Refine Modeling Tools to Forecast Effects of Dam Operations on Reservoir Food Webs

Annual Progress Report

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BACKGROUND

Our work at Blue Mesa has focused on the hypothesis that new dam operations (high spring releases to create a more natural hydrograph) could affect reservoir food webs by altering stratification and thermal regimes, with consequent changes in trophic interactions. We predict that impacts of new operations would be greatest in a warm, dry year. Stratification could be more intense when reservoir content is low. Stronger stratification allows more heat to be concentrated in the epilimnion. The epilimnion is also where the vast majority of the production supporting the food web occurs. Warmer surface waters from stronger stratification could have positive or negative effects on the major players in the food web because the epilimnion can be either a thermal refuge or barrier depending on the physiological characteristics of the organisms of interest.

APPROACH

We have been using CE-THERM (Figure 1) to look at operations and climate effects on the thermal regime. Calibrations and predictions matched 1994 and 1996 profiles extremely well (Figure 2), however, we have some concerns about some components of the model's heat budget. This tool can predict thermal effects of high spring releases in a warm, dry year, or stratification under other climatic conditions or dam operation regimes.

Our next step is to predict thermal impacts on Blue Mesa's top sport fish, kokanee. Until recently, Blue Mesa was actually one of the top kokanee fisheries in world (based on egg supply, growth rate, density, harvest). Predicting their responses to thermal alterations is complicated because kokanee can cope with warm surface temperatures by migrating vertically in the water column. (Figure 3). However, we have been developing a model that simulates kokanee response to changes in the thermal regime (Stockwell and Johnson 1997). The model appears to capture thermal influences on seasonal and age-specific growth and behavior of kokanee (Figure 4; Stockwell and Johnson, in review). This model is easily adapted to other fish species that use daily vertical migrations to cope with stratification of water temperature and food resources.

OVERALL PROJECT GOAL

The overall goal of this research is to improve the reliability of our modeling forecasts about the effects of new operations at Blue Mesa, and to improve the utility of our modeling approach for other western reservoirs.

PROGRESS

Objective 1:
Develop better capabilities to predict thermal effects of operations and climate by making refinements to CE-THERM's heat budget for application of the model in dry, high-elevation regions. Although preliminary calibrations were reasonable, some model parameters had to be set to extreme values to get the fit to the data that we obtained. Good predictions of temperature are critical, as our hypotheses about ecological effects of reservoir operations are based on thermal habitat.

Strategy
Hire Civil Engineering graduate student to modify components of CE-THERM heat budget for use in western reservoirs and re-calibrate with new BMR data.

CSU Civil Engineering student Mary Andre (M.S.) has begun work evaluating water quality parameters, air/stream temperatures, insolation, and evaporation inputs and components of CE-THERM.

Overview of Objective 1
During initial calibration efforts of the CE-THERM model for Blue Mesa Reservoir applications, it was necessary to use a few parameters that were outside of recommended ranges in order to obtain the closest fit of actual temperature profiles to model-predicted profiles (Johnson et al. 1997). The air turbidity factor was increased outside the recommended range to reduce the heat entering the reservoir. The wind speeds for the reservoir were obtained by multiplying Gunnison Airport wind speed records by a factor of 2x. (This was justified by observations of greater wind speeds at the reservoir than at the airport and increased wind speeds allowed the model to distribute surface heat deeper into the reservoir.) While such adjustments resulted in temperature profiles that closely matched measured profiles, calibration refinement is needed to be confident with model predictions under alternate scenarios. This requires a detailed understanding of the underlying equations and computer code for how CE-THERM is modeling each physical process and further research into available climatic data. Particularly, study is focused on equations, subroutines and data relating to insolation, evaporation, and mixing.

Work Plan for Objective 1

1) Determine if CE THERM is modeling insolation and evaporation correctly for Blue Mesa.

2) Adjust calibration parameters to obtain best possible fit for actual measured temperature profiles while ensuring that each is within recommended range and justifiable with available data.

3) If necessary, modify Fortran code to adjust model for application in dry, high altitude, western regions.

4) Document the methodology and data sources used to obtain all input data and calibration parameters.

Progress on Objective 1

In one month, since beginning this project, steps have been taken to learn CE THERM, review the available data and notes, and determine areas to focus on that could be contributing to error in modeling actual conditions. In addition, the following related tasks have been accomplished:

- The most recent version of CE-THERM was obtained from U.S. Army Corps of Engineers, Waterways Experiment Station. Preliminary research was initiated into the basis of equations modeling the processes of radiation and evaporation.

- A meeting with the Assistant State Climatologist provided additional information regarding available data for radiation and evaporation.

- Conversions were determined for several systems of light energy units that are commonly used by limnologists, meteorologists and engineers.

- The operating manuals for LI-COR light meters and data logger were studied to learn how to operate these instruments. On July 30, 1998, the light meters and data logger were used for the first time at BMR to obtain solar radiation profiles in two locations.

- Gunnison climatic data for May - September, 1997 can be obtained from the Western Regional Climate Center in Reno, Nevada for a fee of $75. Alternate means of obtaining the data are being pursued through the National Climatic Data Center. In addition, climatic data for the same period was requested for Curecanti National Recreation Area from the National Park Service.

CE THERM

CE THERM is a one-dimensional (vertical) model for reservoir water quality developed by the US Army Corps of Engineers Waterways Experiment Station for southeastern reservoir applications. It is primarily used to model thermal stratification of reservoirs. The most recent version was released in 1995. Input data include reservoir morphometry, inflows, outflows, meteorologic data (air temperature, wind speed, etc.), and various modeling parameters.

Calibration

Calibration is achieved through comparison of predicted and measured profiles. Particularly, it is important to match the timing of on-set of stratification/thermocline depth, gradient in metalimnion, hypolimnetic temps, and time and temperature of fall overturn. Temperature profiles are primarily used in calibration; however, TDS data can be used to help calibrate mixing and light profiles can be used to help calibrate insolation, radiation, and light.

Issues Requiring Further Analysis and Planned Strategies

In order to fully accomplish the above objectives, the following issues require analysis:

- Conduct water balance and energy balance, focusing on accuracy of evaporation and evaporative cooling predictions.
- Validate stream temperature to air temperature regression correlation with field temperatures collected in 1997
- Verify that CE THERM is using altitude corrections for saturated vapor pressure in both heat and water budgets and if necessary, modify Fortran code to include corrections.
- Research the applicability and additional information required to model BMR using TVA's 2D model instead of CE THERM.
- Check total evaporation predicted by model against pan evaporation estimated for area. {Preliminary examination indicates that the model is only slightly under-predicting evaporation with 6 cm difference from average total of 59 cm for 5 months.}
- Research more accurate ways to model effects of cloud cover and topographic shading.
- Use measured solar radiation values and profiles at BMR in further refine associated calibration parameters in the model.
- Compare wind records obtained by the Gunnison Airport to those obtained by Curecanti National Recreation Area in order to determine the appropriate ratio for modeling purposes. (Is factor of x2 wind speed justifiable?)
- Compare surface area to volume relationship used in the model to the relationship calculated by the Bureau of Reclamation for BMR.
- Check for available TSS data for BMR and evaluate the need to account for inorganic matter, phytoplankton, zooplankton, suspended detritus, using INIT2 an SSOL record or increase EXCO to handle additional attenuation.
- Ask operators of BMR dam whether the nonpower releases are discharged through the diversion tunnel, spillway tunnel, or outlet works?

Objective 2

Conduct laboratory experiments and modeling analyses to more accurately predict kokanee feeding rate as a function of zooplankton density, temperature and light intensity. Knowledge of kokanee feeding rate would greatly reduce the model's range of predicted feeding durations and migration strategies that kokanee could employ to optimize growth.

Strategy: Hire a Fishery and Wildlife M.S. student to conduct laboratory experiments on kokanee feeding rate to refine a key foraging model component.

Marci Koski, B.S. Westchester University, was one of the top students to apply to the CSU Graduate Degree Program in Ecology this spring. She began working on an MS degree on the project on July 29, 1998 with a sampling trip to Blue Mesa Reservoir. On that trip we also visited the CDOW's Roaring Judy State Fish Hatchery in Almont. They are holding about 3,000 75 mm kokanee for us to do feeding experiments. If disease clearance can be obtained the fish will be moved to CSU for the experiments. If disease issues prevent us from using the Roaring Judy fish we plan to obtain clean kokanee eggs from Lake Granby this fall. The eggs will be hatched and the fish reared in the CSU Aquatic Research Facility. Marci is currently evaluating the sensitivity of the exisiting functional response in the Stockwell and Johnson (1997) kokanee foraging model, in preparation for feeding trials.

Other Activities

1998 Limnological Sampling:

The only field monitoring at BMR during 1998 was conducted on July 29-30. The results for physicochemical limnology monitoring are displayed in Figures 1 to 5.

Temperature

The temperature profiles within all three basins show strong thermal stratification with a sharp thermocline at 7 to 10 m for July 30, 1998 (Figure 5). The shape of the temperature profiles is similar to those observed for the same period in 1996; however, the epilimnetic temperatures are generally warmer. The surface temperatures varied between the three basins with 19.7°C for Sapinero, 21°C for Cebolla, and 23.3°C for Iola. This pattern of cooler temperatures in Sapinero and warmer temperatures in Iola relative to temperatures in Cebolla is in agreement with data from previous years (Johnson et al. 1997). The hypolimnetic temperatures for Sapinero and Cebolla are closely matched (within +/- 1°C) and decline steadily to ~ 6°C at 50 m depth.

Dissolved Oxygen

The dissolved oxygen (DO) levels were generally high (> 6 mg/l) in the 0-10 stratum in all three basins (Figure 6). The DO levels for Iola steadily declined from 5.7 mg/l at 10 m depth to 2.8 mg/l at the bottom (~ 21 m). The DO levels for Sapinero were consistently high within the range of 6 - 8 mg/l. The Cebolla DO levels fluctuated between 4 and 7 mg/l with a metalimnetic minima of 5.1 mg/l and a hypolimnetic minima of 4.0 mg/l at a depth of 35 m.

Secchi Depth

The water transparency of Iola and Cebolla is greater than in previous years with secchi depths greater than 8 m (Figure 7). The water transparency of Sapinero was lower, but within the range observed from 1993 to 1997.

Solar Radiation

Incident light is a function of the solar altitude (determined by time of day, time of year, elevation, longitude, and latitude), cloud cover, and air quality. Observations at Blue Mesa reinforced that the incident light is also dependent on whether the sun is behind the clouds at the moment readings are taken. At Sapinero, two readings were made with the same cloud cover (~ 40%); at 10:20 am the incident light was 1,888 W/m^2 and only 2 minutes later when the sun was behind the clouds, the incident light had decreased to 1,400 W/m^2. The cloud cover conditions and subsequently incident light levels can change quickly. Later in the day at Iola, the incident solar radiation measured consistently above 2,100 W/m^2 with ~ 60% cover from 1:00 to 1:30 pm. However by 2:00 pm, the sky was 90% overcast and the incident solar radiation had reduced to 520 W/m^2.

Light profiles were measured at two locations (standard limnology stations at Sapinero and Iola). Two LI-COR light sensors were used simultaneously to measure incident light at the surface and light penetrating the reservoir at one m depth increments. Both light sensors measured light in the 400 to 700 nm spectrum (visible light). The data logger unit was set to update its display with the 15-second running average every second for both sensors.

The solar radiation profile for Sapinero was measured between 08:00 and 08:30 with ~ 50% cloud cover, and the Iola profile was measured between 13:00 and 13:30 with ~60% cloud cover. The curvature of the light profiles displays the exponential decline of light with increasing depth (Figure 8). With the greater secchi depth and monitoring closer to solar noon, it makes sense that the solar radiation penetration at each depth is greater for Iola than Sapinero. Figure 9 displays percentage of incident light penetrating to each depth for both basins and the CE-THERM model prediction. Note that the profiles plotted on a log scale and approximate a straight line, confirming an negative exponential relationship of light vs. depth. The light calibration parameters used to create the model prediction are based on determined by the average seasonal secchi depth for all three basins. Figure 9 also highlights the depth corresponding to 1% incident solar radiation, a level which is significant for chlorophyll a correlations. It is curious that the depth of 1% incident solar radiation is greater for Sapinero than for Iola, since the secchi depth measured at Iola was much greater. In general, the secchi depth corresponds to approximately 10 % of incident light (Wetzel 1983). However, using this relationship and % incident light as a prediction would result in a secchi depth near 5 m for Sapinero and a secchi depth between 4 and 5 m for Iola. This may explain why the actual secchi depth measured differs by a factor of almost 2x the secchi depth predicted by this relationship.

<u>Presentations since March</u>:

Johnson, B. M. 1998. Modeling effects of dam operations on reservoir food webs. Meeting in Salt Lake City with USBR, USGS, USU, UTDWR, WYG&F. (May)

Johnson, B. M. 1998. Biological aspects in water quality modeling. Guest lectures in CE581 Surface Water Quality Modeling, a Civil Engineering class at CSU.(May).

Johnson, B. M. 1998. Effects of dam operations on reservoir food web interations. Department of Fisheries and Wildlife Departmental Seminar, Utah State University, Logan, UT (May).

Stockwell, J. D. 1998. "Kokanee foraging ecology: from dams to daphnia", Pacific Biological Station, Department of Fisheries and Ocean Canada, Nanaimo, BC. (June)

Recent Peer-reviewed Literature:

Stockwell, J. D. and B. M. Johnson. (In review). Field evaluation of a bioenergetics-based foraging model for kokanee (*Oncorhynchus nerka*). Canadian Journal of Fisheries and Aquatic Sciences.

Stockwell, J.D., K.L. Bonfantine, and B.M. Johnson. In Press. Kokanee salmon foraging: a Daphnia in the stomach is worth two in the lake. Transactions of the American Fisheries Society xx:0000-0000.

CONCLUSIONS AND RECOMMENDATIONS

- Significant progress has been made on revisions to CE-THERM simulations. A new version of the model has been implemented and solar radiation components of simulations have been checked against measured data.

- We have a great deal more work to do on CE-THERM in the few remaining weeks of support we have for the Engineering graduate student. Among other things, evaporation, stream temperature: air temperature regressions need to be validated with new climate and temperature logger data. Wind speeds at Curecanti need to be compared to electronic data from Gunnison airport to test correction factor used in past simulations. We need to verify that CE THERM is using altitude corrections for saturated vapor pressure in both heat and water budgets and if necessary, modify Fortran code to include corrections. It is unlikely that all the needed modifications and refinements to CE-THERM can be accomplished with the current funds.

- Experimental fish are lined up for laboratory experiments examining kokanee functional response to variations in food density, temperature, and light. The graduate student has begun reviewing the literature and working with functional response calculations. Feeding experiments will begin in fall or winter, and will need to be repeated in summer-fall 1999.

- Our work to refine modeling tools to forecast effects of dam operations on reservoir food webs is just beginning. Approval of proposed funding for FY 99 is required to continue to make progress.

ACKNOWLEDGMENTS

Stacy Boesch, Brian Graeb, Alex Gravesen, Marci Koski, Josh Hobgood, and Pat Martinez assisted with limnological sampling at Blue Mesa. We thank Terry Robinson, CDOW Roaring Judy State Fish Hatchery Manager, for rearing fish for upcoming feeding experiments. We appreciate financial and logistic support from the Colorado Division of Wildlife. The project is supported by a contract from the U.S. Bureau of Reclamation, Salt Lake City, Utah.

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Stockwell, J. D. and B. M. Johnson. (In review). Field evaluation of a bioenergetics -based foraging model for kokanee (*Oncorhynchus nerka*). Canadian Journal of Fisheries and Aquatic Sciences.

Wetzel, R. G. 1983. Limnology. Saunders College Publishing, Philadelphia, Pennsylvania.

LIST OF FIGURES

Figure 1. Schematic representation of the processes modeled in CE-THERM reservoir thermal model.

Figure 2. Observed (solid lines) and predicted (dotted lines) temperature profiles. Predictions in 1994 were results after calibrating model to match 1994 profiles as closely as possible. Predictions in 1996 were made using all parameterizations establishing during the calibration to 1994 data, and thus are real model predictions.

Figure 3. Typical diel vertical migration pattern displayed by kokanee salmon in Colorado reservoirs.

Figure 4. Maximum model daily growth and observed growth for age 1 and age 3 kokanee in Blue Mesa Reservoir, Colorado. Model growth was estimated using vertical profiles of prey densities and temperature from 8 July 1997. The horizontal dashed lines represent the observed growth, and facilitate comparisons with model results. The vertical bars indicate the ranges in feeding (solid) and non-feeding (dashed) migration depths producing model growth rates within 10% of maximum, and inferred from sonar observations. The observed upper non-feeding depth ranges indicate the nighttime vertical distributions of kokanee, while the bottom ranges indicate daytime and twilight non-feeding depths.

Figure 5. Blue Mesa Reservoir temperature profiles (°C) measured at three stations On July 30, 1998.

Figure 6. Blue Mesa Reservoir dissolved oxygen profiles (mg/L) measured at three stations On July 30, 1998.

Figure 7. Secchi depth values (m) from the three main lake basins in Blue Mesa Reservoir from 1994-1998 and the mean secchi readings at the three basins during 1983-1985 (from Cudlip et al. 1987) and 1993 (Johnson 1994).

Figure 8. Solar radiation (W/m^2) measured with a LiCor photometer at the surface and at 1-m depth intervals at Sapinero and Iola limnological stations on July 30, 1998.

Figure 9. Solar radiation (as a percentage of incident light) measured with a LiCor photometer at the surface and at 1-m depth intervals at Sapinero and Iola limnological stations on July 30, 1998. CE-THERM model predictions of Sapinero light profile for July 30 of an average year is also shown.

Appendix 1.

Definitions Relevant to CE-THERM Analyses

Longwave radiation: same as infrared (0.8 um to 0.1 mm or 800 nm to 100,000 nm)

Shortwave radiation: includes visible and near-visible (0.3 to 4.0 um or 300 to 4000 nm)

Ultraviolet radiation: 1 to 300 nm

Visible light spectrum: 390 to 760 nm

Relative humidity: degree of saturation of water vapor. Warm air holds more water vapor than cool air.

Dew point temperature: temperature to which air must be cooled to become saturated by water vapor present in air.

Latent heat of vaporization: change of state requires heat energy (evaporative cooling).

Albedo: the ratio of the amount of electromagnetic radiation reflected by a body to the amount incident upon it.

Bowen ratio: for any moist surface, the ratio of heat energy used for sensible heating (conduction and convection) to the heat energy used for latent hating (evaporation of water or sublimation of snow) ranges for 0.1 (oceans) to 2.0 (deserts).

Conduction: transfer of energy through a medium for hot to cold regions by measure of internal particle or molecular activity.

Appendix 2.

Operation of the LiCor Photometer and Data Logger

LI-COR radiation sensors

Terrestrial Type SA: LI-190 Quantum Sensor

Calibration Multiplier: -203.25 umol/s/m^2 per microamp

Calibrated: May 28, 1998 (recalibration is recommended every two years)

Error is typically less than +/- 5% for angles less than 80° form the normal axis of the sensor for cosine corrected sensors. At 90°, a perfect cosine collector response would be zero and at that angle any error is infinite.

Measures photosynthetically active radiation (PAR) in the 400 to 700 nm waveband.

Underwater Type SA: LI-193SA Spherical Quantum Sensor

Calibration Multipliers: -183. 82 umol/s/m^2 per microamp (in air)
-297.79 umol/s/m^2 per microamp (in water)

Calibrated: May 28, 1998 (recalibration is recommended every two years)

Measures photosynthetically active radiation (PAR) in the 400 to 700 nm waveband in aquatic environments, and specifically the Photosynthetic Photon Flux Fluence Rate (PPFFR). The PPFFR is defined as those photons having a wavelength between 400 and 700 nm that are incident per unit time on the surface of a sphere divided by the cross-sectional area of the sphere. The sensor responds equally to photons and since the energy of a photon is inversely proportional to its wavelength, the sensor exhibits a linear energy response curve with wavelength. The sensor can also be used in air with accuracy similar to that of the LI-190SA Quantum Sensor.

Error can vary considerably; spatial error due to variations between the diffusing sphere and the sphere area "lost" for the sensor base is < -10% (upwelling radiation is smaller than the downwelling radiation) and error due to sphere displacement in turbid waters is +6.3% for water with an attenuation coefficient of 3/m.

LI-1400 Data Logger

There are 96 Kb of RAM available for data storage. If the LI-1400 becomes wet, dry connectors as soon as possible. Exposure to direct sun or cold temperatures can decrease battery life. The LI-1400 will power itself off after 15 minutes of inactivity. However, if any channels are enabled, it will continue to log data. The LI-1400 has a low battery indicator; the display will blink on and off when the battery voltage reaches 4.0 V, and shut off automatically when the battery voltage reaches 3.8 V. Replace batteries as soon as possible after the low battery indicator activates. The batteries should last approximately 50 hours. External battery packs are available for long-term data storage and last approximately 6 months.

<u>Configuration of LI-1400 for use with a radiation sensor</u>

Example: Configure channel I1 ofr a LI-COR LI-190SA Quantum Sensor whose calibration multiplier is -203.25 umol/s/m^2 per microamp.

1) connect the sensor to the BNC connector on top of the LI-1400 labeled I1.
2) choose *Setup Channels* and press **Enter**.
3) Toggle I1=Light with right or left arrow keys. Press down arrow.
4) Type LAND for description. Press down arrow.
5) Type -203.25 for calibration multiplier. Press down arrow.
6) Type UM for the label (abbreviation for micromoles). Press down arrow.
7) The running average parameter will not be used but could be set to any desired value. Press down arrow.
8) Toggle the Log Routine to none.
9) The remaining options do not need to be set as they apply only when using a Log Routine. Press ESC twice to return to the Setup menu.
10) Press the View key and toggle to New Data. Press Enter.
11) Toggle the display with the right or left arrow keys until channel I1I is displayed; this shows the instantaneous reading from the quantum sensor. The LI-1400 is now configured to display the instantaneous value of the quantum sensor.

VIEW

Pressing VIEW gives two options: New Data or Log Data, accessible with up and down arrow keys. Select New Data to view instantaneous data from one or more sensors. Select Log Data to view data that has already been stored in memory.

3-character channel codes:

<u>First 2 characters</u>:

- I1 to I 5: Current channels
- V1 to V4: Voltage channels
- VB: Battery voltage channel
- CT: Counter channel
- M1 to M9: Math channels.

<u>3rd character</u>:

I: instantaneous value updated once per second

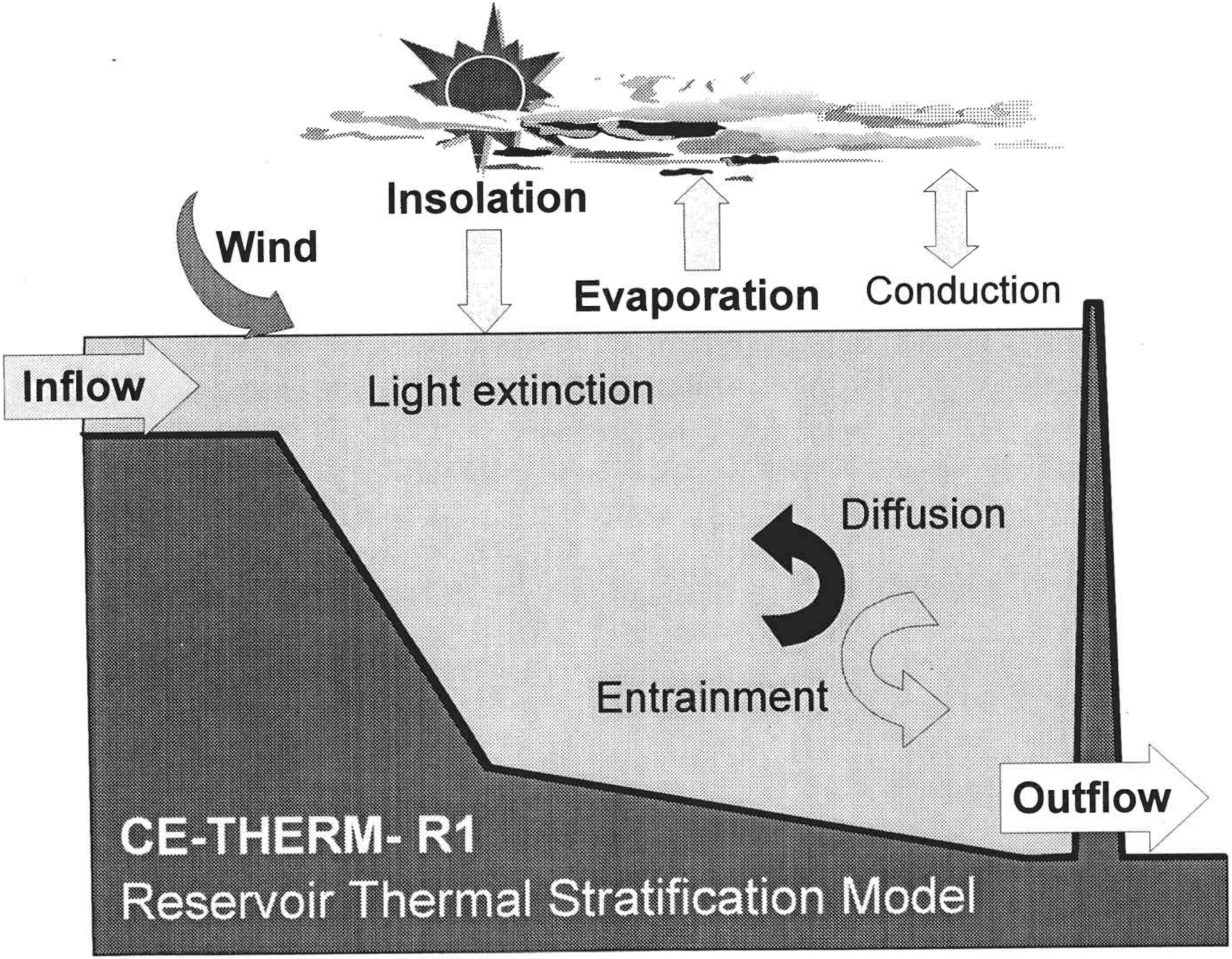
A: running average based on the previous 5, 15, or 30 seconds

M: Mean value calculated from the toatl samples collected during the sampling period

P: Point value of the last sample data point collected during the logging period

T: Integrated value calculated from the total samples collected during the logging period.

L L+ Time H H+Time



Insolation
Wind
Evaporation
Conduction
Inflow
Light extinction
Diffusion
Entrainment
Outflow
CE-THERM- R1
Reservoir Thermal Stratification Model

Figure 1.

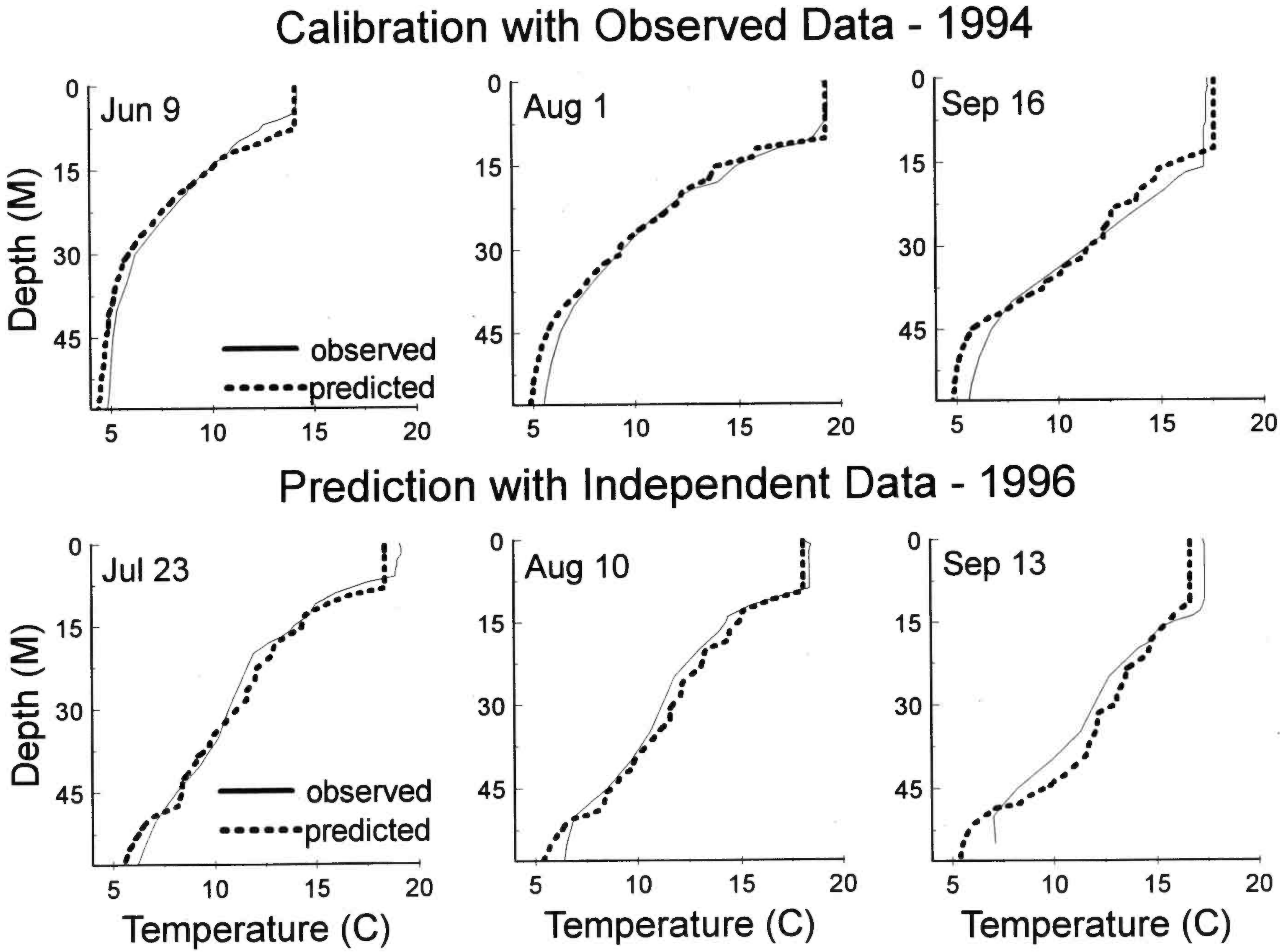

Calibration with Observed Data - 1994
Jun 9
Aug 1
Sep 16
Depth (M)
0
15
30
45
5
10
15
20
observed
predicted
Prediction with Independent Data - 1996
Jul 23
Aug 10
Sep 13
Temperature (C)

Figure 2.

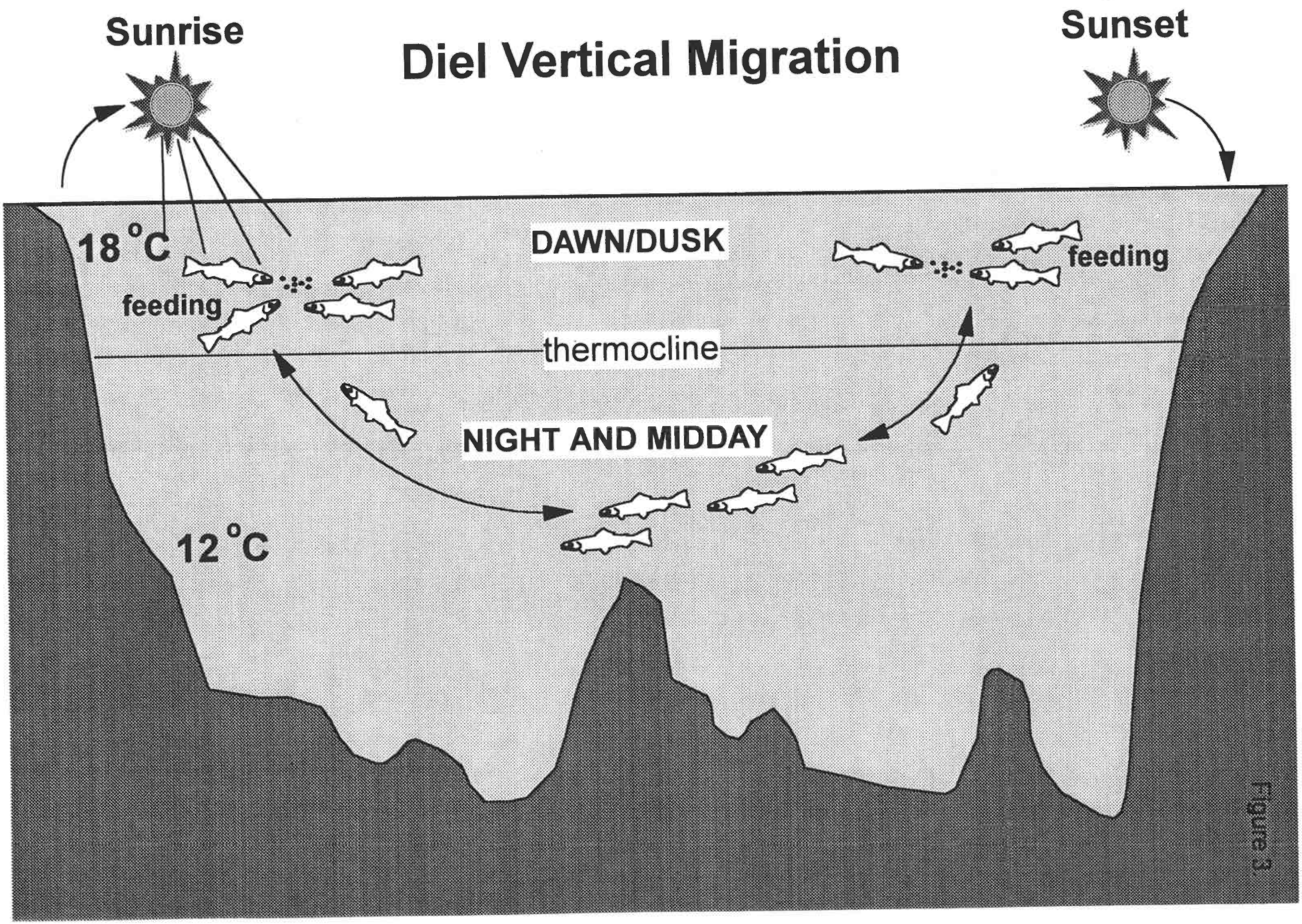

Sunrise
Diel Vertical Migration
Sunset
18 °C
DAWN/DUSK
feeding
feeding
thermocline
NIGHT AND MIDDAY
12 °C

Figure 3

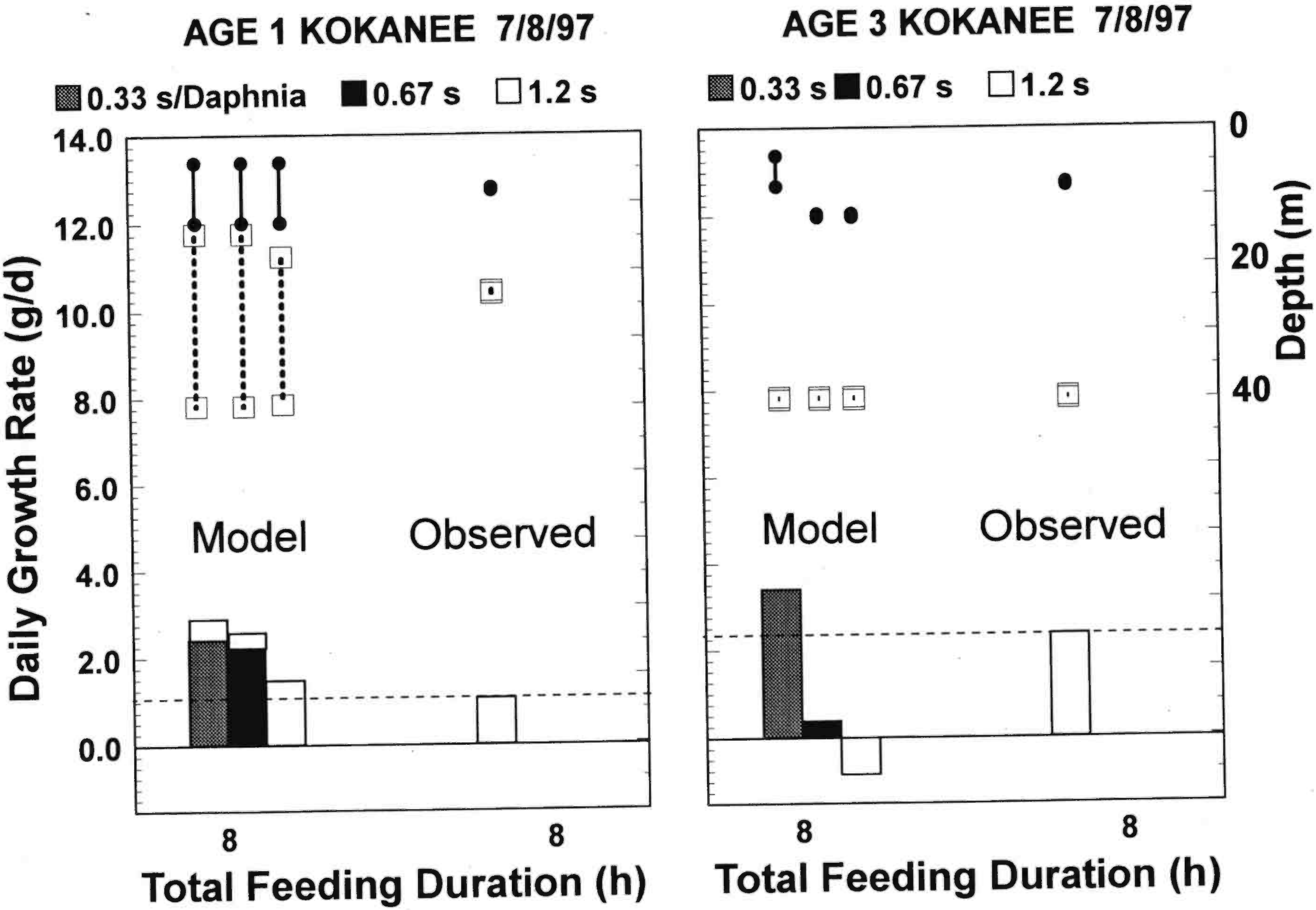
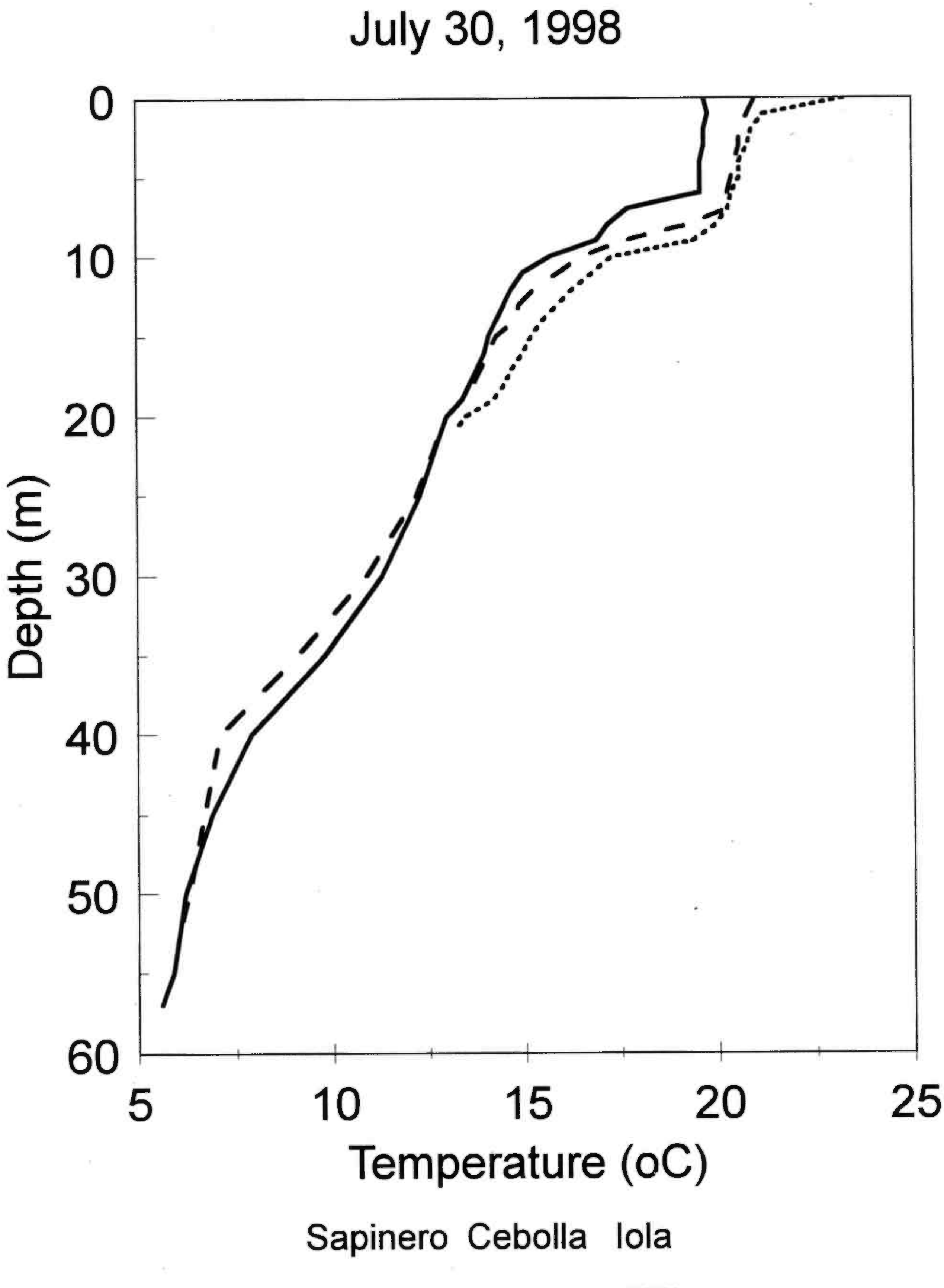
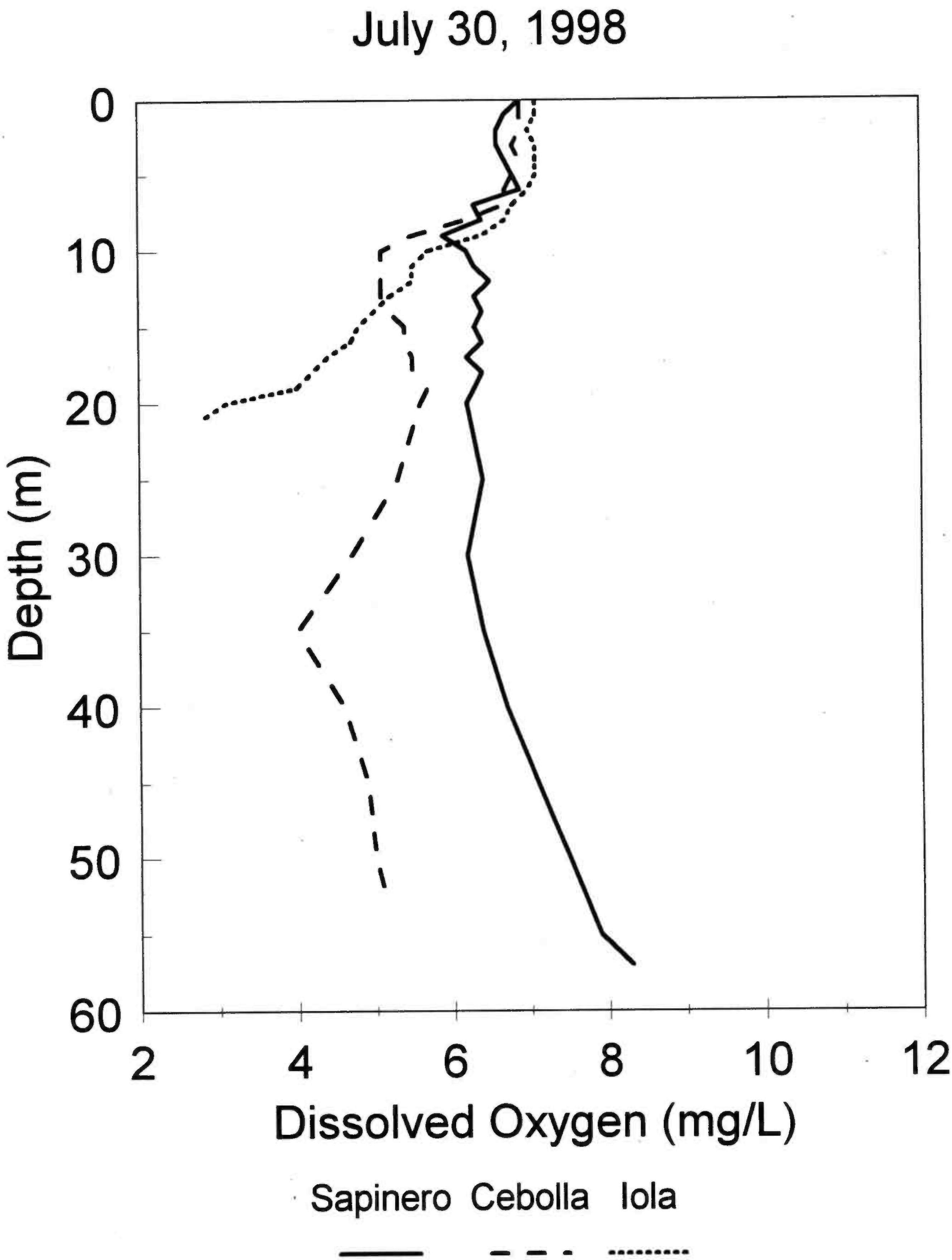

AGE 1 KOKANEE 7/8/97
0.33 s/Daphnia
0.67 s
1.2 s
Daily Growth Rate (g/d)
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Model
Observed
8
8
Total Feeding Duration (h)
AGE 3 KOKANEE 7/8/97
0.33 s
0.67 s
1.2 s
Depth (m)
0
20
40
Model
Observed
8
8
Total Feeding Duration (h)

Figure 4.



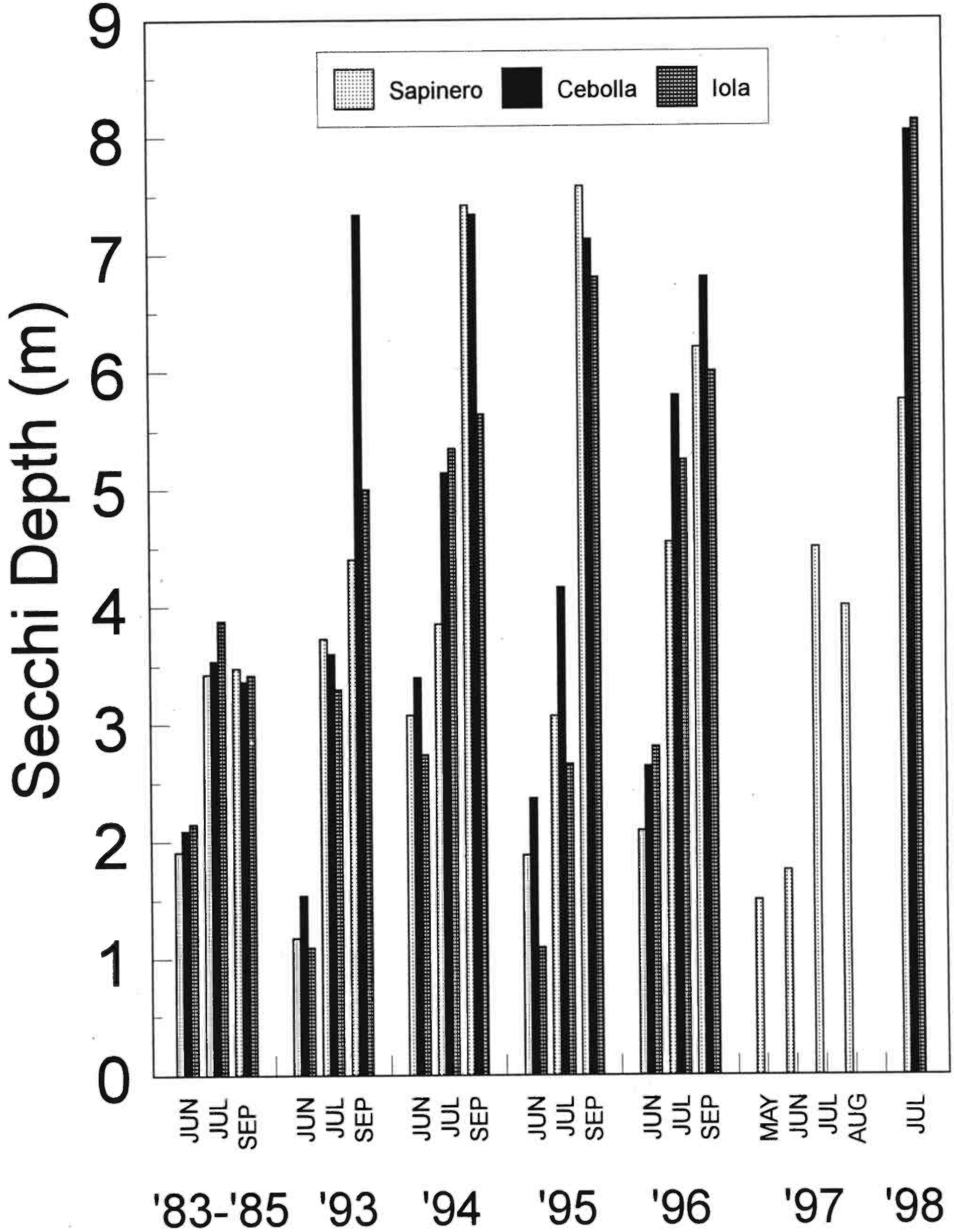
Blue Mesa Reservoir

Figure 6.



Blue Mesa Reservoir

Figure 7.



Sapinero
Cebolla
Iola
Secchi Depth (m)
0
1
2
3
4
5
6
7
8
9
JUN
JUL
SEP
JUN
JUL
SEP
JUN
JUL
SEP
JUN
JUL
SEP
JUN
JUL
SEP
MAY
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JUL
AUG
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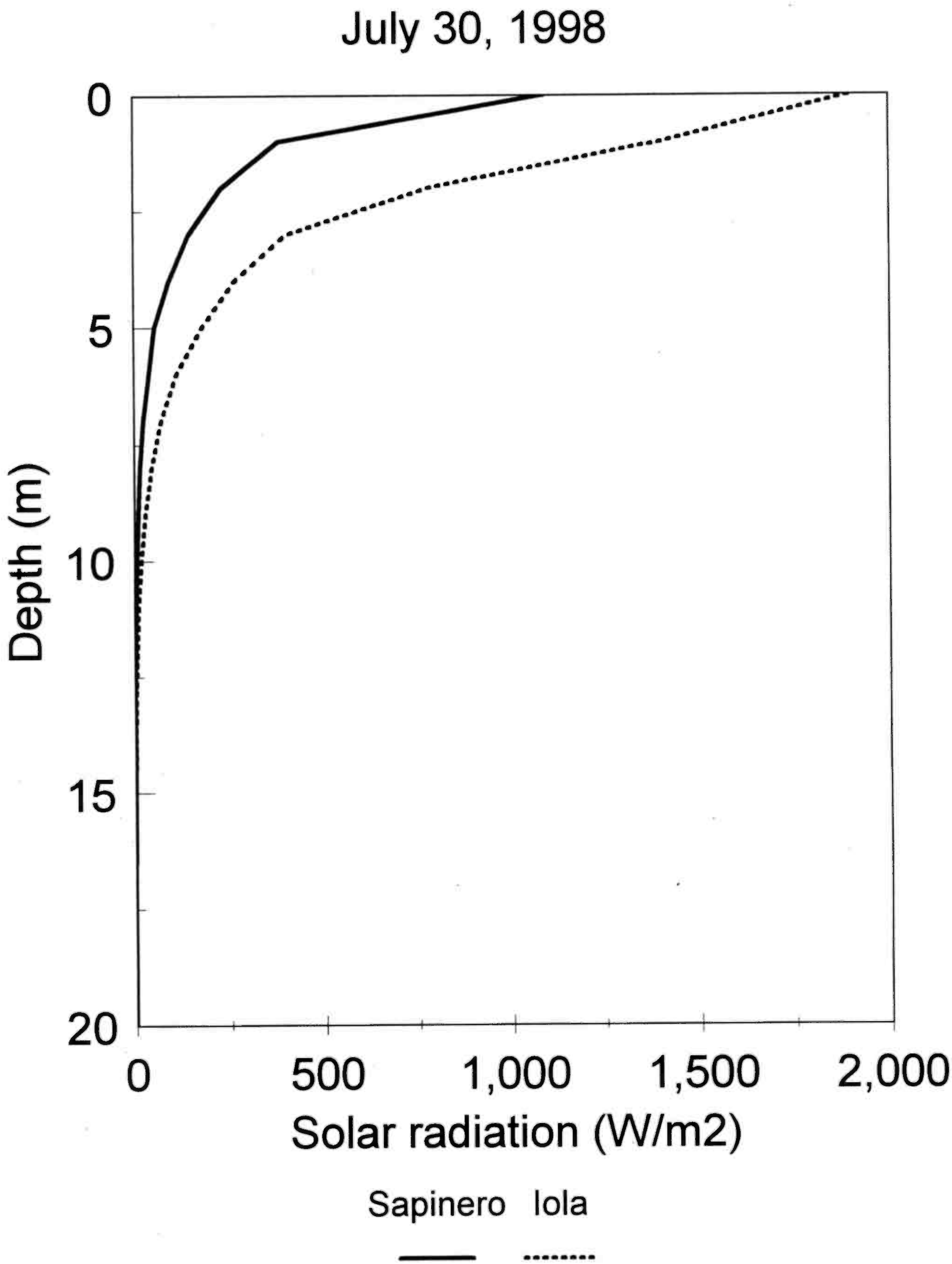
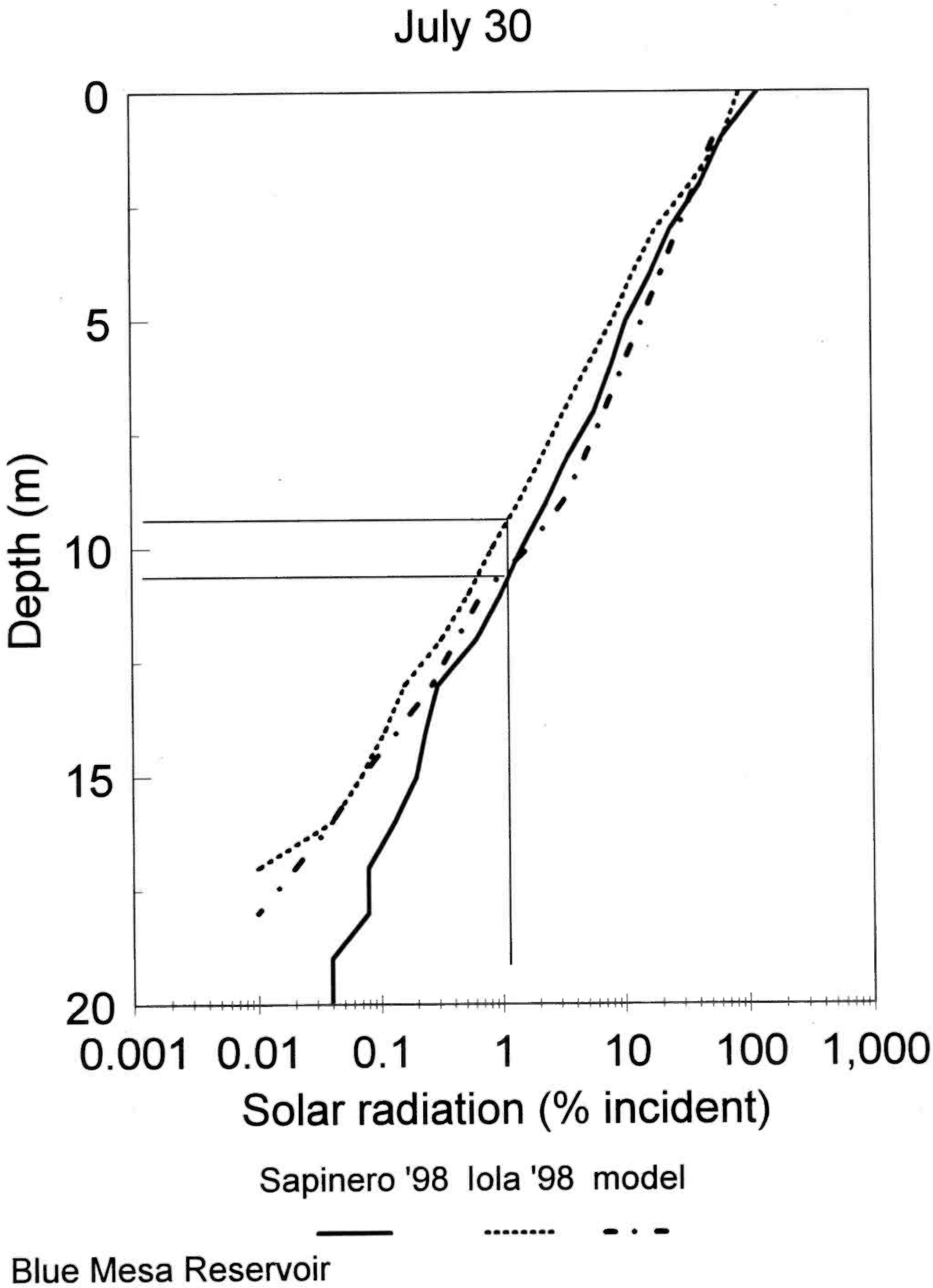
'96
'97
'98

Figure 8.



Blue Mesa Reservoir


July 30
Depth (m)
0
5
10
15
20
0.001 0.01 0.1 1 10 100 1,000
Solar radiation (% incident)
Sapinero '98 Iola '98 model
Blue Mesa Reservoir