2008

Coupling the Hydrodynamic and Water Quality Model CE-QUAL-W2 With a Multi-Trophic Fish Bio-Energetics Model for Lake Roosevelt, Washington

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COUPLING THE HYDRODYNAMIC AND WATER QUALITY MODEL CE-QUAL-W2 WITH A MULTI-TROPHIC FISH BIO-ENERGETICS MODEL FOR LAKE ROOSEVELT, WASHINGTON.

by

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A dissertation submitted in partial fulfillment of the
requirements for the degree of

DOCTOR OF PHILOSOPHY
in
CIVIL AND ENVIRONMENTAL ENGINEERING

Portland State University
2008

DISSERTATION APPROVAL

The abstract and dissertation of Michael Lee McKillip for the Doctor of Philosophy in Civil and Environmental Engineering were presented September 10, 2007, and accepted by the dissertation committee and the doctoral program.

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ABSTRACT

An abstract of the dissertation of Michael Lee McKillip for the Doctor of Philosophy in Civil and Environmental Engineering, presented September 10, 2007.

Title: Coupling the hydrodynamic and water quality model CE-QUAL-W2 with a multi-trophic fish bio-energetics model for Lake Roosevelt, Washington.

Grand Coulee Dam created Franklin D. Roosevelt Lake as part of the Columbia Basin Project. Located in northeastern Washington State, the Project provides economically important hydropower (19 billion kilowatt hours per year), irrigation (225,000 ha), flood control, and sport fishing ($5 to 20 million annually). A good system understanding aids in balancing these beneficial uses for the 230 km long reservoir. The reservoir's atypical 45-day mean residence time is much shorter than a typical lake, and much longer than for a riverine dam. The spring freshet requires drawdowns of 15 to 20 m for flood control—the driving characteristic of reservoir operations.

A physically based two-dimensional hydrodynamic and water quality model, CE-QUAL-W2 Version 3.5 (Cole and Wells, 2006), is coupled with a fish bioenergetics model based on the Stockwell and Johnson model (1997, 1999) to examine the effects of hydrodynamics on the reservoir algae-zooplankton-kokanee food web. This model

was applied and calibrated to Lake Roosevelt with model improvements of multiple zooplankton compartments and zooplankton omnivory. Calibration parameters included temperature, dissolved oxygen, nutrients, algae, and zooplankton. The fish bioenergetics model is applied over the entire reservoir model space to generate a spatial and temporal fish growth potential distribution. The fish model refinements include sub-daily time-steps and an optimized vertical foraging strategy.

The linked model suggests that kokanee fish growth potential is seasonally limited by both warm water and prey densities. While the lake ecology is significantly affected by the reservoir operations in general, the pelagic fish growth potential did not appear sensitive to minor changes in reservoir operations. However, the model suggests that the advantageous foraging locations shift seasonally and that optimal foraging strategies are dependent on fish size.

Acknowledgments

Funds were provided by the Bonneville Power Administration to the Spokane Tribe of Indians to conduct this project for the Lake Roosevelt Fisheries Evaluation Program. Deanne-Pavlik-Kunkel and Ben Scofield (Lake Roosevelt Fisheries Evaluation Program) provided data, system knowledge, and data interpretation. Dr. Mike Mazur and Dr. Dave Beauchamp (University of Washington, School of Aquatic and Fishery Sciences) collaborated on the fish bioenergetics modeling. Dr. Robert Annear and Dr. Chris Berger (Portland State University, Water Resources Research Group) provided technical assistance and advice for the hydrodynamic and water quality model.

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Biological Glossary & Abbreviations

Accessibility: the opportunity to pursue prey

Ad libitum feeding trials: "To the limit. In respect of feeding this term is used to describe when the fish are fed freely until they reach satiation point." From www.aquatext.com/list-a.htm

Allometric: part of the whole; an allometric function is a function of mass.

Allopatric: Occurring in separate, nonoverlapping geographic areas

Autecological: ecological branch dealing with biological relationships of organisms to their environment. Opposed to synecology.

Autochthonous: originating where found; indigenous

Buccal cavity: (oral cavity) the mouth cavity.

Char: any of several small-scaled trout (salmonids)

Crepuscular: pertaining to low light conditions at before dawn and after dusk wherein the available light is solely from atmospheric reflection and not direct sunlight.

Cryptogamic: A member of a formerly recognized taxonomic group that included all seedless plants and plantlike organisms, such as mosses, algae, ferns, and fungi. From http://www.answers.com/cryptogamic

Diel: events occurring on a daily cycle. Thus a "diel variation" is a variation that occurs regularly every day or most days.

DVM: Diel vertical migration

Elasmobranchs: with a cartilage skeleton

Egestion: the elimination of fecal wastes. cf. excretion

Epiphyton: algae attached to plants

Eukaryotic: A single-celled or multicellular organism whose cells contain a distinct membrane-bound nucleus. from http://www.answers.com/eukaryote

Excretion; the elimination of urine. cf. egestion

Gonadal growth: The use of energy for developing reproductive cells (sperm, eggs). Opposed to somatic growth.

HAB: Harmful Algal Bloom

Histology: The anatomical study of the microscopic structure of animal and plant tissues. http://www.answers.com/topic/histology

Intraspecific: same as intraspecies, or within a species

Lentic: referring to standing waters

Lotic: referring to running waters

Macroalgae: macroscopic, colony algae which may be attached or floating.

NTU: Nephelometric turbidity unit

Ontogenetic: Relative to the course of growth and development of an individual organism. (http://science.laborlawtalk.com)

Periphyton: algae attached to substrata;

Photoautotrophs: plants, algae, and some bacteria which are capable of photosynthesis.

Preference: the willingness to pursue prey

Prokaryotic: An organism of the kingdom Monera (or Prokaryotae), comprising the bacteria and cyanobacteria, characterized by the absence of a distinct, membrane-bound nucleus or membrane-bound organelles, and by DNA that is not organized into chromosomes. Also called *moneran*. from http://www.answers.com/topic/prokaryote

Red tides: a type of marine harmful algal blooms which get their name from the distinctive red algae.

Scotopic (vision): Related to nighttime illumination levels in which the eye is adapted to dark and vision is supported by the rod photoreceptors. www.hfeconsulting.com/Expert_Witness/GlossaryStoZ.html

SIT: Saturation intensity threshold: the point at which additional light has little influence on visual predator reaction distance. The term comes from Henderson & Northcote, (1985).

SDA: Specific dynamic action: energy released in deamination of proteins.

Somatic growth: Growth in an organisms body mass. Opposed to gonadal growth.

Sympatric: occupying the same area

Synecology: The study of the ecological interrelationships among communities of organisms

Teleost: fish with a bony skeleton as opposed to cartilidge (elasmobranchs)

VIT: visual irradiance threshold; the maximum quantity of irradiance resulting in a reaction distance of zero.

YTC: "yeast—trout chow—Cerophyll (cereal leaves)" a food for growing zooplankton.

Introduction

Project Overview

The effects of reservoir operations on the Lake Roosevelt hydrodynamics, temperature, water quality, and food web must be understood for effective fisheries management. The Lake Roosevelt system is unusual in that the spring flood control drawdown, a critical function of Grand Coulee Dam and typically 40 to 60 feet, shifts the system ecologically from a lacustrine to a riverine system. While this drawdown certainly influences the exposed littoral and benthic communities, and is felt to be the cause of the sparse macrobenthos, the effect on the fisheries is less well understood.

The goal of this project is to couple a physically based hydrodynamic and water-quality model with a multi-trophic bio-energetics model to better understand how the spatial and temporal variability affect the food web. This will be accomplished by

1) Setting-up a CE-QUAL-W2 model for Lake Roosevelt.
2) Calibrating the model for hydrodynamics, temperature, and water quality.
3) Incorporating bioenergetics algorithms
4) Calibrating the bioenergetics model
5) Applying the model to management scenarios (diagnostic cases)

The US Corp of Engineers hydrodynamic and water-quality code, CE-QUAL-W2 (Cole and Wells, 2006), v.3.5, is a physically based model incorporating all the dominant physical processes. As an open FORTRAN 90/95 source code, it can be readily altered to allow for system specific changes in the algorithms. The code has been in use since 1975 and has been applied to over 400 systems internationally. The model uses lateral-averaging (2-D), but tributaries and arms can be represented separately allowing for a quasi-3-D framework. The 2-D approximation is appropriate for long and narrow reservoirs such as Lake Roosevelt. Besides the normal set of eutrophication parameters, the model includes multiple species of phytoplankton, epiphyton, macrophytes, and zooplankton. Multiple phytoplankton groups have been successfully modeled, typically including diatoms, greens and cyanobacteria (or blue-greens) group. Sometimes model users use a single composite algal group.

Bio-energetics models are elaborate mass and energy balance algorithms. In general, the simpler models operate on a timestep of a day, although some models and subroutines operate on an hourly or 30 minute timestep. While the models utilize the ambient water quality, such as temperature and nutrients, they do not often interact therewith. Also, while most models examine only a single trophic layer, there are some multi-trophic models which may use four components: piscivorous fish, planktivorous fish, zooplankton and phytoplankton. Fish models may be as complicated as warranted and supportable, and most parameters and physical processes can be refined by allometric, ontogenic, and temperature functions.

The coupling of sophisticated bio-energetics and hydrodynamic/water-quality models is a logical progression in the trend of more encompassing models. Multi-trophic models have demonstrated the importance of community composition on nutrient cycling. Sophisticated models are data intensive, but the Lake Roosevelt system has a wealth of water-quality and biological data. Extensive sampling has occurred since 1999, thus six years of biological data are available for calibrating a bio-energetics model. Hydrodynamic, water temperature, and meteorological data are typically available at an hourly frequency. Most water-quality boundary condition data are available at a weekly or monthly frequency: nutrients, dissolved oxygen, pH, alkalinity, suspended solids, and dissolved gases. Vertical profiles of temperature and water-quality are available at a monthly frequency for calibration. Biological data such as net tow zooplankton in biomass and composition, phytoplankton as chlorophyll-a sampling, fish age and size, and fish diet composition are available at a roughly quarterly frequency.

The biological complexities involved in fish spawning and rearing are not well understood in Lake Roosevelt. However, the spring fish population is well sampled, the hatchery releases are known, and the annual Two Rivers Casino Trout Derby provides a large sample size for the end of year growth in addition to sampling. The processes involved in young fish growth is much more understood than the spawning processes, so a single year "put-and-take" fish model calibration is feasible.

The coupled model offers the opportunity to answer important management questions identified by the Lake Roosevelt Fisheries Evaluation Program. While examining the dam operations impact on temperature can be addressed without a bio-energetics model, many of the fish population growth and numbers are correlated with flow. To answer this question, a coupled model is applicable.

Lake Roosevelt Overview

History of Lake Roosevelt

Located in northeastern Washington State (Figure 1), Franklin D. Roosevelt Lake, or Lake Roosevelt for short, was formed through the impoundment of the Columbia River behind Grand Coulee Dam (RM 597). Franklin D. Roosevelt Lake has a total storage of 11.6 billion m^3 (9.5 million acre-feet) and is roughly 225 km (140 mi) long. Full pool does not extend entirely to the Canadian border (RM 745). The lake has some 1000 km (600 mi) of shoreline and a surface area of 33,000 ha (82,000 acres). In 1970, the Lake Roosevelt National Recreation Area was designated by the U.S. Congress.

Grand Coulee Dam is located about 90 miles west of Spokane and 250 miles east of Seattle. Grand Coulee Dam gets its name from the nearby coulee[1] generated by the Missoula floods some 15000 year ago. It is the primary dam in the US Bureau of Reclamation's Columbia Basin Project in central Washington. The dam became operational in 1941 and is the largest concrete structure in North America. In 1975, the additional third powerhouse became fully active. With the additional power production capacity, the dam rarely spills water, typically less than 30 days in a year.

[1] Coulee: "A dry canyon eroded by Pleistocene floods that cut into the lava beds of the Columbia Plateau in the western United States." From odur.let.rug.nl/~usa/GEO/glossary.htm

The dam provides flood control, irrigation, hydropower production, and recreation. Irrigation withdrawal started in 1951. Water is withdrawn just upstream of Grand Coulee Dam and is pumped into nearby Banks Lake. Withdrawals provide water for roughly 225,000 ha (550,000 acres in the Columbia Basin Project. Peak power production is over 6 million KW with annual production just less than 20 billion KWh, the greatest source of power in the northwestern United States. Sport fisheries have historically brought in 5 to 20 millions dollars annually to the region. Grand Coulee Dam does not allow for fish passage, and closed off over 1100 miles of natal stream and tributaries to anadromous fish. Several species were eliminated: steelhead, Chinook, coho, and sockeye salmon. Today, the dominant sport fishes are rainbow trout and walleye. The land-locked sockeye salmon known as kokanee salmon existing in small numbers as wild fish in the lake, but there have been significant recent hatchery efforts to revive the kokanee fishery. The kokanee is of economic and cultural importance to the Confederated Colville Tribes and Spokane Tribe of Indians, both of which adjoin the reservoir.

The Northwest Power and Conservation Council is charged with making recommendations to the Bonneville Power Administration regarding dam mitigation. In 1987, the council recommended operating kokanee hatcheries. The hatcheries have fallen well short of their harvest goals. BPA provides over $100 million annually for hatcheries and projects in the region such as the Lake Roosevelt Fishery Enhancement Program, which was formed as a cooperative effort among the Spokane Tribe of

Indians, Colville Confederated Tribes, Washington Department of Fish and Wildlife, Eastern Washington University, the Lake Roosevelt Development Association (now known as the Net Pen Program), and the National Park Service. The Lake Roosevelt Fisheries Evaluation Program was formed to monitor and evaluate the hatcheries efforts as well as to conduct research questions pertaining to the fishery. There is considerable economic, cultural, and political impetus to better understand and manage the lake and the fisheries.

For a further history of the Columbia Basin Project, refer to Simonds (1998), whose work is available at the USBR website.

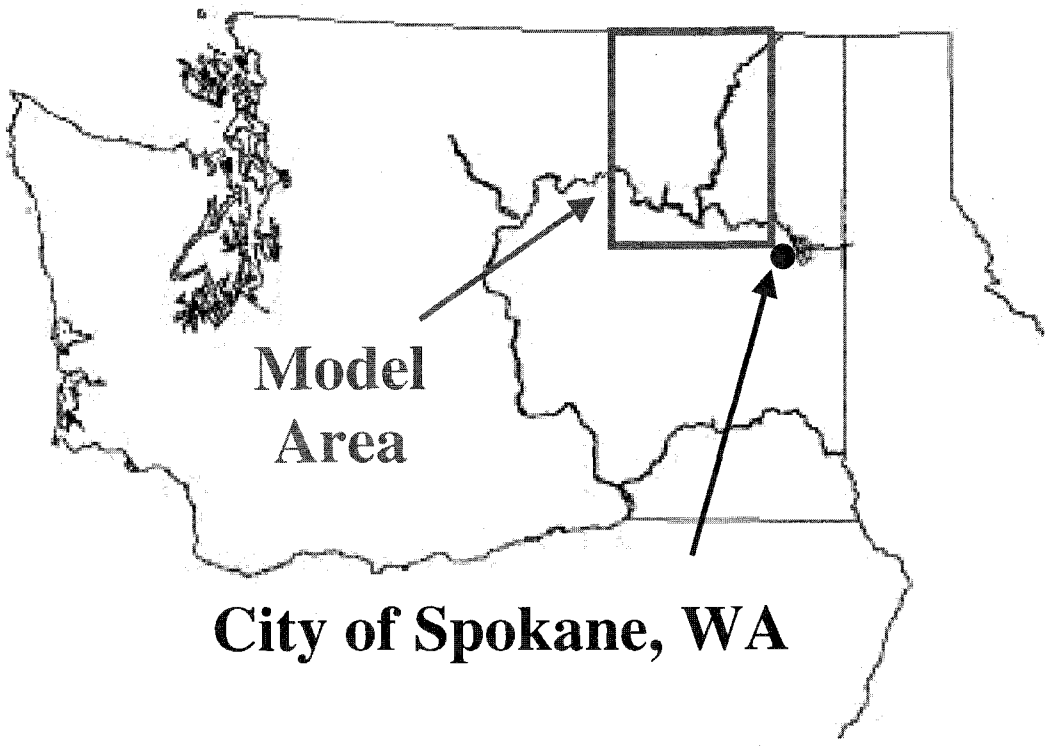

Figure 1. Model area regional sitemap.

Limnological and Ecological Description

While the reservoir receives flow from the Colville, Sanpoil, Spokane, and Kettle Rivers, the Columbia River comprises the bulk of the flow (~80%). The Spokane River provides ~15% of the flow. Columbia River flows are typically cold, below 4 °C in the winter, and warm to 18 to 20 °C in the summer. A basic morphometric summary of the reservoir is shown as Table 1.

Lake Roosevelt is rare in that it behaves like a reservoir most of the year, but while undergoing spring drawdown for flood control, the high flows create a riverine system. Additionally, the drawdown exposes up to 24 m (80 ft) of the banks for a month or more, although 12 to 18 m (40 to 60 ft) is more typical. Benthic ecosystems and shore side vegetation are disturbed and heavily influenced by this seasonal drying. For example, the benthic macroinvertebrate and macrophyte populations are both sparse, composed of a mix of lacustrine and riverine species, and have an atypically small percentage of mature adults.

Native species of fish in the area include: kokanee, rainbow trout, bull trout, white sturgeon, burbot, mountain whitefish, minnow, sculpin and sucker species. Introduced species include: brook trout, brown trout, walleye, yellow perch, largemouth bass, smallmouth bass, black crappie, white crappie, sunfish and yellow bullhead. Of these,

the walleye and rainbow trout are the dominant sport fishes. There have been efforts over the decades to revive the kokanee salmon fishery, which is of particular interest to the Native Americans culturally and economically. Grand Coulee Dam clearly influenced the ecology, as noted by Fields, et al., (2004):

> The dam construction did not allow for fish passage, but the federal government agreed prior to dam construction to mitigate the Indian Tribes' losses to their fisheries. Grand Coulee Dam eliminated steelhead (*Onchorhynchus mykiss*), chinook salmon (*O. tshawytscha*), coho salmon (*O. kisutch*) and sockeye salmon (*O. nerka*) from returning to approximately 1,835 km (1,140 miles) of natal streams and tributaries found in the upper Columbia River drainage in the United States and Canada (Mullan 1984; Mullan et al. 1986). The construction of Grand Coulee Dam also eliminated the anadromous pathway for white sturgeon (*Acipencer transmontanus*) and the periodic deposition of marine derived nutrients from anadromous fish which likely benefited the entire food web (UCWSRI 2002).

Today, the reservoir is generally oligotrophic, with turbidity typically below 5 NTU, although the Spokane River is more turbid, as are the regions of confluence. The Columbia River longitudinal nutrient gradients are weak; the Spokane River has higher nutrient concentrations than the Columbia River. Pelagic algae is typically around 1 to 3 mg/m^3 as chlorophyll-a. The Teck Cominco fertilizer plant located

upstream at Trail, Canada, was closed in mid-1994. Prior to this time, a significant source of phosphorous was present and zooplankton densities were roughly ten times the current densities (Cichosz, et al. (1997, 1999), Spotts, et al. (2002), and McLellan, et al. (2003), Lee, et al. (2003),Scoffield, et al. (2003), Fields, et al. (2004)).

[For a readable and concise system characterization, refer to Underwood (2004). For more detail, refer to the Lake Roosevelt Fisheries Evaluation Program annual reports listed in Table 2.]

Table 1. Morphometric summary of Lake Roosevelt.

Reach length	225 km	140 miles
Width: Upstream riverine section At Grand Coulee Dam Minimum at full pool Maximum at full pool	 ~200 m 1210 m 138 m 3210 m	 ~650 ft 1370 ft 453 ft 10530 ft (2.0 mi)
Depth: at Canadian border at Grand Coulee Dam	 4+ m 122 m	 14+ ft 400 ft
Daily mean detention time (over 2002 period)	Mean: 45 days Minimum.: 19 days Maximum: 147 days	
Annual mean detention time (over 1991-2002 period)	Mean: 44.7 days Minimum.: 29.5 days Maximum: 59.2 days	
Surface area	32780 ha	81,000 acres
Shore length	1014 km	630 miles
Annual Columbia River flow	2200-3600 m^3/sec	80 to 130 kcfs
Annual Precipitation	25 cm/year	10 in/year
Volume	11.6 billion m^3	9.4 million acre-ft 409 billion ft^3

Table 2. Lake Roosevelt Fisheries Evaluation Program annual report references.

Monitoring Year	Reference
1996	Cichosz, et al. (1997)
1997	Cichosz, et al. (1999)
1998	Spotts, et al. (2002)
1999	McLellan et al. (2003)
2000	Lee et al. (2003)
2001	Scofield et al. (2003)
2002	Fields et al. (2004)

Work Impetus

Congress passed the Northwest Power Act in 1980. One component of the act addresses the impact of hydroelectric dams on fish and wildlife and created the Northwest Power Planning Council (now called the Northwest Power and Conservation Council). The council was charged with recommending mitigation projects to the Bonneville Power Administration (BPA), which helps operate many of the dams in the basin. In 1987, the council recommended that the BPA support two kokanee salmon hatcheries to enhance the fishery. Thus the Lake Roosevelt Fishery Enhancement Program was formed as a cooperative effort among the Spokane Tribe of Indians, Colville Confederated Tribes, Washington Department of Fish and Wildlife, Eastern Washington University, the Lake Roosevelt Development Association (now known as the Net Pen Program), and the National Park Service. The Lake Roosevelt Fisheries Evaluation Program (LRFEP) was formed to monitor and evaluate the hatcheries efforts as well as to conduct research questions pertaining to the fishery.

Good fisheries management—with a particular interest in the restoration of the kokanee fishery—requires a strong understanding of the lake system. The LRFEP has identified the need to understand the interaction between the fisheries and the hydrodynamics of the lake, which are largely dictated by the Grand Coulee dam operations.

The first goal of this project is to couple the hydrodynamic and water quality model, CE-QUAL-W2, to the general bio-energetics model currently used for Lake Roosevelt by Dr. Beauchamp of the University of Washington. The combined model includes hydrodynamics, meteorology, water quality such as suspended solids, nutrients, temperature, dissolved oxygen, multiple species of phytoplankton (diatoms and pelagic algae), zooplankton, and kokanee. The second goal involves using the model as a diagnostic tool and identifying improvements in the LRFEP data sampling strategies.

Several negative pressures limit kokanee recruitment. The factors which are unsuitable to address with this project include:

Entrainment: Kokanee are known to follow the current downstream. Entrainment is suspected to be a major cause of low kokanee harvest during and following high flow years.

Predation: Kokanee fry are a major source of food for walleye. A considerable portion of the hatchery released kokanee are quickly consumed.

Angling: Angling is unlikely to limit recruitment since age-0 kokanee are not a target species.

Interspecies competition for prey: Rainbow trout have a large diet overlap (daphnia), but prey availability is best addressed outside this project.

Biological processes: wintering, precocity, and spawning are all concerns not suitable for this analysis.

The factors best addressed by this project include:

Temperature: The horizontal, vertical, and temporal distribution of water temperatures plays a large role among the water quality, algae, zooplankton, and fish food web.

Prey availability and distribution: The horizontal, vertical, and temporal distribution of prey as it relates to the temperature distribution also plays a synergistic role in fish growth potential.

Hence, this project addresses the role of temperature and prey distribution in Lake Roosevelt kokanee fish growth potential.

Some specific questions that could be addressed with this model include:

- How do hydrodynamics and dam operations influence lake temperature?
    - Can operations influence cold water refugia?
    - Would selective withdrawal influence lake temperature and stratification?
- How do hydrodynamics influence the food web?
    - Fish populations are correlated with annual discharge rates, but the mechanisms at work are not understood. Can the model decouple fish, nutrient, and food supply flushing effects from changes in water temperature and drawdown effects—all of which can be related to discharge?

- How does temperature influence the food web?
    - Does warm water increase the supply of fish food and hence fish growth more than it increases metabolic costs, and hence decreases growth, for cold water fishes such as kokanee.
- Why are adult kokanee found near the dam, but not necessarily in the deeper, cooler water? The fisheries biologists are uncertain as to the cause: food supply, water temperature, flushing, predator avoidance, or something else. The model can be used to show the productive regions of the reservoir and evaluate spatial distribution patterns.
- Is the current LRFEP sampling strategy efficient and sufficient in terms of breadth and intensity for a first-cut modeling of the food web?
    - What additional data are necessary for improved accuracy?
    - What model parameters, especially bio-energetic parameters, are most sensitive?
- What would be the effect of increased phosphorous loadings like those of the fertilizer plant closed in 1994?
    - How important is the phosphorous loading to fish growth?
    - Are there ways to increase phosphorous cycling? Can fish growth be increased?
- What is the feasibility of incorporating fish foraging models for planktivores and piscivores into the developed framework?

CE-QUAL-W2 Overview

This section reviews the governing equations and approaches of the hydrodynamic and water quality surface water modeling code, CE-QUAL-W2, v. 3.5. For a more detailed discussion, refer to the user manual, (Cole and Wells, 2006).

Model Introduction

CE-QUAL-W2, v.3.2, is a physically based, two-dimensional, laterally averaged, finite difference model. The model applies spatial and temporal averaging to the Navier-Stokes and Continuity equations to model surface water hydrodynamics. Similarly, the advective-diffusion equation is used for the transport of heat and water quality constituents. Because the model assumes lateral homogeneity, it is best suited for relatively long and narrow waterbodies exhibiting longitudinal and vertical water quality gradients. The model has been applied to rivers, lakes, reservoirs, estuaries, and combinations thereof. Table 3 lists the known applications of the model to date, including in many countries outside the United States such as Columbia, Brazil, Venezuela, Panama, United Kingdom, Spain, Thailand, Italy, New Zealand, China, South Korea, Taiwan, and Norway. Users are reported in 116 different countries.

Table 3. CE-QUAL-W2 applications by water body type.

Water body	*Known Number of Applications*
Reservoirs	319+
Lakes	287+
Rivers	436+
Estuaries	82+
Pit lakes	10

The application of CE-QUAL-W2 requires knowledge in the following areas:

1. Hydrodynamics
2. Aquatic biology
3. Aquatic chemistry
4. Numerical methods
5. Computers and FORTRAN coding
6. Statistics
7. Data assembly and reconstruction

The model includes the following state variables:

1) water temperature
2) any number of generic constituents defined by a 0 and/or a 1st order decay rate and/or a settling velocity and/or an Arrhenius temperature rate multiplier that can be used to define any number of the following:
    a. conservative tracer(s)
    b. water age or hydraulic residence time

c. coliform bacteria(s)

d. contaminant(s)

3) any number of inorganic suspended solids groups

4) any number of phytoplankton groups

5) any number of epiphyton groups

6) any number of macrophyte groups

7) any number of zooplankton groups

8) any number of CBOD groups

9) ammonium

10) nitrate-nitrite

11) bioavailable phosphorus

12) labile dissolved organic matter

13) refractory dissolved organic matter

14) labile particulate organic matter

15) refractory particulate organic matter

16) total inorganic carbon

17) alkalinity

18) total iron

19) dissolved oxygen

20) organic sediments

21) gas entrainment

Hydrodynamic and Heat Governing Equations

The hydrodynamic governing equations are shown in Table 4. The assumptions made include

1) Incompressible fluid.
2) Centripetal acceleration correction to the gravity term is negligible
3) Bousinesque approximation
4) Coriolis forces are not important in an x-z model
5) Within a grid cell, density variation can be taken to be negligible for purposes of temporal averaging
6) Each cell is vertically and laterally averaged
7) The coordinate system is transformed so that the +z direction is vertical downward and perpendicular to the channel slope (thus, for a slope channel, there is a small difference in the +z direction and vertically downward).
8) The vertical momentum equation is simplified by scaling analysis showing that horizontal velocities are much larger than vertical velocities. The vertical momentum equation then becomes the hydrostatic condition.
9) The state equation can be selected to represent freshwater (low salinity) or marine conditions.

Table 4. CE-QUAL-W2 Governing equations.

Equation	Governing Equation
x- momentum	$$\frac{\partial UB}{\partial t}+\frac{\partial UUB}{\partial x}+\frac{\partial WUB}{\partial z}=gB\sin\alpha$$ $$+g\cos\alpha B\frac{\partial \eta}{\partial x}-\frac{g\cos\alpha B}{\rho}\int_{\eta}^{z}\frac{\partial \rho}{\partial x}dz+$$ $$\frac{1}{\rho}\frac{\partial B\tau_{xx}}{\partial x}+\frac{1}{\rho}\frac{\partial B\tau_{xz}}{\partial z}+qBU_x$$
z-momentum	$$0=g\cos\alpha-\frac{1}{\rho}\frac{\partial P}{\partial z}$$
continuity	$$\frac{\partial UB}{\partial x}+\frac{\partial WB}{\partial z}=qB$$
state	$$\rho=f(T_w,\Phi_{TDS},\Phi_{ss})$$
free surface	$$B_\eta\frac{\partial \eta}{\partial t}=\frac{\partial}{\partial x}\int_{\eta}^{h}UBdz-\int_{\eta}^{h}qBdz$$

U = horizontal velocity, $m\,s^{-1}$
W = vertical velocity, $m\,s^{-1}$
B = channel width
P = pressure
α = channel slope
τ_x = x-direction lateral average shear stress
τ_y = y-direction lateral average shear stress
ρ = density
η = water surface

(Taken from Table A-1, Cole and Wells (2006)).

The model allows the user to include the following other physical processes and functions:

1) Channel bottom shear
2) Wind driven surface shear
3) Flow control structures such as weirs, gates, intakes, and pumps as well as selective withdrawal.
4) Surface heat exchange
5) Sediment-water heat exchange
6) Vegetative and topographic shading
7) Ice cover formation
8) Light attenuation with depth
9) Oxygen exchange at the air-water interface (reaeration, degassing)

Water Quality Algorithms

The water quality active constituents modeled by CE-QUAL-W2 and the data needed to generate boundary conditions for them are shown in Table 5. A silica constituent can be added for diatom modeling if silica is found to be a limiting nutrient.

Table 5. CE-QUAL-W2 Active Constituent data requirements.

Abbreviation	CE-QUAL-W2 Active Constituent	Data required or used to generate constituent
TDS	Total dissolved solids	Total dissolved solids
ISS	Inorganic suspended solids	Total suspended solids, organic matter, algae
PO4	Orthophosphate	Orthophosphate or soluble reactive phosphorous
NH4	Ammonium	Ammonium
NOx	Nitrate plus Nitrite	Nitrate plus Nitrite
LDOM	Labile dissolved organic matter	Dissolved organic carbon, stoichiometry (f_{LDOM})
RDOM	Refractory dissolved organic matter	Dissolved organic carbon, stoichiometry (f_{RDOM})
LPOM	Labile particulate organic matter	Total organic matter, stoichiometry (f_{LDOM})
RPOM	Refractory particulate organic matter	Total organic matter, stoichiometry (f_{RDOM})
ALG	Algae, dry weight	Chlorophyll -a and stoichiometry (Algae_to_Chla_Ratio)
DO	Dissolved oxygen	Dissolved oxygen
TIC	Total inorganic carbon	pH and alkalinity
ALK	Alkalinity	Alkalinity
	Intermediate needed data	
TSS	Total suspended solids	Total suspended solids
TOC	Total organic carbon	Dissolved to particulate organic carbon ratio
DOC	Dissolved organic carbon	Dissolved organic carbon
	Stoichiometry needed	
Algae_to_ Chla_Ratio	Ratio of algae dry weight to chlorophyll-a	Assume 100, adjust with calibration
f_{LDOM}	Fraction of labile to total dissolved organic matter	Assume 0.5, adjust with calibration
f_{RDOM}	Fraction of labile to total particulate organic matter	Assume 0.5, adjust with calibration

An examination of the phosphorous constituent gives a good overview of how nutrients are handled by the model. A conceptual flow chart is presented as Figure 2. The phosphorous rate equation includes sources (decay of organic matter in the water column, sediment releases, and algal respiration) and sinks (photosynthesis uptake, settling). The total mass balance includes the rate equation and advective transport (inflow and washout).

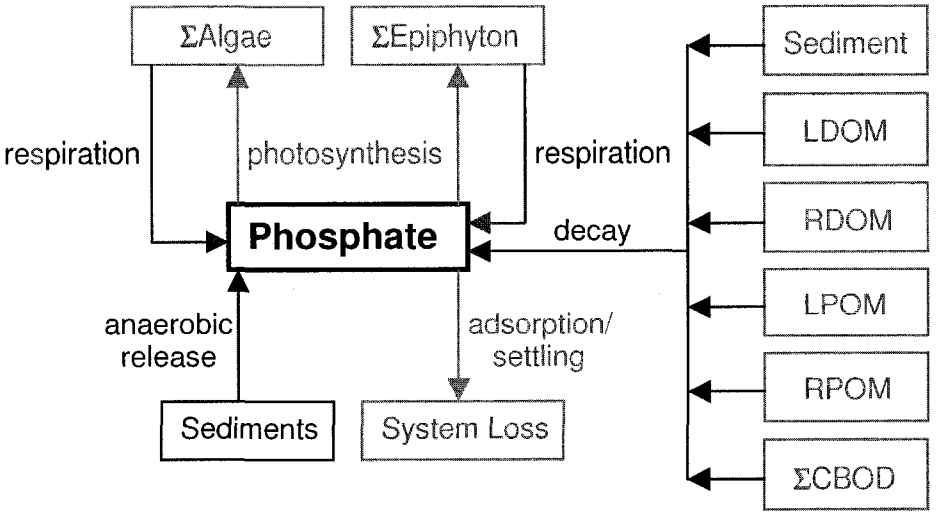

Figure 2. Internal flux between phosphorus and other compartments.
(Reproduction of Figure B-11, Cole and Wells (2004)).

The rate equation for phosphorous is shown in Table 6. The general formulation for each source and sink term is that the time rate of change in phosphorous is proportional to the product of some constituent concentration (φ), stoichiometry (δ), kinetic rate (K), and temperature rate multiplier (γ, Θ) as appropriate.

Table 6. CE-QUAL-W2 Phosphorous rate equation.

$$S_p = \underbrace{\sum (K_{ar} - K_{ag})\delta_{Pa}\Phi_a}_{\text{algal net growth}} + \underbrace{\sum (K_{er} - K_{eg})\delta_{Pe}\Phi_e}_{\text{epiphyte net growth}} + \underbrace{K_{LDOM}\delta_{POM}\gamma_{OM}\Phi_{LDOM}}_{\text{labile DOM decay}}$$
$$+ \underbrace{K_{RDOM}\delta_{POM}\gamma_{OM}\Phi_{RDOM}}_{\text{refractory DOM decay}} + \underbrace{K_{LPOM}\delta_{POM}\gamma_{OM}\Phi_{LPOM}}_{\text{labile POM decay}} + \underbrace{K_{RPOM}\delta_{POM}\gamma_{OM}\Phi_{RPOM}}_{\text{refractory POM decay}}$$
$$+ \underbrace{\sum K_{CBOD}R_{CBOD}\delta_{P-CBOD}\Theta^{T-20}\Phi_{CBOD}}_{\text{CBOD decay}} + \underbrace{K_s\delta_{POM}\gamma_{OM}\Phi_s}_{\text{1st-order sediment release}} + \underbrace{SOD\gamma_{OM}\frac{A_{sed}}{V}}_{\text{0-order sediment release}}$$
$$\underbrace{-\frac{\left(\sum \varpi_{ISS}\Phi_{ISS} + \omega_{Fe}\Phi_{Fe}\right)P_P}{\Delta z}\Phi_P}_{\text{inorganic solids adsorption}}$$

where:

Δz = model cell thickness, m
A_{sed} = sediment surface area, m^2
V = cell volume, m^3
P_P = adsorption coefficient, $m^3\ g^{-1}$
δ_{Pe} = epiphyton stoichiometric coefficient for phosphorus
δ_{Pa} = algal stoichiometric coefficient for phosphorus
δ_{POM} = organic matter stoichiometric coefficient for phosphorus
$\delta_{P\text{-}CBOD}$ = phosphorus/CBOD stoichiometric ratio
γ_{OM} = temperature rate multiplier for organic matter decay
Θ = temperature rate multiplier for CBOD decay
R_{BOD} = conversion ratio for 5-day CBOD to CBOD ultimate
ω_{ISS} = inorganic suspended solids settling velocity, $m\ sec^{-1}$
ω_{Fe} = particulate organic matter settling velocity, $m\ sec^{-1}$
K_{ag} = algal growth rate, sec^{-1}
K_{ar} = algal dark respiration rate, sec^{-1}
K_{eg} = epiphyton growth rate, sec^{-1}
K_{er} = epiphyton dark respiration rate, sec^{-1}
K_{LDOM} = labile DOM decay rate, sec^{-1}
K_{RDOM} = refractory DOM decay rate, sec^{-1}
K_{LPOM} = labile POM decay rate, sec^{-1}
K_{RPOM} = refractory POM decay rate, sec^{-1}
K_{CBOD} = CBOD decay rate, sec^{-1}
K_{sed} = sediment decay rate, sec^{-1}
SOD = anaerobic sediment release rate, $g\ m^{-2}s^{-1}$
Φ_P = phosphorus concentration, $g\ m^{-3}$
Φ_{Fe} = total iron concentration, $g\ m^{-3}$
Φ_{ISS} = inorganic suspended solids concentration, $g\ m^{-3}$
Φ_a = algal concentration, $g\ m^{-3}$
Φ_e = epiphyton concentration, $g\ m^{-3}$
Φ_{LDOM} = labile DOM concentration, $g\ m^{-3}$
Φ_{LPOM} = labile POM concentration, $g\ m^{-3}$
Φ_{RDOM} = refractory DOM concentration, $g\ m^{-3}$
Φ_{RPOM} = refractory POM concentration, $g\ m^{-3}$
Φ_{CBOD} = CBOD concentration, $g\ m^{-3}$
Φ_{sed} = organic sediment concentration, $g\ m^{-3}$

(Taken from Cole and Wells (2004).)

Bio-energetic Fish Model Overview

General approach & history[2]

Winberg (1956) defined bioenergetics as the way in which animals dispose of the energy they acquire, and bioenergetic models are mass-balance equations which partition the energy to its various fates: growth, metabolism, and waste products. The Winberg equation provided the first fish energy budget by partitioning the energy of consumed food (C):

$$C = G + R + W \qquad (1)$$

Where,

G = somatic plus gonadal growth

R = total metabolic costs

W = the energy contained in waste products

The two basic management applications of the bioenergetic equation are to estimate consumption from measured growth, and to estimate growth from estimated consumption. The Winberg equation is the framework for later bio-energetic fish models, which are simply more complex energy budgets.

[2] Ney (1993) and Hansen, et al. (1993) provide a good discussion of bioenergetics modeling techniques, applications, and areas for improvement.

Individual specimen variability is not included in the parameters of the energy equations, even in individual based models. Only individual variability in size has been described. (Adams and DeAngelis, 1987; Huston, et al., 1988; Madenjian and Carpenter, 1991; Madenjjian, et al., 1993). It should be noted that an individual specimen can differ widely from the population average. For example, Hartman and Brandt (1993) examined individual striped bass, *Morone saxatilis*, compared to the sample average. The variabilities reported were:

maximum consumption	11-205%
routine metabolism	58-144%
maximum ration	29-142%

In general, bioenergetic models are considered successful (accurate) if the model-data error is 50% or better.

Improvements to the bioenergetic model approach have included both sophistication in the modeling formulations for each component (consumption, growth, metabolism, waste) and improving the selection of input data as well as the data collection methodology and technology. Of the four components, consumption is the most involved. The following sections will cover the approaches used for formulating each component.

Metabolism

The metabolism is commonly broken down into a few components, although now always with the same partitioning. Almost all models use some base rate called *standard* or resting, and some additional physiological level called *activity*. Simplifications lump the two rates together, and sophistications further partition the rates; for example, *digestion* metabolism.

Ideally, metabolic components should be determined from in situ measurements as opposed to from captive laboratory fish. Telemetry devices measuring bodily functions correlated with metabolism, such as gill ventilation rates, heart rates, and electomuscular activity, are available. (e.g., Lucas, et al., 1993). Sureau and Lagardère (1991) showed that not all fish species show a strong correlation between physiological rates and metabolic expenditures.

In many models, the activity metabolic cost is simply a fixed multiplier applied to the standard metabolic cost (Kitchell et al., 1977; Diana, 1983; Rice and Cochran, 1984; Bevelheimer, et al., 1985; Wahl and Stein, 1991). This assumption is not always appropriate, however. Madon and Culver (1993) found larval and juvenile walleyes *Stizostedion vitreum* varied with weight, and predator and food densities. Variable activity was found to provide much closer model-data comparisons. A myriad of studies show that total metabolic rates vary considerably with ambient conditions and by species and sex, sometimes a fivefold range, and can be a sizable and variable

component in the total energy budget. [See Hansen, et al., (1993), p. 1021 for numerous references.]

Since standard metabolism (R_S) changes with weight (W), and temperature (T), a common formulation is

$$R_S = a\, W^b * \exp(m*T) \qquad (2)$$

where a, b, and m are coefficients. (Kitchell, et al., 1977).

Activity costs can be determined several ways:

- Solving the bio-energetics equations using consumption data (Adams, et al., 1982; Boisclair and Leggett, 1989),
- Physiological telemetry (Lucas, et al., 1993)
- Underwater observation (Boisclair and Sirois, 1993)
- Experimental measures of swimming metabolism, telemetry and time budgets
- or a combination of these methods.

Waste

Metabolic waste is commonly partitioned into egestion (fecal wastes) and excretion (urine). The formulations used by the Bevelhimer & Adams (1993) and Stockwell & Johnson (1997) models for egestion (F) and excretion (U) are

$$F\ (cal/t) = 0.455 * T^{-0.222} * D \qquad (3)$$

$$U\ (cal/t) = 0.0233 * T^{-0.580} * (D-F) \qquad (4)$$

where T is the water temperature (°C) and D is the digestion parameter (cal/t)

The digestion parameter varies depending upon model and species, but can be a function of initial stomach content, consumption, temperature, and the energy content of the food. See the Stockwell & Johnson (1997) model section for a sample formulation.

Growth

The most common applications input growth directly from data. A common formulation is the natural log of the ratios of final to initial mass. While this approach is straightforward for individual-based models such as the Winberg Equation, additional factors must be accounted for to use the model for many fisheries management scenarios. Individual-based models must be melded with mortality, recruitment, angling, and abundance data to achieve population-based models that are suitable management tools.

The production-conversion efficiency approach relates production, P, defined as all growth in the population, to the instantaneous rate of growth, G, and the mean biomass over the time interval, B,

$$P = G * B \quad (5)$$

G is determined as the natural log of the ratio of final to initial weights. P is often determined by cohort then summed to achieve the total production estimate. If the average gross food conversion efficiency is known (G/C), then total consumption (CTOT) can be determined.

$$CTOT = P / (G/C) \quad (6)$$

The production-biomass equation offers a simpler approach (Ney, 1990). For temperate-latitude, freshwater piscivorous fish,

$$CTOT = 2P + 3B \qquad (7)$$

This approach uses broad assumptions, and is roughly equivalent to an energy apportionment of 60% metabolism, 20% growth, and 20% wastes. This ratio is widely applicable (Brett and Groves, 1979). This approach should form a good starting point for checking agreement among a more sophisticated model, data, and the production-biomass method.

A potential problem with all simple models is that with a few number of inputs and parameters, model results become more sensitive to each value.

Consumption & Foraging

The consumption parameter is the most complicated in terms of the number of physical and biological processes which are likely to be important. As such, recent research has focused on improving the consumption formulation. The physical and biological factors affecting consumption are interrelated, making them difficult to categorically discuss. For example, water temperature affects metabolic rates, stratification, and the distribution of both prey and predators. The factors influencing consumption can be organized as

- Functional response (predator-prey interaction rates)
  - Predator and prey distribution and migration
    - Predator avoidance
    - Optimizing consumption
    - Acute temperature stress
  - Foraging, feeding, prey detection
    - Foraging strategy
    - Selective predation
    - Search volume
    - Light
    - Turbidity

- Gastrointestinal
    - Stomach capacity
    - Digestion/evacuation rates
- Rate kinetics
    - Temperature functions
    - Allometric functions
- Metabolic optimization considerations
    - Allometric changes the optimal temperature-consumption relationship
    - Digestion rate and temperature relationship

Functional Response

"Functional response" is a quantification of the consumption rate as a function of prey density. Stated another way, functional response is the "per capita consumption rate of prey per predator" (Morin, 1999). Most literature cites Holling (1959, 1966) as the earliest work describing functional response; however, Soloman (1949) coined the term. The literature commonly refers to type I, II, and III functional responses[3], so a brief overview is warranted.

Functional response types

The type I response is simplest allowing consumption to be proportional to prey abundance. The type I response works well when prey is relatively scarce, but clearly is inappropriate for systems wherein prey levels are saturated. The type II and III response forms both are asymptotic to some functional response level, w, a maximum attack rate. The type II response increases with prey abundance at a continuously decreasing rate. [A familiar form is the Michaelis-Menten equation.] The type III curve is sigmoidal: the response initially increases at an increasing rate and then changes concavity to increase at a decreasing rate. The type III curve reaches the maximum attack rate much faster than the type II curve. The mathematical formulations are shown in Table 7 and a qualitative comparison is plotted in Figure 3.

[3] The type I, II, and III functional responses do not exhaust the possible forms. For example, not discussed are the Holling type IV or Monod-Haldane type functional response, often seen at the microbial level in wastewater treatment.

Table 7. Functional response equation forms, type I, II, and III.

Type I	Type II	Type III
$F(H)=aH$	$F(H)=\frac{wH}{D+H}$	$F(H)=\frac{wH^2}{D^2+H^2}$

where
F(H) = functional response
H = prey abundance
a = linear constant
w = maximum attack rate
D = empirical constant

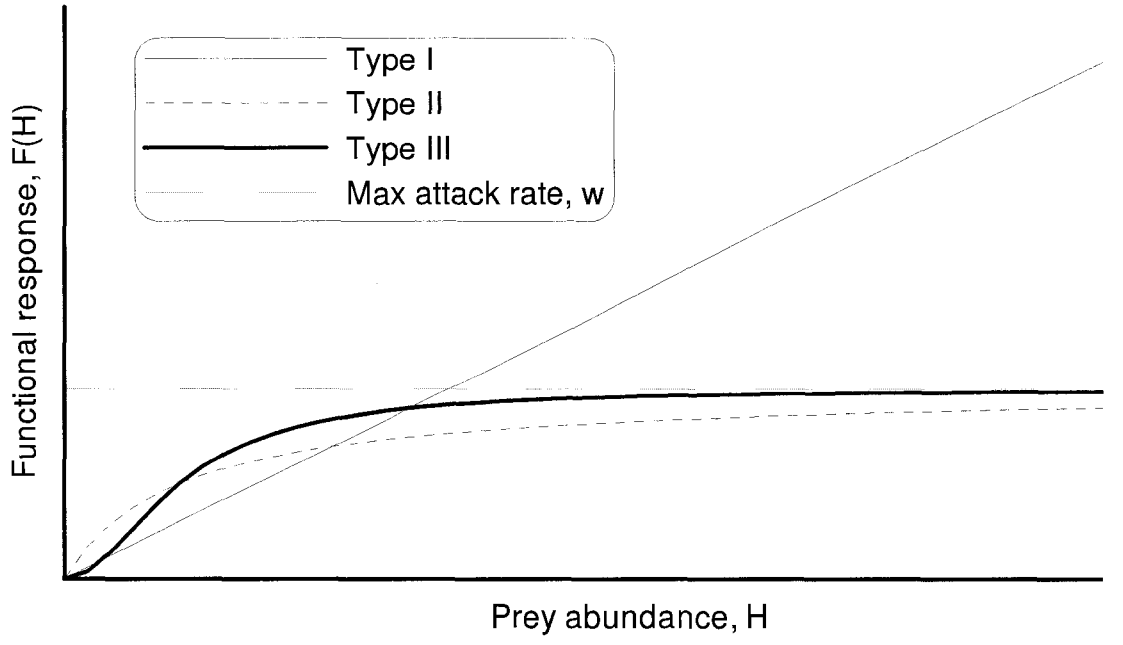

Figure 3. Functional response curves, type I, II, and III.

Koski and Johnson (2002) had the following to note regarding fish functional response types, and helps give a physical interpretation:

A type I functional response is often observed in filter feeders whose prey is distributed homogeneously in the environment. Consumption rate increases linearly with prey density until saturation occurs. Handling time is an important constraint in the type II functional response. As prey density increases, more time is spent handling or processing prey, and less time is spent searching for it until, at prey saturation, all time is spent handling prey. Planktivorous fishes that particulate-feed or gulp-feed, or that forage in environments where prey are patchy, typically exhibit a type II functional response (Smith, 1998). The type III functional response arises when multiple prey types are available and switching behavior occurs (Smith, 1998). As the density of one prey type increases, a search image is developed and the predator switches to feeding on that prey. As with the type II functional response, handling time limits feeding rate at high prey density. (p. 707-708)

Population spatial distributions

Algae, zooplankton, and fish are typically distributed unevenly in both the vertical and horizontal planes. Distributions can vary daily, such as the diel vertical migration; seasonally, such as migrating to different regions of food availability; or by allometric factors—for example, adult zooplanktivores often spend more time in deeper, colder water than juveniles; and adult fish have larger mouths and can seek out different prey and are less vulnerable to predation by other fish.

For large waterbodies, it may be inappropriate to model horizontal movement without some restriction. Henderson and Northcote (1985) found that cutthroat trout spend most of their time within an approximately 100 m^2 area and periodically changed that smaller search area. Also, many fish species form schools to reduce predation risks.

Zooplankton exhibit patchy distributions (Wiebe, 1971; Stavn, 1971; George and Edwards, 1973). Predators are likely to remain near prey patches once found. Thus, spatial patchiness must be directly or indirectly accounted for in modeling predation.

Bioenergetics models often use known or heuristic distribution as model input. The factors influencing movement and migration are complex and can easily be discussed ad nauseum. Broadly, however, the factors include a balance between

food availability vs. predation risk

&

food availability vs. metabolic costs which vary with temperature

These drivers (food availability, predation risk, metabolic costs) are in turn complex and vary among both predator and prey by species, by age and size, and by ambient visibility (light, turbidity, and prey and predator age and species). A common modeling assumption based on field data is that fish will locate themselves at a depth where light is at or above their visual irradiance threshold whenever possible.

In order for a predator-prey encounter to occur, the population distributions must overlap. Given the relatively small visual detection range of predators (~ 1m or less), and that predators tend to search over a horizontal plane, correctly capturing the vertical distribution of predator and prey is critical (Savitz and Bardygula (1989), Beauchamp, 1994).

Visual foraging

Successful foraging requires 1) *accessibility*[4]: that the predator and prey distributions overlap, and the predator must be able to detect the prey; as well as 2) *preference*[5]: that the predator must pursue the prey, and the predator must balance the metabolic

[4] Accessibility: the opportunity to pursue prey.

[5] Preference: the willingness to pursue prey.

costs of foraging with the energy gained and any additional risk of predation. Some key features of visual foraging are discussed.

Reaction distance and search volume

For visual feeders, reaction distance[6] and prey density play an important role in determining feeding & growth strategies. Many visual predators are documented to be most active or successful during crepuscular feeding (Beauchamp, 1990; Beauchamp, et al., 1992) as the dynamic reaction distance and prey distribution allows for increased feeding opportunities. Spatially, the reaction distance changes vertically with light extinction and turbidity; temporally, the reaction distances changes with incident light and changing water chemistry (as applicable). Many mobile prey species will undergo diel vertical migrations to balance feeding opportunities and predation risk.

Pelagic salmonids are predominately visual feeders (Ali, 1959). A common approach in determining predator-prey encounter rates is to assign a volume of water searched (a "search volume") per unit time as a function of swimming rate times the detection (or reactions) distance (E.g., Vogel & Beauchamp, 1999). In effect, this is a cylinder of radius equal to the reaction distance and height of the length traveled during the timestep (i.e.,. swimming speed times time interval). This lumped approach is

[6] Reaction distance is also referred to as reactive distance, especially in older literature.

assigned for each timestep of the model with the appropriate feeding conditions. Note that search volume will vary with the square of reaction distance, making the model sensitive to the value of the reaction distance. Refinements include ontogenic prey preferences, variation of swimming speed with temperature, time, age-class, predator size (mass or length), and variation of the reaction distance with age, light, and turbidity. Ali (1959) demonstrated minimum light level thresholds for salmonid feeding.

Confer, et al., (1978) showed that the cross-section of the search pattern in lake trout is a polygon, and that the reaction distance from the snout in the dorsal, ventral, nasal, and temporal directions differs.

In laboratory settings, reaction distance is determined from the point at which the predator responds to the presence of the prey. Typical behavior includes orienting toward the target, a cessation of forward motion, and flaring of pectoral fins. (E.g., Henderson and Northcote, 1985)

Breck (1993) demonstrated that zooplanktivores and piscivores reaction distances are not comparable due to the differences between acuity-based (zooplanktivores) and contrast-based (piscivores) detection methods. Reaction distances in contrast-limited systems (such as crepuscular visual piscivore systems) are expected to be minimally prey-size dependent at large distances (Eggers, 1977; Breck, 1993).

A list of commonly cited feeding studies for visual zooplanktivores and piscivores are shown in Table 8.

Table 8. List of visual predator feeding studies.

Visual zooplanktivores	Visual piscivores
Ali (1959)	Cerri (1983)
Werner and Hall (1974)	Howick and O'Brien (1983)
O'Brien, et al., (1976)	Savitz and Bardygula (1989)
Vinyard and O'Brien (1976)	Petersen and Gadomski (1994)
Confer, et al., (1978)	Miner and Stein (1996)
Hyatt (1980)	Beauchamp, et al. (1999)
Wright and O'Brien (1984)	Vogel and Beauchamp (1999)
Henderson and Northcote (1985)	Mazur and Beauchamp (2003)
Koski and Johnson (2002)	

Stockwell and Johnson (1999) showed that during periods of weak stratification (spring to early summer), foraging depth had little influence on bio-energetics, so light level and prey density are important variables during these periods. During strong stratification, the hypolimnion has low prey densities and foraging time is increased. Thus, small fish may find it more favorable to reach feeding capacity in epilimnion where the predation risk is higher. Larger fish have an increased search volume often due to increased swimming speed and reaction distance, and may benefit from favorable kinetics in the hypolimnion where they can feed for longer durations. However, the surface may not always be accessible due to high water temperatures.

Mazur and Beauchamp (2003) found that lake char roughly doubled their swimming speed under low light conditions; similar behavior was noted for northern pikeminnow feeding on juvenile salmon by Petersen and Gadomski (1994).

Juvenile Pacific salmon are known to ascend into shallower depths at or after dusk and either swim against the current or become displaced. Ali (1959) found that salmon eyes take longer to become "dark adapted" (i.e., acquire good night vision) than the rate of the loss of light. He asserts that in their nearly blind state, salmon may be using the current to help establish some reference point and that the poor vision accounts for the known displacement of juvenile salmon at dusk.

Some important light levels for kokanee foraging are reported in Table 9.

Table 9. Important light levels for kokanee foraging.

Light level (lx)	Physical interpretation	Feeding rate	Source
$\sim 10^{-5}$	Minimum night vision	Minimum laboratory feeding	Ali (1959)
~ 0.1	Clear moonlit night	Minimum feeding	Koski and Johnson (2002)
15 to 30	Crepuscular periods	Just above SIT	Koski and Johnson (2002)

Visual irradiance threshold (VIT) & Saturation irradiance threshold (SIT)

Visual feeders forage best with some light. Studies have quantified both a minimum light level to allow for visual detection, the visual irradiance threshold, and likewise a saturation irradiance threshold above which the additional light can impede visual foraging.

As a fish develops, the eyes continue to develop; therefore, the VIT and SIT may change with age.

Vogel and Beauchamp (1999) were the first to study the combined effect of light, turbidity, and prey size. (Other studies had simultaneously considered two variables.) They found that reaction distances were not sensitive to prey fish size in clear water (0.09 NTU). A strong correlation existed between reaction distance (RD) and light and turbidity ($R^2 = 0.984$, SIT = 17.83 lx, $P<0.001$). Studies finding a SIT are useful for models as they establish an upward limit to the reaction distance. The authors point out that at higher light levels, prey may benefit more than predators due to greater reaction distances (citing Howick and O'Brien, 1983) and increased predator evasion effectiveness (citing Savitz and Bardygula, 1989; Petersen and Gadomski, 1994).

As seen in Table 10, the SIT varies by both predator and prey.

Table 10. Selected light thresholds for maximum reaction distances

Light threshold (lx)	Predator	Prey	Reference
50-180	lake trout	zooplankton	Confer, et all, 1978
3	Dolly Varden	zooplankton	Henderson and Northcote, 1985
5-56	cutthroat trout	zooplankton	Henderson and Northcote, 1985
>10	bluegill	zooplankton	Vinyard and O'Brien, 1976
5.59	largemouth bass	bluegill	Howick and O'Brien, 1983
17.83	lake trout	rainbow trout & cutthroat trout	Vogel and Beauchamp, 1999
3.4	juvenile pacific salmon	Daphnia	Ali, 1959
17.83	rainbow & cutthroat trout	rainbow & cutthroat trout	Mazur and Beauchamp, 2003

Prey selection

When visual feeders are able to distinguish prey, some species are known to practice selective predation which may include preferentially pursuing larger prey. Kokaneee are highly selective for Daphnia over other zooplankton (Baldwin, et al., 2000; Scheuerell, et al., 2005). At low prey densities, field studies (stomach content analyses) suggest that zooplanktivores will pursue any detected prey; however, at higher prey densities, simultaneously detected prey will be pursued based on some

criteria such as visibility (O'Brien, et al., 1976), or caloric content (Werner and Hall, 1974). Thus, selectiveness increases with prey density and has little effect at low prey densities (Confer, et al., 1978).

Note that for some conditions, only some prey species may be detectable, so zooplanktivores may exhibit selective predation (e.g., based on size) even though the predator is not making any choices in pursuit as the predator is only detecting a single prey species. Confer, et al. (1978) asserts that Galbaith's (1967) data bears this out.

Diel vertical migration (DVM)

Many zooplankton and fish are known to migrate vertically in the water column. Several studies have shown that this behavior in zooplankton is at least partly a predator avoidance strategy (e.g., McNaught and Hasler (1964, 1966), Haney and Hall (1975), Confer, et al. (1978)). Field studies have found zooplankton depths consistently placed below the dominant predator's VIT. However, the DVM of zooplankton can also result in long periods in which the prey reside at optimal foraging depths for predators (McNaught and Hasler ,1964; Clark & Levy, 1988; Scheurell & Schindler, 2003).

Gastrointestinal

The Bevelhimer & Adams (1993) and Stockwell & Johnson (1997) models use an intermediate parameter, digestion (D), to formulate the waste parameters of egestion and excretion. Based on the Bevelhimer & Adams formulation, the Stockwell & Johnson digestion parameter, formulated for kokanee feeding on Daphnia, is

$$D\left(cal/t\right) = \left(\frac{C \cdot m - M_O/r}{1 - e^{-r \cdot t}} + C \cdot m \cdot t \right) \cdot E_{dap} \qquad (8)$$

where

C = consumption (Daphnia/ min)

m = mass of Daphnia, wet (wet mg)

M_O = initial mass of stomach content (wet g)

r = digestion coefficient = 0.0140*T – 0.0154

T = temperature (°C)

t = model timestep (min)

E_{dap} = energy density of Daphnia (cal/ wet g)

Related to the digestion rate is the consumption limiting concept of the stomach capacity. Interestingly, the model predicts an ontogenetic shift in foraging strategy around about 300-g of kokanee mass. Smaller fish reach stomach capacity relatively

quickly, and so must feed longer to increase growth. Larger fish rarely reach stomach capacity, so have the option of feeding faster (reduced handling time, or increased prey size).

Feeding rate and stomach capacity can be sensitive parameters. Laboratory tests may overestimate long term feeding rates. The B & A model does not allow feeding once stomach capacity is reached, but assumes maximum feeding rates even when near satiation. Stockwell and Johnson (1997) point out that Godin (1981) "experimentally demonstrated that feeding rates of juvenile pink salmon (*O. gorbuscha*), after satiation, were approximately equal to their gastric evacuation rate." The determination of feeding rates is difficult, and laboratory determined rates using pelleted food may not be applicable to in situ models (Beauchamp, et al., 1989). Some fish species, such as rainbow trout, are capable of removing water from their prey by squeezing their stomachs, and thereby increasing stomach food densities and increasing the effective stomach capacity. (Luecke and Brandt, 1993). Stockwell, et al. (1999) found that kokanee were able to approximately double the zooplankton dry density in their stomachs.

Rate kinetics

The influence of temperature on rate kinetics is widely studied. A cursory examination of the Stockwell & Johnson model parameters (**Table 11**) shows that temperature affects consumption, swimming speed, and metabolic rates (digestion, egestion, respiration, excretion).

Some parameters may be sensitive to fish allometry, specifically mass, length, and age. Larger, older fish tend to swim faster and require more energy for respiration. As fish age, they use energy differently in terms of physiological development, so the conversion of energy to mass changes. Obviously, larger fish are able to consume larger prey items and have a larger stomach capacity.

Refer to the section of the Stockwell & Johnson model for sample formulations.

Prominent model: Stockwell & Johnson

After the Winberg equation (1956), there are a series of prominent models, the Wisconsin model (Kitchell, et al., 1977), Hewett & Johnson (1987), Hanson, et al. (1997), Bevelhimer & Adams (1993), and Stockwell & Johnson (1997, 1999). Currently, the Stockwell and Johnson model is representative, although each application typically differs in some parameter formulation to be application specific.

Stockwell and Johnson (1997) used a modified Bevelhimer and Adams (1993) bio-energetics model for kokanee salmon in Blue Mesa Reservoir, Colorado. This model will likely be similar to the model incorporated into CE-QUAL-W2, so it is a good choice for an in-depth examination of a fish bio-energetics model. The Bevelhimer and Adams (1993) model, or B & A model, is based on the mass-balance equation used by Kitchell, et al. (1977):

$$G = C - (R + F + U) \qquad (9)$$

where

G = specific growth rate ($g * g^{-1} * day^{-1}$)

C = specific rate of consumption

R = specific rate of respiration

F = specific rate of egestion

U = specific rate of excretion

The B & A model differs from the Wisconsin model in four ways as reported by Stockwell and Johnson, (1997):

1. Consumption is modeled as a type-II functional response, modified by a temperature-dependent digestion function.
2. A 30-minute timestep is used.
3. Fish are allowed to vertically migrate.

Data requirements for the B & A model include vertical profiles of water temperature and prey densities, initial fish mass, a temporal vertical distribution of the fish, fish feeding status (feeding or not feeding)[this also yields a feeding duration], fish swimming speed, and mean prey size. The model is run using 30-minute timesteps over a 24-hour period after which growth is calculated.

In developing the modified model, a corroborated Wisconsin model was used to as a measure. The B & A model was modified to include an explicit feeding function. The respiration and consumption functions were also modified to produce growth estimates comparable to the corroborated Wisconsin model. The respiration function of Beauchamp, et al, (1989) was used. The consumption function was modified so that "the amount of [prey] biomass consumed in each timestep was modified by Thornton and Lessem's (1978) temperature function (Beauchamp, et al., 1989; Table 1)." The other parameter formulations were as per the B & A model. A summary of

the model parameter formulations is taken from Stockwell and Johnson (1997) as Table 11.

The resulting model has respiration and consumption rates qualitatively similar to the Wisconsin model. Figure 4 shows the energy budget for a 500-g kokanee taken from Stockwell and Johnson (1997). "C-losses" is consumption minus losses, which is growth, as evident in Equation (9).

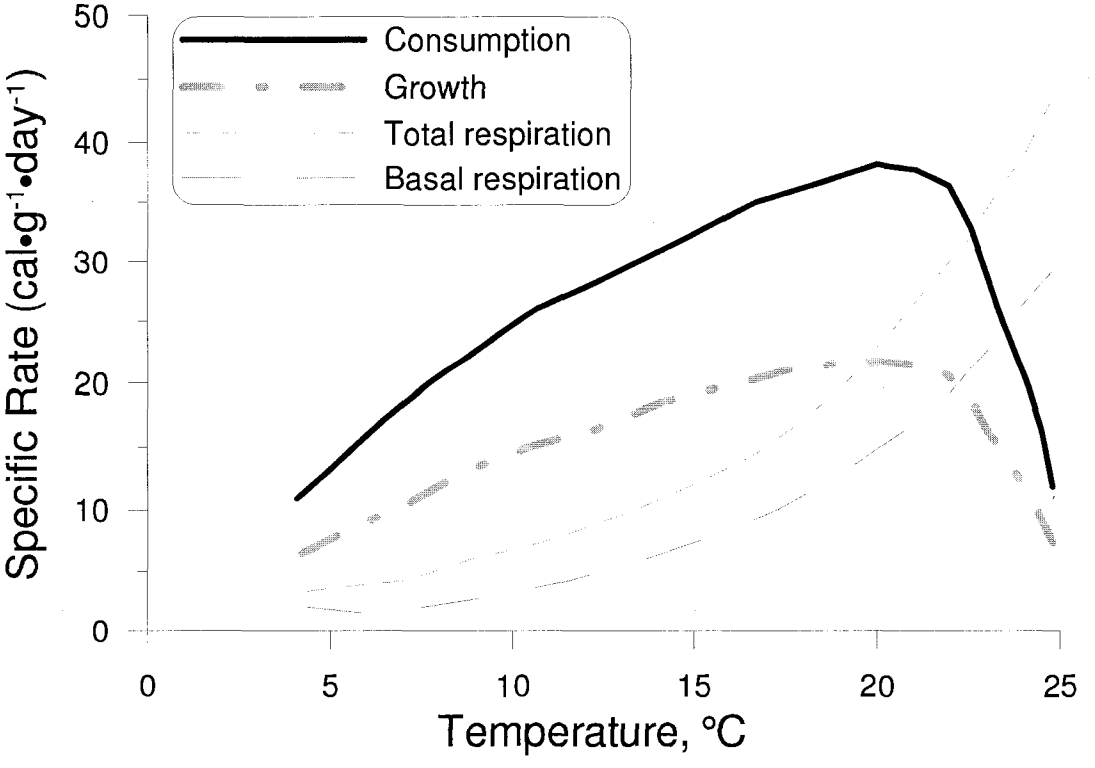

Figure 4. Stockwell and Johnson energy budget for a 500-g kokanee.

Sensitivity analysis and model calibration, by age classes, showed that prey handing time and feeding duration are very sensitive parameters and that using realistic, but

uncalibrated values can result an inability of the model to simulate observed growth or even positive growth. The calibrated model suggested that older fish (age-2, age-3 kokanee) feed most of the day and are capable of gulp or filter feeding. Stockwell and Johnson (1997) stated that they were unaware of any studies of kokanee feeding at high zooplankton densities (only lower prey densities), but stated there were studies of planktivorous fish switching from particulate to filter feeding at threshold prey densities (e.g., Gibson and Ezzi, 1992).

Table 11. Stockwell & Johnson (1997) model summary.

Parameter	Value	Source
	Consumption (C)	
C (Daphnia$_*$min^{-1})	(Ez)/(1+Ezh)TL(60)	
E, volume searched (m^3)	$(\pi R_d^2)/3(3v^2+u^2)/v$	1
TL, Thornton-Lessem function	$[(0.58e^{(0.21(r-3))})/(1+0.58(e^{(0.21(r-3))})-1))]$ $[(0.5e^{(0.97(24-T))})/(1+0.5(e^{(0.97(24-T))})-1))]$	2, 3
R_d, reaction distance (m)	0.08	4
v, kokanee swimming speed (cm/sec)	$9.9\ e^{(0.0405*T)}\ M^{0.13}$	3
u, Daphnia swimming speed (cm/sec)	0	
z, prey density (Daphnia/m^3)		
h, handling time (sec/Daphnia)	0.33 to 1.2	
T, temperature (°C)		
M, kokanee mass (wet g)		
Stomach capacity (wet g)	M [14.1 – 4.95 $\log_{10}$(M)]/100 for M <253.5 g 0.022 M for M ≥ 253.5 g	5
m, Daphnia mass (wet mg)	$0.5*0.052\ L_d^{3.012}$	6
L_d, Daphnia length (mm)		
	Digestion (D)	
D (cal/t)	$[((C_*m - M_o/r)(1-e^{-rt})) + (C_*m_*t)]\ E_{dap}$	7
r, digestion coefficient	0.0140 T – 0.0154	8
M_o, initial stomach content mass (wet g)		
t, model time step (min)	30	9
	Respiration (R)	
R (cal/g/t)	$0.00143\ M^{-0.209}\ e^{(0.086T)}$ ACTIVITY$_*$OXYCAL$_*$t/t_{day}	3
ACTIVITY	$e^{(0.0234*VEL)}$	3
VEL	$9.9\ e^{(0.0405*T)}\ M^{0.13}$	3
OXYCAL, oxycaloric conversion factor (cal/g-O_2)	3241	
t_{day}, length of day (min)	1440	
	Egestion (F)	
F (cal/t)	$0.455_*T^{-0.222}{}_*D$	10
	Excretion (U)	
U (cal/t)	$0.0233_*T^{-0.580}{}_*$ (D-F)	10
	Specific dynamic action (SDA)	
SDA (cal/t)	0.14(D-F)	11
	Energy density	
E_{dap} (cal/wet g – Daphnia)	586	12
E_{kok} (cal/wet g – kokanee)	1.851 M + 1250 for M ≤ 196 g 0.1254 M + 1588 for M ≥ 196 g	10

Notes: Sources are as follows: 1) Gerritsen and Strickler (1977); 2) Thornton and Lessem (1978); 3) Beauchamp, et al. (1989); 4) Hyatt, (1980) and Koski and Johnson, (2002); 5) Brett, (1971); 6) Stockwell & Johnson (1999).; 7) Elliott and Persson, (1978); 8) Brett and Higgs, (1970); 9) Bevelhimer and Adams (1993); 10) Hewett and Johnson (1992); 11) Brett and Groves (1979); 12) Richman (1958).

The model was later used to determine if kokanee diel vertical migration in Blue Mesa Reservoir could be explained (Stockwell & Johnson, 1999). They found that late summer migration patterns could be explained, but not early summer patterns. In late summer, optimal thermal habitat was spatially segregated from the food-rich surface waters and predators. This suggested that the relative importance of factors affecting diel migration are seasonal:

> It is probable that the relative importance of each factor varies from system to system. For example, in the Pacific Northwest, thermal stratification may not be as pronounced, and therefore less important, than at lower latitudes. Consequently, bioenergetic arguments may not be as important as predation n the northwest. Additionally, predation risk may vary greatly from system to system both within and among age-classes.

Hardiman, et al., (2004) subsequently examined diel migration.

Table 12 summarizes the changes in model parameters to the Stockwell and Johnson (1997) model. These values also represent published bioenergetic parameter values. Other, earlier studies may provide additional published bioenergetics parameter values: Brett and Higgs (1970); Kitchell, et al. (1977); Brett, (1983); Hewett and Johnson (1987,1992); Beauchamp, et al. (1989); Bevelhimer and Adams, (1993).

Volume 122 of the Transactions of the American Fisheries Society (1993) is dedicated to bioenergetic fish models.

Table 12. Stockwell & Johnson (1999) model parameter modifications to Stockwell & Johnson (1997) model.

Parameter	Value	Source
h, handling time (s∗*Daphnia*$^{-1}$)	1.2-0.16	Hyatt, 1980; Janssen, 1976
L_d, *Daphnia* length (mm)	1.84	Stockwell, et al. 1999
m, *Daphnia* mass (wet mg)	$0.5(0.052L_d^{3.012})$ in July & August	Stockwell, et al. 1999
r, digestion coefficient	0.0140T + 0.1135	Stockwell & Johnson, 1999
E_{dap}, (kJ∗wet g-*Daphnia*$^{-1}$)	2.42	Snow, 1972; Stockwell, et al. 1999

Table 12 is taken from Table 1 of Stockwell & Johnson (1999).

Lake Roosevelt Data Summary

This section summarizes the data available for model calibration, focusing on the years 1999 through 2004. More detail can be found in the report, "Boundary Conditions and Set-up" (McKillip, Annear, and Wells, 2006), which covered:

- A limnological overview
- Hydrodynamic boundary condition data and model inputs
- Grand Coulee Dam structures (powerhouse and spillway characteristics)
- Water temperature boundary condition data and model inputs
- Meteorological data and model inputs
- Water quality boundary condition data
- Model bathymetry data and model grid development
- Topographic shading
- Primary and secondary production data
- Kokanee hatchery release data

Bathymetry and Topography

The principal bathymetry data used to generate the model grid were the 1949 NOAA depth soundings. These soundings range from above Grand Coulee Dam to the U.S.-Canadian border and include the reservoir arms of the Sanpoil, Spokane, Colville and Kettle Rivers. Soundings were taken roughly every 100 m both longitudinally and laterally and cover the bulk of the system. Other sources were used to fill in the gaps and check for consistency. These sources include the pre-dam USGS surveys conducted in the 1930's, the USGS gage cross-section (ID 12399500), and the 1974 USBR aerial flyover during construction of the third powerhouse. USGS digital elevation coverages were merged near the banks to create a complete topographic coverage.

The resulting model grid uses a 1 m vertical resolution. The longitudinal length (DLX) varies, but is about 500 m for the non-Columbia River branches and all the Columbia River branches above Marcus Flats, which are riverine. The mainstem Columbia River segments have a DLX of roughly 1000 m.

The USGS digital elevation coverages were also used to determine the topographic shading angles for each of the 18 transects (every 20°) about each model segment. Topographic shading is most influential in the narrower reaches such as the upstream

Sanpoil and Spokane Rivers. Figure 5 shows the minimum, maximum, and mean topographic angles for each segment of the mainstem Columbia River.

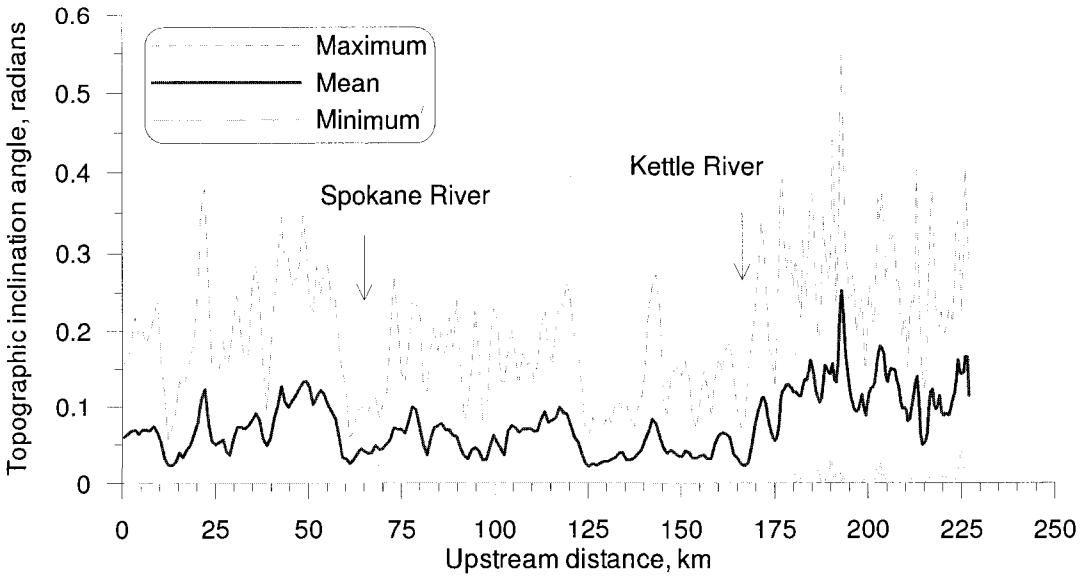

Figure 5. Topographic inclination angles, mainstem Columbia River.

Hydrodynamic Boundary Conditions

Flow data were available for the mainstem Columbia River, Colville River, Spokane River, and Kettle River at a frequency of hourly or better. No recent flow data were available for the Sanpoil River, but a comparison of historical flows showed that the Sanpoil and Colville Rivers had a similar flow magnitude and pattern. The Columbia Basin Project contained a single irrigation withdrawal just upstream of Grand Coulee Dam. Water was typically withdrawn, but under some circumstances, water was returned to Lake Roosevelt to generate additional electricity. Daily average flow records were available for these exchanges, which were roughly 5 to 10% of the mainstem Columbia River flows.

Flow through Grand Coulee Dam occurred primarily through the powerhouses. The left and right powerhouse intakes were deeper than the newer third powerhouse intakes. Hourly flow data were available for these structure flows; however, no data regarding the partitioning of the flows among the powerhouses were available. Some of the flow occurred either through spillway tubes (mainly for the summer laser-light shows) or through the drum gates. Only 5 to 10% of the daily summertime water passed through Grand Coulee Dam that was not used for power production.

The downstream boundary condition consists of both flow through the structures and the water surface elevation at the dam forebay. Flow data were also available downstream of the dam.

The locations of the hydrodynamic gages are shown in Figure 6 and the gages are summarized in Table 13. A graphic comparison of the mainstem Columbia River flows at the U.S.—Canadian border with the tributaries is shown in Figure 7. The mainstem flows typically ranged from 2000 to 4000 m^3/s (45600 to 91300 MGD), with extrema nearing 1000 and 7000 m^3/s.

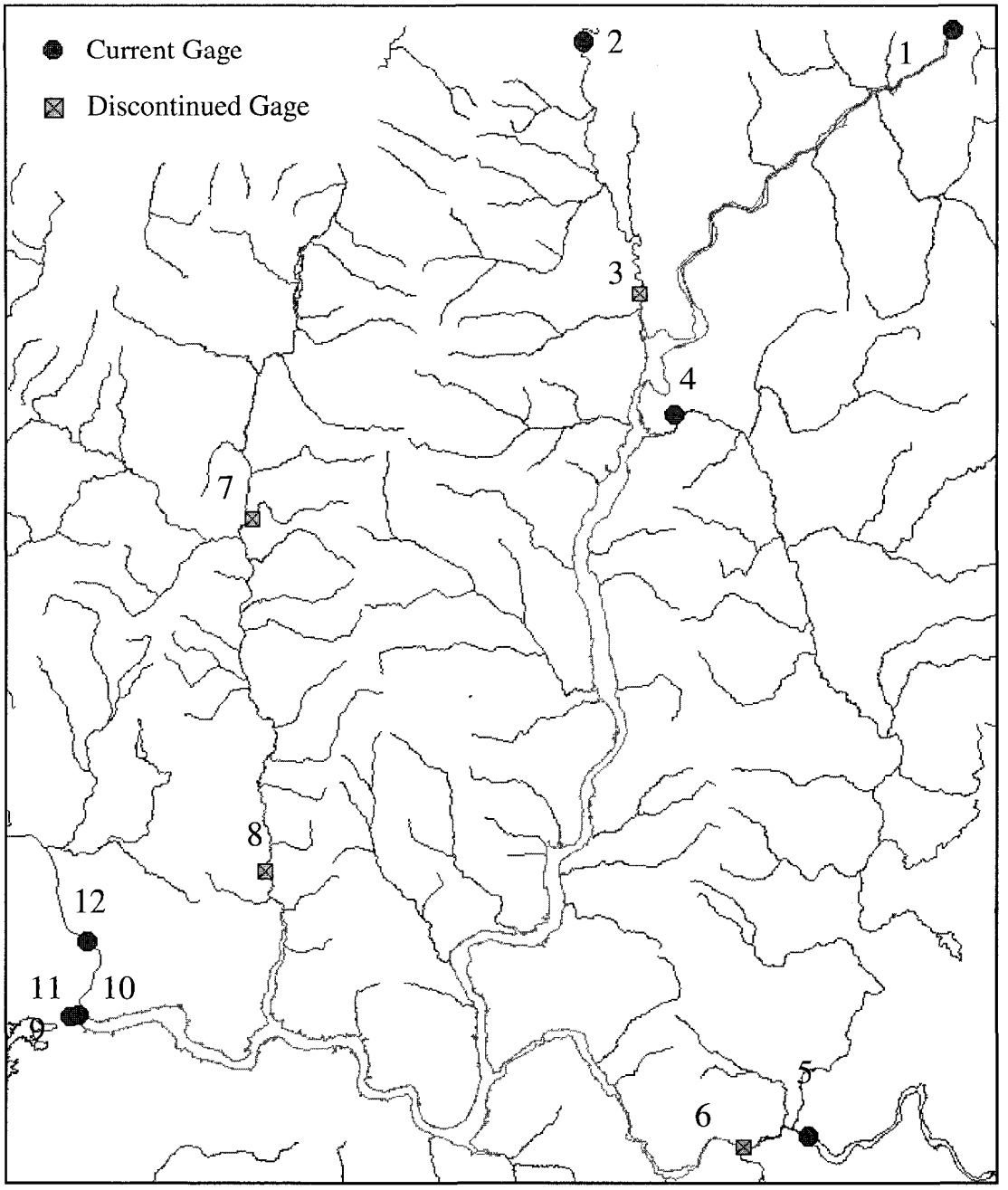

Figure 6. Hydraulic gaging station locations.
See Table 13 for gage number identification.

Table 13. Hydraulic gage station summary.

#	Station Name	Station ID	Agency	Data Freq.	Data Range
1	Columbia River at International Boundary	-12399500 -CIBW	-USGS -USACOE	-Hourly -Hourly	1/3/1938 to present
2	Kettle River near Laurier	12404500	USGS	Hourly	9/1/1929 to present
3	Kettle River at Boyds	12405000	USGS	Daily	9/10/1913 to 10/31/1915
4	Colville River at Kettle Falls	12409000	USGS	Hourly	11/1/1922 to present
5	Spokane River at Long Lake	12433000	USGS	Daily	1/4/1939 to present
6	Spokane River at Little Falls Dam	12433500	USGS	Daily	10/1/1913 to 9/30/1940
	Little Falls Dam tailrace	Little Falls	Avista Corp.	Hourly	4/1/1999 to 3/31/2002
7	Sanpoil River at Keller	12434500	USGS	Daily	9/1/1930 to 3/31/1974
8	Sanpoil R. above 13 mile creek near Republic	12433890	USGS	Daily	3/1/1972 to 3/31/1974
9	Feeder Canal at Grand Coulee	12435500	USGS	Daily	5/1/1952 to present
10	Grand Coulee Forebay	GCL	USACOE	Hourly	11/29/1966 to present
11	Columbia River at Grand Coulee (downstream)	GCGW	USACOE	Daily	1/1/1995 to present
12	Columbia River at Grand Coulee (tailwater)	12436500	USGS	Daily	1/7/1923 to present

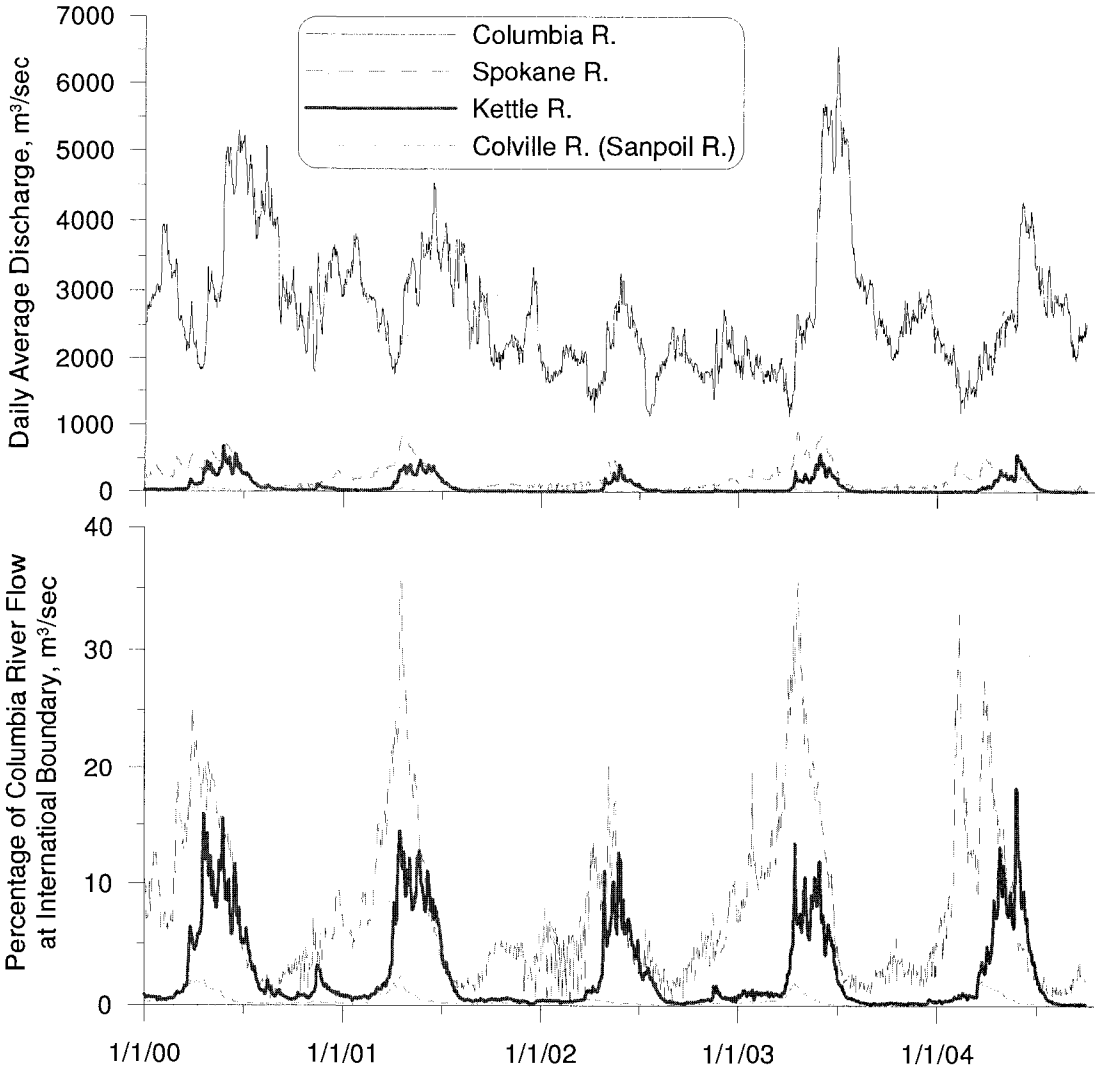

Figure 7. Comparison of daily averaged tributary flows to upstream mainstem flow.

Water Temperature Data

Hourly-averaged continuous water temperature data were available for the mainstem Columbia, Kettle, Colville, and Spokane Rivers, as well as below Grand Coulee Dam. No continuous data were available for the Sanpoil River nor the return flow from Banks Lake (Columbia River Basin Irrigation Project). There were some continuous data available above the mouth of the Spokane River and at the dam forebay. These monitoring stations are shown in Figure 8 and the gages are summarized in Table 14.

Figure 9 shows a comparison of the temperature boundary conditions from 1999 through 2001. In general, temperatures ranged from 4 to 20 °C for the mainstem Columbia and Spokane Rivers. The Kettle River ranged from 4 to 12 °C and the Colville from 6 to 8 °C.

In addition, there were several LRFEP stations reporting temperature profiles at a roughly monthly frequency. A measurement was typically made every 3 meters of depth over much if not all of the water column. These station locations are shown in Figure 10. The temperature profile data are important in establishing the amount of wind driven mixing and stratification of the system.

Table 14. Continuous temperature gage station summary.

Station Name	Station ID	Agency	Data Freq.	Data Range
Columbia River at International Boundary	-CIBW -CIBW	-USBR -USACOE	-Daily -Hourly	1/3/1938 to present
Colville River at Kettle Falls	12409000	USGS	Hourly	11/1/1922 to present
Kettle River near Laurier	12404500	USGS	Hourly	9/1/1929 to present
Columbia River at Grand Coulee (downstream)	-12436500 -GCGW	-USGS -USACOE	-Daily -Hourly	7/1/1923 to present
Grand Coulee Forebay	FDRW*	USACOE	Hourly	11/29/1966 to present
Little Falls Dam tailrace	Little Falls	Avista Corp.	Hourly	4/1/1999 to 3/31/2002
Little Falls Pool	Little Falls Pool	STOI	Daily	6/2/2004 to 11/17/2004
Spokane River	Two Rivers	STOI	Hourly	6/23/2003 to 12/18/2003
Spokane River	Two Rivers	STOI	Daily	5/25/2004 to 11/18/2004

* Temperature is also sometimes reported as USACOE GCL; FDRW and GCL are at the same location, but report different data.

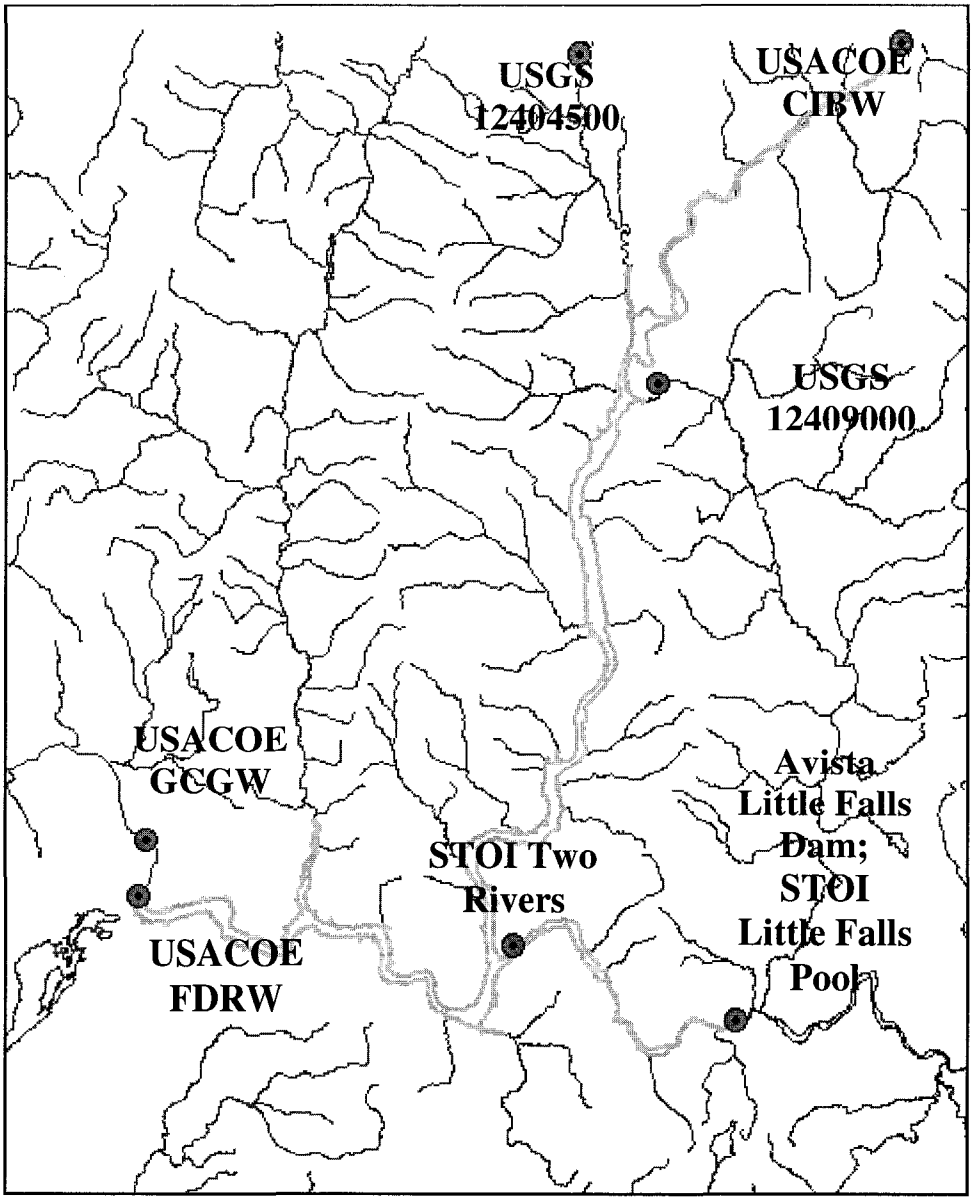

Figure 8. Continuous temperature gaging station locations.

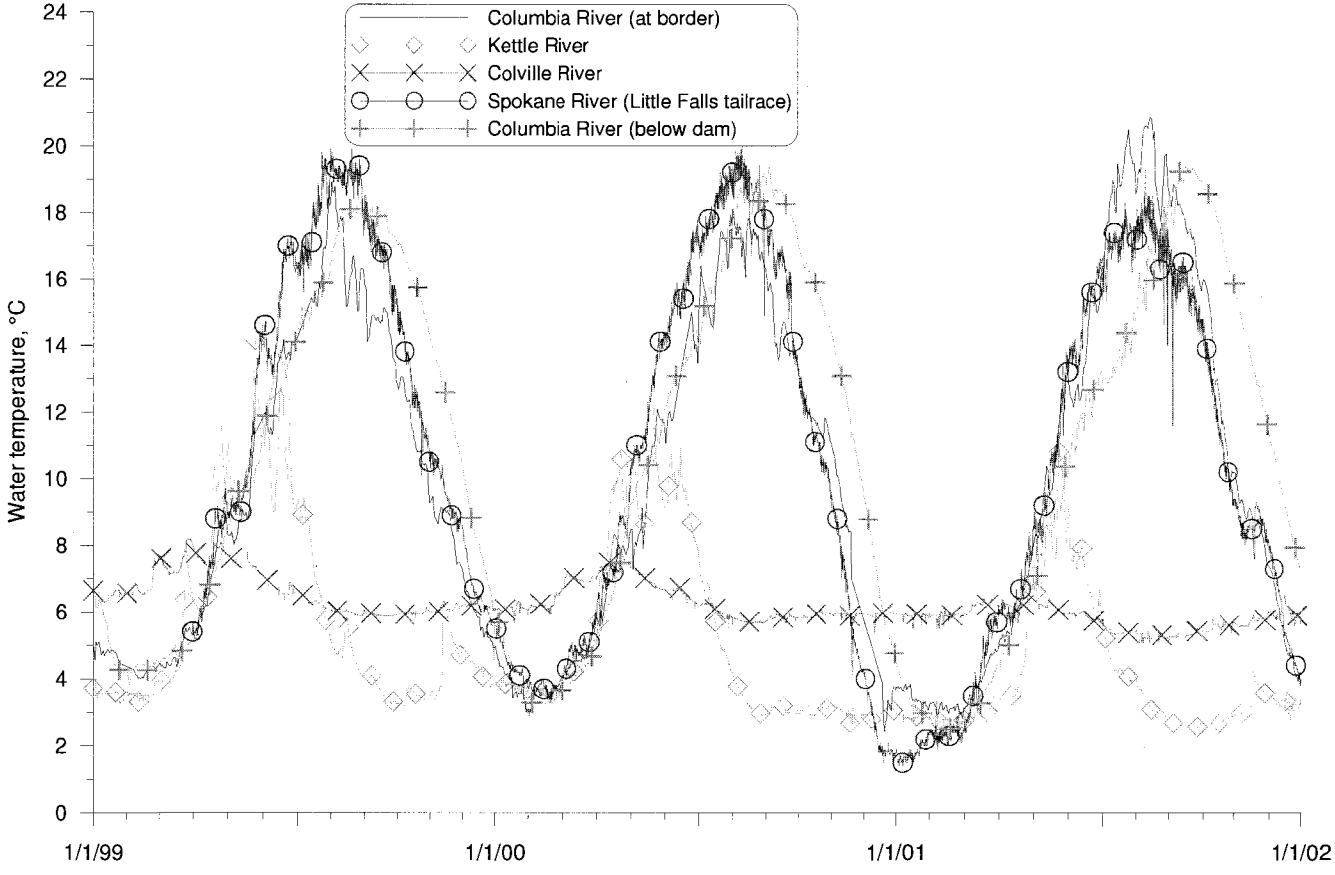

Figure 9. Water temperature boundary conditions.

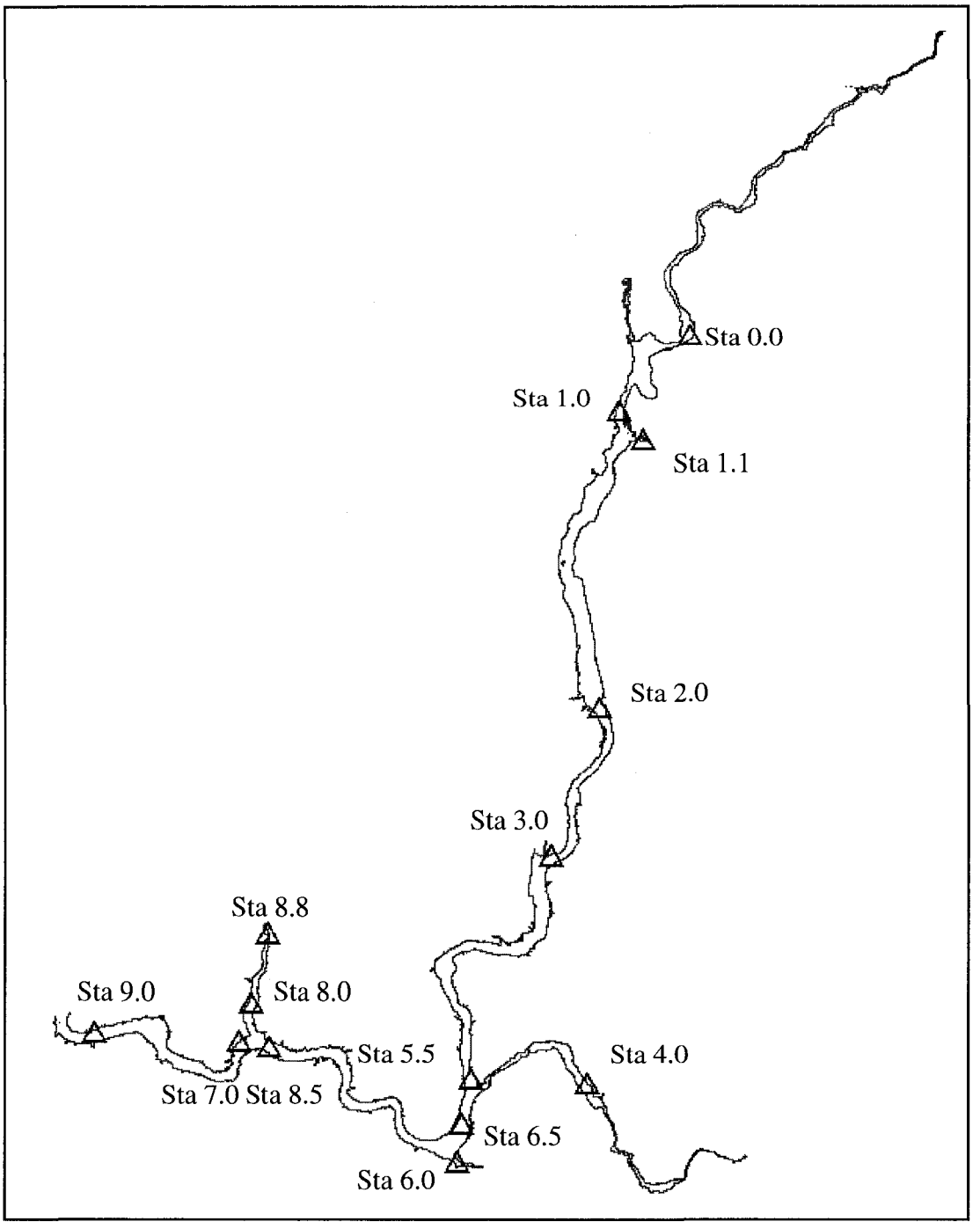

Figure 10. LRFEP water temperature profile stations.

Meteorological Data

Four AgriMet meteorological monitoring stations, the Spokane Airport station, and a single solar radiation gage were located near the model area. The gage locations are shown in Figure 11. A station summary is shown in Table 15. The AgriMet stations monitor air temperature, relative humidity (or dew point temperature), wind speed and direction, and solar radiation. Meteorological data were also collected at the Spokane Airport (WBAN# 24157); however, the climate at the Spokane Airport differed markedly from the climate near Lake Roosevelt and the lower portions of the Spokane River included in the model area. The different geography can be seen in Figure 11. In contrast to the other sites, the Spokane Airport does monitor cloud cover.

The University of Oregon operated the Solar Radiation Monitoring Laboratory (SRML) site at Cheney, Washington. While the AgriMet stations were closer to the model area, the site at Cheney provided another set of data for comparisons as well as a data source to fill in any solar radiation data gaps in the AgriMet solar data.

Table 15. Meteorological station summary.

Station Name	Station ID	Agency	Elev., m	Latitude	Longitude	Install Date
Grand Coulee Dam	GCDW	AgriMet	402	47.945278	118.953611	4/17/2002
Kettle Falls	KFLW	AgriMet	408	48.595000	118.124167	4/18/2002
Seven Bays Marina	SBMW	AgriMet	418	47.855278	118.341111	4/17/2002
Odessa	ODSW	AgriMet	503	47.308889	118.878611	4/24/1984
Spokane Airport	Spokane	NCDC	726	47.617	117.533	1/1/1990
Cheney SRML	Cheney	SRML	777	47.490000	117.589000	10/1/2000

A comparison of the annual rainfall data is shown in Table 16 for 2003 and 2004. The basin received less rainfall as one traveled down the river length.

Statistical summaries are presented for air temperature (Table 17), relative humidity (Table 18), windspeed (Table 19), and solar radiation (Table 20). Air temperatures generally ranged from -5 °C to 30 °C, excepting extrema. Relative humidity generally ranged from 75 to 100 during the winter and 25 to 75 during the summer. Windspeed was generally non-zero, with daily average peaks in the 5 to 10 m/s range. Windspeed varied little both seasonally and among the 3 stations near the lake (KFLW, SBMW, GCGW). Wind direction was generally aligned along the axis of the reservoir near the station. Except the site at Cheney, the solar radiation data exhibited an increasing trend moving south.

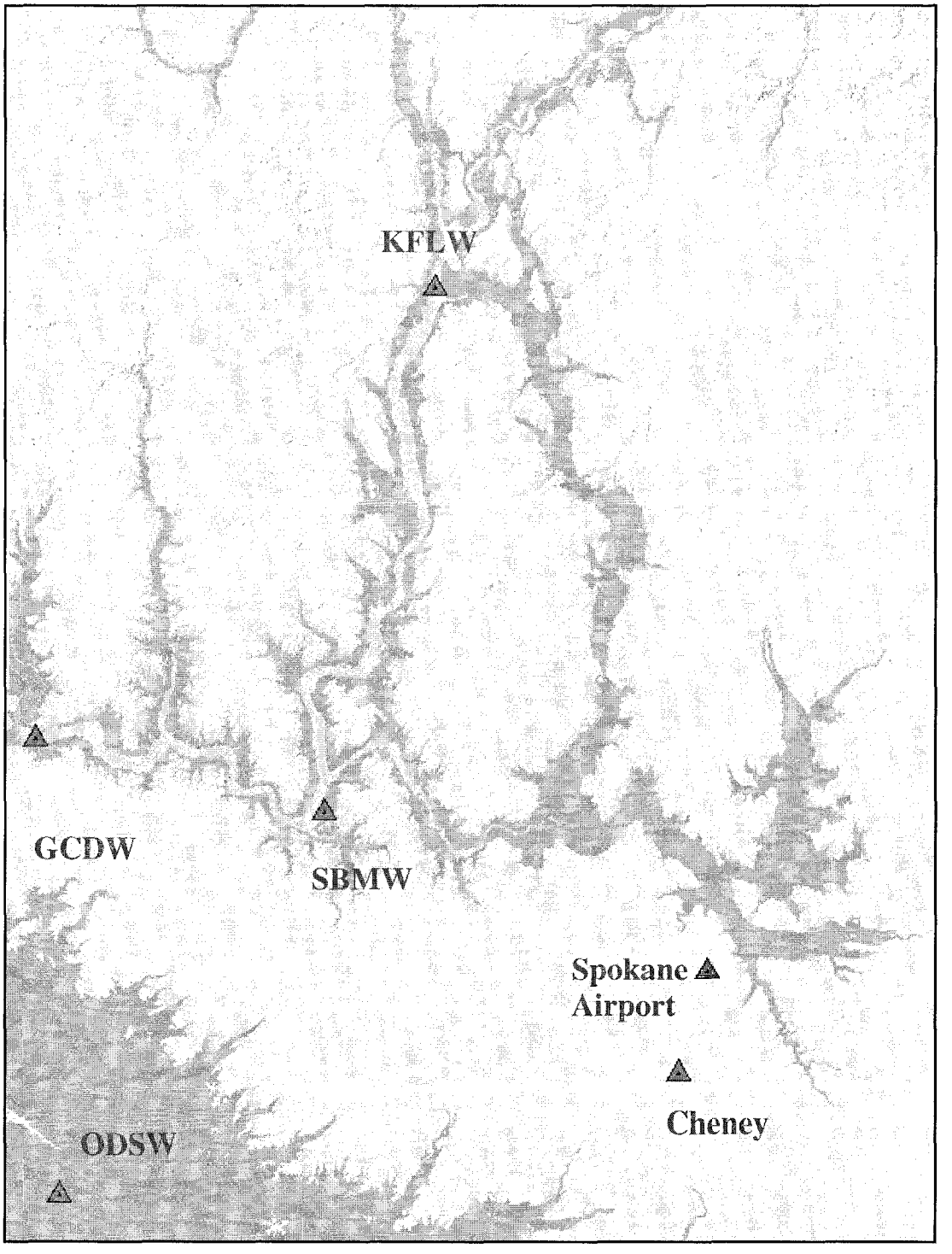

Figure 11. Locations of meteorological stations.
Table 15 shows the site abbreviations.

Table 16. Annual rainfall.

Year	Annual rainfall, mm			
	KFLW	SBMW	GCGW	ODSW
2003	359	278	162	193
2004	337	252	163	154

Table 17. Statistical summary of hourly averaged air temperature data, °C.

Station	N	Mean	Median	St. Dev.	Min.	Max.	Q1	Q3
KFLW	19832	11.28	10.61	9.74	-17.17	39.17	3.03	18.29
SBMW	19859	12.35	11.67	9.64	-11.00	41.00	3.84	19.22
GCDW	19889	13.09	12.73	9.56	-8.08	40.50	4.69	20.26
ODSW	19832	10.91	10.28	9.52	-15.56	40.72	2.69	17.62

Table 18. Statistical summary of hourly averaged relative humidity data.

Station	N	Mean	Median	St. Dev.	Maximum
KFLW	17045	68.49	72.05	22.90	100.0
SBMW	17045	60.93	63.49	24.12	99.6
GCGW	16769*	62.06	63.37	23.45	100.0
ODSW	17045	62.66	64.22	26.83	100.0
*276 missing GCGW values.					

Table 19. Statistical summary of hourly averaged wind speed data, m/s.

Station	N	Mean	Median	St. Dev.	Maximum
KFLW	17045	1.49	0.96	1.31	20.0
SBMW	17045	1.45	1.10	1.08	9.56
GCGW	17045	1.79	1.43	1.23	20.0
ODSW	17045	2.50	2.24	1.62	13.2

Table 20. Statistical summary of hourly averaged solar radiation data, W/m^2.

Station	N	Mean	Median	St. Dev.	Maximum
KFLW	17045	160.64	5.47	248.33	1040
SBMW	17045	169.03	8.26	255.97	1037
GCGW	17045	170.71	8.14	254.91	1022
ODSW	17045	172.07	10.35	251.02	989
Cheney	17520	157.35	4.00	241.13	1077

Water Quality Data

Water quality data were available from the USGS, Environment Canada, Washington Department of Ecology (Ecology), the Lake Roosevelt Fisheries Evaluation Program (LRFEP), the Spokane Tribe of Indians laboratory (STOI), and Avista Utilities. The locations of the monitoring sites are shown in Figure 12 and listed in Table 21. The USGS grab samples were available at both active and historical flow gaging stations. The LRFEP has collected pelagic and shore water quality data at several locations since 1999. These data included the only vertical profile data. In addition to in situ testing using a hydrolab, water samples were collected and analyzed by the STOI laboratory. The Environment Canada data were used to generate most of the upstream Columbia River boundary conditions. The USGS data downstream from the upstream boundary condition were used to complete the upstream model boundary conditions.

Boundary condition data for the model tributaries (Hawk Creek; Spokane, Sanpoil, Kettle, and Colville Rivers) were limited in breadth, frequency, and period of collection. The USGS collected grab samples upstream of the model boundaries on the Spokane, Kettle, and Colville Rivers. The sampling frequency was low (less often than monthly) and sampling for many constituents ceased during the 1960 to 1980 time period. No data were available upstream of the Sanpoil River and Hawk Creek. To address these limitations, the LRFEP data were used to synthesize the tributary water quality inputs.

There were no Army Corps of Engineers or U.S. Bureau of Reclamation water quality data located within the study area.

Figure 13 illustrates the availability of the water quality data by year (1999 to 2004), constituent, and monitoring station. In general, partial or complete data for suspended solids, carbon, phosphorous and nitrogen speciation, and dissolved oxygen existed for the Columbia River, Kettle River, and Spokane River for most years. Generation of the appropriate CE-QUAL-W2 input constituents required some estimation since some years have sparser data than others. Notably, the Spokane River did not have as much data available as the Columbia and Kettle Rivers.

Kiser (1967) found Roosevelt and Banks Lakes to be similar in chemical and plankton characteristics. Since there were no current water quality data for Banks Lake, water returned to Lake Roosevelt from Banks Lake will be characterized similarly to the downstream boundary conditions (i.e., at Grand Coulee Dam where Banks Lake exchanges water).

The LRFEP stations record light extinction data: Secchi disc depth, surface irradiance, and photic zone depth.

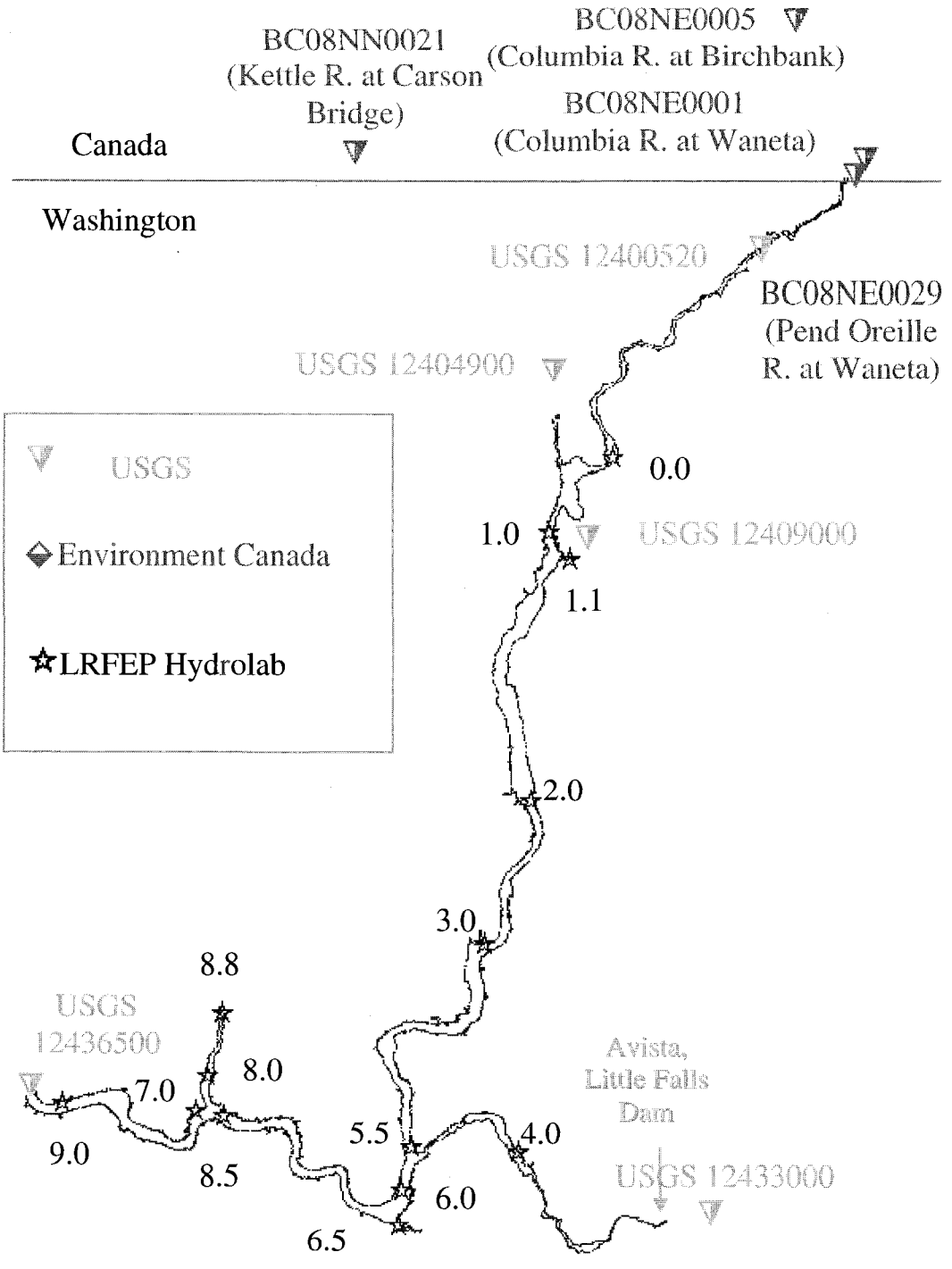

Figure 12. Water quality sampling site locations.

Table 21. Water quality sampling locations.

Lake Roosevelt Fisheries Evaluation Program, STOI					
Gage/Station	**Location Name**	**Latitude**	**Longitude**	**Start**	**End***
0.0	Evan's Landing	48.6830	118.0216	01/19/99	01/15/02
1.0	Kettle Falls	48.5992	118.1310	01/19/99	01/15/02
1.1	Colville River Bridge	48.5697	118.0926	08/24/99	08/24/99
2.0	Gifford	48.2944	118.1540	01/19/99	10/14/02
3.0	Hunters	48.1371	118.2261	01/19/99	01/15/02
4.0	Porcupine Bay	47.9018	118.1651	01/21/99	10/14/02
5.5	Spokane R. Confluence	47.9043	118.3431	01/21/99	05/05/00
6.0	Seven Bays	47.8566	118.3571	01/21/99	10/14/02
6.5	Hawk Creek	47.8175	118.3614	01/21/99	01/17/02
7.0	Keller Ferry	47.9398	118.7046	01/22/99	10/15/02
8.0	Sanpoil R.	47.9814	118.6859	01/22/99	01/16/02
8.5	Sanpoil R. Confluence	48.0545	118.6643	01/22/99	01/16/02
8.8	Sanpoil R. free flowing	47.9351	118.6569	01/22/99	01/16/02
9.0	Spring Canyon	47.9462	118.9285	01/22/99	10/15/02
USGS & Washington Department of Ecology					
12400520	Columbia R. at Northport	48.9225	117.7755	11/15/51	09/07/03
12404900	Kettle R. near Barstow	48.7847	118.1242	07/27/60	09/14/04
12409000	Colville R. at Kettle Falls	48.5944	118.0614	07/27/60	09/11/00
12433000	Spokane R. at Long Lake	47.8367	117.8403	10/01/59	09/10/03
12436500	Columbia R. at Grand Coulee	47.9656	118.9808	12/11/48	09/14/04
Environment Canada					
BC08NE0005	Columbia R. at Birchbank	49.1770	117.7180	05/25/83	02/01/05
BC08NE0001	Columbia R. at Waneta	49.0161	117.6040	11/02/79	02/02/05
BC08NE0029	Pend Oreille R. at Waneta	49.0031	117.6167	11/02/79	02/02/05
BC08NN0021	Kettle R. at Carson Rd. Bridge	49.0200	118.4700	10/10/79	02/02/05
Avista Utilities					
Little Falls	Little Falls Dam			4/1/1999	3/31/02
* The end date reflects the last reported observations that have been processed and released.					

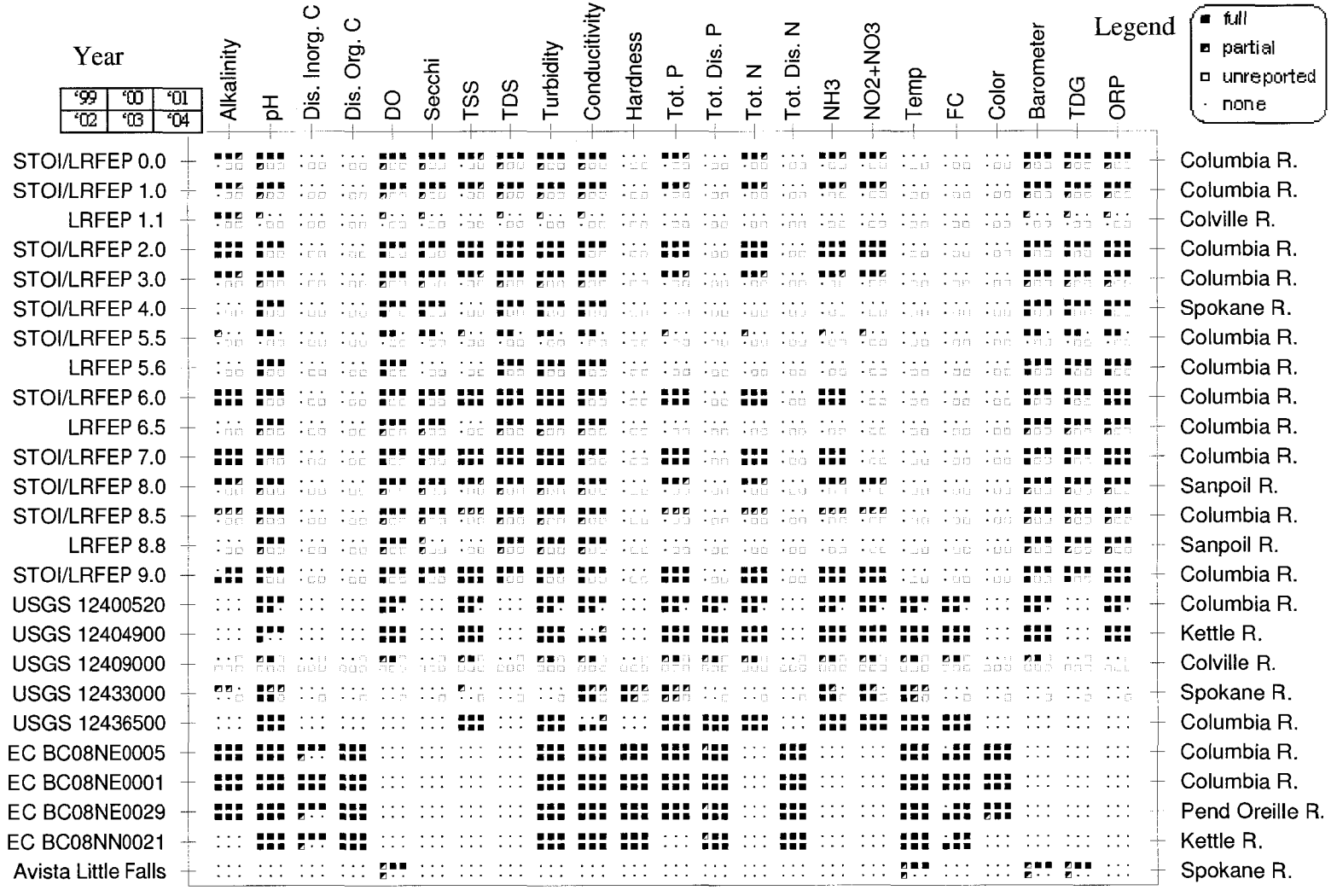

Figure 13. Water quality data availability matrix, 1999 to 2004

Biological Data

The biological data section is divided into primary production (diatoms, algae, cyanobacteria), secondary production (zooplankton), and fish (kokanee salmon). Data sources include the LRFEP, Eastern Washington University, and the fish hatcheries—releases are a combined effort of the Eastern Washington University (EWU) Department of Biology, the Spokane Tribal Hatchery, the Washington Department of Fish and Wildlife, the volunteer net pen program, and the Lake Roosevelt Fisheries Evaluation Program.

A wealth of biological data has been collected by the Lake Roosevelt Fisheries Evaluation Program, generally three or four times a year. Hatcheries operate on the lake and utilize tagging studies. Collected data include:

- Phytoplankton chlorophyll *a*
- Attached algae chlorophyll *a*
- Attached algae pheophytin
- Attached algae chlorophyll *a* accrual rate
- Zooplankton total biomass, percent biomass, total density, and percent density contributed by taxonomic group from 33 m and 66 m tows
- Daphnia densities
- Zooplankton annual mean lengths and standard deviation

- Pelagic and shore zooplankton densities from 17 m tows
- Number, percent relative abundance, and catch-per-unit-effort of fish species collected via boat electrofishing and gill netting over a dozen sampling sites
- Age, length, and weight data for a score of fish species.
- Discrimination among hatchery, wild, and unknown walleye and kokanee angler catches and sampled fish.
- Fish diet composition data
- Kokanee abundance and night distribution from summer hydroacoustic surveys

Creel surveys[7] are conducted nine months of the year yielding number and species of catch, targeted catch, effort per unit catch, and angling location. There is an annual fishing competition (the Two Rivers Casino Trout Derby) which yields a wealth of fish length and weight data as well as location of catch.

[7] A creel (or angler) survey consists of individuals interviewing anglers regarding their fishing practices, time and catches, locations fished, etc. Caught fish are measured and boats and anglers are counted. The data can yield information about the effort, harvest, size distribution of several important species of fish, as well as an estimate of the angler pressure within the fishery.

Primary Production

Phytoplankton speciation and chlorophyll-a analyses were conducted by the LRFEP for 1999 and 2000.

Phytoplankton sampling was conducted using both field fluorometer readings and laboratory techniques. Field measurements were taken at three depths: 0.5 m below the surface, approximately at half the depth of the euphotic zone, and 0.5 m above the bottom of the euphotic zone. The results of the field and laboratory sampling were reported as a composite value. After February 2001, problems with the fluorometer resulted in only laboratory measurements being reported. Figure 14 shows a comparison of the upstream and downstream end of the Columbia River and the single station in the Spokane River arm of the reservoir. The upstream and downstream concentrations were similar, and the concentrations in the Spokane River arm had similar minimum values but higher concentrations during periods of algal blooms.

For all stations, the data showed that higher chlorophyll-a concentrations were recorded during 1999 than the other years. The summer of 2000 shows a large bloom both upstream (Station 2.0), in the Spokane River (Station 4.0), and downstream (Stations 6.5, 8.0, 9.0). In general, concentrations were below 5 µg/L except during 1999 and each summers bloom. The January concentrations were elevated in 1999,

less than 1 µg/L in 2000, and range from 0 to 3 µg/L in 2001 and 2002. The sampling was less frequent in 2002.

Phytoplankton speciation for 1999 is shown in Table 22. Forty-one species from six classes were identified. Bacillariophyceae (diatoms) comprised the largest single division with 37% of the total density and 60% of the total volume sampled. The next largest type was the Cryptophyceae (brown-green algae) at 25% and 24% of the density and volume followed by Chlorophyceae (green algae) at 16% and 8% of the density and volume. Cyanophyta and microplankton were also present. Microplankton made up 16% of the total density.

During the 2000 sampling, phytoplankton speciation was divided into those from shore and pelagic sites. Sampling at the shore sites may have been from piers or ramps or from small boats but were typically not adjacent to the banks. Six classes with forty-two and thirty-eight taxa were identified at the pelagic (Table 23) and shore (Table 24) sites, respectively. Both types of sampling sites followed the trend seen in the 1999 speciation data with Bacillariophyceae comprising the dominant taxa followed by Cryptophyceae and Chlorophyceae with microplankton contributing 12 to 16% of the total density.

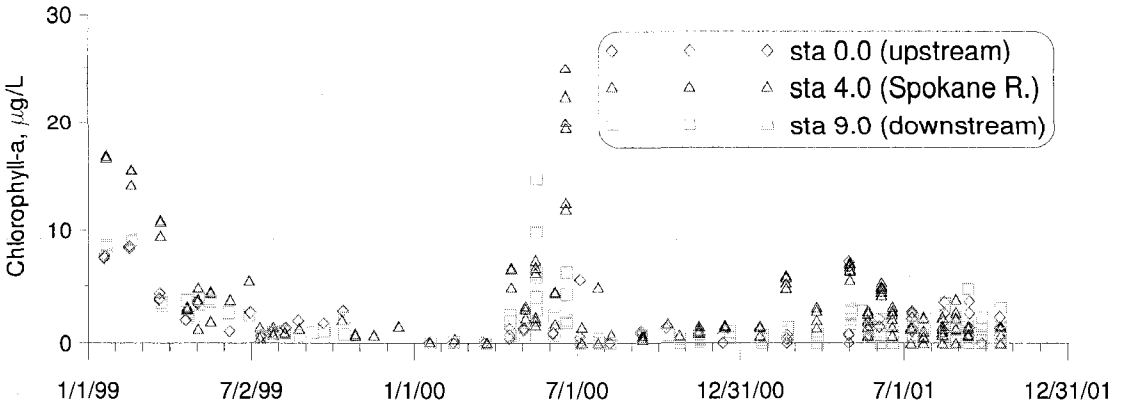

Figure 14. Comparison of chlorophyll-a concentrations at selected stations.

Table 22. LRFEP 1999 unattached algae speciation.

Year 1999					
Division, class, *species*	% of total density	% of total volume	**Division**, class, *species*	% of total density	% of total volume
Chlorophyta			**Chrysophyta**		
Chlorophyceae	**16.2**	**8.4**	Bacillariophyceae	**36.6**	**60.4**
Ankistrodesmus falcatus	*1.4*	*0.0*	*Achnanthes sp.*	*0.1*	*0.0*
Carteria sp.	*0.1*	*0.0*	*Amphora sp.*	*0.0*	*0.1*
Chlamydomonas sp.	*13.8*	*8.0*	*Asterionella formosa*	*18.1*	*30.8*
Eudorina elegans	*0.0*	*0.0*	*Cyclotella sp.*	*0.4*	*1.9*
Mougeotia sp.	*0.0*	*0.1*	*Cymbella sp.*	*0.0*	*0.0*
Oocystis sp.	*0.0*	*0.0*	*Fragilaria crotonensis*	*3.7*	*7.9*
Pediastrum boryanum	*0.0*	*0.0*	*Fragilaria sp.*	*0.2*	*0.3*
Scenedesmus bijuga	*0.2*	*0.1*	*Gomphonema sp.*	*0.0*	*0.0*
Scenedesmus dimorphus	*0.1*	*0.0*	*Melosira distans*	*0.4*	*1.0*
Scenedesmus quadricauda	*0.3*	*0.1*	*Melosira granulata*	*0.0*	*0.0*
Schroederia setigera	*0.2*	*0.1*	*Melosira herzogii*	*0.4*	*1.3*
Spondylosium sp.	*0.0*	*0.0*	*Melosira italica*	*1.1*	*3.8*
Tetraedron minimum	*0.0*	*0.0*	*Melosira varians*	*0.1*	*1.4*
Cryptophyta			*Navicula sp.*	*0.1*	*0.1*
Cryptophyceae	**25.2**	**23.5**	*Rhizosolenia sp.*	*2.8*	*7.8*
Cryptomonas sp.	*3.6*	*13.3*	*Synedra sp.*	*8.9*	*1.6*
Rhodomonas sp.	*21.6*	*10.2*	*Tabellaria sp.*	*0.3*	*2.3*
Cyanophyta			Chrysophyceae	**2.6**	**3.6**
Cyanophyceae	**3.6**	**1.0**	*Dinobryon bavaricum*	*0.2*	*0.2*
Anabaena sp.	*0.2*	*0.1*	*Dinobryon sertularia*	*2.1*	*1.7*
Gloeocapsa sp.	*0.0*	*0.0*	*Mallomonas pseudocoronata*	*0.0*	*0.1*
Oscillatoria limnetica	*1.5*	*0.4*	*Mallomonas sp.*	*0.3*	*1.6*
Oscillatoria sp.	*1.8*	*0.5*			
Pyrrhophyta					
Dinophyceae	*0.0*	*0.4*			
Ceratium hirundinella	*0.0*	*0.4*			
Microplankton	**15.8**	**2.9**			

Table 23. LRFEP 2000 pelagic unattached algae speciation.

Year 2000					
Division, class, *species*	% of total density	% of total volume	**Division**, class, *species*	% of total density	% of total volume
Chlorophyta			**Chrysophyta**		
Chlorophyceae	**16.2**	**7.2**	Bacillariophyceae	**36.9**	**62.4**
Ankistrodesmus falcatus	*1.5*	*0.0*	*Achnanthes sp.*	*0.2*	*0.1*
Carteria sp.	*0.0*	*0.0*	*Amphora sp.*	*0.0*	*0.1*
Chlamydomonas sp.	*13.3*	*6.4*	*Asterionella formosa*	*21.4*	*32.6*
Cosmarium sp.	*0.0*	*0.0*	*Cocconeis sp.*	*0.0*	*0.1*
Eudorina elegans	*0.6*	*0.3*	*Cyclotella sp.*	*0.3*	*0.9*
Mougeotia sp.	*0.0*	*0.0*	*Cymbella sp.*	*0.0*	*0.1*
Pandorina	*0.1*	*0.1*	*Fragilaria crotenensis*	*4.3*	*9.0*
Pediastrum boryanum	*0.1*	*0.0*	*Fragilaria sp.*	*0.1*	*0.5*
Raciborskiella uroglenoides	*0.0*	*0.0*	*Gomphonema sp.*	*0.0*	*1.4*
Scenedesmus bijuga	*0.3*	*0.1*	*Melosira distans*	*0.2*	*0.6*
Scenedesmus dimorphus	*0.0*	*0.0*	*Melosira granulata*	*0.0*	*0.0*
Scenedesmus quadricauda	*0.1*	*0.0*	*Melosira herzogii*	*0.1*	*0.1*
Schroederia setigera	*0.1*	*0.0*	*Melosira italica*	*1.6*	*5.1*
Staurastrum paradoxum	*0.0*	*0.1*	*Melosira varians*	*0.0*	*0.7*
Cryptophyta			*Navicula sp.*	*0.0*	*0.1*
Cryptophyceae	**26.5**	**23.7**	*Rhizosolenia sp.*	*1.2*	*2.9*
Cryptomonas sp.	*4.1*	*14.1*	*Synedra sp.*	*6.6*	*1.1*
Rhodomonas sp.	*22.5*	*9.6*	*Tabellaria sp.*	*0.8*	*7.2*
Cyanophyta			Chrysophyceae	**2.9**	**3.2**
Cyanophyceae	**1.9**	**0.7**	*Dinobryon bavaricum*	*0.1*	*0.1*
Anabaena sp.	*0.7*	*0.3*	*Dinobryon sertularia*	*2.5*	*2.0*
Gloeocapsa sp.	*0.3*	*0.2*	*Mallomonas sp.*	*0.3*	*1.2*
Oscillatoria sp.	*0.9*	*0.2*			
Pyrrhophyta					
Dinophyceae	*0.0*	*0.3*			
Ceratium hirundinella	*0.0*	*0.3*			
Microplankton	**15.6**	**2.6**			

Table 24. LRFEP 2000 shore station unattached algae speciation.

Year 2000					
Division, class, *species*	% of total density	% of total volume	**Division**, class, *species*	% of total density	% of total volume
Chlorophyta			**Chrysophyta**		
Chlorophyceae	**15.2**	**6.2**	Bacillariophyceae	**34.4**	**63.2**
Ankistrodesmus falcatus	*2.0*	*0.0*	*Achnanthes sp.*	*0.5*	*0.2*
Chlamydomonas sp.	*12.3*	*5.5*	*Amphora sp.*	*0.2*	*1.1*
Closterium sp.	*0.0*	*0.2*	*Asterionella formosa*	*20.8*	*29.2*
Eudorina elegans	*0.1*	*0.0*	*Cocconeis sp.*	*0.0*	*0.0*
Pediastrum boryanum	*0.3*	*0.3*	*Cyclotella sp.*	*0.4*	*1.0*
Quadrigula chodatii	*0.1*	*0.0*	*Fragilaria crotenensis*	*2.5*	*5.4*
Scenedesmus bijuga	*0.1*	*0.0*	*Fragilaria sp.*	*0.1*	*0.2*
Scenedesmus dimorphus	*0.0*	*0.0*	*Gomphonema sp.*	*0.0*	*0.0*
Scenedesmus quadricauda	*0.1*	*0.0*	*Melosira distans*	*0.1*	*0.4*
Schroederia setigera	*0.1*	*0.0*	*Melosira italica*	*1.2*	*3.1*
Staurastrum paradoxum	*0.0*	*0.2*	*Navicula sp.*	*0.4*	*1.6*
Cryptophyta			*Rhizosolenia sp.*	*1.7*	*3.9*
Cryptophyceae	**32.3**	**25.2**	*Stephanodiscus sp.*	*0.0*	*0.2*
Cryptomonas sp.	*5.5*	*15.1*	*Synedra sp.*	*5.5*	*0.9*
Rhodomonas sp.	*26.7*	*10.1*	*Tabellaria sp.*	*1.1*	*16.1*
Cyanophyta			Chrysophyceae	**2.4**	**2.4**
Cyanophyceae	*3.5*	*0.7*	Dinobryon bavaricum	*0.1*	*0.1*
Anabaena sp.	*0.1*	*0.0*	Dinobryon sertularia	*2.0*	*1.4*
Aphanocapsa sp.	*1.3*	*0.0*	Mallomonas pseudocoronata	*0.0*	*0.1*
Gloeocapsa sp.	*1.1*	*0.2*	Mallomonas sp.	*0.2*	*0.9*
Oscillatoria sp.	*1.1*	*0.4*			
Pyrrhophyta					
Dinophyceae	*0.0*	*0.3*			
Ceratium hirundinella	*0.0*	*0.4*			
Microplankton	**12.2**	**1.9**			

Secondary Production

Zooplankton have been collected since 1989 and analyzed for density, biomass, and length distributions. Sampling occurred at 9 to 11 stations over a dozen or more rounds using tow nets of assorted sizes and meshes. For a detailed reporting of the results, refer to the LRFEP annual reports. The data were summarized for the following parameters:

- Zooplankton speciation
- Zooplankton biomass (mass per volume)
- Zooplankton density (abundance, organisms per volume)
- Zooplankton length

The species could be grouped into three taxonomically similar groups: Daphnia species, other Cladocera, and Copepoda. The number of species identified varied from 16 to 22 over 1999 to 2002. In general, zooplankton biomass and abundance increased moving downstream. Sampling stations nearer the shore showed higher abundance. Table 25 shows the average speciation from 1999 through 2002. The dominant species by percent of total biomass (including juveniles) were *Daphnia pulex* (38%), *Leptodora kindtii* (10%), *Daphnia thorata* (9%), *Leptodiaptomus ashlandi* (8%), and *Diacyclops bicuxpidatus thomasi* (7%). When organized into the

three taxonomical groups, the total biomass (excluding juveniles) is 60% Daphnia species, followed by 36% Copepoda species, as seen in Table 25.

Table 25. Zooplankton group biomass and density, 1999 to 2002.

Group	density (#/m^3)		biomass (µg/m^3)	
	average	percent	average	percent
Copepoda	10348	84.1	18279	36.4
Daphnia	1702	13.8	30091	59.9
Other Cladocera	264	2.1	1888	3.7
All groups	12305	100	50204	100

Zooplankton lengths for each sampling round were available. A statistical summary for the broad taxonomic groups is shown in Table 26. The mean zooplankton size of the years 1999 to 2002 was around 0.63 mm with Daphnia having the largest mean (1.34 mm), followed by other Cladocera (0.54 mm) and Copepods (0.46 mm). The other Cladocera group had the smallest and largest lengths (0.04 to 12.80 mm). *Daphnia pulex* was the dominate species in the Daphnia group; *Leptodiaptomus ashlandi* and *Diacyclops bicuxpidatus thomasi* were the dominant adult Copepod but nauplii (mean length 0.16 to 0.20 mm) dominated the Copepoda sampling—mean adult Copepoda length was roughly 50% larger (~0.7 to 0.8 mm.) In general, zooplankton lengths were smallest during the spring and peak around August. Zooplankton lengths increased during the winter[8]. Spatially, zooplankton length increased moving downstream.

[8]The cause for the increasing lengths in not clear (Personal communication, Ben Scofield, LRFEP, 2005).

Table 26. Zooplankton length (in mm) statistics, 1999 to 2002.

Group	Statistic	Year			
		1999	2000	2001	2002
Daphnia	Mean	1.18	1.34	1.50	1.30
	St.Dev.	0.56	0.57	0.60	0.50
	Number	4770	4250	4492	627
	Min.	0.15	0.19	0.50	0.50
	Max.	3.15	3.53	3.40	3.10
Other Cladocera	Mean	0.55	0.49	0.60	0.60
	St.Dev.	0.91	0.74	0.90	1.10
	Number	1184	1439	1114	200
	Min.	0.04	0.14	0.20	0.20
	Max.	10.40	10.40	12.80	9.60
Copepoda	Mean	0.43	0.45	0.50	0.50
	St.Dev.	0.34	0.35	0.40	0.30
	Number	21432	18385	18661	3498
	Min.	0.08	0.08	0.10	0.10
	Max.	2.39	2.50	3.00	2.50
Total zooplankton	Mean	0.57	0.61	0.69	0.70
	St.Dev.	0.51	0.55		0.50
	Number	27386	24074	24267	4325
	Min.	0.40	0.08	0.10	0.10
	Max.	10.40	10.40	12.80	9.60

Fish Data

There are three hatcheries in operation on Lake Roosevelt: Sherman Creek, the Spokane Tribal Hatchery, and the Ford (WDFW) (Big Sheep Creek Hatchery)

Eggs are also sometimes acquired from the Lake Whatcom Hatchery (WDFW) in Bellingham, Washington.

These hatcheries record species, brood stock, number, total length, age, and weight for the released fish.

The fish data collected by the LRFEP consists of:

- Summer hydroacoustic survey
- Creel surveys
- Relative abundance and species composition (horizontal and vertical gill netting and electrofishing)
- Total length and weight (from gill netting and electrofishing)
- Movement and entrainment (Floy $^{(R)}$ tagging)
- Fish diet
- Test fishery
- Two Rivers Trout Derby (total length and weight, tag recovery)

For a detailed accounting, refer to the LRFEP annual reports. A summary of the available data follows:

Kokanee hatchery releases were conducted over the model study period. Releases are a combined effort of the Eastern Washington University (EWU) Department of Biology, the Spokane Tribal Hatchery, the Washington Department of Fish and Wildlife, the volunteer net pen program, and the Lake Roosevelt Fisheries Evaluation Program. Partial funding is provided through grants from the Bonneville Power Administration. The annual reports regarding the evaluation of each seasons stocking (recruitment) strategy are shown in Table 27. While these reports do contain much of the release data, the data reported herein was compiled and provided by Holly McLellan (EWU).

Table 27. Annual Kokanee salmon stocking assessment report citations.

Report reference	Assessment year
McLellan, H. J.; and Scholz, A. T. (2004)	2004
McLellan, H. J.; Scholz, A. T.; and McLellan, J. G. (2004)	2003
McLellan, H. J.; and Scholz, A. T. (2003)	2002
McLellan, H. J.; and Scholz, A. T. (2002a)	2001
McLellan, H. J.; and Scholz, A. T. (2001)	2000
McLellan, H. J.; McLellan J. G.; Scholz, A. T.; and Tilson, M. B. (2001)	1999

The release locations vary from year to year to allow for hypothesis testing. The locations reported over the 1998 to 2004 seasons are shown Figure 15. Among the reports in Table 27, the nomenclature for the release points varied slightly. The sites

named "Two Rivers" and "Spokane River" were taken to be the same or nearly the same location. The various Sherman Creek release locations were grouped into the same release location. The Sherman Creek net pens were kept as a separate location.

The fish release data are shown for 1998 through 2000 in Table 29 and 2001 through 2004 in Table 30. The data include brood year, release date, release location, stock, number of fish released, the average total length, and number of fish per pound. The stock descriptions are noted in Table 28.

Table 28. Kokanee stock descriptions.

Stock	Description
WHAL	Lake Whatcom stock kokanee
WHAL*	Lake Whatcom stock that returned to Sherman Creek in 1998 and were spawned
MEAD	Meadow Creek stock
ROOS	Wild and Meadow Creek stock collected and spawned in 2002

Release site No.	Location
1	Spokane River (Two Rivers)
2	Sherman Creek
3	Sherman Cr. Net Pen
4	Seven Bays Net Pen
5	Meyers Falls
6	Little Falls Dam
7	Little Falls Boat Launch
8	Lincoln Net Pen
9	Kettle Falls Net Pen
10	Grand Coulee
11	Gifford
12	Fort Spokane
13	Colville R. Net Pens
14	Big Sheep Ck
15	A-Frame

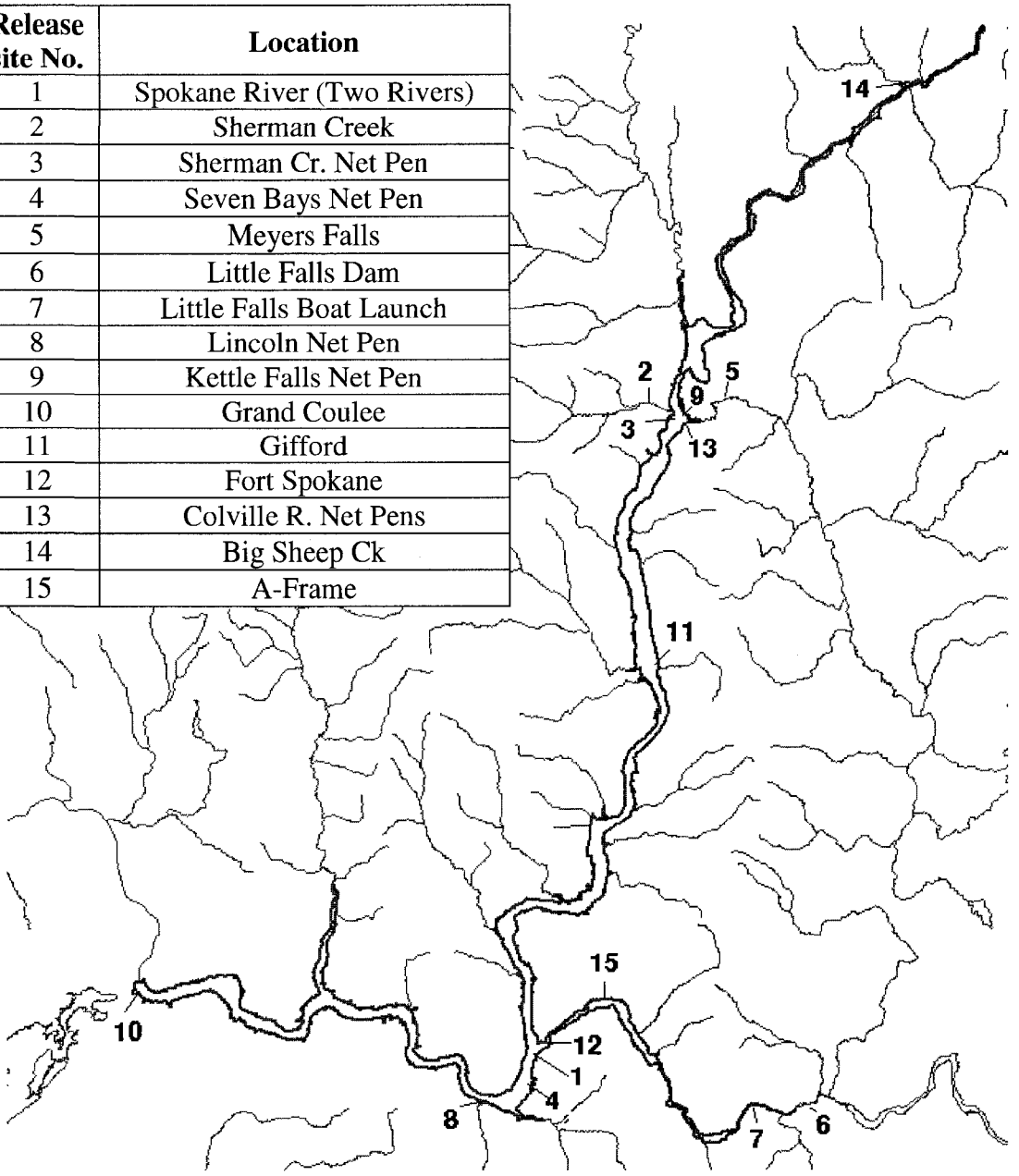

Figure 15. Kokanee salmon stocking release site locations.

Table 29. Kokanee release data, 1998 to 2000.

Brood Year	Date	Release Location	Release site No.	Stock	#Kokanee released	Length (mm)	fish/ lb.
1996	5/16/98	Colville R. Net Pens	13	WHAL	95,638	156	14.4
1996	5/17/98	Little Falls Boat Launch	7	WHAL	15,000	188	8.0
1996	5/19/98	Lincoln Net Pen	8	WHAL	49,492	158	13.8
1996	5/20/98	Seven Bays Net Pen	4	WHAL	49,187	159	13.7
1996	5/23/98	Kettle Falls Net Pen	9	WHAL	67,622	152	15.4
1996	5/25/98	Little Falls Dam	6	WHAL	35,000	176	10.0
1996	5/28/98	Sherman Creek	2	WHAL	73,575	158	11.9
1996	5/28/98	Sherman Creek	2	WHAL	72,394	158	11.9
1996	5/28/98	Sherman Creek	2	WHAL	86,327	158	13.8
1996	5/29/98	Sherman Cr. Net Pen	3	WHAL	56,328	151	13.9
1996	6/3/98	Little Falls Dam	6	WHAL	10,046	166	12.0
1996	6/28/98	Little Falls Dam	6	WHAL	24,470	176	10.0
1996	7/12/98	Sherman Creek	2	WHAL	38,703	181	7.7
		1996 release total			673,782		
1997	5/11/99	Spokane River (Two Rivers)	1	WHAL	41,195	140	17.0
1997	6/7/99	Spokane River (Two Rivers)	1	WHAL	41,482	167	10.0
1997	6/16/99	Sherman Creek	2	WHAL	74,013	141	16.7
1997	6/16/99	Colville R. Net Pens	13	WHAL	41,771	152	13.3
1997	6/16/99	Colville R. Net Pens	13	WHAL	40,982	157	12.0
1997	6/21/99	Spokane River (Two Rivers)	1	WHAL	22,370	177	8.0
1997	6/22/99	Spokane River (Two Rivers)	1	WHAL	22,413	177	8.0
1997	6/28/99	Sherman Creek	2	WHAL	95,736	167	10.1
1997	6/28/99	Sherman Creek	2	WHAL	96,600	167	10.1
1997	6/28/19 99	Sherman Creek	2	WHAL	87,511	165	10.5
1997	7/1/99	Spokane River (Two Rivers)	1	WHAL	11,250	188	7.0
1997	7/29/99	Sherman Creek	2	WHAL	88,775	167	10.0
1997	3/22-31/99	Sherman Creek	2	WHAL	25,000	137	18.2
		1997 release total			689,098		
1998	5/19/00	Spokane River (Two Rivers)	1	WHAL	41,600	137	18.0

(continued)

Brood Year	Date	Release Location	Release site No.	Stock	#Kokanee released	Length (mm)	fish/ lb.
1998	5/30/00	Spokane River (Two Rivers)	1	WHAL	21,600	237	3.5
1998	6/12/00	Spokane River (Two Rivers)	1	WHAL	15,770	150	14.0
1998	6/12/00	Spokane River (Two Rivers)	1	WHAL	30,000	146	15.0
1998	6/14/00	Kettle Falls Net Pen	9	WHAL	197,975	133	19.6
1998	6/28/00	Sherman Creek	2	WHAL	94,518	168	9.6
1998	6/28/00	Sherman Creek	2	MEAD	105,432	168	9.6
1998	6/28/00	Sherman Creek	2	WHAL	95,680	168	9.6
1998	7/25/00	Sherman Creek	2	WHAL *	5,829	173	8.9
1998	7/25/00	Sherman Creek	2	WHAL *	3,557	173	8.9
1998	7/25/00	Sherman Creek	2	WHAL	72,602	173	8.9
1998	6/20-29/00	Spokane River (Two Rivers)	1	WHAL	51,075	167	10.0
1998	6/20-29/00	Spokane River (Two Rivers)	1	MEAD	55,675	167	10.0
		1998 release total			**791,313**		

Table 30. Kokanee release data, 2001 to 2004.

Brood Year	Date	Release Location	Release site No.	Stock	#Kokanee released	Length (mm)	fish/ lb.
1999	4/25/01	Spokane River (Two Rivers)	1	WHAL	46,560	143	16.0
1999	5/4/01	Seven Bays Net Pen	4	MEAD	98,217	159	11.5
1999	5/8/01	Kettle Falls Net Pen	9	MEAD	49,699	137	18.0
1999	5/14/01	Meyers Falls	5	MEAD	21,648	188	7.0
1999	5/25/01	Sherman Creek	2	MEAD	62,928	184	7.6
1999	5/25/01	Sherman Creek	2	MEAD	39,065	167	10.0
1999	5/25/01	Sherman Creek	2	WHAL	35,251	184	7.6
1999	5/25/01	Sherman Creek	2	WHAL	26,037	167	10.0
1999	5/25/01	Sherman Creek	2	WHAL	52,062	167	10.0
1999	5/25/01	Sherman Creek	2	WHAL	92,558	188	7.0
1999	5/27/01	Kettle Falls Net Pen	9	MEAD	334,324	137	18.0
1999	6/1/01	Spokane River (Two Rivers)	1	MEAD	24,533	188	7.0
1999	6/6/01	Spokane River (Two Rivers)	1	MEAD	27,875	188	7.0
1999	6/11-/12/01	Spokane River (Two Rivers)	1	WHAL	57,477	180	8.0
		1999 release total			968,234		
Brood Year	**Date**	**Release Location**	**Release site No.**	**Stock**	**#Kokanee released**	**Length (mm)**	**fish/ lb.**
2000	5/15/02	Fort Spokane	12	WHAL	12,448	180	8.0
2000	5/15/02	Fort Spokane	12	WHAL	12,280	180	8.0
2000	5/16/02	Little Falls Dam	6	WHAL	12,456	180	8.0
2000	5/16/02	Little Falls Dam	6	WHAL	12,656	180	8.0
2000	5/18/02	Seven Bays Net Pen	4	WHAL	109584	143	16.0
2000	5/26/02	Colville R. Net Pens	13	WHAL	247,484	137	18.0
2000	5/29/02	Meyers Falls	5	WHAL	17,000	180	8.0
2000	6/26/02	Sherman Creek	2	WHAL	231,038	167	10.0
		2000 release total			654,946		
2001	5/5/03	Little Falls Dam	6	WHAL	24,900	157	12.0
2001	5/5/03	Lincoln Net Pen	8	WHAL	104,472	134	19.1
2001	5/6/03	Meyers Falls	5	WHAL	24,960	157	12.0
2001	5/21/03	Seven Bays Net Pen	4	WHAL	34,792	141	16.6
2001	6/2/03	Colville R. Net Pens	13	WHAL	232,106	132	20.6
2001	6/6/03	Grand Coulee	10	WHAL	198	137	18.0

(continued)

2001	6/6/03	Grand Coulee	10	WHAL	19,862	137	18.0
2001	6/9/03	Sherman Creek	2	WHAL	24,821	163	10.8
2001	6/9/03	Gifford	11	WHAL	203,596	162	11.0
2001	5/14-1/03	Fort Spokane	12	WHAL	211,461	162	10.9
		2001 release total			881,168		
2002	3/24/04	Little Falls Dam	6	WHAL	33,600	98	50.0
2002	3/30/04	Big Sheep Ck	14	MEAD	322,200	43	600.0
2002	5/10/04	A-Frame	15	WHAL	25,568	143	16.0
2002	5/11/04	Colville R. Net Pens	13	WHAL	238,871	110	34.6
2002	5/12/04	Little Falls Dam	6	WHAL	24,880	143	16.0
2002	5/17/04	Meyers Falls	5	WHAL	24,832	143	16.0
2002	5/21/04	Sherman Creek	2	WHAL	79,803	143	15.9
2002	5/21/04	Sherman Creek	2	WHAL	62,895	143	15.9
2002	5/21/04	Sherman Creek	2	WHAL	74,767	143	15.9
2002	5/6/04	Fort Spokane	12	ROOS/ MEAD	4,550	254	2.5
2002	5/6-14/04	Fort Spokane	12	WHAL	201,405	140	17.0
		2002 release total			**1,093,371**		

Review of existing water quality and bioenergetic models

Several noteworthy models, listed in Table 31, couple water quality with phytoplankton and zooplankton and higher trophic levels.

Table 31. Selected hydrodynamic, water quality, and bioenergetic models.

Model	hydrodynamics	water quality	primary & secondary	fish	Authors
CE-QUAL-W2 v3.0 with Food Web-Energy Transfer Model	X	X	X	X	Saito, et al. (2000)
CE-QUAL-W2 v3.0 and 3.1 (research codes)	X	X	X		Berger (1994); Sullivan and Rounds (2004)
Coupled Eulerian-Lagrangian Hybrid (CEL Hybrid) Modeling Method with CE-QUAL-W2 v3.0	X	X		X	Nestler, Goodwin, and Loucks (2005); Goodwin, et al. (2001)
Fish Individual-based Numerical Simulator (FINS) with MASS2				X	Scheibe and Richamond (2001). [USACOE contract]
Water Quality Dissolved Particulate Model (WQDPM); GEMSS-WQM	X	X	X		Wu, et al. (1998) & Edinger (2001a); Edinger (2001b)
Aquatox Release 2	X	X	X	X	US EPA (2000a,b,c)

Saito, Johnson, Bartholow, and Hanna (2001)

The interdisciplinary model used by Saito, et al. (2001) used the phytoplankton output from CE-QUAL-W2 to drive a linked food web-energy transfer model. Model output (algal volume, gross production, dark respiration, and net production) were output every 3 hours and transformed to daily values. The food web-energy transfer model operated by transferring 10% of total production available at each trophic level to the next higher level. Stable isotope analyses were used to calibrated the food web via establishing each species diet structure.

The CEL Hybrid Concept

Physical and ecological processes and models operate at different temporal and spatial scales; and Eulerian or Lagrangian references may not be the most suitable schemes for all processes. The Coupled Eulerian-Lagrangian Hybrid Ecological Modeling Concept (CEL Hybrid Concept), (Nestler, Goodwin, and Loucks, 2005; Goodwin, et al. (2001)) provides a data exchange and transformation algorithm that couples different models operating under different scales and reference schemes. Applications use CE-QUAL-W2 to model hydrodynamics and water quality—the outputs are transformed for use by fish movement and ecology models; and these models then return information (mortality, excretion) to the W2 model.

The CEL Hybrid was coupled with the Numerical Fish Surrogate (NFS) model (Goodwin, et al., 2001) and a particle-tracking algorithm to model fish movement as a response to environmental stimuli.

Fish Individual-Based Numerical Simulator (FINS)

The Fish Individual-Based Numerical Simulator (FINS) (Scheibe and Richmond, 2001) was developed to describe the movement of migrating juvenile salmonids. This individual based model tracked fish movement according to decision rules based on environmental stimuli (temperature, current speed, light, dissolved oxygen, turbidity, food availability, and so on).

Aquatox Release 2

Aquatox is an ecological risk assessment model that focuses on the combined environmental fate of contaminants. It uses steady-state, 1-D hydrodynamics and a dynamic time-step varying from several minutes to 1 day. Processes include meteorology and water quality inputs, exchange with sediments, and several trophic levels including algae, macrophytes, invertebrates, and fish. The fate portion of the model allows for considerable complexity and includes partitioning among organisms, suspended and sediment detritus and inorganic matter, volatilization, hydrolysis, photolysis, ionization, and microbial degradation. Acute toxicity is allowed to reduce biotic compartments and in turn effect the food web and water quality.

Fish Bioenergetic Parameter Formulation and Units

Growth

While the bioenergetics and foraging model of Stockwell and Johnson (1997) forms the basis of the approach, the specific governing equation follow a Beauchamp, Stewart, and Thomas (1989) formulation to predict growth, as shown in Equation (10). The formulations were resolved into consistent units of joules over each time-step. Equation (10) will be used on a daily timestep to estimate and apply daily growth, which can be negative. The units are $g*g^{-1}*d^{-1}$ (gram consumed per gram of consumer mass per day). The consumption parameter was left in units of prey per minute, and growth remained in units of mass (g). Table 32 lists the parameters and their units.

$$\overset{\text{growth}}{\widetilde{G}} = \overset{\text{consumption}}{\widetilde{C}} - \overbrace{(F+U)}^{\text{waste}} - \overbrace{(R \cdot \text{ACTIVITY} + S)}^{\text{metabolism}} \qquad (10)$$

Growth is computed daily from the sum of the parameters shown in (11) and converted from energy to mass using the fish energy density, E_{fish}.

$$G = \frac{1}{E_{fish}} \sum_{day} (D - U - F - R - S) \qquad (11)$$

$$G = \frac{[J]}{[J \cdot g^{-1}]}$$

$$G = g \text{ (per day)}$$

Table 32. Bioenergetics parameters summary.

Parameter	Symbol	Units
Consumption	C	#/min (prey)
Digestion	D	J (per timestep)
Excretion	U	J (per timestep)
Egestion	F	J (per timestep)
Respiration	R	J (per timestep)
SDA	S	J (per timestep)
Growth	G	g (per day)

Fish energy density

Kokanee energy density uses the allometric piecewise function (Brett, 1983; Beauchamp, et al., 1989): (Equation (12)).

$$E_{fish}\left[\frac{J}{g}\right] = \begin{cases} 4.1868 \cdot (1.8510 \cdot M + 1250) & \text{for} \quad M \le 196 \text{ g} \\ 4.1868 \cdot (1.1254 \cdot M + 1588) & \text{for} \quad M > 196 \text{ g} \end{cases} \qquad (12)$$

where M is the wet mass of the fish

Prey energy density

Daily growth is computed from Equation (1), but requires the energy density of both food and consumer to calculate a change in mass. In actuality, food energy density varies with time, but is commonly assumed to be constant due to lack of data. Energy densities were not available for Lake Roosevelt zooplankton. A value of 2420 J/wet-g was used for copepoda (Stockwell, et al., 1999) and 2800 J/wet-g was used for Daphnia (discussion with Mike. Mazur). The mass-length relationship (Stockwell, et al., 1999) was used with the mean Daphnia length from the LRFEP data (2.4 mm, Ben Scofield) to generate an individual Daphnia mass of 8.82E-5 g. Downing and Rigler (1984) were used for the copepoda size-mass relationships. Table 33 lists some representative prey energy densities.

Table 33. Selected kokanee prey energy densities.

Prey	Caloric content, J/g	Source
Daphnia	2453 (wet weight)	Richman (1958)
Copepods: calanoid and cyclopoid	2464 (wet weight)	Krokhin (1957)
Copepods: *Epischura nevandensis, Diaptomus ashlandi*	2318 (wet weight)	Cummins and Wuycheck (1971)
Daphnia	2420 (wet weight)	Snow (1972); Stockwell, et al. (1999)

Digestion

Digestion is formulated as the energy derived from digested prey over the timestep. The energy from consumption is included in the digestion parameter. Consumption does not explicitly appear in the growth equation (Equation (11)). The approach (Equation (13)) is based on Bevelhimer and Adams (1993); physically, the terms represent the initial stomach content to be digested, the prey consumed during the time-step, and the undigested stomach contents at the end of the time-step. The last term allows for a time-lag between consumption and digestion. The time to digest the bulk of a full stomach can range from a couple hours if near optimal temperature to roughly half a day if at very cold temperatures. The variables and their units are shown in Table 34.

The digestion parameter is a function of several other functions: the Thornton-Lessem function (see ancillary functions section), the digestion coefficient, the consumption parameter, and the stomach content at the start of the time-step.

$$D = \left(\frac{\left(\underbrace{M_o}_{\text{initial content}} + \underbrace{(C \cdot m_z \cdot t) \cdot TL}_{\text{consumption}} \right) - \left(\underbrace{M_o e^{-r \cdot t/60} + \frac{C \cdot m_z \cdot 60 \cdot TL}{r}\left(1 - e^{-r \cdot t/60}\right)}_{\text{undigested contents}} \right)}{} \right) \cdot E_{prey} \qquad (13)$$

$$D = \left(\left(g_{wet} + \left(\frac{\#}{min} \cdot g_{wet} \cdot min \right) \right) - \left(g_{wet} + \frac{\#}{min} \cdot g_{wet} \cdot min \right) \right) \left(\frac{J}{g_{wet}} \right)$$

$$D = [J] \text{ (per timestep)}$$

Table 34. Digestion parameter variables and units.

Variable	Units	Definition
M_o	g_{wet}	Initial stomach content
C	#/min (e.g., Daphnia)	Consumption
m_z	g_{wet}	mass of a single prey zooplankton
t	(30) minutes	Timestep
TL	dimensionless	Thornton-Lessem function
r	dimensionless	digestion coefficient
E_{prey}	J/ g_{wet}	Prey energy content (density)
60	minutes	unit conversion factor

Digestion coefficient (function)

A kokanee digestion coefficient, r, is reported by Stockwell & Johnson (1999) and Bevelhimer and Adams (1993) and reproduced in Table 35. The Stockwell & Johnson formulation is used to avoid non-positive values which may occur at low temperatures. The temperature input to the bioenergetics algorithms is further constrained to a minimum value of 0.01 °C.

Table 35. Digestion coefficient formulations

Equation	Source	#
$r = 0.014 \cdot T - 0.0154$	Bevelhimer and Adams (1993)	(14)
$r = 0.014 \cdot T + 0.1135$	Stockwell & Johnson (1999)	(15)

Stomach content and capacity

Stomach content is updated after each time-step. The remaining stomach content is composed of the undigested initial stomach content and the consumed prey undigested over the time-step, as shown in Equation (16).

$$M_0^{new} = \underbrace{M_o e^{-r \cdot t/60}}_{undigested\ initial content} + \underbrace{\frac{C \cdot m_z \cdot 60 \cdot TL}{r}\left(1 - e^{-r \cdot t/60}\right)}_{undigested\ consumption} \qquad (16)$$

Stomach capacity uses the allometric formulation of Brett (1971). If, at the start of any time-step, the stomach content exceeds the stomach capacity, then consumption is zero for that time-step.

$$\text{Capacity}[g] = \begin{cases} M \cdot (14.1 - 4.95 \cdot \log(M))/100 & \text{for} \quad M \le 253.5\ g \\ 0.022 \cdot M & \text{for} \quad M > 253.5\ g \end{cases} \qquad (17)$$

where M is the wet mass of the fish

Specific Dynamic Action (SDA)

Specific dynamic action (the physiological cost of digesting a meal) is formulated using the approach of Brett & Groves (1979). The coefficient (0.172) in Equation (18) for kokanee is taken from Beauchamp, et al. (1989). The variables and units of SDA are shown in Table 36.

$$SDA = 0.172 \cdot (D - F) \qquad (18)$$

$$SDA = [J] \text{ (per timestep)}$$

Table 36. Specific dynamic action parameter variables and units.

Variable	Units	Definition
D	J (per timestep)	Digestion parameter
F	J (per timestep)	Egestion parameter

Foraging and Consumption

Consumption is based on the Stockwell & Johnson (1997) model (Equation (19)), and is a function of other functions: search volume (aka search rate), and the Thornton-Lessem function (see ancillary functions section).

$$C_{forage} = \frac{E \cdot z}{1 + E \cdot z \cdot h} \cdot TL \cdot 60 \qquad (19)$$

$$C_{forage} = \frac{\mathrm{m^3/s} \cdot \frac{\#}{\mathrm{m^3}}}{\mathrm{m^3/s} \cdot \frac{\#}{\mathrm{m^3}} \cdot \frac{\mathrm{s}}{\#}} \cdot \frac{60\mathrm{s}}{\mathrm{min}}$$

$$C_{forage} = \left[\frac{\#}{\mathrm{min}}\right] \text{ (“prey” per timestep)}$$

Maximum consumption, C_{max}, can be estimated from feeding trials or field studies. It is commonly scaled for temperature effects using a Thornton and Lessem (1978) temperature correction function ranging from 0 to 1,(see subsequent Figure 16). C_{max} is used in a diagnostic capacity and as an upper bounds for consumption predicted by a foraging model, C_{forage},. Thus, consumption, C, is the minimum of the two consumption rates.

$$C = \text{minimum of } (C_{forage}, C_{max}) \qquad (20)$$

Maximum Consumption - C_{max}

The C_{max} formulation developed by Beauchamp, et al.(1989) was used. This formulation was developed using sockeye data from three northern hemisphere lakes.

$$C_{max}\ (g/g/d) = 0.303\ W^{-0.35}\ TL(T) \qquad (21)$$

where TL is the Thornton-Lessem function

Search Volume, and Reaction Distance

The search volume (rate) is the simple cylinder suggested by Eggers (1977) (Equation (22)). The reaction distance is taken to be the radius of a sphere described by Link and Edsall (1996) (Equation (23)). The consumption, search volume, and reaction distance parameter variables and units are shown in Table 37. The ambient light intensity is determined from a stand alone theoretical surface light over one year calculated for the system's location on the earth at 15-minute intervals which is then attenuated to each layer from W2 output light extinction coefficients (which roughly account for turbidity). Note that it is possible to have very turbid water with low light extinction. Turbidity data ranged from 0.1 to 10 NTU with a mean of 1 to 2 NTU.

$$E\left[\frac{m^3}{s}\right] = \pi \cdot R_a^2 \cdot v \qquad (22)$$

$$R_d\,[m] = 0.01 \cdot 4.9424 \cdot lux^{0.086} \qquad (23)$$

Table 37. Consumption parameter variables and units.

Variable	Units	Definition
R_d	m	Predator reaction distance
lux	lux	Ambient light intensity
E	m^3 / s	Search rate
v	m / s	fish swimming speed
z	# / m^3	prey density
h	# / s	handling time
TL	dimensionless	Thornton-Lessem function
60	s / min	unit conversion factor

Egestion & Excretion

Egestion (fecal wastes) and excretion (urinary wastes) are formulated using the approach of Hewett & Johnson (1987). Parameter variables and units are shown for egestion in Table 38 and for excretion in Table 39.

$$F = 0.455 \cdot T^{-0.222} \cdot D \qquad (24)$$

$$F = \left(\frac{1}{°C}\right) °C \cdot J = J$$

$$F = [J] \text{ (per timestep)}$$

Table 38. Egestion parameter variables and units.

Variable	Units	Definition
T	deg. C	Temperature
D	J (per timestep)	Digestion parameter

$$U = 0.0233 \cdot T^{0.58} \cdot (D - F) \qquad (25)$$

$$U = \left(\frac{1}{°C}\right) °C \cdot J = J$$

$$U = [J] \text{ (per timestep)}$$

Table 39. Excretion parameter variables and units.

Variable	Units	Definition
T	deg. C	Temperature
D	J (per timestep)	Digestion parameter
F	J (per timestep)	Egestion parameter

Metabolism and Respiration

The respiration parameter (Equation (26)) is formulated based on the approach of Beauchamp, et al. (1989) as are the activity, ACT, and cruising speed (velocity) functions, Equations (27) and (28), respectively. The respiration, activity, and cruising speed variables and units are shown in Table 40. The value for the oxycaloric conversion factor is that used by Stockwell & Johnson (1997) of 3241 cal/ g-O_2 (13569.4 J/ g-O_2).

The respiration formulation has included fish mass, and was converted from cal to J. The activity formulation was converted from velocity inputs in cm/s to units of m/s. The cruising speed was converted from units of cm/s to units of m/s.

$$R = 0.00143 \cdot M^{-0.209} \cdot e^{0.086 \cdot T} \cdot ACT \cdot OXYCAL \cdot \frac{t}{t_{day}} \cdot M \qquad (26)$$

$$R = \frac{\frac{g - O_2}{(\sim g_{fish}) \cdot (\sim g_{fish})^{-0.209}} (\sim g_{fish})^{-0.209} \frac{J}{g - O_2} \cdot \frac{min}{min} \cdot g_{fish}}{R = \left[\frac{J}{g_{fish}} \cdot g_{fish} \right] = [J] \text{ (per timestep)}}$$

$$ACT = \exp(0.0234 \cdot v \cdot 100) \qquad (27)$$

$$v = 0.01 \cdot 9.9 \cdot \exp(0.0405 \cdot T) \cdot M^{0.13} \qquad (28)$$

Table 40. Respiration parameter variables and units.

Variable	Units	Definition
M	g_{wet}	Fish mass
T	deg. C	Temperature
ACT	dimensionless	Activity
OXYCAL	J / g-O_2	Oxycaloric conversion factor
t	(30) minutes	Timestep
t_{day}	(1440) minutes	Duration of a day

Thornton-Lessem Function

Thornton and Lessem's equation is an algorithm for modifying biological rates as a function of temperature using the basic form of the logistics equation. It can be thought of as a higher-order Arrhenius correction. The Thornton-Lessem function used the formulation for kokanee of Beauchamp, et al. (1989), which was later used by Stockwell & Johnson (1997). A plot of the function is shown as Figure 16, and the parameters are reported in Table 41.

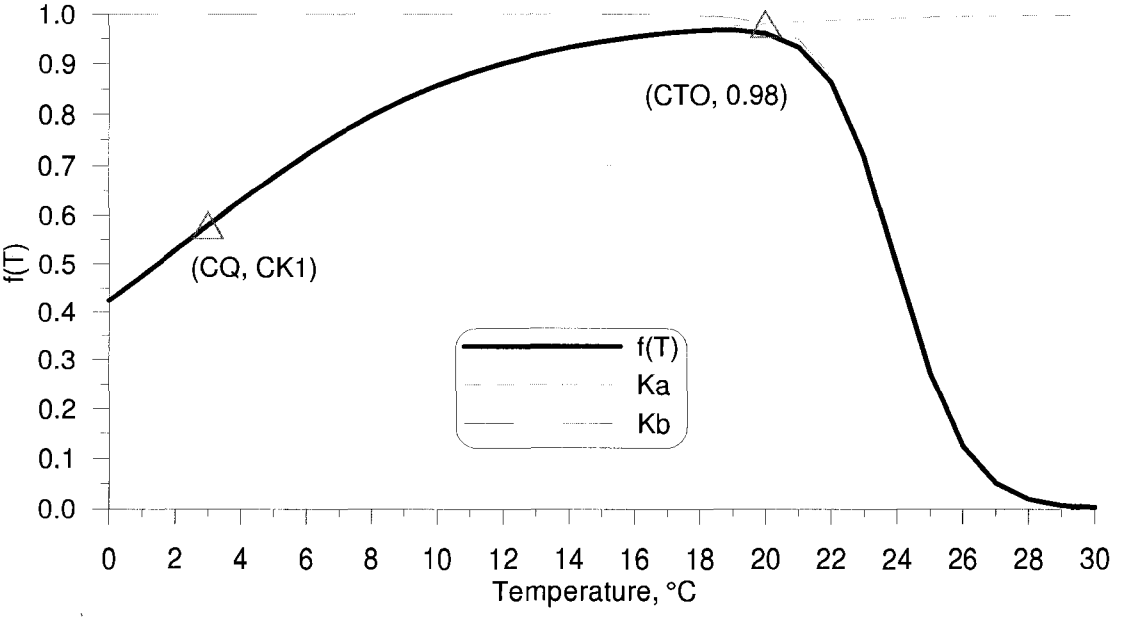

Figure 16. Plot of the Thornton-Lessem function.

Table 41. Thornton-Lessem function parameters for kokanee.

Parameter	Value	Unit
CK1	0.58	--
CQ	3	°C
CTO	20	°C
CTM	20	°C
CTL	24	°C
CK4	0.5	--

Typical Ancillary Function Values

The bioenergetics parameters are a function of other, ancillary functions. Table 42 reports the values of those functions for a 76 and 125 g kokanee at 4 and 20 °C to give a sense of the range and sensitivity of the ancillary functions.

Table 42. Representative ancillary function values for 76 and 125 g kokanee at 4 and 20 °C.

Temperature:	4 °C		20 °C	
Fish mass:	76 g	125 g	76 g	125 g
Ancillary function				
E_{fish}, fish energy density (J/g)	5822.5	6202.2	5822.5	6202.2
TL function	0.58	0.58	0.98	0.98
r, digestion coefficient	0.17	0.17	0.39	0.39
Stomach capacity (g)	3.64	4.65	3.64	4.65
v, velocity (m/s)	0.204	0.218	0.391	0.417
ACT	1.61	1.66	2.50	2.65
at 50,000 lux (summer, noon, near the surface)				
R_d, reaction distance (m)	0.125	0.125	0.125	0.125
E, search volume (m^3/s)	10.00×10^{-3}	10.70×10^{-3}	19.19×10^{-3}	20.47×10^{-3}
at 10 lux (crepuscular or at depth)				
R_d, reaction distance (m)	0.06	0.06	0.06	0.06
E, search volume (m^3/s)	2.31×10^{-3}	2.46×10^{-3}	4.42×10^{-3}	4.72×10^{-3}

CE-QUAL-W2 Model Calibration & Results

This section summarizes the CE-QUAL-W2 model calibration report, "Lake Roosevelt Water Quality and Hydrodynamic Model Calibration with Fish Bioenergetics" (McKillip and Wells, 2006), which covered:

- Hydrodynamic calibration
- Temperature calibration
- Abiotic water quality calibration
- Algae and zooplankton calibration

The model calibration periods are shown in Table 43.

Table 43. Model calibration periods.

Calibration	Start date	End date
Hydrodynamic	January 1, 2000	December 31, 2000
	January 1, 2001	December 31, 2001
	January 1, 2002	December 31, 2002
Water temperature	January 1, 2000	December 31, 2000
Water quality	January 1, 2000	December 31, 2000
Bioenergetics	January 1, 2000	December 31, 2000

Monitoring Sites

The water quality monitoring sites are discussed in McKillip, Annear, and Wells (2005). Figure 12 shows the locations of the water quality monitoring stations. Hydrodynamic calibration sites include USACOE FDRW at Grand Coulee Dam and GCGW downstream of the dam. These sites were used for boundary conditions and for model-data comparisons during calibration within Lake Roosevelt.

Hydrodynamic Calibration

Hydrodynamic calibration was performed by balancing all of the sources and sinks with a waterbalance flow to match the dam forebay water surface elevation data. Sources include tributary and mainstem inflows, precipitation, and return flows from Banks Lake (cogeneration flows). Sinks include outflows at the dam (powerhouse flows, outlet tubes, and spillway flows) irrigation withdrawals to Banks Lake, and evaporation.

Calibration Stations

The sole hydrodynamic calibration station is at the forebay of Grand Coulee Dam, USACOE gage (GCL). The station reports hourly water surface elevation (stage).

Year 2000

Figure 17 shows the model-data comparison of forebay stage. Table 44 reports the model-data comparison statistics. The magnitude of the waterbalance flows are shown in Figure 18. Figure 19 shows the percent of the waterbalance flows compared to the total flow through the dam. The magnitude of the waterbalance flows is largely within the flow gage measurement error range of 5 to 10%.

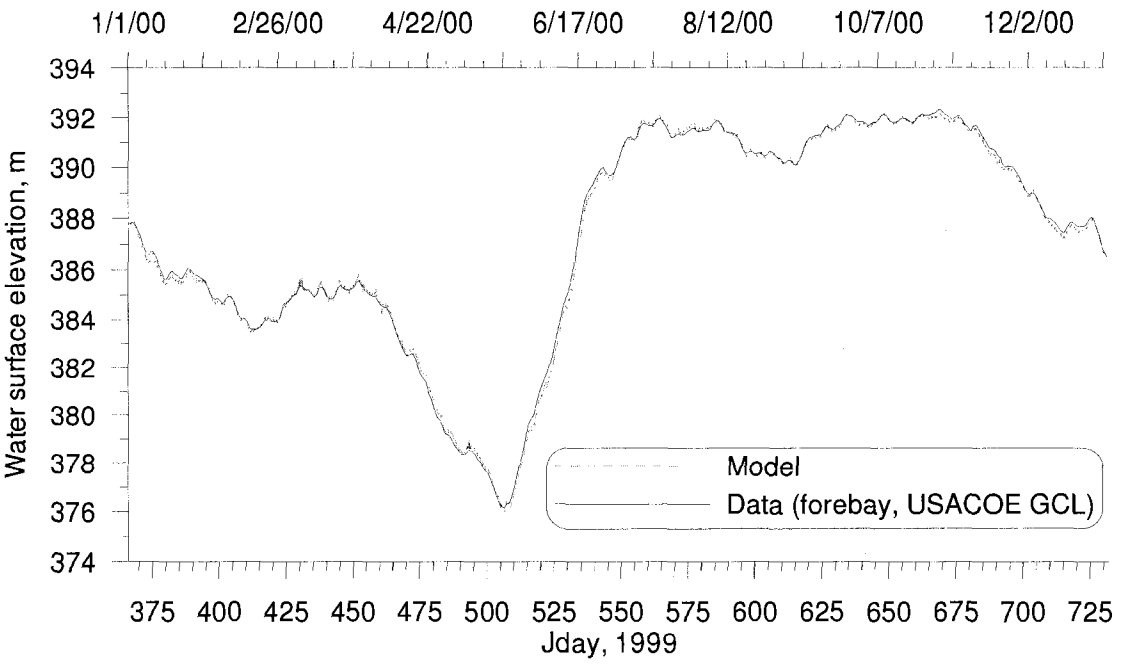

Figure 17. Model-data comparison, Grand Coulee Dam forebay stage, 2000.

Table 44. Grand Coulee Dam forebay stage statistics, 2000.

Statistic (m)	Count	ME*	AME*	RMS*
Daily-average values	366	0.01	0.01	0.01
Hourly-average values	8762	-0.03	0.17	0.17

* ME=mean error, AME=absolute mean error, RMS=root mean square error.

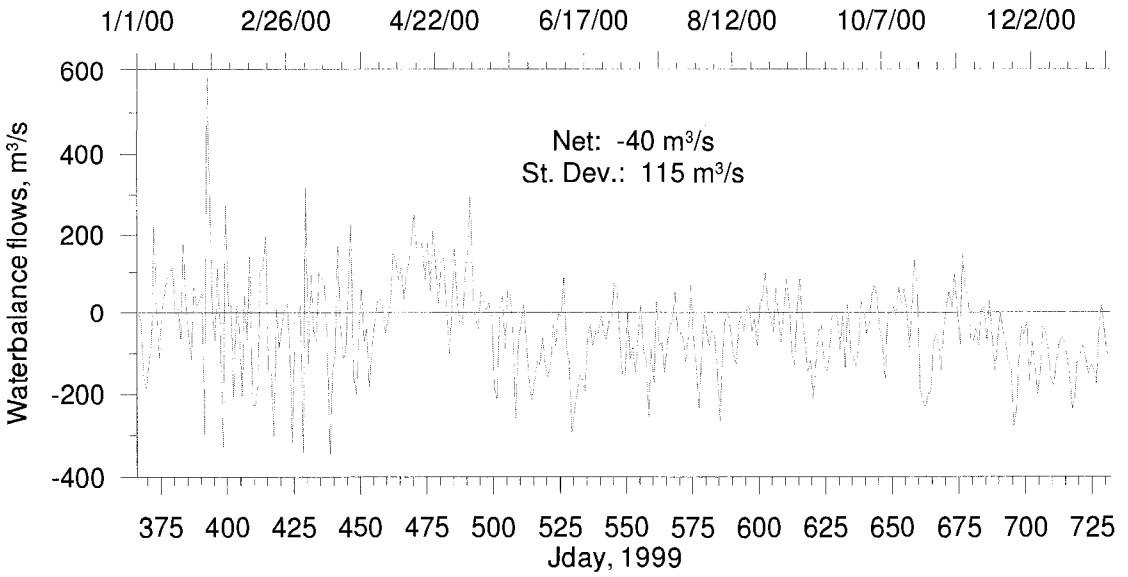

Figure 18. Waterbalance flow magnitudes, 2000.

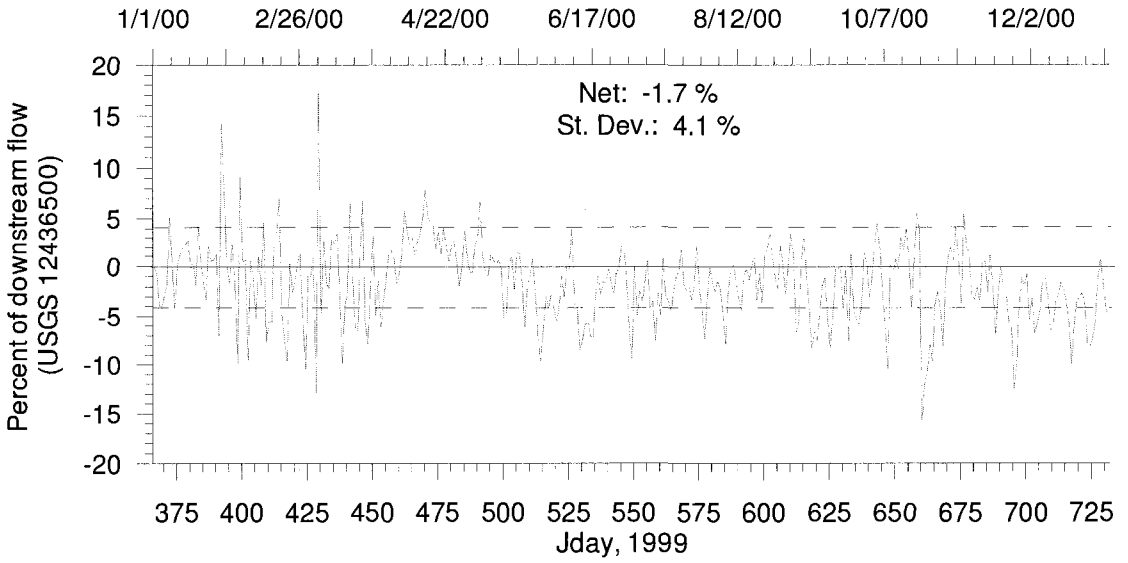

Figure 19. Waterbalance flows as percentage of downstream flows, 2000.

Year 2001

Figure 20 shows the model-data comparison of forebay stage. Table 45 reports the model-data comparison statistics. The waterbalance flows are shown terms of magnitude (Figure 21) and percent of total flow through the dam (Figure 22). Unlike the water balance for 2000, the 2001 water balance shows a bias toward negative flows (water being removed from the river).

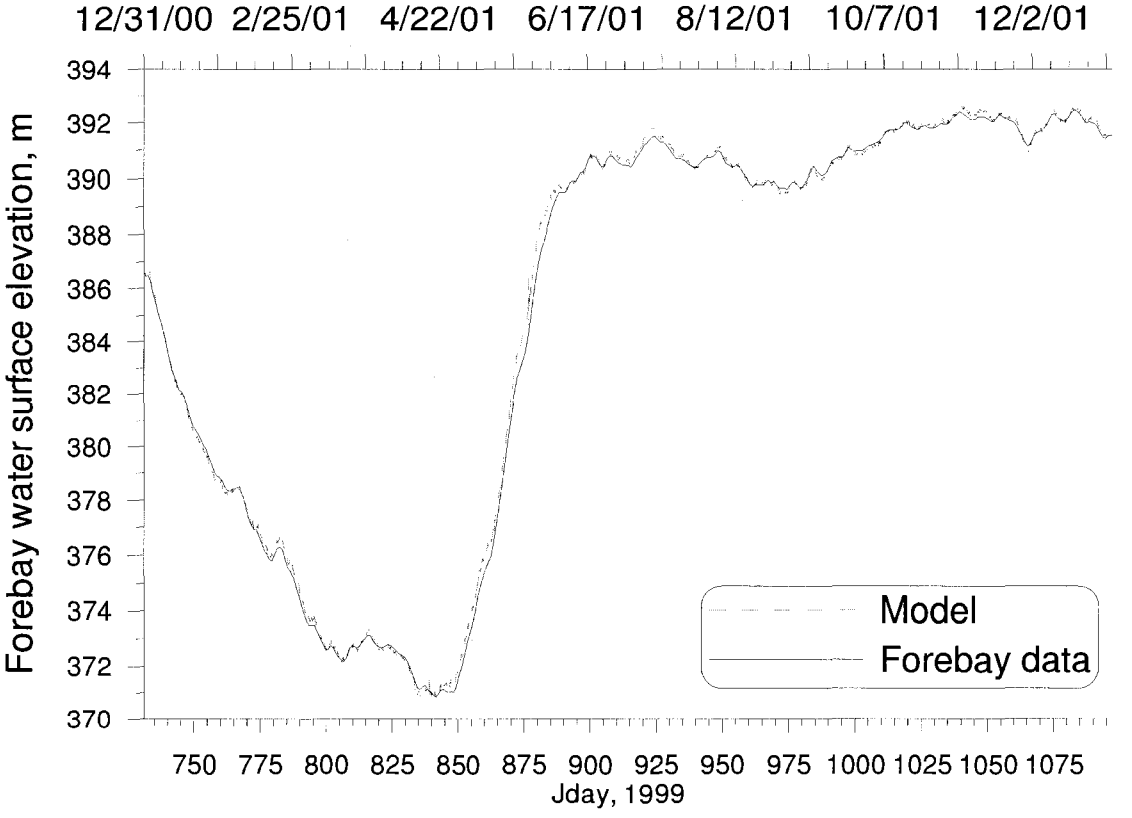

Figure 20. Model-data comparison, Grand Coulee Dam forebay stage, 2001.

Table 45. Grand Coulee Dam forebay stage statistics, 2001.

Statistic (m)	Count	ME*	AME*	RMS*
Daily-average values	366	0.13	0.17	0.27
Hourly-average values	8762	0.01	0.12	0.12

* ME=mean error, AME=absolute mean error, RMS=root mean square error.

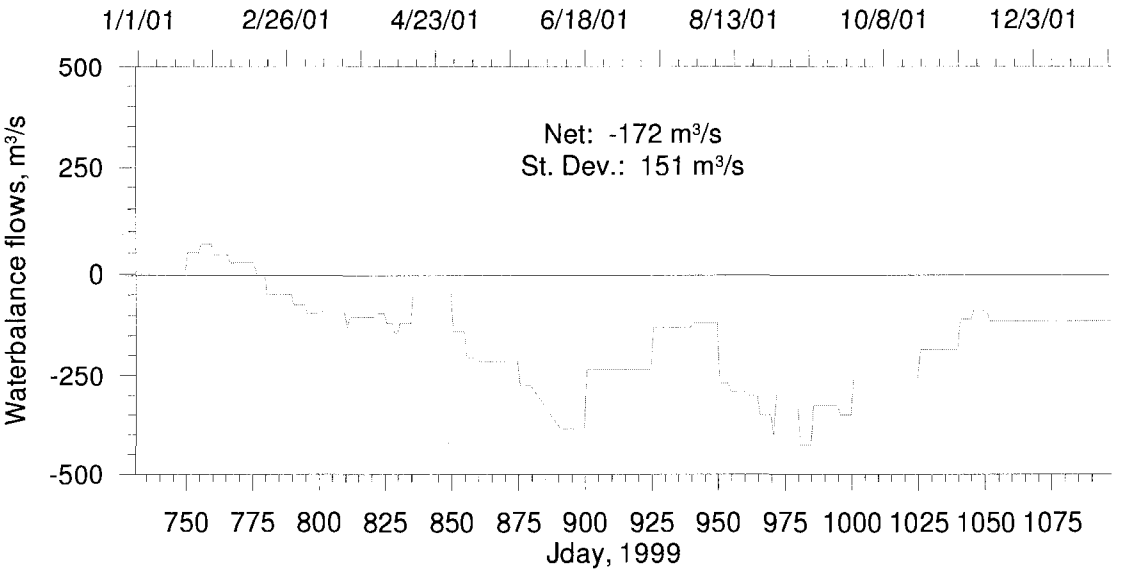

Figure 21. Waterbalance flow magnitudes, 2001.

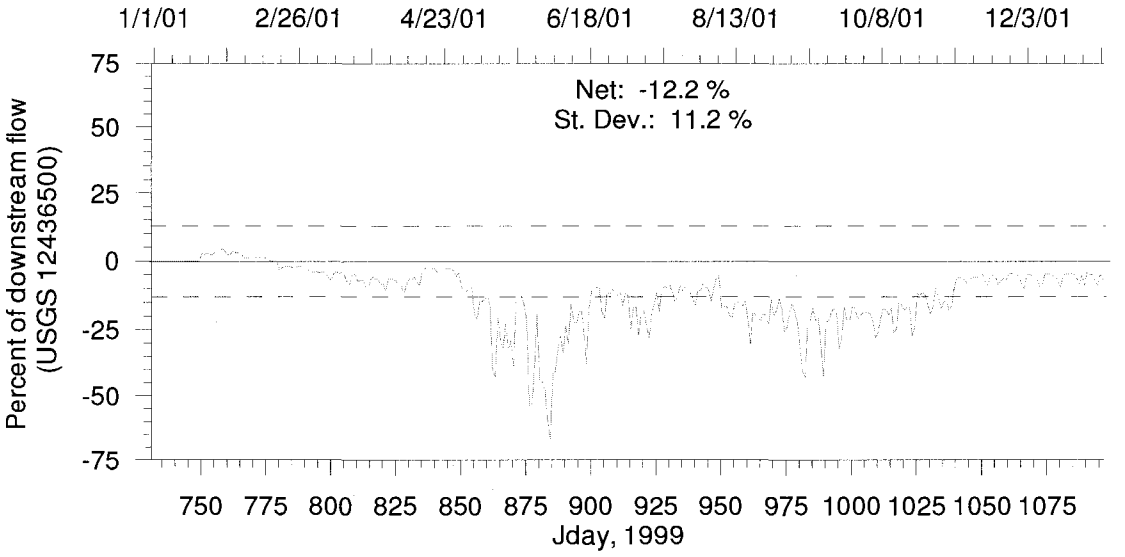

Figure 22. Waterbalance flows as percentage of downstream flows, 2001.

Year 2002

Figure 23 shows the model-data comparison of forebay stage. Table 46 reports the model-data comparison statistics. The waterbalance flows are shown terms of magnitude (Figure 24) and percent of total flow through the dam (Figure 25). Unlike the water balance for 2000, the 2002 water balance shows a bias toward negative flows (water being removed from the river).

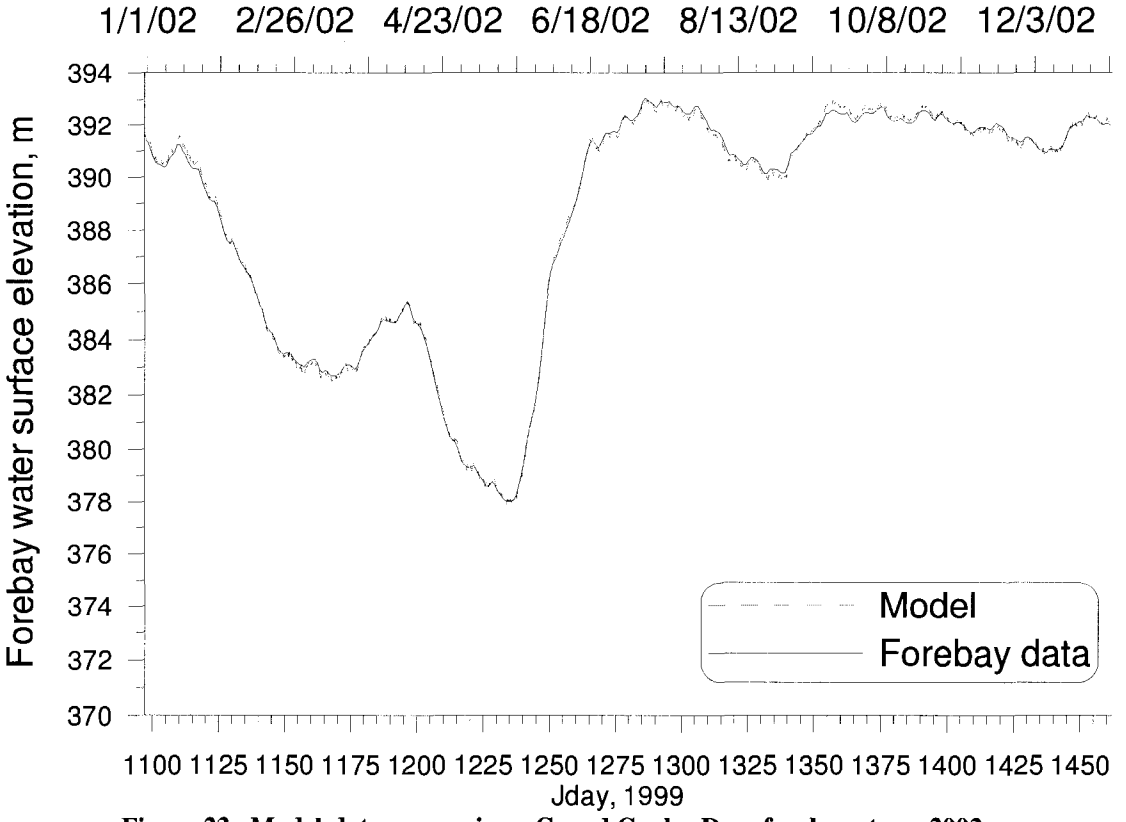

Figure 23. Model-data comparison, Grand Coulee Dam forebay stage, 2002.

Table 46. Grand Coulee Dam forebay stage statistics, 2002.

Statistic (m)	Count	ME*	AME*	RMS*
Daily-average values	366	0.02	0.02	0.02
Hourly-average values	8763	0.01	0.10	0.10

* ME=mean error, AME=absolute mean error, RMS=root mean square error.

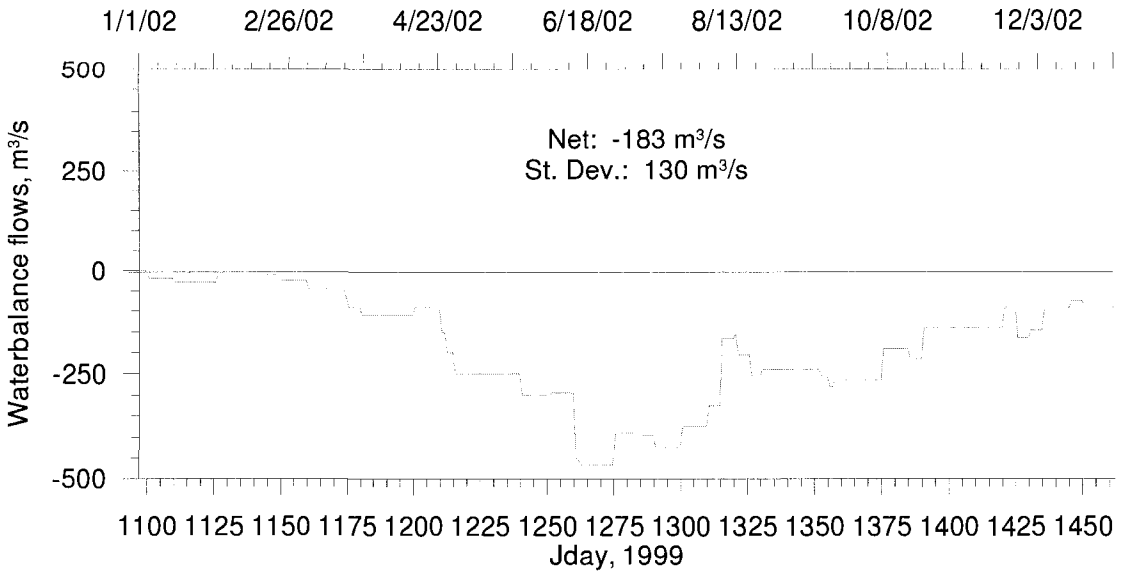

Figure 24. Waterbalance flow magnitudes, 2002.

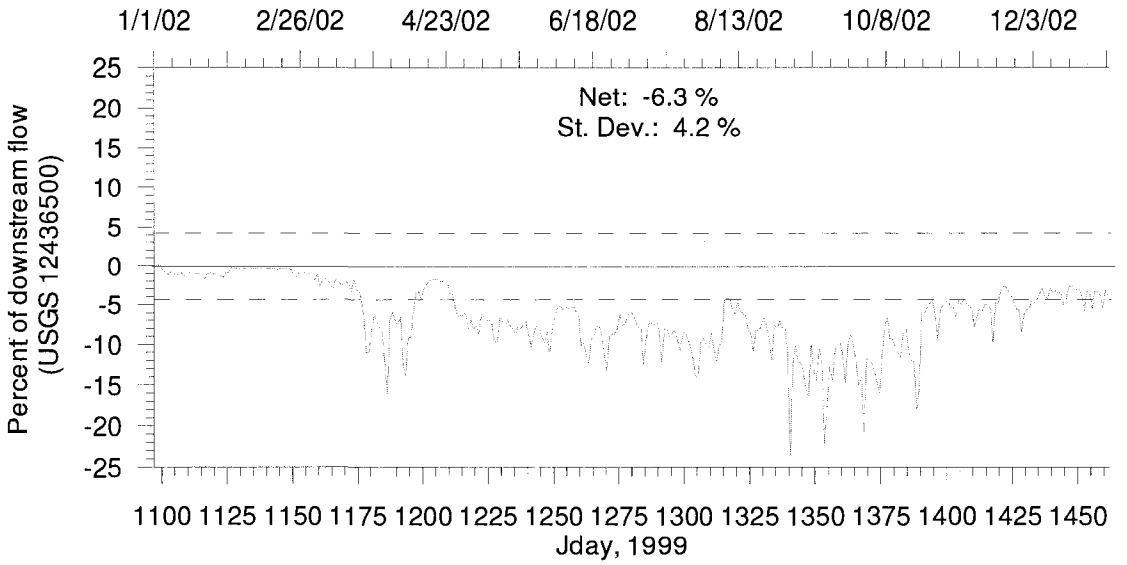

Figure 25. Waterbalance flows as percentage of downstream flows, 2002.

Temperature Calibration

The temperature calibration focused on matching the vertical stratification by adjusting the local wind sheltering coefficient and properly characterizing the powerhouse flows. The selective withdrawal elevation for flow through the third powerhouse had a lower bounds set to allow for more of the warmer surface water characteristic during stratification to be withdrawn. Meteorological inputs were adjusted to allow for the proper level of mean heating in the vertical profile sampling stations and continuous data downstream of Grand Coulee Dam.

Figure 26 shows a comparison of the vertical temperature profile at LRFEP station 9.0 (upstream of Grand Coulee Dam) under the calibrated wind sheltering coefficients [WSC] and with the default values [1.0]. Areas upstream of the dam had decreased WSC values (this in a decrease in wind speed, and hence mixing) which helped to allow greater stratification in the epilimnion.

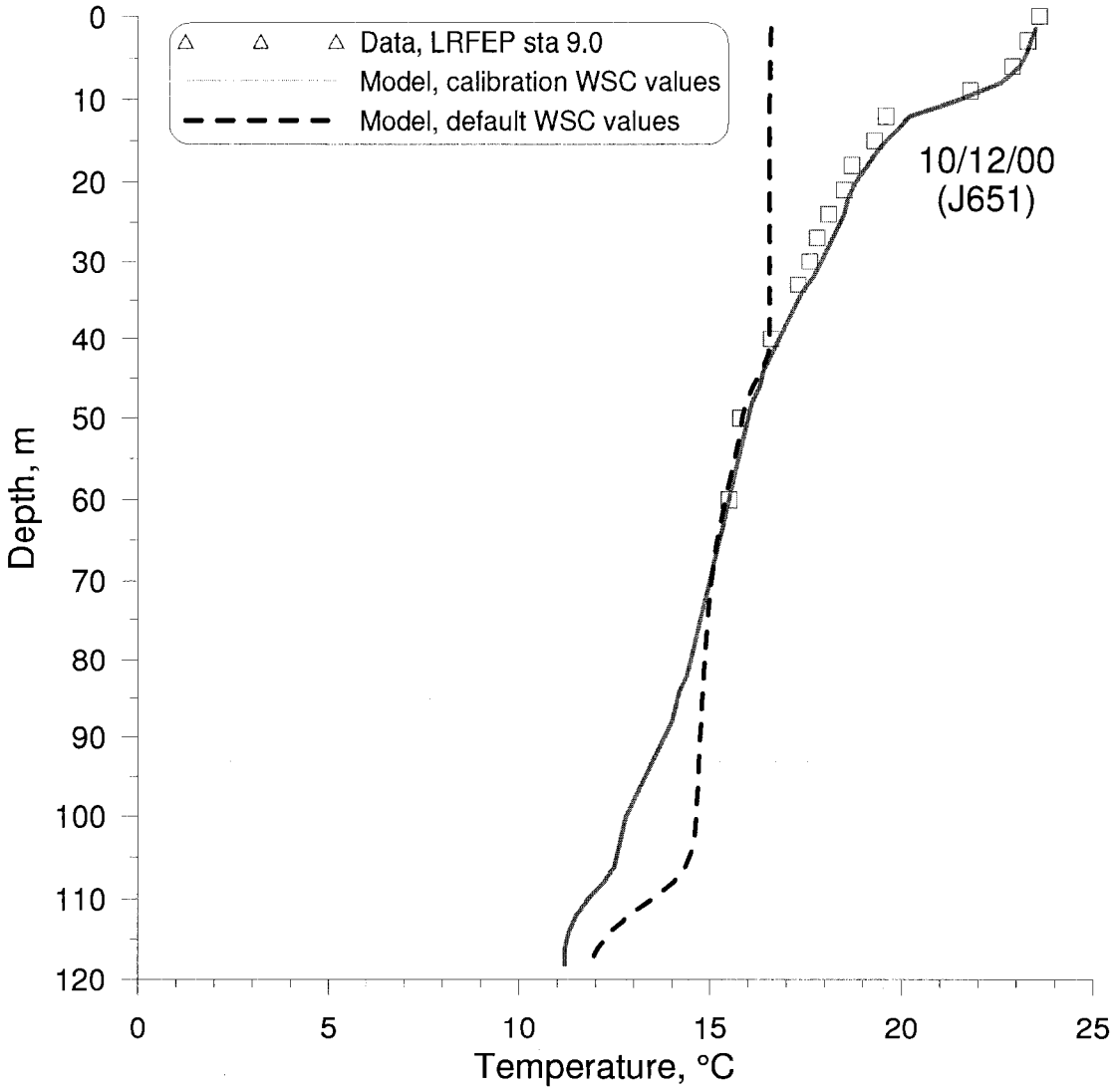

Figure 26. The effects of wind sheltering coefficients on temperature calibration. The default value of WSC of 1.0 was not considered accurate but was used as a basis for comparison to the calibrated value.

Calibration Stations

Two temperature calibration data types were available. Periodic vertical profile data were available at some or all of the 11 LRFEP stations shown in Figure 27. Table 47 lists the gage locations, numbers, and names. Sampling general occurred at a temporal frequency up to monthly at a typical vertical resolution of 3 m over the bulk of the vertical range. Roughly 10 km (6 mi) downstream of Grand Coulee Dam is the USACOE gage (GCGW) which records hourly temperatures. The Columbia River at the gage is riverine, and the temperatures were taken to be representative of the mean temperature.

Two additional temperature data sources were not used for calibration. The USGS gage at Northport (12400520) reported low frequency samples. The values reported were generally much colder than the nearby upstream temperatures reported at the International Boundary (USACOE CIBW) used for the Columbia River temperature boundary condition. The upstream gage, CIBW, agreed well with the most upstream vertical profile station (LRFEP 0.0).

The USBR collects temperatures from a station at the left side of Grand Coulee Dam that floats 60 ft (18.3 m) below the water surface (reported as USACOE: FDRW). These data were likely unrepresentative of the temperatures in the last model segment (which is 1000 m in length) as the instrument was attached to a trash rack near the

dam face. Refer to McKillip, Annear, and Wells (2005) for further discussion of the instrument and data quality.

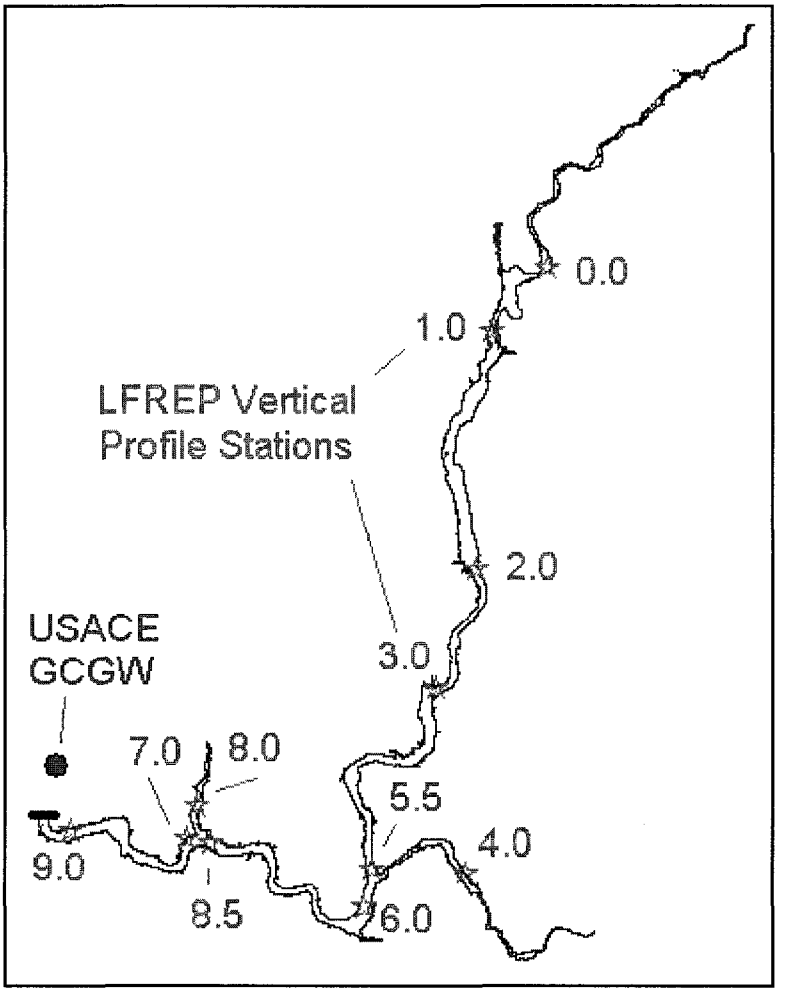

Figure 27. Locations of the temperature calibration sites.

Table 47. LFREP vertical profile stations.

Gage/Station	Location Name	Latitude	Longitude
0.0	Evan's Landing	48.6830	118.0216
1.0	Kettle Falls	48.5992	118.1310
2.0	Gifford	48.2944	118.1540
3.0	Hunters	48.1371	118.2261
4.0	Porcupine Bay	47.9018	118.1651
5.5	Spokane R. Confluence	47.9043	118.3431
6.0	Seven Bays	47.8566	118.3571
7.0	Keller Ferry	47.9398	118.7046
8.0	Sanpoil R.	47.9814	118.6859
8.5	Sanpoil R. Confluence	48.0545	118.6643
9.0	Spring Canyon	47.9462	118.9285

Grand Coulee Dam, Continuous Temperatures

Temperature calibration focused on adjusting the wind magnitude (via the wind sheltering coefficient) temporally and spatially. Because actual wind speed and direction are highly variable around the lake, in order to monitor the wind with sufficient accuracy for calibration, one or a couple of wind monitoring locations may be inadequate to account for the full spatial and temporal variability of the wind field. The temperature data provide a good measure of the level of wind-driven mixing available between stations over the sampling time intervals. Thus, by adjusting the wind magnitude over reaches and time periods where the level of mixing is known (i.e., where temperature data are present), the mean wind speed can be better approximated.

The first target was to approximate the mean downstream temperature data (USACOE GCGW). The second target was to match the vertical temperature profiles, which are a good indicator of the appropriate wind magnitude. In matching the temperatures near Grand Coulee Dam, the vertical profile data at LRFEP station 9.0 were given greater weight than the downstream river temperatures at USACOE GCGW, whose model-data comparison is shown in Figure 28. Statistics are reported in Table 48. The depth of the powerhouse intakes, when compared to the vertical temperature profiles of the data at LRFEP station 9.0 and the model at the last Columbia River segment, suggests that the outflow temperature should be much colder during the summer than the downstream, riverine data. In order to 1) match the downstream, riverine data and 2) obtain the shape of the vertical profile data, the bottom of the selective withdrawal algorithm for the third powerhouse was limited to a minimum elevation of 353 m. This is higher than the centerline intake elevation of 347.5 m. Given the narrow inlet length of the third powerhouse, the surface waters appear to be preferentially withdrawn from the surface. This model characterization is a simplification of the more complicated three-dimensional nature of the flow within the third powerhouse inlet.

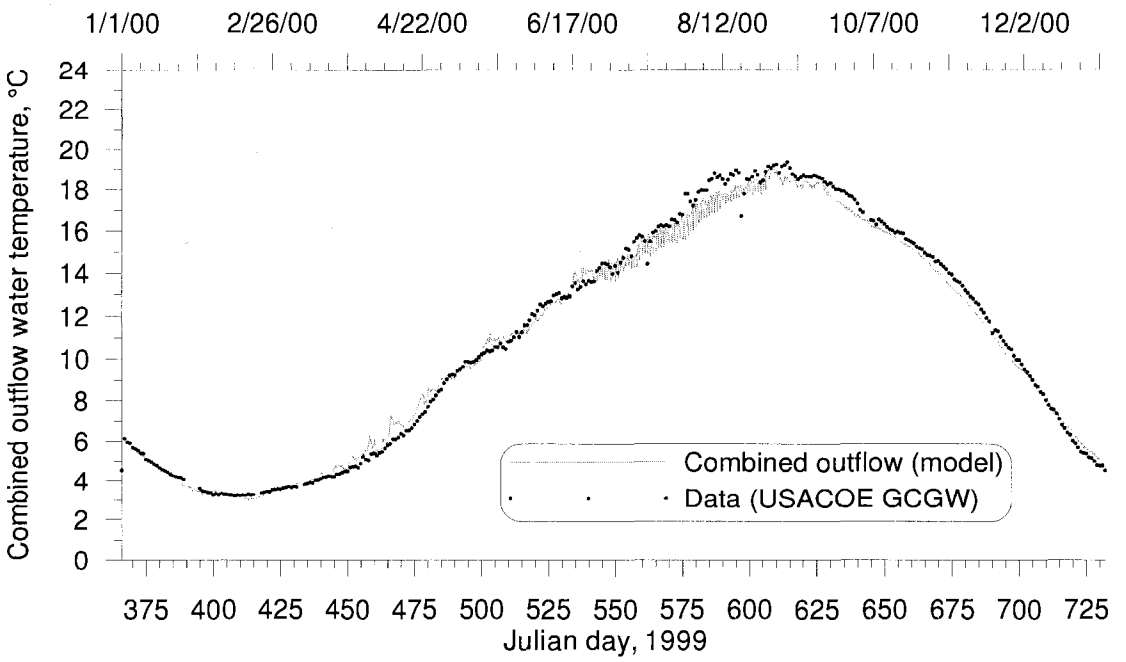

Figure 28. Model-data temperature comparison, below Grand Coulee Dam, 2000.

Table 48. Grand Coulee Dam temperature statistics, 2000.

Statistic (°C)	Count	ME*	AME*	RMS*
Daily-average values	356	-0.12	0.36	0.36
15-min and 60-min average values	24428	-0.24	0.45	0.45

* ME=mean error, AME=absolute mean error, RMS=root mean square error.

Vertical Profile Stations, Periodic Sampling

The temperature calibration plots and statistics from the LRFEP vertical profile station data are reported in McKillip and Wells (2006). Selected profiles are shown for station 4.0 (Figure 29) and station 9.0 (Figure 30) in this section. Three sampling periods are illustrated for the reservoir conditions near minimum spring pool, near peak thermal stratification, and after fall turnover. Overall temperature model-data profile errors were -0.14°C, 0.49°C, and 0.50°C, for the mean error, absolute mean error, and root-mean-square error, respectively, comparing 114 vertical temperature profiles.

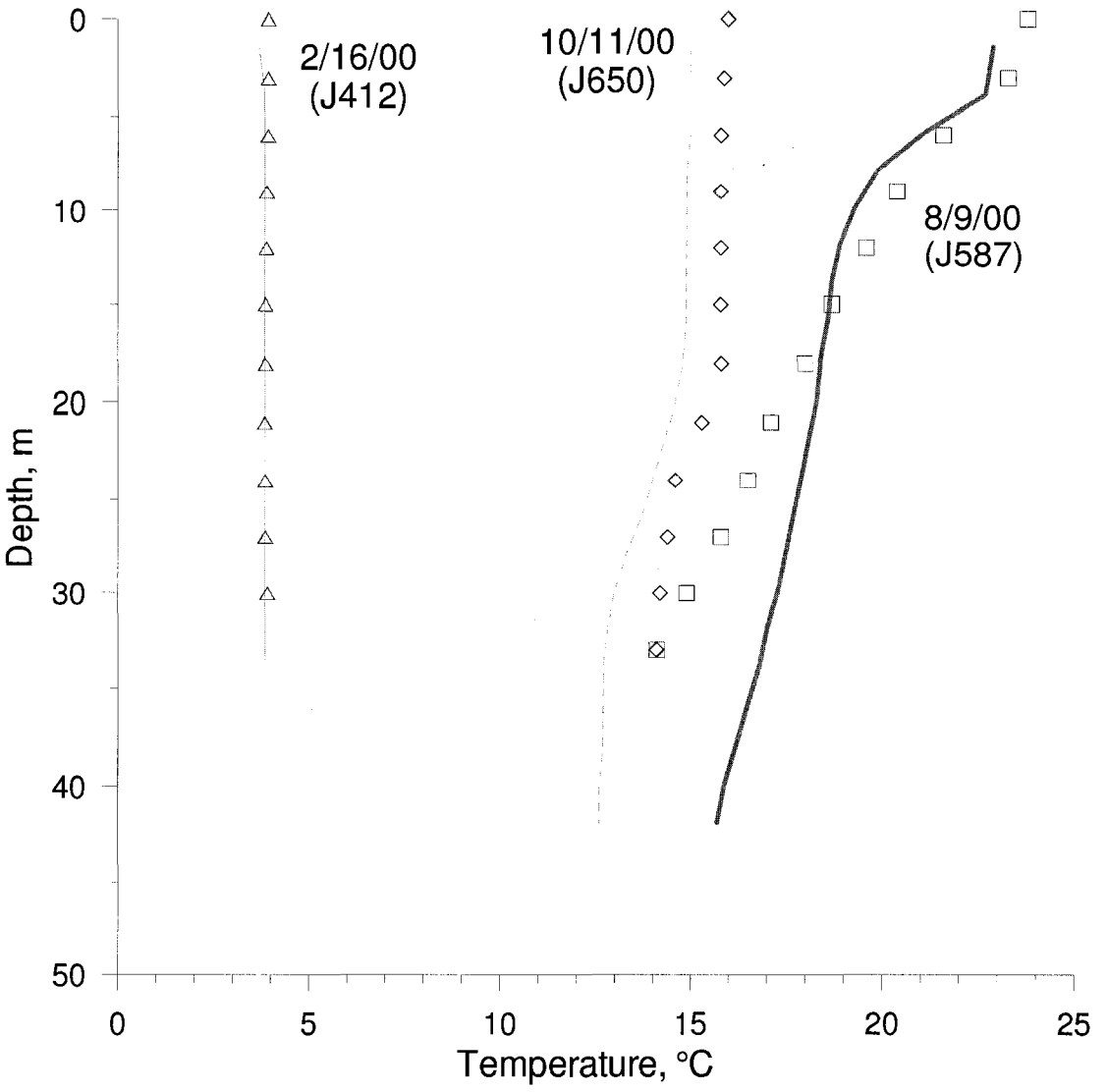

Figure 29. Selected model-data temperature profile comparisons at Porcupine Bay (LRFEP sta 4.0).

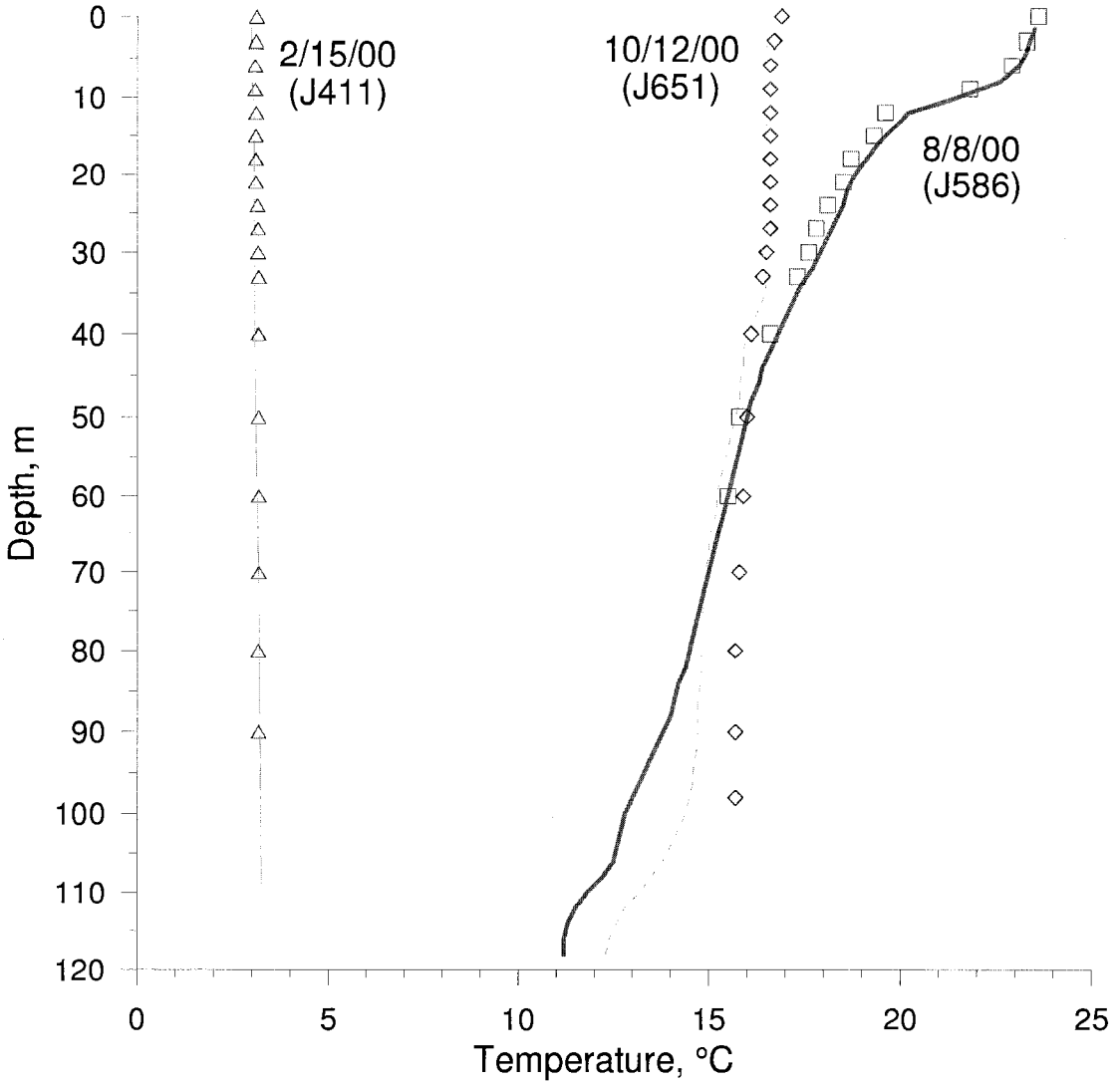

Figure 30. Selected model-data temperature profile comparisons at Spring Canyon (LRFEP sta 9.0).

Abiotic Water Quality Calibration

Calibration Stations and Statistics

The abiotic water quality calibration stations included the LRFEP stations shown in Figure 27 (in the temperature calibration section) and the USGS gage below Grand Coulee Dam (12436500).

The abiotic water quality calibration plots were grouped into three areas to take advantage of the structure of the data.

- The flow weighted constituent values of the outflow at Grand Coulee Dam are reported in the next section (Grand Coulee Dam Outflow). The time-series results are compared with the vertical data upstream of the dam (LRFEP station 9.0) and the grab sampling in the riverine reach below the dam (USGS 12436500). Data below the dam are not available for all constituents.
- The LRFEP monitoring stations report several constituents associated over specific depths. These constituents are total dissolved solids, dissolved oxygen, and pH.
- Many of the constituents sampled by the LRFEP had a depth loosely associated with the sample. The depths were reported as being in the photic or

aphotic zone. The model results were volume-weighted over the upper 10 m to provide a rough estimate of the photic zone constituent value.

Calibration statistics for discrete model-data comparisons are summarized in Table 49. Vertical profile model-data comparison statistics are reported in Table 50.

Table 49. Discrete constituent model-data comparison statistics.

Constituent	Orthophosphate	Ammonium	Nitrate plus nitrite	Alkalinity
Unit	mg/L-P	mg/L-N	mg/L-N	mg/L-$CaCO_3$
Count	25	25	25	25
ME	0.00072	-0.0050	-0.017	0.89
AME	0.00097	0.0067	0.036	4.18
RMS	0.00097	0.0067	0.036	4.18

Table 50. Vertical profile calibration statistics, 2000.

Station	Location	#days, (# points)	Statistic	TDS mg/L	DO mg/L	pH -	Temp °C
0.0	Columbia R.	11 (80)	ME	-0.18	-0.01	-0.42	-0.14
			AME	0.39	0.14	0.43	0.49
			RMS	0.44	0.16	0.43	0.50
1.0	Columbia R.	11 (111)	ME	0.72	0.18	-0.41	-0.15
			AME	0.97	0.38	0.42	0.40
			RMS	1.03	0.40	0.42	0.41
2.0	Columbia R.	18 (194)	ME	-0.91	0.29	-0.55	-0.11
			AME	1.17	0.56	0.59	0.56
			RMS	1.21	0.59	0.59	0.60
3.0	Columbia R.	11 (121)	ME	-0.95	0.12	-0.42	-0.26
			AME	1.52	0.65	0.45	0.58
			RMS	1.56	0.69	0.45	0.61
5.5	Columbia R.	5 (55)	ME	-1.47	0.35	-0.46	0.28
			AME	2.14	0.71	0.51	0.49
			RMS	2.29	0.75	0.52	0.51
7.0	Columbia R.	11 (163)	ME	-0.08	0.21	-0.30	0.15
			AME	1.53	0.87	0.37	0.37
			RMS	1.62	0.90	0.38	0.42
9.0	Columbia R.	18 (284)	ME	-0.70	0.39	-0.40	0.25
			AME	1.37	0.79	0.50	0.46
			RMS	1.48	0.85	0.51	0.55
4.0	Spokane R.	18 (179)	ME	-6.68	1.18	-0.21	-0.49
			AME	10.90	1.44	0.38	0.86
			RMS	11.80	1.51	0.40	0.94
8.0	Sanpoil R.	11 (121)	ME	-0.42	0.16	-0.27	0.35
			AME	1.93	0.83	0.35	0.51
			RMS	2.09	0.87	0.36	0.55
System	**Average**	114 (1308)	ME	-0.18	-0.01	-0.42	-0.14
			AME	0.39	0.14	0.43	0.49
			RMS	0.44	0.16	0.43	0.50

Constituent Calibration Discussion

Calibration to temperature, hydrodynamic, abiotic, and biotic data is to a varying degree simultaneous. A discussion of the abiotic calibration is presented in this section in an attempt to present the calibration adjustments in a single section.

In general, the approach to calibration is to calibrate to hydrodynamic data, and then to the temperature data, which often requires adjustment of the hydrodynamic calibration. The most upstream location is calibrated first, for each calibration target, and the earliest targets (in time) are also calibrated first. The downstream stations, and the later time periods, are heavily influenced by the upstream and earlier periods. Thus, a continuous reevaluation of the upstream calibration and boundary conditions is made during calibration.

While considering this general approach, calibration of specific constituents is discussed below. Not all of plots and statistics are reported. Refer to McKillip and Wells (2006) for more detail.

Alkalinity and pH

Since there is little carbonate chemistry activity in the system, alkalinity behaves like a conservative constituent. The calibration focused on ensuring that all of the carbon chemistry initial conditions were appropriate. The W2 model uses alkalinity, total

inorganic carbon (TIC), and bicarbonate (HCO3) to model the carbon system. pH is a derived constituent, meaning its value is determined from other constituents. Overall, pH model-data profile errors were -0.42 0.43, and 0.43, for the mean error, absolute mean error, and root-mean-square error, respectively, comparing 114 vertical pH profiles.

Ammonium and Nitrate plus Nitrite

Calibration of the nitrogen budget required only small changes from the default conditions. The major change was to reduce the amount of nitrogen in the decaying organic matter [ORGN] to reduce the ammonium concentrations.

Dissolved Oxygen

Dissolved oxygen calibration involved a review of the boundary conditions, inclusion of sediment oxygen demand (SOD), and an investigation of the reaeration equations and algal populations. As might be expected from low algal concentrations, the mainstem Columbia and Spokane River DO concentrations were not sensitive to algal concentration. Similarly, such a large volume system was not sensitive to the reaeration formulation. Inclusion of SOD allowed the model to capture some of the vertical gradients near the bottom of the reservoir. However, the model was not able to fully capture all of the observed vertical gradients—the model predicted less vertical variation. Also, the data exhibit significant shifts in concentrations from month to month and site to site that are not readily explained by known physical

processes. For example, the data showed monthly changes of 1 mg/l at a site that would not occur at the next downstream site. Overall, dissolved oxygen model-data profile errors were -0.01 mg/l, 0.14 mg/l, and 0.16 mg/l, for the mean error, absolute mean error, and root-mean-square error, respectively, comparing 114 vertical dissolved oxygen profiles. Detailed error statistics are shown in Table 50.

Orthophosphate

Phosphorous calibration was problematic given the large spring spike over the entire system, followed by very low concentrations. The physical cause of this phenomenon is not clear. The phenomenon was characterized as early spring inflows which were then sorbed onto inorganic suspended solids. This approach allowed some of the spring spike to be captured by the model, but the summer and fall concentrations were elevated. Additionally, the organic matter stoichiometry [ORGP] was reduced to lower concentrations. The orthophosphate concentrations were not sensitive to algal stoichiometry or algal concentrations within the range of the system.

Total Dissolved Solids

Total dissolved solids are largely conservative, so calibration focused on ensuring good boundary conditions. The calibration was acceptable for the Columbia River, but the Spokane River showed some problems. While the shape of the vertical gradient was typically captured, there were errors (shifts) in the concentrations.

Overall, Total dissolved solids model-data profile errors were -0.18 mg/l, 0.39 mg/l, and 0.44 mg/l, for the mean error, absolute mean error, and root-mean-square error, respectively, comparing 114 vertical TDS profiles. Detailed error statistics are shown in Table 50.

Grand Coulee Dam Outflow

The water quality constituents of the modeled outflow from Grand Coulee Dam are compared to data both upstream at LRFEP station 9.0 and downstream at USGS 12436500. The data at these two points do not always agree. The model uses flow weighting from each outlet structure in reporting the model constituent concentrations. The downstream data are from grab samples at a 2riverine reach. The upstream samples are a mix of vertical profile points and grab samples in both the aphotic and euphotic zones. The vertical profile data points are shown to give a sense of the range of the constituent values at the sampling point.

The model-data comparison statistics for the discrete sampling constituents are shown in Table 49. The statistics for the vertical profile sampling constituents are reported in Table 50.

Alkalinity

The alkalinity model-data comparison near Grand Coulee Dam is shown in Figure 31. After ensuring good boundary conditions and hydrodynamic calibration, no further adjustments were made.

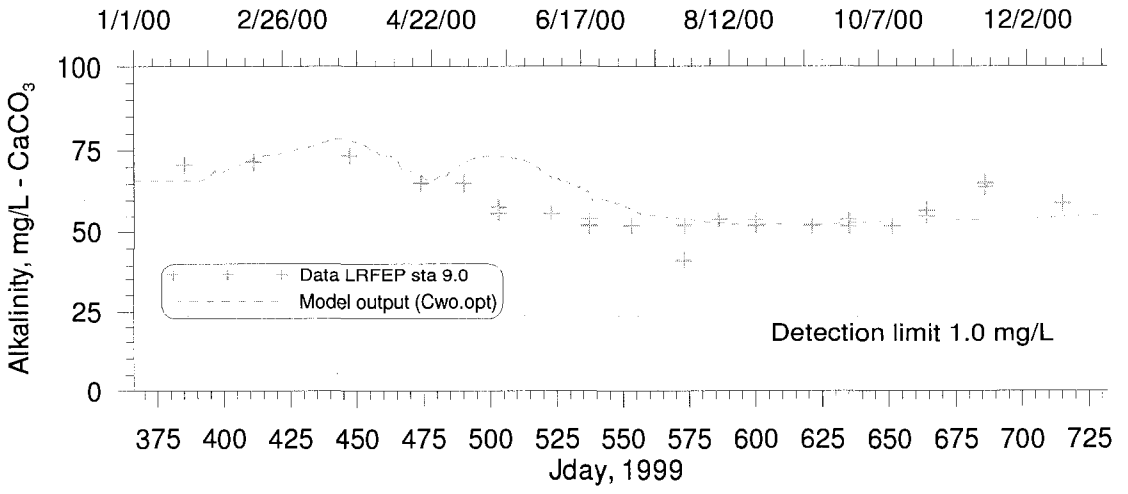

Figure 31. Alkalinity time-series near Grand Coulee Dam.

Ammonium

The ammonium model-data comparison near Grand Coulee Dam is shown in Figure 32. After ensuring good boundary conditions and hydrodynamic calibration, no further adjustments were made. The USGS sampling had a higher detection limit than the LRFEP sampling. The model predicts ammonium concentrations below the USGS sampling detection limit.

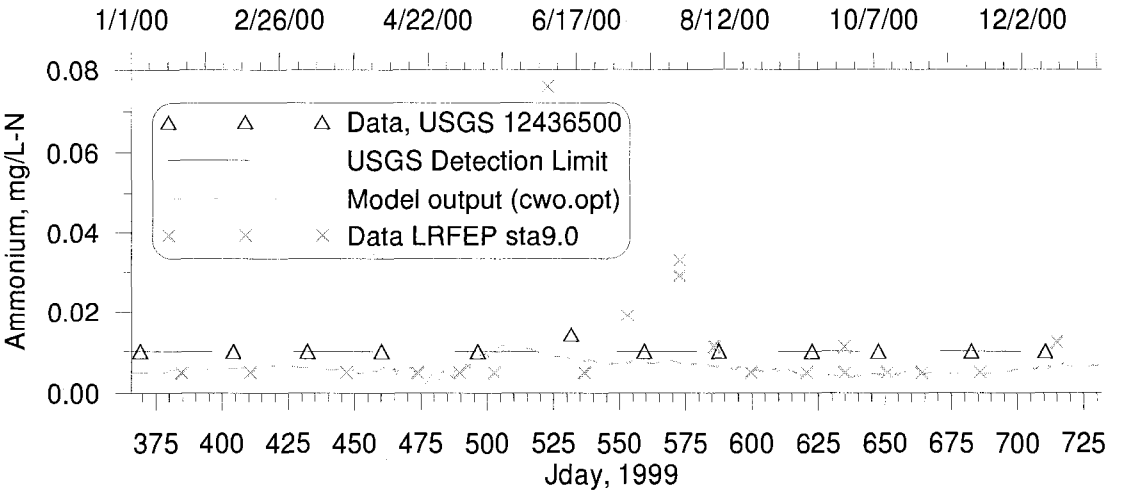

Figure 32. Ammonium time-series near Grand Coulee Dam.

Dissolved Oxygen

The dissolved oxygen model-data comparison near Grand Coulee Dam is shown in Figure 33. After ensuring good boundary conditions and hydrodynamic calibration, no further adjustments were made. The model values are typically near saturation; however, the data are above saturation in the early spring and below saturation in the fall. The source of this discrepancy is unclear. Model results were not sensitive to the algal concentration or the air-water reaeration formulation.

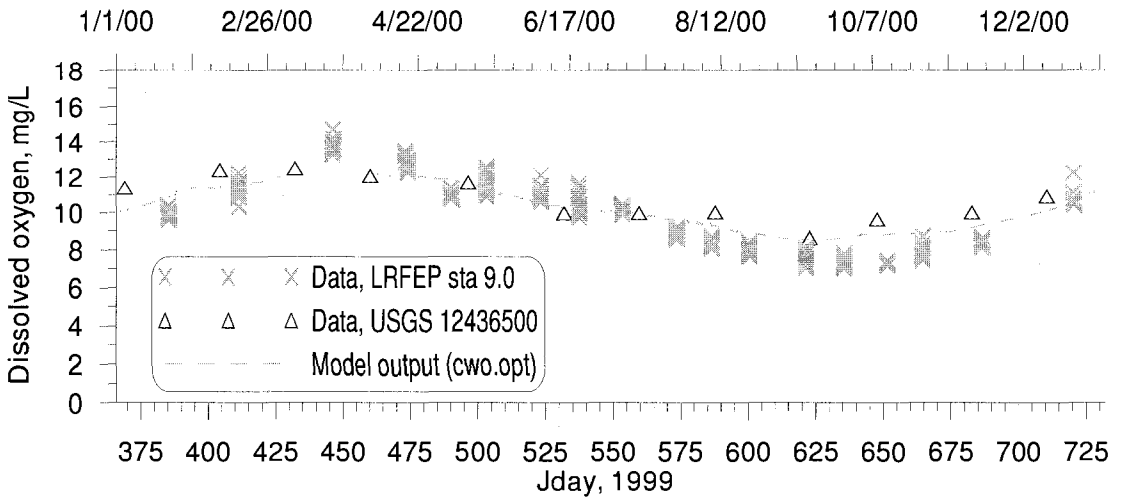

Figure 33. Dissolved oxygen time-series near Grand Coulee Dam.

Nitrate plus nitrite

The nitrate plus nitrite model-data comparison near Grand Coulee Dam is shown in Figure 34. After ensuring good boundary conditions and hydrodynamic calibration, no further adjustments were made.

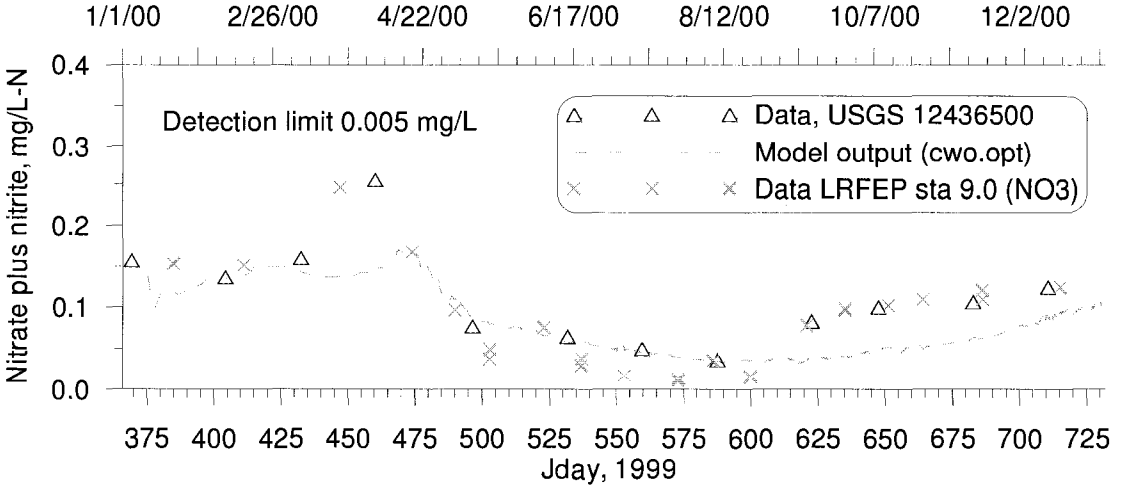

Figure 34. Nitrate time-series near Grand Coulee Dam.

pH

The pH model-data comparison near Grand Coulee Dam is shown in Figure 35. Calibration included ensuring good boundary conditions and good hydrodynamic calibration. While not clearly illustrated in Figure 35, the model does capture the strength of the vertical gradient seen during the summer. Refer to the vertical profile plots in Appendix F. During October and November of 2000, there was a known problem with the sensor probe.

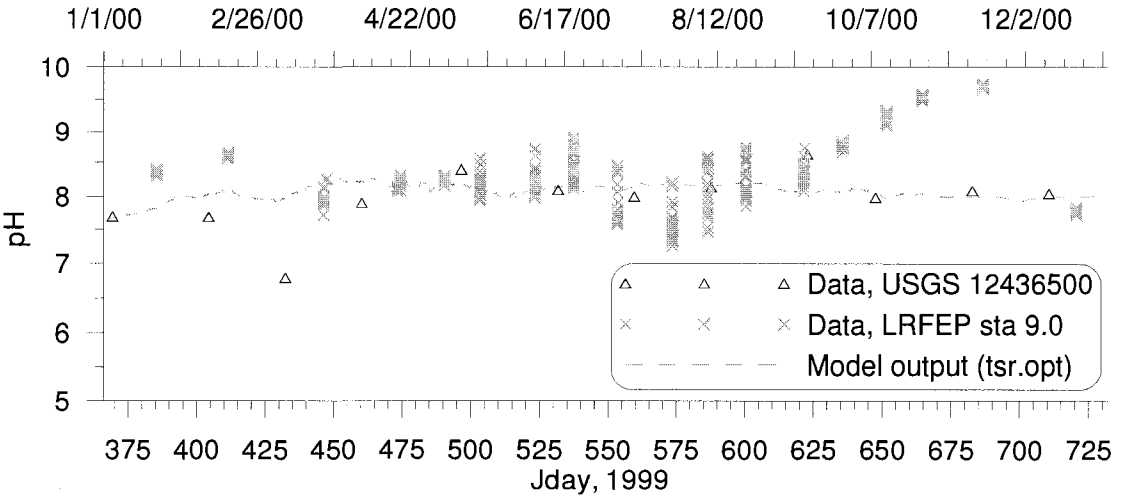

Figure 35. pH time-series near Grand Coulee Dam.

Orthophosphate

The orthophosphate model-data comparison near Grand Coulee Dam is shown in Figure 36. Calibration included ensuring good boundary conditions and good hydrodynamic calibration. The organic mater decay rate was decreased, sorption onto inorganic suspend solids was allowed, and the stoichiometry of organic matter was adjusted to calibrate orthophosphate.

There are several possible sources of the model-data discrepancy. The very low phosphorous concentration makes accurate measurements difficult. The attached algae data are sparse and may not be representative. The relationship between sorbed phosphorous and the stoichiometry of the inflow organic matter is likely neither invariant in time or space. The transition from winter periphyton to spring phytoplankton as the dominant primary production and the heterogeneity in boundary conditions are likely to explain much of the systems behavior.

The USGS sampling had a higher detection limit than the LRFEP sampling. The model predicts orthophosphate concentrations below the USGS sampling detection limit.

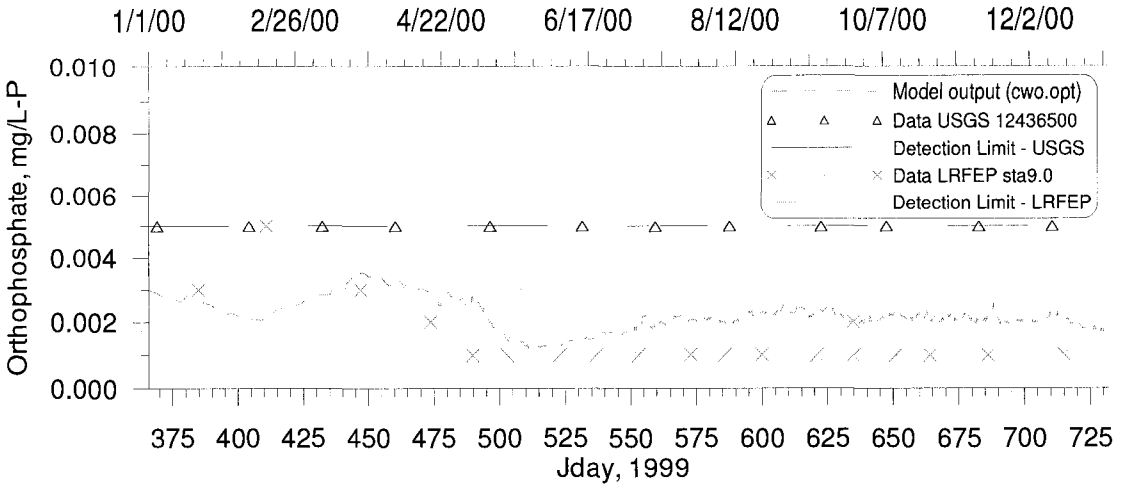

Figure 36. Orthophosphate time-series near Grand Coulee Dam.

Total Dissolved Solids

The total dissolved solids model-data comparison near Grand Coulee Dam is shown in Figure 37. After ensuring good boundary conditions and hydrodynamic calibration, no further adjustments were made.

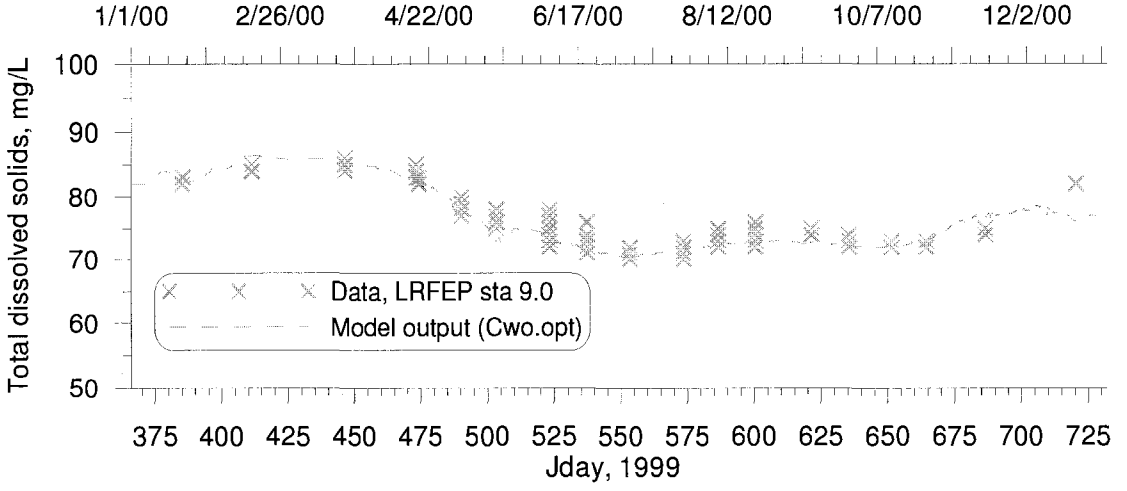

Figure 37. Total dissolved solids time-series near Grand Coulee Dam.

Vertical Profile Stations, Periodic Sampling

Dissolved oxygen, total dissolved solids, and pH calibration plots and statistics from the LRFEP vertical profile station data are reported in McKillip and Wells (2006). Selected profiles are shown for station 4.0 and station 9.0 in this section, and model-data error statistics are reported in Table 50. Three sampling periods are illustrated for the reservoir conditions near minimum spring pool, near peak thermal stratification, and after fall turnover.

Ensuring hydrodynamic and temperature calibration was the first step in water quality constituent calibration.

Dissolved oxygen (Figure 38 and Figure 39) calibration also included sediment oxygen demand (SOD). Total dissolved solids (Figure 40 and Figure 41) are a conservative constituent, so no additional calibration was made. Calibration for pH (Figure 42 and Figure 43) focused on the selection of boundary conditions.

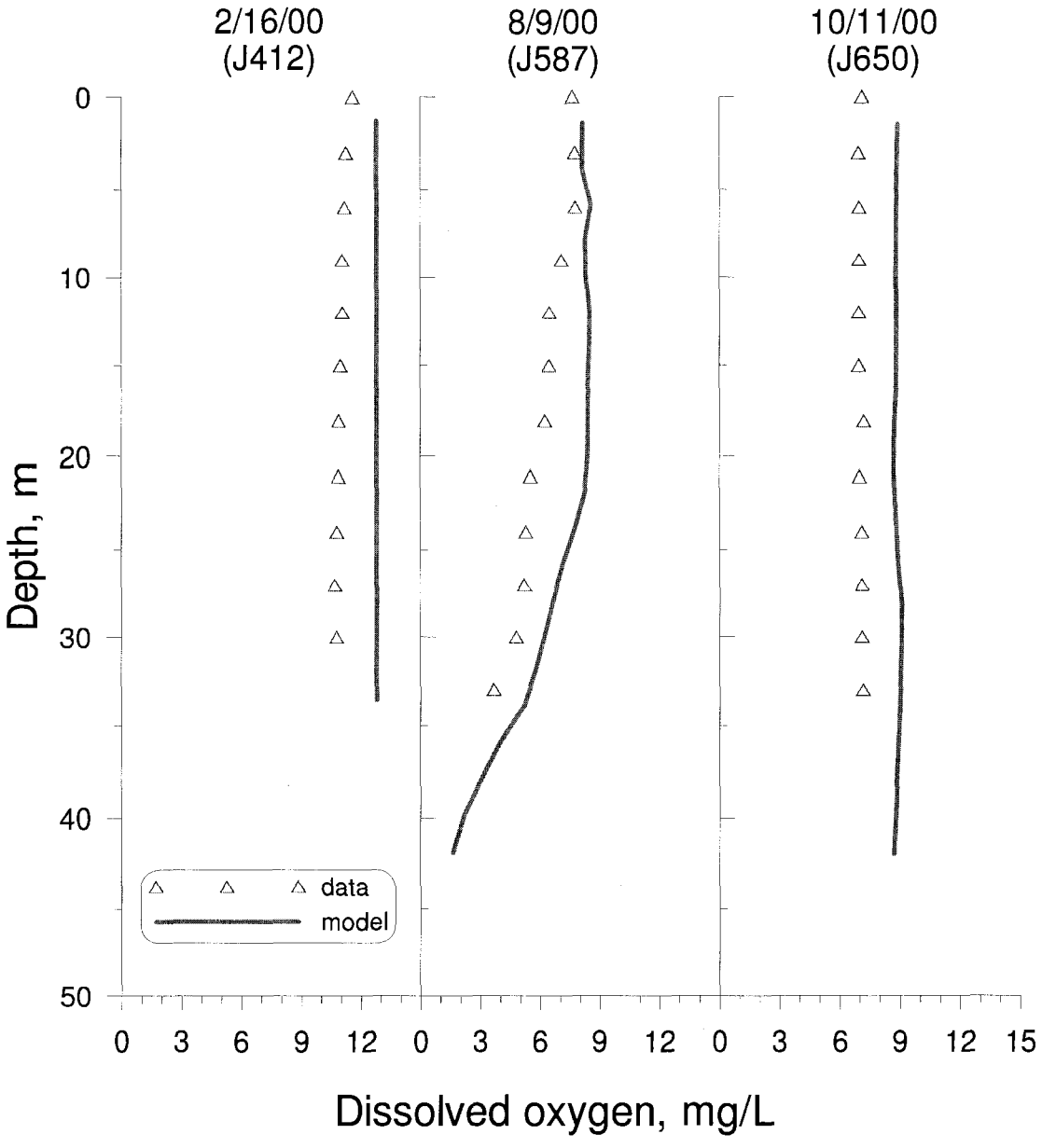

Figure 38. Selected model-data dissolved oxygen vertical profile comparisons at Porcupine Bay (LRFEP stat 4.0).

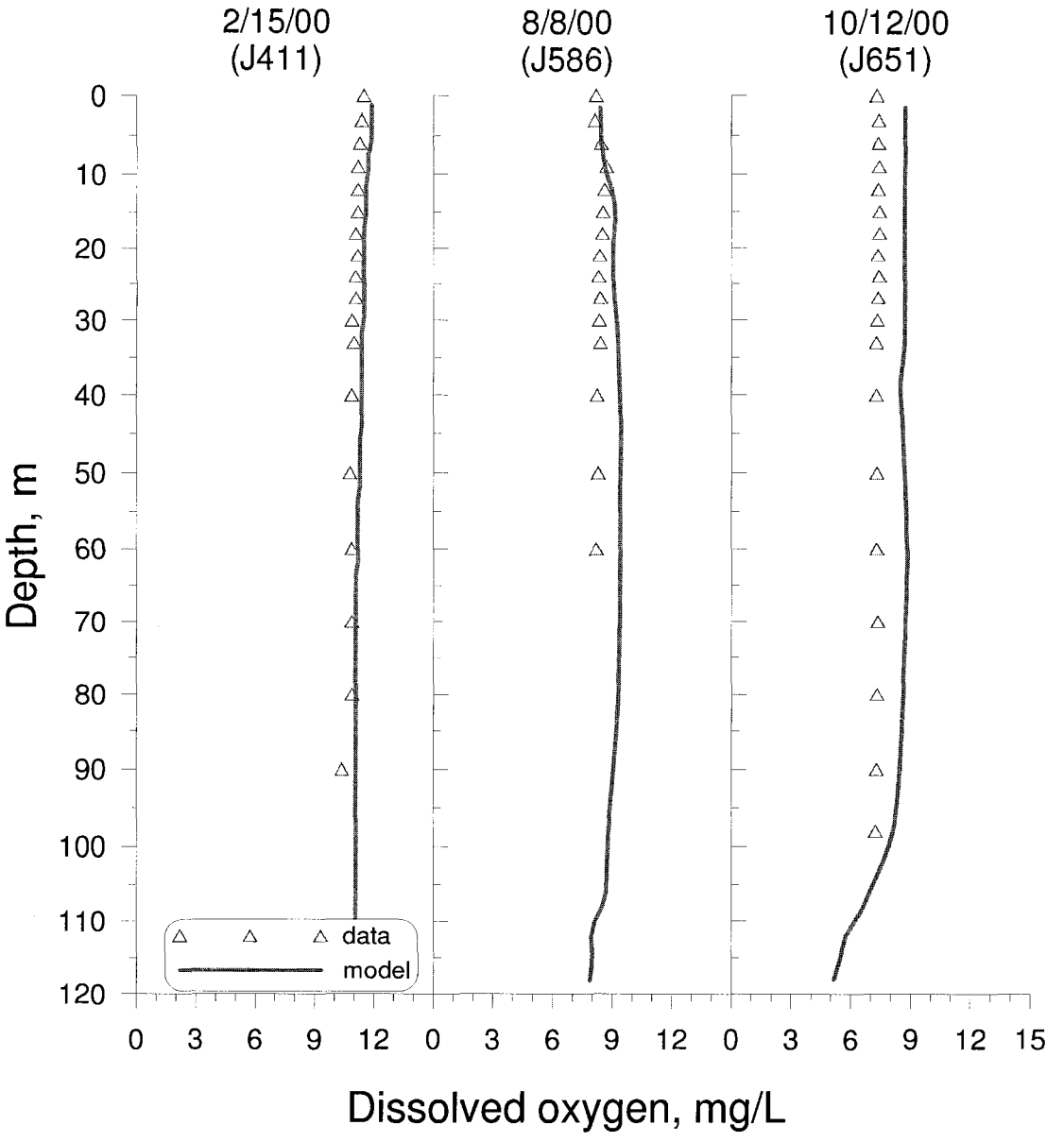

Figure 39. Selected model-data dissolved oxygen vertical profile comparisons at Spring Canyon (LRFEP sta 9.0).

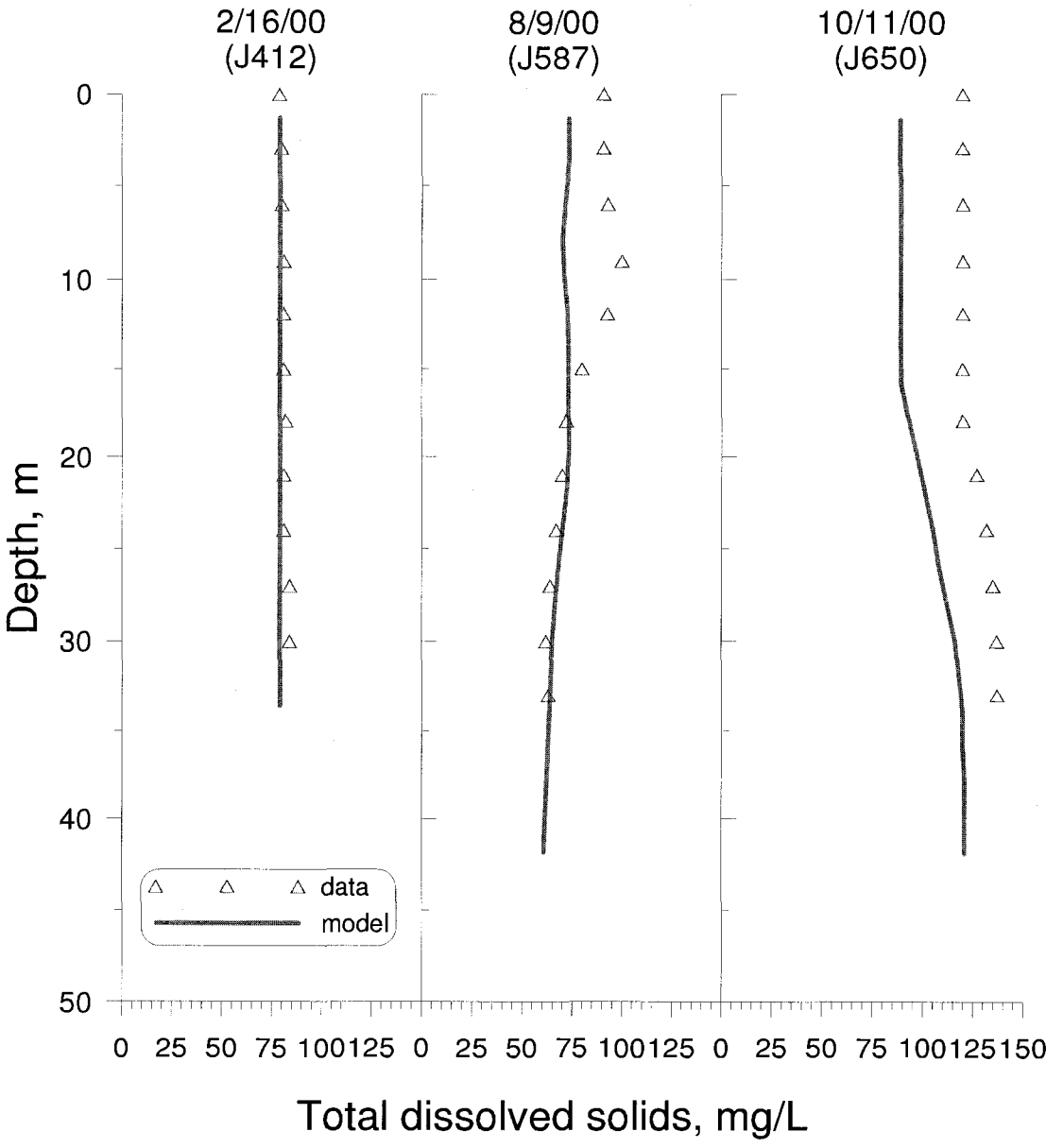

Figure 40. Selected model-data total dissolved solids vertical profile comparisons at Porcupine Bay (LRFEP stat 4.0).

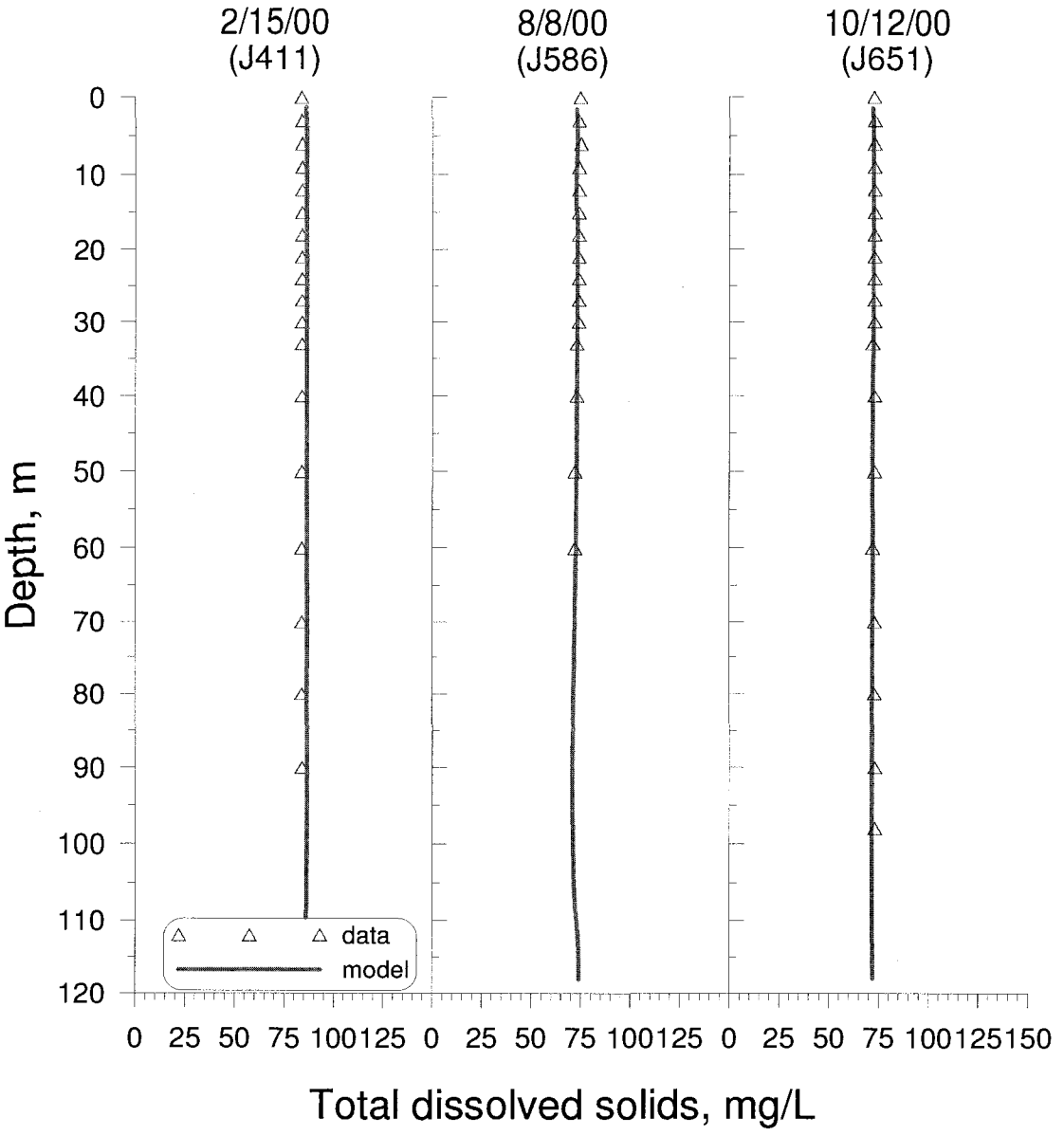

Figure 41. Selected model-data total dissolved solids vertical profile comparisons at Spring Canyon (LRFEP stat 9.0).

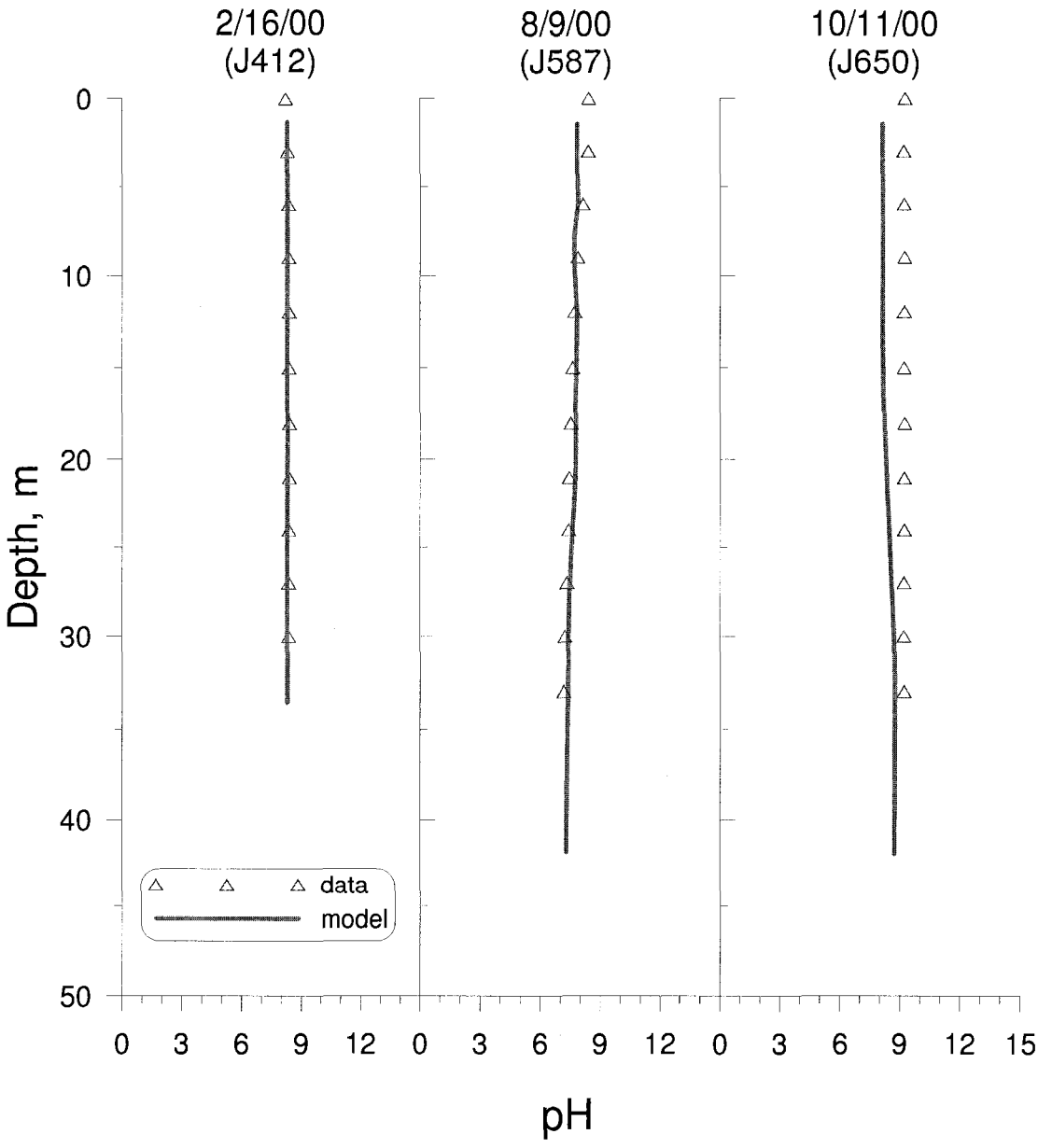

Figure 42. Selected model-data pH vertical profile comparisons at Porcupine Bay (LRFEP stat 4.0).

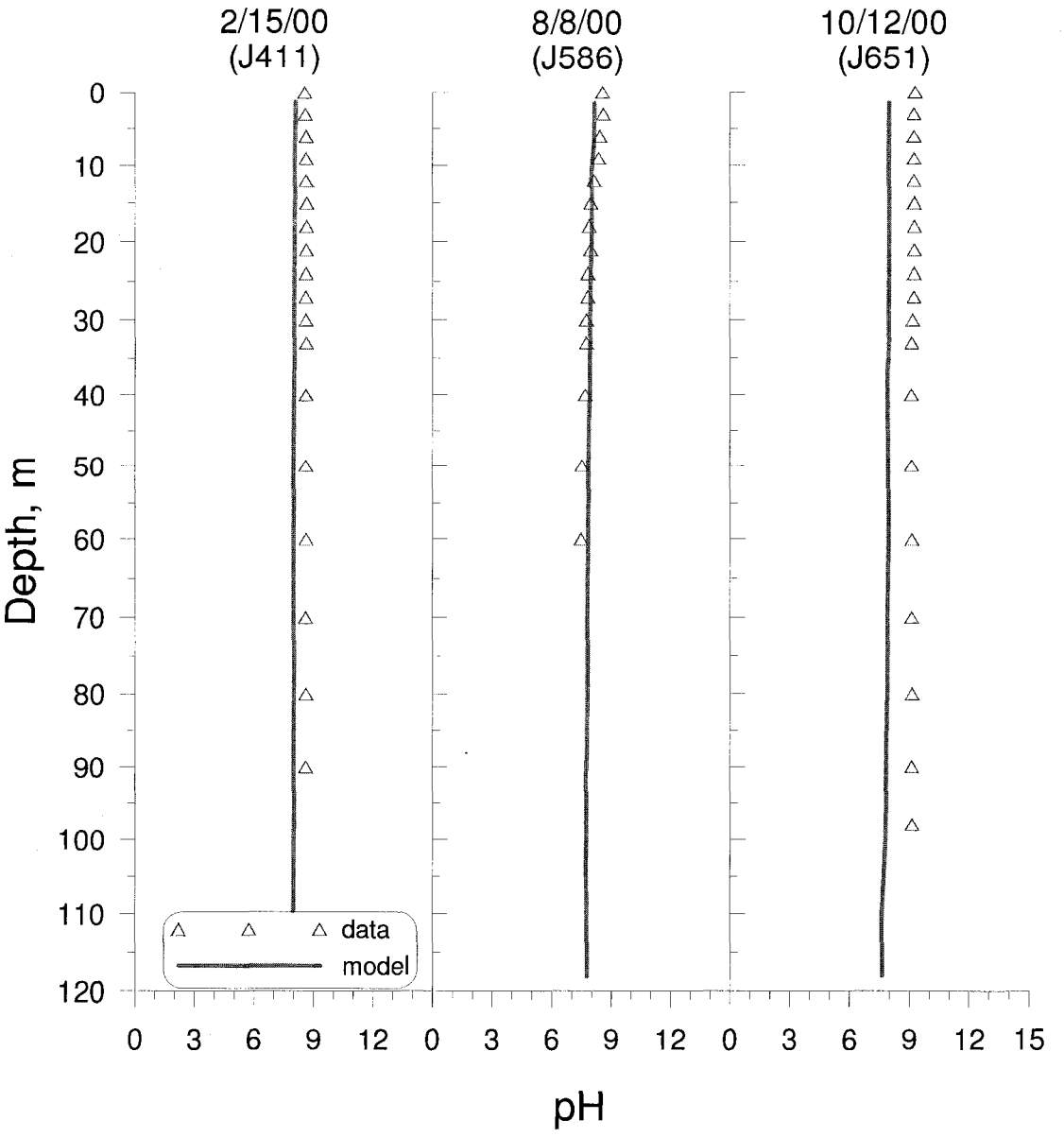

Figure 43. Selected model-data pH vertical profile comparisons at Spring Canyon (LRFEP stat 9.0).

Biotic Modeling Calibration

Algae and zooplankton data are available at the LRFEP stations reported in the temperature calibration section (see Figure 27). Data were collected over a variety of depths. Algae were sampled over the euphotic zone. Zooplankton were collected at 17, 33, and 66 m depths. Duplicate samples at the same depth showed large variability.

All data for a given day were arithmetically averaged. Model results, which vary from layer to layer, were averaged over the first 10 meters of depth for comparison to the averaged data.

Selected weighted total algae model-data comparisons are shown below. For comparisons at all stations, refer to McKillip and Wells (2006).

Algae

The most upstream location (station 0.0) was used as the model boundary condition, and is illustrated in Figure 44. Model-data comparisons on the Spokane River (Figure 45) and downstream of the confluence of the Spokane and Columbia Rivers (Figure 46) show that the two systems have different algal mass concentrations and blooming times. Figure 47 show the total algal concentration upstream of Grand Coulee Dam.

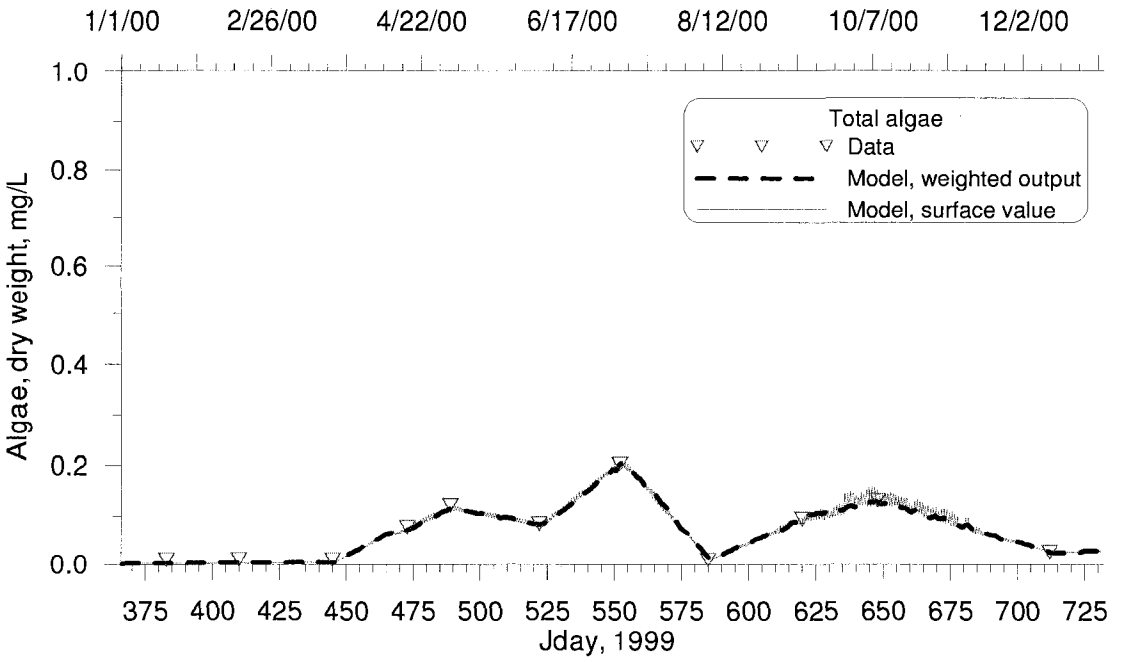

Figure 44. Model-data comparison of weighted total algae, LRFEP station 0.0.

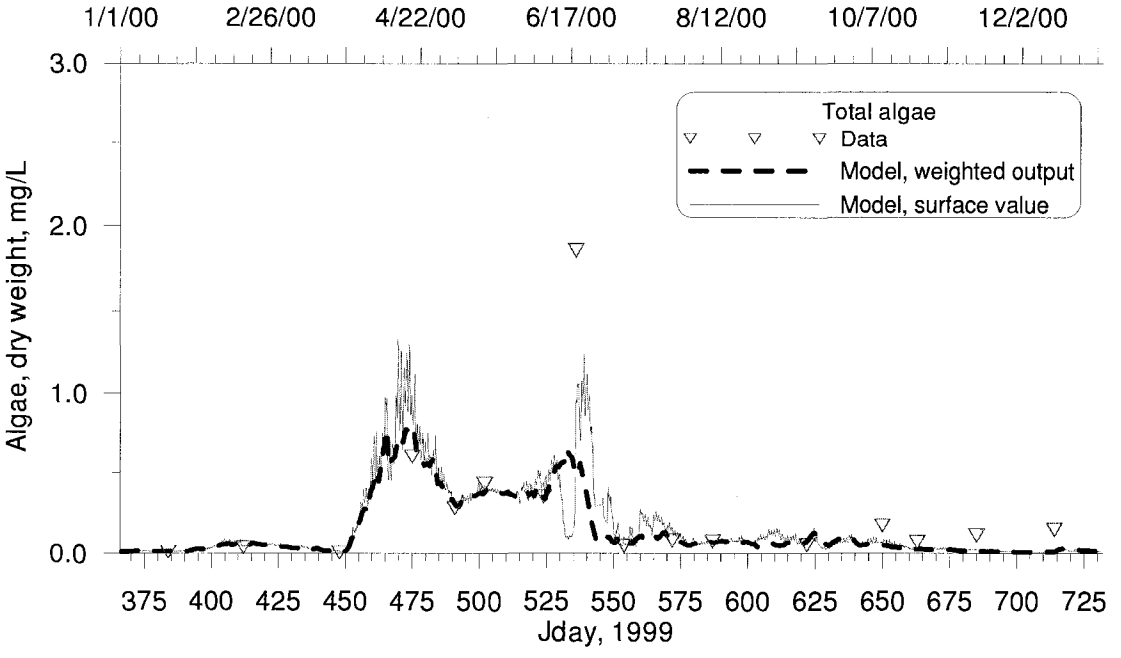

Figure 45. Model-data comparison of weighted total algae, LRFEP station 4.0

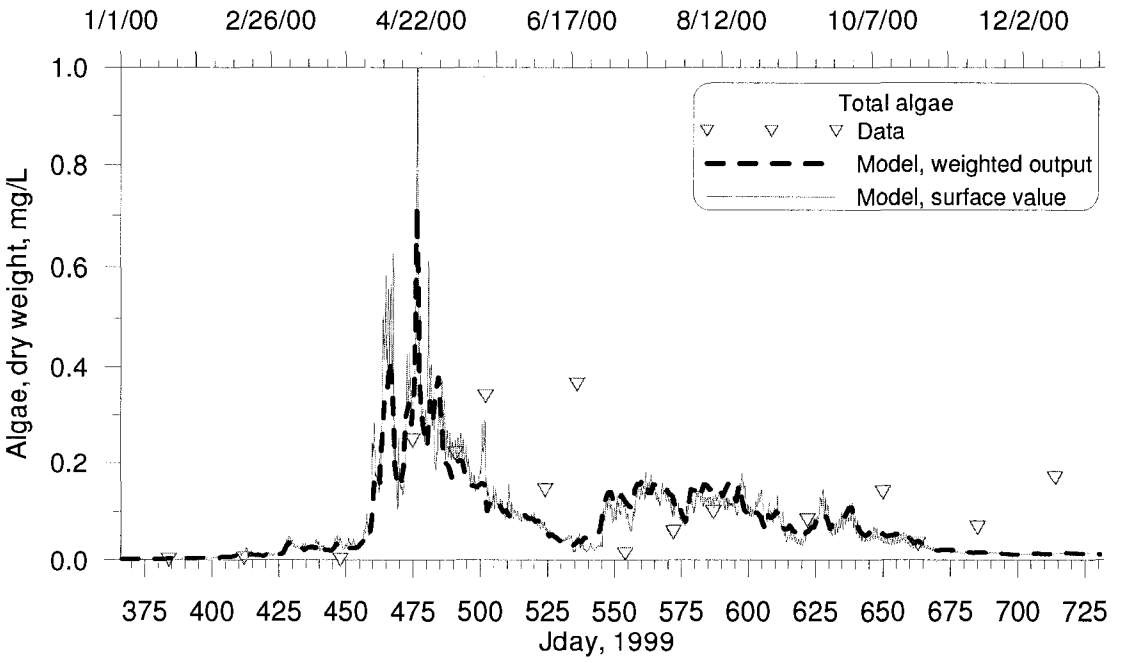

Figure 46. Model-data comparison of weighted total algae, LRFEP station 6.0

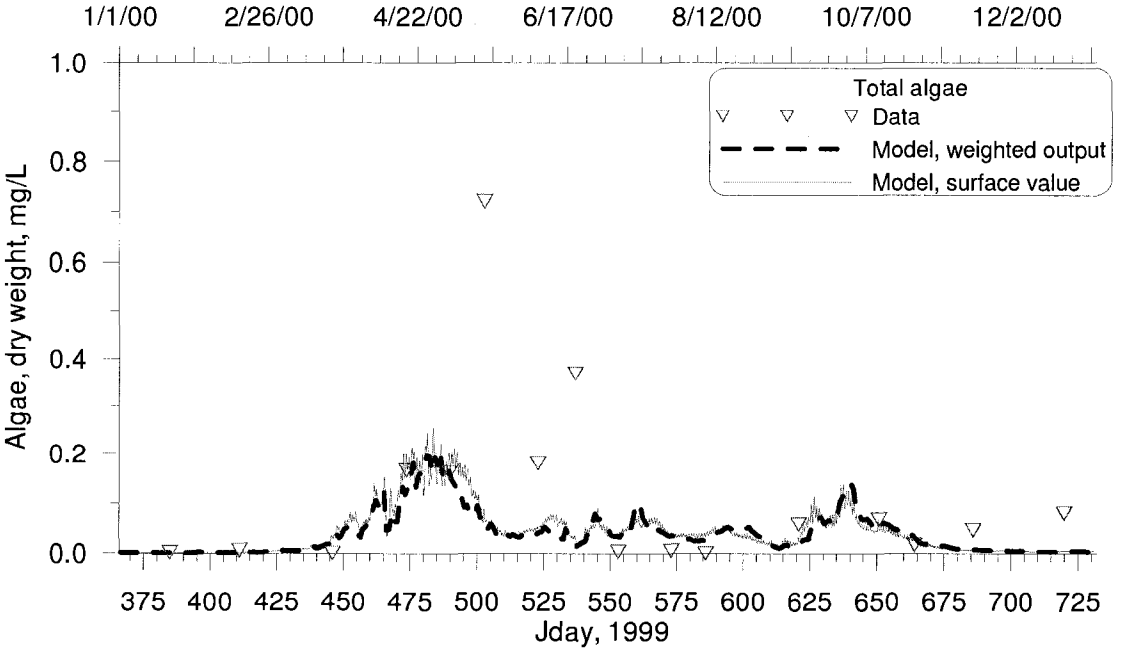

Figure 47. Model-data comparison of weighted total algae, LRFEP station 9.0

Zooplankton

The most upstream locations (station 0.0 & 1.0) were used as the model boundary condition (Figure 48). Model-data comparisons on the Spokane River (Figure 49) and downstream of the confluence of the Spokane and Columbia Rivers (Figure 50) show that the two systems have similar zooplankton densities, unlike the total algae population relationship. Figure 51 show the total zooplankton concentration upstream of Grand Coulee Dam.

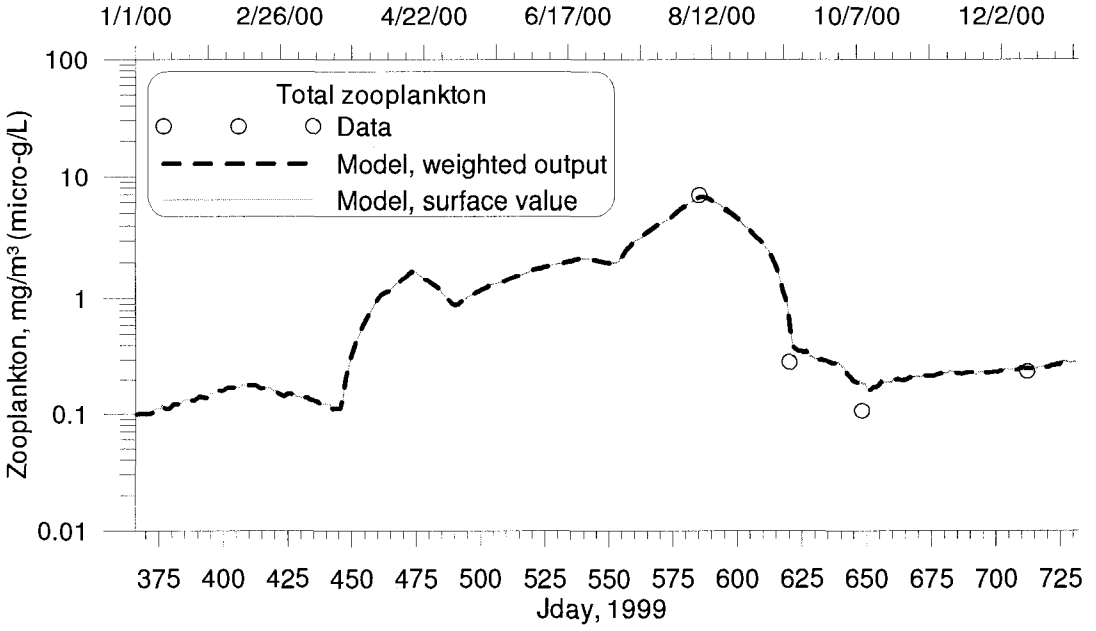

Figure 48. Model-data comparison of weighted total zooplankton, LRFEP station 0.0.

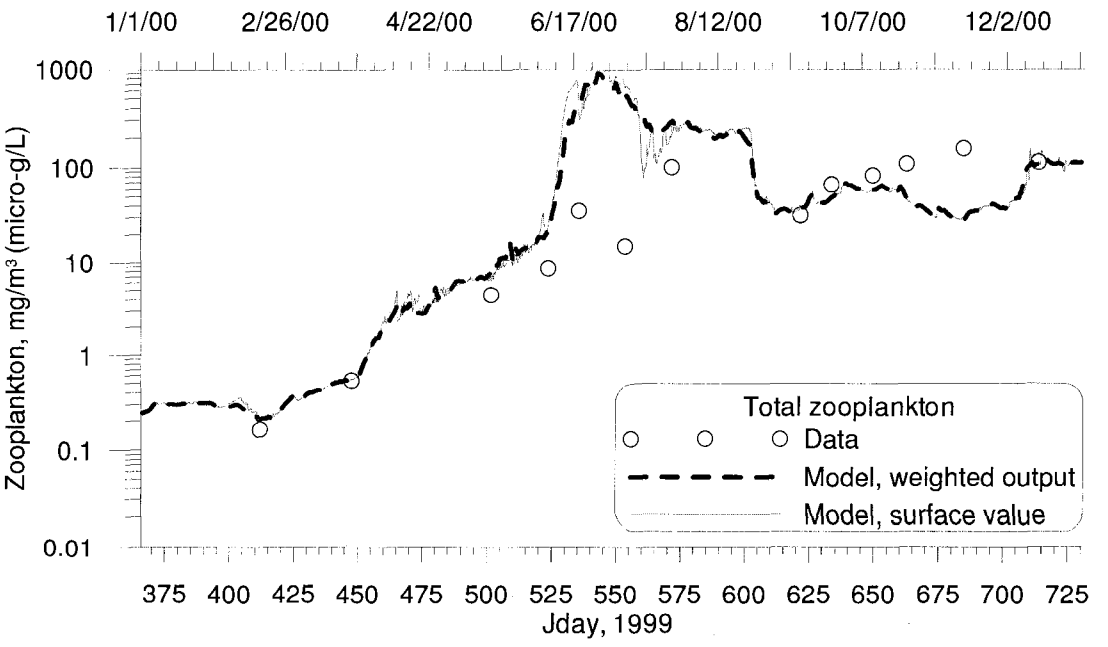

Figure 49. Model-data comparison of weighted total zooplankton, LRFEP station 4.0

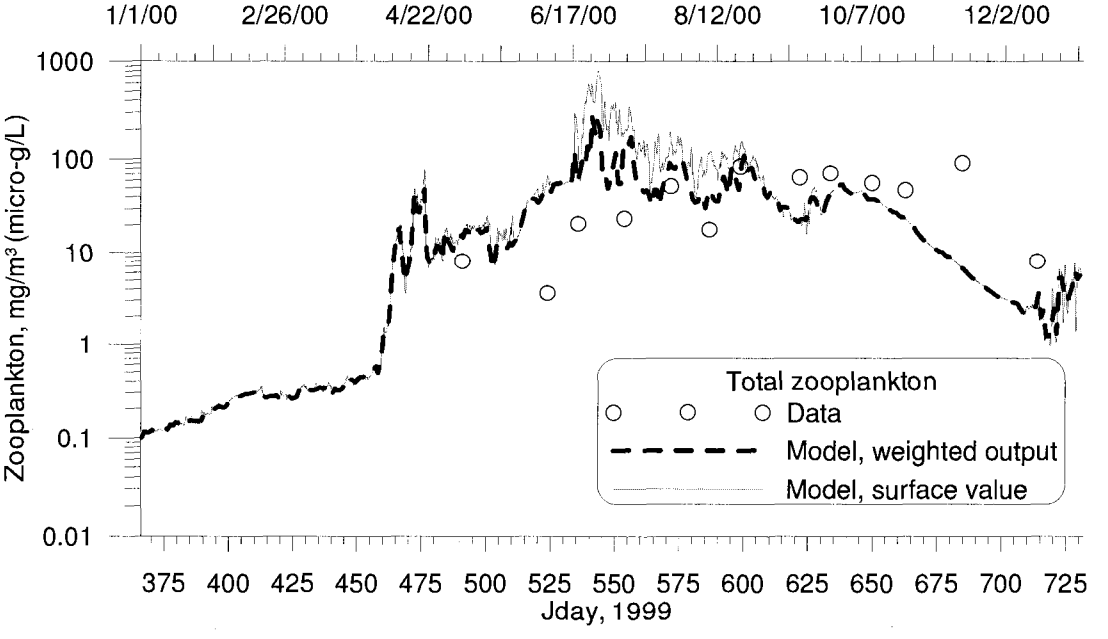

Figure 50. Model-data comparison of weighted total zooplankton, LRFEP station 6.0

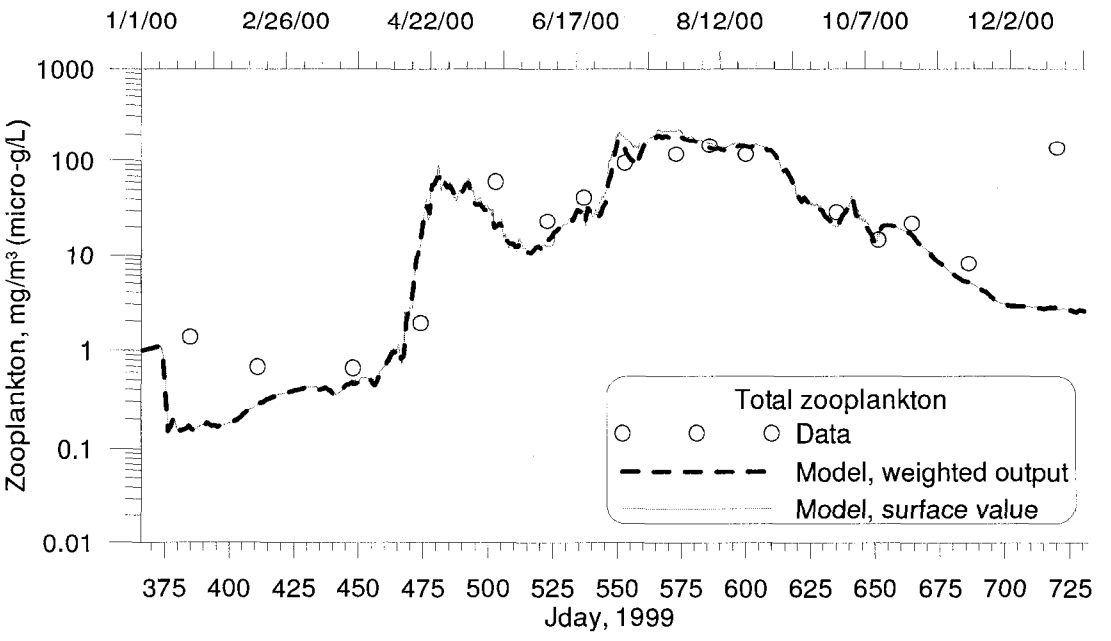

Figure 51. Model-data comparison of weighted total zooplankton, LRFEP station 9.0

Lake Flow Patterns and Water Age (Detention Time)

Mainstem

Mainstem velocities are characterized as primarily longitudinal with lower velocities over roughly the upper quarter (10-20 m) of the water column. Moving downstream, the river cross-section widens and deepens so, in general, the velocities decrease. The largest velocities occur during the spring drawdown. While the late spring flows are only marginally larger, the lowered pool creates a smaller cross-sectional area, and hence higher velocities. Figure 56 illustrates the average velocities over the length of the mainstem.

Vertical velocities are driven by thermal differences. Warm spring inflows generally mix deeply due to the weak gradient. Cold fall inflows, due to the stronger thermal and density gradient, mix less than the warm inflows.

Animations of the spatial and temporal distribution of the water detention, or water age, help illustrate the hydrodynamic patterns in the lake system. FIG A shows the system at minimum pool in May. At this time, the system is generally vertically mixed except for the deep water upstream of Grand Coulee Dam. The small inflows for the Sanpoil River result in greater water age in the arm than compared to the mainstem Columbia River.

By August the system returns to full pool and peak thermal stratification. FIG B shows that the deep water upstream of Grand Coulee Dam does not mix with the mainstem flows. In general, inflows are mixing more over the upper half of the reservoir than the lower half. By October, the mixing trend is reversed and the inflows are mixing with the lower half of the water column more than the upper half. The deep water upstream of the dam is still not generally turning over, however.

By December, the nearly isolinear characteristic of the system has resulted in the deep water upstream of the dam mixing with the water column. Despite the nearly uniform water temperature, the Spokane and Sanpoil Rivers exhibit much older water than the mainstem Columbia River.

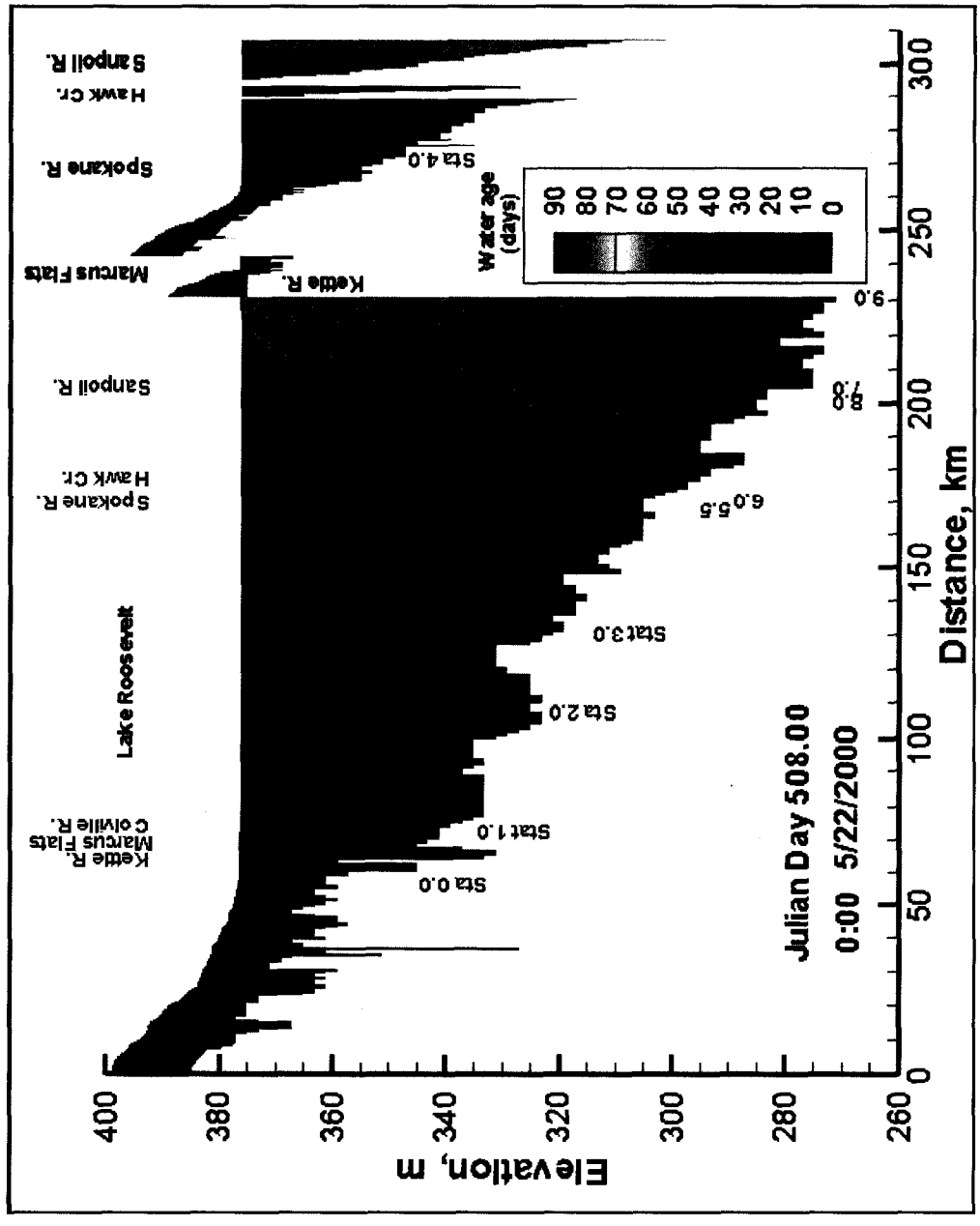

Figure 52. Water age, May 2000.

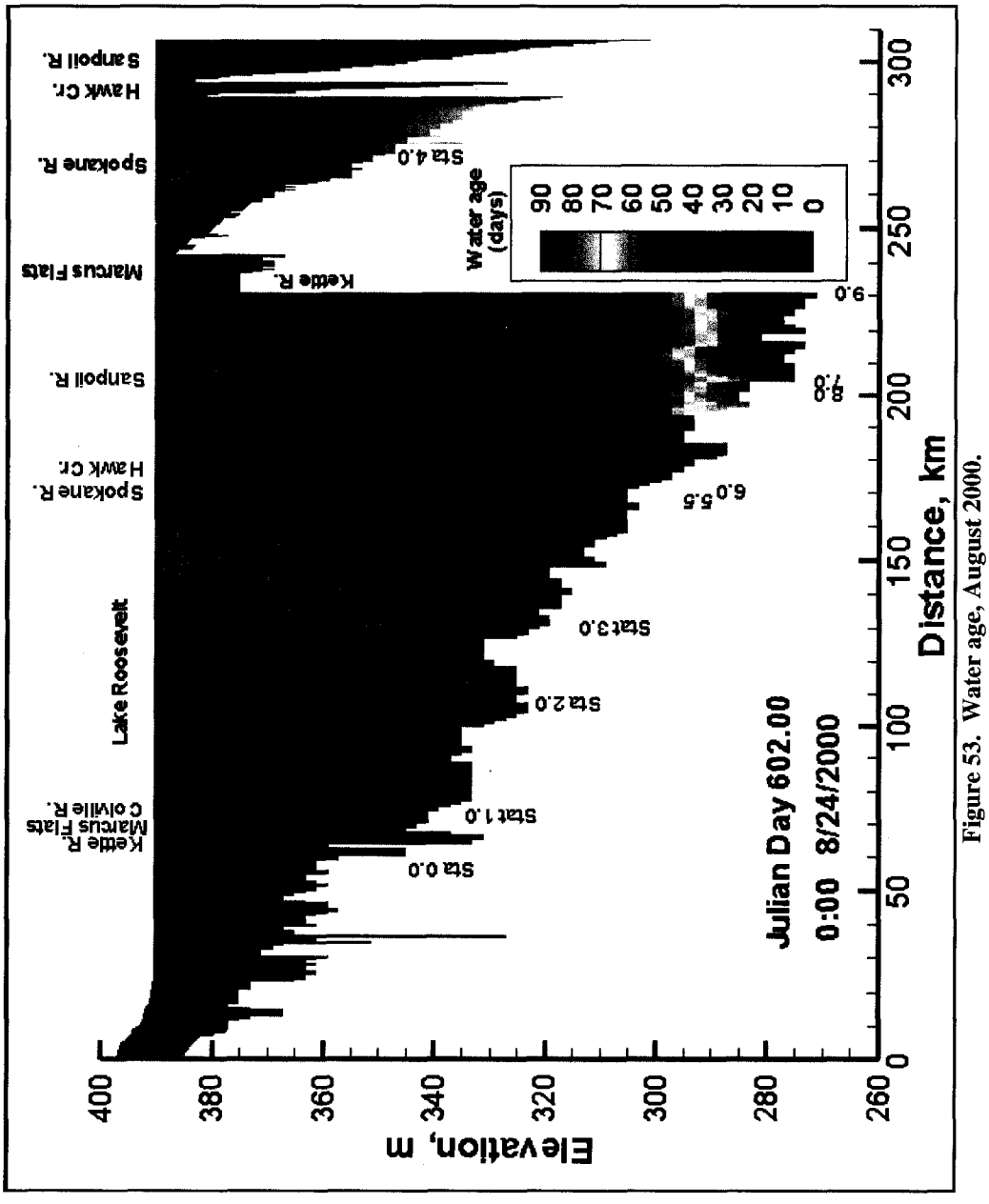

Figure 53. Water age, August 2000.

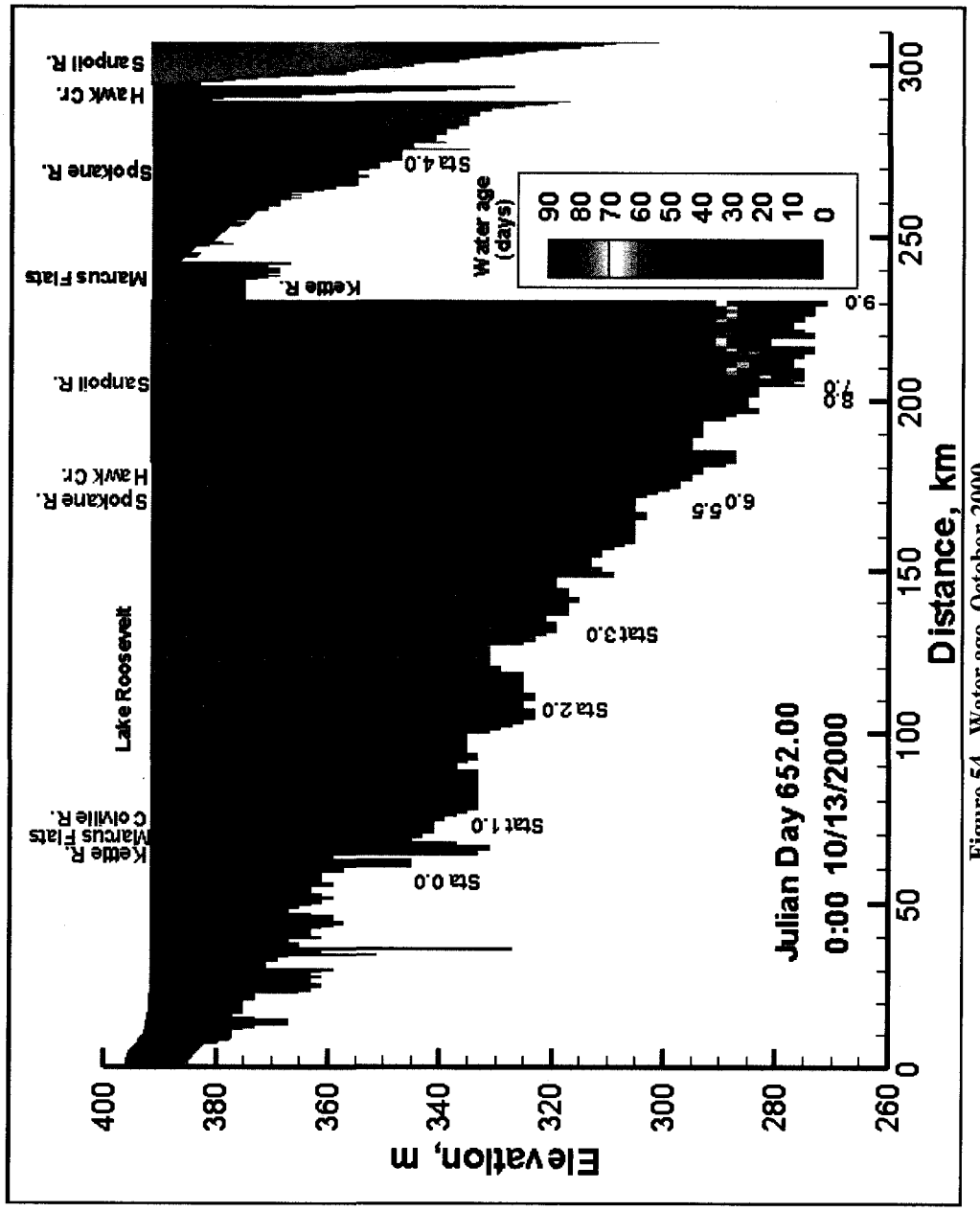

Figure 54. Water age, October 2000.

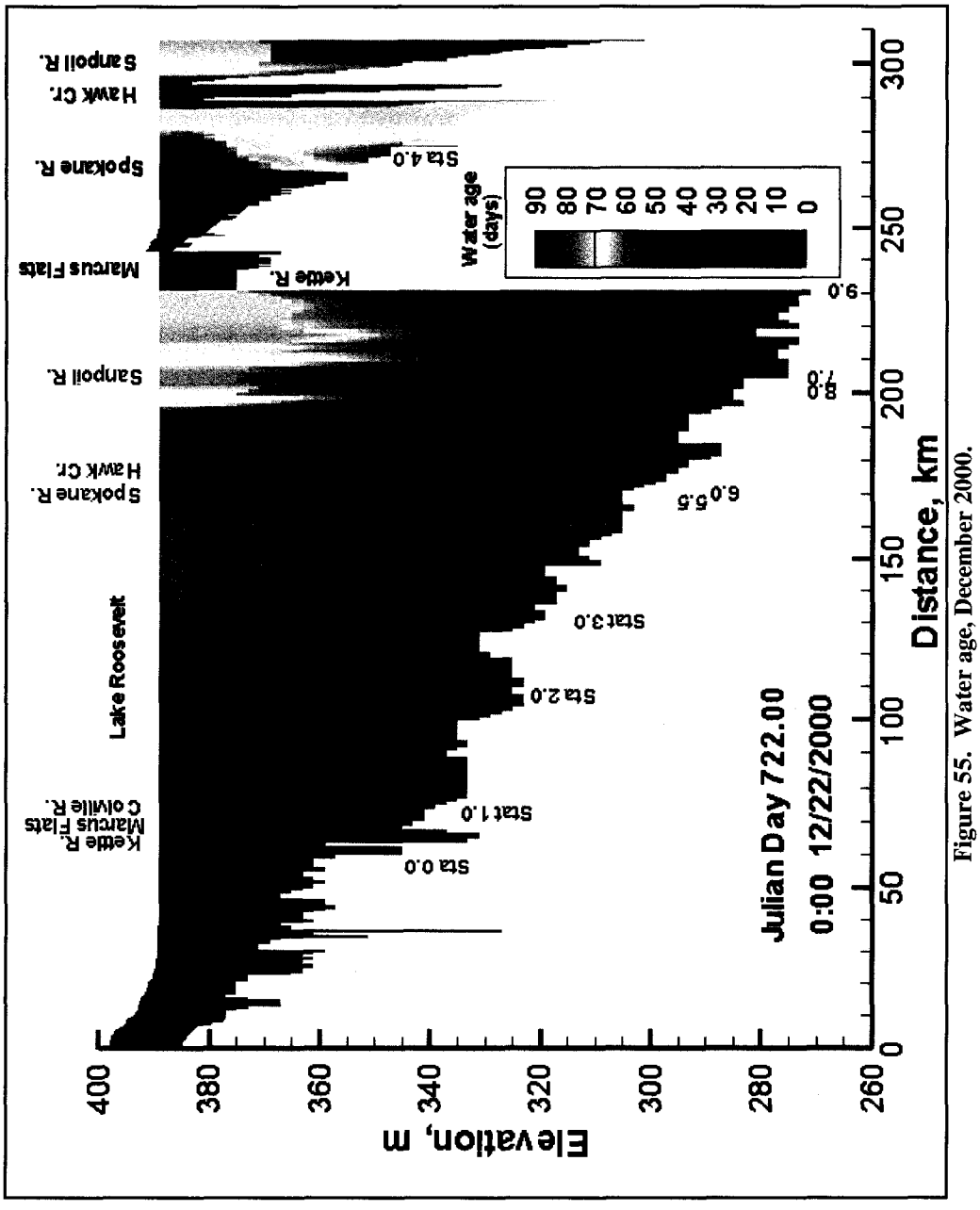

Figure 55. Water age, December 2000.

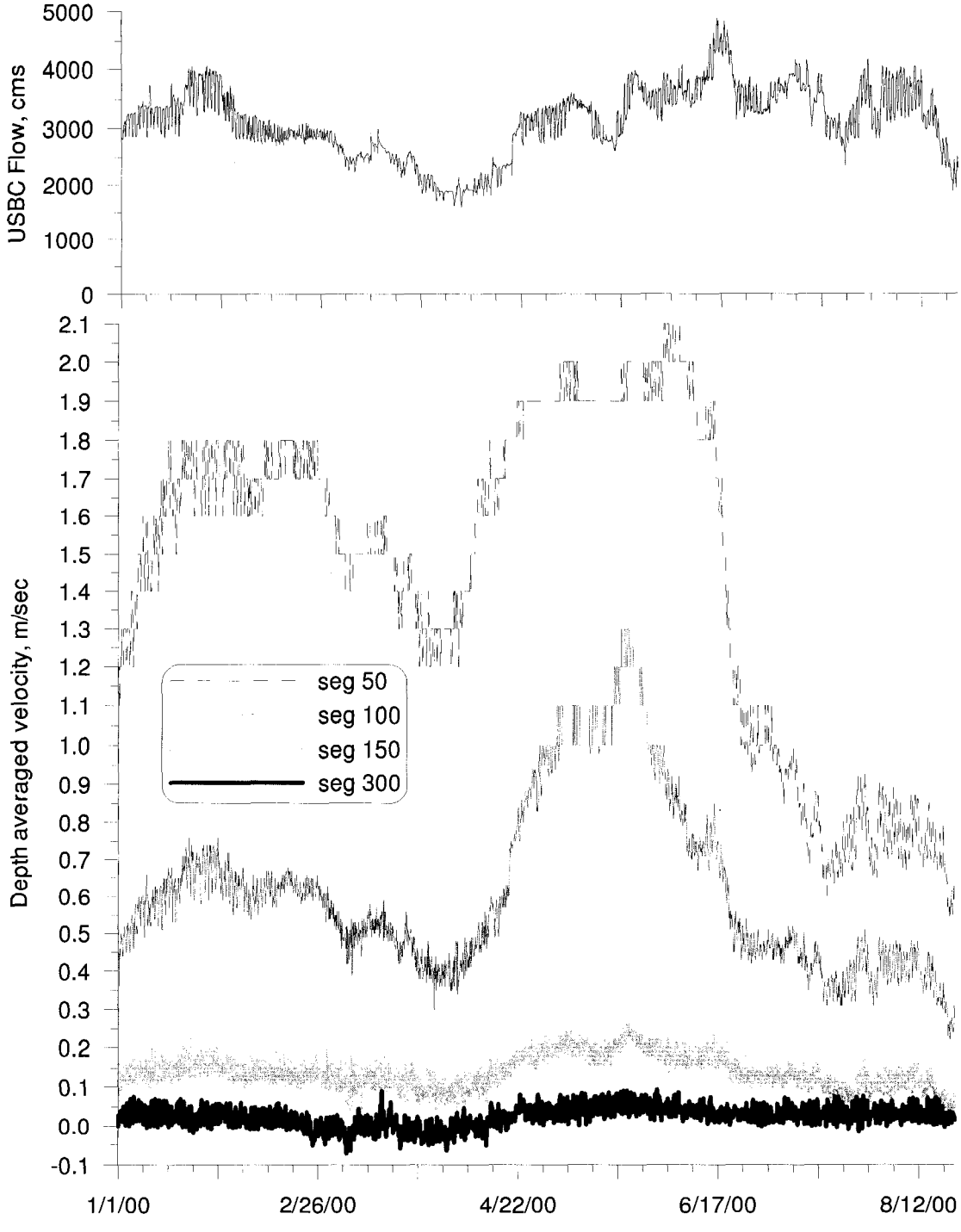

Figure 56. Mainstem Columbia River average velocities and upstream boundary flows, January through August, 2000.

Spokane River

After fall turnover and before spring drawdown, velocities on the Spokane River arm are generally low and uniform longitudinally and vertically except over the uppermost third of the arm. The upstream channel is narrower than the downstream channel, so the velocities are higher. The difference in the velocities is small (~100%) during the winter (Figure 57), but is several orders of magnitude larger during spring drawdown (Figure 58).

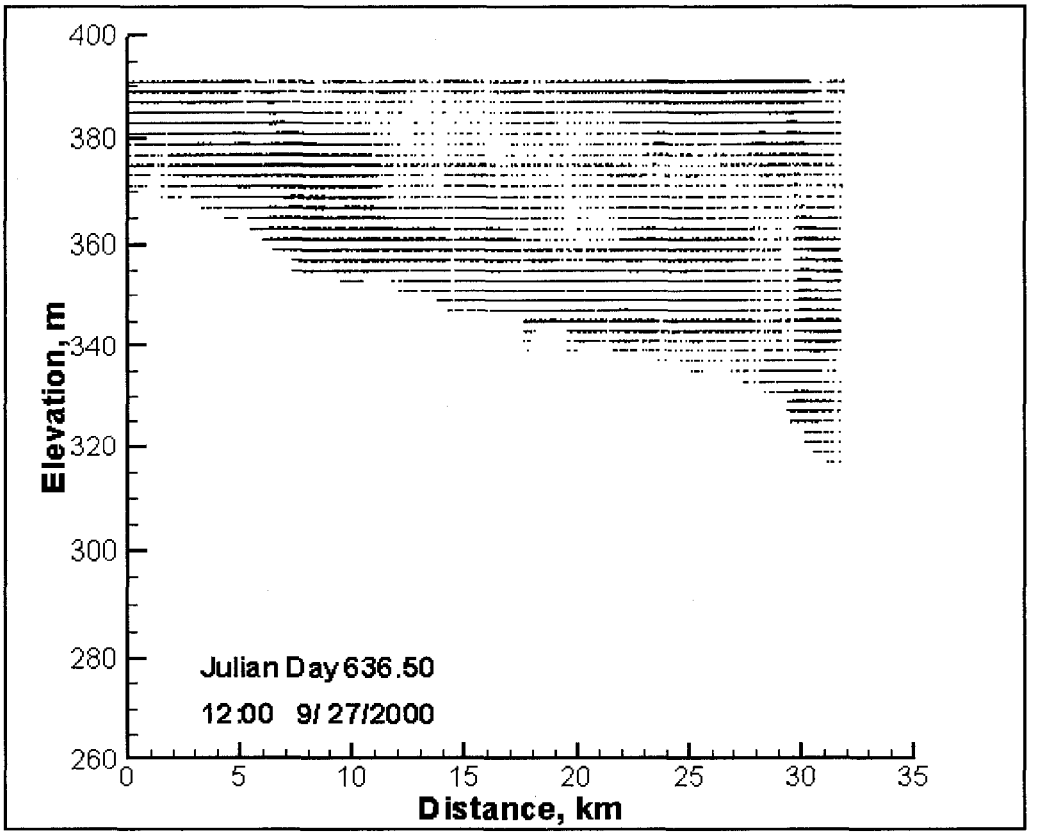

Figure 57. Spokane River velocities after fall turnover.

During the period of summertime thermal stratification, there is an area of increased velocities at depth approximately 3 km upstream from the confluence of the Columbia and Spokane Rivers due to a narrow channel section at depth.

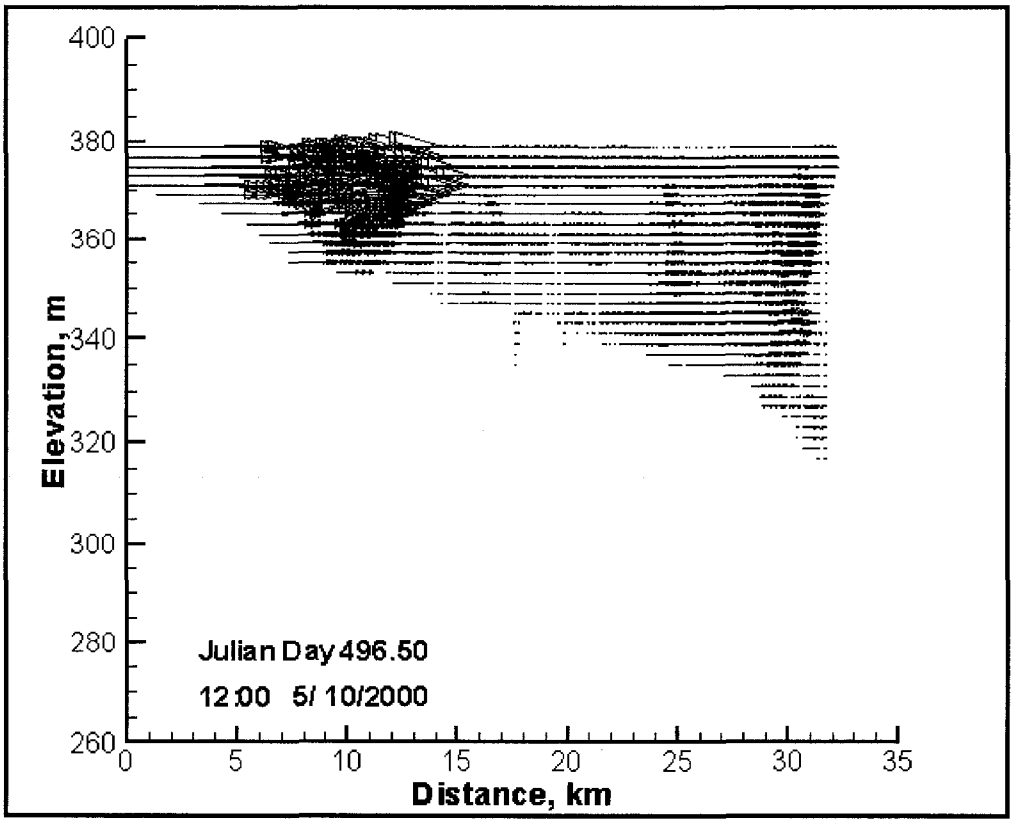

Figure 58. Spokane River velocities during spring drawdown

The water age figures presented in the previous section show that nutrients or hypoxic waters introduced to the Spokane River arm are retained. This retention of nutrients and generally lower velocities and warmer surface temperatures helps to explain some of the greater primary productivity and greater fish concentrations observed in the Spokane River arm.

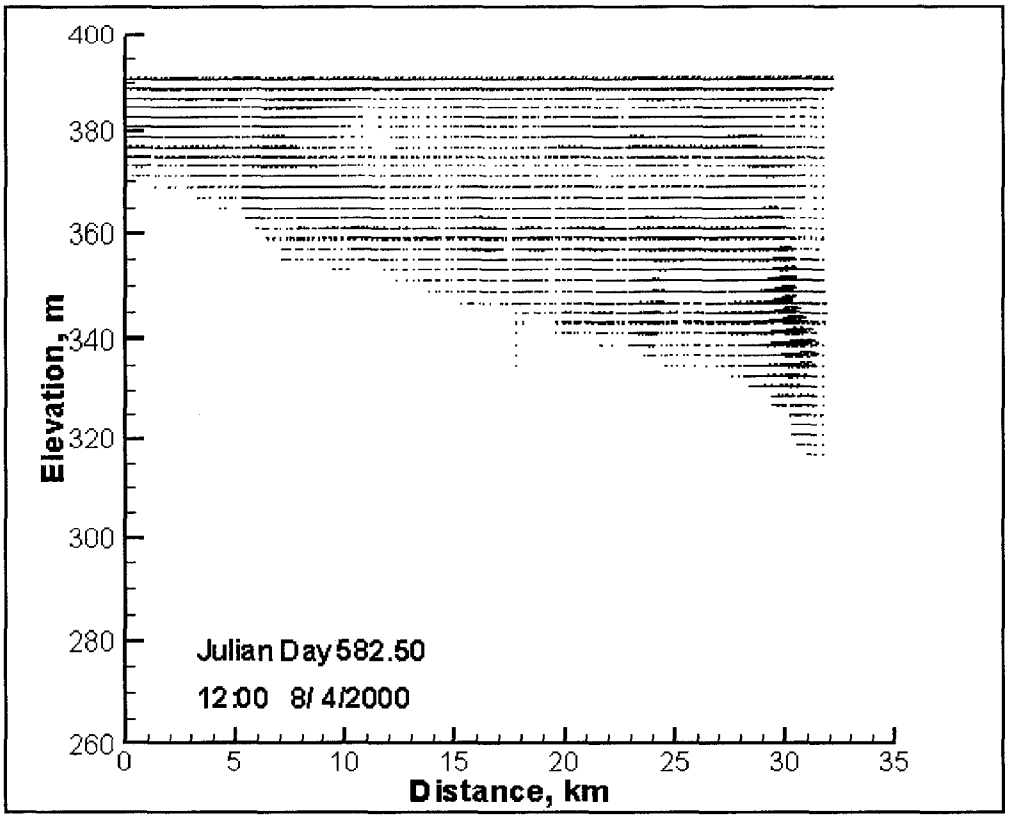

Figure 59. Typical summertime Spokane River velocities.

Fish Bioenergetics Model Diagnostics

The fish bioenergetics routine was run using the Lake Roosevelt inputs modified to isolate test scenarios. These runs helped identify FORTRAN coding problems and ensure that results were consistent with the literature.

Comparison to Literature Studies

The specific growth rate (gram of growth per gram of fish mass) serves as a comprehensive check of the fundamental Winberg growth equation (equation (1)). A comparison of specific growth rates as a function of temperature for 10 g and 100 g sockeye (kokanee) at 100% of the maximum daily consumption (Cmax) shows that the model is performing consistent to literature growth rates. The scenarios in Figure 60 assumes a prey energy density of 2800 $J \cdot g^{-1}$. By constraining the consumption to Cmax, several factors are eliminated as sources of error: handling time, prey density and availability, reaction distance and search volume.

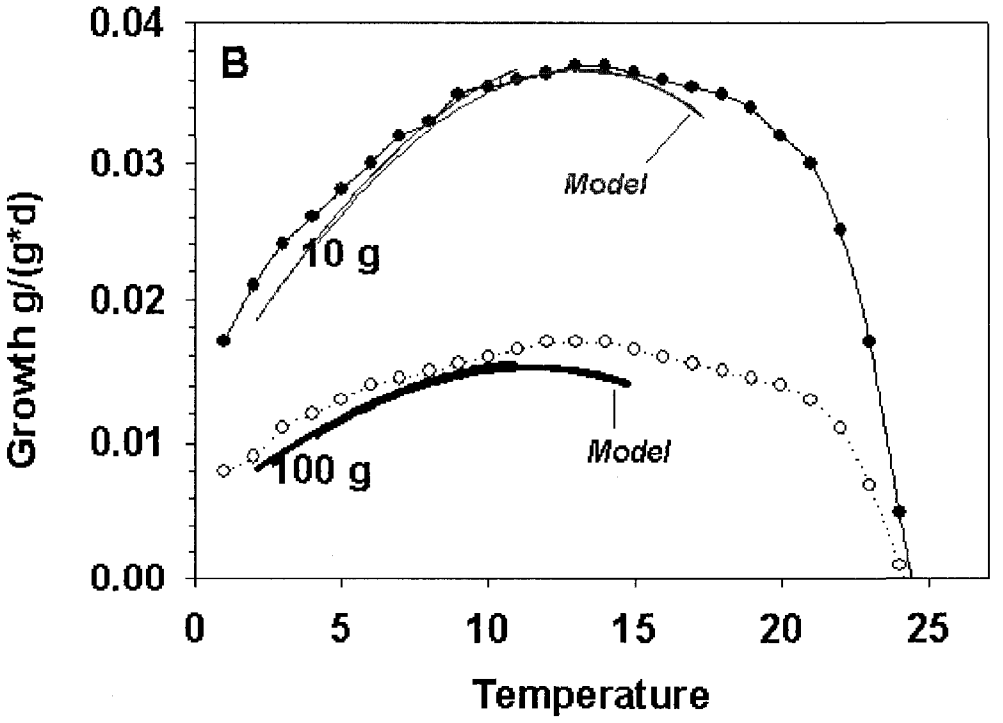

Figure 60. Model-literature specific growth rate comparison.

Single Variable Diagnostics

Runs were made using the same code used to evaluate the Lake Roosevelt system that were further restrained to a single variable input. Light intensity and zooplankton bioavailability were held constant. Handling time was constant at 0.33 seconds. When temperature and prey density were allowed to vary, model inputs were used. The inputs are summarized below:

Variable	Value
Temperature	10 °C
Fish Mass	100 g
Prey density	1000 wet g/m^3
Prey energy density	2800 J/g
Surface illuminance	10 lux
Prey availability	1.0

The basic results (no inputs varied) are illustrated in Figure 61. The proportion of maximum consumption (p-value) is 0.87. The specific growth rate compares favorably with the rate seen in Figure 60.

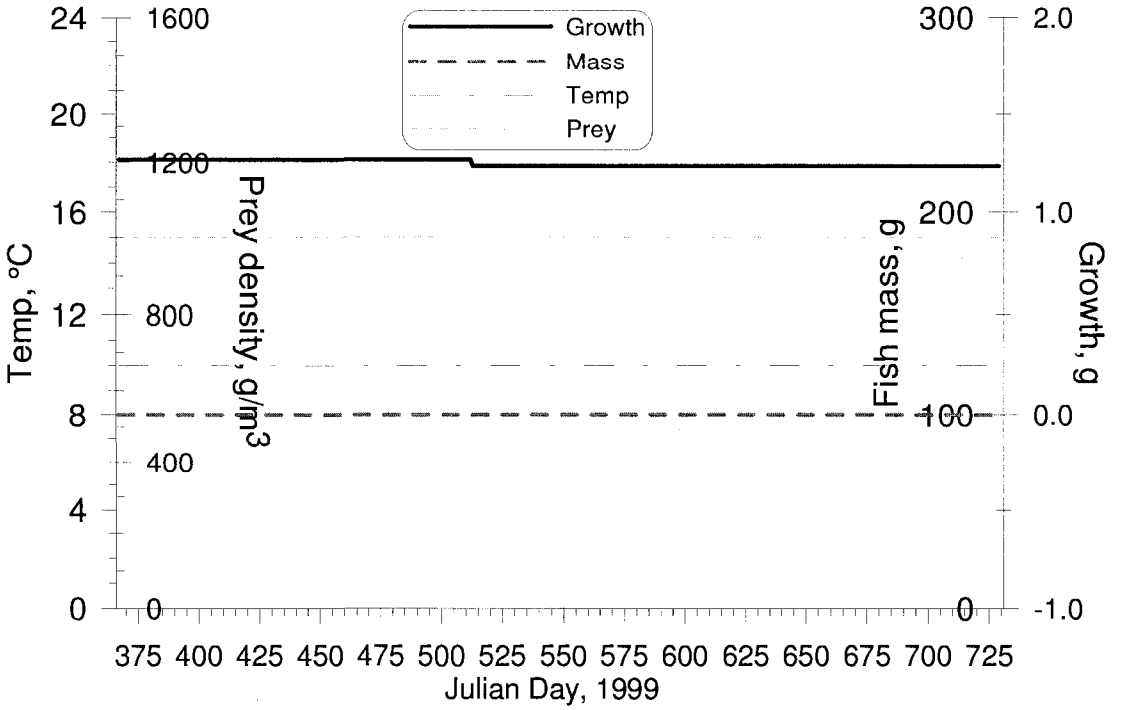

Figure 61. Diagnostic steady basecase: mass, temperture, and prey density held constant.

Variable Temperature (fish mass and prey density constant)

The Lake Roosevelt temperatures at Spring Canyon (LRFEP station 9.0) were input with the fixed temperature and prey density to generate the daily growth potential shown in Figure 62. P-values range from 0.73 to 0.97 in the late summer. The temperatures reported are the daily average temperature of the vertically mobile forager. The use of the Lake Roosevelt temperature regime demonstrates that the fish will avoid water temperatures above roughly 15 °C at the given prey density.

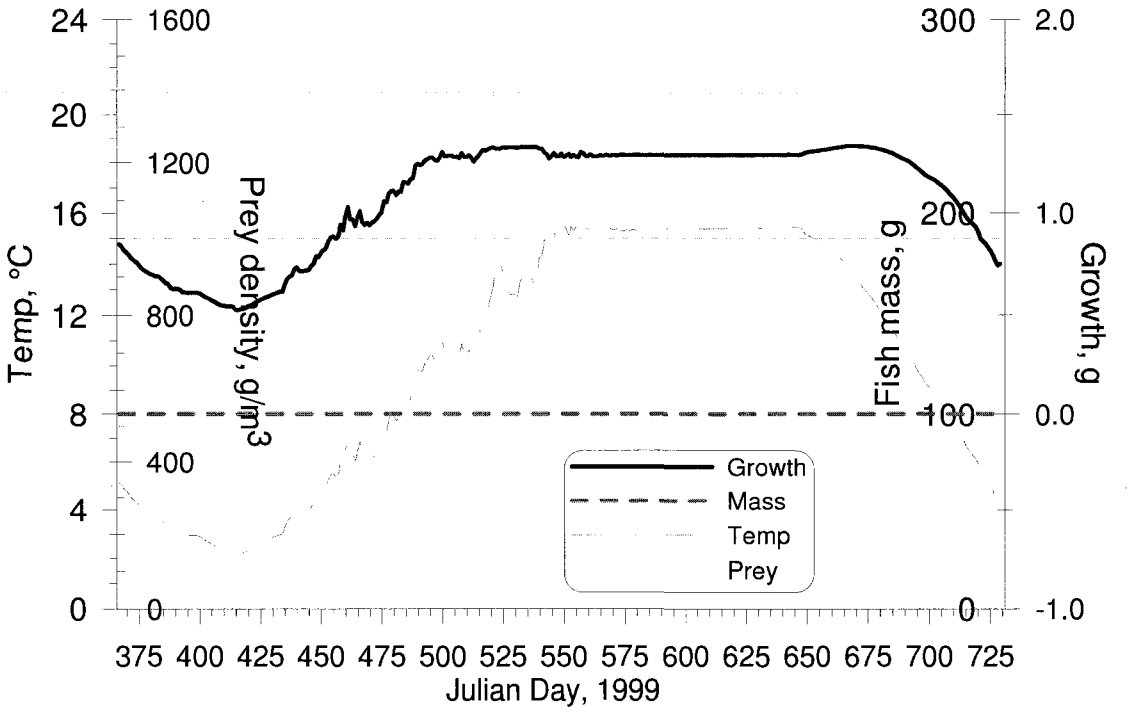

Figure 62. Diagnostic: constant mass and prey density-unsteady temperature.

Variable Prey Density (fish mass and temperature constant)

The Lake Roosevelt prey density were input with the fixed temperature and fish mass to generate the daily growth potential shown in Figure 63. P-values are near 1.0 from roughly J550 to J610, and are less than 0.1 for much of the rest of the year. The negative growth values suggest that growth potential is prey limited over much of the year.

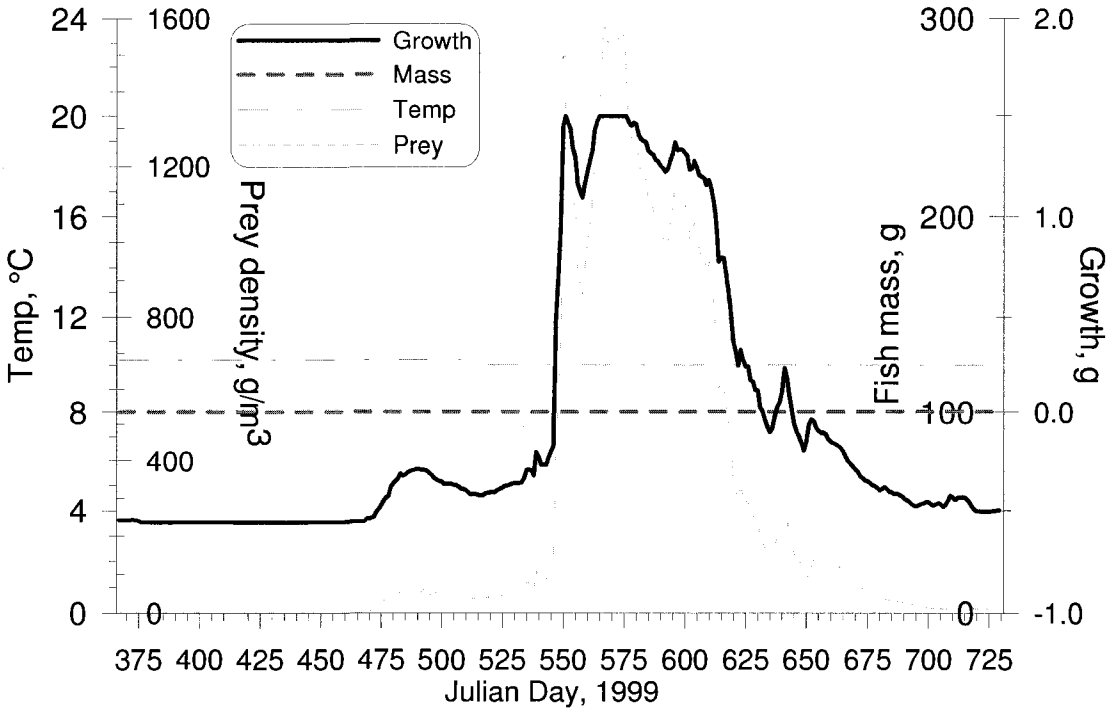

Figure 63. Diagnostic: steady mass and temperature-unsteady prey density

Variable Fish Mass (prey density and temperature constant)

The Lake Roosevelt fish mass regression curve was input with the fixed temperature and prey density to generate the daily growth potential shown in Figure 64. The prescribed mass curve uses a specific growth rate of 0.0049, which is based on data and roughly one-third of the maximum growth rate at C_{max}. The temperature and prey densities would not result in the mass curve shown; the model predicted mass curve is shown and has a much faster growth rate The increasing arm of the growth curve is the result of the increasing fish mass at a p-value of 1.0. P-values after the peak fall to 0.38 at the largest fish mass. A further clarification of the curves in Figure 64 is presented as Table 51.

Table 51. Legend clarification.

Mass – prescribed:	A prescribed growth curve based on data.
Growth – from prescribed mass:	The growth predicted from the inputs and the prescribed mass – on a daily basis
Growth – actual prescribed mass:	The growth that is prescribed by the prescribed mass curve.
Growth – model mass:	The growth predicted by the model using the model predicted mass (below).
Mass – model predicted:	The model mass curve based on the model predicted growth (above).

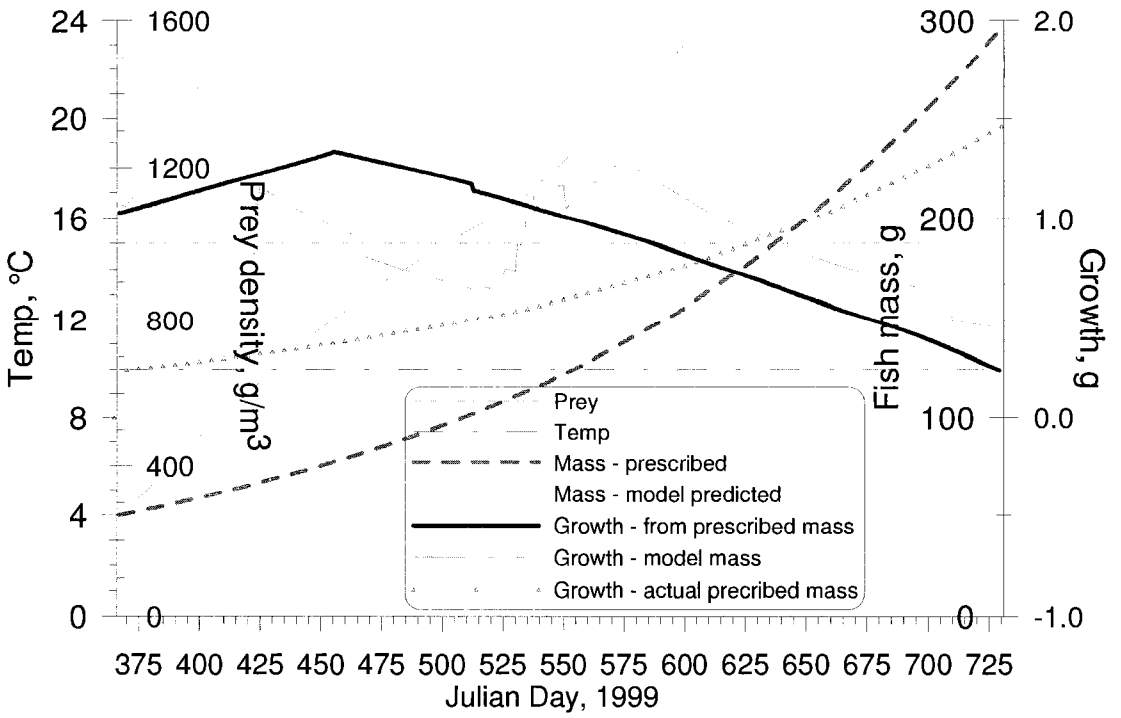

Figure 64. Diagnostic: constant prey density and temperature-prescribed and model predicted unsteady mass.

Fish Bioenergetics Model Results

Results for a variety of cases are reported and show that the model is behaving appropriately, and that some diagnostic conclusions can be drawn.

A prescribed mass case, based on fish growth data, is examined at the Spring Canyon monitoring location (upstream of Grand Coulee Dam). The cell of best growth was selected at each time-step, and stomach content was passed on to the other vertical cells. At the end of the day (taken to be midnight), growth was determined and passed on. A similar case was examined at the Porcupine Bay monitoring location (on the Spokane River arm). The Spokane arm is known to have different fish habitat characteristics, and provides a contrast with the Columbia River site.

A simple vertical foraging strategy was employed to try to capture some realistic foraging behavior; the best growth strategy predicts a period of minimal consumption in the late summer and fall when prey is abundant. The decision process at each time-step is:

1) Use the cell of best growth if
    a. growth is positive
    b. during nighttime (selects least negative)
2) If daylight (surface lux >1), alternate foraging and "digesting"
    a. Forage at the cell of greatest consumption, C
    b. "Digest" or "rest" at the cell of minimum respiration, R
    c. alternate foraging and digesting time-steps during daylight.

These cases show that fish growth can be reasonably modeled. They also predict that there are periods when foraging at some locations in the reservoir are not practical due to the large metabolic costs associated with warm water. Specifically, near the time of fall turnover, the smallest respiration costs at Spring Canyon exceed the best energy gain from consumption. This indicates that fish are unlikely to a) inhabit that part of the reservoir, and/or b) are utilizing a strategy not modeled. Possibilities include finding cold water inflows, or foraging under more successful techniques such as high prey density littoral regions. The comparison between the two sites suggests the possibility of horizontal migration. When the bioenergetics are poor at Spring Canyon in the late fall and winter, they are more favorable at Porcupine Bay.

The shown runs used a handling time of 0.5 sec. Runs with a 0.33 sec handling time do not greatly influence the results: the positive and negative growth periods are the same, but the magnitude is slightly improved.

Base Lake Roosevelt Results at Spring Canyon (LRFEP sta 9.0)

Energy content of prey: a constant of 2420 J/g

Growth method: prescribed function based on data.

Feeding: model output prey densities are used.

Foraging: Best cell at each time-step; growth calculated and passed on to all cells in the segment daily.

Comments: During the warm water periods in roughly July through October, the best place to be for a single time-step is at the bottom of the lake. However, only negligible consumption is then possible. This is unlikely the actual fish behavior to these conditions. Compare with the next section.

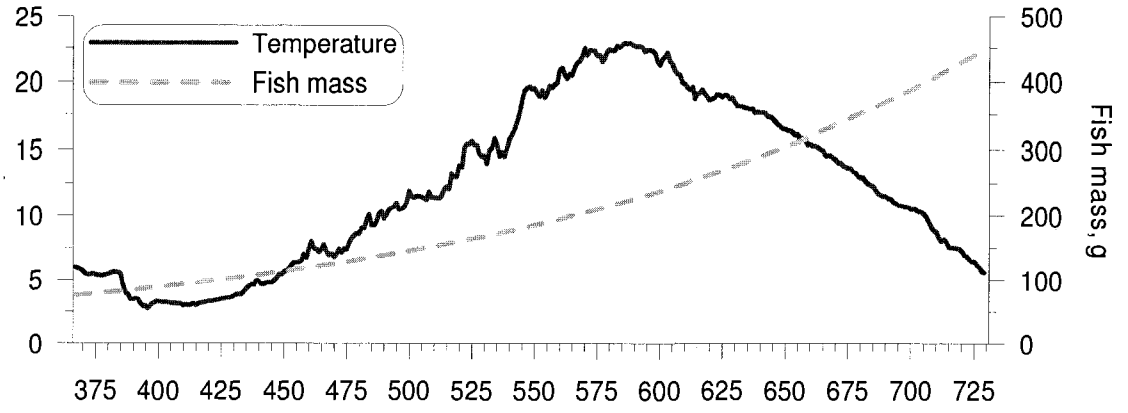

Figure 65. Base case temperature and prescribed fish mass function.

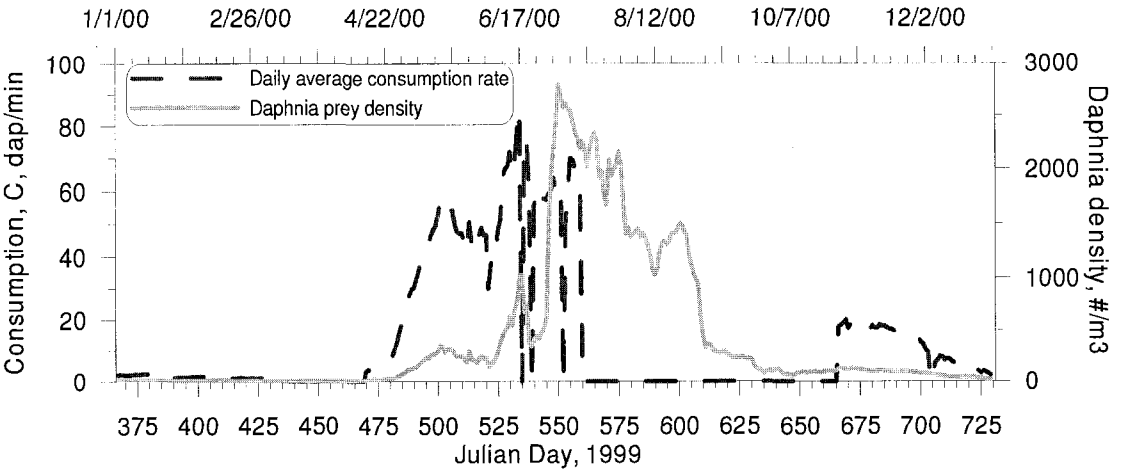

Figure 66. Daily average consumption (includes nighttime) and prey density.

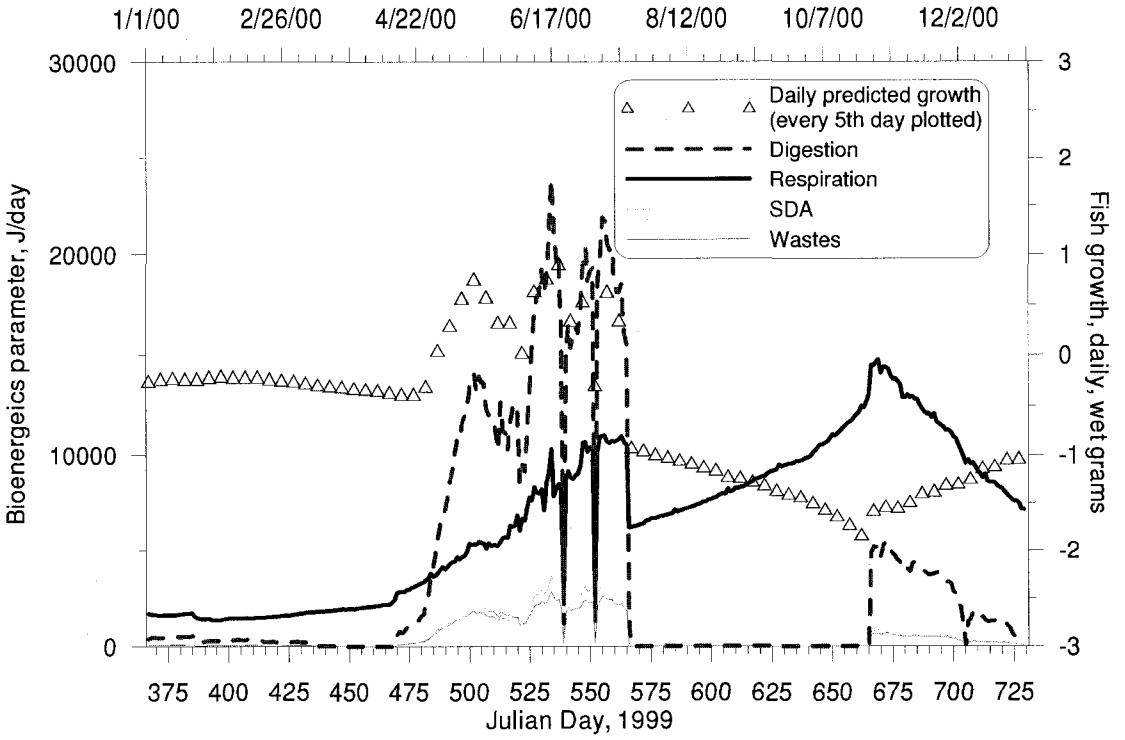

Figure 67. Daily growth and bioenergetic parameters.

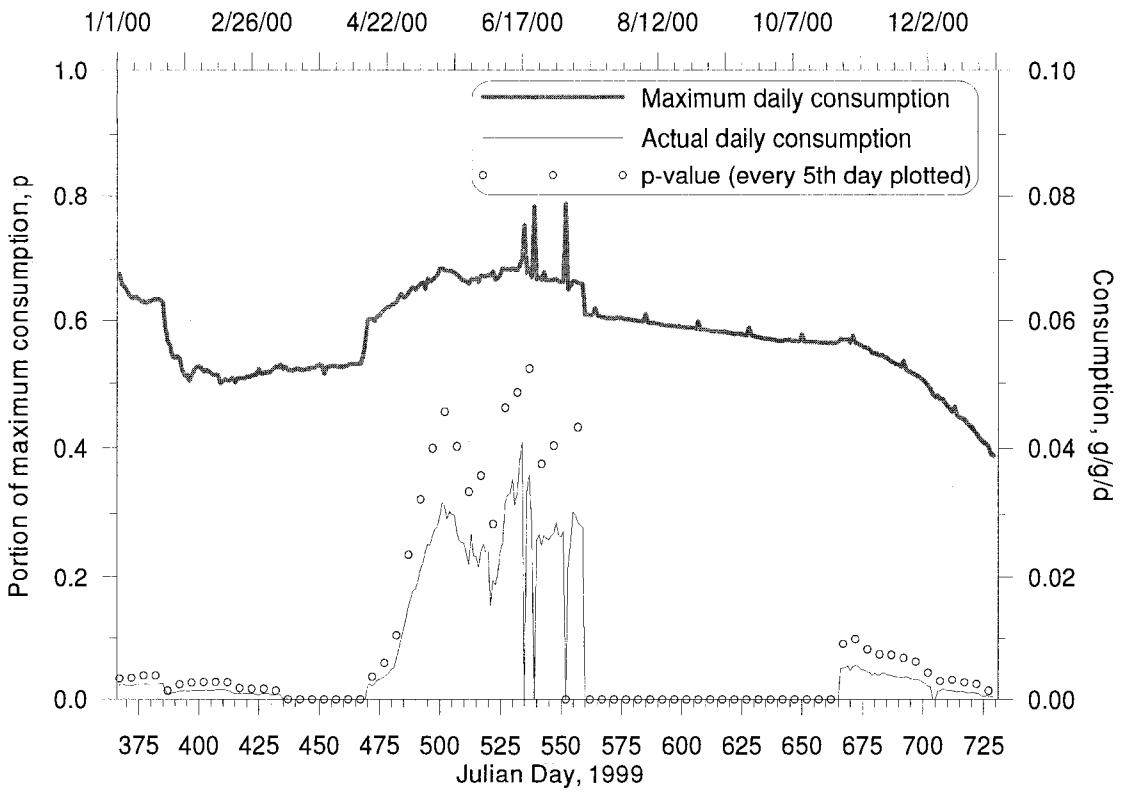

Figure 68. Daily maximum and actual consumption; p-values.

Base Lake Roosevelt Results at Spring Canyon (LRFEP sta 9.0)

Simple foraging algorithm

Energy content of prey: a constant of 2420 J/g

Growth method: prescribed function based on data.

Feeding: model output prey densities are used.

Foraging: "Best growth" with conditional vertical foraging during the day. The decision process at each time-step:

1) Use the cell of best growth if
    d. growth is positive
    e. during nighttime (selects least negative)
2) If daylight (surface lux >1), alternate foraging and "digesting"
    f. Forage at the cell of greatest consumption, C
    g. "Digest" or "rest" at the cell of minimum respiration, R
    h. alternate foraging and digesting time-steps during daylight.

Comments: This is an attempt at simple vertical foraging in an attempt to optimize consumption and respiration. Also, when assessing which cell has the best growth, 20% of the consumption is directly added to the digestion parameter to allow for potential digestion (Brett & Groves, 1979). Without this estimate (only used to estimate the best cell, and not for any parameter calculations), the model will pick the most favorable growth locations using the stomach content at the start of the time-step. Since only a small portion of the prey consumed are digested in the same time-step,

the model tends to pick the locations of least respiration cost when the waters become warm which in turn leads to empty stomachs.

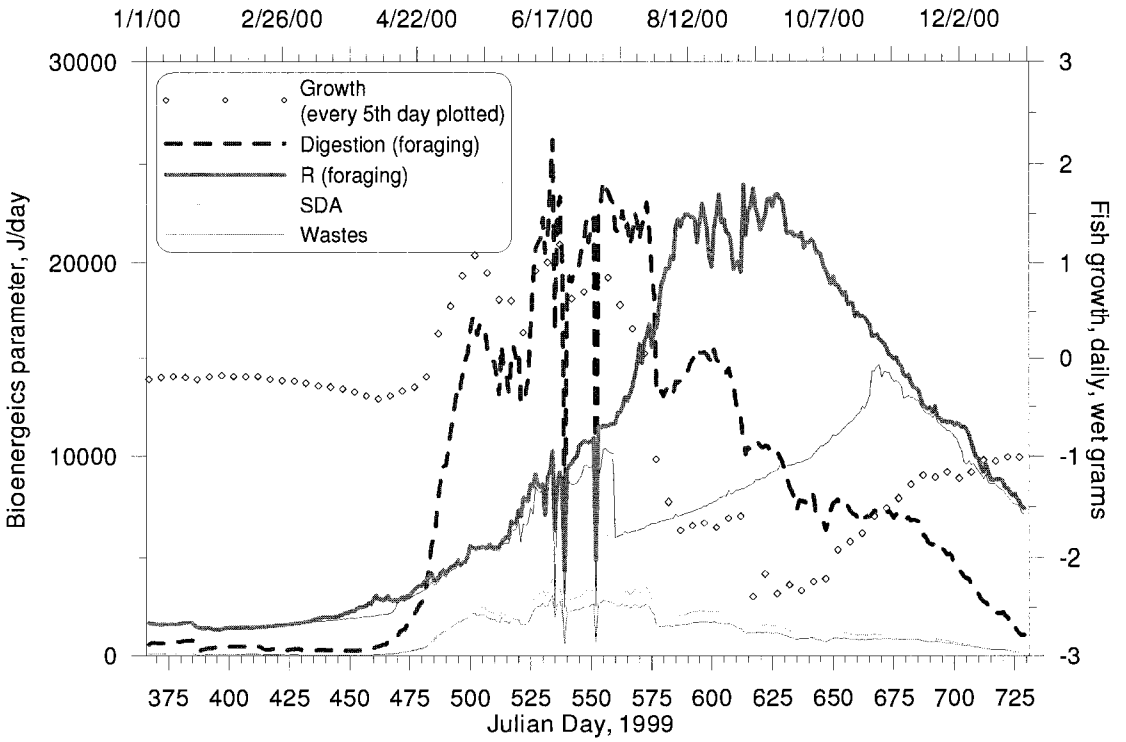

Figure 69. Daily growth and bioenergetic parameters, vertical foraging strategy.

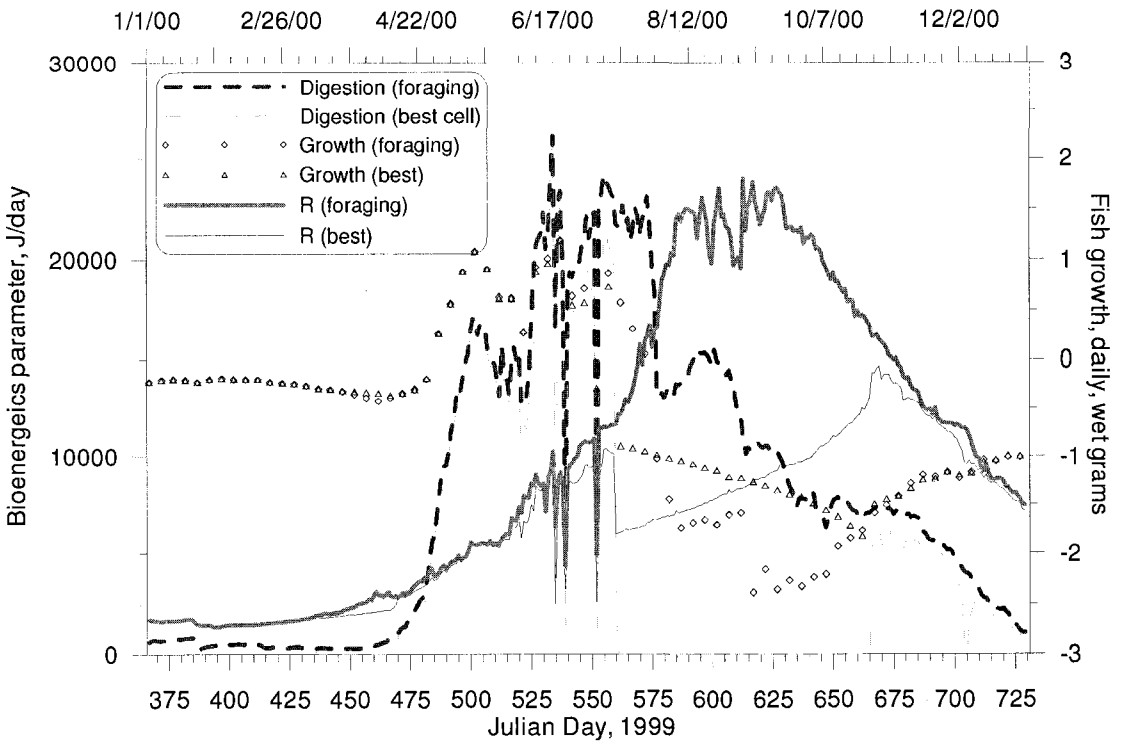

Figure 70. Comparison of fish location optimization strategies: best growth cell and vertical foraging.

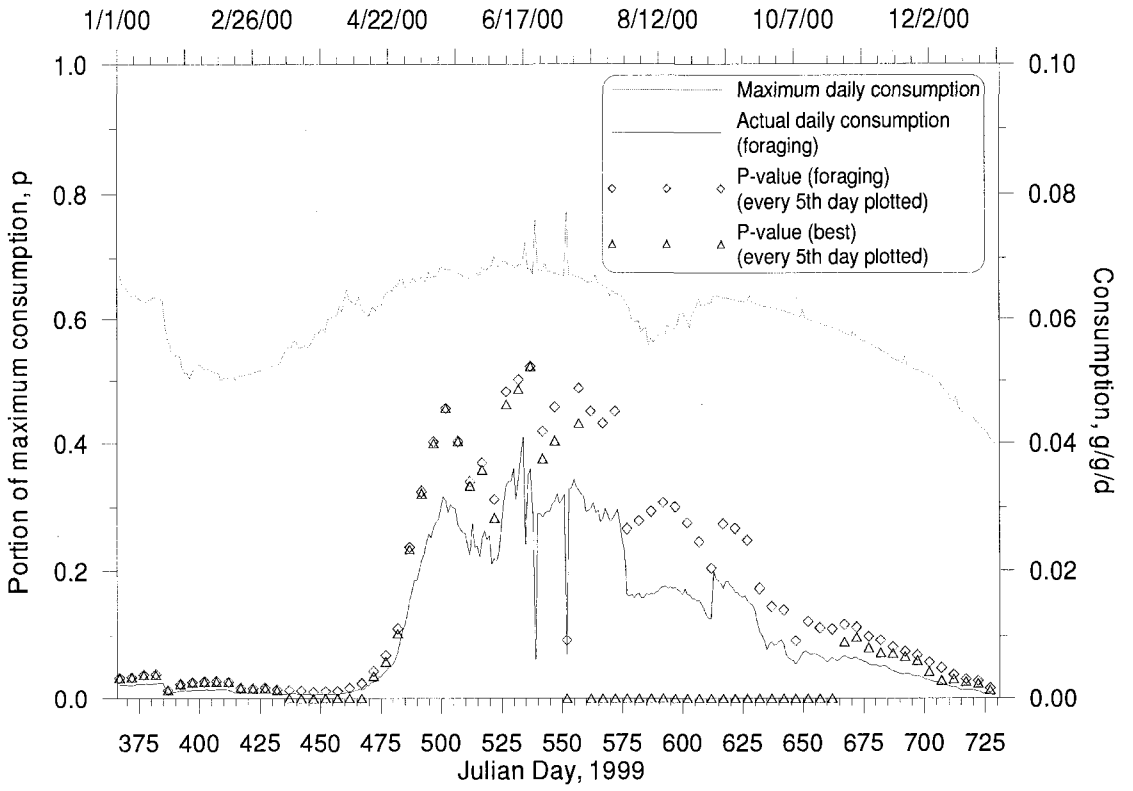

Figure 71. Daily maximum and actual consumption for the foraging model. Comparison of best growth cell and vertical foraging p-values.

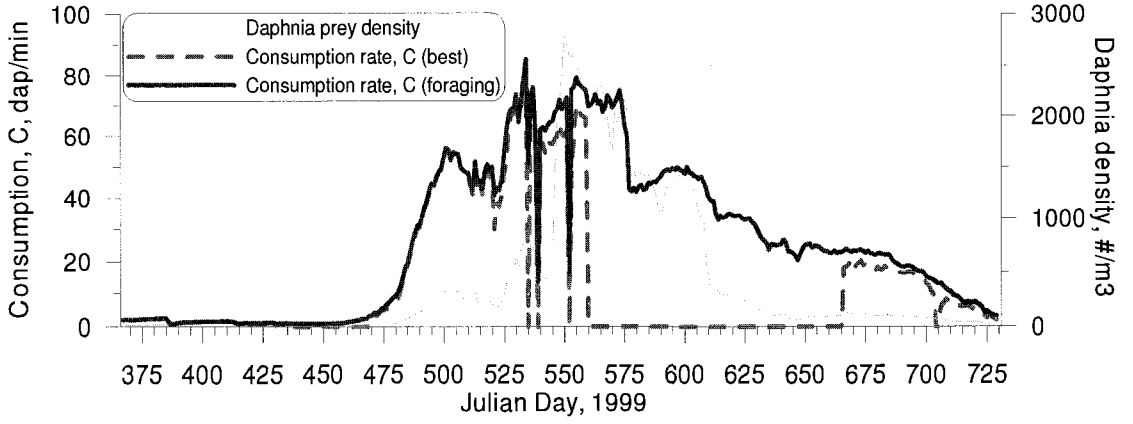

Figure 72. Comparison of daily average consumption rates.

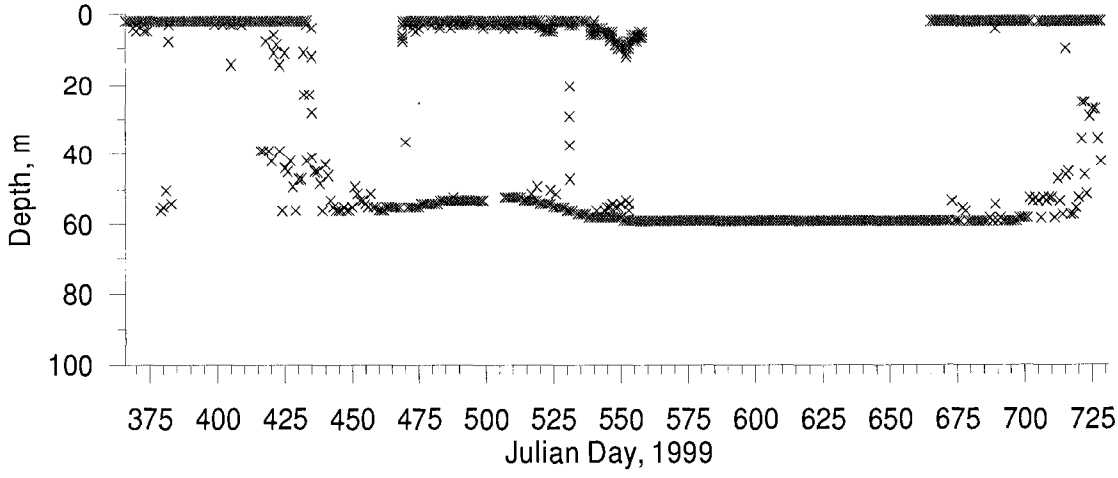

Figure 73. Foraging depths at each time-step, best growth cell method.

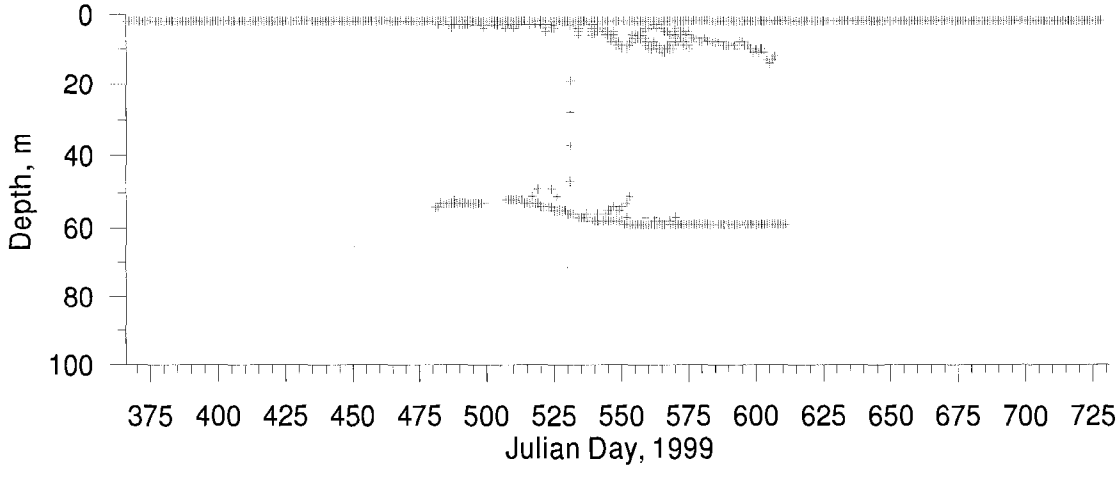

Figure 74. Foraging depths at each time-step, vertical foraging method.

[Figure 73 and Figure 74 were hard to distinguish on the same plot; individual points which look to be the same generally are.]

Comparison of Base Lake Roosevelt Results at Porcupine Bay (Spokane River, LRFEP sta 4.0) with Spring Canyon (Columbia River, LRFEP sta 9.0)

Energy content of prey: a constant of 2420 J/g

Growth method: prescribed function based on data.

Feeding: model output prey densities are used.

Foraging: "Best growth" with conditional vertical foraging during the day. The decision process at each time-step:

1) Use the cell of best growth if
    i. growth is positive
    j. during nighttime (selects least negative)
2) If daylight (surface lux >1), alternate foraging and "digesting"
    k. Forage at the cell of greatest consumption, C
    l. "Digest" or "rest" at the cell of minimum respiration, R
    m. alternate foraging and digesting time-steps during daylight.

Comments: This is the same run as previously reported; a new location is added.

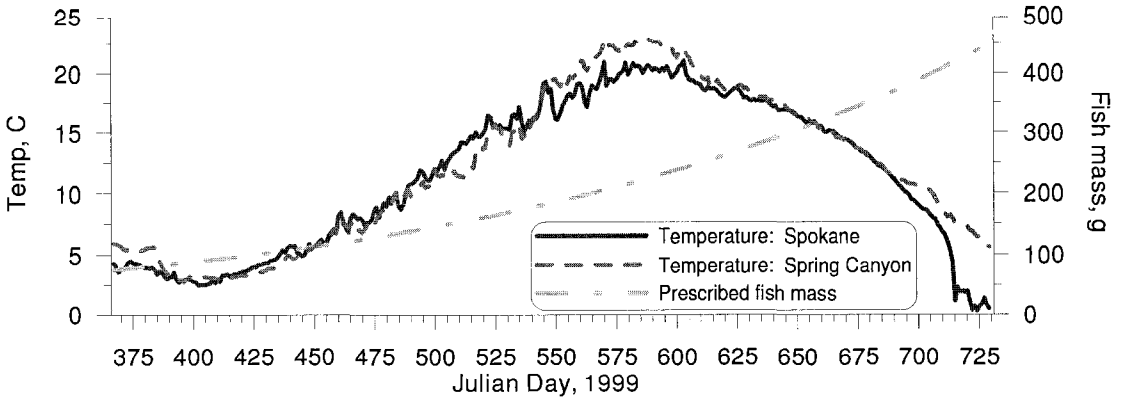

Figure 75. Comparison of water temperatures.

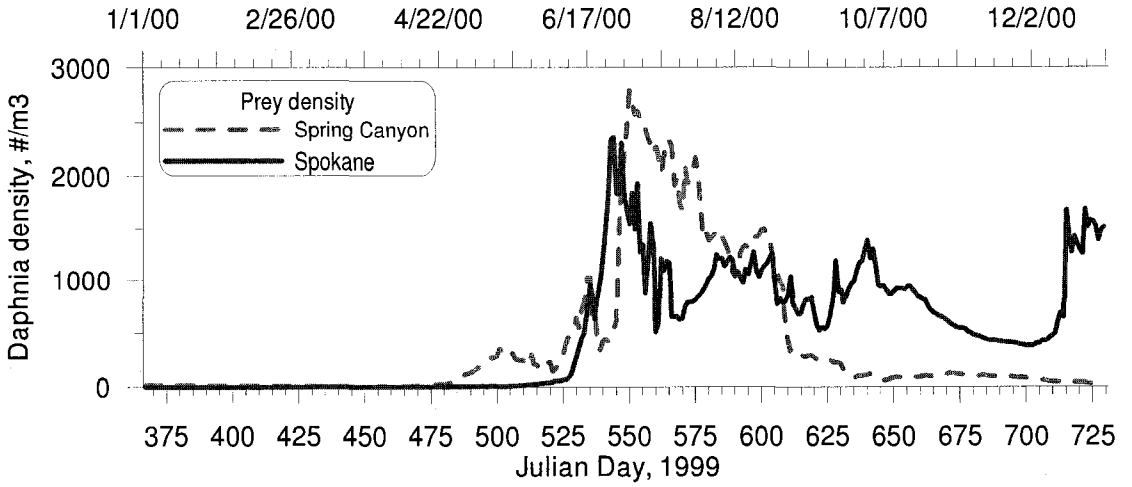

Figure 76. Comparison of prey densities.

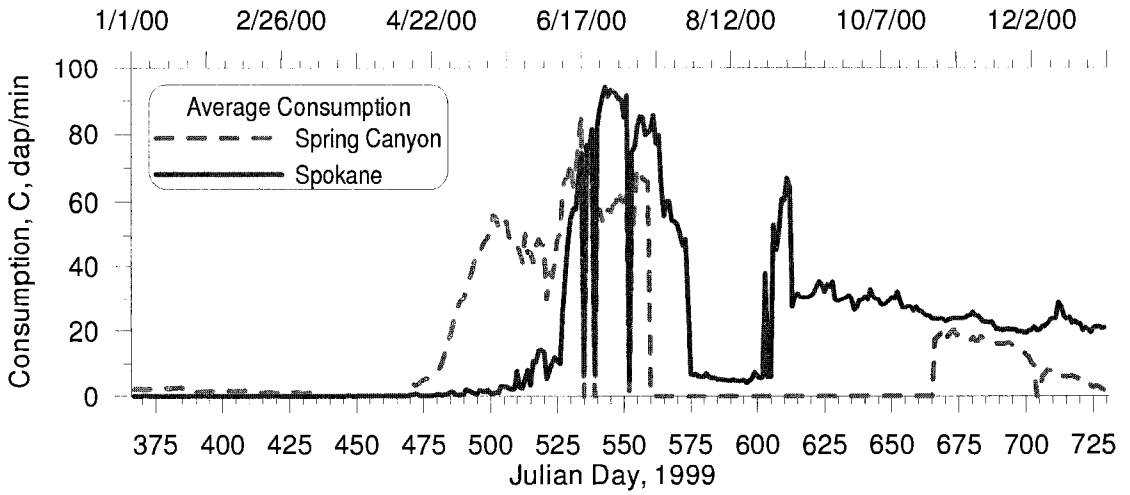

Figure 77. Comparison of consumption rates.

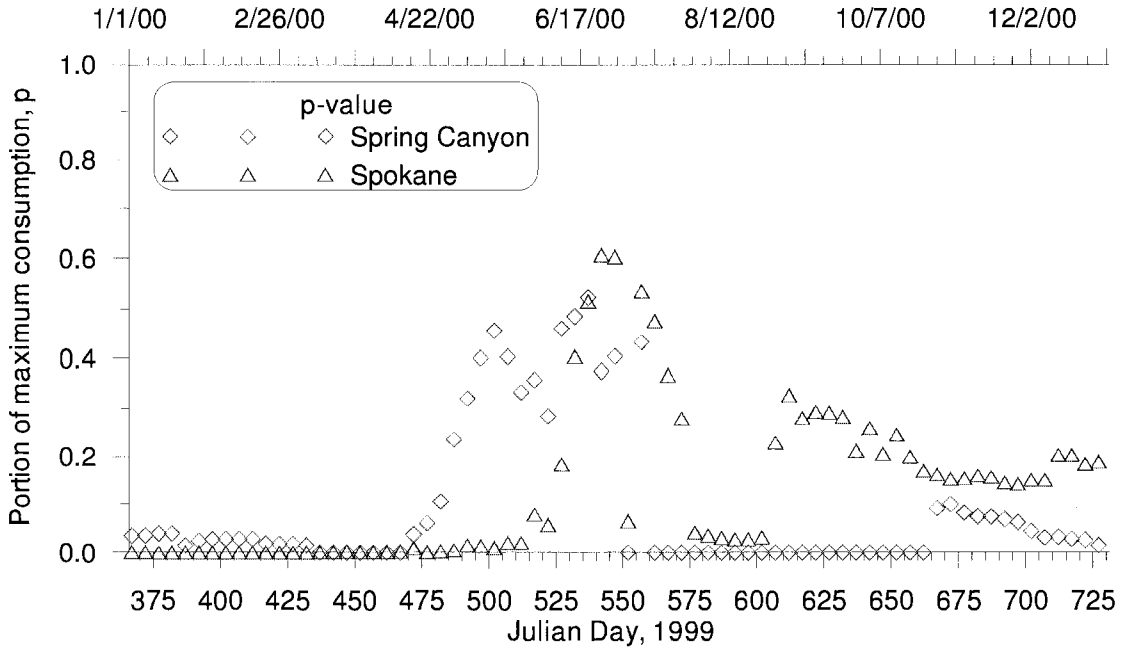

Figure 78. Comparison of p-values.

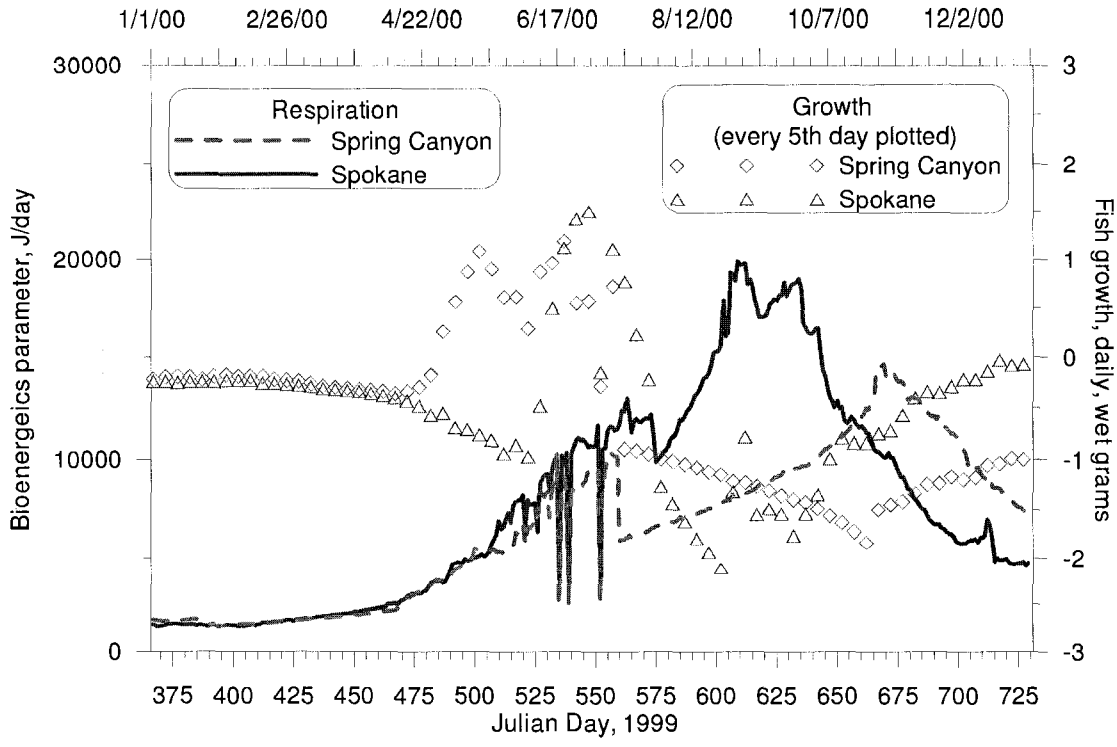

Figure 79. Comparison of respiration and daily growth.

Alternative Consumption Formulation

The Thornton-Lessem function is used to reflect the temperature dependence of foraging interaction. Many of the consumption terms are a function of temperature, and as such, the application of the Thornton-Lessem function to these terms may be redundant and produce an under prediction of consumption. Specifically, the search volume term in Equation (19) is a function of allometry and temperature. An alternative foraging consumption is formulated as Equation (19 B) by removing the Thornton-Lessem function. Consumption is limited by the minimum of Equation (19 B) and Equation (21), C_{max}, an empirical maximum consumption formulation. In execution, model predicted consumption was limited by C_{max}, but not by stomach content.

$$C_{forage} = \frac{E \cdot z}{1 + E \cdot z \cdot h} \cdot TL \cdot 60 \qquad (29)$$

$$C_{forage} = \frac{E \cdot z}{1 + E \cdot z \cdot h} \cdot 60 \qquad (30\,B)$$

A priori, the alternative consumption formulation predicts greater daily fish growth and fish mass. Figure 80 shows the difference between the predicted daily fish growths. Figure 81, a comparison of predicted fish mass, more clearly illustrates the magnitude of the difference in growth. The magnitude is near 5% over the year. Figure 81 also shows that the difference in formulation is only actualized during the spring to fall time period when consumption is large. Another way to examine the

difference in consumption formulation is shown in Figure 82, a difference plot in the daily P-values. Figure 82 shows that the difference is negligible during the winter when consumption is small and during the peak summer feeding period when both model formulations are feeding at the maximum rate.

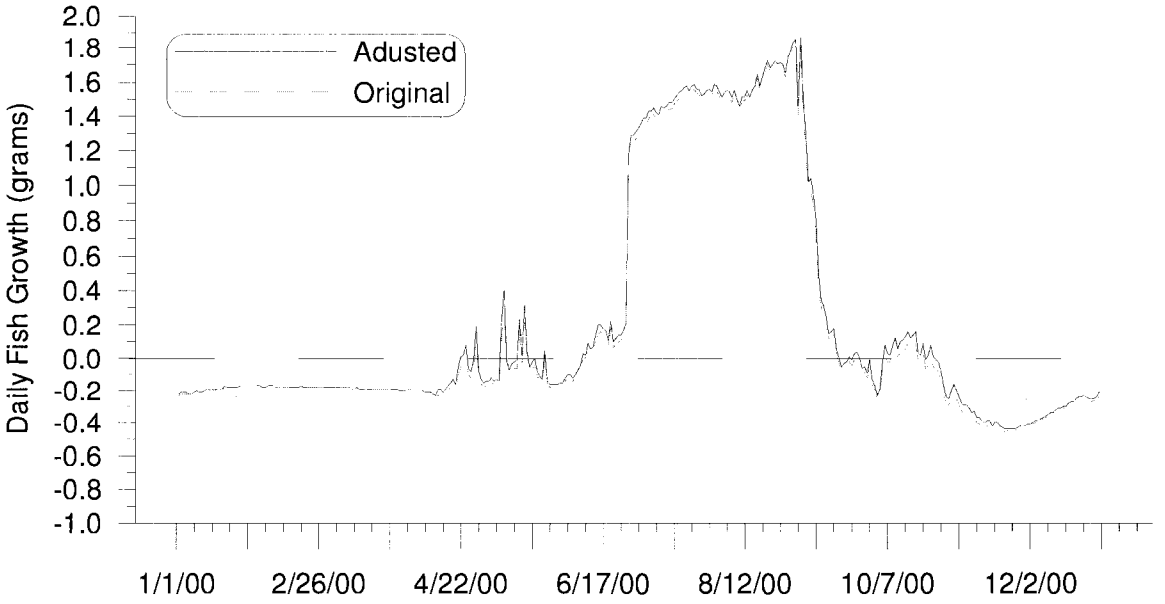

Figure 80. Alternative consumption formulation: Comparison of predicted daily fish growth.

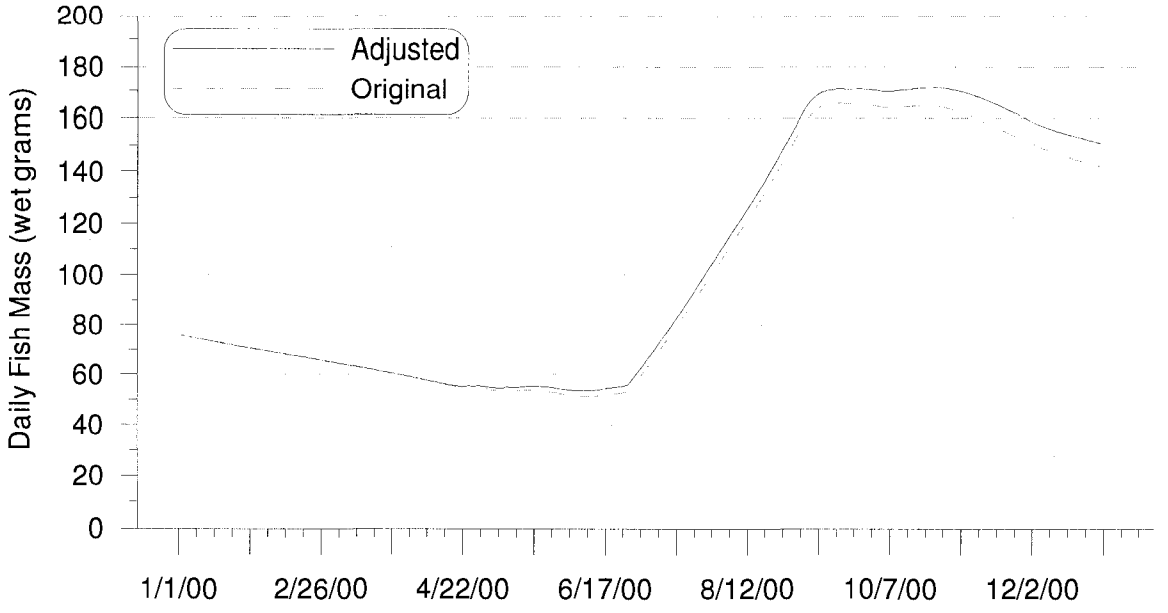

Figure 81. Alternative consumption formulation: Comparison of predicted daily fish mass.

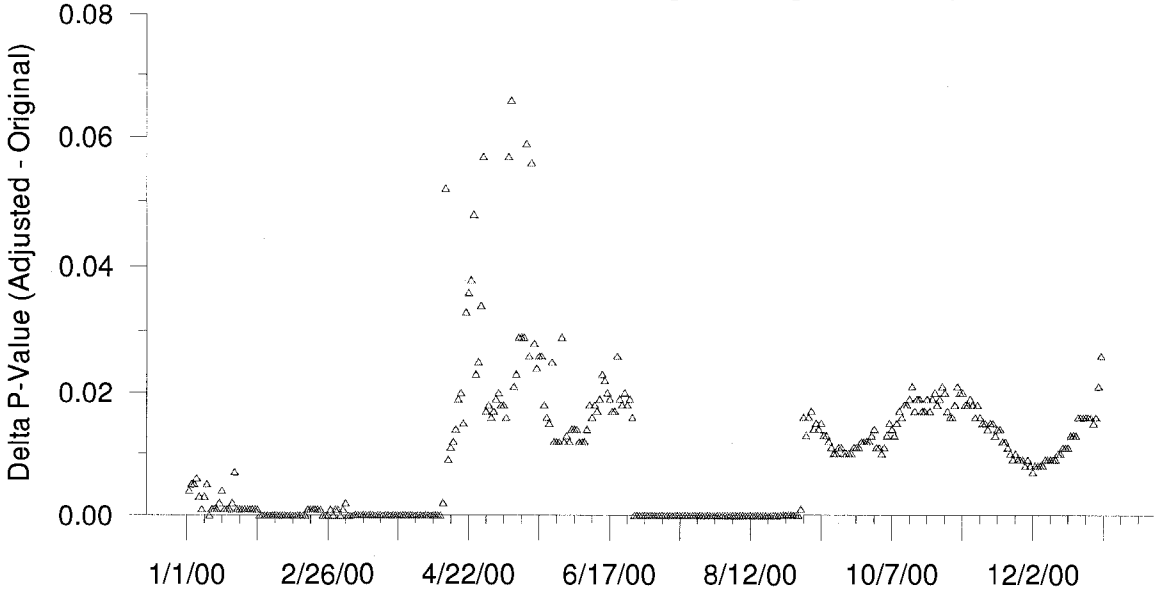

Figure 82. Alternative consumption formulation: Delta-plot of predicted daily P-values.

Phosphorous effects

Beckman, et al. (1985) identified the then plentiful zooplankton population as being able to support a kokanee fishery. To evaluate the pre-1994 zooplankton density's effect on fish growth, the mainstem orthophosphorous concentration was increased tenfold for all values. As would be expected, the zooplankton population increased. While the peak blooming period concentration showed modest increases (~20%), the main benefit was to extend the blooming period from July through August to April through October. Figure 83 shows selected comparisons under a prescribed fish mass function scenario. Under a model-predicted fish mass scenario (Figure 84), there is a ~50% (65 g) increase in fish mass.

It is important to note that even under the increased prey densities, fall turnover (at ~J600) results in the removal of pelagic cold water and the ensuing 21°C temperature is well above the literature optimal temperature (15°C) and at the avoidance temperature (Wismer and Christie, 1987). The model predicted consumption falls to zero as the simulated fish cannot consume enough food to generate growth at that combination of prey density and water temperature.

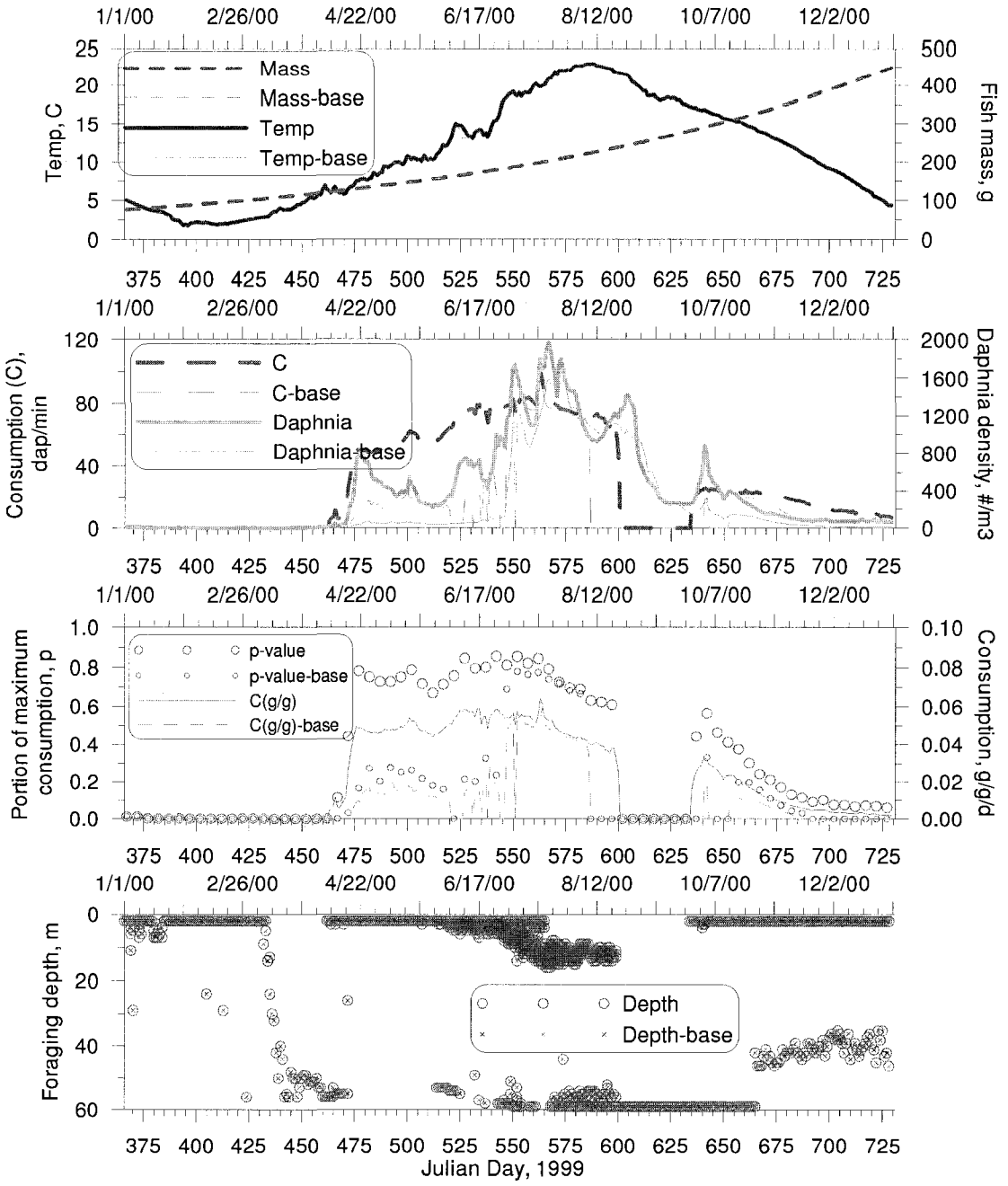

Figure 83. Increased phosphorous results compared to base case under prescribed fish mass function.

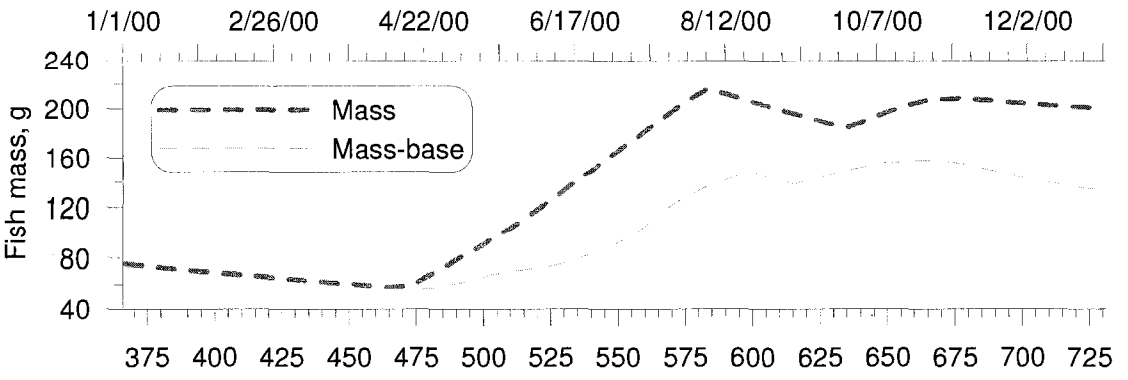

Figure 84. Effects of increased phosphorous on model-predicted fish mass.

Pool elevation effects

Reservoir operations are constrained by the need for flood control drawdown, the effect of stage on the efficiency of hydropower operations, and the need for fish access to spawning areas in the fall (which requires a high stage). There is a small range of summer & fall target pool elevations that is tractable, however. A scenario was examined where an additional 250 m3/s were withdrawn through the three powerhouses from J520 (June 3) through J550 (July 3) which resulted in a roughly 2 m lower pool elevation in the summer and fall, as illustrated in Figure 85.

The model predicted fish mass and temperature are shown in Figure 86. Differences between the lowered pool scenario and base case are shown in Figure 87, Figure 88, and Figure 89. In general, the effects are nearly negligible, although there does appear to be a greater predicted mass during the period of increased powerhouse flows. This can also be seen in a comparison of predicted daily fish growth (under a prescribed growth function) in Figure 90. An examination of the model output shows that while the tailwater cladocera concentration is slightly elevated (Figure 91), an examination of the spatially integrated cladocera mass over the middle and lower thirds of the mainstem reservoir (Figure 92) shows that the increased growth at the downstream stations is the result of increased advection of zooplankton from the middle of the reservoir. Temperature is not appreciably influenced: while the colder late fall and

winter temperatures might suggest some improved respiration costs, there is not enough prey to see any increased growth.

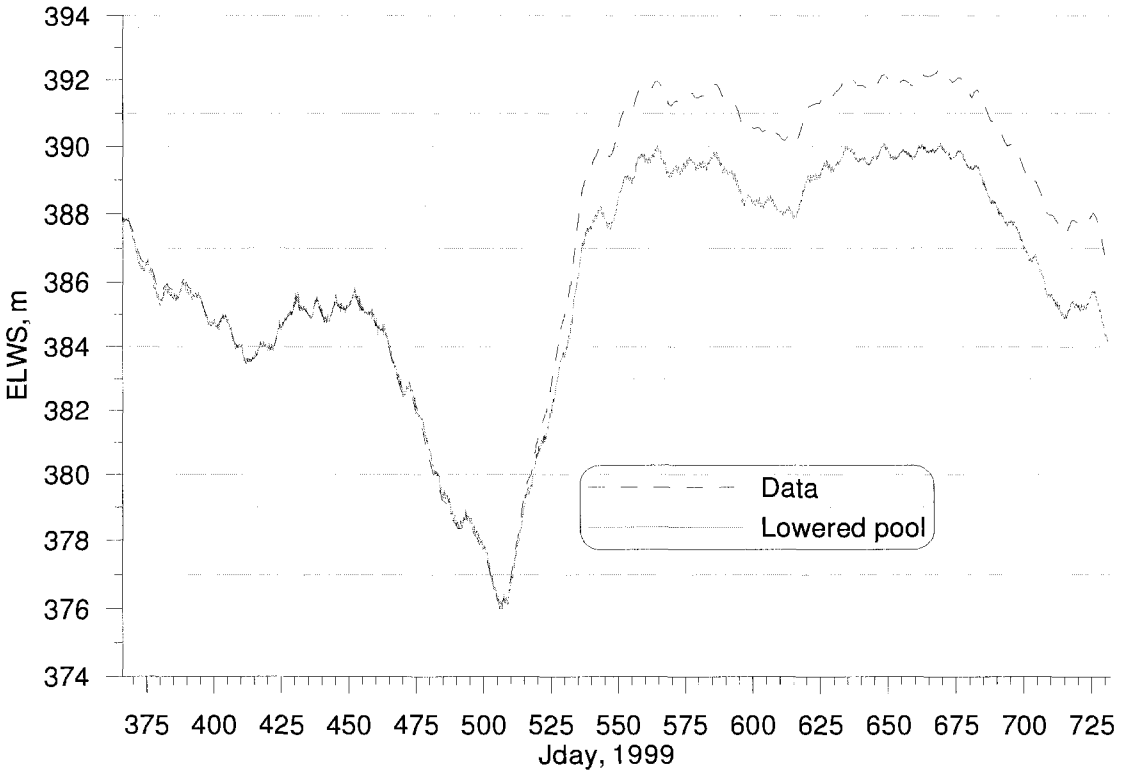

Figure 85. Grand Coulee Dam forebay stage comparison.

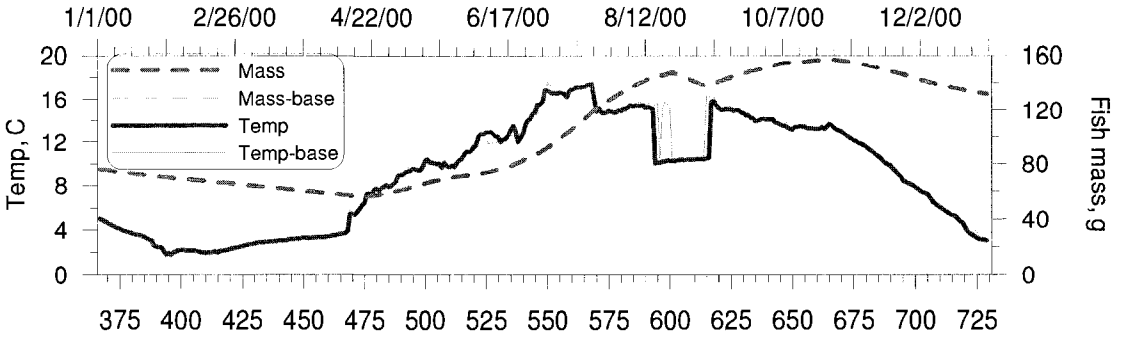

Figure 86. Fish mass and foraging temperatures.

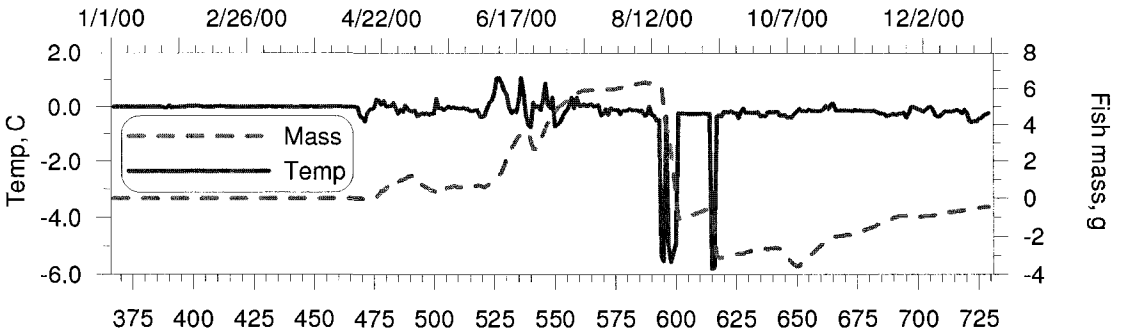

Figure 87. Difference in fish mass and foraging temperatures under lower pool scenario.

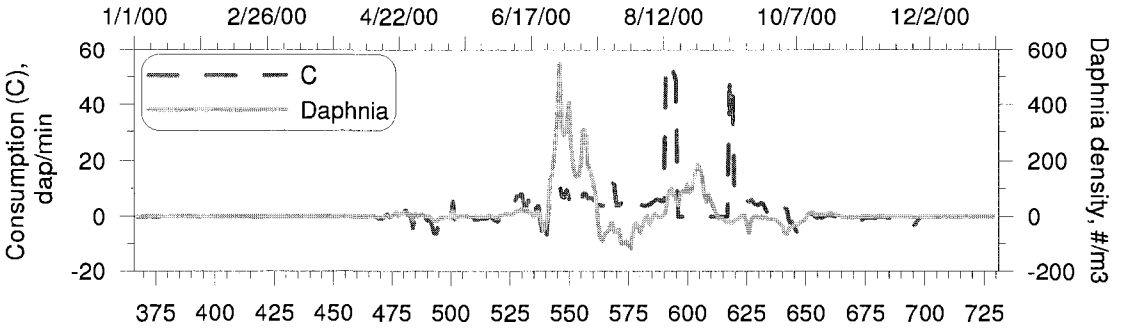

Figure 88. Difference in consumption and prey density under lower pool scenario.

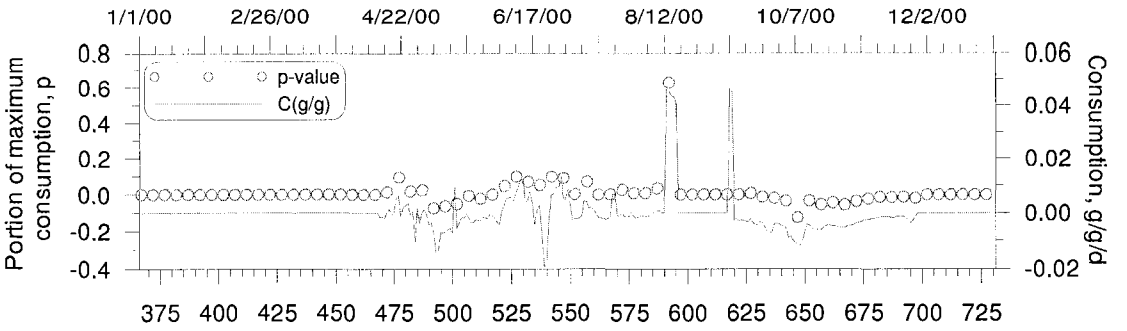

Figure 89. Difference in p-values and consumption under lower pool scenario.

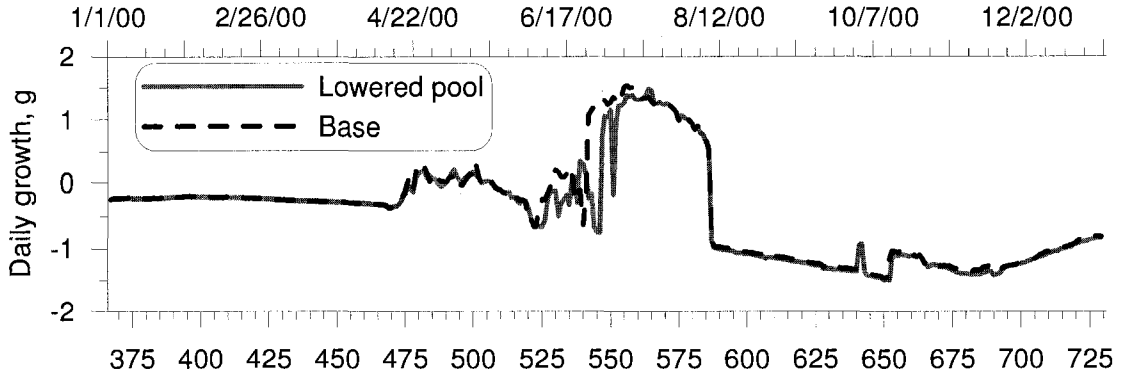

Figure 90. Prescribed fish mass daily growth comparison under lowered pool scenario.

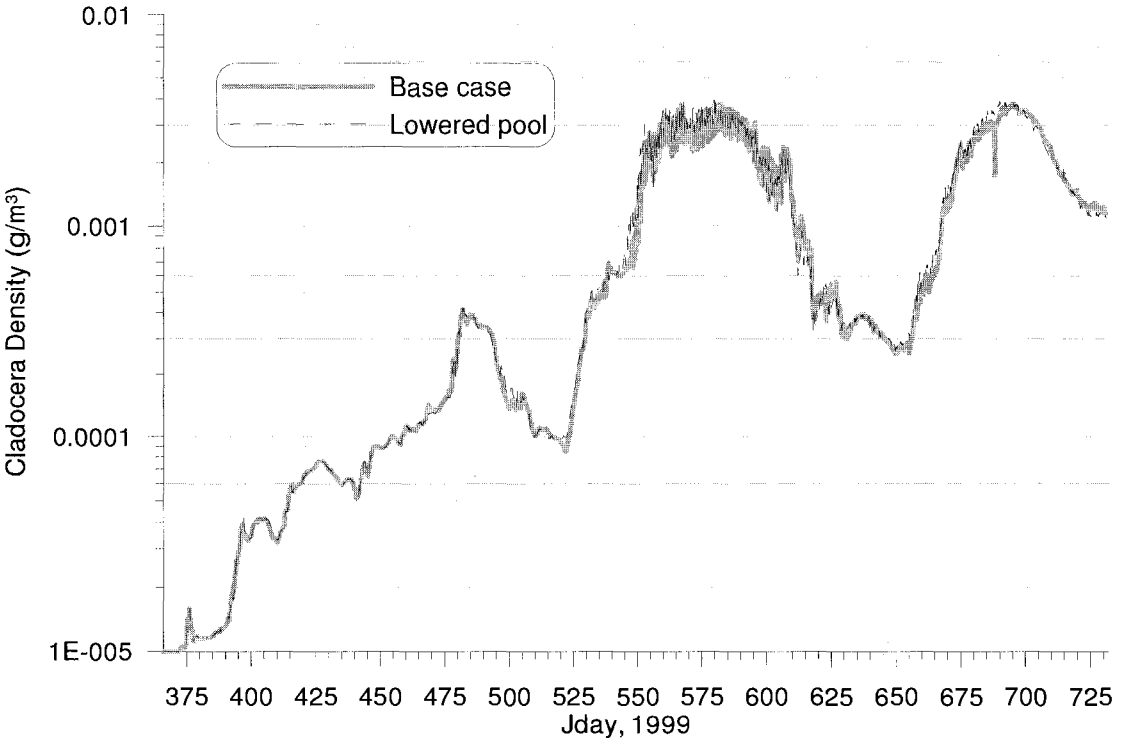

Figure 91. Cladocera concentration in tailwaters compared with lowered pool scenario.

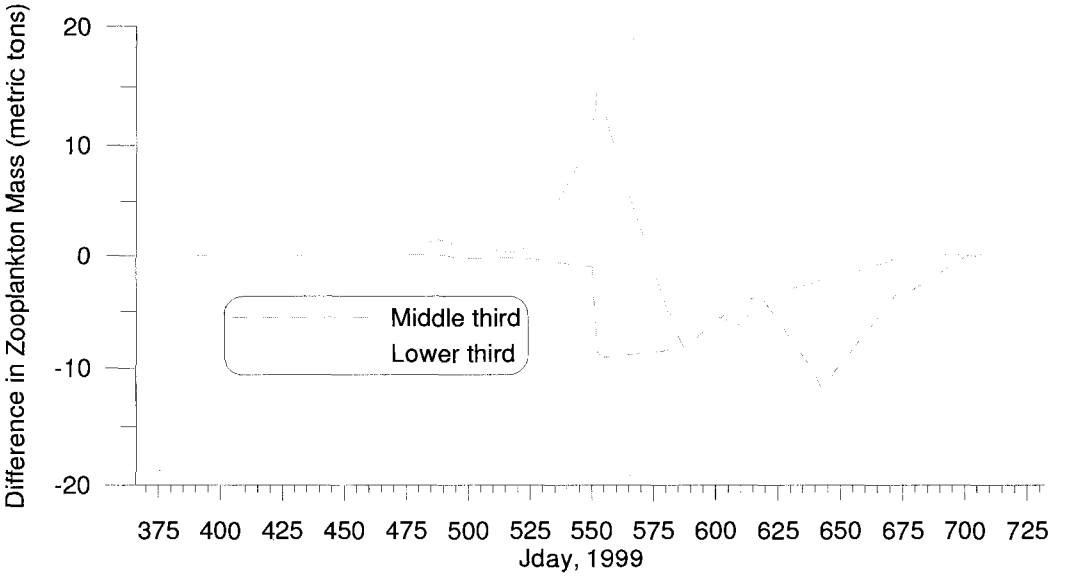

Figure 92. Changes in total cladocera mass in middle and lower third of the reservoir under lowered pool scenario.

Release Size

The initial fish mass was varied at the Spring Canyon site (LRFEP sta 9.0). While 10, 50, 100, 150, and 200 grams were used, only 10, 100, and 200 g are shown on Figure 93 for clarity. In addition to the mass time-series, the foraging temperature is shown as a surrogate for foraging depth. The temperature shows that different prey density and temperature distributions result in different favorable conditions depending upon fish size. From the results, fish size is not a reliable predictor of foraging depth. At fall turnover, the larger fish sought out the cold water refugia while the small fish continued to forage in the prey rich warm water; however, as the prey density fell in the fall, the small fish went deep and the larger fish came shallow. A similar, yet reverse scenario is seen during spring drawdown and after reaching full pool.

Another interesting feature is the similar slope of the mass curve during the summer bloom. While the larger fish suffer a larger decrease in mass from January to June, all three fish sizes show a roughly 50 g increase in mass over June to August.

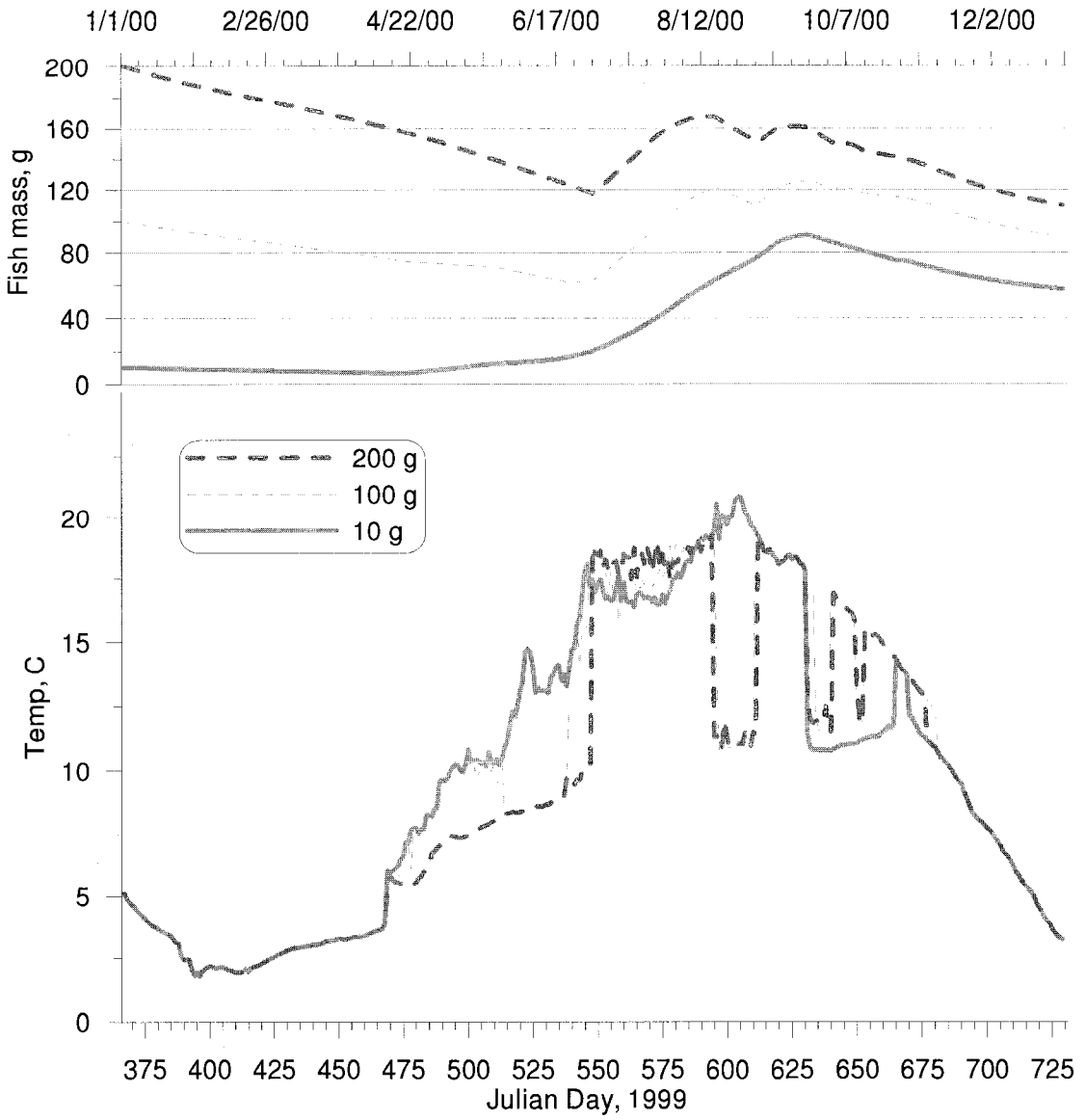

Figure 93. Mass and foraging temperature for 10, 100, and 200 g starting masses.

Fish Hydroacoustic Data

Fish hydroacoustic data were collected in 2001 and 2002 by the Washington Department of Fish and Wildlife for the Lake Roosevelt Fisheries Evaluation Program (Baldwin, Woller, and Polacek, 2001; Baldwin and Woller, 2002). Nighttime sampling was performed over 23 zigzag shaped transects over the length of the reservoir over a three day period in August and October of each year. Sampling used vertical and horizontal sampling gear. Vertical gill netting was also conducted during these periods. The fish densities for all species at each transect are shown in Figure 94 for 2001 and in Figure 95 for 2002.

For each reservoir section (upper, middle, lower), species composition from gill netting was used to estimate the kokanee portion of the sampled fish data. Figure 96 shows the percent of the total sampled kokanee population in each reservoir section for each sampling period. In 2001, the data suggest that kokanee favored the lower reaches in both August and October. In 2002, the data suggest that kokanee favored the lower section in August and the middle section in October. Figure 97 shows the model predicted fish mass for an initial 76 g kokanee at 6 locations on the mainstem Columbia. Segment 50 is near the U.S. – Canadian border and segment 300 is upstream of Grand Coulee Dam. The model predicts that fish growth has a temporal dependence and to a lesser extent, there is a spatial dependence as well. To reconcile

the model to the spatial distribution data, two known influences on spatial distribution need to be incorporated into the model:

1) Young kokanee are known to avoid predators. This will require some measure of predation risk at each model location, vertically and longitudinally over the temporal period.
2) Kokanee, especially juveniles, are known to favor higher water velocities, especially at night. This environmental preference sometimes explains juvenile kokanee downstream migration behavior.

A longitudinal component needs to be added to the coupled W2-bioenergetics model to accurately represent the effects of these behavioral drivers.

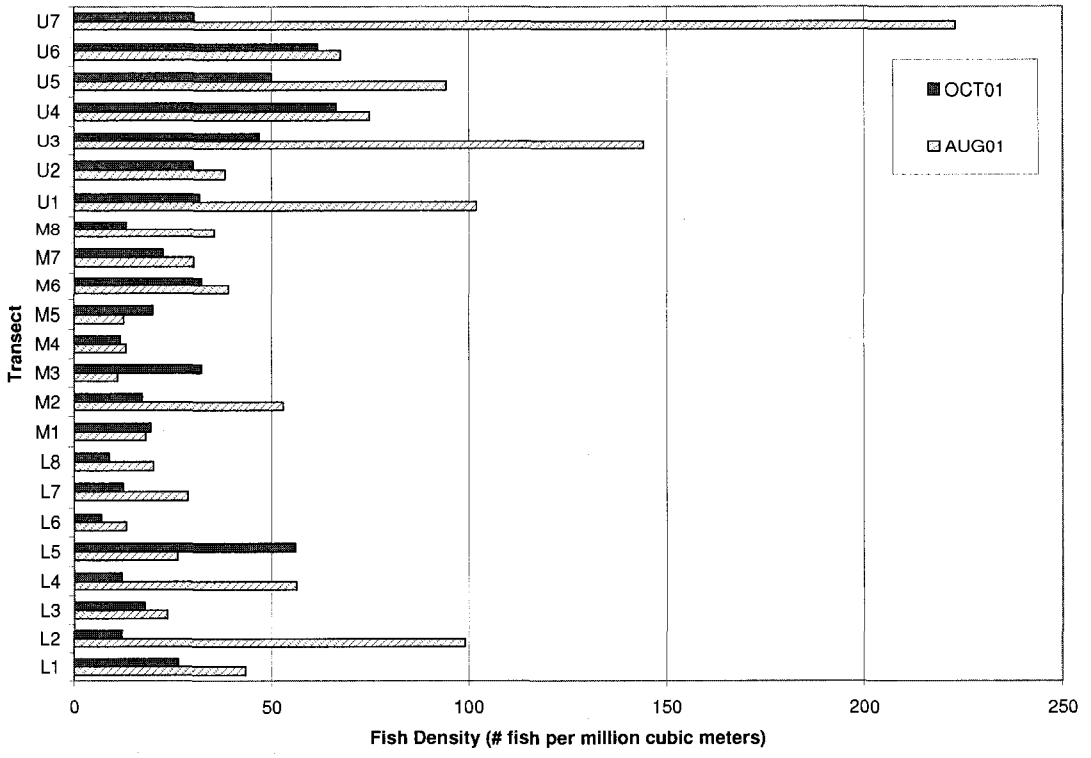

Figure 94. Fish hydroacoustic data, all species, LRFEP Annual Report 2001.

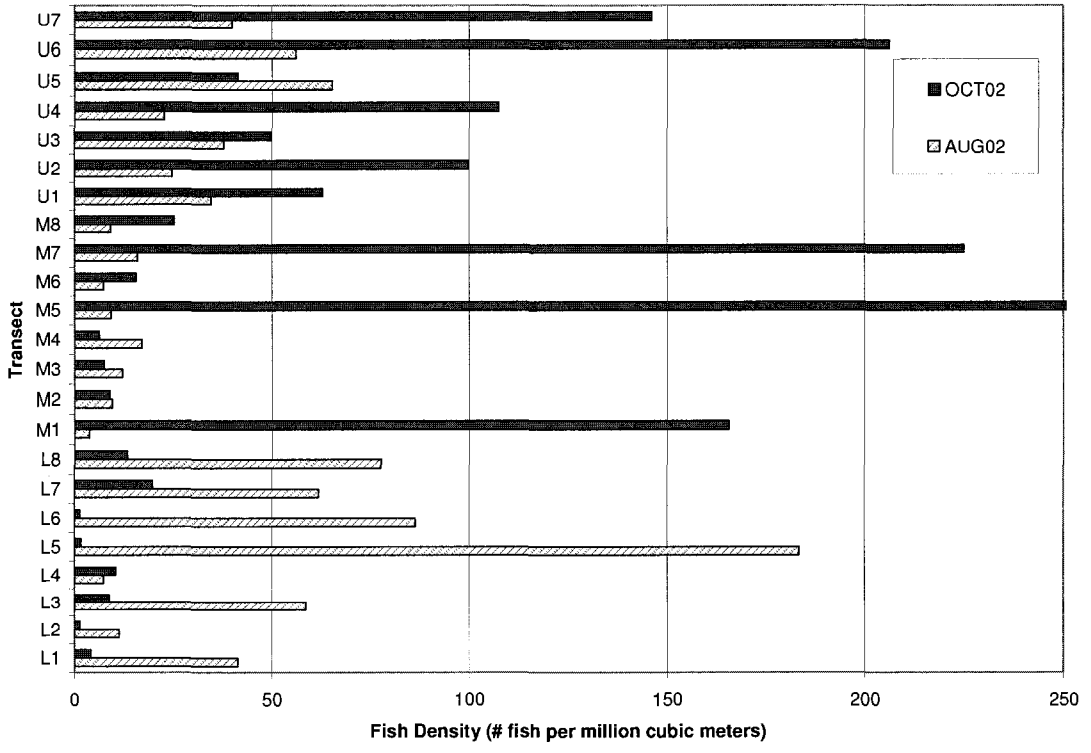

Figure 95. Fish hydroacoustic data, all species, LRFEP Annual Report 2002.

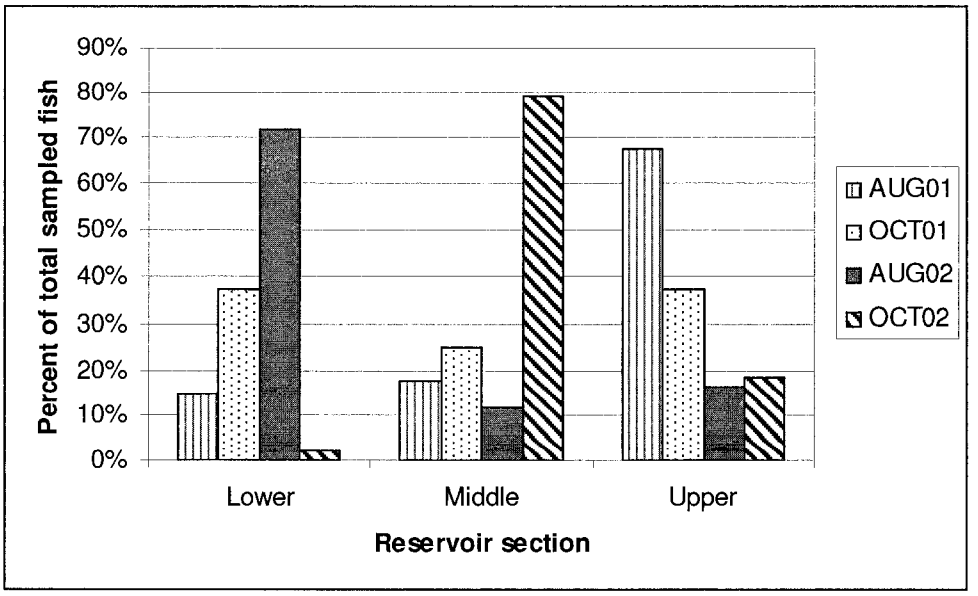

Figure 96. Fish hydroacoustic data, percent kokanee species by reservoir section.

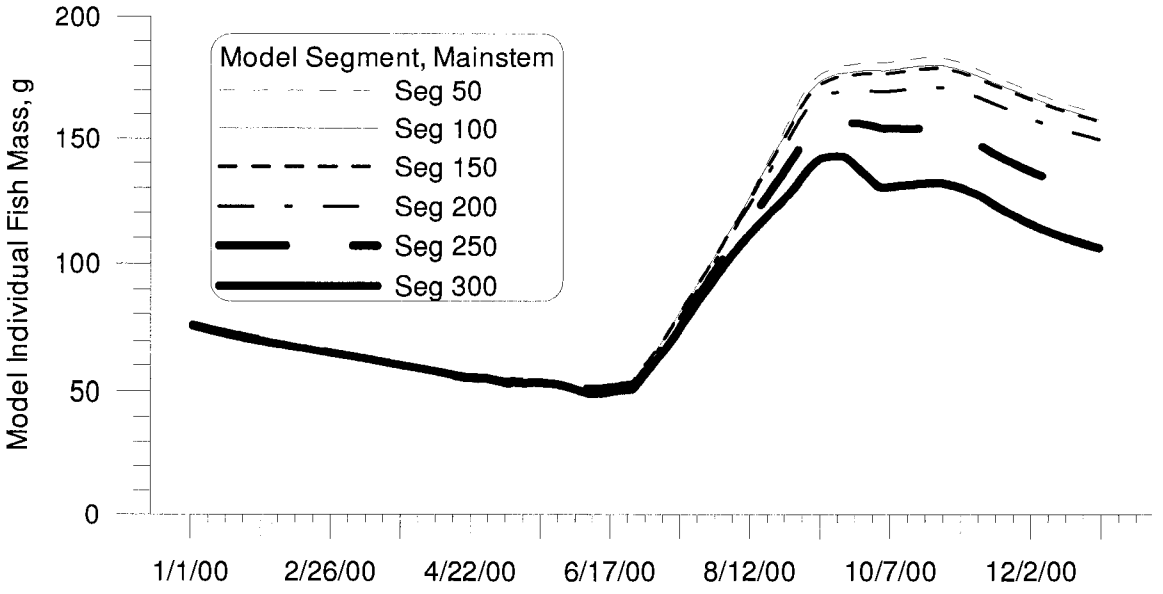

Figure 97. Model predicted individual fish mass (grams) at 6 locations on the mainstem.

Calibration Sensitivity and Model Confidence

A summary of the calibration statistics for the year 2000 are presented in Table 52. A discussion of the calibration follows. Refer to McKillip and Wells (2006) for a full report of the model calibration.

Table 52. Calibration statistics summary, 2000.

Parameter/Constituent	Unit	Count	ME*	AME*	RMS*
Grand Coulee Dam Forebay					
Daily-average ELWS**	m	366	0.01	0.01	0.01
Hourly-average ELWS**	m	8762	-0.03	0.17	0.17
LRFEP vertical profile stations					
Total Dissolved Solids	mg/L	1308	-0.18	0.39	0.44
Dissolved Oxygen	mg/L	1308	-0.01	0.14	0.16
pH	-	1308	-0.42	0.43	0.43
Water Temperature	°C	1308	-0.14	0.49	0.50
Below Grand Coulee Dam					
Orthophosphate	mg/L-P	25	0.00072	0.00097	0.00097
Ammonium	mg/L-N	25	-0.005	0.0067	0.0067
Nitrate plus nitrite	mg/L-N	25	-0.017	0.036	0.036
Alkalinity	mg/L-$CaCO_3$	25	0.89	4.18	4.18

* ME=mean error, AME=absolute mean error, RMS=root mean square error, see Appendix G.

** ELWS = Elevation, Water Surface.

Hydrodynamics

The hydrodynamic calibration to the 2000 data is acceptable. The daily-average water surface elevation is within 1 cm, and the hourly-average elevation is within 17 cm with little bias. The water balance flows have a minimal bias and the magnitudes are within the range of river discharge measurement error.

Water Temperature

The most comprehensive and representative temperature data are from the LRFEP vertical profiles. The calibrated model shows a slight bias toward underpredicting temperature (by ~0.1 °C), which is acceptable. The RMS error, representing the typical difference in temperature between the model and data, is 0.5 °C, which is considered a good calibration. The calibration of the station data in the Columbia River is good, but there is greater error in the calibration of the Spokane River data. Adjustments to the boundary conditions for wind, the wind sheltering coefficient, effects model temperature calibration the most. After accounting for wind effects, the next largest source of model-data discrepancies arises from conflicts among temperature boundary condition and calibration data both between the different agencies and between the sampling locations.

Alkalinity and pH

Calibration of alkalinity and pH largely focused on generating good boundary condition data. As the modeled water quality and fish growth potential formulations are not functions of carbonate chemistry, the calibration of alkalinity and pH does not effect the confidence of the other model results.

Ammonium and Nitrate plus Nitrite

The nitrogen balance in the system is largely conservative, so the calibration is straightforward. As with the bulk of the parameters, while the Columbia River calibration is good, the calibration at the Spokane River station shows more disagreement.

Orthophosphate

While the orthophosphate calibration is acceptable, it could be improved. A further investigation into the spring spike in phosphorous is warranted. Discussions with LRFEP suggest that attached algae may be a significant player in the spring phosphorous balance prior to the spring phytoplankton bloom. The phosphorous balance is relatively conservative otherwise. Phosphorous concentrations are also very low (near the detection limit), so sampling error may be significant. Within the W2

model, phosphorous calibration included including sorbtion onto sediments and adjusting the organic matter stoichiometry. An organic matter stoichiometry study may provide some insight into the nutrient loadings of the system. An examination of the proposed phosphorous TMDL showed that the proposed TMDL is not predicted to effect fish growth potential in Lake Roosevelt.

Total Dissolved Solids

The total dissolved solids calibration is acceptable. TDS is largely conservative.

Algae

The algae calibration is acceptable in terms of total algae available for zooplankton consumption. The spring diatom bloom is generally captured. A general problem occurs in matching the dieback in June/July seen over most of the system, which is presumably due to either the hydrodynamic change in reservoir operation or in the spring zooplankton blooms. The algal populations within Lake Roosevelt experience significant washout and have low nutrient availability. While most stations have a good total algae calibration, the Hawk Creek station underpredicts total algae. W2 is largely a pelagic model, so a further consideration of the littoral primary production may be significant in terms of zooplankton, and hence fish, ecosystems.

Zooplankton

Zooplankton sampling presents many challenges, as does zooplankton modeling. In general, zooplankton concentrations range over 3 to 4 orders of magnitude over a year. The calibration concentration is typically within 1 order of magnitude, and much of the discrepancy occurs during the late winter and early spring. Fortunately, the fish growth potential model is not sensitive to zooplankton prey densities within 1 order of magnitude. Improvements to the zooplankton calibration would incorporate suggestions from biologists as to the important changes in driving factors during the seasonal shifts from winter to spring to summer and an improved understanding of the effects of zooplankton washout and retardation.

Fish Growth Potential

The fish growth potential suggests that growth is limited in the winter by prey availability and in the summer by warm temperatures relative to the available prey. The Spokane River arm demonstrates higher growth potential that the lower Columbia River reaches. This is consistent with anecdotal data and prevailing opinions amongst the fisheries biologists. Further improvements to the fish bioenergetics model would include identification of potential cold water refugia and investigation into the actual fish movement behavior such as diel migration/foraging, spatial distribution in terms of location and depths, and seasonal changes in that distribution. It is important to

note that the fish growth potential does not consider entrainment, predation, nor spawning—all of which are not well understood within the Lake Roosevelt system for kokanee salmon.

Spokane River Phosphorous TMDL Scenario

Due to algae and other water quality problems on the Spokane River, phosphorous loading is controlled through tertiary treatment and best management practices. The effect of a proposed phosphorous TMDL on Lake Roosevelt fish growth potential was examined.

Figure 98 illustrates the comparison of the phosphorous upstream boundary condition between the base model scenario and the proposed TMDL. Model runs using the actual TMDL resulted in increased algae production during the summer due to the marked increase in phosphorous loading during the summer period. As the TMDL would not increase phosphorous loading, the lesser of the actual TMDL and the base model boundary condition was used to generate a modified TDML boundary condition.

Figure 99 shows that the downstream orthophosphate concentration at Porcupine Bay (LRFEP Station 4.0) largely mirrors the upstream boundary condition. The decreased loading during the winter and spring does not significantly lower the summertime phosphorous levels. As a result, the zooplankton (prey) density and the predicted model fish mass at Porcupine Bay, Figure 100 and Figure 101, respectively, are not influenced by the modified TMDL.

During the winter and spring, the higher flows and spring drawdown for flood control result in a small residence time (8 to 20 days during the winter and 4 to 8 days during drawdown compared to 20 to 60 days during the summer). In terms of the Spokane River arm of Lake Roosevelt, this flushing makes phosphorous control during the winter much less critical than controlling phosphorous during the summer months of high primary production.

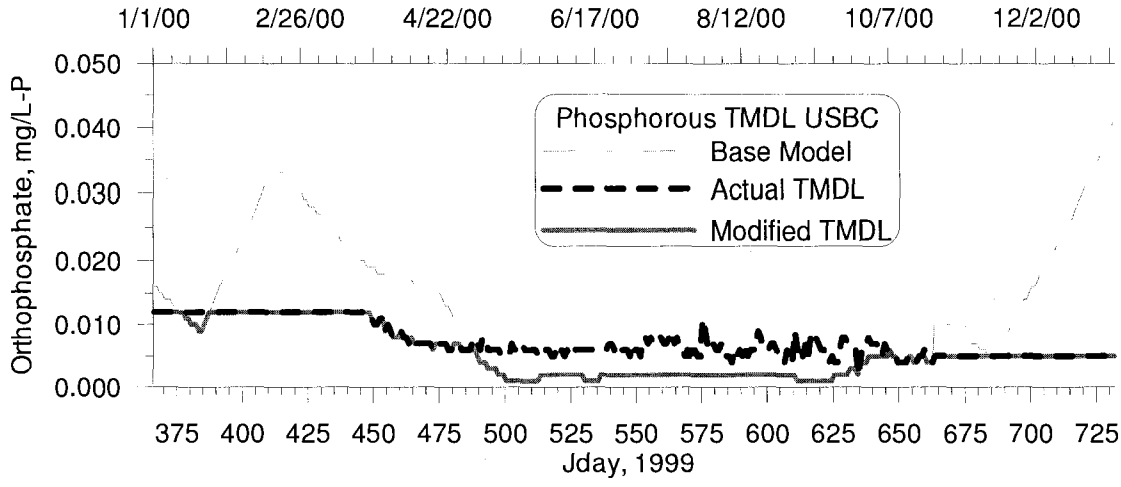

Figure 98. Comparison of model and proposed TMDL model upstream boundary condition for phosphorous.

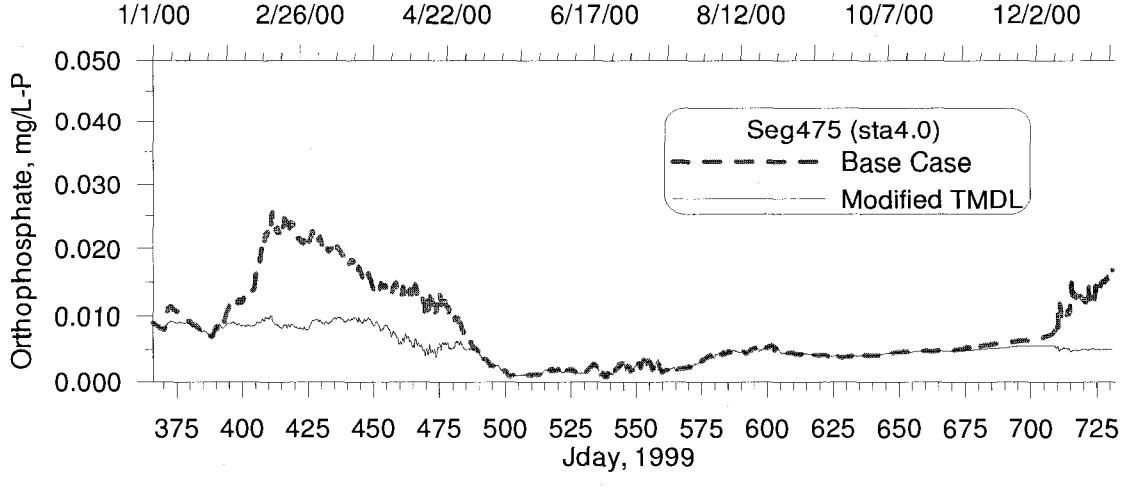

Figure 99. Comparison of Porcupine Bay orthophosphate levels between the base and modified TMDL scenarios.

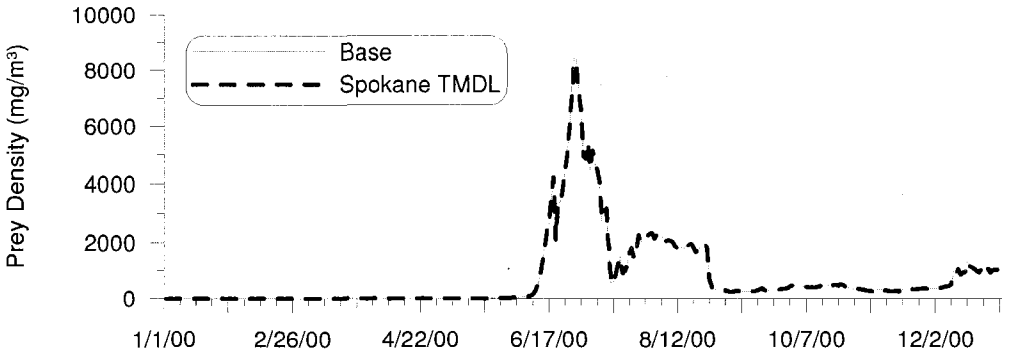

Figure 100. Comparison of Porcupine Bay prey densities between the base and modified TMDL scenarios.

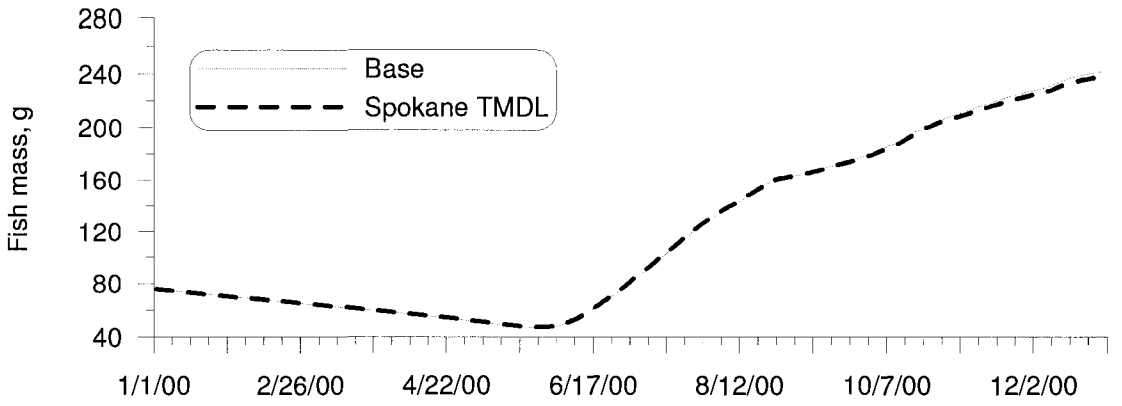

Figure 101. Comparison of Porcupine Bay predicted fish mass between the base and modified TMDL scenarios.

Conclusions

While the model shows that kokanee growth potential is positive, and kokanee are known to grow in the reservoir, the model also shows that growth is seasonally limited by both the food supply and the water temperature. Outside of the spring and summer zooplankton bloom, the zooplankton density does not appear to be high enough to maintain fish mass; the algae-zooplankton population appears to be phosphorous limited. While fish diet studies show a shift from Daphnia to copepoda during the winter, winter copepoda densities are similar to cladocera densities. Lake Roosevelt is also marked by sparse zoobenthos, with even nominally obligate benthivores taking in considerable pelagic food (Underwood, et al., 2004).

Simulations of higher input phosphorous resulted in higher algae and zooplankton densities, which in turn resulted in greater fish growth potential. However, during fall turnover, the warm water mixes and removes much of the lake's cold water refugia, although some colder water appears to remain in the lower reaches. Data are lacking regarding the use of this very deep water during the fall by young and/or adult kokanee. During fall turnover, the fish growth potential is still temperature limited under the increased prey densities. Actual fish foraging strategies not modeled may be able to address this difficulty. Possible strategies include finding suitable littoral sites not captured by the model or small, localized thermal refugia.

During the late summer, as surface waters heat up, the kokanee appear avoid water temperatures above 15 to 16 °C. Some success was made using a vertical foraging approach of foraging in warmer, food rich waters for a time-step followed by moving to colder, deeper waters to take advantage of the lower respiration costs. This behavior has been observed in other reservoir systems.

The impoundment created by Grand Coulee Dam has a limited impact on peak temperatures (1 to 2 °C), but does extend the period when the fish target temperature of 16 °C is exceeded by roughly a month (Underwood, et al., 2004). Alternative reservoir operations are unlikely to significantly influence peak pelagic water temperatures.

Apart from the temperature and prey density limitations, other factors also contribute to a poor kokanee fishery. Entrainment during high flow years appears to significantly deplete the population. Walleye predation is likely a major source of poor recruitment of hatchery released fish. Wild kokanee are limited by limited spawning areas that are not adversely impacted by the annual desiccation as part of the spring flood control operations.

An important function of the project is system diagnosis. The model underpredicts annual growth by roughly 50%. While this is not outside of the literature range of +/- 10 to 50 % (Ney, 1993), the magnitude of the underprediction suggests the possibility

of improvement. Is the underprediction a model simplification, misparameterization, or omission of an important process or foraging strategy? This issue should guide future refinement of the coupled model and suggest avenues of data collection and study.

An investigation into the actual spatial and temporal distribution of kokanee would be fruitful. A study of diel movement, preferential spatial locations by fish age, and seasonal migrations would help support model and biological behavioral observations. Kokanee are anecdotally known to prefer the area upstream of Grand Coulee Dam, but not necessarily the deeper, colder water. The model predicts that the upper 20 m of the lower third of the reservoir, to include the Spokane and Sanpoil River arms, has the highest density prey concentration. Also, reasonably high prey densities exist just below the weak thermocline and temperatures avoided by modeled kokanee. This suggest that there is a favorable mix of food and temperature in the lower third of the reservoir, and also explains the anecdotal foraging depths. The model also suggests that there are seasonal shifts in favorable foraging locations, especially from the Spokane to Columbia Rivers.

Calibration of a W2 reservoir model for a low flow year could provide insights into the relative importance of flow on water temperature, zooplankton densities, fish growth potential and their spatial and temporal distributions. While entrainment likely

plays a factor in the low kokanee recruitment in high flows years, it is unclear if other factors are influencing recruitment as well.

While Grand Coulee Dam significantly influences the system biology through impoundment and flood control operations, pelagic fish growth potential does not appear to be sensitive to changes in reservoir operation. Only dramatic scenarios, which were not examined, would have a large effect (for example, a scenario of no flood control operation; or selective withdrawal to control water temperature). However, factors other than pelagic growth potential may be sensitive to reservoir operations.

The W2 model shows that the water quality conditions in Lake Roosevelt are largely a reflection of the upstream boundary conditions. Within the mainstem, the system is predominantly plug flow. The relative simplicity of the abiotic system lends itself to reasonably accurate analysis using less model complexity. For example, topographic shading has a very minor effect on water temperatures due to the width of the system, whereas the effect of wind is a dominant temperature forcing function.

While the abiotic system is relatively simple, the biotic system requires greater abiotic system complexity to allow the biotic compartments to interact properly. For example, the vertical distribution of temperature and nutrients effects the distribution of algae and hence zooplankton, which in turn effects the fish growth potential. For

interpolation, simpler models may produce adequate predictions; however, for extrapolations—or examinations of conditions other than those seen in the data sets—more complex physically determinant models should be employed.

Future Work

Three major areas of future work can be considered. The first is the application of the existing framework to other systems. The ability to examine the interaction of hydrodynamics and prey distributions would be ideally suited to a system with stronger thermal stratification. For example, Blue Mesa Reservoir, Colorado, has been well-studied (Hardiman, et al., 2004; Stockwell and Johnson, 1999; and others) and shows a stronger stratification, but still contains kokanee.

A second conceptual improvement would to allow greater interaction between the fish compartment and the ambient water quality. The interaction among trophic layers—both predator prey and nutrient recycling—has been demonstrated to be significant for some systems (He, et al., 1993; Schindler, et al., 1993; Kraft, 1993). For large detention time lakes, nutrient recycling is critically important to primary production and food web interactions. Heretofore, these systems have not been examined considering a dynamic food web and ambient lake system.

A third conceptual improvement would be the integration of the "particle tracking" work (Goodwin, et al., 2001; Goodwin, et al., 2006; Nestler, et al., 2005) where discrete fish are allowed to move dynamically. Each fish "particle" is allowed to response to sensory inputs within range of its sensory ovoid according to response functions. This approach has been used to successfully model diel migrations in

response to prey distributions and to respond to seasonal changes in thermal structure. Versions have been integrated into the CE-QUAL-W2 code.

Summary

The coupling of water quality and bioenergetics models allows investigations that each model alone would be unable to address. The bioenergetic component allows for quantification of the operational impacts on fish growth. The hydrodynamic and water quality model allows for predictions of food availability and the ambient environment. The understanding of hydrodynamics, water quality, and the food web interactions is an important tool in managing the Lake Roosevelt fisheries.

The goal of this project is to couple the physically based hydrodynamic and water-quality model CE-QUAL-W2, v3.2, with a fish bio-energetics model, based on the general Stockwell & Johnson (1997, 1999) framework, and apply the coupled model to the Lake Roosevelt system to understand better how the spatial and temporal variability affect the food web and provide a new tool for fisheries management. This project has accomplished the following:

1) Generation of a CE-QUAL-W2 model for Lake Roosevelt.
2) Calibration the model for hydrodynamics, temperature, and water quality.
3) Documentation of model inputs and calibration.
4) Review of bioenergetics model approaches.
5) Incorporation of a Stockwell & Johnson based fish bioenergetics model.

6) Calibration of the bioenergetics model & refinement of the bioenergetics formulations to meet system specific considerations.
7) Application of the coupled model to diagnostic scenarios.
8) Application of the coupled model to management scenarios.
9) Suggestions for future work and model improvements

Analyses show that kokanee growth potential is seasonally limited by both water temperature and food supply. The zooplankton population is phosphorous limited. Fish growth potential was positive and the spatial distribution of positive growth areas agree with anecdotal fish distribution data.

While Grand Coulee Dam has an impact on peak maximum temperatures and extends the warm water into the fall roughly one month, alternative reservoir operations are unlikely to significantly influence peak pelagic water temperatures and pelagic fish growth potential.

The underprediction of fish growth should be used to further investigate system dynamics and model formulation and parameterization. Calibration of a W2 reservoir model for a low flow year could provide insights into the relative importance of flow on water temperature, zooplankton densities, fish growth potential and their spatial and temporal distributions.

Future work could include applications of the developed framework to different systems, addition of full water quality feedback from the fish compartment (which would be important in long residence time and nutrient poor systems), and incorporation of fish bioenergetics modeling into the discrete fish particle approach (Goodwin, et al., 2001; Goodwin, et al., 2006; Nestler, et al., 2005).

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Appendices:

Appendix A: Fish Bioenergetics FORTRAN routine

```
! PROGRAM BIOENERGETICS
! MIKE MCKILLIP (2006)
! STOCKWELL AND JOHNSON APPROACH, AS SUGGESTED BY MAZUR AND BEAUCHAMP
! STAND ALONE PROGRAM FOR TESTING MODULES TO BE INCORPORATED WITH THE W2 CODE

!************************************
!   TASK B.1. MODULE DECLARATION
!************************************
MODULE MAINW2 ! REPETIION OF W2-CODE VARIABLES
 REAL*8,             ALLOCATABLE, DIMENSION (:,:)     :: DEPTHM,T1,GAMMA,BH,EL
 REAL*8,             ALLOCATABLE, DIMENSION (:,:,:)   :: C2
 REAL JDAY,JEND !BIOF = FREQUENCY OF BIOEXP OUTPUT
 REAL FBIONXT ! NEXT DAY TO GET CALCULATION INPUTS
 INTEGER,            ALLOCATABLE, DIMENSION(:)        :: BIOINFN
 INTEGER,            ALLOCATABLE, DIMENSION(:)        :: KTI,KBI
 INTEGER KMX, IMX,NUNIT,NZP,K,I,DLT,JI,NWB
 INTEGER NCT,JZ,NZOOS,NZOOE,NOD
 CHARACTER*72,       ALLOCATABLE, DIMENSION(:)        :: BIOINNAME
 CHARACTER*72 FRED,SEGNUM
END MODULE MAINW2
MODULE ROOSEVELT !THIS MODULE TAKEN FROM W2-ROOSEVELT; ALLOWs THE W2_ANC_CON.NPT TO BE READ
  INTEGER,           ALLOCATABLE, DIMENSION(:)        :: IBIO,BIODP,BIOEXPFN
  REAL*8,            ALLOCATABLE, DIMENSION(:)        :: BIOD, BIOF
  INTEGER,           ALLOCATABLE, DIMENSION(:,:)      :: NVIOL_LOC
  CHARACTER*8 NVIOLC, BIOC
  LOGICAL BIOEXP
  INTEGER NBIO,NIBIO
  REAL*8 NXBIO,NXTBIO,GAMMAB
  CHARACTER*72 BIOFN,WEIGHTFN
END MODULE ROOSEVELT
MODULE FISH ! FOR FISH BIOENERGETICS ROUTINE (DIRECT INCLUSION)
 REAL*8,             ALLOCATABLE, DIMENSION(:)        :: EZOO,LZOO,MZOO,FTL,F1I
 REAL*8,             ALLOCATABLE, DIMENSION(:,:)      :: FCON,FVEL,FACT,GAMMAFDC,FVELAVE,FACTAVE
 REAL*8,             ALLOCATABLE, DIMENSION(:,:,:)    :: F1
 REAL*8,             ALLOCATABLE, DIMENSION(:,:)      :: F2,AVEC,MINC,MAXC
 REAL*8,             ALLOCATABLE, DIMENSION(:,:)      :: F_F,F_U,F_D,F_R,F_S,F_C,F_G,F_W ! UNITS OF J
(DAILY SCALE)
 REAL*8,             ALLOCATABLE, DIMENSION(:,:)      :: F_G2
 REAL*8,             ALLOCATABLE, DIMENSION(:,:)      :: F_DINI,F_DCON,F_DUNDIG
 REAL*8,             ALLOCATABLE, DIMENSION(:,:)      :: DAYC,SRCHVOL,RDZ
```

```
 REAL*8,              ALLOCATABLE, DIMENSION(:,:,:)    :: C1Z
 REAL*8,              ALLOCATABLE, DIMENSION(:,:)      :: F_FC,F_UC,F_DC,F_RC,F_SC,F_CC ! UNITS OF J
(TIME-STEP SCALE)
  REAL*8,              ALLOCATABLE, DIMENSION(:)        :: ZAVAIL, ZAVAILNX,CEFF,Z1Z,L1Z,CELL_PER
 REAL*8,              ALLOCATABLE, DIMENSION(:,:)      :: T1Z
 REAL*8,              ALLOCATABLE, DIMENSION(:,:)      :: FCONMAXGG,FCONGG,FCONMAXJ,FCONJ,DAYCM,FCONP
 REAL*8,              ALLOCATABLE, DIMENSION(:)        :: T1BZ
 REAL NXTFISH,NXTFOPT,FG1,FG2,FKA,FKB,FL1,FL2,DIGK,JUNK, FDLTM,FDLTH,FOXYCAL
 REAL FISHT1,FISHT2,FISHT3,FISHT4,FISHK1,FISHK2,FISHK3,FISHK4 ! TEMPERATURE RATE TERMS
 REAL FJDAYNXT,HANDLE,FVELA,FVELB,FVELE,THRESHV,DAP_IN,JAVAIL,FGPD,FGPF
 REAL FBIODAYNXT,FBIOSUBNXT,FBIODAYLST,ZAVJD,ZAVNX
 REAL GIM, BIM, DIM, GALP, BALP, DALP, GTI, BTI, DTI
 REAL F1M,F1J,WILMA1,WILMA2
 INTEGER,             ALLOCATABLE, DIMENSION (:)       :: ZDEPTH,DATA_FILENUM,BIOOUTFN, CELL_POS,
CELL_NEG,FGPFN
 INTEGER,             ALLOCATABLE, DIMENSION (:,:)     :: FULLSTO
 INTEGER,             ALLOCATABLE, DIMENSION (:)       :: KBIP
 INTEGER CUR_FJDAY, FJDAYINT,ZHOLDNUM,DIAGLOGFN, JJZ,FOPTNUM,THRESHZ,ZAVFN,BIOCON,NUMSTEPS,FUF
 CHARACTER*72,        ALLOCATABLE, DIMENSION(:)        :: BIOOUTNAME,FGPFNAME
 INTEGER FXNFN(3)
 CHARACTER*72 ZAVFNAME
 CHARACTER*8 FHEAD(30),FUNIT(20),FCALC,FGPC,CMAXC
 CHARACTER*8 GENMTP,BESTMTP,DIELMTP
 CHARACTER*72 FXNFNAME(3)
 LOGICAL,             ALLOCATABLE, DIMENSION(:)        :: FIRST_BIO,THRESHFEED
 LOGICAL SAMEDAY,FIRSTLIGHT,FIRST_OUTPUT,DAILY_FISH_OPT,BIOSUB_CALC, BIODAY_CALC
 LOGICAL HAPPY, NEWDAY,FBIOCALC,FGPPLOT,FISHCALC,THRESHOLD,CMAXCALC
 LOGICAL
GMTPCELL,GMTPFXN,GMTPUSER,GMTPFIXED,BMTPSEG,BMTPFXN,BMTPUSER,BMTPFIXED,DMTPSEG,DMTPFXN,DMTPUSER,DMTP
FIXED
 LOGICAL GMTOK,BMTOK,DMTOK
END MODULE FISH
MODULE FISH2 ! FOR USE WITH THIS PROGRAM; WILL NEED TO BE ALTERED FOR INCORPORATION WITH W2-CODE
 REAL LUX, LUX1, LUX2 ! TEMPORARY LIGHT DATA TERMS
 REAL LJDAY1,LJDAY2
 INTEGER LIGHTNUM
END MODULE FISH2
MODULE BIOEXPDATATRANSFORM ! FOR CONVERTING THE BIOEXP DATA OUTPUT INTO W2 ARRAYS AND VARIABLES
 REAL ZDAY1,ZDAY2
 INTEGER FIRSTK,LASTK,SEGK,GRCT
```

```
 CHARACTER*20 GREGORY(1000)
 LOGICAL,            ALLOCATABLE, DIMENSION(:)       :: FIRSTREAD
END MODULE BIOEXPDATATRANSFORM
MODULE GROWTH_ANIMATION
 INTEGER ANIMFN,ANIMFN2,ZONECNT,ZONEFIRST,NNODE,NELEM
 CHARACTER*52 HEADER1,HEADER2
 REAL LEFT(999), RIGHT(999)
 REAL*8,             ALLOCATABLE, DIMENSION(:)       :: DISTL,DISTR,BOTTOME
 REAL*8,             ALLOCATABLE, DIMENSION(:,:)     :: GELEV,X1,X2,X3,X4,Y1,Y2,Y3,Y4
 REAL    VLL,VLR
 INTEGER,            ALLOCATABLE, DIMENSION(:)       :: BOTSEG
 LOGICAL,            ALLOCATABLE, DIMENSION(:)       :: ANIMEXP
END MODULE GROWTH_ANIMATION
MODULE DIAGNOSTIC
 REAL*8,             ALLOCATABLE, DIMENSION(:,:,:)   :: DIET
 REAL*8,             ALLOCATABLE, DIMENSION(:,:)     :: VISIBLE
 REAL*8,             ALLOCATABLE, DIMENSION(:)       :: MAXG,MAXM
 INTEGER BYSEGMFN,BYSEGGFN,BYSEGMFN2,BYSEGGFN2,BYSEGMFN3,BYSEGGFN3,SURFSEGMFN,SURFSEGGFN
 INTEGER TLCALCFN
 CHARACTER*8 FDIAGC,THRESHC,SURFC,TLC
 LOGICAL FDIAG,BYSEG,SURFDIAG
 REAL*8,             ALLOCATABLE, DIMENSION(:)       :: MF_GI,MF_RI,MF_DI,MF_CI,MF_WI,MF_SI
 CHARACTER*8 FISHC, BIOPARC, CONSC, DIGC, RESPC,SINGLEC
 LOGICAL FISHDIAG, BIOPARDIAG, CONSDIAG, DIGDIAG, RESPDIAG,SINGLEDIAG,TLCALC
 INTEGER SINGFN, SINIBIO
END MODULE DIAGNOSTIC
MODULE MOVEMENT
 REAL*8,             ALLOCATABLE, DIMENSION(:,:)     :: BFCON,BFVEL,BFACT
 REAL*8,             ALLOCATABLE, DIMENSION(:)       :: BFVELAVE,BFACTAVE
 REAL*8,             ALLOCATABLE, DIMENSION(:,:)     :: DFCON,DFVEL,DFACT
 REAL*8,             ALLOCATABLE, DIMENSION(:)       :: DFVELAVE,DFACTAVE
 REAL*8,             ALLOCATABLE, DIMENSION(:,:,:)   :: BF1, DF1,BDIET, DDIET
 REAL*8,             ALLOCATABLE, DIMENSION(:,:)     :: BF_F,BF_U,BF_D,BF_R,BF_S,BF_C,BF_G,BF_W
 REAL*8,             ALLOCATABLE, DIMENSION(:,:)     :: DF_F,DF_U,DF_D,DF_R,DF_S,DF_C,DF_G,DF_W
 REAL*8,             ALLOCATABLE, DIMENSION(:,:)     :: BF_FC,BF_UC,BF_DC,BF_RC,BF_SC,BF_CC
 REAL*8,             ALLOCATABLE, DIMENSION(:,:)     :: DF_FC,DF_UC,DF_DC,DF_RC,DF_SC,DF_CC
 REAL*8,             ALLOCATABLE, DIMENSION(:)       ::
BF_GI,BF_RI,BF_DI,BF_CI,BF_WI,BF_SI,BF_UI,BF_FI
 REAL*8,             ALLOCATABLE, DIMENSION(:)       ::
DF_GI,DF_RI,DF_DI,DF_CI,DF_WI,DF_SI,DF_UI,DF_FI
```

```
 REAL*8,              ALLOCATABLE, DIMENSION(:,:)      :: BDAYC,BSRCHVOL,BRDZ
 REAL*8,              ALLOCATABLE, DIMENSION(:,:)      :: DDAYC,DSRCHVOL,DRDZ
 REAL*8,              ALLOCATABLE, DIMENSION(:)        :: BCELL_PER,DCELL_PER
 REAL*8,              ALLOCATABLE, DIMENSION(:)        :: BESTG,TEPI,THYPO
 REAL*8,              ALLOCATABLE, DIMENSION(:,:)      ::
BFCONMAXGG,BFCONGG,BFCONMAXJ,BFCONJ,BDAYCM,BFCONP
 REAL*8,              ALLOCATABLE, DIMENSION(:,:)      ::
DFCONMAXGG,DFCONGG,DFCONMAXJ,DFCONJ,DDAYCM,DFCONP
 REAL*8,              ALLOCATABLE, DIMENSION(:)        :: BAVEC,BMINC,BMAXC
 REAL*8,              ALLOCATABLE, DIMENSION(:)        :: DAVEC,DMINC,DMAXC
 REAL*8,              ALLOCATABLE, DIMENSION(:)        ::
BFCONMAXJI,BFCONMAXGGI,BFCONI,BFCONPI,BFDAYCI,BFDAYCMI,BFCONJI,BFCONGGI
 REAL*8,              ALLOCATABLE, DIMENSION(:)        ::
DFCONMAXJI,DFCONMAXGGI,DFCONI,DFCONPI,DFDAYCI,DFDAYCMI,DFCONJI,DFCONGGI
 REAL*8,              ALLOCATABLE, DIMENSION(:)        :: BDAYCI,BDAYCMI
 REAL*8,              ALLOCATABLE, DIMENSION(:)        :: DDAYCI,DDAYCMI
 REAL*8,              ALLOCATABLE, DIMENSION(:,:)      :: BF_DC_EXT,BF_G_EXT
 REAL*8,              ALLOCATABLE, DIMENSION(:,:)      :: DF_DC_EXT,DF_G_EXT
 REAL GMAXG,DIELLUX,DIELG,DIELS,RMIN,CMAX
 INTEGER,             ALLOCATABLE, DIMENSION(:)        :: BCELL_POS,BCELL_NEG,BFULLSTOI
 INTEGER,             ALLOCATABLE, DIMENSION(:)        :: DCELL_POS,DCELL_NEG,DFULLSTOI
 INTEGER,             ALLOCATABLE, DIMENSION(:,:)      :: BESTK,DIELK,BFULLSTO,DFULLSTO
 INTEGER GMAXK, BESTSTEP,KDIEL,RMINK,CMAXK,KBEST
 CHARACTER*8 BESTC,DIELC,DEPTHC
 LOGICAL BESTCALC,DIELCALC,DIELDEEP,DAYLIGHT,DEPTHCALC
 REAL*8,              ALLOCATABLE, DIMENSION(:)        :: BVISIBLE,DVISIBLE
 REAL*8,              ALLOCATABLE, DIMENSION(:,:)      :: BDIETI,DDIETI
 INTEGER BESTDIAGFN
 LOGICAL,             ALLOCATABLE, DIMENSION(:)        :: FORAY
END MODULE MOVEMENT

!*************************************
!   TASK B.2.0 MAIN PROGRAM DECLARATIONS
!*************************************
PROGRAM BIOENERGETICS
USE MAINW2; USE FISH; USE FISH2;USE BIOEXPDATATRANSFORM; USE GROWTH_ANIMATION; USE DIAGNOSTIC; USE
ROOSEVELT; USE MOVEMENT
!****TEMPORARY FILES
OPEN(999,FILE='TEMP.DAT',STATUS='UNKNOWN')
OPEN(998,FILE='TEMP2.DAT',STATUS='UNKNOWN')
```

```
!****VARIABLE/ ARRAY ALLOCATION & INITIAL VALUES*****
NOD = 100
! ROOSEVELT
  OPEN (12,FILE='W2_CON_ANC.NPT',STATUS='OLD')
  DO II = 1,16
    READ(12,'(A8)') BIOC
  END DO
  ALLOCATE (BIOD(NOD), BIOF(NOD),BIODP(NOD))
  ! BIOENERGETICS OUTPUT CARDS
  READ(12,'(//(8X,A8,2I8))') BIOC,NBIO,NIBIO
  ALLOCATE (BIOEXPFN(NIBIO),IBIO(NIBIO))
  ROO2 = 0.0; C2W = 0.0
  READ(12,'(//(:8X,9F8.0))') (BIOD(II),II=1,NBIO)
  READ(12,'(//(:8X,9F8.0))') (BIOF(II),II=1,NBIO)
  READ(12,'(//(:8X,9I8))') (IBIO(II),II=1,NIBIO)
  READ(12,'(//(8X,A72))') BIOFN
  CLOSE(12)
! END ROOSEVELT
! MAINW2
IMX = 583; KMX = 76;NUNIT = 100; NWB = 1; FBIONXT = 366.5
JDAY = 366.0; JEND = 400.5; DLT = 1; NCT = 22; NZOOS = 20; NZOOE = 22; NZP = 3
ALLOCATE(DEPTHM(KMX,IMX),T1(KMX,IMX),GAMMA(KMX,IMX),BH(KMX,IMX),EL(KMX,IMX))
ALLOCATE(C2(KMX,IMX,NCT),KTI(IMX),KBI(IMX))
ALLOCATE(BIOINNAME(NIBIO), BIOINFN(NIBIO)) ! ULTIMATELY, IMX (& NEW VARIABLE)
! FISH
ALLOCATE (BIOOUTFN(NIBIO),EZOO(NZP),LZOO(NZP),MZOO(NZP))
ALLOCATE (BIOOUTNAME(NIBIO),FCON(KMX,IMX),FVEL(KMX,IMX),FACT(KMX,IMX),F1I(3))
ALLOCATE (F1(KMX,IMX,5)) ! 1 = MASS; 2 = LENGTH; 3 = STOMACH CONTENT; 4 = ENERGY DENSITY OF FISH; 5
= STOMACH CAPACITY
ALLOCATE (FTL(KMX),SRCHVOL(KMX,IMX),RDZ(KMX,IMX),F2(KMX,IMX))
ALLOCATE (CELL_POS(IMX), CELL_NEG(IMX),CELL_PER(IMX),FULLSTO(KMX,IMX))
ALLOCATE (F_F(KMX,IMX),F_U(KMX,IMX),F_D(KMX,IMX),F_R(KMX,IMX),F_S(KMX,IMX),F_C(KMX,IMX))
ALLOCATE (F_G(KMX,IMX),F_W(KMX,IMX),DAYC(KMX,IMX))
ALLOCATE (F_FC(KMX,IMX),F_UC(KMX,IMX),F_DC(KMX,IMX),F_RC(KMX,IMX),F_SC(KMX,IMX),F_CC(KMX,IMX))
ALLOCATE (T1Z(KMX,IMX),C1Z(KMX,IMX,NZP),Z1Z(KMX),L1Z(KMX),ZDEPTH(KMX))
ALLOCATE (FIRST_BIO(NIBIO),GAMMAFDC(KMX,IMX))
ALLOCATE (ZAVAIL(NZP),ZAVAILNX(NZP),CEFF(KMX))
ALLOCATE (FGPFN(NWB),FGPFNAME(NWB),GELEV(KMX,IMX),DISTL(IMX),DISTR(IMX))
ALLOCATE (X1(KMX,IMX),X2(KMX,IMX),X3(KMX,IMX),X4(KMX,IMX))
```

```
ALLOCATE (Y1(KMX,IMX),Y2(KMX,IMX),Y3(KMX,IMX),Y4(KMX,IMX))
ALLOCATE (DIET(KMX,IMX,NZP),THRESHFEED(KMX),VISIBLE(KMX,IMX))
ALLOCATE (ANIMEXP(NIBIO),BOTSEG(IMX),BOTTOME(IMX))
ALLOCATE (MAXG(IMX),MAXM(IMX),KBIP(IMX))
ALLOCATE (FCONMAXGG(KMX,IMX),FCONGG(KMX,IMX),FCONMAXJ(KMX,IMX),FCONJ(KMX,IMX),FCONP(KMX,IMX))
ALLOCATE (F_DINI(KMX,IMX),F_DCON(KMX,IMX),F_DUNDIG(KMX,IMX),DAYCM(KMX,IMX))
ALLOCATE (FVELAVE(KMX,IMX),FACTAVE(KMX,IMX))
ALLOCATE (AVEC(KMX,IMX),MINC(KMX,IMX),MAXC(KMX,IMX))
ALLOCATE (F_G2(KMX,IMX))
!IF(SINGLEDIAG) THEN
  ALLOCATE (MF_GI(KMX),MF_RI(KMX),MF_DI(KMX),MF_CI(KMX),MF_WI(KMX),MF_SI(KMX))
  MF_GI = 0.0;MF_RI = 0.0;MF_DI = 0.0;MF_CI = 0.0;MF_WI = 0.0;MF_SI = 0.0
!END IF
TLCALC = .FALSE.
F1(:,:,4) = 5821.9*4.1868 ; F1(:,:,5) = 3.64 ; FCON = 0.0
F_R  = 0.0; F_D  = 0.0; F_C  = 0.0; F_F  = 0.0; F_U  = 0.0; F_S  = 0.0; F_G = 0.0; F_W = 0.0
F_RC = 0.0; F_DC = 0.0; F_CC = 0.0; F_FC = 0.0; F_UC = 0.0; F_SC = 0.0
F_DINI = 0.0; F_DCON = 0.0; F_DUNDIG = 0.0; DAYCM = 0.0
AVEC = 0.0; MINC = 0.0; MAXC = 0.0
FVELAVE = 0.0; FACTAVE = 0.0
KBIP = 1
FBIOSUBNXT = 366.0; FBIODAYNXT = 367.0; FBIODAYLST = 366.0
CELL_POS = 0; CELL_NEG = 0; DAYC = 0.0; CELL_PER = 0.0; FULLSTO = 0
DAP_IN = 0.0; RDZ = 0.08; GAMMAFDC = 0.0
FCONMAXGG = 0.0; FCONGG = 0.0; FCONMAXJ = 0.0; FCONJ = 0.0
BIOSUB_CALC  = .FALSE.; BIODAY_CALC    = .FALSE.;   HAPPY  = .TRUE. ; NEWDAY    = .TRUE.; FIRSTLIGHT
= .TRUE.
FIRST_OUTPUT = .TRUE. ; DAILY_FISH_OPT = .FALSE.; FBIOCALC = .FALSE.; FIRST_BIO = .TRUE.
GMTPCELL = .FALSE.;GMTPFXN   = .FALSE.;GMTPUSER = .FALSE.;GMTPFIXED = .FALSE.;BMTPSEG  =
.FALSE.;BMTPFXN   = .FALSE.
BMTPUSER = .FALSE.;BMTPFIXED = .FALSE.;DMTPSEG  = .FALSE.;DMTPFXN   = .FALSE.;DMTPUSER =
.FALSE.;DMTPFIXED = .FALSE.
GMTOK    = .FALSE.;BMTOK     = .FALSE.;DMTOK    = .FALSE.
SINGLEDIAG = .FALSE.;SURFDIAG = .FALSE.
FISHDIAG = .FALSE.; BIOPARDIAG = .FALSE.; CONSDIAG = .FALSE.; DIGDIAG = .FALSE.; RESPDIAG =
.FALSE.;SINGLEDIAG  = .FALSE.
 F_G2 = 0.0
! FISH2
LJDAY1 = 360.0; LJDAY2 = 361.0; LUX = 0.0 ! TEMPORARY SET UP VALUES
MAXG = -999.0; MAXM = -999.0; DIELDEEP = .TRUE.;CMAXCALC = .FALSE.
```

```
! BIOEXP
ALLOCATE (FIRSTREAD(NIBIO))
FIRSTREAD = .TRUE.
! GROWTH ANIMATION
 HEADER1 = 'TITLE ="Lake Roosevelt"'
 HEADER2 = 'VARIABLES = "Distance, km", "Elevation, m", "FGP"'
 GELEV = 0.0; DISTL = 0.0; DISTR = 0.0
 ZONECNT = 0 ; ZONEFIRST = INT(JDAY)
 DIET = 0.0 ; THRESHFEED = .FALSE.; VISIBLE = 0.0
OPEN(13,FILE='CHANNEL_BOT.OPT',STATUS='OLD')
READ(13,*) BESTC
DO I = 1,IMX
  READ(13,'(I10,50X,F10.0)',END=1199) BOTSEG(I),BOTTOME(I)
END DO
1199 CONTINUE
CALL GETFISHDATA
 FDLTM = FUF*1.0 ! IN MINUTES
 FDLTH = FDLTM/60.0; ZHOLDNUM = 4+NZP; NUMSTEPS = 1440/FUF
 GRCT = 1
 ANIMEXP = .TRUE.; ANIMEXP(12) = .FALSE.; ANIMEXP(21) = .FALSE.; ANIMEXP(24) = .FALSE.
! BYSEG
BYSEG = .TRUE.
! MOVEMENT
IF(BESTCALC) THEN
 ALLOCATE (BFCON(KMX,IMX),BFVEL(KMX,IMX),BFACT(KMX,IMX),BF1(KMX,IMX,5))
 ALLOCATE (BF_F(KMX,IMX),BF_U(KMX,IMX),BF_D(KMX,IMX),BF_R(KMX,IMX),BF_S(KMX,IMX),BF_C(KMX,IMX))
 ALLOCATE (BF_G(KMX,IMX),BF_W(KMX,IMX),BDAYC(KMX,IMX),BDAYCM(KMX,IMX))
 ALLOCATE
(BF_FC(KMX,IMX),BF_UC(KMX,IMX),BF_DC(KMX,IMX),BF_RC(KMX,IMX),BF_SC(KMX,IMX),BF_CC(KMX,IMX))
 ALLOCATE (BSRCHVOL(KMX,IMX),BRDZ(KMX,IMX))
 ALLOCATE (BCELL_POS(IMX),BCELL_NEG(IMX),BCELL_PER(IMX))
 ALLOCATE (BESTK(IMX,NUMSTEPS+1),BESTG(IMX))
 ALLOCATE (BDIETI(IMX,NZP),BDIET(KMX,IMX,NZP))
 ALLOCATE (BF_GI(IMX),BF_RI(IMX),BF_DI(IMX),BF_CI(IMX),BF_WI(IMX),BF_SI(IMX),BF_UI(IMX),BF_FI(IMX))
 ALLOCATE (BFCONMAXGG(KMX,IMX),BFCONGG(KMX,IMX),BFCONMAXJ(KMX,IMX),BFCONJ(KMX,IMX),BFCONP(KMX,IMX))
 ALLOCATE (BFULLSTO(KMX,IMX),BFULLSTOI(IMX),BVISIBLE(IMX))
 ALLOCATE (BFVELAVE(IMX),BFACTAVE(IMX))
 ALLOCATE (BAVEC(IMX),BMINC(IMX),BMAXC(IMX))
```

```
 ALLOCATE
(BFCONMAXJI(IMX),BFCONMAXGGI(IMX),BFCONI(IMX),BFCONPI(IMX),BFDAYCI(IMX),BFDAYCMI(IMX),BFCONGGI(IMX),
BFCONJI(IMX))
 ALLOCATE (BDAYCI(IMX),BDAYCMI(IMX))
 ALLOCATE (BF_DC_EXT(KMX,IMX),BF_G_EXT(KMX,IMX))
 ALLOCATE (T1BZ(IMX))
 BFCON = 0.0  ;BF1 = F1; BDAYC = 0.0; BFULLSTO = 0; BFULLSTOI = 0
 BCELL_POS = 0; BCELL_POS = 0; BESTSTEP = 0
 BVISIBLE = 0.0; BDIET = 0.0; BESTK = 0
 BF_F = 0.0 ;BF_U = 0.0 ;BF_D = 0.0 ;BF_R = 0.0 ;BF_S = 0.0 ;BF_C = 0.0 ;BF_G = 0.0 ;BF_W = 0.0
 BF_FC = 0.0;BF_UC = 0.0;BF_DC = 0.0;BF_RC = 0.0;BF_SC = 0.0;BF_CC = 0.0
 BF_GI = 0.0;BF_RI = 0.0;BF_DI = 0.0;BF_CI = 0.0;BF_WI = 0.0;BF_SI = 0.0; BF_UI = 0.0; BF_FI = 0.0
 BFVELAVE = 0.0; BFACTAVE = 0.0
 BAVEC = 0.0; BMINC = 0.0; BMAXC = 0.0
 BFCONMAXJI = 0.0; BFCONMAXGGI = 0.0; BFCONI = 0.0; BDAYCI = 0.0; BDAYCMI = 0.0; BFCONPI = 0.0;
BFCONJI = 0.0; BFCONGGI = 0.0
 BF_DC_EXT = 0.0;BF_G_EXT =0.0
 T1BZ = 0.0
END IF
IF(DIELCALC) THEN
 ALLOCATE(DFCON(KMX,IMX),DFVEL(KMX,IMX),DFACT(KMX,IMX),DF1(KMX,IMX,5))
 ALLOCATE (DF_F(KMX,IMX),DF_U(KMX,IMX),DF_D(KMX,IMX),DF_R(KMX,IMX),DF_S(KMX,IMX),DF_C(KMX,IMX))
 ALLOCATE (DF_G(KMX,IMX),DF_W(KMX,IMX),DDAYC(KMX,IMX),DDAYCM(KMX,IMX))
 ALLOCATE
(DF_FC(KMX,IMX),DF_UC(KMX,IMX),DF_DC(KMX,IMX),DF_RC(KMX,IMX),DF_SC(KMX,IMX),DF_CC(KMX,IMX))
 ALLOCATE (DSRCHVOL(KMX,IMX),DRDZ(KMX,IMX))
 ALLOCATE (DCELL_POS(IMX),DCELL_NEG(IMX),DCELL_PER(IMX))
 ALLOCATE (DIELK(IMX,NUMSTEPS+1),TEPI(IMX),THYPO(IMX))
 ALLOCATE (DF_GI(IMX),DF_RI(IMX),DF_DI(IMX),DF_CI(IMX),DF_WI(IMX),DF_SI(IMX),DF_UI(IMX),DF_FI(IMX))
 ALLOCATE (DFVELAVE(IMX),DFACTAVE(IMX),DVISIBLE(IMX))
 ALLOCATE (DAVEC(IMX),DMINC(IMX),DMAXC(IMX))
 ALLOCATE
(DFCONMAXJI(IMX),DFCONMAXGGI(IMX),DFCONI(IMX),DFCONPI(IMX),DFDAYCI(IMX),DFDAYCMI(IMX),DFCONGGI(IMX),
DFCONJI(IMX))
 ALLOCATE (DDAYCI(IMX),DDAYCMI(IMX))
 ALLOCATE (DF_DC_EXT(KMX,IMX),DF_G_EXT(KMX,IMX))
 ALLOCATE (DFCONMAXGG(KMX,IMX),DFCONGG(KMX,IMX),DFCONMAXJ(KMX,IMX),DFCONJ(KMX,IMX),DFCONP(KMX,IMX))
 ALLOCATE (DDIETI(IMX,NZP),DDIET(KMX,IMX,NZP),DFULLSTO(KMX,IMX),DFULLSTOI(IMX))
 ALLOCATE (FORAY(IMX))
 DFCON = 0.0  ;DF1 = F1; DDAYC = 0.0; DFULLSTO = 0; DFULLSTOI = 0
```

```
 DCELL_POS = 0; DCELL_POS = 0; DIELK = 0
 DF_F = 0.0 ;DF_U = 0.0 ;DF_D = 0.0 ;DF_R = 0.0 ;DF_S = 0.0 ;DF_C = 0.0 ;DF_G = 0.0 ;DF_W = 0.0
 DF_FC = 0.0;DF_UC = 0.0;DF_DC = 0.0;DF_RC = 0.0;DF_SC = 0.0;DF_CC = 0.0
 DF_GI = 0.0;DF_RI = 0.0;DF_DI = 0.0;DF_CI = 0.0;DF_WI = 0.0;DF_SI = 0.0; DF_UI = 0.0; DF_FI = 0.0
 DFVELAVE = 0.0; DFACTAVE = 0.0
 DAVEC = 0.0; DMINC = 0.0; DMAXC = 0.0;DVISIBLE = 0
 DFCONMAXJI = 0.0; DFCONMAXGGI = 0.0; DFCONI = 0.0; DDAYCI = 0.0; DDAYCMI = 0.0; DFCONPI = 0.0;
DFCONJI = 0.0; DFCONGGI = 0.0
 DF_DC_EXT = 0.0;DF_G_EXT =0.0
 FORAY = .FALSE.
END IF

! ************************************************************************************
! *                              TASK B.2.1 FILE SET UP                              *
! ************************************************************************************
CALL INITIALFILESETUP
!*************************************
!   TASK B.2.1 PSEUDO W2-TIME CONTROL AND VARIABLE UPDATE
!*************************************
!   TASK B.2.1.1 PSEUDO W2 TIME ADVANCEMENT
2110 CONTINUE
GOTO 2111 ! BY PASS  FOR FIXED FISH TIMESTEPS
JDAY = JDAY + DLT/3600.0/24.0
! CHECK FOR END OF SIMULATION
IF(JDAY.GT.JEND) THEN
  GOTO 997
END IF
! CHECK FOR ROUTING TO SUB-DAILY CALCULATIONS
IF(JDAY.GE.FBIOSUBNXT) THEN
  FBIOSUBNXT = FBIOSUBNXT + 1.0/48.0
  BIOSUB_CALC = .TRUE.
  IF(JDAY.GE.FBIODAYNXT) THEN
    FBIODAYLST = FBIODAYNXT; FBIODAYNXT = FBIODAYNXT + 1.0
    BIODAY_CALC = .TRUE.
      NEWDAY = .TRUE.; GRCT = GRCT+1
  END IF
END IF
IF(BIOSUB_CALC) THEN
  CONTINUE
  ELSE
```

```
    GOTO 2110
END IF
2111 continue
JDAY = JDAY + 1.0/48.0
IF(JDAY.GT.JEND) THEN
  GOTO 997
END IF
IF(JDAY.GE.FBIOSUBNXT) THEN
  !JDAY = INT(JDAY)*1.0 +0.0
    FBIOSUBNXT = JDAY + 1.0/48.0
  !FBIOSUBNXT = INT(JDAY+1.0)*1.0 + 0.0
  BIOSUB_CALC = .TRUE.
  IF(JDAY.GE.FBIODAYNXT) THEN
    FBIODAYLST = FBIODAYNXT; FBIODAYNXT = FBIODAYNXT + 1.0
      JDAY = 1.0*INT(JDAY)
    BIODAY_CALC = .TRUE.
      NEWDAY = .TRUE.; GRCT = GRCT+1
  END IF
END IF

! ******ZOOPLANKTON AVAILABILITY UPDATE********
  IF(JDAY.GE.ZAVNX) THEN ! THIS UPDATE MUST OCCUR AFTER THE COMPUTATIONS IN W2 OR RISK AN END OF
FILE READ ERROR
    ZAVJD = ZAVNX; ZAVAIL = ZAVAILNX
      READ(ZAVFN,'(:F8.0,9F8.0)')  ZAVNX,(ZAVAILNX(II),II=1,NZP)
  END IF
!**************************************
!   TASK B.2.2 SUBDAILY CALCULATIONS
!**************************************
!   TASK B.2.2.1 GET UPDATED SOLAR INPUTS
IF(JDAY.LT.LJDAY1) LUX = LUX1
IF(JDAY.LE.LJDAY2) LUX = (LJDAY2-JDAY)/(LJDAY2-LJDAY1)*(LUX2-LUX1)

2200 CONTINUE
IF(JDAY.GE.LJDAY2) THEN
  CALL LIGHTOUT
  IF(JDAY.GE.LJDAY1.AND.JDAY.LE.LJDAY2) THEN
    LUX = LUX1 + (LJDAY2-JDAY)/(LJDAY2-LJDAY1)*(LUX2-LUX1)
  ELSE
    GOTO 2200
```

```
  END IF
END IF

LUX = MAX(LUX,0.0) ! REDUDANT CHECK
IF(LUX.GE.1.0) THEN !ARBITRARY; USED FOR VERTICAL MIGRATION
  DAYLIGHT = .TRUE.
ELSE
  DAYLIGHT = .FALSE.
END IF
!NOON CHECK ( FOR DEBUGGING )
IF(JDAY.GT.557.5) THEN
  IF(JDAY.LT.557.51) THEN
    CONTINUE
  END IF
END IF
! BESTCALC TIMESTEP COUNT
IF(BESTCALC) BESTSTEP = BESTSTEP + 1
!************************************
!   TASK B.2.2.2 SUB-DAILY BIOENERGETICS
!************************************
write (999,'(a12,f8.3)') 'JDAY ', jday
! NEED TO MATCH DEPTHS TO K-LAYERS FOR W2 APPLICATION; ! ITERATE BY SEGMENT, SO ONLY K DIMENSION IS
NEEDED
DO JI = 1,NIBIO ! THIS IS THE MAIN W2 LOOP SIMULATION
  I = IBIO(JI)
  KBIP = KTI
 ! GET BIOEXP DATA AND DETERMINE KTI,KBI
  IF(FIRST_BIO(JI)) THEN
    CALL BIOEXPTRANSFORM
  END IF
write(999,'(a12,2i4,f8.2)') "Loop JI, I ",JI,I,t1z(2,I)
! MAIN VERTICAL LOOP
 DO K = KTI(I),KBI(I)
   ! GROWTH ANIMATION NODE COUNT
   NELEM = NELEM+1
   ! CONVERT LIGHTOUT DATA AT SURFACE TO DEPTH CORRECTED VALUES
   !** UPDATE WHEN INTEGRATING WITH MAIN W2 CODE
   GAMMAFDC(K,I) = LUX*EXP(-1*DEPTHM(K,I)*0.36) ! ARBITRARY LIGHT EXTINCTION VALUE OF 0.36 /M
   ! DIAGNOSTIC
   IF(GAMMAFDC(K,I).GT.1) THEN
```

```
      VISIBLE(K,I) = VISIBLE(K,I) + FDLTM
    END IF
    ! UPDATE REACTION DISTANCE AND SEARCH VOLUME
    FVEL(K,I) = 0.01*9.9*EXP(0.0405*T1Z(K,I)) * F1(K,I,1)**0.13 ! PULLED FROM METABOLISM, NEEDED FOR
SEARCH VOLUME
    FVELAVE(K,I) = FVELAVE(K,I) + FVEL(K,I)*FDLTM/1440
    RDZ(K,I) = 0.01*4.9424*GAMMAFDC(K,I)**0.086 ! METERS
    SRCHVOL(K,I) = 3.141596*RDZ(K,I)*RDZ(K,I)*FVEL(K,I)
      IF(BESTCALC) THEN
       BFVEL(K,I) = 0.01*9.9*EXP(0.0405*T1Z(K,I)) * BF1(K,I,1)**0.13
       BRDZ(K,I) = 0.01*4.9424*GAMMAFDC(K,I)**0.086
       BSRCHVOL(K,I) = 3.141596*BRDZ(K,I)*BRDZ(K,I)*BFVEL(K,I)
      END IF
      IF(DIELCALC) THEN
       DFVEL(K,I) = 0.01*9.9*EXP(0.0405*T1Z(K,I)) * DF1(K,I,1)**0.13
       DRDZ(K,I) = 0.01*4.9424*GAMMAFDC(K,I)**0.086
       DSRCHVOL(K,I) = 3.141596*DRDZ(K,I)*DRDZ(K,I)*DFVEL(K,I)
      END IF

    !************************************ PUT THE TL TERM INTO THE CONSUMPTION TERM; DEVIATES FROM
COMMON FORMULATIONS *******
    ! *** THORNTON-LESSEM FUNCTION
    FL1 = EXP(FG1*(T1Z(K,I)-FISHT1)); FL2 = EXP(FG2*(FISHT4-T1Z(K,I)))
    FKA = (FISHK1*FL1)/(1+FISHK1*(FL1-1)); FKB = (FISHK4*FL2)/(1+FISHK4*(FL2-1)); FTL(K) = FKA*FKB
    ! CHECKING FUNCTION
    IF(SINGLEDIAG) THEN
      RJINT=JDAY-INT(JDAY)
      IF(RJINT.LT.0.1) THEN
        IF(K.EQ.KTI(I)) THEN
          WRITE(TLCALCFN,'(F8.2,F8.4)') T1Z(K,I),FTL(K)
        END IF
      END IF
    END IF
! ***************************************************************************************
! *                              TASK ....  CONSUMPTION                                 *
! ***************************************************************************************
 ! DETERMINE MAXIMUM PRACTICAL FEEDING RATES ! FROM BEAUCHAMP, ET AL 1989, CMAX
   FCONMAXJ(K,I) = (0.303*F1(K,I,1)**-0.275)*EZOO(3)*F1(K,I,1)*FTL(K) ! UNITS OF J/DAY
   FCONMAXGG(K,I) = (0.303*F1(K,I,1)**-0.275)*FTL(K) ! UNITS OF G/G/ DAY
 ! CHECK STOMACH CONTENT COMPARED TO CAPACITY
```

```
   IF(F1(K,I,3).GT.F1(K,I,5)) THEN ! FORAGING
    FCON(K,I) = 0.0 !STOMACH FULL
      FULLSTO(K,I) = FULLSTO(K,I) + 1
   ELSE ! FORAGING
     IF(CMAXCALC) THEN       ! PRACTICAL FEEDING LIMIT?
        ! FCON(K,I) = FCONMAXGG(K,I)*F1(K,I,1)/MZOO(3)/1440
         WILMA1 = FCONMAXGG(K,I)*F1(K,I,1)/MZOO(3)/1440
         WILMA2 = (SRCHVOL(K,I)*CEFF(K)/(1+SRCHVOL(K,I)*CEFF(K)*HANDLE))*60*FTL(K)
       IF (WILMA2.GT.WILMA1) THEN
            FCON(K,I) = WILMA1
            ELSE
              FCON(K,I) = WILMA2
        END IF
     ELSE
       FCON(K,I) = (SRCHVOL(K,I)*CEFF(K)/(1+SRCHVOL(K,I)*CEFF(K)*HANDLE))*60*FTL(K)
     END IF
     DAYC(K,I) = DAYC(K,I) + FCON(K,I)*FDLTM
       DAYCM(K,I) = DAYC(K,I)*MZOO(3)
     AVEC(K,I) = AVEC(K,I) + FCON(K,I)*FDLTM/1440
       MINC(K,I) = MIN(MINC(K,I),FCON(K,I))
       MAXC(K,I) = MAX(MAXC(K,I),FCON(K,I))
       IF(FDIAG) THEN ! DIET REPORTING
       IF(THRESHFEED(K)) THEN
           DIET(K,I,THRESHZ) = DIET(K,I,THRESHZ) +
FCON(K,I)*C1Z(K,I,THRESHZ)*ZAVAIL(THRESHZ)/CEFF(K)*FDLTM
         ELSE
           DO JJZ = 1,NZP
             DIET(K,I,JJZ) = DIET(K,I,JJZ) +  FCON(K,I)*C1Z(K,I,JJZ)*ZAVAIL(JJZ)/CEFF(K)*FDLTM
           END DO
         END IF
     END IF
   END IF ! FORAGING
   ! ACTUAL CONSUMPTION DIAGNOSTIC
   FCONJ(K,I)  = DAYC(K,I)*MZOO(3)*EZOO(3)
   FCONGG(K,I) = DAYC(K,I)*MZOO(3)/F1(K,I,1)
   FCONP(K,I)  = FCONGG(K,I)/FCONMAXGG(K,I)
! ***********  BESTCALC  *************
IF(BESTCALC) THEN
   BFCONMAXJ(K,I) = (0.303*BF1(K,I,1)**-0.275)*EZOO(3)*BF1(K,I,1)*FTL(K) ! UNITS OF J/DAY
   BFCONMAXGG(K,I) = (0.303*BF1(K,I,1)**-0.275)*FTL(K) ! UNITS OF G/G/ DAY
```

```
   IF(BF1(K,I,3).GT.BF1(K,I,5)) THEN ! FORAGING
    PRINT *,'FULL_STOMACH'
    BFCON(K,I) = 0.0 !STOMACH FULL
      BFULLSTO(K,I) =  1
   ELSE ! FORAGING
    BFULLSTO(K,I) = 0
     IF(CMAXCALC) THEN
       BFCON(K,I) = BFCONMAXGG(K,I)*BF1(K,I,1)/MZOO(3)/1440
         WILMA1 = BFCONMAXGG(K,I)*BF1(K,I,1)/MZOO(3)/1440
         WILMA2 = (SRCHVOL(K,I)*CEFF(K)/(1+SRCHVOL(K,I)*CEFF(K)*HANDLE))*60*FTL(K)
       IF (WILMA2.GT.WILMA1) THEN
            BFCON(K,I) = WILMA1
            ELSE
              BFCON(K,I) = WILMA2
         END IF
      ELSE
       BFCON(K,I) = (BSRCHVOL(K,I)*CEFF(K)/(1+BSRCHVOL(K,I)*CEFF(K)*HANDLE))*60*FTL(K)
     END IF
     BDAYC(K,I) = BFCON(K,I)*FDLTM ! DIFFERS FROM MAIN: ONLY ONE TIMESTEP
       BDAYCM(K,I) = BDAYC(K,I)*MZOO(3)
     IF(FDIAG) THEN ! DIET REPORTING ! DIFFERS FROM MAIN ROUTINE; THIS IS ONLY PER TIMESTEP; BDIETI
IS CUMMULATIVE
       IF(THRESHFEED(K)) THEN
           BDIET(K,I,THRESHZ) = BFCON(K,I)*C1Z(K,I,THRESHZ)*ZAVAIL(THRESHZ)/CEFF(K)*FDLTM
         ELSE
           DO JJZ = 1,NZP
             BDIET(K,I,JJZ) = BFCON(K,I)*C1Z(K,I,JJZ)*ZAVAIL(JJZ)/CEFF(K)*FDLTM
           END DO
         END IF
     END IF
   END IF ! FORAGING
   BFCONJ(K,I)  = BDAYC(K,I)*MZOO(3)*EZOO(3)
   BFCONGG(K,I) = BDAYC(K,I)*MZOO(3)/BF1(K,I,1)
   BFCONP(K,I)  = BFCONGG(K,I)/BFCONMAXGG(K,I)
END IF ! BESTCALC
! ***********  DIELCALC  *************
IF(DIELCALC) THEN
   DFCONMAXJ(K,I) = (0.303*DF1(K,I,1)**-0.275)*EZOO(3)*DF1(K,I,1)*FTL(K) ! UNITS OF J/DAY
   DFCONMAXGG(K,I) = (0.303*DF1(K,I,1)**-0.275)*FTL(K) ! UNITS OF G/G/ DAY
   IF(DF1(K,I,3).GT.DF1(K,I,5)) THEN ! FORAGING
```

```
     DFCON(K,I) = 0.0 !STOMACH FULL
       DFULLSTO(K,I) =  1
    ELSE ! FORAGING
     DFULLSTO(K,I) = 0
      IF(CMAXCALC) THEN
          WILMA1 = DFCONMAXGG(K,I)*DF1(K,I,1)/MZOO(3)/1440
          WILMA2 = (SRCHVOL(K,I)*CEFF(K)/(1+SRCHVOL(K,I)*CEFF(K)*HANDLE))*60*FTL(K)
        IF (WILMA2.GT.WILMA1) THEN
             DFCON(K,I) = WILMA1
             ELSE
               DFCON(K,I) = WILMA2
          END IF
      ELSE
        DFCON(K,I) = (DSRCHVOL(K,I)*CEFF(K)/(1+DSRCHVOL(K,I)*CEFF(K)*HANDLE))*60*FTL(K)
      END IF
      DDAYC(K,I) = DFCON(K,I)*FDLTM ! DIFFERS FROM MAIN: ONLY ONE TIMESTEP
        DDAYCM(K,I) = DDAYC(K,I)*MZOO(3)
      IF(FDIAG) THEN ! DIET REPORTING ! DIFFERS FROM MAIN ROUTINE; THIS IS ONLY PER TIMESTEP; BDIETI
IS CUMMULATIVE
        IF(THRESHFEED(K)) THEN
            DDIET(K,I,THRESHZ) = DFCON(K,I)*C1Z(K,I,THRESHZ)*ZAVAIL(THRESHZ)/CEFF(K)*FDLTM
          ELSE
            DO JJZ = 1,NZP
              DDIET(K,I,JJZ) = DFCON(K,I)*C1Z(K,I,JJZ)*ZAVAIL(JJZ)/CEFF(K)*FDLTM
            END DO
          END IF
      END IF
    END IF ! FORAGING
    DFCONJ(K,I)  = DDAYC(K,I)*MZOO(3)*EZOO(3)
    DFCONGG(K,I) = DDAYC(K,I)*MZOO(3)/DF1(K,I,1)
    DFCONP(K,I)  = DFCONGG(K,I)/DFCONMAXGG(K,I)
  END IF ! DIELCALC

  ! ***************************************************************************
  ! *                            TASK ....  NON-CONSUMPTION PARAMETERS          *
  ! ***************************************************************************
    !****DIGESTION (SDA)
    DIGK = 0.014*T1Z(K,I)+0.1135
    !** MAZUR'S B&A
    F_DC(K,I) = (F1(K,I,3) + FCON(K,I)*MZOO(3)*FDLTM - (F1(K,I,3)*EXP(-1*DIGK*FDLTH) &
```

```
     + FCON(K,I)*MZOO(3)*60/DIGK*(1-EXP(-1*DIGK*FDLTH)) )) *EZOO(3)
   ! DIAGNOSTIC:  DIGENSTION BY PARTS
   F_DINI(K,I) = F1(K,I,3)*EZOO(3)
   F_DCON(K,I) = FCON(K,I)*MZOO(3)*FDLTM*EZOO(3)
   !F_DUNDIG(K,I) = ((F1(K,I,3)*EXP(-1*DIGK*FDLTH)+FCON(K,I)*MZLW(3)*60/DIGK*(1-EXP(-
1*DIGK*FDLTH))))*EZOO(3)
   F_DUNDIG(K,I) = ((F1(K,I,3)*EXP(-1*DIGK*FDLTH)+FCON(K,I)*MZOO(3)*60/DIGK*(1-EXP(-
1*DIGK*FDLTH))))*EZOO(3)
   !****EGESTION
   F_FC(K,I)    = 0.212*(T1Z(K,I)**-0.222)*F_DC(K,I)
   !****EXCRETION
   F_UC(K,I) = 0.0233*(T1Z(K,I)**-0.580)*(F_DC(K,I)-F_FC(K,I))
   !****METABOLISM/RESPIRATION (ACTIVITY)
   FACT(K,I) = EXP(0.02334*100.0*FVEL(K,I))
   FACTAVE(K,I) = FACTAVE(K,I) + FACT(K,I)*FDLTM/1440
   F_RC(K,I) = 0.00143*(F1(K,I,1)**-
0.209)*EXP(0.086*T1Z(K,I))*FACT(K,I)*FOXYCAL*FDLTM/1440*F1(K,I,1)
   !****SPECIFIC DYNAMIC ACTION
   F_SC(K,I) = 0.172*(F_DC(K,I)-F_FC(K,I))
   !****FISH ENERGY DENSITY (IN J/G)
   IF(F1(K,I,1).LE.196.0) THEN
     F1(K,I,4) = (1.851*F1(K,I,1)+1250.0)*4.1868
   ELSE
     F1(K,I,4) = (0.1254*F1(K,I,1) + 1588.0)*4.1868
   END IF
   !****UPDATE STOMACH CONTENT ! THIS CAN PROBABLY BE MOVED INTO THE DIGESTION SECTION, BUT WILL
KEEP SEPARATE FOR CLARITY
   F_CC(K,I) = FCON(K,I)*MZOO(3)*FDLTM*EZOO(3)
   F1(K,I,3) = F1(K,I,3)*EXP(-1*DIGK*FDLTH)+FCON(K,I)*MZOO(3)*60/DIGK*(1-EXP(-1*DIGK*FDLTH))

! ***********  BESTCALC  *************
IF(BESTCALC) THEN
       BF_DC(K,I) = (BF1(K,I,3) + BFCON(K,I)*MZOO(3)*FDLTM - (BF1(K,I,3)*EXP(-1*DIGK*FDLTH) &
     + BFCON(K,I)*MZOO(3)*60/DIGK*(1-EXP(-1*DIGK*FDLTH)) )) *EZOO(3)
       BF_DC_EXT(K,I) = BF_DC(K,I) + 0.2*BFCONJ(K,I)
       BF_FC(K,I)    = 0.212*(T1Z(K,I)**-0.222)*BF_DC(K,I)
       BF_UC(K,I) = 0.0233*(T1Z(K,I)**-0.580)*(BF_DC(K,I)-BF_FC(K,I))
       BFACT(K,I) = EXP(0.02334*100.0*BFVEL(K,I))
       BF_RC(K,I) = 0.00143*(BF1(K,I,1)**-
0.209)*EXP(0.086*T1Z(K,I))*BFACT(K,I)*FOXYCAL*FDLTM/1440*BF1(K,I,1)
```

```
        BF_SC(K,I) = 0.172*(BF_DC(K,I)-BF_FC(K,I))
        IF(BF1(K,I,1).LE.196.0) THEN
          BF1(K,I,4) = (1.851*BF1(K,I,1)+1250.0)*4.1868
        ELSE
          BF1(K,I,4) = (0.1254*BF1(K,I,1) + 1588.0)*4.1868
        END IF
        BF_CC(K,I) = BFCON(K,I)*MZOO(3)*FDLTM*EZOO(3)
        BF1(K,I,3) = BF1(K,I,3)*EXP(-1*DIGK*FDLTH)+BFCON(K,I)*MZOO(3)*60/DIGK*(1-EXP(-1*DIGK*FDLTH))
END IF !BESTCALC

! ***********  DIELCALC  *************
IF(DIELCALC) THEN
        DF_DC(K,I) = (DF1(K,I,3) + DFCON(K,I)*MZOO(3)*FDLTM   -    (DF1(K,I,3)*EXP(-1*DIGK*FDLTH) &
          + DFCON(K,I)*MZOO(3)*60/DIGK*(1-EXP(-1*DIGK*FDLTH))    )) *EZOO(3)
        DF_DC_EXT(K,I) = DF_DC(K,I) + 0.2*DFCONJ(K,I)
        DF_FC(K,I)     = 0.212*(T1Z(K,I)**-0.222)*DF_DC(K,I)
        DF_UC(K,I) = 0.0233*(T1Z(K,I)**-0.580)*(DF_DC(K,I)-DF_FC(K,I))
        DFACT(K,I) = EXP(0.02334*100.0*DFVEL(K,I))
        DF_RC(K,I) = 0.00143*(DF1(K,I,1)**-
0.209)*EXP(0.086*T1Z(K,I))*DFACT(K,I)*FOXYCAL*FDLTM/1440*DF1(K,I,1)
        DF_SC(K,I) = 0.172*(DF_DC(K,I)-DF_FC(K,I))
        IF(DF1(K,I,1).LE.196.0) THEN
          DF1(K,I,4) = (1.851*DF1(K,I,1)+1250.0)*4.1868
        ELSE
          DF1(K,I,4) = (0.1254*DF1(K,I,1) + 1588.0)*4.1868
        END IF
        DF_CC(K,I) = DFCON(K,I)*MZOO(3)*FDLTM*EZOO(3)
        DF1(K,I,3) = DF1(K,I,3)*EXP(-1*DIGK*FDLTH)+DFCON(K,I)*MZOO(3)*60/DIGK*(1-EXP(-1*DIGK*FDLTH))
END IF !DIELCALC
END DO ! MAIN K LOOP

! ***************************************************************************
! *                          TASK ....  DAILY PARAMETER UPDATES              *
! ***************************************************************************
 ! DAILY PARAMETER UPDATES
 CELL_POS(I) = 0; CELL_NEG(I) = 0
 DO K = KTI(I),KBI(I)
   F_R(K,I) = F_R(K,I) + F_RC(K,I)
   F_D(K,I) = F_D(K,I) + F_DC(K,I)
   F_C(K,I) = F_C(K,I) + F_CC(K,I)
```

```
   F_W(K,I) = F_W(K,I) + F_UC(K,I) + F_FC(K,I)
   F_S(K,I) = F_S(K,I) + F_SC(K,I)
   F_G(K,I) = F_G(K,I) + (F_DC(K,I) - (F_SC(K,I) + F_FC(K,I) + F_UC(K,I))- F_RC(K,I))/F1(K,I,4)
   F2(K,I) =F_G(K,I)/F1(K,I,1)
   IF(F_G(K,I).GT.0) CELL_POS(I) = CELL_POS(I) +1
   IF(F_G(K,I).LT.0) CELL_NEG(I) = CELL_NEG(I) +1
 END DO
 CELL_PER(I) = (CELL_POS(I)*1.0)/(CELL_POS(I)*1.0+CELL_NEG(I)*1.0)*100.0
! ***********  BESTCALC  *************
IF(BESTCALC) THEN
      BCELL_POS(I) = 0; BCELL_NEG(I) = 0
        GMAXG = -99999.0; GMAXK = 2
      DO K = KTI(I),KBI(I)
        BF_G(K,I) = (BF_DC(K,I) - (BF_SC(K,I) + BF_FC(K,I) + BF_UC(K,I))- BF_RC(K,I))/BF1(K,I,4)
        BF_G_EXT(K,I) = (BF_DC_EXT(K,I) - (BF_SC(K,I) + BF_FC(K,I) + BF_UC(K,I))-
BF_RC(K,I))/BF1(K,I,4)
           F_G2(K,I) = F_G2(K,I) + BF_G(K,I)
        IF(BF_G_EXT(K,I).GT.GMAXG) THEN ! FIND BEST LAYER
          GMAXG = BF_G_EXT(K,I); GMAXK = K
          END IF
       IF(BF_G(K,I).GT.0) BCELL_POS = BCELL_POS + 1
         IF(BF_G(K,I).LT.0) BCELL_NEG = BCELL_NEG + 1
      END DO
        ! APPLY BEST LAYER TO CUMMALATIVE TERMS
       BF_GI(I) = BF_GI(I) + BF_G(GMAXK,I)
         BESTK(I,BESTSTEP) = GMAXK
       BF_RI(I) = BF_RI(I) + BF_RC(GMAXK,I)
       BF_DI(I) = BF_DI(I) + BF_DC(GMAXK,I)
         BF_CI(I) = BF_CI(I) + BF_CC(GMAXK,I)
         BF_WI(I) = BF_WI(I) + BF_UC(GMAXK,I) + BF_FC(GMAXK,I)
         BF_UI(I) = BF_UI(I) + BF_UC(GMAXK,I)
         BF_FI(I) = BF_FI(I) + BF_FC(GMAXK,I)
         BF_SI(I) = BF_SI(I) + BF_SC(GMAXK,I)
               T1BZ(I)  = T1BZ(I)  + T1Z(GMAXK,I)/48.0       ! average over a day
       ! UPDATE DIAGNOSTIC ACCOUNTING TERMS
       BFVELAVE(I) = BFVELAVE(I) + BFVEL(GMAXK,I)*FDLTM/1440
         BFACTAVE(I) = BFACTAVE(I) + BFACT(GMAXK,I)*FDLTM/1440
         BAVEC(I) = BAVEC(I) + BFCON(GMAXK,I)*FDLTM/1440
         BMINC(I) = MIN(BMINC(I),BFCON(GMAXK,I))
         BMAXC(I) = MAX(BMAXC(I),BFCON(GMAXK,I))
```

```
          BFULLSTOI(I) = BFULLSTOI(I) + BFULLSTO(GMAXK,I)
        BFCONI(I) = BFCONI(I) + BFCON(GMAXK,I)
          BDAYCI(I) = BDAYCI(I) + BDAYC(GMAXK,I)
          BDAYCMI(I) = BDAYCMI(I) + BDAYCM(GMAXK,I)
          BFCONMAXJI(I) = BFCONMAXJI(I) + BFCONMAXJ(GMAXK,I)/48.0      ! average over a day
          BFCONMAXGGI(I) = BFCONMAXGGI(I) + BFCONMAXGG(GMAXK,I)/48.0   ! average over a day
          BFCONJI(I) = BFCONJI(I) + BFCONJ(GMAXK,I)
          BFCONGGI(I) = BFCONGGI(I) + BFCONGG(GMAXK,I)
        BFCONPI(I) = BFCONGGI(I)/BFCONMAXGGI(I)
    IF(SINGLEDIAG.AND.DEPTHCALC) THEN
      IF(I.EQ.SINIBIO) THEN
           WRITE(BIOOUTFN(21),'(F8.3,3I8)') JDAY, I, BESTK(I,BESTSTEP),DIELK(I,BESTSTEP)
      END IF
    END IF
          ! TRANFER STOMACH CONTENTS
          BF1(:,I,3) = BF1(GMAXK,I,3)
        BCELL_PER(I) = (BCELL_POS(I)*1.0)/(BCELL_POS(I)*1.0+BCELL_NEG(I)*1.0)*100.0
        IF(GAMMAFDC(GMAXK,I).GT.1) THEN
          BVISIBLE(I) = BVISIBLE(I) + FDLTM
        END IF
          DO JJZ = 1,NZP
            BDIETI(I,JJZ) = BDIETI(I,JJZ) + BDIET(GMAXK,I,JJZ)
          END DO
        BDAYC(:,I) = BDAYC(GMAXK,I)
END IF !BESTCALC
! ************  DIELCALC  *************
    IF(DIELCALC) THEN
      DCELL_POS(I) = 0; DCELL_NEG(I) = 0
        GMAXG = -99999.0; GMAXK = 2
        RMIN = -99999.0 ; RMINK = 2; CMAX = -99999.0 ; CMAXK = 2
      DO K = KTI(I),KBI(I)
        DF_G(K,I) = (DF_DC(K,I) - (DF_SC(K,I) + DF_FC(K,I) + DF_UC(K,I))- DF_RC(K,I))/DF1(K,I,4)
        DF_G_EXT(K,I) = (DF_DC_EXT(K,I) - (DF_SC(K,I) + DF_FC(K,I) + DF_UC(K,I))-
DF_RC(K,I))/DF1(K,I,4)
        IF(DF_G_EXT(K,I).GT.GMAXG) THEN ! FIND BEST LAYER
          GMAXG = DF_G_EXT(K,I); GMAXK = K
          END IF
        IF(DF_R(K,I).LT.RMIN) THEN ! FIND BEST LAYER
          RMIN = DF_R(K,I); RMINK = K
          END IF
```

```
        IF(DF_CC(K,I).GT.CMAX) THEN ! FIND BEST LAYER
          CMAX = DF_CC(K,I); CMAXK = K
          END IF
        IF(DF_G(K,I).GT.0) DCELL_POS = DCELL_POS + 1
         IF(DF_G(K,I).LT.0) DCELL_NEG = DCELL_NEG + 1
      END DO
! ************************************************************
        ! APPLY BEST LAYER TO CUMMALATIVE TERMS
IF(DF_G(GMAXK,I).GT.0.0) THEN
  KBEST = GMAXK
ELSE
  IF(DAYLIGHT) THEN
    IF(DF_G(CMAXK,I).GE.0.0) THEN
        KBEST = CMAXK
      ELSE
        IF(FORAY(I)) THEN
          IF(T1Z(CMAXK,I).GT.20.0) THEN
              DO KK = CMAXK,KBI(I)-1
                IF(T1Z(KK,I).GT.20.0) THEN
                    CONTINUE
                  ELSE
                    KBEST = KK
                    EXIT
                  END IF
              END DO
            ELSE
              KBEST = CMAXK
            END IF
            FORAY(I) = .FALSE.
        ELSE
          KBEST = RMINK
            FORAY(I) = .TRUE.
        END IF
      END IF
  ELSE
    KBEST = RMINK
  END IF
END IF
       DF_GI(I) = DF_GI(I) + DF_G(KBEST,I)
         DIELK(I,BESTSTEP) = KBEST
```

```
        DF_RI(I) = DF_RI(I) + DF_RC(KBEST,I)
        DF_DI(I) = DF_DI(I) + DF_DC(KBEST,I)
          DF_CI(I) = DF_CI(I) + DF_CC(KBEST,I)
          DF_WI(I) = DF_WI(I) + DF_UC(KBEST,I) + DF_FC(KBEST,I)
          DF_UI(I) = DF_UI(I) + DF_UC(KBEST,I)
          DF_FI(I) = DF_FI(I) + DF_FC(KBEST,I)
          DF_SI(I) = DF_SI(I) + DF_SC(KBEST,I)
        ! UPDATE DIAGNOSTIC ACCOUNTING TERMS
        DFVELAVE(I) = DFVELAVE(I) + DFVEL(KBEST,I)*FDLTM/1440
          DFACTAVE(I) = DFACTAVE(I) + DFACT(KBEST,I)*FDLTM/1440
          DAVEC(I) = DAVEC(I) + DFCON(KBEST,I)*FDLTM/1440
          DMINC(I) = MIN(DMINC(I),DFCON(KBEST,I))
          DMAXC(I) = MAX(DMAXC(I),DFCON(KBEST,I))
          DFULLSTOI(I) = DFULLSTOI(I) + DFULLSTO(KBEST,I)
        DFCONI(I) = DFCONI(I) + DFCON(KBEST,I)
          DDAYCI(I) = DDAYCI(I) + DDAYC(KBEST,I)
          DDAYCMI(I) = DDAYCMI(I) + DDAYCM(KBEST,I)
          DFCONMAXJI(I) = DFCONMAXJI(I) + DFCONMAXJ(KBEST,I)/48.0     ! average over a day
          DFCONMAXGGI(I) = DFCONMAXGGI(I) + DFCONMAXGG(KBEST,I)/48.0  ! average over a day
          DFCONJI(I) = DFCONJI(I) + DFCONJ(KBEST,I)
          DFCONGGI(I) = DFCONGGI(I) + DFCONGG(KBEST,I)
        DFCONPI(I) = DFCONGGI(I)/DFCONMAXGGI(I)
          DF1(:,I,3) = DF1(KBEST,I,3)
        DCELL_PER(I) = (DCELL_POS(I)*1.0)/(DCELL_POS(I)*1.0+DCELL_NEG(I)*1.0)*100.0
        IF(GAMMAFDC(KBEST,I).GT.1) THEN
          DVISIBLE(I) = DVISIBLE(I) + FDLTM
        END IF
          DO JJZ = 1,NZP
            DDIETI(I,JJZ) = DDIETI(I,JJZ) + DDIET(KBEST,I,JJZ)
          END DO
        DDAYC(:,I) = DDAYC(KBEST,I)
      END IF !DIELCALC

! ***************************************************************************
! *                            TASK ....  DAILY CALCULATIONS AND UPDATES     *
! ***************************************************************************
 IF(BIODAY_CALC) THEN !BIODAY
  ! IF(KBI(I).GT.KTI(I)+1) F_G(KBI(I)-1,I) = F_G(KBI(I)-2,I)
  ! IF(KBI(I).GT.KTI(I)) F_G(KBI(I),I) = F_G(KBI(I)-1,I)
   IF(FDIAG) CALL FOUTPUT_DAILY
```

```
    IF(JI.EQ.NIBIO) then
       print *,'ji = ', ji
       CALL ANIMATION_DATA
         continue
    end if
    CALL DAILY_GROWTH
    IF(JI.EQ.NIBIO) CALL BY_SEG_OUTPUT
    IF(JI.EQ.NIBIO) PRINT *,JDAY,BF1(2,312,1),T1Z(2,I)
    KBIP(I) = KBI(I)
    CALL BIOEXPTRANSFORM
  ! CHECK FOR CHANGES IN KTI (LAYER ADDITION/SUBTRACTION REQUIRES INITIALIZING):  SHOWS UP IN
ANIMATIONS
  IF(KBI(I).GT.KBIP(I)) THEN
     ! WRITE(999,*)'INITIALIZING, JDAY, I ',INT(JDAY),I
    DO K = KBI(I),3,-1
        F1(KBI(I),I,:) = F1(KBI(I)-1,I,:)
      F_R(KBI(I),I) = F_R(KBI(I)-1,I)
      F_D(KBI(I),I) = F_D(KBI(I)-1,I)
      F_C(KBI(I),I) = F_C(KBI(I)-1,I)
      F_W(KBI(I),I) = F_W(KBI(I)-1,I)
      F_S(KBI(I),I) = F_S(KBI(I)-1,I)
      F_G(KBI(I),I) = F_G(KBI(I)-1,I)
    END DO
        F1(2,I,:) = F1(3,I,:)
      F_R(2,I) = F_R(3,I)
      F_D(2,I) = F_D(3,I)
      F_C(2,I) = F_C(3,I)
      F_W(2,I) = F_W(3,I)
      F_S(2,I) = F_S(3,I)
      F_G(2,I) = F_G(3,I)
   END IF
  IF(KBI(I).LT.KBIP(I)) THEN
       ! WRITE(999,*)'INITIALIZING, JDAY, I ',INT(JDAY),I
    DO K = KBI(I),2,-1
        F1(KBI(I),I,:) = F1(KBI(I)+1,I,:)
      F_R(KBI(I),I) = F_R(KBI(I)+1,I)
      F_D(KBI(I),I) = F_D(KBI(I)+1,I)
      F_C(KBI(I),I) = F_C(KBI(I)+1,I)
      F_W(KBI(I),I) = F_W(KBI(I)+1,I)
      F_S(KBI(I),I) = F_S(KBI(I)+1,I)
```

```
      F_G(KBI(I),I) = F_G(KBI(I)+1,I)
     END DO
    END IF
! ***********  ANIMATION  *************
    ! ANIMATION ELEVATION DETERMINATION (TEMPORARY APPROACH)
     ! FIND BOTTOM ELEVATION
    DO II = 1,IMX
      IF(I.EQ.BOTSEG(II)) THEN
          GELEV(KBI(I),I) = BOTTOME(II)
          EXIT
        END IF
    END DO
     ! ASSIGN ELEVATIONS
    DO K=KBI(I)-1,2,-1
      GELEV(K,I)=GELEV(K+1,I)+2.0
    END DO
   END IF !BIODAY
   FIRST_BIO(JI) = .FALSE.
 998 CONTINUE
END DO ! MAIN LOOP (SEGMENT ADVANCEMENT)
! ********************************************************************************
! *                              TASK ....  REZERO CUMMULATIVE DAILY TERMS          *
! ********************************************************************************
! REZERO CUMMULATIVE DAILY TERMS
NELEM = 0; NNODE = 0
IF(BIODAY_CALC) THEN
 F_R  = 0.0  ;F_D  = 0.0  ;F_C  = 0.0  ;F_F   = 0.0  ;F_U      = 0.0 ; VISIBLE = 0.0
 F_S  = 0.0  ;F_G  = 0.0  ;F_W  = 0.0  ;DAYC  = 0.0  ;FULLSTO  = 0   ; DIET    = 0.0
 FVELAVE = 0.0; FACTAVE = 0.0;AVEC = 0.0; MINC = 0.0; MAXC = 0.0
 MAXG = -999.0; MAXM = -999.0; F_G2 = 0.0
    ! ***********  BESTCALC  *************
 IF(BESTCALC) THEN
  BF_R  = 0.0 ;BF_D  = 0.0 ;BF_C  = 0.0 ;BF_F   = 0.0 ;BF_U    = 0.0
  BF_S  = 0.0 ;BF_G  = 0.0 ;BF_W  = 0.0 ;BDAYC  = 0.0 ;BDIET  = 0.0; BDIETI = 0.0
  BESTSTEP = 0
  BF_GI = 0.0 ;BF_RI = 0.0 ;BF_DI = 0.0 ;BF_CI  = 0.0 ;BF_WI   = 0.0  ; BF_SI = 0.0; BF_UI = 0.0;
BF_FI = 0.0
  BFVELAVE = 0.0; BFACTAVE = 0.0;  BAVEC = 0.0; BMINC = 0.0; BMAXC = 0.0; BVISIBLE = 0.0
  BFULLSTO = 0; BFULLSTOI = 0
```

```
  BFCONMAXJI = 0.0; BFCONMAXGGI = 0.0; BFCONI = 0.0; BDAYCI = 0.0; BDAYCMI = 0.0; BFCONPI = 0.0;
BFCONJI = 0.0; BFCONGGI = 0.0
  T1BZ = 0.0
 END IF
   ! ***********  DIELCALC  *************
 IF(DIELCALC) THEN
  DF_R  = 0.0 ;DF_D  = 0.0 ;DF_C  = 0.0 ;DF_F   = 0.0 ;DF_U    = 0.0
  DF_S  = 0.0 ;DF_G  = 0.0 ;DF_W  = 0.0 ;DDAYC  = 0.0 ;DDIET  = 0.0; DDIETI = 0.0
  DF_GI = 0.0 ;DF_RI = 0.0 ;DF_DI = 0.0 ;DF_CI  = 0.0 ;DF_WI   = 0.0  ; DF_SI = 0.0; DF_UI = 0.0;
DF_FI = 0.0
  DFVELAVE = 0.0; DFACTAVE = 0.0;  DAVEC = 0.0; DMINC = 0.0; DMAXC = 0.0; DVISIBLE = 0.0
  DFULLST0 = 0; DFULLSTOI = 0
  DFCONMAXJI = 0.0; DFCONMAXGGI = 0.0; DFCONI = 0.0; DDAYCI = 0.0; DDAYCMI = 0.0; DFCONPI = 0.0;
DFCONJI = 0.0; DFCONGGI = 0.0
 END IF
END IF
BIOSUB_CALC = .FALSE.;  BIODAY_CALC = .FALSE.

! ***************************************************************************************
! *                              TASK ....  END TIME-STEP                                 *
! ***************************************************************************************
GOTO 2110 ! RETURN TO JDAY ADVANCEMENT
!*****************************************************************************************
*********************************
!**                                                    E N D   P R O G R A M
**
!*****************************************************************************************
*********************************
997 CONTINUE
! GROWTH ANIMATION DATE/TEXT
DO IZ = 1,ZONECNT
  IZZ = IZ+ZONEFIRST-1
  WRITE(ANIMFN,863) IZ,IZZ
  WRITE(ANIMFN,864) IZ,GREGORY(IZ)
END DO
863 FORMAT('TEXT X=0.2, y=0.15, H=3.0, ZN=',i4,',',' C=BLACK,','T= "Julian Day ',I6,'"')
864 FORMAT('TEXT X=0.2, y=0.20, H=3.0, ZN=',i4,',',' C=BLACK,','T= "',A20,'"')
DO II = 1,NIBIO
  CLOSE(BIOINFN(II))
END DO
```

```
CLOSE(LIGHTNUM)
STOP
END !PROGRAM END

!*****************************************************************************************************
**********************************
!**                                                S U B R O U T I N E  L I G H T O U T
**
!*****************************************************************************************************
**********************************

SUBROUTINE LIGHTOUT
 USE MAINW2; USE FISH; USE FISH2; USE BIOEXPDATATRANSFORM; USE DIAGNOSTIC; USE ROOSEVELT; USE
MOVEMENT
    LJDAY1 = LJDAY2; LUX1 = LUX2
    READ(LIGHTNUM,'(10X,F10.0,20X,E10.2)') LJDAY2,LUX2
RETURN
END SUBROUTINE LIGHTOUT

!*****************************************************************************************************
**********************************
!**                                              S U B R O U T I N E  D A I L Y  G R O W T H
**
!*****************************************************************************************************
**********************************

SUBROUTINE DAILY_GROWTH
 USE MAINW2; USE FISH; USE FISH2; USE BIOEXPDATATRANSFORM; USE DIAGNOSTIC; USE ROOSEVELT; USE
MOVEMENT
! UPDATE MASS & STOMACH CAPACITY
! GENERAL EQUATION
  IF(GMTPCELL) THEN
    DO K = KTI(I),KBI(I)
      F1(K,I,1) = F1(K,I,1) + F_G(K,I)
      IF(F1(K,I,1).LE.253.5) THEN ! UPDATE STOMACH CAPACITY (BRETT, 1971)
        F1(K,I,5) = (14.1-4.95*LOG10(F1(K,I,1)))/100.0*F1(K,I,1)
      ELSE
        F1(K,I,5) = 0.0022*F1(K,I,1)
      END IF
      MAXM(I) = MAX(MAXM(I),F1(K,I,1))  ! MAXMASS
```

```
        MAXG(I) = MAX(MAXG(I),F_G(K,I))    ! MAXGROWTH
      END DO
    END IF
    IF(GMTPFXN) THEN
      DO K = KTI(I),KBI(I)
        F1(K,I,1) = GIM*EXP(GALP*(JDAY-GTI))
        IF(F1(K,I,1).LE.253.5) THEN ! UPDATE STOMACH CAPACITY (BRETT, 1971)
          F1(K,I,5) = (14.1-4.95*LOG10(F1(K,I,1)))/100.0*F1(K,I,1)
        ELSE
          F1(K,I,5) = 0.0022*F1(K,I,1)
        END IF
        MAXM(I) = MAX(MAXM(I),F1(K,I,1))   ! MAXMASS
        MAXG(I) = MAX(MAXG(I),F_G(K,I))    ! MAXGROWTH
      END DO
    END IF
    IF(GMTPFIXED) THEN
      CONTINUE
    END IF
    IF(GMTPUSER) THEN
      READ(FXNFN(1),'(2F8.0)') F1J,F1M
        F1(:,I,1) = F1M
        IF(INT(JDAY).NE.INT(F1J)) THEN
        PRINT *,'POSSIBLE PRESCRIBED MASS ERROR :',F1J,JDAY
      END IF
    END IF
  IF(BESTCALC) THEN
    IF(BMTPSEG) THEN
      DO K = KTI(I),KBI(I)
        BF1(K,I,1) = BF1(K,I,1) + BF_GI(I)
        IF(BF1(K,I,1).LE.253.5) THEN ! UPDATE STOMACH CAPACITY (BRETT, 1971)
          BF1(K,I,5) = (14.1-4.95*LOG10(BF1(K,I,1)))/100.0*BF1(K,I,1)
        ELSE
          BF1(K,I,5) = 0.022*BF1(K,I,1)
        END IF
      END DO
    END IF
    IF(BMTPFXN) THEN
      DO K = KTI(I)-1,KBI(I)+1
        BF1(K,I,1) = BIM*EXP(BALP*(JDAY-BTI))
        IF(BF1(K,I,1).LE.253.5) THEN ! UPDATE STOMACH CAPACITY (BRETT, 1971)
```

```
          BF1(K,I,5) = (14.1-4.95*LOG10(BF1(K,I,1)))/100.0*BF1(K,I,1)
        ELSE
          BF1(K,I,5) = 0.022*BF1(K,I,1)
        END IF
      END DO
    END IF
    IF(BMTPFIXED) THEN
      CONTINUE
    END IF
    IF(BMTPUSER) THEN
      READ(FXNFN(2),'(2F8.0)') F1J,F1M
        BF1(:,I,1) = F1M
        IF(INT(JDAY).NE.INT(F1J)) THEN
        PRINT *,'POSSIBLE PRESCRIBED MASS ERROR :',F1J,JDAY
      END IF
    END IF
  END IF
IF(DIELCALC) THEN
  IF(DMTPSEG) THEN
    DO K = KTI(I),KBI(I)
      DF1(K,I,1) = DF1(K,I,1) + DF_GI(I)
      IF(DF1(K,I,1).LE.253.5) THEN ! UPDATE STOMACH CAPACITY (BRETT, 1971)
        DF1(K,I,5) = (14.1-4.95*LOG10(DF1(K,I,1)))/100.0*DF1(K,I,1)
      ELSE
        DF1(K,I,5) = 0.022*DF1(K,I,1)
      END IF
    END DO
  END IF
  IF(DMTPFXN) THEN
    DO K = KTI(I),KBI(I)
      DF1(K,I,1) = DIM*EXP(DALP*(JDAY-DTI))
      IF(DF1(K,I,1).LE.253.5) THEN ! UPDATE STOMACH CAPACITY (BRETT, 1971)
        DF1(K,I,5) = (14.1-4.95*LOG10(DF1(K,I,1)))/100.0*DF1(K,I,1)
      ELSE
        DF1(K,I,5) = 0.022*DF1(K,I,1)
      END IF
    END DO
  END IF
  IF(DMTPFIXED) THEN
    CONTINUE
```

```
  END IF
  IF(DMTPUSER) THEN
    READ(FXNFN(3),'(2F8.0)') F1J,F1M
      DF1(:,I,1) = F1M
      IF(INT(JDAY).NE.INT(F1J)) THEN
      PRINT *,'POSSIBLE PRESCRIBED MASS ERROR :',F1J,JDAY
    END IF
  END IF
END IF
END SUBROUTINE DAILY_GROWTH

!*****************************************************************************************************
*********************************
!**                                        S U B R O U T I N E   F I S H O U T P U T   D A I L Y
**
!*****************************************************************************************************
*********************************

SUBROUTINE FOUTPUT_DAILY
USE MAINW2; USE FISH; USE FISH2;USE BIOEXPDATATRANSFORM; USE GROWTH_ANIMATION; USE DIAGNOSTIC; USE
ROOSEVELT; USE MOVEMENT

  IF(FISHDIAG) THEN
    DO K = KTI(I),KBI(I)
       WRITE(BIOOUTFN(1),77771)
JDAY,I,F_G(K,I),F1(K,I,1),CELL_PER(I),FULLSTO(K,I),VISIBLE(K,I),T1Z(K,I)
      END DO
      77771 FORMAT(F8.3,X,I8,X,F8.4,X,2(F8.2,X),I8,X,2(F8.2,X))
      77871 FORMAT(F8.3,X,I8,X,F8.4,X,2(F8.2,X),I8,X,2(F8.2,X),F8.5)
    IF(SURFDIAG) THEN
       K = KTI(I)
      WRITE(BIOOUTFN(16),77771)
JDAY,I,F_G(K,I),F1(K,I,1),CELL_PER(I),FULLSTO(K,I),VISIBLE(K,I),T1Z(K,I)
      END IF
      IF(BESTCALC) THEN
        K = KTI(I)
      WRITE(BIOOUTFN(2),77871)
JDAY,I,BF_GI(I),BF1(K,I,1),BCELL_PER(I),BFULLSTOI(I),BVISIBLE(I),T1BZ(I),GAMMAFDC(K,I)
      END IF
      IF(DIELCALC) THEN
```

```
        K = KTI(I)
       WRITE(BIOOUTFN(3),77771)
JDAY,I,DF_GI(I),DF1(K,I,1),DCELL_PER(I),DFULLSTOI(I),DVISIBLE(I),T1Z(K,I)
       END IF
  END IF ! FISHDIAG
  IF(BIOPARDIAG) THEN
    DO K = KTI(I),KBI(I)
        WRITE(BIOOUTFN(4),77772)
JDAY,I,F_G(K,I),F_D(K,I),F_R(K,I),F_S(K,I),F_W(K,I),F_U(K,I),F_F(K,I)
       END DO
       77772 FORMAT(F8.3,X,I8,X,7(F8.1,X))
    IF(SURFDIAG) THEN
        K = KTI(I)
       WRITE(BIOOUTFN(17),77772)
JDAY,I,F_G(K,I),F_D(K,I),F_R(K,I),F_S(K,I),F_W(K,I),F_U(K,I),F_F(K,I)
       END IF
       IF(BESTCALC) THEN
         K = KTI(I)
         WRITE(BIOOUTFN(5),77772)
JDAY,I,BF_GI(I),BF_DI(I),BF_RI(I),BF_SI(I),BF_WI(I),BF_UI(I),BF_FI(I)
       END IF
       IF(DIELCALC) THEN
         K = KTI(I)
         WRITE(BIOOUTFN(6),77772)
JDAY,I,DF_GI(I),DF_DI(I),DF_RI(I),DF_SI(I),DF_WI(I),DF_UI(I),DF_FI(I)
       END IF
  END IF ! BIOPARDIAG
  IF(CONSDIAG) THEN
    DO K = KTI(I),KBI(I)
        WRITE(BIOOUTFN(7),77773)
JDAY,I,CEFF(K),AVEC(K,I),MINC(K,I),MAXC(K,I),DAYC(K,I),DAYCM(K,I),DIET(K,I,1),DIET(K,I,2),&
          DIET(K,I,3),FCONMAXJ(K,I),FCONMAXGG(K,I),FCONJ(K,I),FCONGG(K,I),FCONP(K,I)
       END DO
       77773 FORMAT(F8.3,X,I8,X,5(F8.1,X),F8.2,X,3(F8.2,X),2(F8.1,X,F8.4,X),F8.3,X)
       77873 FORMAT(F8.3,X,I8,X,5(F8.1,X),F8.2,X,3(F8.2,X),2(F8.1,X,F8.4,X),2(F8.3,X))
    IF(SURFDIAG) THEN
        K = KTI(I)
       WRITE(BIOOUTFN(18),77773)
JDAY,I,CEFF(K),AVEC(K,I),MINC(K,I),MAXC(K,I),DAYC(K,I),DAYCM(K,I),DIET(K,I,1),DIET(K,I,2),&
          DIET(K,I,3),FCONMAXJ(K,I),FCONMAXGG(K,I),FCONJ(K,I),FCONGG(K,I),FCONP(K,I)
```

```
      END IF
      IF(BESTCALC) THEN
        K = KTI(I)
        WRITE(BIOOUTFN(8),77873)
JDAY,I,CEFF(K),BAVEC(I),BMINC(I),BMAXC(I),BDAYCI(I),BDAYCMI(I),BDIETI(I,1),BDIETI(I,2),BDIETI(I,3),&
          BFCONMAXJI(I),BFCONMAXGGI(I),BFCONJI(I),BFCONGGI(I),BFCONPI(I),T1BZ(I)
      END IF
    IF(DIELCALC) THEN  ! NEED TO ADD TERMS
      K = KTI(I)
      WRITE(BIOOUTFN(9),77773)
JDAY,I,CEFF(K),DAVEC(I),DMINC(I),DMAXC(I),DDAYCI(I),DDAYCMI(I),DDIETI(I,1),DDIETI(I,2),DDIETI(I,3),&
        DFCONMAXJI(I),DFCONMAXGGI(I),DFCONJI(I),DFCONGGI(I),DFCONPI(I)
    END IF
  END IF ! CONSDIAG
  IF(DIGDIAG) THEN
    DO K = KTI(I),KBI(I)
       WRITE(BIOOUTFN(10),77774)
JDAY,I,F_D(K,I),F_DINI(K,I),F_DCON(K,I),F_DUNDIG(K,I),F1(K,I,3),F1(K,I,5),F1(K,I,4)
      END DO
      77774 FORMAT(F8.3,X,I8,X,4(F8.1X),3(F8.2,X))
    IF(SURFDIAG) THEN
       K = KTI(I)
      WRITE(BIOOUTFN(19),77774)
JDAY,I,F_D(K,I),F_DINI(K,I),F_DCON(K,I),F_DUNDIG(K,I),F1(K,I,3),F1(K,I,5),F1(K,I,4)
      END IF
      IF(BESTCALC) THEN ! ADD THE DIGESTIVE DIAGNOSTIC TERMS TO THE CODE
        K = KTI(I)
        WRITE(BIOOUTFN(11),77774)
JDAY,I,BF_DI(I),F_DINI(K,I),F_DCON(K,I),F_DUNDIG(K,I),BF1(K,I,3),BF1(K,I,5),BF1(K,I,4)
      END IF
    IF(DIELCALC) THEN   ! NEED TO ADD TERMS
      K = KTI(I)
      WRITE(BIOOUTFN(12),77774)
JDAY,I,DF_DI(I),F_DINI(K,I),F_DCON(K,I),F_DUNDIG(K,I),DF1(K,I,3),DF1(K,I,5),DF1(K,I,4)
    END IF
  END IF ! DIGDIAG
  IF(RESPDIAG) THEN
    DO K = KTI(I),KBI(I)
       WRITE(BIOOUTFN(13),77775) JDAY,I,F_R(K,I),FACTAVE(K,I),FVELAVE(K,I)
      END DO
```

```
      77775 FORMAT(F8.3,X,I8,X,F8.1,X,2(F8.3,X))
    IF(SURFDIAG) THEN
        K = KTI(I)
      WRITE(BIOOUTFN(20),77775) JDAY,I,F_R(K,I),FACTAVE(K,I),FVELAVE(K,I)
      END IF
      IF(BESTCALC) THEN
        K = KTI(I)
        WRITE(BIOOUTFN(14),77775) JDAY,I,BF_RI(I),BFACTAVE(I),BFVELAVE(I)
      END IF
      IF(DIELCALC) THEN
        K = KTI(I)
        WRITE(BIOOUTFN(15),77775) JDAY,I,DF_RI(I),DFACTAVE(I),DFVELAVE(I)
      END IF
  END IF ! RESPDIAG
GOTO 2121
  IF(SINGLEDIAG.AND.DEPTHCALC) THEN
    IF(I.EQ.SINIBIO) THEN
      DO II = 1, BESTSTEP
          WRITE(BIOOUTFN(21),'(4I8)') INT(JDAY-0.5), I, BESTK(I,II),DIELK(I,II)
      END DO
    END IF
  END IF
2121 CONTINUE
RETURN
END SUBROUTINE FOUTPUT_DAILY

!*******************************************************************************************************
*********************************
!**                                        S U B R O U T I N E   B I O E X P T R A N S F O R M
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!*******************************************************************************************************
*********************************

! KTI,KBI ARE NOT W2 VALUES; NEED TO UPDATE TO INCORPORATE INTO W2
SUBROUTINE BIOEXPTRANSFORM
USE MAINW2; USE FISH; USE FISH2; USE BIOEXPDATATRANSFORM; USE GROWTH_ANIMATION; USE DIAGNOSTIC; USE
ROOSEVELT; USE MOVEMENT
GOTO 5001
REWIND(BIOINFN(JI))
READ(BIOINFN(JI),'(A72)') FRED
```

```
FIRSTK = -1; LASTK = -1
DO K = 1,10000000
  READ(BIOINFN(JI),'(F8.0)') ZDAY1
  IF(ZDAY1.LT.FBIODAYLST) FIRSTK = K
  IF(ZDAY1.LT.FBIODAYNXT) LASTK = K
  IF(ZDAY1.GE.FBIODAYNXT) EXIT
END DO
! POSITION CURSOR TO READ THE INTENDED DAY
REWIND(BIOINFN(JI))
READ(BIOINFN(JI),'(A72)') FRED
DO K = 1, FIRSTK
  READ(BIOINFN(JI),'(F8.0)') ZDAY1
END DO
KTI(I) = 2; KBI(I) = LASTK-FIRSTK
IF(KBI(I).LT.KTI(I)) KBI(I) = KTI(I)
5001 CONTINUE
IF(FIRSTREAD(JI)) THEN
 REWIND(BIOINFN(JI))
 READ(BIOINFN(JI),'(A72)') FRED
 FIRSTREAD(JI) = .FALSE.
END IF
 DO K = 2,10000000
   READ(BIOINFN(JI),'(F8.0)') ZDAY1
   IF(ZDAY1.LT.FBIODAYNXT) LASTK = K
   IF(ZDAY1.GE.FBIODAYNXT) EXIT
 END DO
 DO K = 2,LASTK+1
   BACKSPACE(BIOINFN(JI))
 END DO
KTI(I) = 2; KBI(I) = LASTK
DO K = KTI(I),KBI(I) ! WILL NEED TO CONVERT C2 (:,:,JZ) FROM NZP TO NZOOS,NZOOE FOR MAIN W2 PROGRAM
  READ(BIOINFN(JI),'(F8.0,8X,3F8.2,3F8.3,I8,2F8.0,A20)') ZDAY1,DEPTHM(K,I),T1(K,I),GAMMA(K,I),&
       (C2(K,I,JZ),JZ=1,NZP),SEGK,BH(K,I),EL(K,I),GREGORY(GRCT)
 ! T1Z(K,I) = T1Z(K,I) - 1.0 !temperature sensitivity
  T1Z(K,I) = MAX(T1(K,I)-1,0.01) ! TEMPERATURES BELOW FREEZING
  DO JJZ = 1,NZP
    C1Z(K,I,JJZ)=C2(K,I,JJZ)/MZOO(JJZ)/1000.0 !C1Z HAS UNITS OF ORGANISMS PER M3 ! CONVERT FROM MG
TO G
  END DO
  ! AVAILABILITY COMPUTATION (MAZUR)
```

```
  IF(THRESHOLD) THEN
    DAP_IN = C2(K,I,3)*1000.0
    IF(DAP_IN.GE.THRESHV) THEN
        THRESHFEED(K) = .TRUE.
      CEFF(K) = C1Z(K,I,3)*ZAVAIL(3)
    ELSE
        THRESHFEED(K) = .FALSE.
      CEFF(K) = (C1Z(K,I,1)*ZAVAIL(1)+C1Z(K,I,2)*ZAVAIL(2)+C1Z(K,I,3)*ZAVAIL(3))
    END IF
  ELSE
    CEFF(K) = (C1Z(K,I,1)*ZAVAIL(1)+C1Z(K,I,2)*ZAVAIL(2)+C1Z(K,I,3)*ZAVAIL(3))
  END IF !THRESHOLD
END DO
END SUBROUTINE BIOEXPTRANSFORM

!*****************************************************************************************************
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!**                                        S U B R O U T I N E   G E T  F I S H  D A T A
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!*****************************************************************************************************
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SUBROUTINE GETFISHDATA
USE MAINW2; USE FISH; USE FISH2; USE BIOEXPDATATRANSFORM; USE DIAGNOSTIC; USE ROOSEVELT; USE
MOVEMENT
  NUNIT = NUNIT+1; BIOCON = NUNIT
  OPEN(BIOCON,FILE='W2_BIO_CON.NPT',STATUS='OLD')
  DO II = 1,8
   READ(BIOCON,*)
  END DO
  READ(BIOCON,'(/(8X,A8,I8,4A8))') FCALC,FUF,FDIAGC,BESTC,DIELC,CMAXC
   FISHCALC = FCALC == '      ON'  ; FDIAG = FDIAGC == '      ON';BESTCALC = BESTC == '      ON'  ;
DIELCALC = DIELC == '      ON'
   CMAXCALC = CMAXC == '      ON'
  READ(BIOCON,'(//(8X,2F8.0))') JDAY, JEND
  READ(BIOCON,'(//(8X,8F8.0))') FISHT1,FISHT2,FISHT3,FISHT4,FISHK1,FISHK2,FISHK3,FISHK4
   FG1=(1/(FISHT2-FISHT1))*LOG((FISHK2*(1-FISHK1))/(FISHK1*(1-FISHK2)))
   FG2=(1/(FISHT4-FISHT3))*LOG((FISHK3*(1-FISHK4))/(FISHK4*(1-FISHK3)))
  READ(BIOCON,'(//(8X,F8.0))') FOXYCAL
  READ(BIOCON,'(//(8X,3F8.0))') (F1I(II),II=1,3)
```

```
   F1(:,:,1) = F1I(1); F1(:,:,2) = F1I(2); F1(:,:,3) = F1I(3)
  READ(BIOCON,'(/)')
  READ(BIOCON,'(:8X,9F8.0)') (LZOO(II),II = 1,3)
  READ(BIOCON,'(/)')
  READ(BIOCON,'(:8X,9F8.0)') (MZOO(II),II = 1,3)
  READ(BIOCON,'(/)')
  READ(BIOCON,'(:8X,9F8.0)') (EZOO(II),II = 1,3)
  READ(BIOCON,'(//(8X,4F8.0,A8,F8.0,I8,F8.0))')
HANDLE,FVELA,FVELB,FVELE,THRESHC,THRESHV,THRESHZ,DIELLUX
   THRESHOLD = THRESHC == '      ON'
  READ(BIOCON,'(//(8X,A8))') FGPC
   FGPPLOT = FGPC == '      ON'
  READ(BIOCON,'(//(8X,F8.0))') FGPD
  READ(BIOCON,'(//(8X,F8.0))') FGPF
  READ(BIOCON,'(//(8X,3A8))') GENMTP,BESTMTP,DIELMTP
   GMTPCELL = GENMTP  == '    CELL';GMTPFXN = GENMTP  == '      FXN';GMTPUSER = GENMTP  == '
USER';GMTPFIXED = GENMTP  == '   FIXED'
   BMTPSEG  = BESTMTP == '     SEG';BMTPFXN = BESTMTP == '      FXN';BMTPUSER = BESTMTP == '
USER';DMTPFIXED = BESTMTP == '   FIXED'
   DMTPSEG  = DIELMTP == '     SEG';DMTPFXN = DIELMTP == '      FXN';DMTPUSER = DIELMTP == '
USER';BMTPFIXED = DIELMTP == '   FIXED'
   IF(GMTPCELL.OR.GMTPFXN.OR.GMTPUSER.OR.GMTPFIXED) GMTOK = .TRUE.
   IF(BMTPSEG.OR.BMTPFXN.OR.BMTPUSER.OR.BMTPFIXED) BMTOK = .TRUE.
   IF(DMTPSEG.OR.DMTPFXN.OR.DMTPUSER.OR.DMTPFIXED) DMTOK = .TRUE.
   IF(.NOT.GMTOK) THEN
     PRINT *,'GENERAL FISH MASS TYPE NOT RECOGNIZED: ',GENMTP
       STOP
   END IF
   IF(.NOT.BMTOK) THEN
     PRINT *,'BEST FISH MASS TYPE NOT RECOGNIZED: ',BESTMTP
       STOP
   END IF
   IF(.NOT.DMTOK) THEN
     PRINT *,'FORAGING FISH MASS TYPE NOT RECOGNIZED: ',DIELMTP
       STOP
   END IF
  READ(BIOCON,'(//(8X,9F8.0))') GIM,BIM,DIM,GALP,BALP,DALP,GTI,BTI,DTI
  READ(BIOCON,'(//(8X,7A8))') FISHC, BIOPARC, CONSC, DIGC, RESPC, SURFC,DEPTHC
   FISHDIAG = FISHC  == '      ON'; BIOPARDIAG = BIOPARC  == '      ON'; CONSDIAG = CONSC   == '
ON'
```

```
   DIGDIAG  = DIGC   == '      ON'; RESPDIAG   = RESPC    == '      ON'; SURFDIAG = SURFC   == '
ON'
   DEPTHCALC= DEPTHC == '      ON'
  READ(BIOCON,'(//(8X,A8,2I8,A8))') SINGLEC, SINGFN, SINIBIO,TLC
   SINGLEDIAG   = SINGLEC    == '      ON'
   IF(SINGLEDIAG) TLCALC = TLC    == '      ON'
   IF(TLCALC) THEN
     NUNIT = NUNIT + 1; TLCALCFN = NUNIT
       OPEN(TLCALCFN,FILE='TLDIAG.DAT',STATUS='UNKNOWN')
       WRITE(TLCALCFN,'(2A8)') '    TEMP','      TL'
   END IF
  READ(BIOCON,'(//(8X,A72))') ZAVFNAME
   FRED = ADJUSTL(ZAVFNAME)
   L      = LEN_TRIM(FRED)
   ZAVFNAME = FRED(1:L)
   NUNIT = NUNIT+1; ZAVFN = NUNIT
  READ(BIOCON,'(/)')
   DO II = 1,NWB
     NUNIT = NUNIT+1; FGPFN = NUNIT
     READ(BIOCON,'(8X,A72)') FGPFNAME(II)
      FRED = ADJUSTL(FGPFNAME(II))
      L      = LEN_TRIM(FRED)
      FGPFNAME(II) = FRED(1:L)
   END DO
   READ(BIOCON,'(//(8X,A72))') FXNFNAME(1)
   READ(BIOCON,'((8X,A72))')   FXNFNAME(2)
   READ(BIOCON,'((8X,A72))')   FXNFNAME(3)
   DO II = 1,3
     FRED = ADJUSTL(FXNFNAME(II))
     L      = LEN_TRIM(FRED)
     FXNFNAME(II) = FRED(1:L)
     NUNIT = NUNIT+1; FXNFN(II) = NUNIT
   END DO
   IF(GMTPUSER) THEN
     OPEN(FXNFN(1),FILE=FXNFNAME(1),STATUS='OLD')
       READ(FXNFN(1),'(///)')
   END IF
   IF(BMTPUSER) THEN
     OPEN(FXNFN(2),FILE=FXNFNAME(2),STATUS='OLD')
       READ(FXNFN(2),'(///)')
```

```
   END IF
   IF(DMTPUSER) THEN
     OPEN(FXNFN(3),FILE=FXNFNAME(3),STATUS='OLD')
       READ(FXNFN(3),'(///)')
   END IF
CLOSE(BIOCON)
RETURN
END SUBROUTINE GETFISHDATA

!*****************************************************************************************************
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!**                                          S U B R O U T I N E   A N I M A T I O N   D A T A
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!*****************************************************************************************************
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SUBROUTINE ANIMATION_DATA
USE MAINW2; USE FISH; USE FISH2; USE BIOEXPDATATRANSFORM; USE GROWTH_ANIMATION; USE ROOSEVELT; USE
MOVEMENT

NELEM = 0
DO JJI = 1,NIBIO
 IF(ANIMEXP(JJI)) THEN
  II = IBIO(JJI)
  DO K = KTI(II),KBI(II)
   NELEM = NELEM+1
  END DO
 END IF
END DO
NNODE = NELEM*4
WRITE(ANIMFN,906) NNODE,NELEM
906 FORMAT('ZONE N=',i5,' E=',i6,', F=FEPOINT, ET=QUADRILATERAL')
LEFT = 0.0
DO JJI = 1,NIBIO
 IF(ANIMEXP(JJI)) THEN
  II = IBIO(JJI)
  DO K = KTI(II),KBI(II)
    IF(JJI.EQ.1) THEN
        X1(K,II) = 0.0; X4(K,II) = 0.0
    ELSE
```

```
          X1(K,II) = LEFT(1); X4(K,II) = LEFT(1)
        END IF
        X2(K,II) = DISTR(II)     ; X3(K,II) = DISTR(II)
      IF(K.EQ.KTI(I)) THEN
       Y1(K,II) = EL(K+1,II)+3  ; Y2(K,II) = EL(K+1,II)+3
       Y3(K,II) = EL(K+1,II)+1  ; Y4(K,II) = EL(K+1,II)+1
      ELSE
       Y1(K,II) = EL(K,II)+1  ; Y2(K,II) = EL(K,II)+1
       Y3(K,II) = EL(K,II)-1  ; Y4(K,II) = EL(K,II)-1
      END IF
       WRITE(ANIMFN,'(f8.1,X,f7.2,X,f7.3)') X1(K,II),Y1(K,II), F_G(K,II)
       WRITE(ANIMFN,'(f8.1,X,f7.2,X,f7.3)') X2(K,II),Y2(K,II), F_G(K,II)
         WRITE(ANIMFN,'(f8.1,X,f7.2,X,f7.3)') X3(K,II),Y3(K,II), F_G(K,II)
       WRITE(ANIMFN,'(f8.1,X,f7.2,X,f7.3)') X4(K,II),Y4(K,II), F_G(K,II)
    END DO
    LEFT(1) = DISTR(II)
   END IF
  END DO
  DO IM=1,NELEM
    MPOS=IM*4
    WRITE(ANIMFN,'(4I6)')MPOS-3,MPOS-2,MPOS-1,MPOS
  END DO
  ZONECNT=ZONECNT+1
  END SUBROUTINE ANIMATION_DATA

  !*****************************************************************************************************
  ********************************
  !**                                    S U B R O U T I N E   B Y   S E G M E N T   O U T P U T
  **
  !*****************************************************************************************************
  ********************************

  SUBROUTINE BY_SEG_OUTPUT
  USE MAINW2; USE FISH; USE FISH2; USE BIOEXPDATATRANSFORM; USE GROWTH_ANIMATION; USE ROOSEVELT; USE
  MOVEMENT; USE DIAGNOSTIC

    WRITE(BYSEGMFN,'(F7.1,500(X,F6.2))') JDAY,(MAXM(IBIO(II)),II=1,NIBIO)
    WRITE(BYSEGGFN,'(F7.1,500(X,F6.2))') JDAY,(MAXG(IBIO(II)),II=1,NIBIO)
    IF(BESTCALC) THEN
      WRITE(BYSEGMFN2,'(F7.1,500(X,F6.2))') JDAY,(BF1(2,IBIO(II),1),II=1,NIBIO)
```

```
    WRITE(BYSEGGFN2,'(F7.1,500(X,F6.2))') JDAY,(BF_GI(IBIO(II)),II=1,NIBIO)
  END IF
  IF(DIELCALC) THEN
    WRITE(BYSEGMFN3,'(F7.1,500(X,F6.2))') JDAY,(DF1(2,IBIO(II),1),II=1,NIBIO)
    WRITE(BYSEGGFN3,'(F7.1,500(X,F6.2))') JDAY,(DF_GI(IBIO(II)),II=1,NIBIO)
  END IF
  WRITE(SURFSEGMFN,'(F7.1,500(X,F6.2))') JDAY,(F1(2,IBIO(II),1),II=1,NIBIO)
  WRITE(SURFSEGGFN,'(F7.1,500(X,F6.2))') JDAY,(F_G(2,IBIO(II)),II=1,NIBIO)
END SUBROUTINE BY_SEG_OUTPUT

!*******************************************************************************************************
*********************************
!**                                    S U B R O U T I N E   F I L E   S E T U P
**
!*******************************************************************************************************
*********************************

SUBROUTINE INITIALFILESETUP
USE MAINW2; USE FISH; USE FISH2; USE BIOEXPDATATRANSFORM; USE GROWTH_ANIMATION; USE ROOSEVELT; USE
MOVEMENT; USE DIAGNOSTIC

! *** ZOOPLANKTON AVAILABLITY ( REPLACE WITH INPUT FILE FORMAT (WILL NEED TIME CONTROL VARIABLES))
OPEN(ZAVFN,FILE=ZAVFNAME,STATUS='OLD')
READ(ZAVFN,'(//)')
ZAVJD = -9999.99
DO WHILE (ZAVJD.LT.JDAY)
  READ(ZAVFN,'(:F8.0,9F8.0)')  ZAVJD,(ZAVAIL(II),II=1,NZP)
END DO
  READ(ZAVFN,'(:F8.0,9F8.0)')  ZAVNX,(ZAVAILNX(II),II=1,NZP)
! *** ASSIGN BIOEXP DATA FILE NUMBERS AND FILENAMES
  DO JI = 1,NIBIO
   IF(FIRST_BIO(JI)) THEN
    NUNIT = NUNIT +1; BIOINFN(JI) = NUNIT
        WRITE (SEGNUM,'(I0)') JI
        SEGNUM = ADJUSTL(SEGNUM)
        L      = LEN_TRIM(SEGNUM)
        OPEN   (BIOINFN(JI),FILE='BIOEXP_'//SEGNUM(1:L)//'.opt',STATUS='OLD')
    END IF
  END DO
IF(SINGLEDIAG) THEN
```

```
  NIBIO = 1.0
  BIOINFN(1) = BIOINFN(SINGFN)
  IBIO(1) = SINIBIO
END IF

! *********   RESULTS AND DIAGNOSTIC OUTPUT FILES *******
IF(FDIAG) THEN
  IF(FISHDIAG) THEN
    NUNIT = NUNIT+1; BIOOUTFN(1) = NUNIT; OPEN(BIOOUTFN(1),FILE='BIO_FISH.DAT',STATUS='UNKNOWN')
    FHEAD(1) = 'JDAY'    ;FHEAD(2) = 'SEG'      ;FHEAD(3) = 'GROWTH'  ;FHEAD(4) = 'FMASS'   ;FHEAD(5)
= '%POS'    ;&
    FHEAD(6) = 'FULLSTO';FHEAD(7) = 'LIGHTMIN';FHEAD(8) = 'TEMP'
    WRITE(BIOOUTFN(1),'(8(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,8)
    IF(SURFDIAG) THEN
      NUNIT = NUNIT+1; BIOOUTFN(16) = NUNIT;
OPEN(BIOOUTFN(16),FILE='BIO_FISH_SURF.DAT',STATUS='UNKNOWN')
      WRITE(BIOOUTFN(16),'(8(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,8)
    END IF
    IF(BESTCALC) THEN
    NUNIT = NUNIT+1; BIOOUTFN(2) = NUNIT;
OPEN(BIOOUTFN(2),FILE='BIO_FISH_BEST.DAT',STATUS='UNKNOWN')
      WRITE(BIOOUTFN(2),'(8(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,8)
    END IF
    IF(DIELCALC) THEN
    NUNIT = NUNIT+1; BIOOUTFN(3) = NUNIT;
OPEN(BIOOUTFN(3),FILE='BIO_FISH_DIEL.DAT',STATUS='UNKNOWN')
      WRITE(BIOOUTFN(3),'(8(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,8)
    END IF
  END IF ! FISHDIAG
  IF(BIOPARDIAG) THEN
    NUNIT = NUNIT+1; BIOOUTFN(4) = NUNIT; OPEN(BIOOUTFN(4),FILE='BIO_PARA.DAT',STATUS='UNKNOWN')
    FHEAD(1) = 'JDAY'    ;FHEAD(2) = 'SEG'      ;FHEAD(3) = 'GROWTH'  ;FHEAD(4) = 'DIGEST'  ;FHEAD(5)
= 'RESP'    ;&
    FHEAD(6) = 'SDA'     ;FHEAD(7) = 'WASTE'    ;FHEAD(8) = 'EXCRETE' ;FHEAD(9) = 'EGEST'
    WRITE(BIOOUTFN(4),'(9(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,9)
    IF(SURFDIAG) THEN
      NUNIT = NUNIT+1; BIOOUTFN(17) = NUNIT;
OPEN(BIOOUTFN(17),FILE='BIO_PARA_SURF.DAT',STATUS='UNKNOWN')
      WRITE(BIOOUTFN(17),'(9(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,9)
    END IF
```

```
      IF(BESTCALC) THEN
      NUNIT = NUNIT+1; BIOOUTFN(5) = NUNIT;
OPEN(BIOOUTFN(5),FILE='BIO_PARA_BEST.DAT',STATUS='UNKNOWN')
        WRITE(BIOOUTFN(5),'(9(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,9)
      END IF
      IF(DIELCALC) THEN
      NUNIT = NUNIT+1; BIOOUTFN(6) = NUNIT;
OPEN(BIOOUTFN(6),FILE='BIO_PARA_DIEL.DAT',STATUS='UNKNOWN')
        WRITE(BIOOUTFN(6),'(9(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,9)
      END IF
  END IF ! BIOPARDIAG
  IF(CONSDIAG) THEN
    NUNIT = NUNIT+1; BIOOUTFN(7) = NUNIT; OPEN(BIOOUTFN(7),FILE='BIO_CONS.DAT',STATUS='UNKNOWN')
    FHEAD(1) = 'JDAY'    ;FHEAD(2) = 'SEG'     ;FHEAD(3) = 'PREYDEN' ;FHEAD(4) = 'AVEC'    ;FHEAD(5)
= 'MINC'    ;&
    FHEAD(6) = 'MAXC'    ;FHEAD(7) = '#CON'    ;FHEAD(8) = 'MASSCON' ;FHEAD(9) = 'DIET1'
;!FHEAD(10)= 'DIET1'   ;&
    FHEAD(10)= 'DIET2'   ;FHEAD(11)= 'DIET3'   ;FHEAD(12)= 'MAXC_J'  ;FHEAD(13)=
'MAXC_G/G';FHEAD(14)= 'ACTC_J'  ;&
      FHEAD(15)= 'ACTC_G/G';FHEAD(16)= 'P_VALUE'
      WRITE(BIOOUTFN(7),'(16(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,16)
    IF(SURFDIAG) THEN
      NUNIT = NUNIT+1; BIOOUTFN(18) = NUNIT;
OPEN(BIOOUTFN(18),FILE='BIO_CONS_SURF.DAT',STATUS='UNKNOWN')
        WRITE(BIOOUTFN(18),'(16(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,16)
      END IF
      IF(BESTCALC) THEN
      NUNIT = NUNIT+1; BIOOUTFN(8) = NUNIT;
OPEN(BIOOUTFN(8),FILE='BIO_CONS_BEST.DAT',STATUS='UNKNOWN')
        WRITE(BIOOUTFN(8),'(16(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,16)
      END IF
      IF(DIELCALC) THEN
      NUNIT = NUNIT+1; BIOOUTFN(9) = NUNIT;
OPEN(BIOOUTFN(9),FILE='BIO_CONS_DIEL.DAT',STATUS='UNKNOWN')
        WRITE(BIOOUTFN(9),'(16(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,16)
      END IF
  END IF ! CONSDIAG
  IF(DIGDIAG) THEN
    NUNIT = NUNIT+1; BIOOUTFN(10) = NUNIT; OPEN(BIOOUTFN(10),FILE='BIO_DIG.DAT',STATUS='UNKNOWN')
```

```
    FHEAD(1) = 'JDAY'    ;FHEAD(2) = 'SEG'     ;FHEAD(3) = 'DIG_J'   ;FHEAD(4) = 'INITIAL' ;FHEAD(5)
= 'CONSUMED';&
    FHEAD(6) = 'UNDIGEST';FHEAD(7) = 'STOMCON' ;FHEAD(8) = 'STOMCAP' ;FHEAD(9) = 'EDENSITY'
      FHEAD(16)= 'ACTC_G/G';FHEAD(17)= 'P_VALUE'
      WRITE(BIOOUTFN(10),'(9(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,9)
    IF(SURFDIAG) THEN
      NUNIT = NUNIT+1; BIOOUTFN(19) = NUNIT;
OPEN(BIOOUTFN(19),FILE='BIO_DIG_SURF.DAT',STATUS='UNKNOWN')
      WRITE(BIOOUTFN(19),'(9(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,9)
    END IF
    IF(BESTCALC) THEN
    NUNIT = NUNIT+1; BIOOUTFN(11) = NUNIT;
OPEN(BIOOUTFN(11),FILE='BIO_DIG_BEST.DAT',STATUS='UNKNOWN')
      WRITE(BIOOUTFN(11),'(9(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,9)
    END IF
    IF(DIELCALC) THEN
    NUNIT = NUNIT+1; BIOOUTFN(12) = NUNIT;
OPEN(BIOOUTFN(12),FILE='BIO_DIG_DIEL.DAT',STATUS='UNKNOWN')
      WRITE(BIOOUTFN(12),'(9(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,9)
    END IF
  END IF ! DIGDIAG
  IF(RESPDIAG) THEN
    NUNIT = NUNIT+1; BIOOUTFN(13) = NUNIT; OPEN(BIOOUTFN(13),FILE='BIO_RESP.DAT',STATUS='UNKNOWN')
    FHEAD(1) = 'JDAY'    ;FHEAD(2) = 'SEG'     ;FHEAD(3) = 'RESP_J'  ;FHEAD(4) = 'FACTAVE' ;FHEAD(5)
= 'FVELAVE'
      WRITE(BIOOUTFN(13),'(5(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,5)
    IF(SURFDIAG) THEN
      NUNIT = NUNIT+1; BIOOUTFN(20) = NUNIT;
OPEN(BIOOUTFN(20),FILE='BIO_RESP_SURF.DAT',STATUS='UNKNOWN')
      WRITE(BIOOUTFN(20),'(5(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,5)
    END IF
    IF(BESTCALC) THEN
    NUNIT = NUNIT+1; BIOOUTFN(14) = NUNIT;
OPEN(BIOOUTFN(14),FILE='BIO_RESP_BEST.DAT',STATUS='UNKNOWN')
      WRITE(BIOOUTFN(14),'(5(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,5)
    END IF
    IF(DIELCALC) THEN
    NUNIT = NUNIT+1; BIOOUTFN(15) = NUNIT;
OPEN(BIOOUTFN(15),FILE='BIO_RESP_DIEL.DAT',STATUS='UNKNOWN')
      WRITE(BIOOUTFN(15),'(5(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,5)
```

```
      END IF
  END IF ! RESPDIAG
  IF(SINGLEDIAG) THEN
    IF(DEPTHCALC) THEN
     NUNIT = NUNIT +1; BIOOUTFN(21) = NUNIT;
OPEN(BIOOUTFN(21),FILE='FORAGING_DEPTHS.DAT',STATUS='UNKNOWN')
     FHEAD(1) = 'JDAY'    ;FHEAD(2) = 'SEG'     ;FHEAD(3) = 'BESTDTH'  ;FHEAD(4) = 'DIELDTH'
       WRITE(BIOOUTFN(21),'(4(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,4)
    END IF
  END IF
END IF ! FDIAG

! ***********  GROWTH ANIMATION OUTPUT FILE  *************************
    NUNIT = NUNIT+1; ANIMFN = NUNIT
    OPEN(ANIMFN,FILE='FGP_ANIM.DAT',STATUS='UNKNOWN') ! BASIC OUTPUT
  WRITE(ANIMFN,'(A52)') HEADER1
  WRITE(ANIMFN,'(A52)') HEADER2
    IF(BESTCALC) THEN
      NUNIT = NUNIT+1; ANIMFN2 = NUNIT
      OPEN(ANIMFN2,FILE='FGP_ANIM_BEST.DAT',STATUS='UNKNOWN') ! BEST LOCATION OUTPUT
      WRITE(ANIMFN2,'(A52)') HEADER1
      WRITE(ANIMFN2,'(A52)') HEADER2
    END IF
  ! PREP DISTANCE VALUES (TEMPORARY APPROACH)
  NUNIT = NUNIT+1
  OPEN(NUNIT,FILE='DLX.PRN',STATUS='OLD')
  READ(NUNIT,*)
  DO J = 1,1000
    READ(NUNIT,'(I8,8X,2F8.0)',END=107) I,VLL,VLR
    DISTL(I) = VLL; DISTR(I) = VLR
  END DO
107 CONTINUE
  ! REMOVE ZEROS
  DO J = 2,IMX
    IF(DISTR(J).EQ.0.0) THEN
        DISTR(J) = DISTR(J-1)
      END IF
  END DO
  ! FIX ERRORS
  DO II = 2,NIBIO
```

```
      IF(DISTR(IBIO(II-1)).EQ.0.0) THEN
          PRINT *,'ZERO ', II-1, IBIO(II-1)
         ! DISTR(IBIO(II-1) = DISTR(IBIO(II
        END IF
      DISTL(IBIO(II)) = DISTR(IBIO(II-1))
        IF(DISTL(IBIO(II)).NE.DISTR(IBIO(II-1)) ) THEN
          PRINT *,'NE ', II, IBIO(II)
        END IF
    END DO
   CLOSE(NUNIT)

  ! *********** BYSEG FILE PREP  ******************
   IF(BYSEG) THEN
      NUNIT = NUNIT+1; BYSEGMFN = NUNIT
      OPEN(BYSEGMFN,FILE='MASS.DAT',STATUS='UNKNOWN')
      NUNIT = NUNIT+1; BYSEGGFN = NUNIT
      OPEN(BYSEGGFN,FILE='GROWTH.DAT',STATUS='UNKNOWN')
        WRITE(BYSEGMFN,'(A7,500(I6,A))') '    JDAY',((IBIO(II),'S'),II = 1,NIBIO)
      WRITE(BYSEGGFN,'(A7,500(I6,A))') '    JDAY',((IBIO(II),'S'),II = 1,NIBIO)
        IF(BESTCALC) THEN
        NUNIT = NUNIT+1; BYSEGMFN2 = NUNIT
        OPEN(BYSEGMFN2,FILE='MASS_BEST.DAT',STATUS='UNKNOWN')
        NUNIT = NUNIT+1; BYSEGGFN2 = NUNIT
        OPEN(BYSEGGFN2,FILE='GROWTH_BEST.DAT',STATUS='UNKNOWN')
          WRITE(BYSEGMFN2,'(A7,500(I6,A))') '    JDAY',((IBIO(II),'S'),II = 1,NIBIO)
        WRITE(BYSEGGFN2,'(A7,500(I6,A))') '    JDAY',((IBIO(II),'S'),II = 1,NIBIO)
        NUNIT = NUNIT+1; BESTDIAGFN = NUNIT
          OPEN(BESTDIAGFN,FILE='BESTDIAG.DAT',STATUS='UNKNOWN')
        END IF
        IF(DIELCALC) THEN
        NUNIT = NUNIT+1; BYSEGMFN3 = NUNIT
        OPEN(BYSEGMFN3,FILE='MASS_DIEL.DAT',STATUS='UNKNOWN')
        NUNIT = NUNIT+1; BYSEGGFN3 = NUNIT
        OPEN(BYSEGGFN3,FILE='GROWTH_DIEL.DAT',STATUS='UNKNOWN')
          WRITE(BYSEGMFN3,'(A7,500(I6,A))') '    JDAY',((IBIO(II),'S'),II = 1,NIBIO)
        WRITE(BYSEGGFN3,'(A7,500(I6,A))') '    JDAY',((IBIO(II),'S'),II = 1,NIBIO)
        END IF
      ! SURFACE SEGMENT
      NUNIT = NUNIT+1; SURFSEGMFN = NUNIT
      OPEN(SURFSEGMFN,FILE='MASS_SURF.DAT',STATUS='UNKNOWN')
```

```
! PROGRAM BIOENERGETICS
! MIKE MCKILLIP (2006)
! STOCKWELL AND JOHNSON APPROACH, AS SUGGESTED BY MAZUR AND BEAUCHAMP
! STAND ALONE PROGRAM FOR TESTING MODULES TO BE INCORPORATED WITH THE W2 CODE

!************************************
!   TASK B.1. MODULE DECLARATION
!************************************
MODULE MAINW2 ! REPETIION OF W2-CODE VARIABLES
 REAL*8,             ALLOCATABLE, DIMENSION (:,:)     :: DEPTHM,T1,GAMMA,BH,EL
 REAL*8,             ALLOCATABLE, DIMENSION (:,:,:)   :: C2
 REAL JDAY,JEND !BIOF = FREQUENCY OF BIOEXP OUTPUT
 REAL FBIONXT ! NEXT DAY TO GET CALCULATION INPUTS
 INTEGER,            ALLOCATABLE, DIMENSION(:)        :: BIOINFN
 INTEGER,            ALLOCATABLE, DIMENSION(:)        :: KTI,KBI
 INTEGER KMX, IMX,NUNIT,NZP,K,I,DLT,JI,NWB
 INTEGER NCT,JZ,NZOOS,NZOOE,NOD
 CHARACTER*72,       ALLOCATABLE, DIMENSION(:)        :: BIOINNAME
 CHARACTER*72 FRED,SEGNUM
END MODULE MAINW2
MODULE ROOSEVELT !THIS MODULE TAKEN FROM W2-ROOSEVELT; ALLOWs THE W2_ANC_CON.NPT TO BE READ
  INTEGER,           ALLOCATABLE, DIMENSION(:)        :: IBIO,BIODP,BIOEXPFN
  REAL*8,            ALLOCATABLE, DIMENSION(:)        :: BIOD, BIOF
  INTEGER,           ALLOCATABLE, DIMENSION(:,:)      :: NVIOL_LOC
  CHARACTER*8 NVIOLC, BIOC
  LOGICAL BIOEXP
  INTEGER NBIO,NIBIO
  REAL*8 NXBIO,NXTBIO,GAMMAB
  CHARACTER*72 BIOFN,WEIGHTFN
END MODULE ROOSEVELT
MODULE FISH ! FOR FISH BIOENERGETICS ROUTINE (DIRECT INCLUSION)
 REAL*8,             ALLOCATABLE, DIMENSION(:)        :: EZOO,LZOO,MZOO,FTL,F1I
 REAL*8,             ALLOCATABLE, DIMENSION(:,:)      :: FCON,FVEL,FACT,GAMMAFDC,FVELAVE,FACTAVE
 REAL*8,             ALLOCATABLE, DIMENSION(:,:,:)    :: F1
 REAL*8,             ALLOCATABLE, DIMENSION(:,:)      :: F2,AVEC,MINC,MAXC
 REAL*8,             ALLOCATABLE, DIMENSION(:,:)      :: F_F,F_U,F_D,F_R,F_S,F_C,F_G,F_W ! UNITS OF J
(DAILY SCALE)
 REAL*8,             ALLOCATABLE, DIMENSION(:,:)      :: F_G2
 REAL*8,             ALLOCATABLE, DIMENSION(:,:)      :: F_DINI,F_DCON,F_DUNDIG
 REAL*8,             ALLOCATABLE, DIMENSION(:,:)      :: DAYC,SRCHVOL,RDZ
```

```
 REAL*8,              ALLOCATABLE, DIMENSION(:,:,:)    :: C1Z
 REAL*8,              ALLOCATABLE, DIMENSION(:,:)      :: F_FC,F_UC,F_DC,F_RC,F_SC,F_CC ! UNITS OF J
(TIME-STEP SCALE)
  REAL*8,              ALLOCATABLE, DIMENSION(:)        :: ZAVAIL, ZAVAILNX,CEFF,Z1Z,L1Z,CELL_PER
 REAL*8,              ALLOCATABLE, DIMENSION(:,:)      :: T1Z
 REAL*8,              ALLOCATABLE, DIMENSION(:,:)      :: FCONMAXGG,FCONGG,FCONMAXJ,FCONJ,DAYCM,FCONP
 REAL*8,              ALLOCATABLE, DIMENSION(:)        :: T1BZ
 REAL NXTFISH,NXTFOPT,FG1,FG2,FKA,FKB,FL1,FL2,DIGK,JUNK, FDLTM,FDLTH,FOXYCAL
 REAL FISHT1,FISHT2,FISHT3,FISHT4,FISHK1,FISHK2,FISHK3,FISHK4 ! TEMPERATURE RATE TERMS
 REAL FJDAYNXT,HANDLE,FVELA,FVELB,FVELE,THRESHV,DAP_IN,JAVAIL,FGPD,FGPF
 REAL FBIODAYNXT,FBIOSUBNXT,FBIODAYLST,ZAVJD,ZAVNX
 REAL GIM, BIM, DIM, GALP, BALP, DALP, GTI, BTI, DTI
 REAL F1M,F1J,WILMA1,WILMA2
 INTEGER,             ALLOCATABLE, DIMENSION (:)       :: ZDEPTH,DATA_FILENUM,BIOOUTFN, CELL_POS,
CELL_NEG,FGPFN
 INTEGER,             ALLOCATABLE, DIMENSION (:,:)     :: FULLSTO
 INTEGER,             ALLOCATABLE, DIMENSION (:)       :: KBIP
 INTEGER CUR_FJDAY, FJDAYINT,ZHOLDNUM,DIAGLOGFN, JJZ,FOPTNUM,THRESHZ,ZAVFN,BIOCON,NUMSTEPS,FUF
 CHARACTER*72,        ALLOCATABLE, DIMENSION(:)        :: BIOOUTNAME,FGPFNAME
 INTEGER FXNFN(3)
 CHARACTER*72 ZAVFNAME
 CHARACTER*8 FHEAD(30),FUNIT(20),FCALC,FGPC,CMAXC
 CHARACTER*8 GENMTP,BESTMTP,DIELMTP
 CHARACTER*72 FXNFNAME(3)
 LOGICAL,             ALLOCATABLE, DIMENSION(:)        :: FIRST_BIO,THRESHFEED
 LOGICAL SAMEDAY,FIRSTLIGHT,FIRST_OUTPUT,DAILY_FISH_OPT,BIOSUB_CALC, BIODAY_CALC
 LOGICAL HAPPY, NEWDAY,FBIOCALC,FGPPLOT,FISHCALC,THRESHOLD,CMAXCALC
 LOGICAL
GMTPCELL,GMTPFXN,GMTPUSER,GMTPFIXED,BMTPSEG,BMTPFXN,BMTPUSER,BMTPFIXED,DMTPSEG,DMTPFXN,DMTPUSER,DMTP
FIXED
 LOGICAL GMTOK,BMTOK,DMTOK
END MODULE FISH
MODULE FISH2 ! FOR USE WITH THIS PROGRAM; WILL NEED TO BE ALTERED FOR INCORPORATION WITH W2-CODE
 REAL LUX, LUX1, LUX2 ! TEMPORARY LIGHT DATA TERMS
 REAL LJDAY1,LJDAY2
 INTEGER LIGHTNUM
END MODULE FISH2
MODULE BIOEXPDATATRANSFORM ! FOR CONVERTING THE BIOEXP DATA OUTPUT INTO W2 ARRAYS AND VARIABLES
 REAL ZDAY1,ZDAY2
 INTEGER FIRSTK,LASTK,SEGK,GRCT
```

```
 CHARACTER*20 GREGORY(1000)
 LOGICAL,            ALLOCATABLE, DIMENSION(:)       :: FIRSTREAD
END MODULE BIOEXPDATATRANSFORM
MODULE GROWTH_ANIMATION
 INTEGER ANIMFN,ANIMFN2,ZONECNT,ZONEFIRST,NNODE,NELEM
 CHARACTER*52 HEADER1,HEADER2
 REAL LEFT(999), RIGHT(999)
 REAL*8,             ALLOCATABLE, DIMENSION(:)       :: DISTL,DISTR,BOTTOME
 REAL*8,             ALLOCATABLE, DIMENSION(:,:)     :: GELEV,X1,X2,X3,X4,Y1,Y2,Y3,Y4
 REAL    VLL,VLR
 INTEGER,            ALLOCATABLE, DIMENSION(:)       :: BOTSEG
 LOGICAL,            ALLOCATABLE, DIMENSION(:)       :: ANIMEXP
END MODULE GROWTH_ANIMATION
MODULE DIAGNOSTIC
 REAL*8,             ALLOCATABLE, DIMENSION(:,:,:)   :: DIET
 REAL*8,             ALLOCATABLE, DIMENSION(:,:)     :: VISIBLE
 REAL*8,             ALLOCATABLE, DIMENSION(:)       :: MAXG,MAXM
 INTEGER BYSEGMFN,BYSEGGFN,BYSEGMFN2,BYSEGGFN2,BYSEGMFN3,BYSEGGFN3,SURFSEGMFN,SURFSEGGFN
 INTEGER TLCALCFN
 CHARACTER*8 FDIAGC,THRESHC,SURFC,TLC
 LOGICAL FDIAG,BYSEG,SURFDIAG
 REAL*8,             ALLOCATABLE, DIMENSION(:)       :: MF_GI,MF_RI,MF_DI,MF_CI,MF_WI,MF_SI
 CHARACTER*8 FISHC, BIOPARC, CONSC, DIGC, RESPC,SINGLEC
 LOGICAL FISHDIAG, BIOPARDIAG, CONSDIAG, DIGDIAG, RESPDIAG,SINGLEDIAG,TLCALC
 INTEGER SINGFN, SINIBIO
END MODULE DIAGNOSTIC
MODULE MOVEMENT
 REAL*8,             ALLOCATABLE, DIMENSION(:,:)     :: BFCON,BFVEL,BFACT
 REAL*8,             ALLOCATABLE, DIMENSION(:)       :: BFVELAVE,BFACTAVE
 REAL*8,             ALLOCATABLE, DIMENSION(:,:)     :: DFCON,DFVEL,DFACT
 REAL*8,             ALLOCATABLE, DIMENSION(:)       :: DFVELAVE,DFACTAVE
 REAL*8,             ALLOCATABLE, DIMENSION(:,:,:)   :: BF1, DF1,BDIET, DDIET
 REAL*8,             ALLOCATABLE, DIMENSION(:,:)     :: BF_F,BF_U,BF_D,BF_R,BF_S,BF_C,BF_G,BF_W
 REAL*8,             ALLOCATABLE, DIMENSION(:,:)     :: DF_F,DF_U,DF_D,DF_R,DF_S,DF_C,DF_G,DF_W
 REAL*8,             ALLOCATABLE, DIMENSION(:,:)     :: BF_FC,BF_UC,BF_DC,BF_RC,BF_SC,BF_CC
 REAL*8,             ALLOCATABLE, DIMENSION(:,:)     :: DF_FC,DF_UC,DF_DC,DF_RC,DF_SC,DF_CC
 REAL*8,             ALLOCATABLE, DIMENSION(:)       ::
BF_GI,BF_RI,BF_DI,BF_CI,BF_WI,BF_SI,BF_UI,BF_FI
 REAL*8,             ALLOCATABLE, DIMENSION(:)       ::
DF_GI,DF_RI,DF_DI,DF_CI,DF_WI,DF_SI,DF_UI,DF_FI
```

```
 REAL*8,              ALLOCATABLE, DIMENSION(:,:)      :: BDAYC,BSRCHVOL,BRDZ
 REAL*8,              ALLOCATABLE, DIMENSION(:,:)      :: DDAYC,DSRCHVOL,DRDZ
 REAL*8,              ALLOCATABLE, DIMENSION(:)        :: BCELL_PER,DCELL_PER
 REAL*8,              ALLOCATABLE, DIMENSION(:)        :: BESTG,TEPI,THYPO
 REAL*8,              ALLOCATABLE, DIMENSION(:,:)      ::
BFCONMAXGG,BFCONGG,BFCONMAXJ,BFCONJ,BDAYCM,BFCONP
 REAL*8,              ALLOCATABLE, DIMENSION(:,:)      ::
DFCONMAXGG,DFCONGG,DFCONMAXJ,DFCONJ,DDAYCM,DFCONP
 REAL*8,              ALLOCATABLE, DIMENSION(:)        :: BAVEC,BMINC,BMAXC
 REAL*8,              ALLOCATABLE, DIMENSION(:)        :: DAVEC,DMINC,DMAXC
 REAL*8,              ALLOCATABLE, DIMENSION(:)        ::
BFCONMAXJI,BFCONMAXGGI,BFCONI,BFCONPI,BFDAYCI,BFDAYCMI,BFCONJI,BFCONGGI
 REAL*8,              ALLOCATABLE, DIMENSION(:)        ::
DFCONMAXJI,DFCONMAXGGI,DFCONI,DFCONPI,DFDAYCI,DFDAYCMI,DFCONJI,DFCONGGI
 REAL*8,              ALLOCATABLE, DIMENSION(:)        :: BDAYCI,BDAYCMI
 REAL*8,              ALLOCATABLE, DIMENSION(:)        :: DDAYCI,DDAYCMI
 REAL*8,              ALLOCATABLE, DIMENSION(:,:)      :: BF_DC_EXT,BF_G_EXT
 REAL*8,              ALLOCATABLE, DIMENSION(:,:)      :: DF_DC_EXT,DF_G_EXT
 REAL GMAXG,DIELLUX,DIELG,DIELS,RMIN,CMAX
 INTEGER,             ALLOCATABLE, DIMENSION(:)        :: BCELL_POS,BCELL_NEG,BFULLSTOI
 INTEGER,             ALLOCATABLE, DIMENSION(:)        :: DCELL_POS,DCELL_NEG,DFULLSTOI
 INTEGER,             ALLOCATABLE, DIMENSION(:,:)      :: BESTK,DIELK,BFULLSTO,DFULLSTO
 INTEGER GMAXK, BESTSTEP,KDIEL,RMINK,CMAXK,KBEST
 CHARACTER*8 BESTC,DIELC,DEPTHC
 LOGICAL BESTCALC,DIELCALC,DIELDEEP,DAYLIGHT,DEPTHCALC
 REAL*8,              ALLOCATABLE, DIMENSION(:)        :: BVISIBLE,DVISIBLE
 REAL*8,              ALLOCATABLE, DIMENSION(:,:)      :: BDIETI,DDIETI
 INTEGER BESTDIAGFN
 LOGICAL,             ALLOCATABLE, DIMENSION(:)        :: FORAY
END MODULE MOVEMENT

!*************************************
!   TASK B.2.0 MAIN PROGRAM DECLARATIONS
!*************************************
PROGRAM BIOENERGETICS
USE MAINW2; USE FISH; USE FISH2;USE BIOEXPDATATRANSFORM; USE GROWTH_ANIMATION; USE DIAGNOSTIC; USE
ROOSEVELT; USE MOVEMENT
!****TEMPORARY FILES
OPEN(999,FILE='TEMP.DAT',STATUS='UNKNOWN')
OPEN(998,FILE='TEMP2.DAT',STATUS='UNKNOWN')
```

```
!****VARIABLE/ ARRAY ALLOCATION & INITIAL VALUES*****
NOD = 100
! ROOSEVELT
  OPEN (12,FILE='W2_CON_ANC.NPT',STATUS='OLD')
  DO II = 1,16
    READ(12,'(A8)') BIOC
  END DO
  ALLOCATE (BIOD(NOD), BIOF(NOD),BIODP(NOD))
  ! BIOENERGETICS OUTPUT CARDS
  READ(12,'(//(8X,A8,2I8))') BIOC,NBIO,NIBIO
  ALLOCATE (BIOEXPFN(NIBIO),IBIO(NIBIO))
  ROO2 = 0.0; C2W = 0.0
  READ(12,'(//(:8X,9F8.0))') (BIOD(II),II=1,NBIO)
  READ(12,'(//(:8X,9F8.0))') (BIOF(II),II=1,NBIO)
  READ(12,'(//(:8X,9I8))') (IBIO(II),II=1,NIBIO)
  READ(12,'(//(8X,A72))') BIOFN
  CLOSE(12)
! END ROOSEVELT
! MAINW2
IMX = 583; KMX = 76;NUNIT = 100; NWB = 1; FBIONXT = 366.5
JDAY = 366.0; JEND = 400.5; DLT = 1; NCT = 22; NZOOS = 20; NZOOE = 22; NZP = 3
ALLOCATE(DEPTHM(KMX,IMX),T1(KMX,IMX),GAMMA(KMX,IMX),BH(KMX,IMX),EL(KMX,IMX))
ALLOCATE(C2(KMX,IMX,NCT),KTI(IMX),KBI(IMX))
ALLOCATE(BIOINNAME(NIBIO), BIOINFN(NIBIO)) ! ULTIMATELY, IMX (& NEW VARIABLE)
! FISH
ALLOCATE (BIOOUTFN(NIBIO),EZOO(NZP),LZOO(NZP),MZOO(NZP))
ALLOCATE (BIOOUTNAME(NIBIO),FCON(KMX,IMX),FVEL(KMX,IMX),FACT(KMX,IMX),F1I(3))
ALLOCATE (F1(KMX,IMX,5)) ! 1 = MASS; 2 = LENGTH; 3 = STOMACH CONTENT; 4 = ENERGY DENSITY OF FISH; 5
= STOMACH CAPACITY
ALLOCATE (FTL(KMX),SRCHVOL(KMX,IMX),RDZ(KMX,IMX),F2(KMX,IMX))
ALLOCATE (CELL_POS(IMX), CELL_NEG(IMX),CELL_PER(IMX),FULLSTO(KMX,IMX))
ALLOCATE (F_F(KMX,IMX),F_U(KMX,IMX),F_D(KMX,IMX),F_R(KMX,IMX),F_S(KMX,IMX),F_C(KMX,IMX))
ALLOCATE (F_G(KMX,IMX),F_W(KMX,IMX),DAYC(KMX,IMX))
ALLOCATE (F_FC(KMX,IMX),F_UC(KMX,IMX),F_DC(KMX,IMX),F_RC(KMX,IMX),F_SC(KMX,IMX),F_CC(KMX,IMX))
ALLOCATE (T1Z(KMX,IMX),C1Z(KMX,IMX,NZP),Z1Z(KMX),L1Z(KMX),ZDEPTH(KMX))
ALLOCATE (FIRST_BIO(NIBIO),GAMMAFDC(KMX,IMX))
ALLOCATE (ZAVAIL(NZP),ZAVAILNX(NZP),CEFF(KMX))
ALLOCATE (FGPFN(NWB),FGPFNAME(NWB),GELEV(KMX,IMX),DISTL(IMX),DISTR(IMX))
ALLOCATE (X1(KMX,IMX),X2(KMX,IMX),X3(KMX,IMX),X4(KMX,IMX))
```

```
ALLOCATE (Y1(KMX,IMX),Y2(KMX,IMX),Y3(KMX,IMX),Y4(KMX,IMX))
ALLOCATE (DIET(KMX,IMX,NZP),THRESHFEED(KMX),VISIBLE(KMX,IMX))
ALLOCATE (ANIMEXP(NIBIO),BOTSEG(IMX),BOTTOME(IMX))
ALLOCATE (MAXG(IMX),MAXM(IMX),KBIP(IMX))
ALLOCATE (FCONMAXGG(KMX,IMX),FCONGG(KMX,IMX),FCONMAXJ(KMX,IMX),FCONJ(KMX,IMX),FCONP(KMX,IMX))
ALLOCATE (F_DINI(KMX,IMX),F_DCON(KMX,IMX),F_DUNDIG(KMX,IMX),DAYCM(KMX,IMX))
ALLOCATE (FVELAVE(KMX,IMX),FACTAVE(KMX,IMX))
ALLOCATE (AVEC(KMX,IMX),MINC(KMX,IMX),MAXC(KMX,IMX))
ALLOCATE (F_G2(KMX,IMX))
!IF(SINGLEDIAG) THEN
  ALLOCATE (MF_GI(KMX),MF_RI(KMX),MF_DI(KMX),MF_CI(KMX),MF_WI(KMX),MF_SI(KMX))
  MF_GI = 0.0;MF_RI = 0.0;MF_DI = 0.0;MF_CI = 0.0;MF_WI = 0.0;MF_SI = 0.0
!END IF
TLCALC = .FALSE.
F1(:,:,4) = 5821.9*4.1868 ; F1(:,:,5) = 3.64 ; FCON = 0.0
F_R  = 0.0; F_D  = 0.0; F_C  = 0.0; F_F  = 0.0; F_U  = 0.0; F_S  = 0.0; F_G = 0.0; F_W = 0.0
F_RC = 0.0; F_DC = 0.0; F_CC = 0.0; F_FC = 0.0; F_UC = 0.0; F_SC = 0.0
F_DINI = 0.0; F_DCON = 0.0; F_DUNDIG = 0.0; DAYCM = 0.0
AVEC = 0.0; MINC = 0.0; MAXC = 0.0
FVELAVE = 0.0; FACTAVE = 0.0
KBIP = 1
FBIOSUBNXT = 366.0; FBIODAYNXT = 367.0; FBIODAYLST = 366.0
CELL_POS = 0; CELL_NEG = 0; DAYC = 0.0; CELL_PER = 0.0; FULLSTO = 0
DAP_IN = 0.0; RDZ = 0.08; GAMMAFDC = 0.0
FCONMAXGG = 0.0; FCONGG = 0.0; FCONMAXJ = 0.0; FCONJ = 0.0
BIOSUB_CALC  = .FALSE.; BIODAY_CALC    = .FALSE.;   HAPPY  = .TRUE. ; NEWDAY    = .TRUE.; FIRSTLIGHT
= .TRUE.
FIRST_OUTPUT = .TRUE. ; DAILY_FISH_OPT = .FALSE.; FBIOCALC = .FALSE.; FIRST_BIO = .TRUE.
GMTPCELL = .FALSE.;GMTPFXN   = .FALSE.;GMTPUSER = .FALSE.;GMTPFIXED = .FALSE.;BMTPSEG  =
.FALSE.;BMTPFXN   = .FALSE.
BMTPUSER = .FALSE.;BMTPFIXED = .FALSE.;DMTPSEG  = .FALSE.;DMTPFXN   = .FALSE.;DMTPUSER =
.FALSE.;DMTPFIXED = .FALSE.
GMTOK    = .FALSE.;BMTOK     = .FALSE.;DMTOK    = .FALSE.
SINGLEDIAG = .FALSE.;SURFDIAG = .FALSE.
FISHDIAG = .FALSE.; BIOPARDIAG = .FALSE.; CONSDIAG = .FALSE.; DIGDIAG = .FALSE.; RESPDIAG =
.FALSE.;SINGLEDIAG  = .FALSE.
 F_G2 = 0.0
! FISH2
LJDAY1 = 360.0; LJDAY2 = 361.0; LUX = 0.0 ! TEMPORARY SET UP VALUES
MAXG = -999.0; MAXM = -999.0; DIELDEEP = .TRUE.;CMAXCALC = .FALSE.
```

```
! BIOEXP
ALLOCATE (FIRSTREAD(NIBIO))
FIRSTREAD = .TRUE.
! GROWTH ANIMATION
 HEADER1 = 'TITLE ="Lake Roosevelt"'
 HEADER2 = 'VARIABLES = "Distance, km", "Elevation, m", "FGP"'
 GELEV = 0.0; DISTL = 0.0; DISTR = 0.0
 ZONECNT = 0 ; ZONEFIRST = INT(JDAY)
 DIET = 0.0 ; THRESHFEED = .FALSE.; VISIBLE = 0.0
OPEN(13,FILE='CHANNEL_BOT.OPT',STATUS='OLD')
READ(13,*) BESTC
DO I = 1,IMX
  READ(13,'(I10,50X,F10.0)',END=1199) BOTSEG(I),BOTTOME(I)
END DO
1199 CONTINUE
CALL GETFISHDATA
 FDLTM = FUF*1.0 ! IN MINUTES
 FDLTH = FDLTM/60.0; ZHOLDNUM = 4+NZP; NUMSTEPS = 1440/FUF
 GRCT = 1
 ANIMEXP = .TRUE.; ANIMEXP(12) = .FALSE.; ANIMEXP(21) = .FALSE.; ANIMEXP(24) = .FALSE.
! BYSEG
BYSEG = .TRUE.
! MOVEMENT
IF(BESTCALC) THEN
 ALLOCATE (BFCON(KMX,IMX),BFVEL(KMX,IMX),BFACT(KMX,IMX),BF1(KMX,IMX,5))
 ALLOCATE (BF_F(KMX,IMX),BF_U(KMX,IMX),BF_D(KMX,IMX),BF_R(KMX,IMX),BF_S(KMX,IMX),BF_C(KMX,IMX))
 ALLOCATE (BF_G(KMX,IMX),BF_W(KMX,IMX),BDAYC(KMX,IMX),BDAYCM(KMX,IMX))
 ALLOCATE
(BF_FC(KMX,IMX),BF_UC(KMX,IMX),BF_DC(KMX,IMX),BF_RC(KMX,IMX),BF_SC(KMX,IMX),BF_CC(KMX,IMX))
 ALLOCATE (BSRCHVOL(KMX,IMX),BRDZ(KMX,IMX))
 ALLOCATE (BCELL_POS(IMX),BCELL_NEG(IMX),BCELL_PER(IMX))
 ALLOCATE (BESTK(IMX,NUMSTEPS+1),BESTG(IMX))
 ALLOCATE (BDIETI(IMX,NZP),BDIET(KMX,IMX,NZP))
 ALLOCATE (BF_GI(IMX),BF_RI(IMX),BF_DI(IMX),BF_CI(IMX),BF_WI(IMX),BF_SI(IMX),BF_UI(IMX),BF_FI(IMX))
 ALLOCATE (BFCONMAXGG(KMX,IMX),BFCONGG(KMX,IMX),BFCONMAXJ(KMX,IMX),BFCONJ(KMX,IMX),BFCONP(KMX,IMX))
 ALLOCATE (BFULLSTO(KMX,IMX),BFULLSTOI(IMX),BVISIBLE(IMX))
 ALLOCATE (BFVELAVE(IMX),BFACTAVE(IMX))
 ALLOCATE (BAVEC(IMX),BMINC(IMX),BMAXC(IMX))
```

```
 ALLOCATE
(BFCONMAXJI(IMX),BFCONMAXGGI(IMX),BFCONI(IMX),BFCONPI(IMX),BFDAYCI(IMX),BFDAYCMI(IMX),BFCONGGI(IMX),
BFCONJI(IMX))
 ALLOCATE (BDAYCI(IMX),BDAYCMI(IMX))
 ALLOCATE (BF_DC_EXT(KMX,IMX),BF_G_EXT(KMX,IMX))
 ALLOCATE (T1BZ(IMX))
 BFCON = 0.0  ;BF1 = F1; BDAYC = 0.0; BFULLSTO = 0; BFULLSTOI = 0
 BCELL_POS = 0; BCELL_POS = 0; BESTSTEP = 0
 BVISIBLE = 0.0; BDIET = 0.0; BESTK = 0
 BF_F = 0.0 ;BF_U = 0.0 ;BF_D = 0.0 ;BF_R = 0.0 ;BF_S = 0.0 ;BF_C = 0.0 ;BF_G = 0.0 ;BF_W = 0.0
 BF_FC = 0.0;BF_UC = 0.0;BF_DC = 0.0;BF_RC = 0.0;BF_SC = 0.0;BF_CC = 0.0
 BF_GI = 0.0;BF_RI = 0.0;BF_DI = 0.0;BF_CI = 0.0;BF_WI = 0.0;BF_SI = 0.0; BF_UI = 0.0; BF_FI = 0.0
 BFVELAVE = 0.0; BFACTAVE = 0.0
 BAVEC = 0.0; BMINC = 0.0; BMAXC = 0.0
 BFCONMAXJI = 0.0; BFCONMAXGGI = 0.0; BFCONI = 0.0; BDAYCI = 0.0; BDAYCMI = 0.0; BFCONPI = 0.0;
BFCONJI = 0.0; BFCONGGI = 0.0
 BF_DC_EXT = 0.0;BF_G_EXT =0.0
 T1BZ = 0.0
END IF
IF(DIELCALC) THEN
 ALLOCATE(DFCON(KMX,IMX),DFVEL(KMX,IMX),DFACT(KMX,IMX),DF1(KMX,IMX,5))
 ALLOCATE (DF_F(KMX,IMX),DF_U(KMX,IMX),DF_D(KMX,IMX),DF_R(KMX,IMX),DF_S(KMX,IMX),DF_C(KMX,IMX))
 ALLOCATE (DF_G(KMX,IMX),DF_W(KMX,IMX),DDAYC(KMX,IMX),DDAYCM(KMX,IMX))
 ALLOCATE
(DF_FC(KMX,IMX),DF_UC(KMX,IMX),DF_DC(KMX,IMX),DF_RC(KMX,IMX),DF_SC(KMX,IMX),DF_CC(KMX,IMX))
 ALLOCATE (DSRCHVOL(KMX,IMX),DRDZ(KMX,IMX))
 ALLOCATE (DCELL_POS(IMX),DCELL_NEG(IMX),DCELL_PER(IMX))
 ALLOCATE (DIELK(IMX,NUMSTEPS+1),TEPI(IMX),THYPO(IMX))
 ALLOCATE (DF_GI(IMX),DF_RI(IMX),DF_DI(IMX),DF_CI(IMX),DF_WI(IMX),DF_SI(IMX),DF_UI(IMX),DF_FI(IMX))
 ALLOCATE (DFVELAVE(IMX),DFACTAVE(IMX),DVISIBLE(IMX))
 ALLOCATE (DAVEC(IMX),DMINC(IMX),DMAXC(IMX))
 ALLOCATE
(DFCONMAXJI(IMX),DFCONMAXGGI(IMX),DFCONI(IMX),DFCONPI(IMX),DFDAYCI(IMX),DFDAYCMI(IMX),DFCONGGI(IMX),
DFCONJI(IMX))
 ALLOCATE (DDAYCI(IMX),DDAYCMI(IMX))
 ALLOCATE (DF_DC_EXT(KMX,IMX),DF_G_EXT(KMX,IMX))
 ALLOCATE (DFCONMAXGG(KMX,IMX),DFCONGG(KMX,IMX),DFCONMAXJ(KMX,IMX),DFCONJ(KMX,IMX),DFCONP(KMX,IMX))
 ALLOCATE (DDIETI(IMX,NZP),DDIET(KMX,IMX,NZP),DFULLSTO(KMX,IMX),DFULLSTOI(IMX))
 ALLOCATE (FORAY(IMX))
 DFCON = 0.0  ;DF1 = F1; DDAYC = 0.0; DFULLSTO = 0; DFULLSTOI = 0
```

```
 DCELL_POS = 0; DCELL_POS = 0; DIELK = 0
 DF_F = 0.0 ;DF_U = 0.0 ;DF_D = 0.0 ;DF_R = 0.0 ;DF_S = 0.0 ;DF_C = 0.0 ;DF_G = 0.0 ;DF_W = 0.0
 DF_FC = 0.0;DF_UC = 0.0;DF_DC = 0.0;DF_RC = 0.0;DF_SC = 0.0;DF_CC = 0.0
 DF_GI = 0.0;DF_RI = 0.0;DF_DI = 0.0;DF_CI = 0.0;DF_WI = 0.0;DF_SI = 0.0; DF_UI = 0.0; DF_FI = 0.0
 DFVELAVE = 0.0; DFACTAVE = 0.0
 DAVEC = 0.0; DMINC = 0.0; DMAXC = 0.0;DVISIBLE = 0
 DFCONMAXJI = 0.0; DFCONMAXGGI = 0.0; DFCONI = 0.0; DDAYCI = 0.0; DDAYCMI = 0.0; DFCONPI = 0.0;
DFCONJI = 0.0; DFCONGGI = 0.0
 DF_DC_EXT = 0.0;DF_G_EXT =0.0
 FORAY = .FALSE.
END IF

! ************************************************************************************
! *                              TASK B.2.1 FILE SET UP                              *
! ************************************************************************************
CALL INITIALFILESETUP
!*************************************
!   TASK B.2.1 PSEUDO W2-TIME CONTROL AND VARIABLE UPDATE
!*************************************
!   TASK B.2.1.1 PSEUDO W2 TIME ADVANCEMENT
2110 CONTINUE
GOTO 2111 ! BY PASS  FOR FIXED FISH TIMESTEPS
JDAY = JDAY + DLT/3600.0/24.0
! CHECK FOR END OF SIMULATION
IF(JDAY.GT.JEND) THEN
  GOTO 997
END IF
! CHECK FOR ROUTING TO SUB-DAILY CALCULATIONS
IF(JDAY.GE.FBIOSUBNXT) THEN
  FBIOSUBNXT = FBIOSUBNXT + 1.0/48.0
  BIOSUB_CALC = .TRUE.
  IF(JDAY.GE.FBIODAYNXT) THEN
    FBIODAYLST = FBIODAYNXT; FBIODAYNXT = FBIODAYNXT + 1.0
    BIODAY_CALC = .TRUE.
      NEWDAY = .TRUE.; GRCT = GRCT+1
  END IF
END IF
IF(BIOSUB_CALC) THEN
  CONTINUE
  ELSE
```

```
    GOTO 2110
END IF
2111 continue
JDAY = JDAY + 1.0/48.0
IF(JDAY.GT.JEND) THEN
  GOTO 997
END IF
IF(JDAY.GE.FBIOSUBNXT) THEN
  !JDAY = INT(JDAY)*1.0 +0.0
    FBIOSUBNXT = JDAY + 1.0/48.0
  !FBIOSUBNXT = INT(JDAY+1.0)*1.0 + 0.0
  BIOSUB_CALC = .TRUE.
  IF(JDAY.GE.FBIODAYNXT) THEN
    FBIODAYLST = FBIODAYNXT; FBIODAYNXT = FBIODAYNXT + 1.0
      JDAY = 1.0*INT(JDAY)
    BIODAY_CALC = .TRUE.
      NEWDAY = .TRUE.; GRCT = GRCT+1
  END IF
END IF

! ******ZOOPLANKTON AVAILABILITY UPDATE********
  IF(JDAY.GE.ZAVNX) THEN ! THIS UPDATE MUST OCCUR AFTER THE COMPUTATIONS IN W2 OR RISK AN END OF
FILE READ ERROR
    ZAVJD = ZAVNX; ZAVAIL = ZAVAILNX
      READ(ZAVFN,'(:F8.0,9F8.0)')  ZAVNX,(ZAVAILNX(II),II=1,NZP)
  END IF
!**************************************
!   TASK B.2.2 SUBDAILY CALCULATIONS
!**************************************
!   TASK B.2.2.1 GET UPDATED SOLAR INPUTS
IF(JDAY.LT.LJDAY1) LUX = LUX1
IF(JDAY.LE.LJDAY2) LUX = (LJDAY2-JDAY)/(LJDAY2-LJDAY1)*(LUX2-LUX1)

2200 CONTINUE
IF(JDAY.GE.LJDAY2) THEN
  CALL LIGHTOUT
  IF(JDAY.GE.LJDAY1.AND.JDAY.LE.LJDAY2) THEN
    LUX = LUX1 + (LJDAY2-JDAY)/(LJDAY2-LJDAY1)*(LUX2-LUX1)
  ELSE
    GOTO 2200
```

```
  END IF
END IF

LUX = MAX(LUX,0.0) ! REDUDANT CHECK
IF(LUX.GE.1.0) THEN !ARBITRARY; USED FOR VERTICAL MIGRATION
  DAYLIGHT = .TRUE.
ELSE
  DAYLIGHT = .FALSE.
END IF
!NOON CHECK ( FOR DEBUGGING )
IF(JDAY.GT.557.5) THEN
  IF(JDAY.LT.557.51) THEN
    CONTINUE
  END IF
END IF
! BESTCALC TIMESTEP COUNT
IF(BESTCALC) BESTSTEP = BESTSTEP + 1
!************************************
!   TASK B.2.2.2 SUB-DAILY BIOENERGETICS
!************************************
write (999,'(a12,f8.3)') 'JDAY ', jday
! NEED TO MATCH DEPTHS TO K-LAYERS FOR W2 APPLICATION; ! ITERATE BY SEGMENT, SO ONLY K DIMENSION IS
NEEDED
DO JI = 1,NIBIO ! THIS IS THE MAIN W2 LOOP SIMULATION
  I = IBIO(JI)
  KBIP = KTI
 ! GET BIOEXP DATA AND DETERMINE KTI,KBI
  IF(FIRST_BIO(JI)) THEN
    CALL BIOEXPTRANSFORM
  END IF
write(999,'(a12,2i4,f8.2)') "Loop JI, I ",JI,I,t1z(2,I)
! MAIN VERTICAL LOOP
 DO K = KTI(I),KBI(I)
   ! GROWTH ANIMATION NODE COUNT
   NELEM = NELEM+1
   ! CONVERT LIGHTOUT DATA AT SURFACE TO DEPTH CORRECTED VALUES
   !** UPDATE WHEN INTEGRATING WITH MAIN W2 CODE
   GAMMAFDC(K,I) = LUX*EXP(-1*DEPTHM(K,I)*0.36) ! ARBITRARY LIGHT EXTINCTION VALUE OF 0.36 /M
   ! DIAGNOSTIC
   IF(GAMMAFDC(K,I).GT.1) THEN
```

```
      VISIBLE(K,I) = VISIBLE(K,I) + FDLTM
    END IF
    ! UPDATE REACTION DISTANCE AND SEARCH VOLUME
    FVEL(K,I) = 0.01*9.9*EXP(0.0405*T1Z(K,I)) * F1(K,I,1)**0.13 ! PULLED FROM METABOLISM, NEEDED FOR
SEARCH VOLUME
    FVELAVE(K,I) = FVELAVE(K,I) + FVEL(K,I)*FDLTM/1440
    RDZ(K,I) = 0.01*4.9424*GAMMAFDC(K,I)**0.086 ! METERS
    SRCHVOL(K,I) = 3.141596*RDZ(K,I)*RDZ(K,I)*FVEL(K,I)
      IF(BESTCALC) THEN
       BFVEL(K,I) = 0.01*9.9*EXP(0.0405*T1Z(K,I)) * BF1(K,I,1)**0.13
       BRDZ(K,I) = 0.01*4.9424*GAMMAFDC(K,I)**0.086
       BSRCHVOL(K,I) = 3.141596*BRDZ(K,I)*BRDZ(K,I)*BFVEL(K,I)
      END IF
      IF(DIELCALC) THEN
       DFVEL(K,I) = 0.01*9.9*EXP(0.0405*T1Z(K,I)) * DF1(K,I,1)**0.13
       DRDZ(K,I) = 0.01*4.9424*GAMMAFDC(K,I)**0.086
       DSRCHVOL(K,I) = 3.141596*DRDZ(K,I)*DRDZ(K,I)*DFVEL(K,I)
      END IF

    !************************************ PUT THE TL TERM INTO THE CONSUMPTION TERM; DEVIATES FROM
COMMON FORMULATIONS *******
    ! *** THORNTON-LESSEM FUNCTION
    FL1 = EXP(FG1*(T1Z(K,I)-FISHT1)); FL2 = EXP(FG2*(FISHT4-T1Z(K,I)))
    FKA = (FISHK1*FL1)/(1+FISHK1*(FL1-1)); FKB = (FISHK4*FL2)/(1+FISHK4*(FL2-1)); FTL(K) = FKA*FKB
    ! CHECKING FUNCTION
    IF(SINGLEDIAG) THEN
      RJINT=JDAY-INT(JDAY)
      IF(RJINT.LT.0.1) THEN
        IF(K.EQ.KTI(I)) THEN
          WRITE(TLCALCFN,'(F8.2,F8.4)') T1Z(K,I),FTL(K)
        END IF
      END IF
    END IF
! ***************************************************************************************
! *                              TASK ....  CONSUMPTION                                 *
! ***************************************************************************************
 ! DETERMINE MAXIMUM PRACTICAL FEEDING RATES ! FROM BEAUCHAMP, ET AL 1989, CMAX
   FCONMAXJ(K,I) = (0.303*F1(K,I,1)**-0.275)*EZOO(3)*F1(K,I,1)*FTL(K) ! UNITS OF J/DAY
   FCONMAXGG(K,I) = (0.303*F1(K,I,1)**-0.275)*FTL(K) ! UNITS OF G/G/ DAY
 ! CHECK STOMACH CONTENT COMPARED TO CAPACITY
```

```
   IF(F1(K,I,3).GT.F1(K,I,5)) THEN ! FORAGING
    FCON(K,I) = 0.0 !STOMACH FULL
      FULLSTO(K,I) = FULLSTO(K,I) + 1
   ELSE ! FORAGING
     IF(CMAXCALC) THEN       ! PRACTICAL FEEDING LIMIT?
        ! FCON(K,I) = FCONMAXGG(K,I)*F1(K,I,1)/MZOO(3)/1440
         WILMA1 = FCONMAXGG(K,I)*F1(K,I,1)/MZOO(3)/1440
         WILMA2 = (SRCHVOL(K,I)*CEFF(K)/(1+SRCHVOL(K,I)*CEFF(K)*HANDLE))*60*FTL(K)
       IF (WILMA2.GT.WILMA1) THEN
            FCON(K,I) = WILMA1
            ELSE
              FCON(K,I) = WILMA2
        END IF
     ELSE
       FCON(K,I) = (SRCHVOL(K,I)*CEFF(K)/(1+SRCHVOL(K,I)*CEFF(K)*HANDLE))*60*FTL(K)
     END IF
     DAYC(K,I) = DAYC(K,I) + FCON(K,I)*FDLTM
       DAYCM(K,I) = DAYC(K,I)*MZOO(3)
     AVEC(K,I) = AVEC(K,I) + FCON(K,I)*FDLTM/1440
       MINC(K,I) = MIN(MINC(K,I),FCON(K,I))
       MAXC(K,I) = MAX(MAXC(K,I),FCON(K,I))
       IF(FDIAG) THEN ! DIET REPORTING
       IF(THRESHFEED(K)) THEN
           DIET(K,I,THRESHZ) = DIET(K,I,THRESHZ) +
FCON(K,I)*C1Z(K,I,THRESHZ)*ZAVAIL(THRESHZ)/CEFF(K)*FDLTM
         ELSE
           DO JJZ = 1,NZP
             DIET(K,I,JJZ) = DIET(K,I,JJZ) +  FCON(K,I)*C1Z(K,I,JJZ)*ZAVAIL(JJZ)/CEFF(K)*FDLTM
           END DO
         END IF
     END IF
   END IF ! FORAGING
   ! ACTUAL CONSUMPTION DIAGNOSTIC
   FCONJ(K,I)  = DAYC(K,I)*MZOO(3)*EZOO(3)
   FCONGG(K,I) = DAYC(K,I)*MZOO(3)/F1(K,I,1)
   FCONP(K,I)  = FCONGG(K,I)/FCONMAXGG(K,I)
! ***********  BESTCALC  *************
IF(BESTCALC) THEN
   BFCONMAXJ(K,I) = (0.303*BF1(K,I,1)**-0.275)*EZOO(3)*BF1(K,I,1)*FTL(K) ! UNITS OF J/DAY
   BFCONMAXGG(K,I) = (0.303*BF1(K,I,1)**-0.275)*FTL(K) ! UNITS OF G/G/ DAY
```

```
   IF(BF1(K,I,3).GT.BF1(K,I,5)) THEN ! FORAGING
    PRINT *,'FULL_STOMACH'
    BFCON(K,I) = 0.0 !STOMACH FULL
      BFULLSTO(K,I) =  1
   ELSE ! FORAGING
    BFULLSTO(K,I) = 0
     IF(CMAXCALC) THEN
       BFCON(K,I) = BFCONMAXGG(K,I)*BF1(K,I,1)/MZOO(3)/1440
         WILMA1 = BFCONMAXGG(K,I)*BF1(K,I,1)/MZOO(3)/1440
         WILMA2 = (SRCHVOL(K,I)*CEFF(K)/(1+SRCHVOL(K,I)*CEFF(K)*HANDLE))*60*FTL(K)
       IF (WILMA2.GT.WILMA1) THEN
            BFCON(K,I) = WILMA1
            ELSE
              BFCON(K,I) = WILMA2
         END IF
      ELSE
       BFCON(K,I) = (BSRCHVOL(K,I)*CEFF(K)/(1+BSRCHVOL(K,I)*CEFF(K)*HANDLE))*60*FTL(K)
     END IF
     BDAYC(K,I) = BFCON(K,I)*FDLTM ! DIFFERS FROM MAIN: ONLY ONE TIMESTEP
       BDAYCM(K,I) = BDAYC(K,I)*MZOO(3)
     IF(FDIAG) THEN ! DIET REPORTING ! DIFFERS FROM MAIN ROUTINE; THIS IS ONLY PER TIMESTEP; BDIETI
IS CUMMULATIVE
       IF(THRESHFEED(K)) THEN
           BDIET(K,I,THRESHZ) = BFCON(K,I)*C1Z(K,I,THRESHZ)*ZAVAIL(THRESHZ)/CEFF(K)*FDLTM
         ELSE
           DO JJZ = 1,NZP
             BDIET(K,I,JJZ) = BFCON(K,I)*C1Z(K,I,JJZ)*ZAVAIL(JJZ)/CEFF(K)*FDLTM
           END DO
         END IF
     END IF
   END IF ! FORAGING
   BFCONJ(K,I)  = BDAYC(K,I)*MZOO(3)*EZOO(3)
   BFCONGG(K,I) = BDAYC(K,I)*MZOO(3)/BF1(K,I,1)
   BFCONP(K,I)  = BFCONGG(K,I)/BFCONMAXGG(K,I)
END IF ! BESTCALC
! ***********  DIELCALC  *************
IF(DIELCALC) THEN
   DFCONMAXJ(K,I) = (0.303*DF1(K,I,1)**-0.275)*EZOO(3)*DF1(K,I,1)*FTL(K) ! UNITS OF J/DAY
   DFCONMAXGG(K,I) = (0.303*DF1(K,I,1)**-0.275)*FTL(K) ! UNITS OF G/G/ DAY
   IF(DF1(K,I,3).GT.DF1(K,I,5)) THEN ! FORAGING
```

```
     DFCON(K,I) = 0.0 !STOMACH FULL
       DFULLSTO(K,I) =  1
    ELSE ! FORAGING
     DFULLSTO(K,I) = 0
      IF(CMAXCALC) THEN
          WILMA1 = DFCONMAXGG(K,I)*DF1(K,I,1)/MZOO(3)/1440
          WILMA2 = (SRCHVOL(K,I)*CEFF(K)/(1+SRCHVOL(K,I)*CEFF(K)*HANDLE))*60*FTL(K)
        IF (WILMA2.GT.WILMA1) THEN
             DFCON(K,I) = WILMA1
             ELSE
               DFCON(K,I) = WILMA2
          END IF
      ELSE
        DFCON(K,I) = (DSRCHVOL(K,I)*CEFF(K)/(1+DSRCHVOL(K,I)*CEFF(K)*HANDLE))*60*FTL(K)
      END IF
      DDAYC(K,I) = DFCON(K,I)*FDLTM ! DIFFERS FROM MAIN: ONLY ONE TIMESTEP
        DDAYCM(K,I) = DDAYC(K,I)*MZOO(3)
      IF(FDIAG) THEN ! DIET REPORTING ! DIFFERS FROM MAIN ROUTINE; THIS IS ONLY PER TIMESTEP; BDIETI
IS CUMMULATIVE
        IF(THRESHFEED(K)) THEN
            DDIET(K,I,THRESHZ) = DFCON(K,I)*C1Z(K,I,THRESHZ)*ZAVAIL(THRESHZ)/CEFF(K)*FDLTM
          ELSE
            DO JJZ = 1,NZP
              DDIET(K,I,JJZ) = DFCON(K,I)*C1Z(K,I,JJZ)*ZAVAIL(JJZ)/CEFF(K)*FDLTM
            END DO
          END IF
      END IF
    END IF ! FORAGING
    DFCONJ(K,I)  = DDAYC(K,I)*MZOO(3)*EZOO(3)
    DFCONGG(K,I) = DDAYC(K,I)*MZOO(3)/DF1(K,I,1)
    DFCONP(K,I)  = DFCONGG(K,I)/DFCONMAXGG(K,I)
  END IF ! DIELCALC

  ! ***************************************************************************
  ! *                            TASK ....  NON-CONSUMPTION PARAMETERS          *
  ! ***************************************************************************
    !****DIGESTION (SDA)
    DIGK = 0.014*T1Z(K,I)+0.1135
    !** MAZUR'S B&A
    F_DC(K,I) = (F1(K,I,3) + FCON(K,I)*MZOO(3)*FDLTM - (F1(K,I,3)*EXP(-1*DIGK*FDLTH) &
```

```
     + FCON(K,I)*MZOO(3)*60/DIGK*(1-EXP(-1*DIGK*FDLTH)) )) *EZOO(3)
   ! DIAGNOSTIC:  DIGENSTION BY PARTS
   F_DINI(K,I) = F1(K,I,3)*EZOO(3)
   F_DCON(K,I) = FCON(K,I)*MZOO(3)*FDLTM*EZOO(3)
   !F_DUNDIG(K,I) = ((F1(K,I,3)*EXP(-1*DIGK*FDLTH)+FCON(K,I)*MZLW(3)*60/DIGK*(1-EXP(-
1*DIGK*FDLTH))))*EZOO(3)
   F_DUNDIG(K,I) = ((F1(K,I,3)*EXP(-1*DIGK*FDLTH)+FCON(K,I)*MZOO(3)*60/DIGK*(1-EXP(-
1*DIGK*FDLTH))))*EZOO(3)
   !****EGESTION
   F_FC(K,I)    = 0.212*(T1Z(K,I)**-0.222)*F_DC(K,I)
   !****EXCRETION
   F_UC(K,I) = 0.0233*(T1Z(K,I)**-0.580)*(F_DC(K,I)-F_FC(K,I))
   !****METABOLISM/RESPIRATION (ACTIVITY)
   FACT(K,I) = EXP(0.02334*100.0*FVEL(K,I))
   FACTAVE(K,I) = FACTAVE(K,I) + FACT(K,I)*FDLTM/1440
   F_RC(K,I) = 0.00143*(F1(K,I,1)**-
0.209)*EXP(0.086*T1Z(K,I))*FACT(K,I)*FOXYCAL*FDLTM/1440*F1(K,I,1)
   !****SPECIFIC DYNAMIC ACTION
   F_SC(K,I) = 0.172*(F_DC(K,I)-F_FC(K,I))
   !****FISH ENERGY DENSITY (IN J/G)
   IF(F1(K,I,1).LE.196.0) THEN
     F1(K,I,4) = (1.851*F1(K,I,1)+1250.0)*4.1868
   ELSE
     F1(K,I,4) = (0.1254*F1(K,I,1) + 1588.0)*4.1868
   END IF
   !****UPDATE STOMACH CONTENT ! THIS CAN PROBABLY BE MOVED INTO THE DIGESTION SECTION, BUT WILL
KEEP SEPARATE FOR CLARITY
   F_CC(K,I) = FCON(K,I)*MZOO(3)*FDLTM*EZOO(3)
   F1(K,I,3) = F1(K,I,3)*EXP(-1*DIGK*FDLTH)+FCON(K,I)*MZOO(3)*60/DIGK*(1-EXP(-1*DIGK*FDLTH))

! ***********  BESTCALC  *************
IF(BESTCALC) THEN
       BF_DC(K,I) = (BF1(K,I,3) + BFCON(K,I)*MZOO(3)*FDLTM - (BF1(K,I,3)*EXP(-1*DIGK*FDLTH) &
     + BFCON(K,I)*MZOO(3)*60/DIGK*(1-EXP(-1*DIGK*FDLTH)) )) *EZOO(3)
       BF_DC_EXT(K,I) = BF_DC(K,I) + 0.2*BFCONJ(K,I)
       BF_FC(K,I)    = 0.212*(T1Z(K,I)**-0.222)*BF_DC(K,I)
       BF_UC(K,I) = 0.0233*(T1Z(K,I)**-0.580)*(BF_DC(K,I)-BF_FC(K,I))
       BFACT(K,I) = EXP(0.02334*100.0*BFVEL(K,I))
       BF_RC(K,I) = 0.00143*(BF1(K,I,1)**-
0.209)*EXP(0.086*T1Z(K,I))*BFACT(K,I)*FOXYCAL*FDLTM/1440*BF1(K,I,1)
```

```
        BF_SC(K,I) = 0.172*(BF_DC(K,I)-BF_FC(K,I))
        IF(BF1(K,I,1).LE.196.0) THEN
          BF1(K,I,4) = (1.851*BF1(K,I,1)+1250.0)*4.1868
        ELSE
          BF1(K,I,4) = (0.1254*BF1(K,I,1) + 1588.0)*4.1868
        END IF
        BF_CC(K,I) = BFCON(K,I)*MZOO(3)*FDLTM*EZOO(3)
        BF1(K,I,3) = BF1(K,I,3)*EXP(-1*DIGK*FDLTH)+BFCON(K,I)*MZOO(3)*60/DIGK*(1-EXP(-1*DIGK*FDLTH))
END IF !BESTCALC

! ***********  DIELCALC  *************
IF(DIELCALC) THEN
        DF_DC(K,I) = (DF1(K,I,3) + DFCON(K,I)*MZOO(3)*FDLTM   -    (DF1(K,I,3)*EXP(-1*DIGK*FDLTH) &
          + DFCON(K,I)*MZOO(3)*60/DIGK*(1-EXP(-1*DIGK*FDLTH))    )) *EZOO(3)
        DF_DC_EXT(K,I) = DF_DC(K,I) + 0.2*DFCONJ(K,I)
        DF_FC(K,I)     = 0.212*(T1Z(K,I)**-0.222)*DF_DC(K,I)
        DF_UC(K,I) = 0.0233*(T1Z(K,I)**-0.580)*(DF_DC(K,I)-DF_FC(K,I))
        DFACT(K,I) = EXP(0.02334*100.0*DFVEL(K,I))
        DF_RC(K,I) = 0.00143*(DF1(K,I,1)**-
0.209)*EXP(0.086*T1Z(K,I))*DFACT(K,I)*FOXYCAL*FDLTM/1440*DF1(K,I,1)
        DF_SC(K,I) = 0.172*(DF_DC(K,I)-DF_FC(K,I))
        IF(DF1(K,I,1).LE.196.0) THEN
          DF1(K,I,4) = (1.851*DF1(K,I,1)+1250.0)*4.1868
        ELSE
          DF1(K,I,4) = (0.1254*DF1(K,I,1) + 1588.0)*4.1868
        END IF
        DF_CC(K,I) = DFCON(K,I)*MZOO(3)*FDLTM*EZOO(3)
        DF1(K,I,3) = DF1(K,I,3)*EXP(-1*DIGK*FDLTH)+DFCON(K,I)*MZOO(3)*60/DIGK*(1-EXP(-1*DIGK*FDLTH))
END IF !DIELCALC
END DO ! MAIN K LOOP

! ***************************************************************************
! *                          TASK ....  DAILY PARAMETER UPDATES              *
! ***************************************************************************
 ! DAILY PARAMETER UPDATES
 CELL_POS(I) = 0; CELL_NEG(I) = 0
 DO K = KTI(I),KBI(I)
   F_R(K,I) = F_R(K,I) + F_RC(K,I)
   F_D(K,I) = F_D(K,I) + F_DC(K,I)
   F_C(K,I) = F_C(K,I) + F_CC(K,I)
```

```
   F_W(K,I) = F_W(K,I) + F_UC(K,I) + F_FC(K,I)
   F_S(K,I) = F_S(K,I) + F_SC(K,I)
   F_G(K,I) = F_G(K,I) + (F_DC(K,I) - (F_SC(K,I) + F_FC(K,I) + F_UC(K,I))- F_RC(K,I))/F1(K,I,4)
   F2(K,I) =F_G(K,I)/F1(K,I,1)
   IF(F_G(K,I).GT.0) CELL_POS(I) = CELL_POS(I) +1
   IF(F_G(K,I).LT.0) CELL_NEG(I) = CELL_NEG(I) +1
 END DO
 CELL_PER(I) = (CELL_POS(I)*1.0)/(CELL_POS(I)*1.0+CELL_NEG(I)*1.0)*100.0
! ***********  BESTCALC  *************
IF(BESTCALC) THEN
      BCELL_POS(I) = 0; BCELL_NEG(I) = 0
        GMAXG = -99999.0; GMAXK = 2
      DO K = KTI(I),KBI(I)
        BF_G(K,I) = (BF_DC(K,I) - (BF_SC(K,I) + BF_FC(K,I) + BF_UC(K,I))- BF_RC(K,I))/BF1(K,I,4)
        BF_G_EXT(K,I) = (BF_DC_EXT(K,I) - (BF_SC(K,I) + BF_FC(K,I) + BF_UC(K,I))-
BF_RC(K,I))/BF1(K,I,4)
           F_G2(K,I) = F_G2(K,I) + BF_G(K,I)
        IF(BF_G_EXT(K,I).GT.GMAXG) THEN ! FIND BEST LAYER
          GMAXG = BF_G_EXT(K,I); GMAXK = K
          END IF
       IF(BF_G(K,I).GT.0) BCELL_POS = BCELL_POS + 1
         IF(BF_G(K,I).LT.0) BCELL_NEG = BCELL_NEG + 1
      END DO
        ! APPLY BEST LAYER TO CUMMALATIVE TERMS
       BF_GI(I) = BF_GI(I) + BF_G(GMAXK,I)
         BESTK(I,BESTSTEP) = GMAXK
       BF_RI(I) = BF_RI(I) + BF_RC(GMAXK,I)
       BF_DI(I) = BF_DI(I) + BF_DC(GMAXK,I)
         BF_CI(I) = BF_CI(I) + BF_CC(GMAXK,I)
         BF_WI(I) = BF_WI(I) + BF_UC(GMAXK,I) + BF_FC(GMAXK,I)
         BF_UI(I) = BF_UI(I) + BF_UC(GMAXK,I)
         BF_FI(I) = BF_FI(I) + BF_FC(GMAXK,I)
         BF_SI(I) = BF_SI(I) + BF_SC(GMAXK,I)
               T1BZ(I)  = T1BZ(I)  + T1Z(GMAXK,I)/48.0       ! average over a day
       ! UPDATE DIAGNOSTIC ACCOUNTING TERMS
       BFVELAVE(I) = BFVELAVE(I) + BFVEL(GMAXK,I)*FDLTM/1440
         BFACTAVE(I) = BFACTAVE(I) + BFACT(GMAXK,I)*FDLTM/1440
         BAVEC(I) = BAVEC(I) + BFCON(GMAXK,I)*FDLTM/1440
         BMINC(I) = MIN(BMINC(I),BFCON(GMAXK,I))
         BMAXC(I) = MAX(BMAXC(I),BFCON(GMAXK,I))
```

```
          BFULLSTOI(I) = BFULLSTOI(I) + BFULLSTO(GMAXK,I)
        BFCONI(I) = BFCONI(I) + BFCON(GMAXK,I)
          BDAYCI(I) = BDAYCI(I) + BDAYC(GMAXK,I)
          BDAYCMI(I) = BDAYCMI(I) + BDAYCM(GMAXK,I)
          BFCONMAXJI(I) = BFCONMAXJI(I) + BFCONMAXJ(GMAXK,I)/48.0      ! average over a day
          BFCONMAXGGI(I) = BFCONMAXGGI(I) + BFCONMAXGG(GMAXK,I)/48.0   ! average over a day
          BFCONJI(I) = BFCONJI(I) + BFCONJ(GMAXK,I)
          BFCONGGI(I) = BFCONGGI(I) + BFCONGG(GMAXK,I)
        BFCONPI(I) = BFCONGGI(I)/BFCONMAXGGI(I)
    IF(SINGLEDIAG.AND.DEPTHCALC) THEN
      IF(I.EQ.SINIBIO) THEN
           WRITE(BIOOUTFN(21),'(F8.3,3I8)') JDAY, I, BESTK(I,BESTSTEP),DIELK(I,BESTSTEP)
      END IF
    END IF
          ! TRANFER STOMACH CONTENTS
          BF1(:,I,3) = BF1(GMAXK,I,3)
        BCELL_PER(I) = (BCELL_POS(I)*1.0)/(BCELL_POS(I)*1.0+BCELL_NEG(I)*1.0)*100.0
        IF(GAMMAFDC(GMAXK,I).GT.1) THEN
          BVISIBLE(I) = BVISIBLE(I) + FDLTM
        END IF
          DO JJZ = 1,NZP
            BDIETI(I,JJZ) = BDIETI(I,JJZ) + BDIET(GMAXK,I,JJZ)
          END DO
        BDAYC(:,I) = BDAYC(GMAXK,I)
END IF !BESTCALC
! ************  DIELCALC  *************
    IF(DIELCALC) THEN
      DCELL_POS(I) = 0; DCELL_NEG(I) = 0
        GMAXG = -99999.0; GMAXK = 2
        RMIN = -99999.0 ; RMINK = 2; CMAX = -99999.0 ; CMAXK = 2
      DO K = KTI(I),KBI(I)
        DF_G(K,I) = (DF_DC(K,I) - (DF_SC(K,I) + DF_FC(K,I) + DF_UC(K,I))- DF_RC(K,I))/DF1(K,I,4)
        DF_G_EXT(K,I) = (DF_DC_EXT(K,I) - (DF_SC(K,I) + DF_FC(K,I) + DF_UC(K,I))-
DF_RC(K,I))/DF1(K,I,4)
        IF(DF_G_EXT(K,I).GT.GMAXG) THEN ! FIND BEST LAYER
          GMAXG = DF_G_EXT(K,I); GMAXK = K
          END IF
        IF(DF_R(K,I).LT.RMIN) THEN ! FIND BEST LAYER
          RMIN = DF_R(K,I); RMINK = K
          END IF
```

```
        IF(DF_CC(K,I).GT.CMAX) THEN ! FIND BEST LAYER
          CMAX = DF_CC(K,I); CMAXK = K
          END IF
        IF(DF_G(K,I).GT.0) DCELL_POS = DCELL_POS + 1
         IF(DF_G(K,I).LT.0) DCELL_NEG = DCELL_NEG + 1
      END DO
! ************************************************************
        ! APPLY BEST LAYER TO CUMMALATIVE TERMS
IF(DF_G(GMAXK,I).GT.0.0) THEN
  KBEST = GMAXK
ELSE
  IF(DAYLIGHT) THEN
    IF(DF_G(CMAXK,I).GE.0.0) THEN
        KBEST = CMAXK
      ELSE
        IF(FORAY(I)) THEN
          IF(T1Z(CMAXK,I).GT.20.0) THEN
              DO KK = CMAXK,KBI(I)-1
                IF(T1Z(KK,I).GT.20.0) THEN
                    CONTINUE
                  ELSE
                    KBEST = KK
                    EXIT
                  END IF
              END DO
            ELSE
              KBEST = CMAXK
            END IF
            FORAY(I) = .FALSE.
        ELSE
          KBEST = RMINK
            FORAY(I) = .TRUE.
        END IF
      END IF
  ELSE
    KBEST = RMINK
  END IF
END IF
       DF_GI(I) = DF_GI(I) + DF_G(KBEST,I)
         DIELK(I,BESTSTEP) = KBEST
```

```
        DF_RI(I) = DF_RI(I) + DF_RC(KBEST,I)
        DF_DI(I) = DF_DI(I) + DF_DC(KBEST,I)
          DF_CI(I) = DF_CI(I) + DF_CC(KBEST,I)
          DF_WI(I) = DF_WI(I) + DF_UC(KBEST,I) + DF_FC(KBEST,I)
          DF_UI(I) = DF_UI(I) + DF_UC(KBEST,I)
          DF_FI(I) = DF_FI(I) + DF_FC(KBEST,I)
          DF_SI(I) = DF_SI(I) + DF_SC(KBEST,I)
        ! UPDATE DIAGNOSTIC ACCOUNTING TERMS
        DFVELAVE(I) = DFVELAVE(I) + DFVEL(KBEST,I)*FDLTM/1440
          DFACTAVE(I) = DFACTAVE(I) + DFACT(KBEST,I)*FDLTM/1440
          DAVEC(I) = DAVEC(I) + DFCON(KBEST,I)*FDLTM/1440
          DMINC(I) = MIN(DMINC(I),DFCON(KBEST,I))
          DMAXC(I) = MAX(DMAXC(I),DFCON(KBEST,I))
          DFULLSTOI(I) = DFULLSTOI(I) + DFULLSTO(KBEST,I)
        DFCONI(I) = DFCONI(I) + DFCON(KBEST,I)
          DDAYCI(I) = DDAYCI(I) + DDAYC(KBEST,I)
          DDAYCMI(I) = DDAYCMI(I) + DDAYCM(KBEST,I)
          DFCONMAXJI(I) = DFCONMAXJI(I) + DFCONMAXJ(KBEST,I)/48.0     ! average over a day
          DFCONMAXGGI(I) = DFCONMAXGGI(I) + DFCONMAXGG(KBEST,I)/48.0  ! average over a day
          DFCONJI(I) = DFCONJI(I) + DFCONJ(KBEST,I)
          DFCONGGI(I) = DFCONGGI(I) + DFCONGG(KBEST,I)
        DFCONPI(I) = DFCONGGI(I)/DFCONMAXGGI(I)
          DF1(:,I,3) = DF1(KBEST,I,3)
        DCELL_PER(I) = (DCELL_POS(I)*1.0)/(DCELL_POS(I)*1.0+DCELL_NEG(I)*1.0)*100.0
        IF(GAMMAFDC(KBEST,I).GT.1) THEN
          DVISIBLE(I) = DVISIBLE(I) + FDLTM
        END IF
          DO JJZ = 1,NZP
            DDIETI(I,JJZ) = DDIETI(I,JJZ) + DDIET(KBEST,I,JJZ)
          END DO
        DDAYC(:,I) = DDAYC(KBEST,I)
      END IF !DIELCALC

! ***************************************************************************
! *                            TASK ....  DAILY CALCULATIONS AND UPDATES     *
! ***************************************************************************
 IF(BIODAY_CALC) THEN !BIODAY
  ! IF(KBI(I).GT.KTI(I)+1) F_G(KBI(I)-1,I) = F_G(KBI(I)-2,I)
  ! IF(KBI(I).GT.KTI(I)) F_G(KBI(I),I) = F_G(KBI(I)-1,I)
   IF(FDIAG) CALL FOUTPUT_DAILY
```

```
    IF(JI.EQ.NIBIO) then
       print *,'ji = ', ji
       CALL ANIMATION_DATA
         continue
    end if
    CALL DAILY_GROWTH
    IF(JI.EQ.NIBIO) CALL BY_SEG_OUTPUT
    IF(JI.EQ.NIBIO) PRINT *,JDAY,BF1(2,312,1),T1Z(2,I)
    KBIP(I) = KBI(I)
    CALL BIOEXPTRANSFORM
  ! CHECK FOR CHANGES IN KTI (LAYER ADDITION/SUBTRACTION REQUIRES INITIALIZING):  SHOWS UP IN
ANIMATIONS
  IF(KBI(I).GT.KBIP(I)) THEN
     ! WRITE(999,*)'INITIALIZING, JDAY, I ',INT(JDAY),I
    DO K = KBI(I),3,-1
        F1(KBI(I),I,:) = F1(KBI(I)-1,I,:)
      F_R(KBI(I),I) = F_R(KBI(I)-1,I)
      F_D(KBI(I),I) = F_D(KBI(I)-1,I)
      F_C(KBI(I),I) = F_C(KBI(I)-1,I)
      F_W(KBI(I),I) = F_W(KBI(I)-1,I)
      F_S(KBI(I),I) = F_S(KBI(I)-1,I)
      F_G(KBI(I),I) = F_G(KBI(I)-1,I)
    END DO
        F1(2,I,:) = F1(3,I,:)
      F_R(2,I) = F_R(3,I)
      F_D(2,I) = F_D(3,I)
      F_C(2,I) = F_C(3,I)
      F_W(2,I) = F_W(3,I)
      F_S(2,I) = F_S(3,I)
      F_G(2,I) = F_G(3,I)
   END IF
  IF(KBI(I).LT.KBIP(I)) THEN
       ! WRITE(999,*)'INITIALIZING, JDAY, I ',INT(JDAY),I
    DO K = KBI(I),2,-1
        F1(KBI(I),I,:) = F1(KBI(I)+1,I,:)
      F_R(KBI(I),I) = F_R(KBI(I)+1,I)
      F_D(KBI(I),I) = F_D(KBI(I)+1,I)
      F_C(KBI(I),I) = F_C(KBI(I)+1,I)
      F_W(KBI(I),I) = F_W(KBI(I)+1,I)
      F_S(KBI(I),I) = F_S(KBI(I)+1,I)
```

```
      F_G(KBI(I),I) = F_G(KBI(I)+1,I)
     END DO
    END IF
! ***********  ANIMATION  *************
    ! ANIMATION ELEVATION DETERMINATION (TEMPORARY APPROACH)
     ! FIND BOTTOM ELEVATION
    DO II = 1,IMX
      IF(I.EQ.BOTSEG(II)) THEN
          GELEV(KBI(I),I) = BOTTOME(II)
          EXIT
        END IF
    END DO
     ! ASSIGN ELEVATIONS
    DO K=KBI(I)-1,2,-1
      GELEV(K,I)=GELEV(K+1,I)+2.0
    END DO
   END IF !BIODAY
   FIRST_BIO(JI) = .FALSE.
 998 CONTINUE
END DO ! MAIN LOOP (SEGMENT ADVANCEMENT)
! ********************************************************************************
! *                              TASK ....  REZERO CUMMULATIVE DAILY TERMS          *
! ********************************************************************************
! REZERO CUMMULATIVE DAILY TERMS
NELEM = 0; NNODE = 0
IF(BIODAY_CALC) THEN
 F_R  = 0.0  ;F_D  = 0.0  ;F_C  = 0.0  ;F_F   = 0.0  ;F_U      = 0.0 ; VISIBLE = 0.0
 F_S  = 0.0  ;F_G  = 0.0  ;F_W  = 0.0  ;DAYC  = 0.0  ;FULLSTO  = 0   ; DIET    = 0.0
 FVELAVE = 0.0; FACTAVE = 0.0;AVEC = 0.0; MINC = 0.0; MAXC = 0.0
 MAXG = -999.0; MAXM = -999.0; F_G2 = 0.0
    ! ***********  BESTCALC  *************
 IF(BESTCALC) THEN
  BF_R  = 0.0 ;BF_D  = 0.0 ;BF_C  = 0.0 ;BF_F   = 0.0 ;BF_U    = 0.0
  BF_S  = 0.0 ;BF_G  = 0.0 ;BF_W  = 0.0 ;BDAYC  = 0.0 ;BDIET  = 0.0; BDIETI = 0.0
  BESTSTEP = 0
  BF_GI = 0.0 ;BF_RI = 0.0 ;BF_DI = 0.0 ;BF_CI  = 0.0 ;BF_WI   = 0.0  ; BF_SI = 0.0; BF_UI = 0.0;
BF_FI = 0.0
  BFVELAVE = 0.0; BFACTAVE = 0.0;  BAVEC = 0.0; BMINC = 0.0; BMAXC = 0.0; BVISIBLE = 0.0
  BFULLSTO = 0; BFULLSTOI = 0
```

```
  BFCONMAXJI = 0.0; BFCONMAXGGI = 0.0; BFCONI = 0.0; BDAYCI = 0.0; BDAYCMI = 0.0; BFCONPI = 0.0;
BFCONJI = 0.0; BFCONGGI = 0.0
  T1BZ = 0.0
 END IF
   ! ***********  DIELCALC  *************
 IF(DIELCALC) THEN
  DF_R  = 0.0 ;DF_D  = 0.0 ;DF_C  = 0.0 ;DF_F   = 0.0 ;DF_U    = 0.0
  DF_S  = 0.0 ;DF_G  = 0.0 ;DF_W  = 0.0 ;DDAYC  = 0.0 ;DDIET  = 0.0; DDIETI = 0.0
  DF_GI = 0.0 ;DF_RI = 0.0 ;DF_DI = 0.0 ;DF_CI  = 0.0 ;DF_WI   = 0.0  ; DF_SI = 0.0; DF_UI = 0.0;
DF_FI = 0.0
  DFVELAVE = 0.0; DFACTAVE = 0.0;  DAVEC = 0.0; DMINC = 0.0; DMAXC = 0.0; DVISIBLE = 0.0
  DFULLST0 = 0; DFULLSTOI = 0
  DFCONMAXJI = 0.0; DFCONMAXGGI = 0.0; DFCONI = 0.0; DDAYCI = 0.0; DDAYCMI = 0.0; DFCONPI = 0.0;
DFCONJI = 0.0; DFCONGGI = 0.0
 END IF
END IF
BIOSUB_CALC = .FALSE.;  BIODAY_CALC = .FALSE.

! ***************************************************************************************
! *                              TASK ....  END TIME-STEP                                 *
! ***************************************************************************************
GOTO 2110 ! RETURN TO JDAY ADVANCEMENT
!*****************************************************************************************
*********************************
!**                                                    E N D   P R O G R A M
**
!*****************************************************************************************
*********************************
997 CONTINUE
! GROWTH ANIMATION DATE/TEXT
DO IZ = 1,ZONECNT
  IZZ = IZ+ZONEFIRST-1
  WRITE(ANIMFN,863) IZ,IZZ
  WRITE(ANIMFN,864) IZ,GREGORY(IZ)
END DO
863 FORMAT('TEXT X=0.2, y=0.15, H=3.0, ZN=',i4,',',' C=BLACK,','T= "Julian Day ',I6,'"')
864 FORMAT('TEXT X=0.2, y=0.20, H=3.0, ZN=',i4,',',' C=BLACK,','T= "',A20,'"')
DO II = 1,NIBIO
  CLOSE(BIOINFN(II))
END DO
```

```
CLOSE(LIGHTNUM)
STOP
END !PROGRAM END

!*****************************************************************************************************
**********************************
!**                                                S U B R O U T I N E  L I G H T O U T
**
!*****************************************************************************************************
**********************************

SUBROUTINE LIGHTOUT
 USE MAINW2; USE FISH; USE FISH2; USE BIOEXPDATATRANSFORM; USE DIAGNOSTIC; USE ROOSEVELT; USE
MOVEMENT
    LJDAY1 = LJDAY2; LUX1 = LUX2
    READ(LIGHTNUM,'(10X,F10.0,20X,E10.2)') LJDAY2,LUX2
RETURN
END SUBROUTINE LIGHTOUT

!*****************************************************************************************************
**********************************
!**                                              S U B R O U T I N E  D A I L Y  G R O W T H
**
!*****************************************************************************************************
**********************************

SUBROUTINE DAILY_GROWTH
 USE MAINW2; USE FISH; USE FISH2; USE BIOEXPDATATRANSFORM; USE DIAGNOSTIC; USE ROOSEVELT; USE
MOVEMENT
! UPDATE MASS & STOMACH CAPACITY
! GENERAL EQUATION
  IF(GMTPCELL) THEN
    DO K = KTI(I),KBI(I)
      F1(K,I,1) = F1(K,I,1) + F_G(K,I)
      IF(F1(K,I,1).LE.253.5) THEN ! UPDATE STOMACH CAPACITY (BRETT, 1971)
        F1(K,I,5) = (14.1-4.95*LOG10(F1(K,I,1)))/100.0*F1(K,I,1)
      ELSE
        F1(K,I,5) = 0.0022*F1(K,I,1)
      END IF
      MAXM(I) = MAX(MAXM(I),F1(K,I,1))  ! MAXMASS
```

```
        MAXG(I) = MAX(MAXG(I),F_G(K,I))    ! MAXGROWTH
      END DO
    END IF
    IF(GMTPFXN) THEN
      DO K = KTI(I),KBI(I)
        F1(K,I,1) = GIM*EXP(GALP*(JDAY-GTI))
        IF(F1(K,I,1).LE.253.5) THEN ! UPDATE STOMACH CAPACITY (BRETT, 1971)
          F1(K,I,5) = (14.1-4.95*LOG10(F1(K,I,1)))/100.0*F1(K,I,1)
        ELSE
          F1(K,I,5) = 0.0022*F1(K,I,1)
        END IF
        MAXM(I) = MAX(MAXM(I),F1(K,I,1))   ! MAXMASS
        MAXG(I) = MAX(MAXG(I),F_G(K,I))    ! MAXGROWTH
      END DO
    END IF
    IF(GMTPFIXED) THEN
      CONTINUE
    END IF
    IF(GMTPUSER) THEN
      READ(FXNFN(1),'(2F8.0)') F1J,F1M
        F1(:,I,1) = F1M
        IF(INT(JDAY).NE.INT(F1J)) THEN
        PRINT *,'POSSIBLE PRESCRIBED MASS ERROR :',F1J,JDAY
      END IF
    END IF
  IF(BESTCALC) THEN
    IF(BMTPSEG) THEN
      DO K = KTI(I),KBI(I)
        BF1(K,I,1) = BF1(K,I,1) + BF_GI(I)
        IF(BF1(K,I,1).LE.253.5) THEN ! UPDATE STOMACH CAPACITY (BRETT, 1971)
          BF1(K,I,5) = (14.1-4.95*LOG10(BF1(K,I,1)))/100.0*BF1(K,I,1)
        ELSE
          BF1(K,I,5) = 0.022*BF1(K,I,1)
        END IF
      END DO
    END IF
    IF(BMTPFXN) THEN
      DO K = KTI(I)-1,KBI(I)+1
        BF1(K,I,1) = BIM*EXP(BALP*(JDAY-BTI))
        IF(BF1(K,I,1).LE.253.5) THEN ! UPDATE STOMACH CAPACITY (BRETT, 1971)
```

```
          BF1(K,I,5) = (14.1-4.95*LOG10(BF1(K,I,1)))/100.0*BF1(K,I,1)
        ELSE
          BF1(K,I,5) = 0.022*BF1(K,I,1)
        END IF
      END DO
    END IF
    IF(BMTPFIXED) THEN
      CONTINUE
    END IF
    IF(BMTPUSER) THEN
      READ(FXNFN(2),'(2F8.0)') F1J,F1M
        BF1(:,I,1) = F1M
        IF(INT(JDAY).NE.INT(F1J)) THEN
        PRINT *,'POSSIBLE PRESCRIBED MASS ERROR :',F1J,JDAY
      END IF
    END IF
  END IF
IF(DIELCALC) THEN
  IF(DMTPSEG) THEN
    DO K = KTI(I),KBI(I)
      DF1(K,I,1) = DF1(K,I,1) + DF_GI(I)
      IF(DF1(K,I,1).LE.253.5) THEN ! UPDATE STOMACH CAPACITY (BRETT, 1971)
        DF1(K,I,5) = (14.1-4.95*LOG10(DF1(K,I,1)))/100.0*DF1(K,I,1)
      ELSE
        DF1(K,I,5) = 0.022*DF1(K,I,1)
      END IF
    END DO
  END IF
  IF(DMTPFXN) THEN
    DO K = KTI(I),KBI(I)
      DF1(K,I,1) = DIM*EXP(DALP*(JDAY-DTI))
      IF(DF1(K,I,1).LE.253.5) THEN ! UPDATE STOMACH CAPACITY (BRETT, 1971)
        DF1(K,I,5) = (14.1-4.95*LOG10(DF1(K,I,1)))/100.0*DF1(K,I,1)
      ELSE
        DF1(K,I,5) = 0.022*DF1(K,I,1)
      END IF
    END DO
  END IF
  IF(DMTPFIXED) THEN
    CONTINUE
```

```
  END IF
  IF(DMTPUSER) THEN
    READ(FXNFN(3),'(2F8.0)') F1J,F1M
      DF1(:,I,1) = F1M
      IF(INT(JDAY).NE.INT(F1J)) THEN
      PRINT *,'POSSIBLE PRESCRIBED MASS ERROR :',F1J,JDAY
    END IF
  END IF
END IF
END SUBROUTINE DAILY_GROWTH

!*****************************************************************************************************
*********************************
!**                                        S U B R O U T I N E   F I S H O U T P U T   D A I L Y
**
!*****************************************************************************************************
*********************************

SUBROUTINE FOUTPUT_DAILY
USE MAINW2; USE FISH; USE FISH2;USE BIOEXPDATATRANSFORM; USE GROWTH_ANIMATION; USE DIAGNOSTIC; USE
ROOSEVELT; USE MOVEMENT

  IF(FISHDIAG) THEN
    DO K = KTI(I),KBI(I)
       WRITE(BIOOUTFN(1),77771)
JDAY,I,F_G(K,I),F1(K,I,1),CELL_PER(I),FULLSTO(K,I),VISIBLE(K,I),T1Z(K,I)
      END DO
      77771 FORMAT(F8.3,X,I8,X,F8.4,X,2(F8.2,X),I8,X,2(F8.2,X))
      77871 FORMAT(F8.3,X,I8,X,F8.4,X,2(F8.2,X),I8,X,2(F8.2,X),F8.5)
    IF(SURFDIAG) THEN
       K = KTI(I)
      WRITE(BIOOUTFN(16),77771)
JDAY,I,F_G(K,I),F1(K,I,1),CELL_PER(I),FULLSTO(K,I),VISIBLE(K,I),T1Z(K,I)
      END IF
      IF(BESTCALC) THEN
        K = KTI(I)
      WRITE(BIOOUTFN(2),77871)
JDAY,I,BF_GI(I),BF1(K,I,1),BCELL_PER(I),BFULLSTOI(I),BVISIBLE(I),T1BZ(I),GAMMAFDC(K,I)
      END IF
      IF(DIELCALC) THEN
```

```
        K = KTI(I)
       WRITE(BIOOUTFN(3),77771)
JDAY,I,DF_GI(I),DF1(K,I,1),DCELL_PER(I),DFULLSTOI(I),DVISIBLE(I),T1Z(K,I)
       END IF
  END IF ! FISHDIAG
  IF(BIOPARDIAG) THEN
    DO K = KTI(I),KBI(I)
        WRITE(BIOOUTFN(4),77772)
JDAY,I,F_G(K,I),F_D(K,I),F_R(K,I),F_S(K,I),F_W(K,I),F_U(K,I),F_F(K,I)
       END DO
       77772 FORMAT(F8.3,X,I8,X,7(F8.1,X))
    IF(SURFDIAG) THEN
        K = KTI(I)
       WRITE(BIOOUTFN(17),77772)
JDAY,I,F_G(K,I),F_D(K,I),F_R(K,I),F_S(K,I),F_W(K,I),F_U(K,I),F_F(K,I)
       END IF
       IF(BESTCALC) THEN
         K = KTI(I)
         WRITE(BIOOUTFN(5),77772)
JDAY,I,BF_GI(I),BF_DI(I),BF_RI(I),BF_SI(I),BF_WI(I),BF_UI(I),BF_FI(I)
       END IF
       IF(DIELCALC) THEN
         K = KTI(I)
         WRITE(BIOOUTFN(6),77772)
JDAY,I,DF_GI(I),DF_DI(I),DF_RI(I),DF_SI(I),DF_WI(I),DF_UI(I),DF_FI(I)
       END IF
  END IF ! BIOPARDIAG
  IF(CONSDIAG) THEN
    DO K = KTI(I),KBI(I)
        WRITE(BIOOUTFN(7),77773)
JDAY,I,CEFF(K),AVEC(K,I),MINC(K,I),MAXC(K,I),DAYC(K,I),DAYCM(K,I),DIET(K,I,1),DIET(K,I,2),&
          DIET(K,I,3),FCONMAXJ(K,I),FCONMAXGG(K,I),FCONJ(K,I),FCONGG(K,I),FCONP(K,I)
       END DO
       77773 FORMAT(F8.3,X,I8,X,5(F8.1,X),F8.2,X,3(F8.2,X),2(F8.1,X,F8.4,X),F8.3,X)
       77873 FORMAT(F8.3,X,I8,X,5(F8.1,X),F8.2,X,3(F8.2,X),2(F8.1,X,F8.4,X),2(F8.3,X))
    IF(SURFDIAG) THEN
        K = KTI(I)
       WRITE(BIOOUTFN(18),77773)
JDAY,I,CEFF(K),AVEC(K,I),MINC(K,I),MAXC(K,I),DAYC(K,I),DAYCM(K,I),DIET(K,I,1),DIET(K,I,2),&
          DIET(K,I,3),FCONMAXJ(K,I),FCONMAXGG(K,I),FCONJ(K,I),FCONGG(K,I),FCONP(K,I)
```

```
      END IF
      IF(BESTCALC) THEN
        K = KTI(I)
        WRITE(BIOOUTFN(8),77873)
JDAY,I,CEFF(K),BAVEC(I),BMINC(I),BMAXC(I),BDAYCI(I),BDAYCMI(I),BDIETI(I,1),BDIETI(I,2),BDIETI(I,3),&
          BFCONMAXJI(I),BFCONMAXGGI(I),BFCONJI(I),BFCONGGI(I),BFCONPI(I),T1BZ(I)
      END IF
    IF(DIELCALC) THEN  ! NEED TO ADD TERMS
      K = KTI(I)
      WRITE(BIOOUTFN(9),77773)
JDAY,I,CEFF(K),DAVEC(I),DMINC(I),DMAXC(I),DDAYCI(I),DDAYCMI(I),DDIETI(I,1),DDIETI(I,2),DDIETI(I,3),&
        DFCONMAXJI(I),DFCONMAXGGI(I),DFCONJI(I),DFCONGGI(I),DFCONPI(I)
    END IF
  END IF ! CONSDIAG
  IF(DIGDIAG) THEN
    DO K = KTI(I),KBI(I)
       WRITE(BIOOUTFN(10),77774)
JDAY,I,F_D(K,I),F_DINI(K,I),F_DCON(K,I),F_DUNDIG(K,I),F1(K,I,3),F1(K,I,5),F1(K,I,4)
      END DO
      77774 FORMAT(F8.3,X,I8,X,4(F8.1X),3(F8.2,X))
    IF(SURFDIAG) THEN
       K = KTI(I)
      WRITE(BIOOUTFN(19),77774)
JDAY,I,F_D(K,I),F_DINI(K,I),F_DCON(K,I),F_DUNDIG(K,I),F1(K,I,3),F1(K,I,5),F1(K,I,4)
      END IF
      IF(BESTCALC) THEN ! ADD THE DIGESTIVE DIAGNOSTIC TERMS TO THE CODE
        K = KTI(I)
        WRITE(BIOOUTFN(11),77774)
JDAY,I,BF_DI(I),F_DINI(K,I),F_DCON(K,I),F_DUNDIG(K,I),BF1(K,I,3),BF1(K,I,5),BF1(K,I,4)
      END IF
    IF(DIELCALC) THEN   ! NEED TO ADD TERMS
      K = KTI(I)
      WRITE(BIOOUTFN(12),77774)
JDAY,I,DF_DI(I),F_DINI(K,I),F_DCON(K,I),F_DUNDIG(K,I),DF1(K,I,3),DF1(K,I,5),DF1(K,I,4)
    END IF
  END IF ! DIGDIAG
  IF(RESPDIAG) THEN
    DO K = KTI(I),KBI(I)
       WRITE(BIOOUTFN(13),77775) JDAY,I,F_R(K,I),FACTAVE(K,I),FVELAVE(K,I)
      END DO
```

```
      77775 FORMAT(F8.3,X,I8,X,F8.1,X,2(F8.3,X))
    IF(SURFDIAG) THEN
        K = KTI(I)
      WRITE(BIOOUTFN(20),77775) JDAY,I,F_R(K,I),FACTAVE(K,I),FVELAVE(K,I)
      END IF
      IF(BESTCALC) THEN
        K = KTI(I)
        WRITE(BIOOUTFN(14),77775) JDAY,I,BF_RI(I),BFACTAVE(I),BFVELAVE(I)
      END IF
      IF(DIELCALC) THEN
        K = KTI(I)
        WRITE(BIOOUTFN(15),77775) JDAY,I,DF_RI(I),DFACTAVE(I),DFVELAVE(I)
      END IF
  END IF ! RESPDIAG
GOTO 2121
  IF(SINGLEDIAG.AND.DEPTHCALC) THEN
    IF(I.EQ.SINIBIO) THEN
      DO II = 1, BESTSTEP
          WRITE(BIOOUTFN(21),'(4I8)') INT(JDAY-0.5), I, BESTK(I,II),DIELK(I,II)
      END DO
    END IF
  END IF
2121 CONTINUE
RETURN
END SUBROUTINE FOUTPUT_DAILY

!*******************************************************************************************************
*********************************
!**                                        S U B R O U T I N E   B I O E X P T R A N S F O R M
**
!*******************************************************************************************************
*********************************

! KTI,KBI ARE NOT W2 VALUES; NEED TO UPDATE TO INCORPORATE INTO W2
SUBROUTINE BIOEXPTRANSFORM
USE MAINW2; USE FISH; USE FISH2; USE BIOEXPDATATRANSFORM; USE GROWTH_ANIMATION; USE DIAGNOSTIC; USE
ROOSEVELT; USE MOVEMENT
GOTO 5001
REWIND(BIOINFN(JI))
READ(BIOINFN(JI),'(A72)') FRED
```

```
FIRSTK = -1; LASTK = -1
DO K = 1,10000000
  READ(BIOINFN(JI),'(F8.0)') ZDAY1
  IF(ZDAY1.LT.FBIODAYLST) FIRSTK = K
  IF(ZDAY1.LT.FBIODAYNXT) LASTK = K
  IF(ZDAY1.GE.FBIODAYNXT) EXIT
END DO
! POSITION CURSOR TO READ THE INTENDED DAY
REWIND(BIOINFN(JI))
READ(BIOINFN(JI),'(A72)') FRED
DO K = 1, FIRSTK
  READ(BIOINFN(JI),'(F8.0)') ZDAY1
END DO
KTI(I) = 2; KBI(I) = LASTK-FIRSTK
IF(KBI(I).LT.KTI(I)) KBI(I) = KTI(I)
5001 CONTINUE
IF(FIRSTREAD(JI)) THEN
 REWIND(BIOINFN(JI))
 READ(BIOINFN(JI),'(A72)') FRED
 FIRSTREAD(JI) = .FALSE.
END IF
 DO K = 2,10000000
   READ(BIOINFN(JI),'(F8.0)') ZDAY1
   IF(ZDAY1.LT.FBIODAYNXT) LASTK = K
   IF(ZDAY1.GE.FBIODAYNXT) EXIT
 END DO
 DO K = 2,LASTK+1
   BACKSPACE(BIOINFN(JI))
 END DO
KTI(I) = 2; KBI(I) = LASTK
DO K = KTI(I),KBI(I) ! WILL NEED TO CONVERT C2 (:,:,JZ) FROM NZP TO NZOOS,NZOOE FOR MAIN W2 PROGRAM
  READ(BIOINFN(JI),'(F8.0,8X,3F8.2,3F8.3,I8,2F8.0,A20)') ZDAY1,DEPTHM(K,I),T1(K,I),GAMMA(K,I),&
       (C2(K,I,JZ),JZ=1,NZP),SEGK,BH(K,I),EL(K,I),GREGORY(GRCT)
 ! T1Z(K,I) = T1Z(K,I) - 1.0 !temperature sensitivity
  T1Z(K,I) = MAX(T1(K,I)-1,0.01) ! TEMPERATURES BELOW FREEZING
  DO JJZ = 1,NZP
    C1Z(K,I,JJZ)=C2(K,I,JJZ)/MZOO(JJZ)/1000.0 !C1Z HAS UNITS OF ORGANISMS PER M3 ! CONVERT FROM MG
TO G
  END DO
  ! AVAILABILITY COMPUTATION (MAZUR)
```

```
  IF(THRESHOLD) THEN
    DAP_IN = C2(K,I,3)*1000.0
    IF(DAP_IN.GE.THRESHV) THEN
        THRESHFEED(K) = .TRUE.
      CEFF(K) = C1Z(K,I,3)*ZAVAIL(3)
    ELSE
        THRESHFEED(K) = .FALSE.
      CEFF(K) = (C1Z(K,I,1)*ZAVAIL(1)+C1Z(K,I,2)*ZAVAIL(2)+C1Z(K,I,3)*ZAVAIL(3))
    END IF
  ELSE
    CEFF(K) = (C1Z(K,I,1)*ZAVAIL(1)+C1Z(K,I,2)*ZAVAIL(2)+C1Z(K,I,3)*ZAVAIL(3))
  END IF !THRESHOLD
END DO
END SUBROUTINE BIOEXPTRANSFORM

!*****************************************************************************************************
*******************************
!**                                        S U B R O U T I N E   G E T  F I S H  D A T A
**
!*****************************************************************************************************
*******************************

SUBROUTINE GETFISHDATA
USE MAINW2; USE FISH; USE FISH2; USE BIOEXPDATATRANSFORM; USE DIAGNOSTIC; USE ROOSEVELT; USE
MOVEMENT
  NUNIT = NUNIT+1; BIOCON = NUNIT
  OPEN(BIOCON,FILE='W2_BIO_CON.NPT',STATUS='OLD')
  DO II = 1,8
   READ(BIOCON,*)
  END DO
  READ(BIOCON,'(/(8X,A8,I8,4A8))') FCALC,FUF,FDIAGC,BESTC,DIELC,CMAXC
   FISHCALC = FCALC == '      ON'  ; FDIAG = FDIAGC == '      ON';BESTCALC = BESTC == '      ON'  ;
DIELCALC = DIELC == '      ON'
   CMAXCALC = CMAXC == '      ON'
  READ(BIOCON,'(//(8X,2F8.0))') JDAY, JEND
  READ(BIOCON,'(//(8X,8F8.0))') FISHT1,FISHT2,FISHT3,FISHT4,FISHK1,FISHK2,FISHK3,FISHK4
   FG1=(1/(FISHT2-FISHT1))*LOG((FISHK2*(1-FISHK1))/(FISHK1*(1-FISHK2)))
   FG2=(1/(FISHT4-FISHT3))*LOG((FISHK3*(1-FISHK4))/(FISHK4*(1-FISHK3)))
  READ(BIOCON,'(//(8X,F8.0))') FOXYCAL
  READ(BIOCON,'(//(8X,3F8.0))') (F1I(II),II=1,3)
```

```
   F1(:,:,1) = F1I(1); F1(:,:,2) = F1I(2); F1(:,:,3) = F1I(3)
  READ(BIOCON,'(/)')
  READ(BIOCON,'(:8X,9F8.0)') (LZOO(II),II = 1,3)
  READ(BIOCON,'(/)')
  READ(BIOCON,'(:8X,9F8.0)') (MZOO(II),II = 1,3)
  READ(BIOCON,'(/)')
  READ(BIOCON,'(:8X,9F8.0)') (EZOO(II),II = 1,3)
  READ(BIOCON,'(//(8X,4F8.0,A8,F8.0,I8,F8.0))')
HANDLE,FVELA,FVELB,FVELE,THRESHC,THRESHV,THRESHZ,DIELLUX
   THRESHOLD = THRESHC == '      ON'
  READ(BIOCON,'(//(8X,A8))') FGPC
   FGPPLOT = FGPC == '      ON'
  READ(BIOCON,'(//(8X,F8.0))') FGPD
  READ(BIOCON,'(//(8X,F8.0))') FGPF
  READ(BIOCON,'(//(8X,3A8))') GENMTP,BESTMTP,DIELMTP
   GMTPCELL = GENMTP  == '    CELL';GMTPFXN = GENMTP  == '      FXN';GMTPUSER = GENMTP  == '
USER';GMTPFIXED = GENMTP  == '   FIXED'
   BMTPSEG  = BESTMTP == '     SEG';BMTPFXN = BESTMTP == '      FXN';BMTPUSER = BESTMTP == '
USER';DMTPFIXED = BESTMTP == '   FIXED'
   DMTPSEG  = DIELMTP == '     SEG';DMTPFXN = DIELMTP == '      FXN';DMTPUSER = DIELMTP == '
USER';BMTPFIXED = DIELMTP == '   FIXED'
   IF(GMTPCELL.OR.GMTPFXN.OR.GMTPUSER.OR.GMTPFIXED) GMTOK = .TRUE.
   IF(BMTPSEG.OR.BMTPFXN.OR.BMTPUSER.OR.BMTPFIXED) BMTOK = .TRUE.
   IF(DMTPSEG.OR.DMTPFXN.OR.DMTPUSER.OR.DMTPFIXED) DMTOK = .TRUE.
   IF(.NOT.GMTOK) THEN
     PRINT *,'GENERAL FISH MASS TYPE NOT RECOGNIZED: ',GENMTP
       STOP
   END IF
   IF(.NOT.BMTOK) THEN
     PRINT *,'BEST FISH MASS TYPE NOT RECOGNIZED: ',BESTMTP
       STOP
   END IF
   IF(.NOT.DMTOK) THEN
     PRINT *,'FORAGING FISH MASS TYPE NOT RECOGNIZED: ',DIELMTP
       STOP
   END IF
  READ(BIOCON,'(//(8X,9F8.0))') GIM,BIM,DIM,GALP,BALP,DALP,GTI,BTI,DTI
  READ(BIOCON,'(//(8X,7A8))') FISHC, BIOPARC, CONSC, DIGC, RESPC, SURFC,DEPTHC
   FISHDIAG = FISHC  == '      ON'; BIOPARDIAG = BIOPARC  == '      ON'; CONSDIAG = CONSC   == '
ON'
```

```
   DIGDIAG  = DIGC   == '      ON'; RESPDIAG   = RESPC    == '      ON'; SURFDIAG = SURFC   == '
ON'
   DEPTHCALC= DEPTHC == '      ON'
  READ(BIOCON,'(//(8X,A8,2I8,A8))') SINGLEC, SINGFN, SINIBIO,TLC
   SINGLEDIAG   = SINGLEC    == '      ON'
   IF(SINGLEDIAG) TLCALC = TLC    == '      ON'
   IF(TLCALC) THEN
     NUNIT = NUNIT + 1; TLCALCFN = NUNIT
       OPEN(TLCALCFN,FILE='TLDIAG.DAT',STATUS='UNKNOWN')
       WRITE(TLCALCFN,'(2A8)') '    TEMP','      TL'
   END IF
  READ(BIOCON,'(//(8X,A72))') ZAVFNAME
   FRED = ADJUSTL(ZAVFNAME)
   L      = LEN_TRIM(FRED)
   ZAVFNAME = FRED(1:L)
   NUNIT = NUNIT+1; ZAVFN = NUNIT
  READ(BIOCON,'(/)')
   DO II = 1,NWB
     NUNIT = NUNIT+1; FGPFN = NUNIT
     READ(BIOCON,'(8X,A72)') FGPFNAME(II)
      FRED = ADJUSTL(FGPFNAME(II))
      L      = LEN_TRIM(FRED)
      FGPFNAME(II) = FRED(1:L)
   END DO
   READ(BIOCON,'(//(8X,A72))') FXNFNAME(1)
   READ(BIOCON,'((8X,A72))')   FXNFNAME(2)
   READ(BIOCON,'((8X,A72))')   FXNFNAME(3)
   DO II = 1,3
     FRED = ADJUSTL(FXNFNAME(II))
     L      = LEN_TRIM(FRED)
     FXNFNAME(II) = FRED(1:L)
     NUNIT = NUNIT+1; FXNFN(II) = NUNIT
   END DO
   IF(GMTPUSER) THEN
     OPEN(FXNFN(1),FILE=FXNFNAME(1),STATUS='OLD')
       READ(FXNFN(1),'(///)')
   END IF
   IF(BMTPUSER) THEN
     OPEN(FXNFN(2),FILE=FXNFNAME(2),STATUS='OLD')
       READ(FXNFN(2),'(///)')
```

```
   END IF
   IF(DMTPUSER) THEN
     OPEN(FXNFN(3),FILE=FXNFNAME(3),STATUS='OLD')
       READ(FXNFN(3),'(///)')
   END IF
CLOSE(BIOCON)
RETURN
END SUBROUTINE GETFISHDATA

!*****************************************************************************************************
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!**                                          S U B R O U T I N E   A N I M A T I O N   D A T A
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!*****************************************************************************************************
*********************************

SUBROUTINE ANIMATION_DATA
USE MAINW2; USE FISH; USE FISH2; USE BIOEXPDATATRANSFORM; USE GROWTH_ANIMATION; USE ROOSEVELT; USE
MOVEMENT

NELEM = 0
DO JJI = 1,NIBIO
 IF(ANIMEXP(JJI)) THEN
  II = IBIO(JJI)
  DO K = KTI(II),KBI(II)
   NELEM = NELEM+1
  END DO
 END IF
END DO
NNODE = NELEM*4
WRITE(ANIMFN,906) NNODE,NELEM
906 FORMAT('ZONE N=',i5,' E=',i6,', F=FEPOINT, ET=QUADRILATERAL')
LEFT = 0.0
DO JJI = 1,NIBIO
 IF(ANIMEXP(JJI)) THEN
  II = IBIO(JJI)
  DO K = KTI(II),KBI(II)
    IF(JJI.EQ.1) THEN
        X1(K,II) = 0.0; X4(K,II) = 0.0
    ELSE
```

```
          X1(K,II) = LEFT(1); X4(K,II) = LEFT(1)
        END IF
        X2(K,II) = DISTR(II)     ; X3(K,II) = DISTR(II)
      IF(K.EQ.KTI(I)) THEN
       Y1(K,II) = EL(K+1,II)+3  ; Y2(K,II) = EL(K+1,II)+3
       Y3(K,II) = EL(K+1,II)+1  ; Y4(K,II) = EL(K+1,II)+1
      ELSE
       Y1(K,II) = EL(K,II)+1  ; Y2(K,II) = EL(K,II)+1
       Y3(K,II) = EL(K,II)-1  ; Y4(K,II) = EL(K,II)-1
      END IF
       WRITE(ANIMFN,'(f8.1,X,f7.2,X,f7.3)') X1(K,II),Y1(K,II), F_G(K,II)
       WRITE(ANIMFN,'(f8.1,X,f7.2,X,f7.3)') X2(K,II),Y2(K,II), F_G(K,II)
         WRITE(ANIMFN,'(f8.1,X,f7.2,X,f7.3)') X3(K,II),Y3(K,II), F_G(K,II)
       WRITE(ANIMFN,'(f8.1,X,f7.2,X,f7.3)') X4(K,II),Y4(K,II), F_G(K,II)
    END DO
    LEFT(1) = DISTR(II)
   END IF
  END DO
  DO IM=1,NELEM
    MPOS=IM*4
    WRITE(ANIMFN,'(4I6)')MPOS-3,MPOS-2,MPOS-1,MPOS
  END DO
  ZONECNT=ZONECNT+1
  END SUBROUTINE ANIMATION_DATA

  !*****************************************************************************************************
  ********************************
  !**                                    S U B R O U T I N E   B Y   S E G M E N T   O U T P U T
  **
  !*****************************************************************************************************
  ********************************

  SUBROUTINE BY_SEG_OUTPUT
  USE MAINW2; USE FISH; USE FISH2; USE BIOEXPDATATRANSFORM; USE GROWTH_ANIMATION; USE ROOSEVELT; USE
  MOVEMENT; USE DIAGNOSTIC

    WRITE(BYSEGMFN,'(F7.1,500(X,F6.2))') JDAY,(MAXM(IBIO(II)),II=1,NIBIO)
    WRITE(BYSEGGFN,'(F7.1,500(X,F6.2))') JDAY,(MAXG(IBIO(II)),II=1,NIBIO)
    IF(BESTCALC) THEN
      WRITE(BYSEGMFN2,'(F7.1,500(X,F6.2))') JDAY,(BF1(2,IBIO(II),1),II=1,NIBIO)
```

```
    WRITE(BYSEGGFN2,'(F7.1,500(X,F6.2))') JDAY,(BF_GI(IBIO(II)),II=1,NIBIO)
  END IF
  IF(DIELCALC) THEN
    WRITE(BYSEGMFN3,'(F7.1,500(X,F6.2))') JDAY,(DF1(2,IBIO(II),1),II=1,NIBIO)
    WRITE(BYSEGGFN3,'(F7.1,500(X,F6.2))') JDAY,(DF_GI(IBIO(II)),II=1,NIBIO)
  END IF
  WRITE(SURFSEGMFN,'(F7.1,500(X,F6.2))') JDAY,(F1(2,IBIO(II),1),II=1,NIBIO)
  WRITE(SURFSEGGFN,'(F7.1,500(X,F6.2))') JDAY,(F_G(2,IBIO(II)),II=1,NIBIO)
END SUBROUTINE BY_SEG_OUTPUT

!*******************************************************************************************************
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!**                                    S U B R O U T I N E   F I L E   S E T U P
**
!*******************************************************************************************************
*********************************

SUBROUTINE INITIALFILESETUP
USE MAINW2; USE FISH; USE FISH2; USE BIOEXPDATATRANSFORM; USE GROWTH_ANIMATION; USE ROOSEVELT; USE
MOVEMENT; USE DIAGNOSTIC

! *** ZOOPLANKTON AVAILABLITY ( REPLACE WITH INPUT FILE FORMAT (WILL NEED TIME CONTROL VARIABLES))
OPEN(ZAVFN,FILE=ZAVFNAME,STATUS='OLD')
READ(ZAVFN,'(//)')
ZAVJD = -9999.99
DO WHILE (ZAVJD.LT.JDAY)
  READ(ZAVFN,'(:F8.0,9F8.0)')  ZAVJD,(ZAVAIL(II),II=1,NZP)
END DO
  READ(ZAVFN,'(:F8.0,9F8.0)')  ZAVNX,(ZAVAILNX(II),II=1,NZP)
! *** ASSIGN BIOEXP DATA FILE NUMBERS AND FILENAMES
  DO JI = 1,NIBIO
   IF(FIRST_BIO(JI)) THEN
    NUNIT = NUNIT +1; BIOINFN(JI) = NUNIT
        WRITE (SEGNUM,'(I0)') JI
        SEGNUM = ADJUSTL(SEGNUM)
        L      = LEN_TRIM(SEGNUM)
        OPEN   (BIOINFN(JI),FILE='BIOEXP_'//SEGNUM(1:L)//'.opt',STATUS='OLD')
    END IF
  END DO
IF(SINGLEDIAG) THEN
```

```
  NIBIO = 1.0
  BIOINFN(1) = BIOINFN(SINGFN)
  IBIO(1) = SINIBIO
END IF

! *********   RESULTS AND DIAGNOSTIC OUTPUT FILES *******
IF(FDIAG) THEN
  IF(FISHDIAG) THEN
    NUNIT = NUNIT+1; BIOOUTFN(1) = NUNIT; OPEN(BIOOUTFN(1),FILE='BIO_FISH.DAT',STATUS='UNKNOWN')
    FHEAD(1) = 'JDAY'    ;FHEAD(2) = 'SEG'      ;FHEAD(3) = 'GROWTH'  ;FHEAD(4) = 'FMASS'   ;FHEAD(5)
= '%POS'    ;&
    FHEAD(6) = 'FULLSTO';FHEAD(7) = 'LIGHTMIN';FHEAD(8) = 'TEMP'
    WRITE(BIOOUTFN(1),'(8(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,8)
    IF(SURFDIAG) THEN
      NUNIT = NUNIT+1; BIOOUTFN(16) = NUNIT;
OPEN(BIOOUTFN(16),FILE='BIO_FISH_SURF.DAT',STATUS='UNKNOWN')
      WRITE(BIOOUTFN(16),'(8(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,8)
    END IF
    IF(BESTCALC) THEN
    NUNIT = NUNIT+1; BIOOUTFN(2) = NUNIT;
OPEN(BIOOUTFN(2),FILE='BIO_FISH_BEST.DAT',STATUS='UNKNOWN')
      WRITE(BIOOUTFN(2),'(8(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,8)
    END IF
    IF(DIELCALC) THEN
    NUNIT = NUNIT+1; BIOOUTFN(3) = NUNIT;
OPEN(BIOOUTFN(3),FILE='BIO_FISH_DIEL.DAT',STATUS='UNKNOWN')
      WRITE(BIOOUTFN(3),'(8(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,8)
    END IF
  END IF ! FISHDIAG
  IF(BIOPARDIAG) THEN
    NUNIT = NUNIT+1; BIOOUTFN(4) = NUNIT; OPEN(BIOOUTFN(4),FILE='BIO_PARA.DAT',STATUS='UNKNOWN')
    FHEAD(1) = 'JDAY'    ;FHEAD(2) = 'SEG'      ;FHEAD(3) = 'GROWTH'  ;FHEAD(4) = 'DIGEST'  ;FHEAD(5)
= 'RESP'    ;&
    FHEAD(6) = 'SDA'     ;FHEAD(7) = 'WASTE'    ;FHEAD(8) = 'EXCRETE' ;FHEAD(9) = 'EGEST'
    WRITE(BIOOUTFN(4),'(9(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,9)
    IF(SURFDIAG) THEN
      NUNIT = NUNIT+1; BIOOUTFN(17) = NUNIT;
OPEN(BIOOUTFN(17),FILE='BIO_PARA_SURF.DAT',STATUS='UNKNOWN')
      WRITE(BIOOUTFN(17),'(9(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,9)
    END IF
```

```
      IF(BESTCALC) THEN
      NUNIT = NUNIT+1; BIOOUTFN(5) = NUNIT;
OPEN(BIOOUTFN(5),FILE='BIO_PARA_BEST.DAT',STATUS='UNKNOWN')
        WRITE(BIOOUTFN(5),'(9(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,9)
      END IF
      IF(DIELCALC) THEN
      NUNIT = NUNIT+1; BIOOUTFN(6) = NUNIT;
OPEN(BIOOUTFN(6),FILE='BIO_PARA_DIEL.DAT',STATUS='UNKNOWN')
        WRITE(BIOOUTFN(6),'(9(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,9)
      END IF
  END IF ! BIOPARDIAG
  IF(CONSDIAG) THEN
    NUNIT = NUNIT+1; BIOOUTFN(7) = NUNIT; OPEN(BIOOUTFN(7),FILE='BIO_CONS.DAT',STATUS='UNKNOWN')
    FHEAD(1) = 'JDAY'    ;FHEAD(2) = 'SEG'     ;FHEAD(3) = 'PREYDEN' ;FHEAD(4) = 'AVEC'    ;FHEAD(5)
= 'MINC'    ;&
    FHEAD(6) = 'MAXC'    ;FHEAD(7) = '#CON'    ;FHEAD(8) = 'MASSCON' ;FHEAD(9) = 'DIET1'
;!FHEAD(10)= 'DIET1'   ;&
    FHEAD(10)= 'DIET2'   ;FHEAD(11)= 'DIET3'   ;FHEAD(12)= 'MAXC_J'  ;FHEAD(13)=
'MAXC_G/G';FHEAD(14)= 'ACTC_J'  ;&
      FHEAD(15)= 'ACTC_G/G';FHEAD(16)= 'P_VALUE'
      WRITE(BIOOUTFN(7),'(16(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,16)
    IF(SURFDIAG) THEN
      NUNIT = NUNIT+1; BIOOUTFN(18) = NUNIT;
OPEN(BIOOUTFN(18),FILE='BIO_CONS_SURF.DAT',STATUS='UNKNOWN')
        WRITE(BIOOUTFN(18),'(16(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,16)
      END IF
      IF(BESTCALC) THEN
      NUNIT = NUNIT+1; BIOOUTFN(8) = NUNIT;
OPEN(BIOOUTFN(8),FILE='BIO_CONS_BEST.DAT',STATUS='UNKNOWN')
        WRITE(BIOOUTFN(8),'(16(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,16)
      END IF
      IF(DIELCALC) THEN
      NUNIT = NUNIT+1; BIOOUTFN(9) = NUNIT;
OPEN(BIOOUTFN(9),FILE='BIO_CONS_DIEL.DAT',STATUS='UNKNOWN')
        WRITE(BIOOUTFN(9),'(16(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,16)
      END IF
  END IF ! CONSDIAG
  IF(DIGDIAG) THEN
    NUNIT = NUNIT+1; BIOOUTFN(10) = NUNIT; OPEN(BIOOUTFN(10),FILE='BIO_DIG.DAT',STATUS='UNKNOWN')
```

```
    FHEAD(1) = 'JDAY'    ;FHEAD(2) = 'SEG'     ;FHEAD(3) = 'DIG_J'   ;FHEAD(4) = 'INITIAL' ;FHEAD(5)
= 'CONSUMED';&
    FHEAD(6) = 'UNDIGEST';FHEAD(7) = 'STOMCON' ;FHEAD(8) = 'STOMCAP' ;FHEAD(9) = 'EDENSITY'
      FHEAD(16)= 'ACTC_G/G';FHEAD(17)= 'P_VALUE'
      WRITE(BIOOUTFN(10),'(9(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,9)
    IF(SURFDIAG) THEN
      NUNIT = NUNIT+1; BIOOUTFN(19) = NUNIT;
OPEN(BIOOUTFN(19),FILE='BIO_DIG_SURF.DAT',STATUS='UNKNOWN')
      WRITE(BIOOUTFN(19),'(9(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,9)
    END IF
    IF(BESTCALC) THEN
    NUNIT = NUNIT+1; BIOOUTFN(11) = NUNIT;
OPEN(BIOOUTFN(11),FILE='BIO_DIG_BEST.DAT',STATUS='UNKNOWN')
      WRITE(BIOOUTFN(11),'(9(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,9)
    END IF
    IF(DIELCALC) THEN
    NUNIT = NUNIT+1; BIOOUTFN(12) = NUNIT;
OPEN(BIOOUTFN(12),FILE='BIO_DIG_DIEL.DAT',STATUS='UNKNOWN')
      WRITE(BIOOUTFN(12),'(9(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,9)
    END IF
  END IF ! DIGDIAG
  IF(RESPDIAG) THEN
    NUNIT = NUNIT+1; BIOOUTFN(13) = NUNIT; OPEN(BIOOUTFN(13),FILE='BIO_RESP.DAT',STATUS='UNKNOWN')
    FHEAD(1) = 'JDAY'    ;FHEAD(2) = 'SEG'     ;FHEAD(3) = 'RESP_J'  ;FHEAD(4) = 'FACTAVE' ;FHEAD(5)
= 'FVELAVE'
      WRITE(BIOOUTFN(13),'(5(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,5)
    IF(SURFDIAG) THEN
      NUNIT = NUNIT+1; BIOOUTFN(20) = NUNIT;
OPEN(BIOOUTFN(20),FILE='BIO_RESP_SURF.DAT',STATUS='UNKNOWN')
      WRITE(BIOOUTFN(20),'(5(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,5)
    END IF
    IF(BESTCALC) THEN
    NUNIT = NUNIT+1; BIOOUTFN(14) = NUNIT;
OPEN(BIOOUTFN(14),FILE='BIO_RESP_BEST.DAT',STATUS='UNKNOWN')
      WRITE(BIOOUTFN(14),'(5(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,5)
    END IF
    IF(DIELCALC) THEN
    NUNIT = NUNIT+1; BIOOUTFN(15) = NUNIT;
OPEN(BIOOUTFN(15),FILE='BIO_RESP_DIEL.DAT',STATUS='UNKNOWN')
      WRITE(BIOOUTFN(15),'(5(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,5)
```

```
      END IF
  END IF ! RESPDIAG
  IF(SINGLEDIAG) THEN
    IF(DEPTHCALC) THEN
     NUNIT = NUNIT +1; BIOOUTFN(21) = NUNIT;
OPEN(BIOOUTFN(21),FILE='FORAGING_DEPTHS.DAT',STATUS='UNKNOWN')
     FHEAD(1) = 'JDAY'    ;FHEAD(2) = 'SEG'     ;FHEAD(3) = 'BESTDTH'  ;FHEAD(4) = 'DIELDTH'
       WRITE(BIOOUTFN(21),'(4(A8,1X))') (ADJUSTR(FHEAD(TT)), TT = 1,4)
    END IF
  END IF
END IF ! FDIAG

! ***********  GROWTH ANIMATION OUTPUT FILE  *************************
    NUNIT = NUNIT+1; ANIMFN = NUNIT
    OPEN(ANIMFN,FILE='FGP_ANIM.DAT',STATUS='UNKNOWN') ! BASIC OUTPUT
  WRITE(ANIMFN,'(A52)') HEADER1
  WRITE(ANIMFN,'(A52)') HEADER2
    IF(BESTCALC) THEN
      NUNIT = NUNIT+1; ANIMFN2 = NUNIT
      OPEN(ANIMFN2,FILE='FGP_ANIM_BEST.DAT',STATUS='UNKNOWN') ! BEST LOCATION OUTPUT
      WRITE(ANIMFN2,'(A52)') HEADER1
      WRITE(ANIMFN2,'(A52)') HEADER2
    END IF
  ! PREP DISTANCE VALUES (TEMPORARY APPROACH)
  NUNIT = NUNIT+1
  OPEN(NUNIT,FILE='DLX.PRN',STATUS='OLD')
  READ(NUNIT,*)
  DO J = 1,1000
    READ(NUNIT,'(I8,8X,2F8.0)',END=107) I,VLL,VLR
    DISTL(I) = VLL; DISTR(I) = VLR
  END DO
107 CONTINUE
  ! REMOVE ZEROS
  DO J = 2,IMX
    IF(DISTR(J).EQ.0.0) THEN
        DISTR(J) = DISTR(J-1)
      END IF
  END DO
  ! FIX ERRORS
  DO II = 2,NIBIO
```

```
      IF(DISTR(IBIO(II-1)).EQ.0.0) THEN
          PRINT *,'ZERO ', II-1, IBIO(II-1)
         ! DISTR(IBIO(II-1) = DISTR(IBIO(II
        END IF
      DISTL(IBIO(II)) = DISTR(IBIO(II-1))
        IF(DISTL(IBIO(II)).NE.DISTR(IBIO(II-1)) ) THEN
          PRINT *,'NE ', II, IBIO(II)
        END IF
    END DO
   CLOSE(NUNIT)

  ! *********** BYSEG FILE PREP  ******************
   IF(BYSEG) THEN
      NUNIT = NUNIT+1; BYSEGMFN = NUNIT
      OPEN(BYSEGMFN,FILE='MASS.DAT',STATUS='UNKNOWN')
      NUNIT = NUNIT+1; BYSEGGFN = NUNIT
      OPEN(BYSEGGFN,FILE='GROWTH.DAT',STATUS='UNKNOWN')
        WRITE(BYSEGMFN,'(A7,500(I6,A))') '    JDAY',((IBIO(II),'S'),II = 1,NIBIO)
      WRITE(BYSEGGFN,'(A7,500(I6,A))') '    JDAY',((IBIO(II),'S'),II = 1,NIBIO)
        IF(BESTCALC) THEN
        NUNIT = NUNIT+1; BYSEGMFN2 = NUNIT
        OPEN(BYSEGMFN2,FILE='MASS_BEST.DAT',STATUS='UNKNOWN')
        NUNIT = NUNIT+1; BYSEGGFN2 = NUNIT
        OPEN(BYSEGGFN2,FILE='GROWTH_BEST.DAT',STATUS='UNKNOWN')
          WRITE(BYSEGMFN2,'(A7,500(I6,A))') '    JDAY',((IBIO(II),'S'),II = 1,NIBIO)
        WRITE(BYSEGGFN2,'(A7,500(I6,A))') '    JDAY',((IBIO(II),'S'),II = 1,NIBIO)
        NUNIT = NUNIT+1; BESTDIAGFN = NUNIT
          OPEN(BESTDIAGFN,FILE='BESTDIAG.DAT',STATUS='UNKNOWN')
        END IF
        IF(DIELCALC) THEN
        NUNIT = NUNIT+1; BYSEGMFN3 = NUNIT
        OPEN(BYSEGMFN3,FILE='MASS_DIEL.DAT',STATUS='UNKNOWN')
        NUNIT = NUNIT+1; BYSEGGFN3 = NUNIT
        OPEN(BYSEGGFN3,FILE='GROWTH_DIEL.DAT',STATUS='UNKNOWN')
          WRITE(BYSEGMFN3,'(A7,500(I6,A))') '    JDAY',((IBIO(II),'S'),II = 1,NIBIO)
        WRITE(BYSEGGFN3,'(A7,500(I6,A))') '    JDAY',((IBIO(II),'S'),II = 1,NIBIO)
        END IF
      ! SURFACE SEGMENT
      NUNIT = NUNIT+1; SURFSEGMFN = NUNIT
      OPEN(SURFSEGMFN,FILE='MASS_SURF.DAT',STATUS='UNKNOWN')
```

```
      NUNIT = NUNIT+1; SURFSEGGFN = NUNIT
    OPEN(SURFSEGGFN,FILE='GROWTH_SURF.DAT',STATUS='UNKNOWN')
      WRITE(SURFSEGMFN,'(A7,500(I6,A))') '    JDAY',((IBIO(II),'S'),II = 1,NIBIO)
    WRITE(SURFSEGGFN,'(A7,500(I6,A))') '    JDAY',((IBIO(II),'S'),II = 1,NIBIO)
  END IF
! *** LIGHTOUT
    NUNIT = NUNIT+1; LIGHTNUM=NUNIT
      OPEN(LIGHTNUM,FILE='LIGHTOUT.PRN',STATUS='OLD')
      FIRSTLIGHT = .FALSE.
    READ(LIGHTNUM,'(10X,F10.0,20X,E10.2)') LJDAY1,LUX1
      READ(LIGHTNUM,'(10X,F10.0,20X,E10.2)') LJDAY2,LUX2

END SUBROUTINE INITIALFILESETUP
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```
      NUNIT = NUNIT+1; SURFSEGGFN = NUNIT
    OPEN(SURFSEGGFN,FILE='GROWTH_SURF.DAT',STATUS='UNKNOWN')
      WRITE(SURFSEGMFN,'(A7,500(I6,A))') '    JDAY',((IBIO(II),'S'),II = 1,NIBIO)
    WRITE(SURFSEGGFN,'(A7,500(I6,A))') '    JDAY',((IBIO(II),'S'),II = 1,NIBIO)
  END IF
! *** LIGHTOUT
    NUNIT = NUNIT+1; LIGHTNUM=NUNIT
      OPEN(LIGHTNUM,FILE='LIGHTOUT.PRN',STATUS='OLD')
      FIRSTLIGHT = .FALSE.
    READ(LIGHTNUM,'(10X,F10.0,20X,E10.2)') LJDAY1,LUX1
      READ(LIGHTNUM,'(10X,F10.0,20X,E10.2)') LJDAY2,LUX2

END SUBROUTINE INITIALFILESETUP
```