Using reservoir operations to address ecosystem impacts at Shasta Lake

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DSP Jan 2014

Acknowledgments

- Collaborators:
  - J. Bartholow, USGS
  - R. J. Caldwell, USBR
  - R. B. Hanna
  - D. Kauneckis, UNR
  - B. Rajagopalan, Univ of CO
  - J. Sapin, UNR
  - J. Sandelin
- Funding:
  - NOAA-SARP
  - US Bureau of Reclamation
  - US Geological Survey
  - University of NV Reno

Presentation outline

- Background
- Previous work
- Current work
- Future work

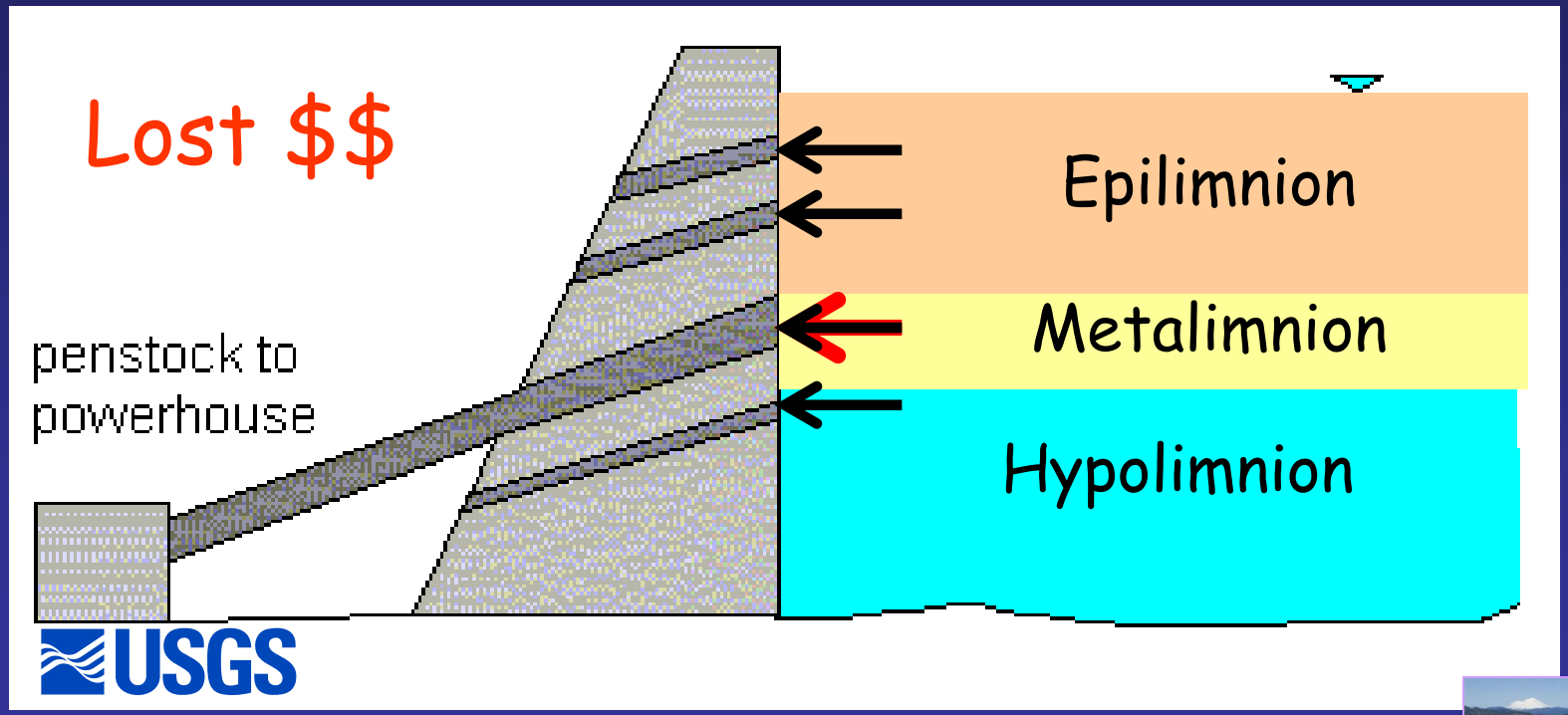
Shasta Lake, CA

Shasta Dam and Lake

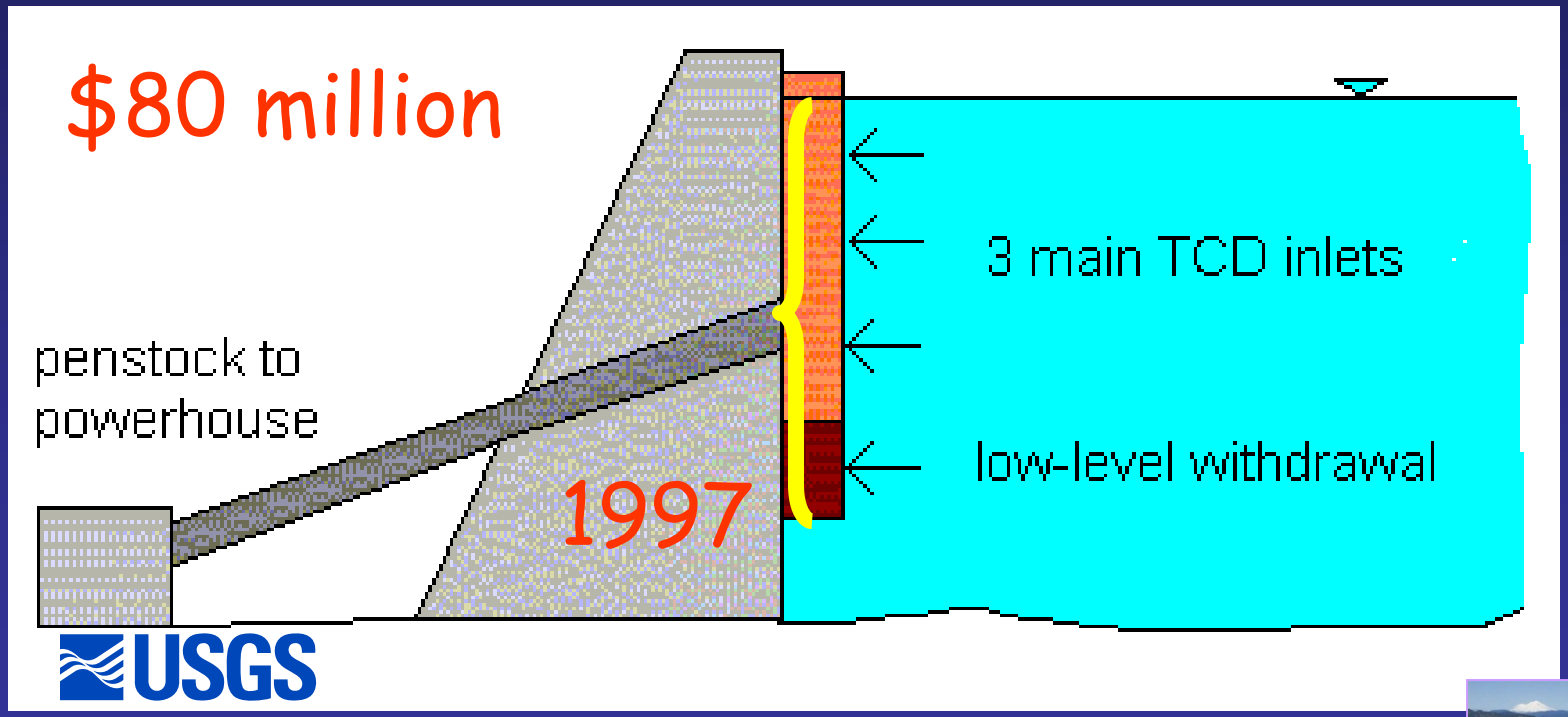
Fisheries issues

- Shasta Dam and Lake
  - Constructed in 1945
  - Prevented migration of Chinook salmon
  - Winter-run chinook listed as endangered in 1989

Altered reservoir operations



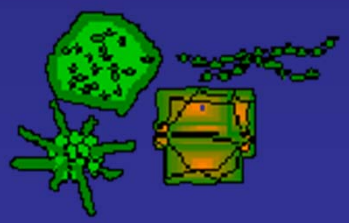
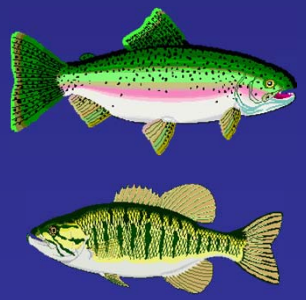
Temperature control device (TCD)



Interdisciplinary modeling at Shasta Lake

TCD operation

- Increases hydropower
- Improves downstream habitat
- In-reservoir effects???

Interdisciplinary modeling at Shasta Lake

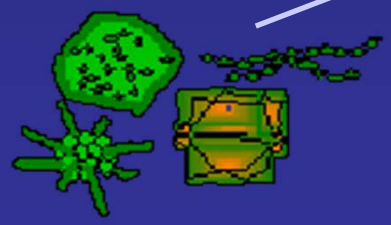
Specific modeling objective: Investigate the effect of TCD operations on growth of sport fish

- Hydraulics
  - *Hydrodynamics through reservoir and TCD*
- Water resources and hydrology
  - *TCD operation under different hydrologic conditions*
- Environmental science
  - *Water quality dynamics*
- Ecology
  - *Ecosystem dynamics*

Interdisciplinary modeling at Shasta Lake

CEQUALW2

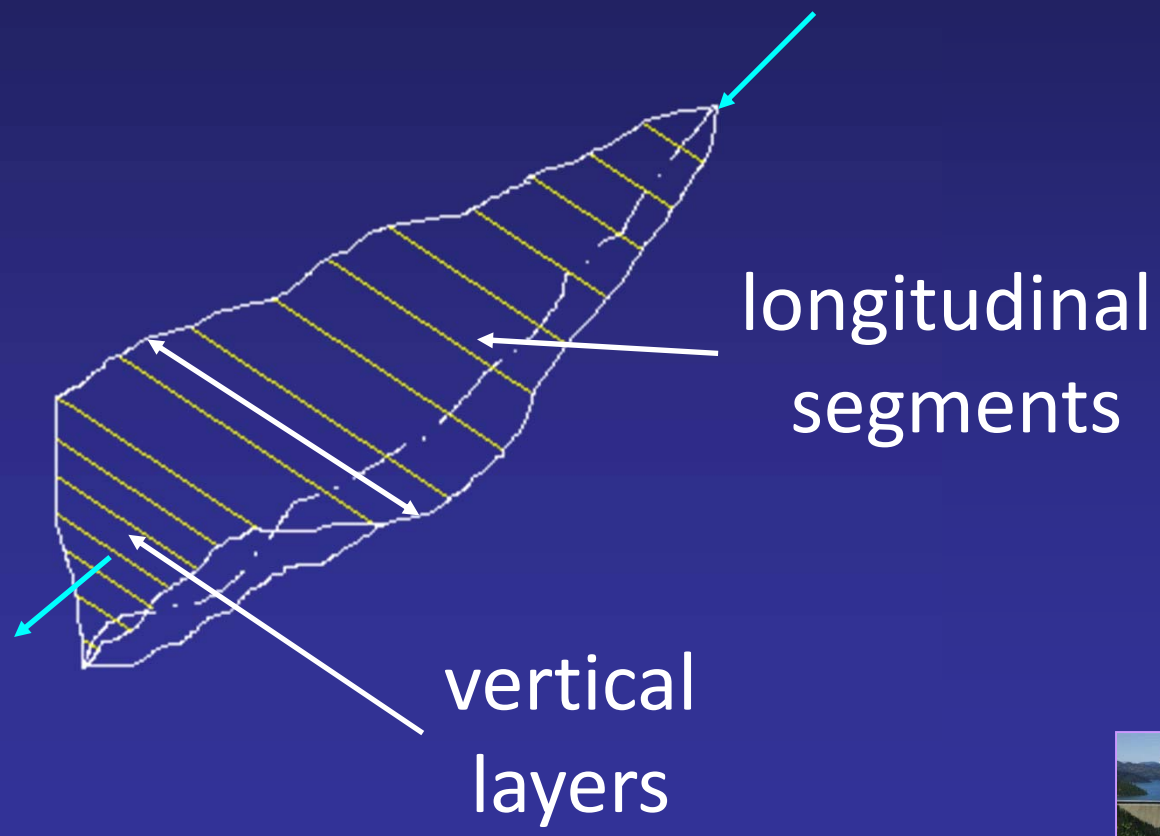
Bioenergetics



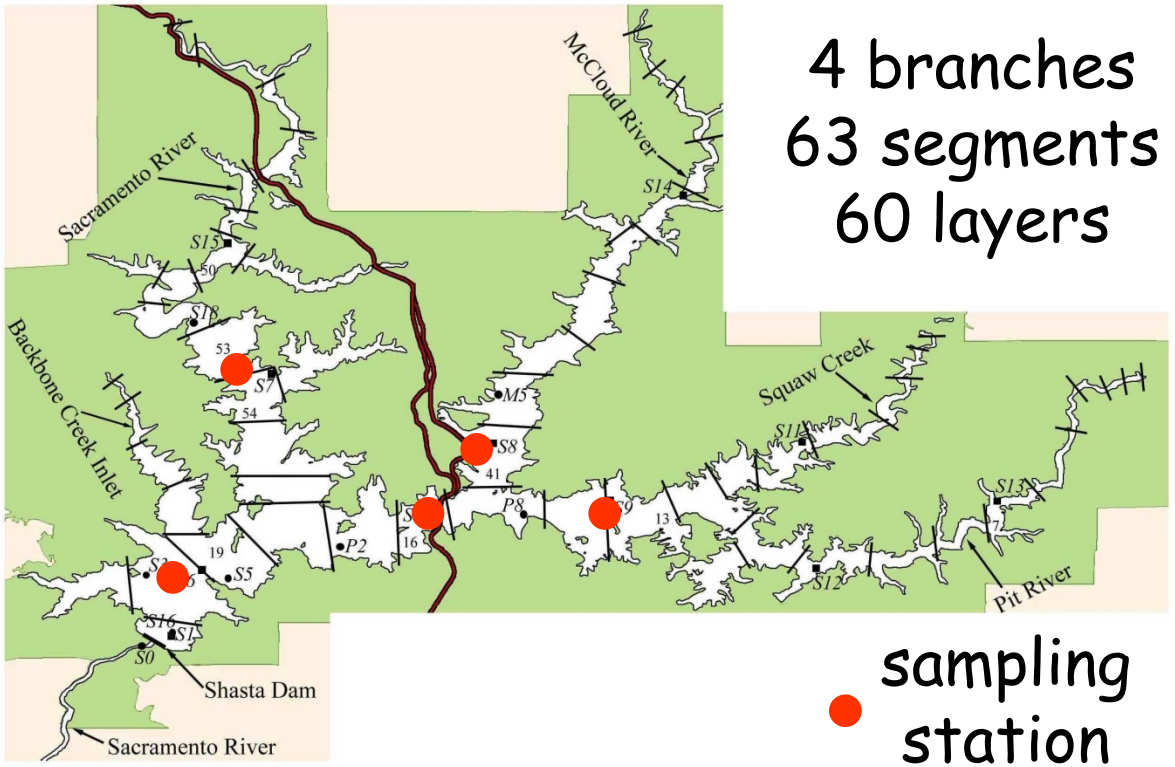
Food web-energy transfer

CE-QUAL-W2 model

2-dimensional

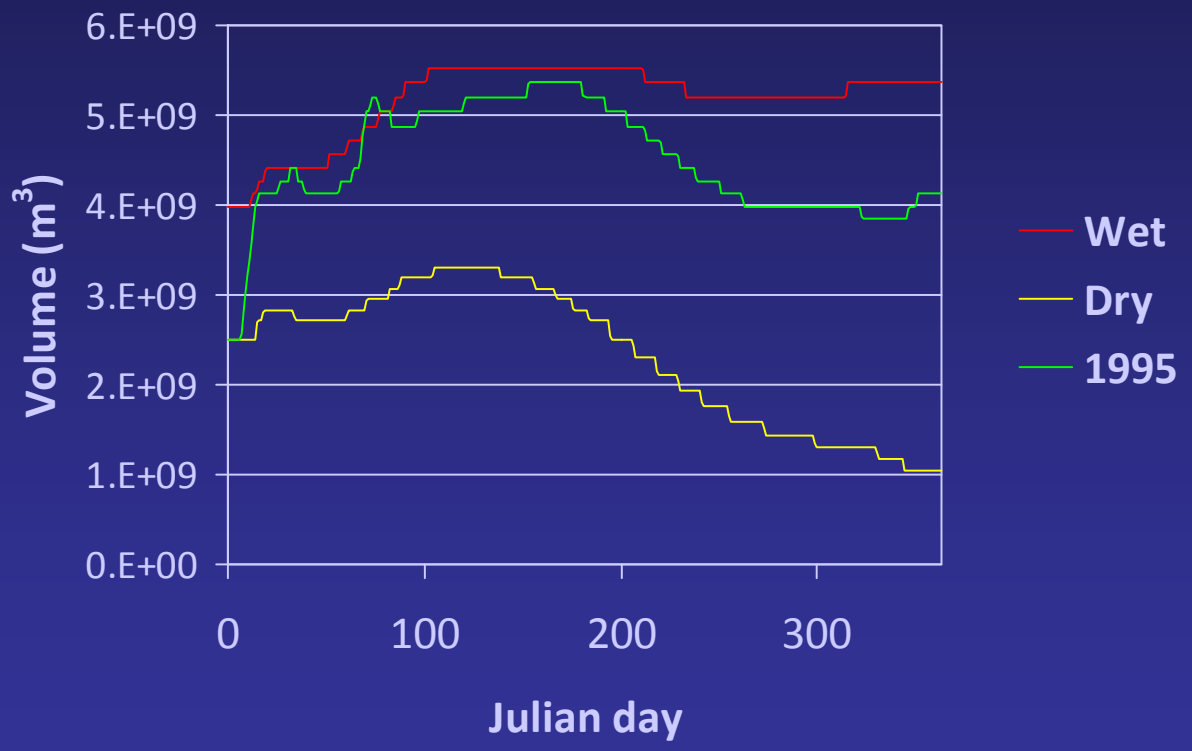


CE-QUAL-W2


4 branches
63 segments
60 layers
sampling station
Sacramento River
McCloud River
Backbone Creek Inlet
Squaw Creek
Pit River
Shasta Dam
Sacramento River

CE-QUAL-W2 Scenarios

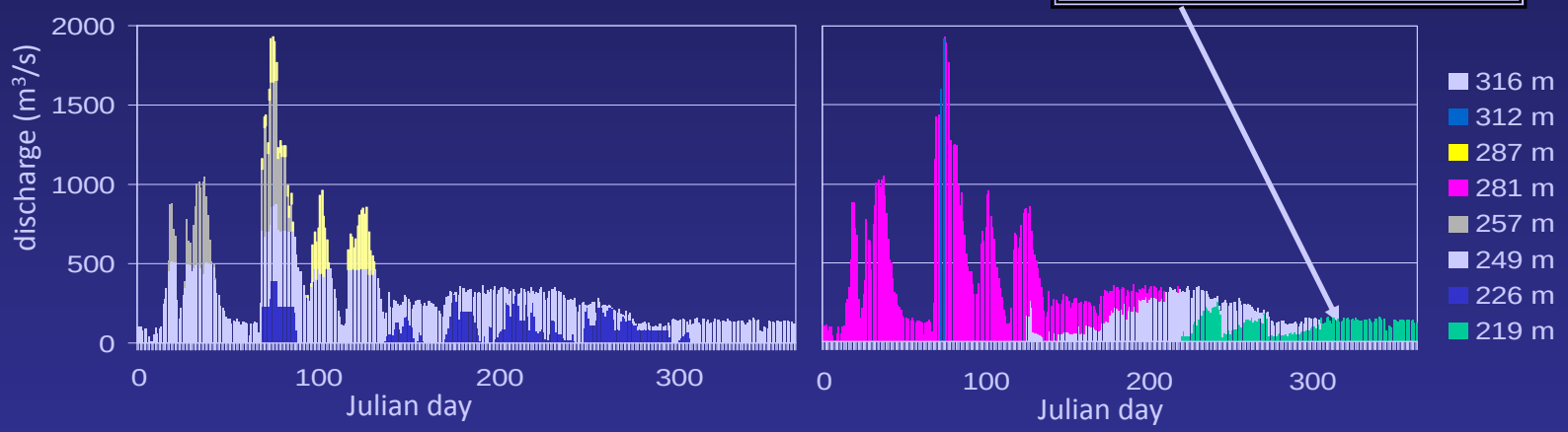
- Hydrologic:
  - Wet
  - Dry
  - Actual



CE-QUAL-W2 Scenarios

- Without- and with-TCD

Releases from lowest outlet



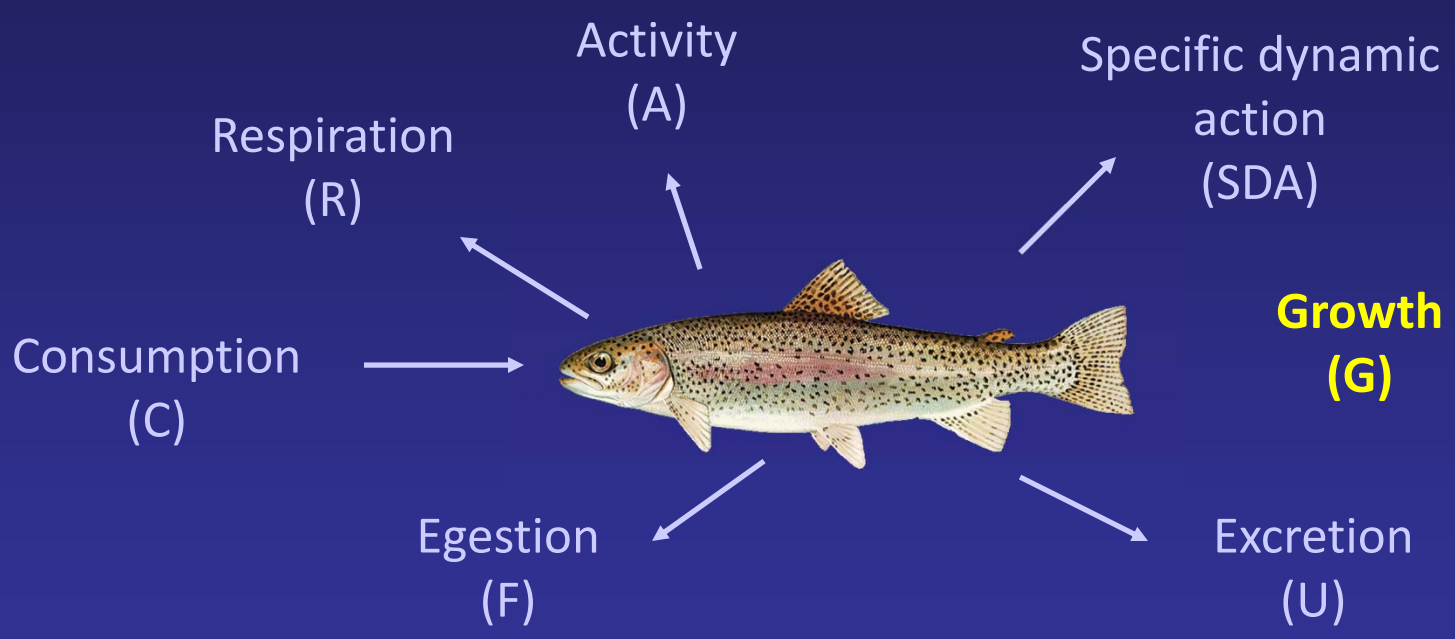
Without TCD

With TCD

Differences: (with-TCD – without-TCD)

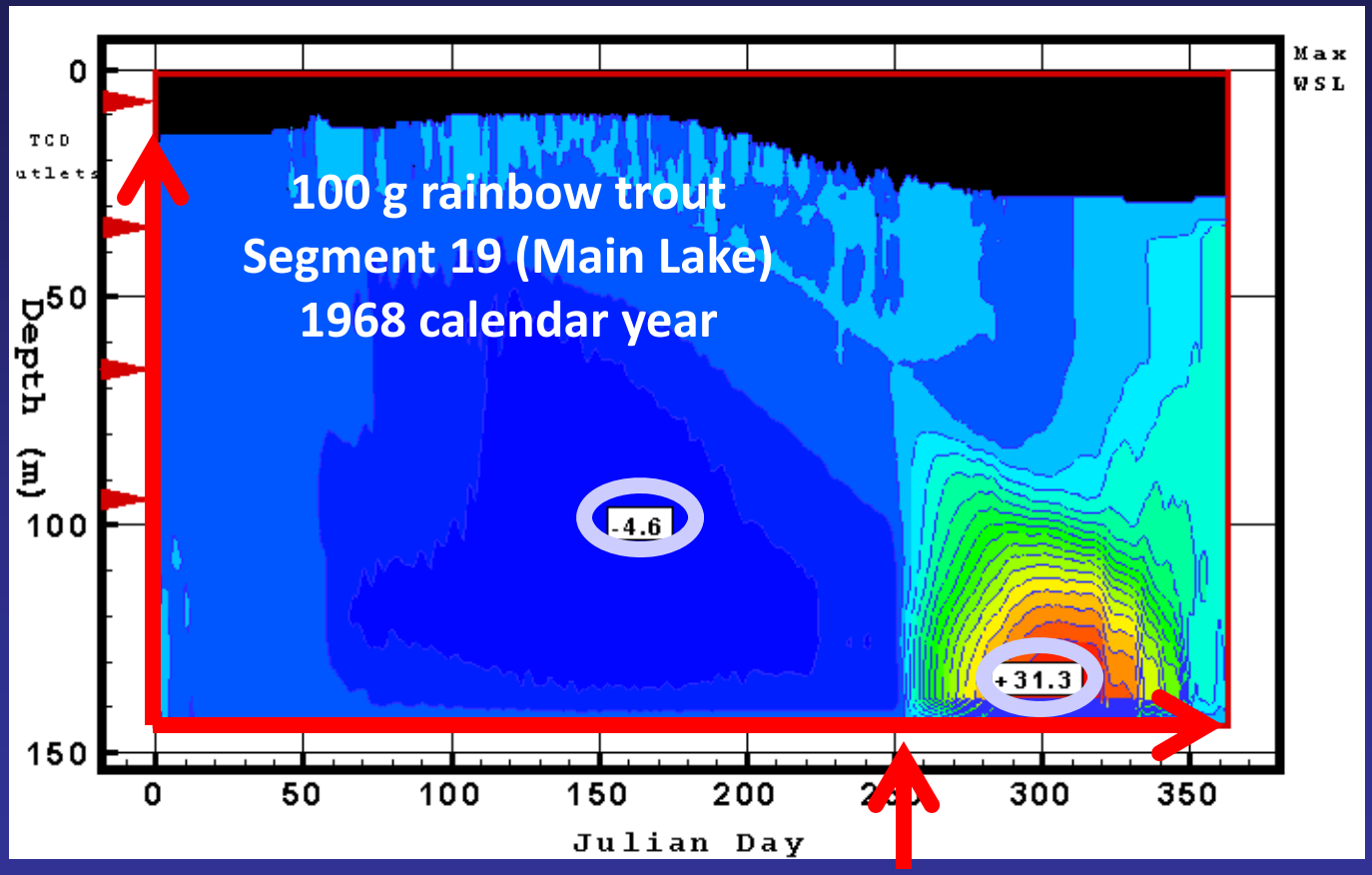
Bioenergetics model

INPUTS = OUTPUTS

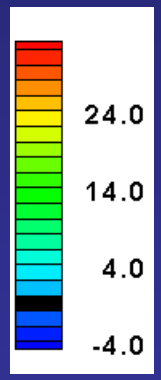


$$G = C - R - A - SDA - F - U$$

Shasta bioenergetics results

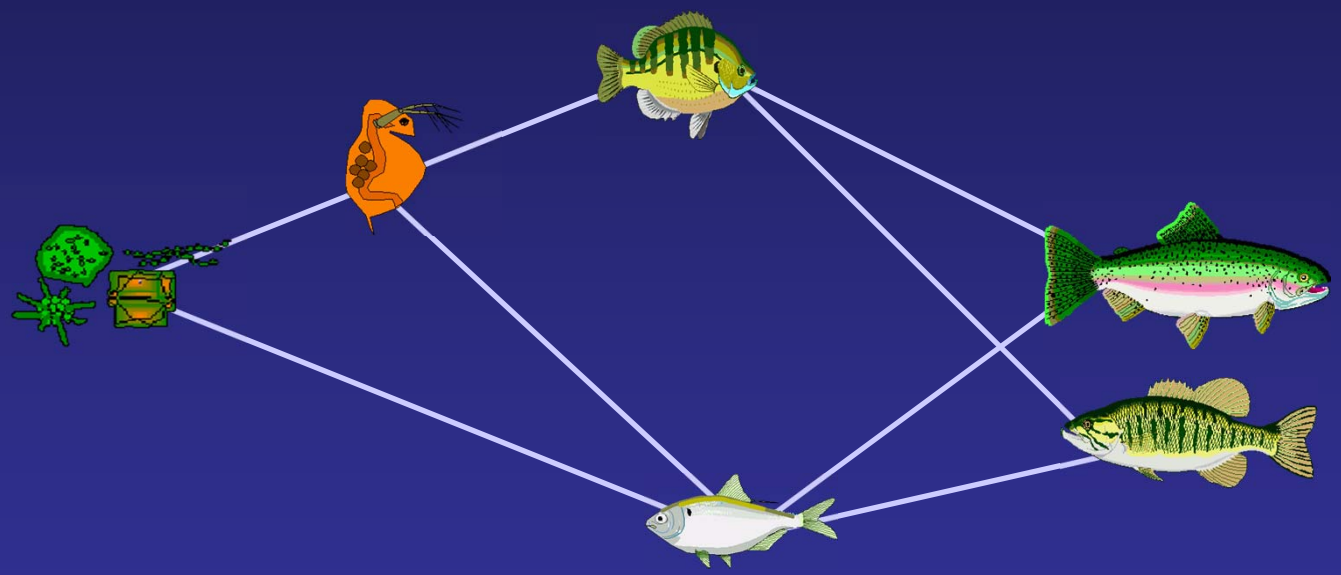


% max. SFG diff.



Scope for growth diffs = [(with-TCD) – (without-TCD)]

Food web-energy transfer model



Stable isotope analysis

Stable isotope analysis in food web studies

"You are what you eat"

$\delta^{13}C$

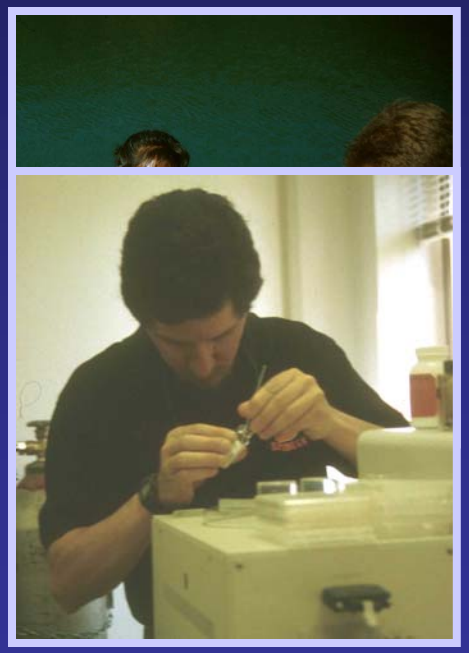
Carbon values increase slightly (0.2 – 1.0 $^0/_{00}$)

$\delta^{15}N$

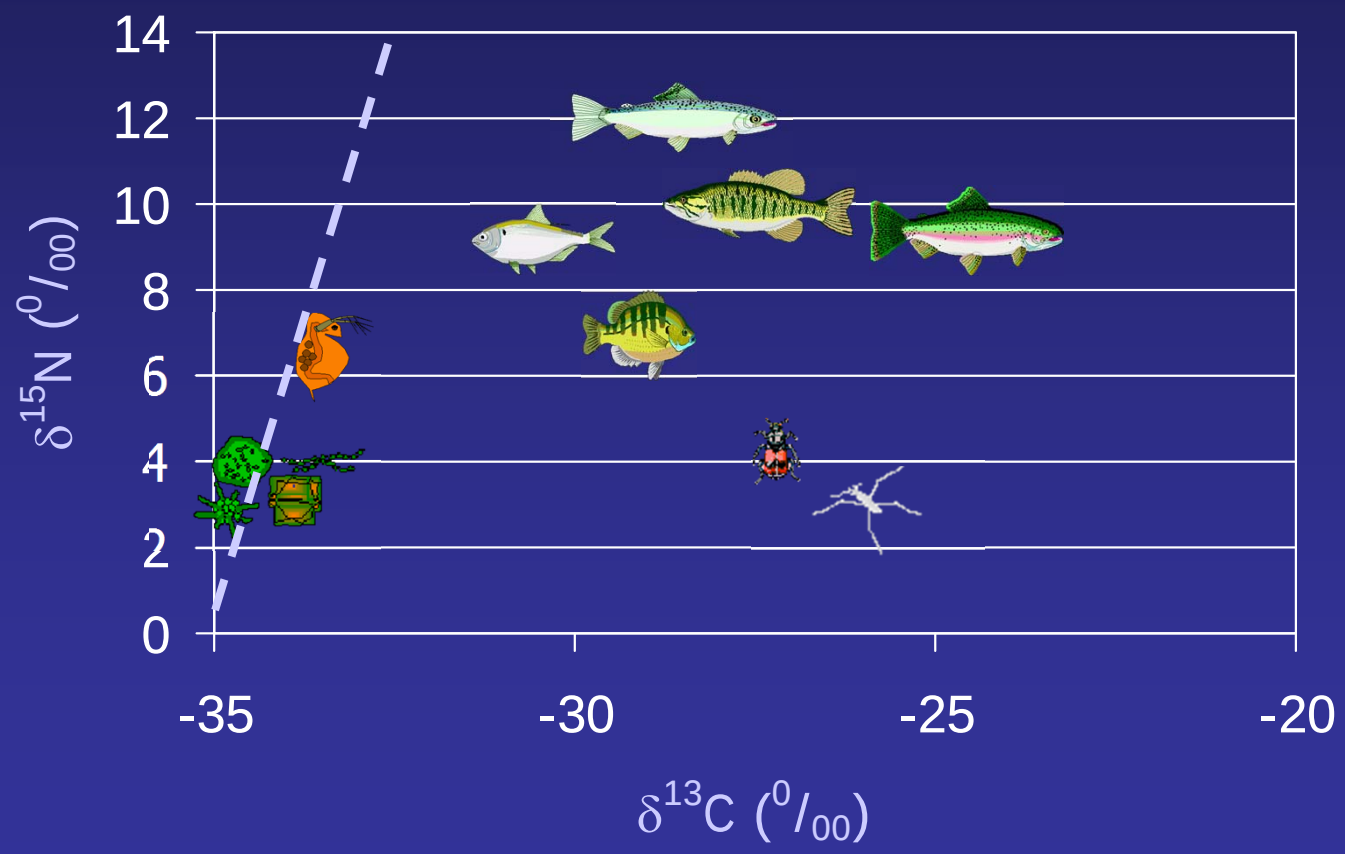
Nitrogen values increase greatly (3.0 – 4.0 $^0/_{00}$)

Food web construction

- Stable isotope sampling
  - July 1998
  - Over 300 individual samples
  - 4 reservoir locations
  - 18 species of fish
- Stable isotope analysis



Estimating Shasta food web



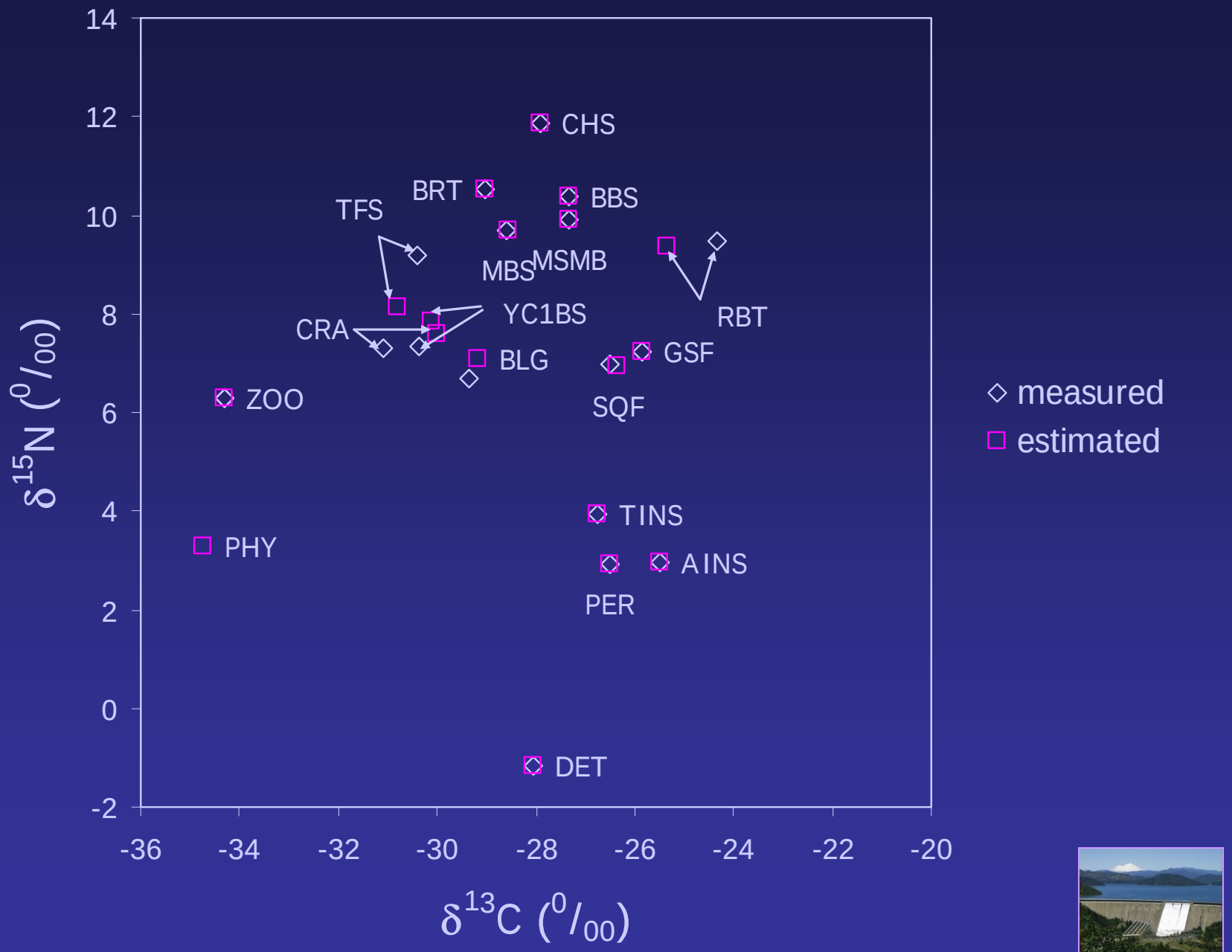
Food web model setup

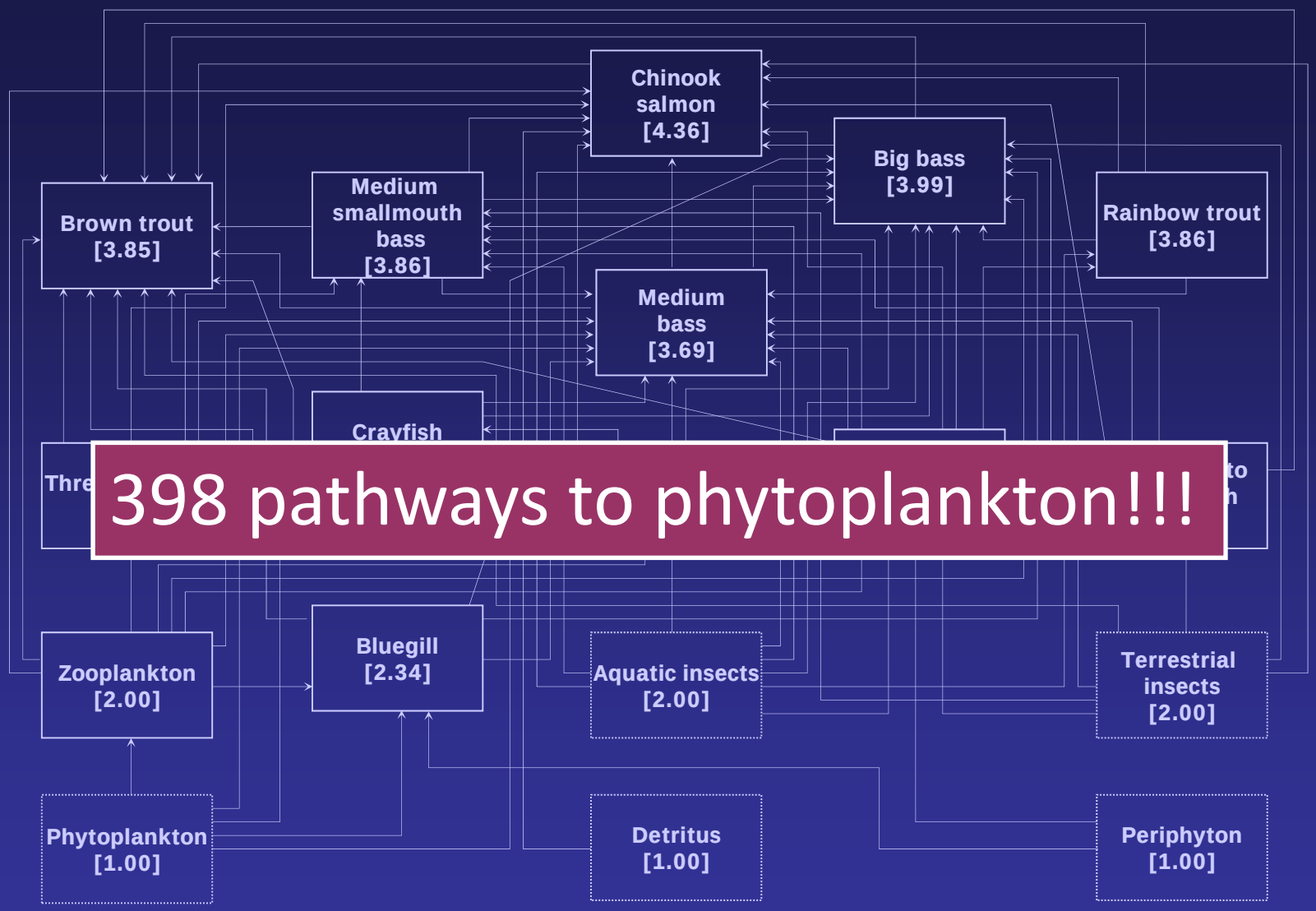
Numbers are fractions of diet

	CHS	RBT	TFS	BLG	ZOO
CHS	0	0	0	0	0
RBT	0.05	0	0	0	0
TFS	0.45	0.25	0	0	0
BLG	0.15	0.15	0	0	0
ZOO	0.35	0.60	0.75	0.85	0
ALG	0	0	0.25	0.15	1
SUM	1	1	1	1	1

Estimate isotope values

Objective Function: Minimize sum of squared errors of isotope values


14
12
10
8
6
4
2
0
-2
-36
-34
-32
-30
-28
-26
-24
-22
-20
δ15N (0/00)
δ13C (0/00)
CHS
BRT
BBS
TFS
MBS
MSMB
YC1BS
RBT
CRA
BLG
GSF
ZOO
SQF
TINS
PHY
AINS
PER
DET
measured
estimated



398 pathways to phytoplankton!!!

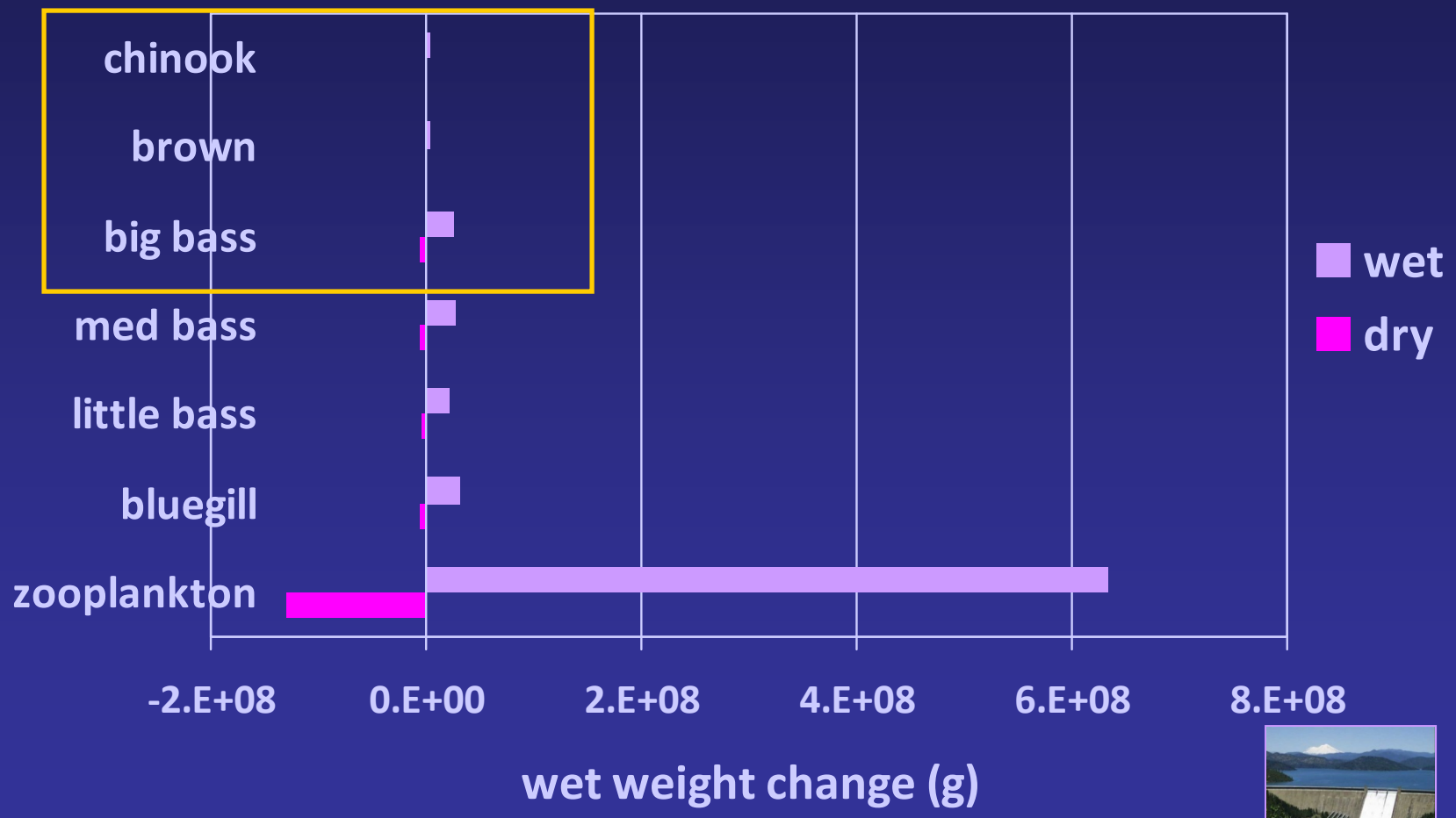
Change in weight due to TCD

Determined from food web-energy transfer model

$$\Delta Biomass_i = \Delta E_{phyto} \frac{ET_i}{ED_i}$$

Determined from CE-QUAL-W2

Change in weight due to TCD

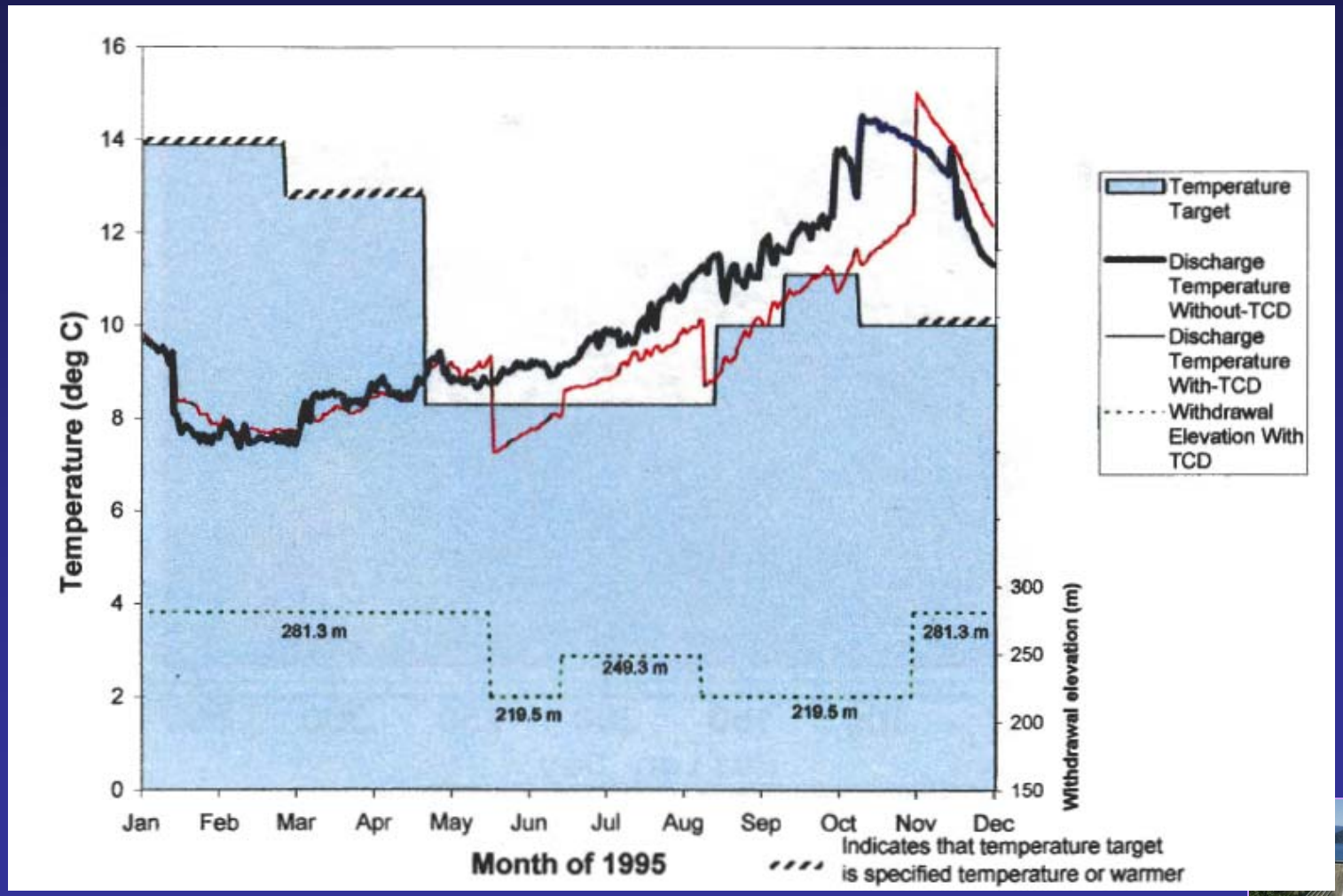


Conclusions regarding effects of TCD operation

- Hydraulics, water resources, and hydrology
  - Simulated TCD operations, flow through reservoir, and hydrodynamics for different hydrologic scenarios
- Environmental science
  - Thermal effects negligible
  - Simulated water quality dynamics
- Ecology
  - Increased net production in wet years
  - Decreased net production in dry years
  - Thermal effects on fish are negligible
  - Rainbow trout not affected
  - Bass species most affected

Bartholow et al. (2001)
Hanna et al. (1999)
Saito et al. (2001)

Meeting temperature targets



Hanna et al. (1999)

Current work

Forecasting reservoir operations to mitigate climate impacts on fish sustainability below Shasta Lake

Award Number NA12OAR4310093

NOAA-Sector Applications and Research Program

Project objectives

- Examine impacts of climate variability on meeting downstream temperature targets for Chinook salmon
- Assess effectiveness of different operations regimes in meeting downstream temperature targets under historic and projected climate conditions
- Objectives centered around using CE-QUAL-W2 to simulate reservoir operations

Methodology

- Task 1: Develop stochastic Shasta Lake inflow scenarios
- Task 2: Develop stochastic weather scenarios
- Task 3: Implement workshops with reservoir managers
- Task 4: Develop and simulate historic and future climate scenarios using CE-QUAL-W2 model
- Task 5: Assess outflow temperatures regarding meeting downstream temperature targets
- Task 6: Disseminate project results

Modeling methodology

Stochastic Daily Inflow Generation

Stochastic Sub-Daily Weather Generation

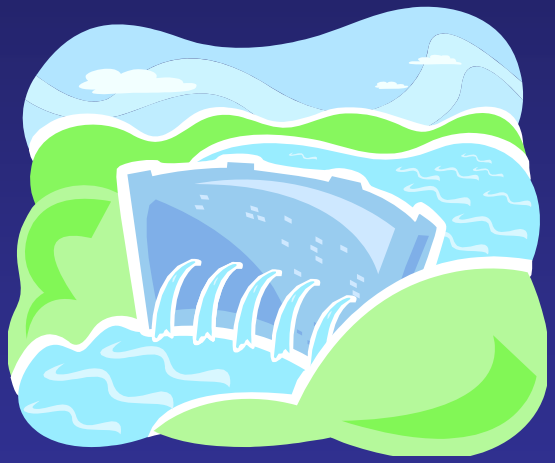
Operational Considerations

CE-QUAL-W2 Simulations

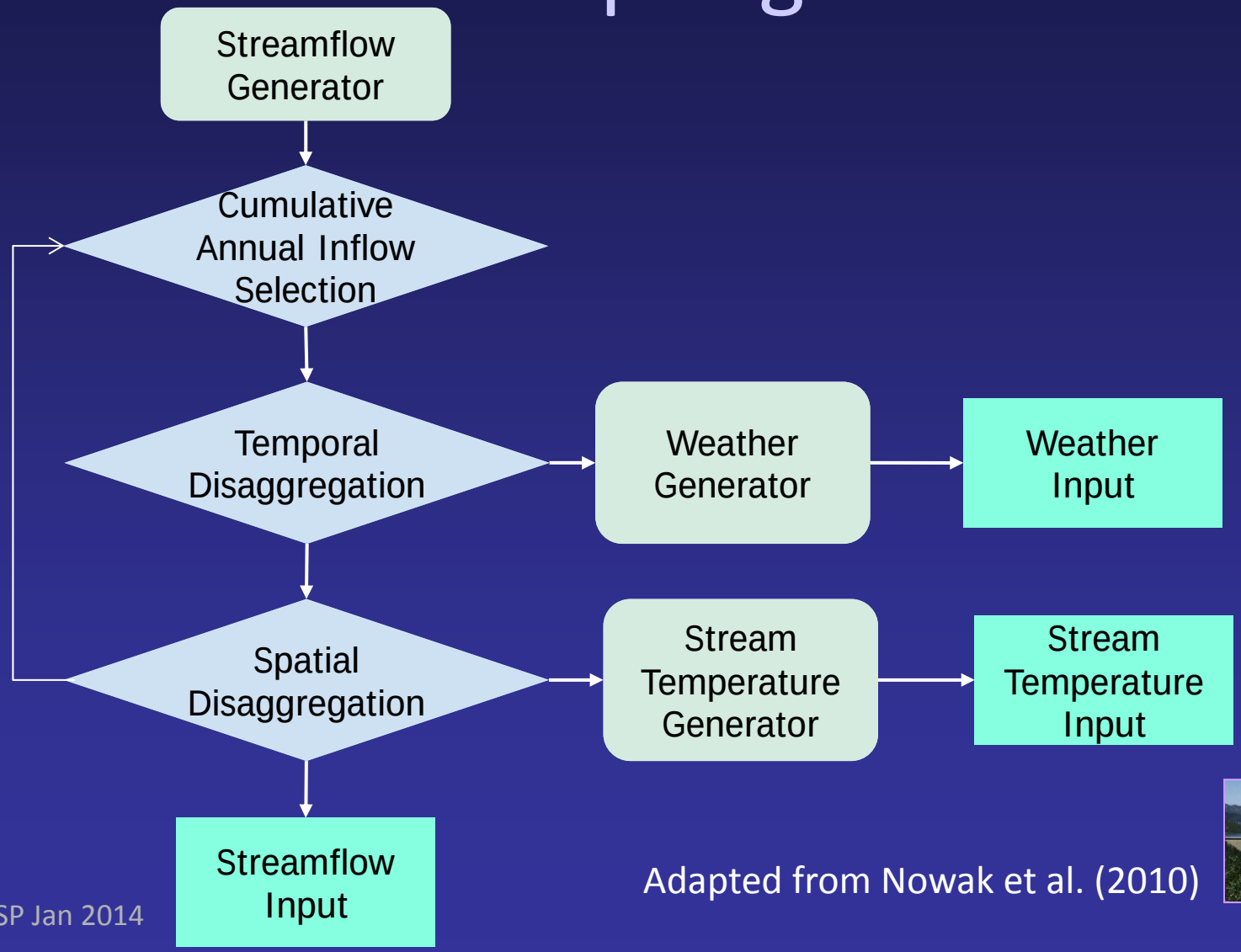
Outflow Temperature Assessment

CE-QUAL-W2 model inputs

- Inputs
  - Day 1 water surface elevation
  - Daily inflow quantities
  - Daily inflow temperatures
  - Sub-daily meteorology
    - Air temperature
    - Dewpoint temperature
    - Wind speed
    - Wind direction
    - Cloud cover



Stochastic input generation



Adapted from Nowak et al. (2010)

Flow scenarios

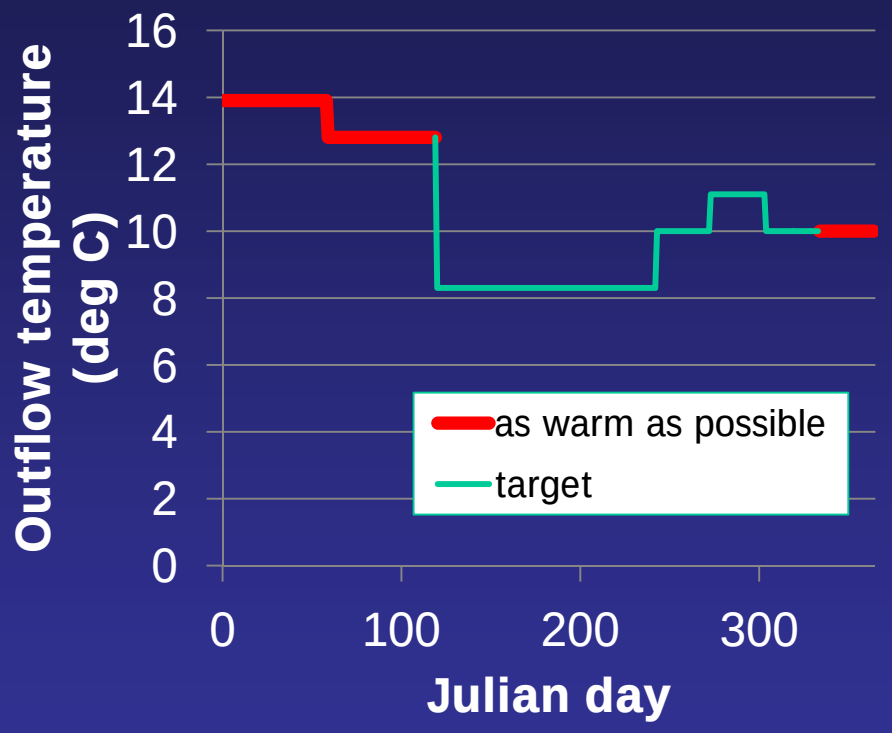
- Wet year
  - 99% flow from stochastic ensembles
- Dry year
  - 1% flow from stochastic ensembles
- Drought
  - 3 successive dry years
- Wet year with dry fall
- Wet year with warm fall
- Climate change trends from CCCC (2012)

Operations regimes

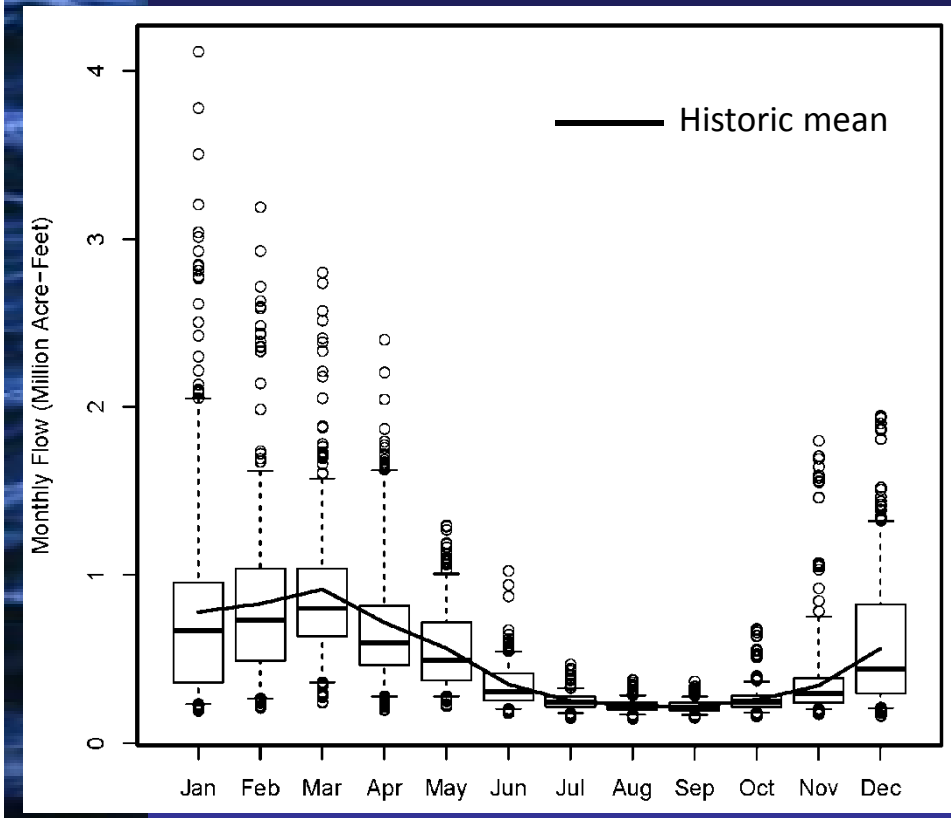
- Outflow quantities
  - Guided by storage for selected starting inflow year
  - Adjustments made to comply with
    - Minimum flow 3250 cfs (Sep 1 to Feb 29)
    - Ramping limits from OCAP 2-38
- Outflow distributions
  - Regimes:
    - All out the lowest outlet
    - All out the highest allowable outlet
    - Generalized operations from Hanna et al. (1999)
    - Pseudo-optimized distributions to match temperature targets

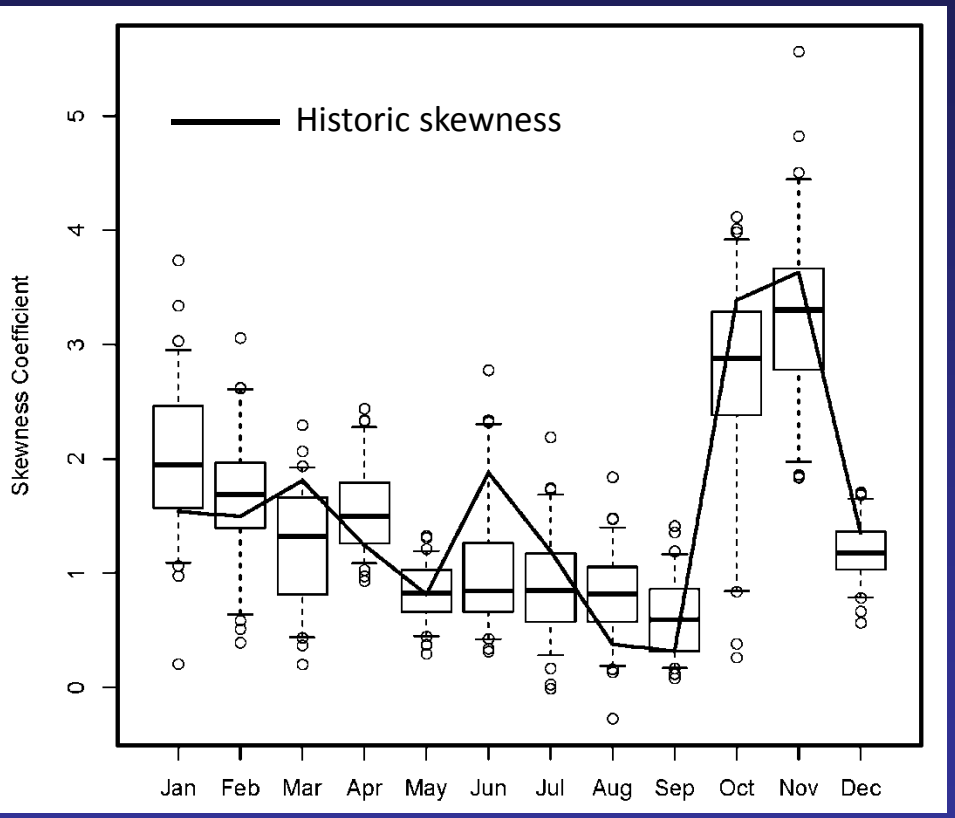
Evaluation of output

- Degree days
- Cold pool volume
- Cold pool depletion date



Preliminary results
Combined stochastic flows

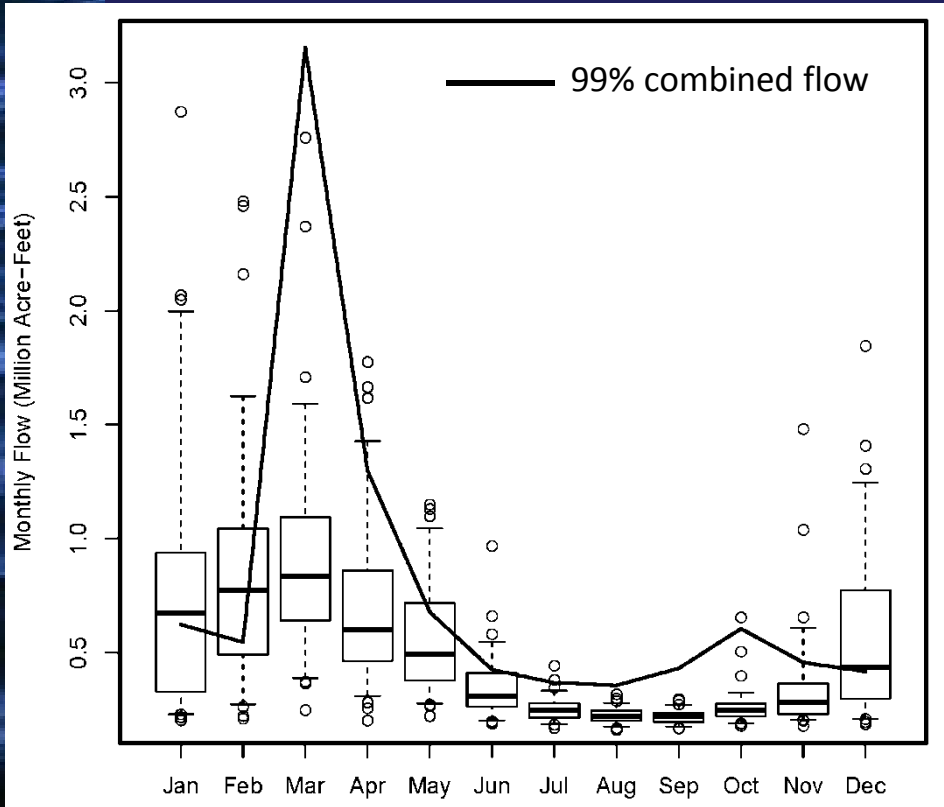


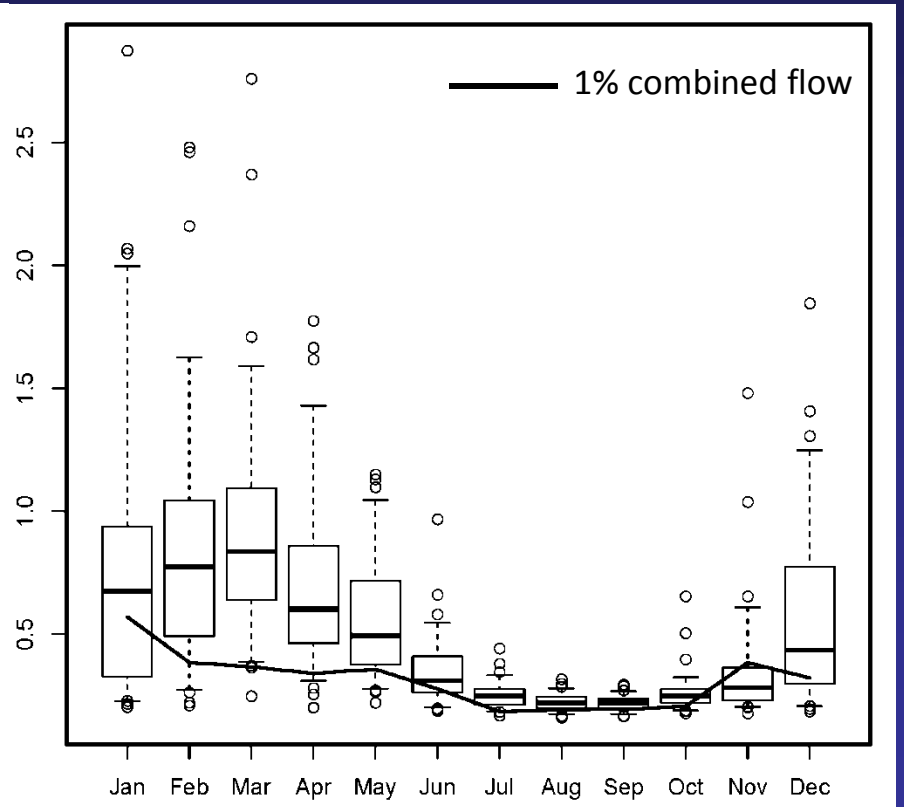


Combined streamflow

Streamflow skewness

Preliminary results
Extreme stochastic flows

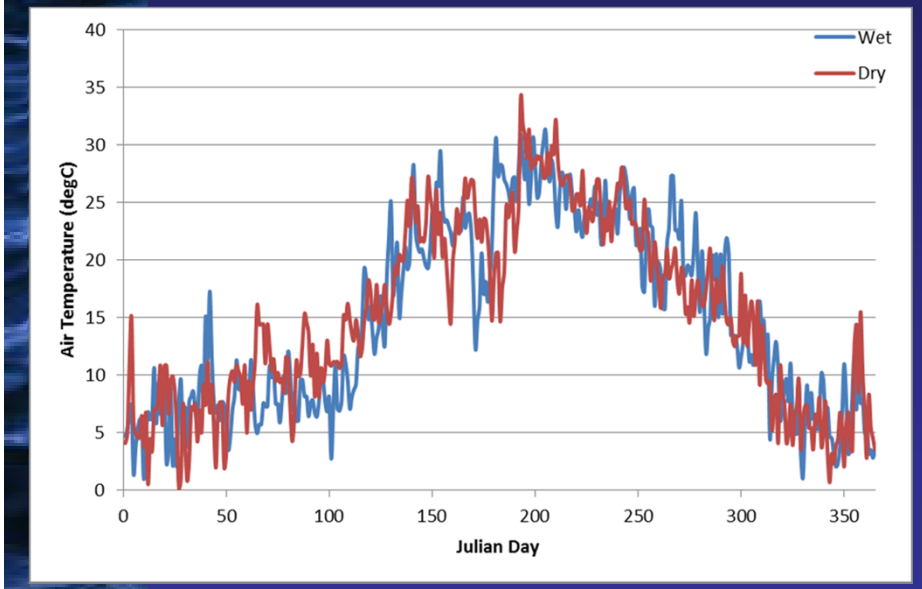




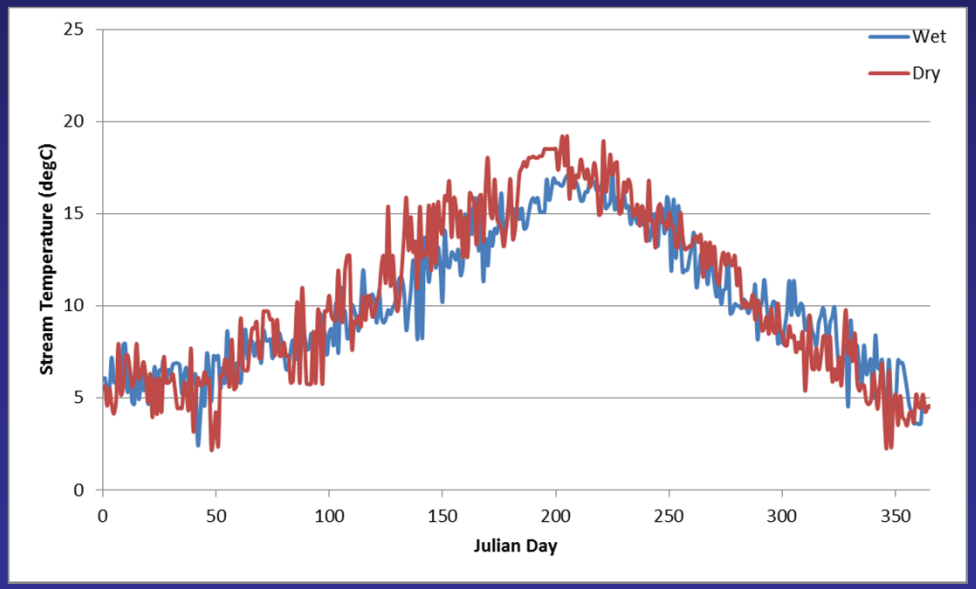
Wet year combined streamflow

Dry year combined streamflow

Preliminary results
Stochastic air and water temperatures



Shasta Lake air temperature



McCloud River stream temperature

Preliminary results
Degree days over target

Note: Preliminary results. Values will be corrected.

Preliminary results
Cold pool volume on Nov. 1

Note: Preliminary results. Values will be corrected.

Preliminary results
Tradeoff plots

Note: Preliminary results. Values will be corrected.

Next steps

- Complete simulations
  - ‘optimized’ flows
  - Additional flow scenarios
    - Drought
    - Wet year with dry fall
    - Wet year with warm fall
    - Climate change
- Workshop with reservoir managers in May 2014
- Development of additional scenarios

Future work

- Juvenile fish passage at Shasta Lake
  - USBR funding
  - Modeling temperature curtains with CE-QUAL-W2
- Proposal to NSF
  - Translating climate variability to aquatic ecosystem
  - Linked stochastic modeling with CE-QUAL-W2 and bioenergetics

References

Bartholow J, Hanna RB, Saito L, Lieberman D, Horn M. 2001. Simulated limnological effects of the Shasta Lake temperature control device. Environmental Management 27(4): 600-626.

Hanna RB, Saito L, Bartholow JM, Sandelin J. 1999. Results of simulated temperature control device operations on in-reservoir and discharge water temperatures using CEQUAL-W2. Lake Reserv Manage 15(2):87-102.

Nowak K, Prairie J, Rajagopalan B, Lall U. 2010. A nonparametric stochastic approach for multisitedisaggregation of annual to daily streamflow. Water Resour. Res. 46: W08529.

Saito L, Johnson BM, Bartholow J, Hanna RB. 2001. Assessing ecosystem effects of reservoir operations using food web-energy transfer and water quality models. Ecosystems 4:105-125.

QUESTIONS?