross-sectional area, top-width, and tributary inflow) at each grid point for each time step. To simplify the procedure, the assumption was made that only velocity changes with discharge at a grid point. This assumption is valid because there is little change in top-width for changes in discharge (stage) at many locations on the McKenzie River reach under consideration. Initial inputs of top-width and cross-sectional area were kept constant and only a new velocity was computed for each time step. A data file containing upstream and tributary inflow discharges for each time step was also required.

Table 5.--Comparison of mean obsolute deviation (MAD) model results using additional data collected within the basin versus only permanent station data

[Lea Met = Leaburg meteorological data (air temperature and windspeed), Eug Met = Eugene meteorological data, MAD is in degrees celsius]

	Number	Leaburg Dam				Near Vida				Finn Rock			
	of	Lea Met		Eug Met		Lea Met		Eug Met		Lea Met		Eug Met	
Period	days	mean	MAD	mean	MAD	mean	MAD	mean	MAD	mean	MAD	mean	MAD
6/2 - 7/08/83	37	-0.18	0.40	+0.19	0.85	-0.35	0.37	-0.12	0.63	+0.04	0.12	-0.23	0.50
8/8 - 9/30/83	54	+0.10	0.39	+0.75	0.89	+0.05	0.25	+0.57	0.62	-0.21	0.27	+0.27	0.32
10/1 - 10/31/83	31	-0.06	0.32	-0.51	0.55	-0.03	0.27	-0.36	0.46	-0.77	0.77	-0.87	0.87
5/25 - 6/23/84	30	+0.05	0.31	-0.06	0.43	-0.05	0.15	-0.30	0.38	-0.08	0.13	-0.45	0.45
7/11 - 9/30/84	82	+0.01	0.41	+1.19	1.25	-0.24	0.31	+0.51	0.63	-0.39	0.40	-0.19	0.35
All	234	0.00	0.38	+0.54	0.91	-0.14	0.28	+0.21	0.57	-0.29	0.34	-0.21	0.45

A comparison between steady and unsteady model runs for 1983 and 1984, using the additional basin data, showed no major change in accuracy (<0.10 °C MAD). Thus, the assumption of steady state in these periods was valid. Since the required data were available at all permanent stations, the necessary program changes were made and unsteady discharge mode was used for the historic simulations.

Graphs showing the comparison between historic with- and without-project conditions near Vida (RKM 76.8) are shown in figure 10. This site was chosen for the comparison because the tradeoff between model accuracy and distance downstream of the projects appeared most equitable at this location. A cross-hatched region between +0.5 and -0.5 °C denotes the range in which effects, if any, are less than model accuracy. A cooling effect occurs when the difference between with- and without-project conditions is less than -0.5 °C (absolute value of negative differences is greater than 0.5 °C). A warming effect occurs when the difference is greater than 0.5 °C. Comparisons were made for calendar years 1977, 1979, 1982, 1983, and 1984. These years were chosen for various reasons: 1977 was a drought year; 1979 was a warm year; 1982 had a cold spring; 1983 had a cool, wet summer; and 1984 had a wet spring and then a dry summer. In addition, an "average" year was simulated by using mean daily temperatures and flows at permanent stations for the period of record. Simulations were confined to those periods when data were available simultaneously at the upstream station (14159000) and at inflow and outflow stations for both reservoirs. Periods for selected years when COE projects had cooling effects, warming effects, or no effect are shown in line-chart form in figure 11. Gaps in lines indicate insufficient data for analysis.

Although each year is unique, the results of the average year show what can be generally expected. COE projects have little or no effect on stream temperatures of the McKenzie River, from the beginning of the calendar year to the end of May. Projects have a cooling effect (less than -0.5 °C) from the beginning of June to the first part of September. There is a short transition period of about 2 weeks as the project effect goes from cooling to warming. The warming effect (greater than +0.5 °C) lasts from the middle of September to about the end of November.

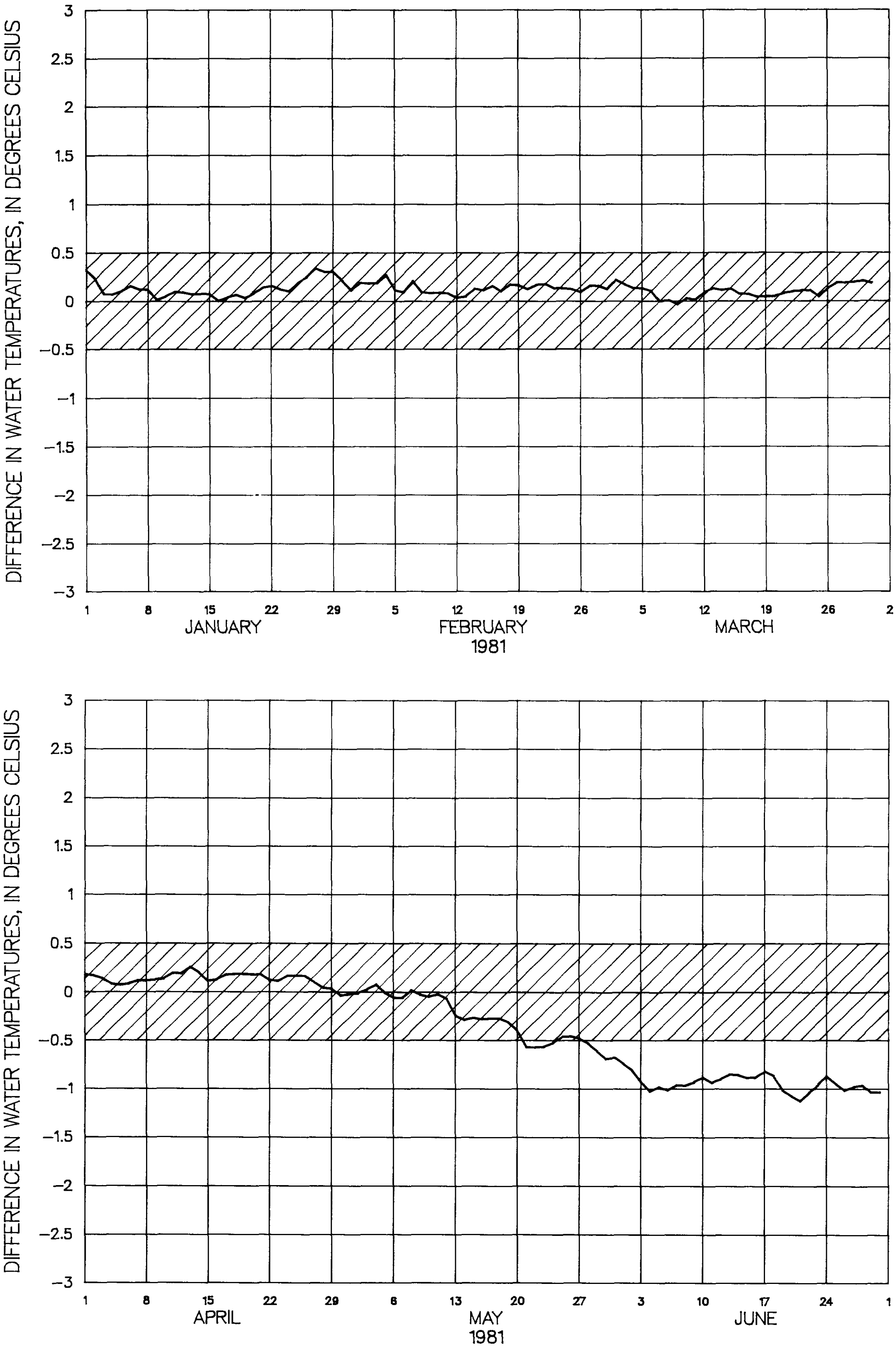

FIGURE 10.--Difference between simulated water temperatures with, and without, U.S. Army Corps of Engineers projects for the "average" year at selected sites on the McKenzie River.

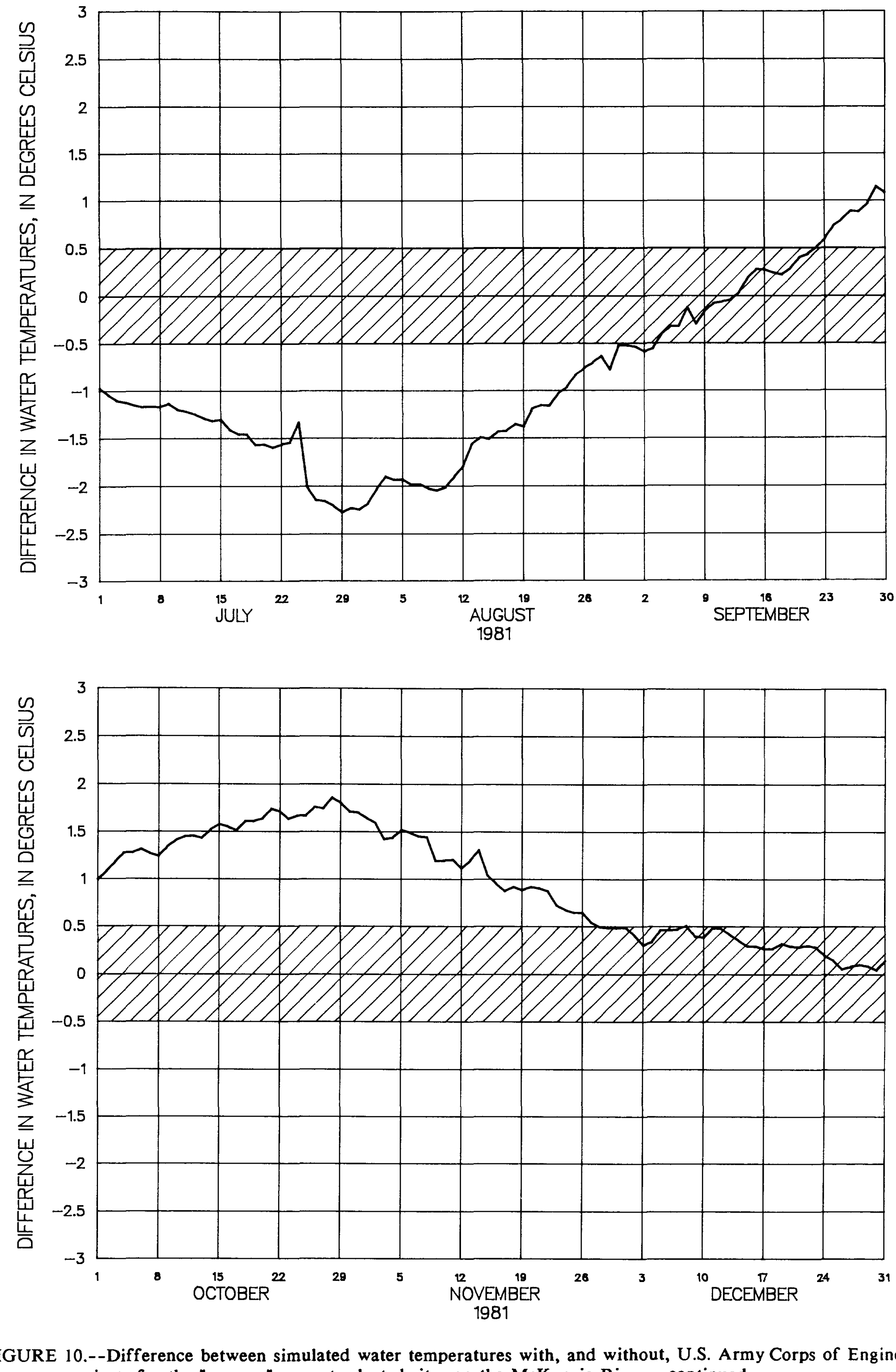

FIGURE 10.--Difference between simulated water temperatures with, and without, U.S. Army Corps of Engineers projects for the "average" year at selected sites on the McKenzie River--continued.

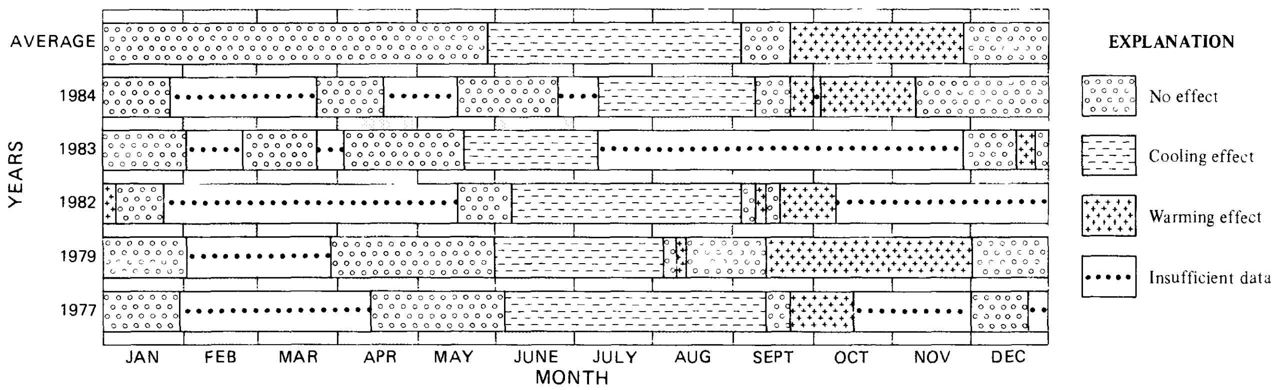

FIGURE 11.--Effects of Corps of Engineers projects on the McKenzie River near Vida (RKM 76.8) from model simulation results for selected years and the "average" year.

Not surprisingly, temperature effects correspond to project operations. There are minimal to no temperature effects during the flood-control and filling seasons. During flood control the reservoirs are, for the most part, flow-through (inflow discharge equals outflow discharge, except during storms), and inflow temperatures are close to outflow temperatures. Inflow and outflow temperatures also are about the same during reservoir filling. The projects have a cooling effect during conservation holding, because the water released is colder than that flowing into the reservoirs. Augmentation of low flows with stored waters also results in a cooling effect, since, in addition to being cooler, releases are of greater volume than inflow. By the middle of September, however, reservoirs have been lowered enough so that the remaining stored water is as warm or warmer than water flowing into the reservoirs. Release flows are still in excess of inflows as reservoirs are lowered in preparation for winter floods.

COE project effects for the historic simulations for the McKenzie River near Vida (RKM 76.8) are summarized in table 6. This table shows the number of days in each year in which COE projects had a warming or cooling effect and what the average effect was. Because warming or cooling effects must be greater than +0.5 or less than -0.5 °C respectively, the average is necessarily larger (or smaller) than these values. Since complete data for the entire year were not available for any of the 5 historic years, comparisons between years are meaningless.

Table 6.--Summary Corps of Engineers project effects for selected years for the McKenzie River near Vida (RKM 76.8)

Year	Cooler (less than -0.5 °C)		Warmer (greater than 0.5 °C)	
	Number days	Average temperature °C	Number days	Average temperature °C
Average year	103	-1.22	68	1.24
1977	99	-1.78	35	0.95
1979	71	-1.02	85	1.28
1982	96	-1.01	32	1.02
1983	51	-0.87	13	0.92
1984	65	-1.06	53	1.42

Analyses to this point have been made of with- or without-project simulation for the combined effects of both projects. Analysis of each reservoir individually determines which reservoir has the greater effect. Toward this end, simulations of outflow (discharge and temperature) from one reservoir and inflows to the other reservoir were made to simulate the effects of each reservoir individually. (If record had been available at an upstream location for the period when Cougar Dam was completed and before Blue River Dam was completed, part of these simulations would not have been necessary.) The simulations were made for the "average year," since a complete data set was available. The effects of both reservoirs and of each reservoir individually are summarized in table 7. In addition, the number of days with a cooling effect or a warming effect was calculated for each simulation.

Table 7 shows that, for the "average" year, Cougar Lake alone would cause the water temperature of the McKenzie River to be colder for more than twice as many days as would Blue River Lake alone. The average change downstream from Cougar (near Vida) is less because inflow temperatures to Cougar Lake are colder than inflows to Blue River Lake, and, although Cougar Lake is deeper, the difference between inflow and outflow temperatures at Blue River Lake is greater. In addition, water is released from Blue River Lake earlier than from Cougar Lake and at a time when the difference between inflow and outflow temperatures is near its largest. On the other hand each project causes the water temperature near Vida to be warmer for almost the same number of days, with Cougar Lake having a slightly greater average effect than Blue River Lake. It bears repeating that these simulations are for an "average" year and any particular year can show different results.

Table 7.--Summary data for simulations to determine effects of both reservoirs, and for each reservoir individually

[A = 1/1 to 3/31, B = 4/1 to 6/30, C = 7/1 to 9/30, D = 10/1 to 12/31]

Number days		Both MAD °C	Both Max °C	Both Min °C	Cougar only MAD °C	Cougar only Max °C	Cougar only Min °C	Blue only MAD °C	Blue only Max °C	Blue only Min °C
90	A	0.12	0.34	-0.04	0.08	0.26	-0.02	0.06	0.23	-0.06
91	B	0.46	0.26	-1.13	0.29	0.17	-0.74	0.40	0.09	-2.04
92	C	1.13	1.15	-2.28	0.71	0.56	-1.12	0.73	0.76	-1.66
92	D	0.95	1.86	0.04	0.70	1.35	0.09	0.35	0.82	-0.06

Both Cooler no. days	Both Cooler avg. °C	Both Warmer no. days	Both Warmer avg. °C	Cougar Cooler no. days	Cougar Cooler avg. °C	Cougar Warmer no. days	Cougar Warmer avg. °C	Blue Cooler no. days	Blue Cooler avg. °C	Blue Warmer no. days	Blue Warmer avg. °C
103	-1.22	68	1.24	101	-0.76	57	0.97	46	-1.02	58	0.63

SUMMARY AND CONCLUSIONS

A one-dimensional unsteady temperature model based on the equilibrium temperature approach has been used to evaluate the temperature effects of two COE multipurpose water projects on the McKenzie River. Both projects are on tributaries to the McKenzie River and are used primarily for flood control.

Introduction of an effective top-width parameter (ETW) enabled calibration to be reduced to manipulating one parameter rather than several. ETW allows more (value >1) or less (value <1) heat to be added to the system. ETW was introduced to account for the "effective" top width of the reach modeled. Air-water interface heat exchange increases due to turbulence caused by riffles in much of the reach modeled.

Atmospheric data collected within the basin yield a more accurate model than meteorological data from a site outside the basin. However, the length of the record severely limits the hydrologic and meteorologic conditions available for simulation. The use of data from outside the basin was necessary to extend analysis to more varied conditions.

The following are the responses to the specific questions the study intended to answer.

(1) Using atmospheric data collected within the basin and water temperatures collected approximately every 10 km, the water-temperature model can predict daily mean temperatures to within 0.4 °C at Leaburg Dam, 37.5 km downstream of the initial site.

(2) Using atmospheric data collected at a station just outside the basin, water-temperature data collected at permanent stations (only two for over 48 km of river modeled), and no recalibration, accuracy decreased to over 0.9 °C at Leaburg Dam.

(3) Results from an "average" year simulation show that the combined projects have a cooling effect (defined as post-project temperatures minus pre-project temperatures at this location less than -0.5 °C) from the beginning of June to the first part of September near Vida (RKM 76.8). Warming effects (as above but greater than 0.5 °C) occur from about the middle of September to the end of November. Projects have no effect (between ± 0.5 °C) during the remaining times of the year.

(4) Selective withdrawal could be used to modify the severity of reservoir effects downstream by releasing warmer water when reservoirs have a cooling effect and cooler water when reservoirs have a warming effect. The quantities and temperatures of water available in the reservoirs for release at specific times are beyond the scope of this study.

Project effects are the result of project operations. Flood-control operations have little or no effect on the McKenzie River. Once reservoirs have filled and inflow temperatures exceed outflow temperatures (both projects have only bottom-withdrawal capabilities), reservoirs have a cooling effect. Low-flow augmentation has a cooling effect because outflow temperatures are less than inflow temperatures, and outflow volumes exceed inflow volumes. Evacuation of reservoir water to prepare for flood control has a warming effect when heat stored in the reservoir from the summer is released (inflow water temperatures and volumes are less than outflow water temperatures and volumes).

Evaluation of COE project effects below Leaburg Dam requires the use of a more sophisticated routing mechanism than that contained in the model used. A model with branched routing capabilities is needed to track flow through the McKenzie River and diversion/return power generation canals simultaneously.

REFERENCES CITED

Edinger, J. E., and Geyer, J. C., 1965, Heat exchange in the environment: EEI Publication No. 65-902, Edison Electric Institute, New York, 259 p.

Hansen. R. P., 1986, Analysis and prediction of the water temperature of the McKenzie River, Oregon, using the equilibrium temperature approach: Master's Thesis, Portland State University, 96 p.

Harris, D. D., 1968, Travel rates of water for selected streams in the Willamette River basin, Oregon: U.S. Geological Survey Hydrologic Investigation Atlas, HA-273, 2 sheets.

Jobson, H. E., 1980a, Temperature and solute-transport simulation in streamflow using a Lagrangian reference frame: U.S. Geological Survey Water-Resources Investigations Report 81-2, 165 p.

_____1980b, Thermal modeling of flow in the San Diego Aqueduct, California, and its relation to evaporation: U.S. Geological Survey Professional Paper 1122, 24 p.

Jobson, H. E., and Keefer, T. N., 1979, Modeling highly transient flow, mass, and heat transport in the Chattahoochee River near Atlanta, Georgia: U.S. Geological Survey Professional Paper 1136, 41 p.

Laenen, A., and Hansen, R. P., 1985, Preliminary study of the water-temperature regime of the North Santiam River downstream from Detroit and Big Cliff Dams, Oregon: U.S. Geological Survey Water-Resources Investigations Report 84-4105, 45 p.

State Water Resources Board, 1961, Upper Willamette River Basin: Oregon State Water Resources Board Publication, 186 p.