Modeling eco-hydrological impacts of stream temperature changes in a catchment

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Research Objectives

1. Develop integrated hydro-ecological models to relate environmental stressors in a catchment to an indicator of ecosystem status.

2. To quantify changes in ecosystem status caused by changes in catchment management.

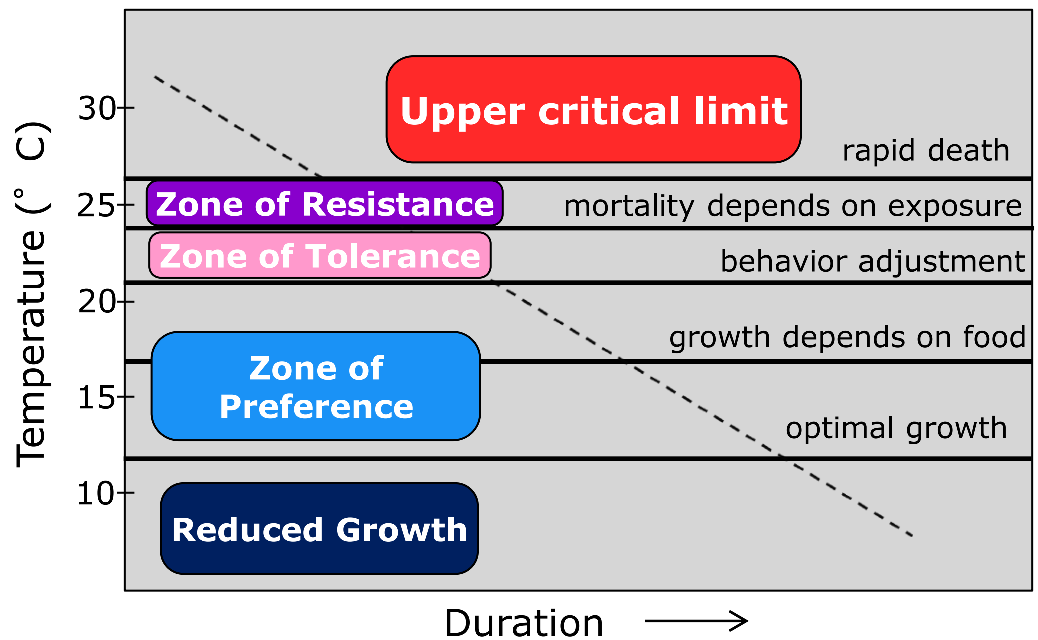
Stream Temperature: a critical element in fish ecology

- Short period exposure: death
  - Lethal temperatures (LT50)

- Long period exposure: physiological responses
  - Metabolism
  - Food intake

- Important factors:
  - Food availability
  - Habitat conditions
    - Oxygen, pollution
    - Physical stream conditions

Effects of temperature on salmonids



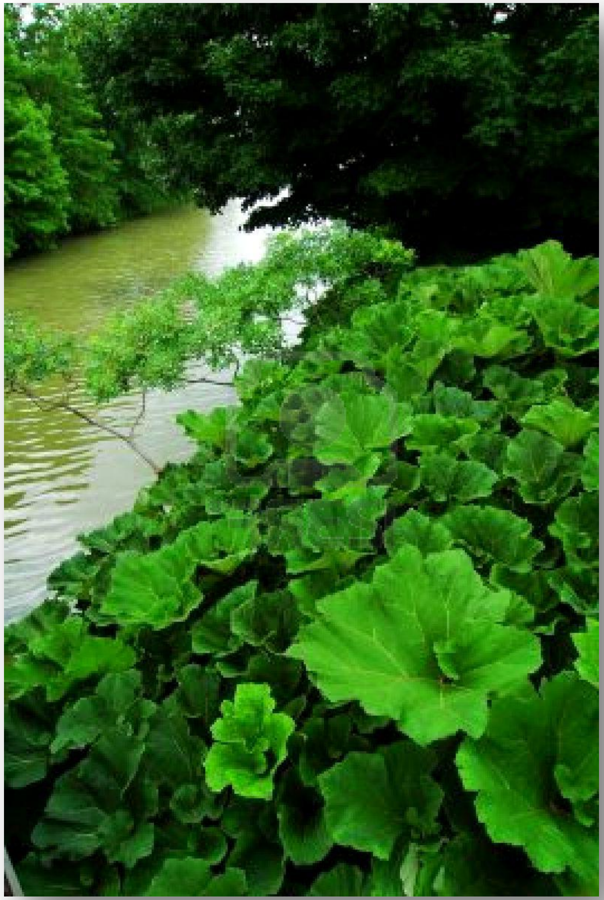
from Sullivan et al., 2000

Catchment factors that impact stream temperature

- Land use/water use impact on flows
  - Groundwater
  - Tributaries
  - Agricultural drains

- Geomorphology
  - Channel width-to-depth increase (bank erosion, accumulation of sediments)
  - Channelization
  - Ponding

- Bank Vegetation (shade)

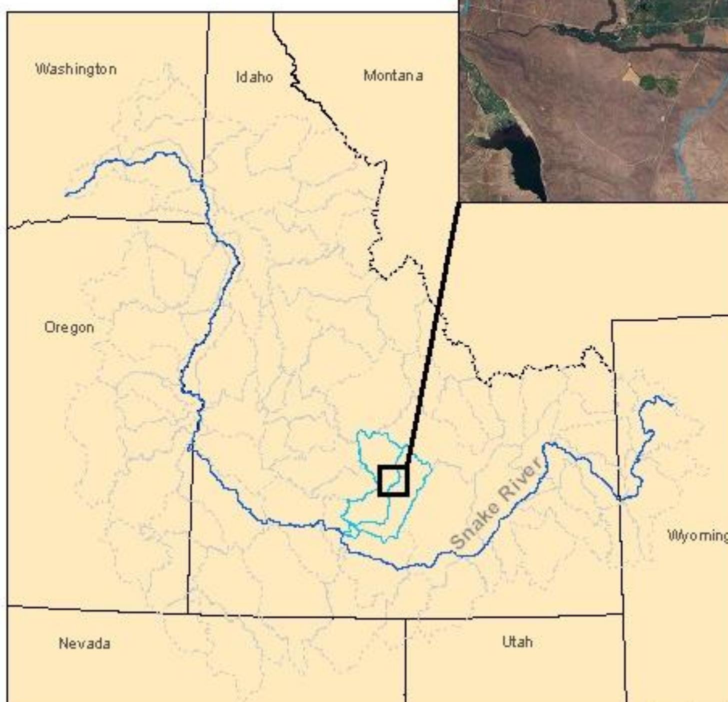


Silver Creek Basin, Idaho

Silver Creek is a spring-fed system abundant in wildlife and also a valuable trout habitat.

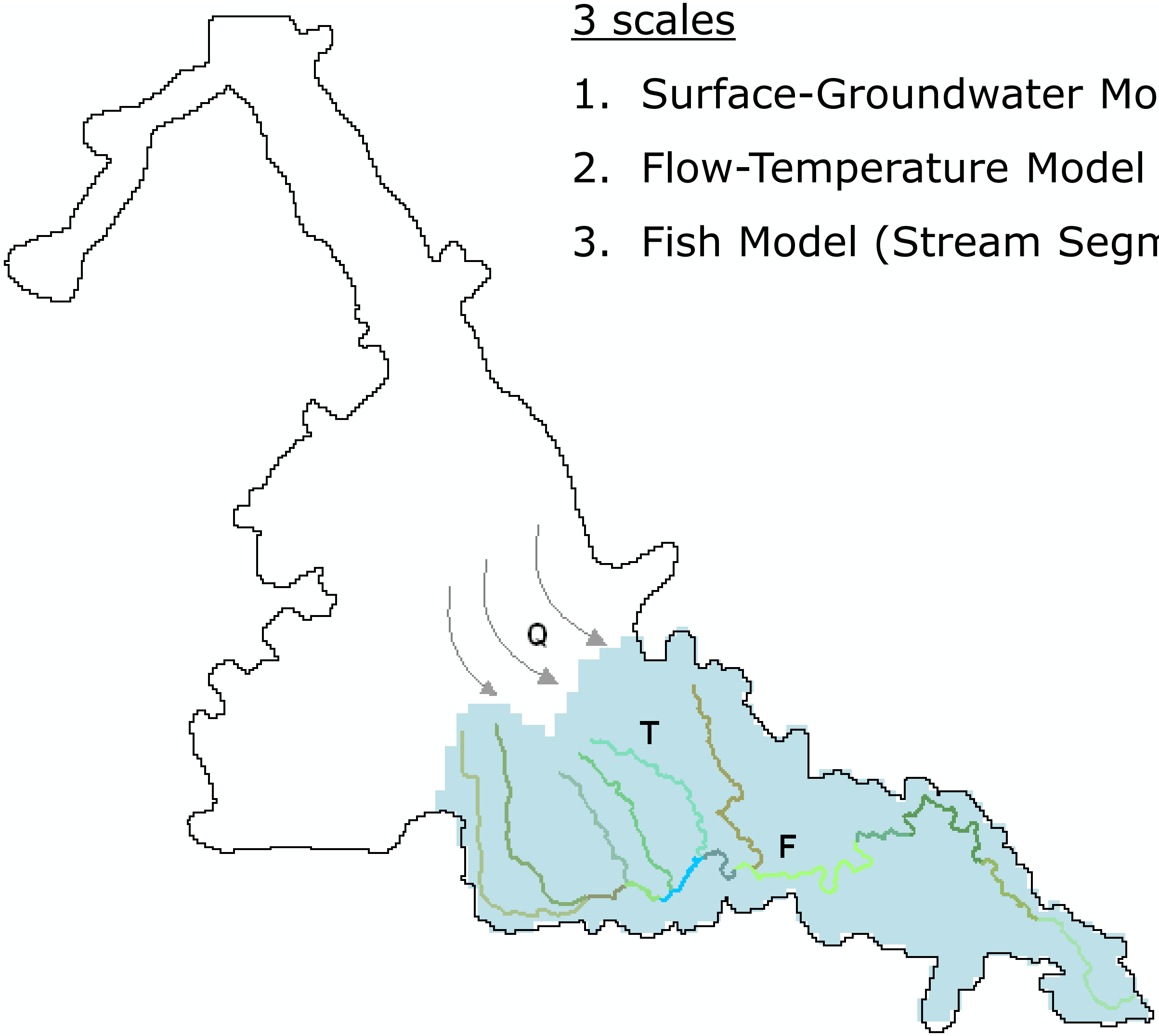
The climate is of a semi-desert valley with low precipitation and high evaporation.

Approximately 60% of the lower valley is culvitated, of which 80% is irrigated.



IDFG, 2007
Brockway and Kahlown, 1994

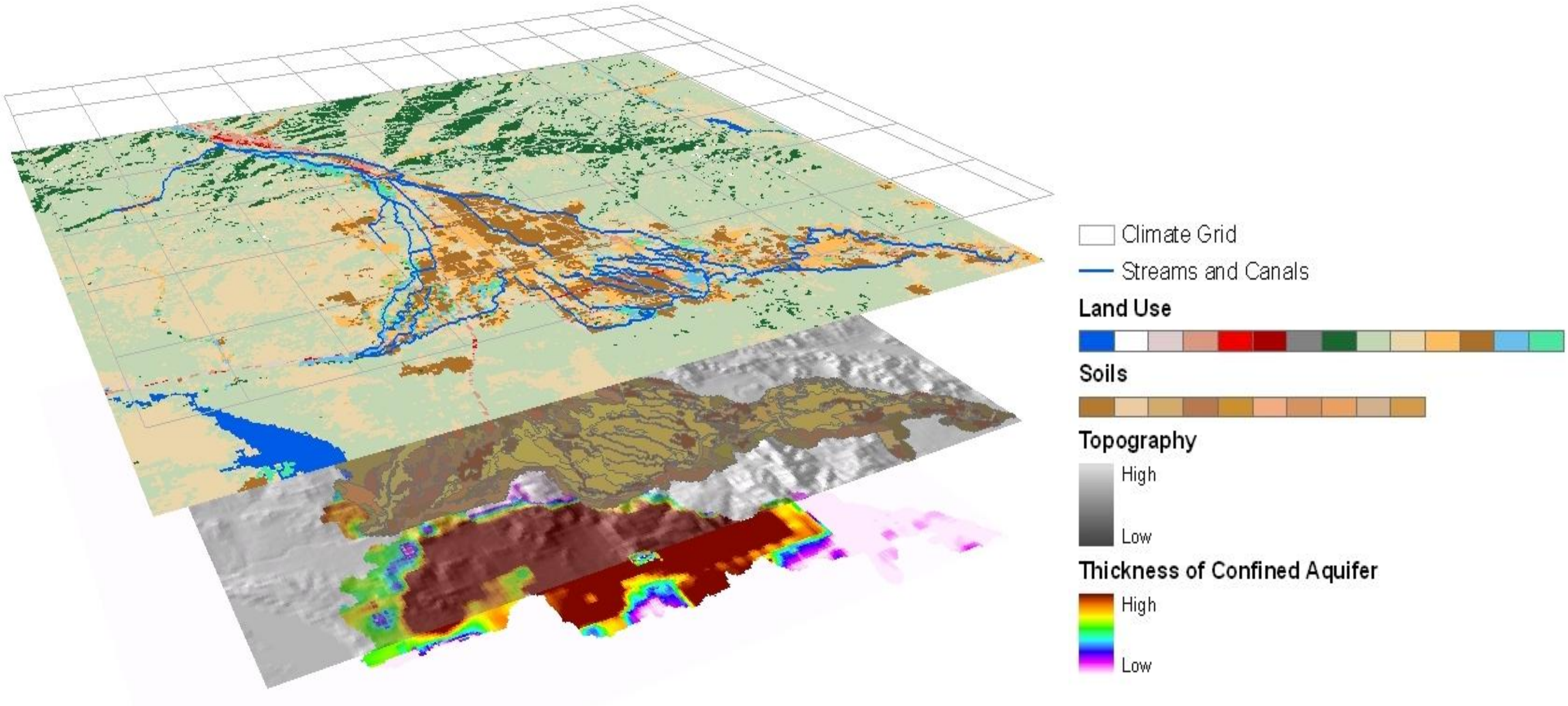
Modeling approach



3 scales

1. Surface-Groundwater Model (Wood River Aquifer)
2. Flow-Temperature Model (Silver Creek Basin)
3. Fish Model (Stream Segments)

Flow Model (MIKE SHE)



Spatially distributed model, 300m resolution

3 geologic layers, 62 soil types, 20 land use types, distributed irrigation system

207 km total stream and canal length, ~200 cross-sections

Stream Temperature Model (MIKE 11-Ecolab)

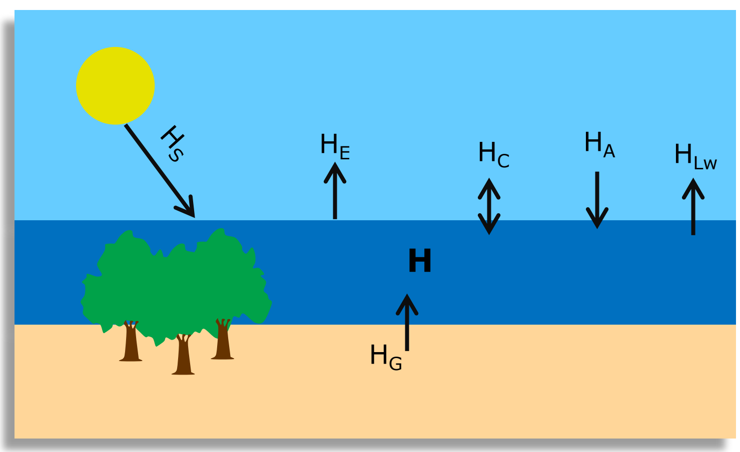
$$T = \frac{H}{\rho C_p V}$$ ρC_p = heat capacity (J/m^3°C)

1D Surface water heat transport:

$$\frac{\partial T}{\partial t} = -\frac{1}{A}\frac{\partial (QT)}{\partial x} + \frac{1}{A}\frac{\partial}{\partial x}\left(DA\frac{\partial T}{\partial x}\right) + \frac{H}{\rho C_p d}$$

Q = flow
A = surface area
D = longitudinal dispersion
d = water depth
H = atmosphere and sediment heat flux

Net heat flux into the water (H) = H_S + H_A - H_C - H_E – H_{Lw}+ H_G



H_S = net solar radiation
H_A= net atmospheric long wave radiation
H_C = sensible heat flux between water and atmosphere (T_w)
H_E = evaporation/condensation (T_w)
H_{Lw} = outgoing long wave radiation from water (T_w)
H_G = groundwater heat flux (ag drains + baseflow)

Bioenergetics: Fish growth model

- Based on energy balance:

  Consumption = Metabolism + Wastes + Growth $E_{in} \rightarrow$  $\rightarrow E_{out}$

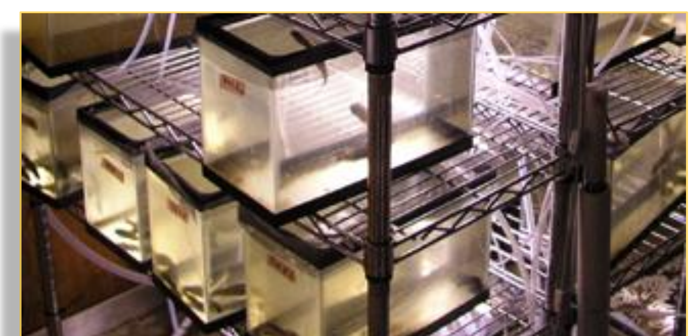
- All processes are size and temperature dependent

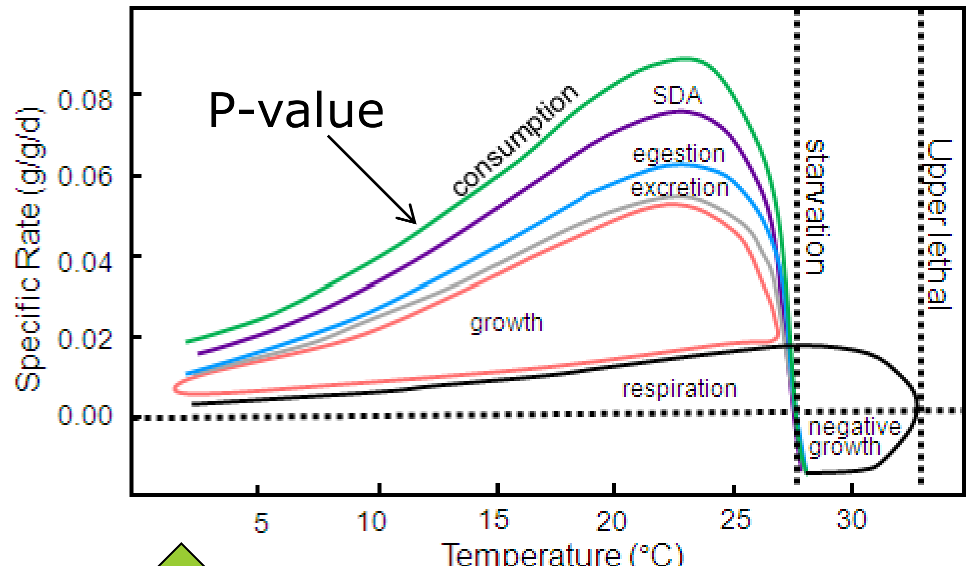
- Growth model: $\Delta w_i = g_i \cdot w_i$

  Δw_i = *current day growth (grams/day)*

  g_i = *specific growth rate (g/g·day)*

  w_i = *weight at day i (grams)*





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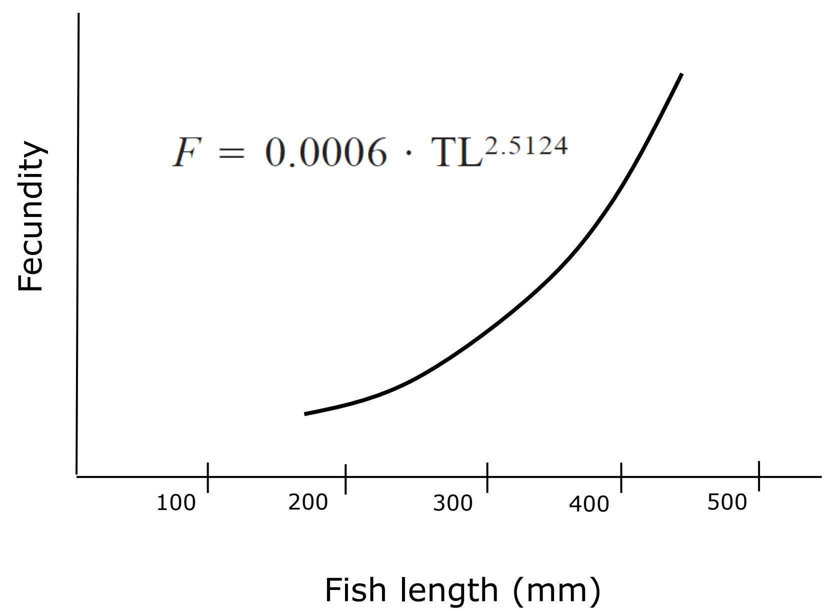
Hanson et al., 1997

Ecological Suitability Indicators

- Fish growth in under certain conditions relation to growth under natural conditions at maturity age: $weight_{scenario}/weight_{natural}$

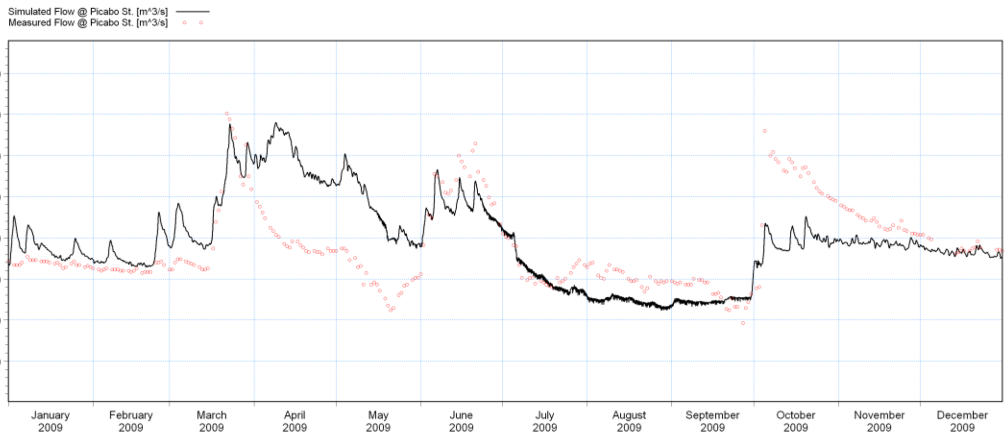
- Reproduction capability and time it takes to reach maturity

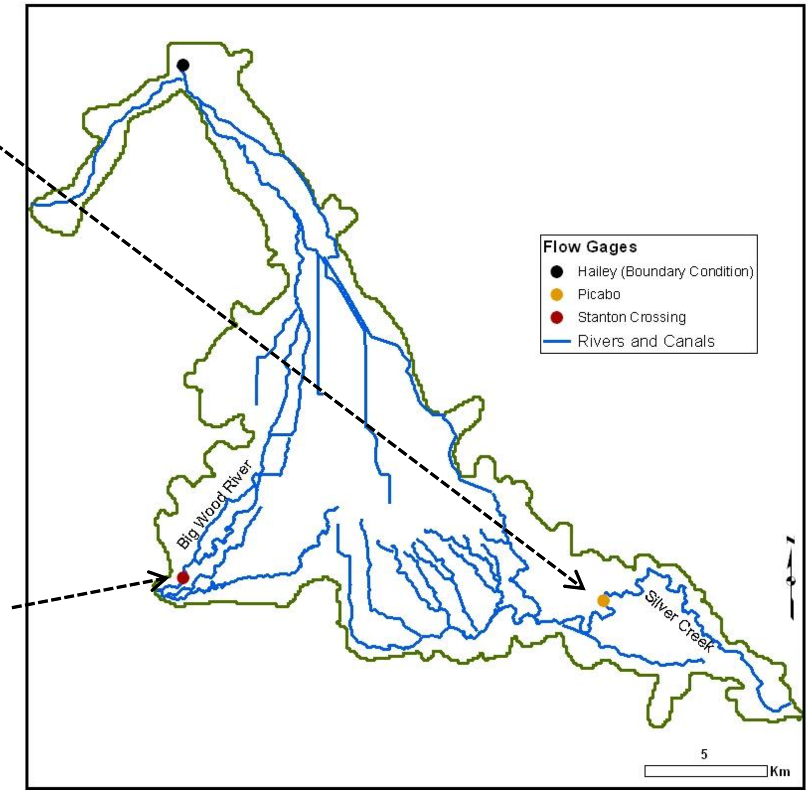


Meyer et al., 2003

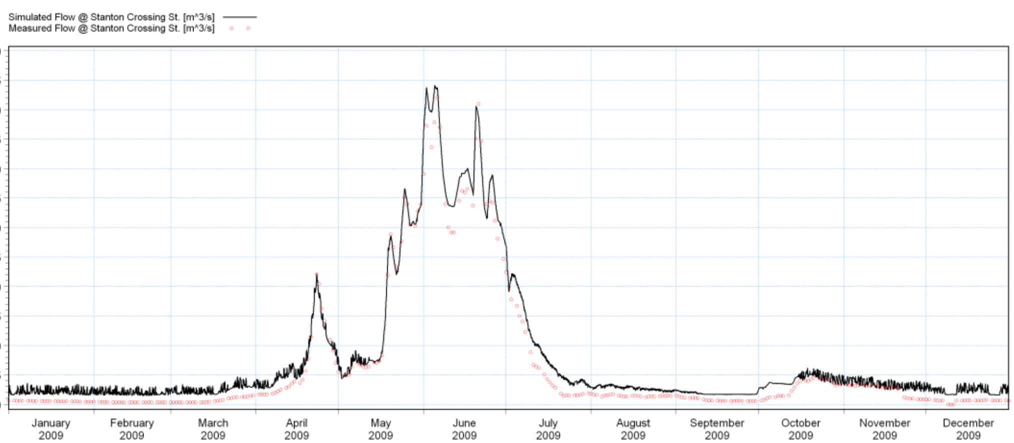
Flow Calibration

Picabo St @ Silver Creek

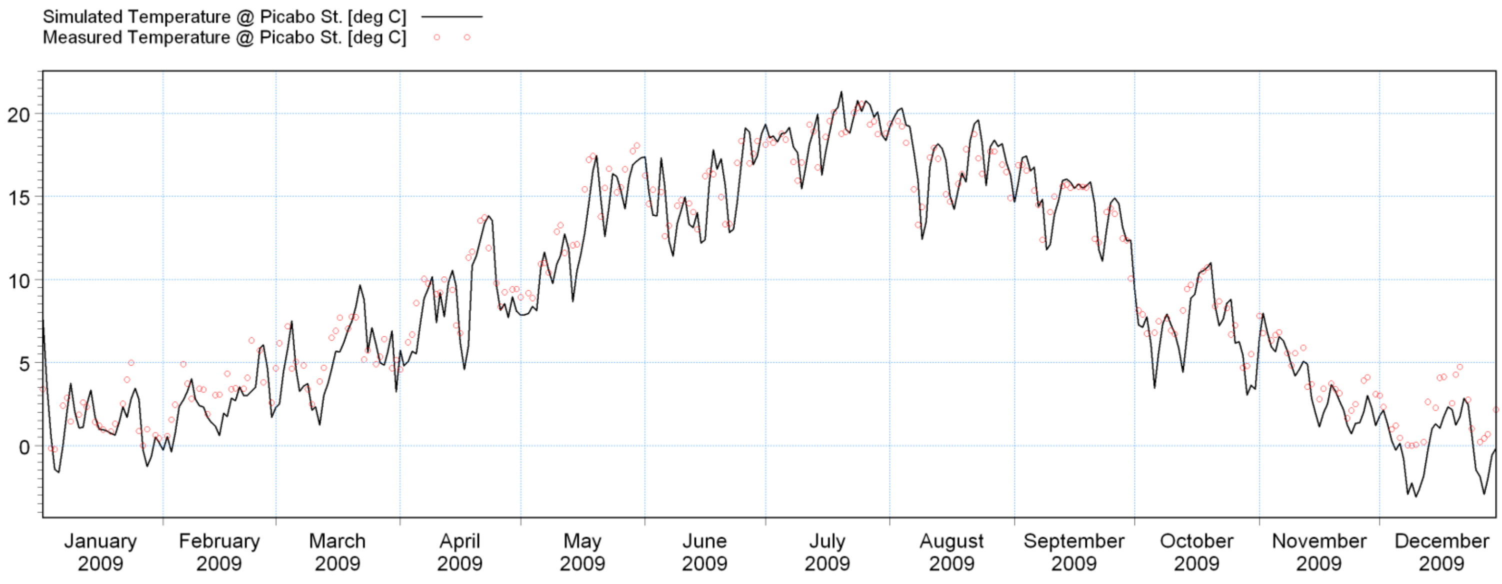




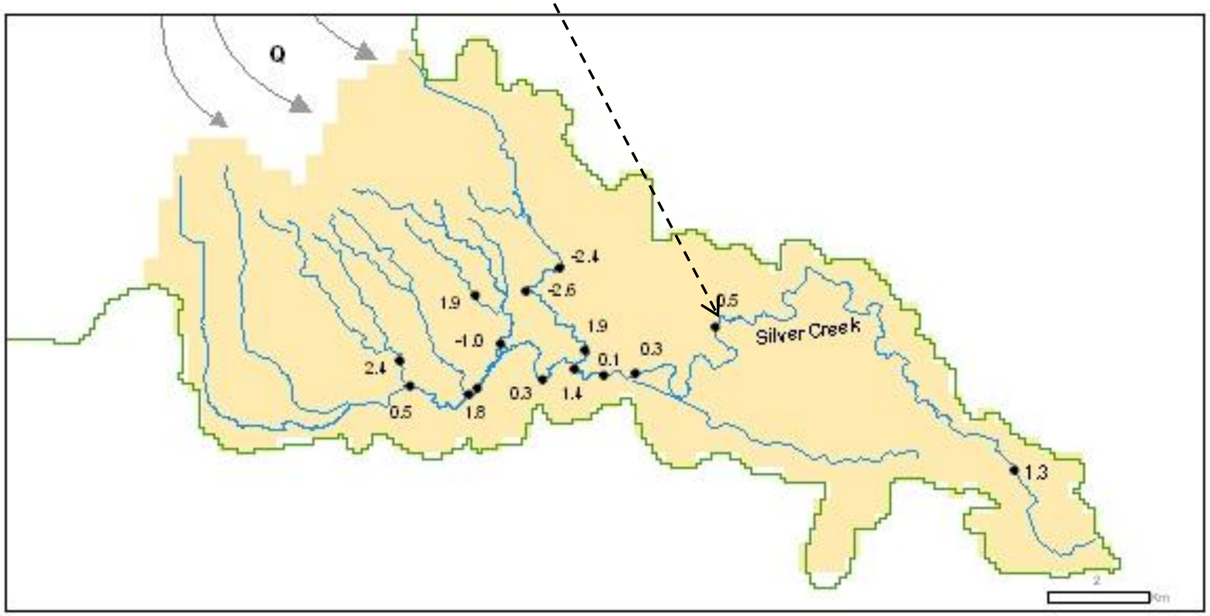
Stanton Crossing St @ Big Wood River



Temperature Calibration



$$ME_i = \overline{E}_i = \frac{\sum_t (Obs_{i,t} - Calc_{i,t})}{n}$$



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Model Scenarios

1. Natural System (NS): Replace agriculture and urban with natural areas, eliminate all canals and irrigation system

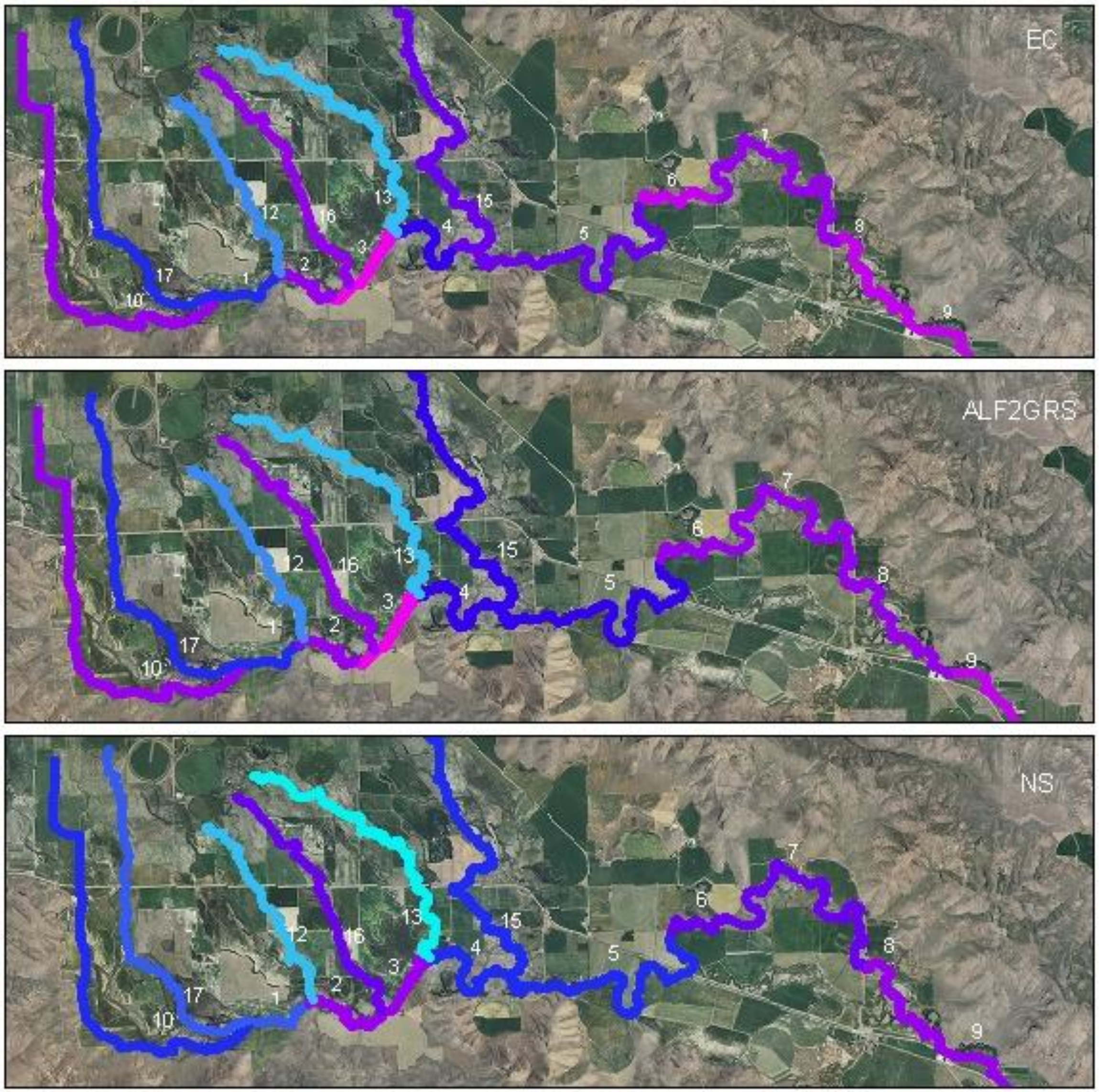
2. Crop change (ALF2BAR): alfalfa to barley

3. Land use change (ALF2GRS): alfalfa to grass

4. Bank vegetation (VH): increase bank vegetation

5. Geomorphology (WOKP): remove Kilpatrick dam and pond, replace with narrower cross-sections and natural profile.

Temperature Results



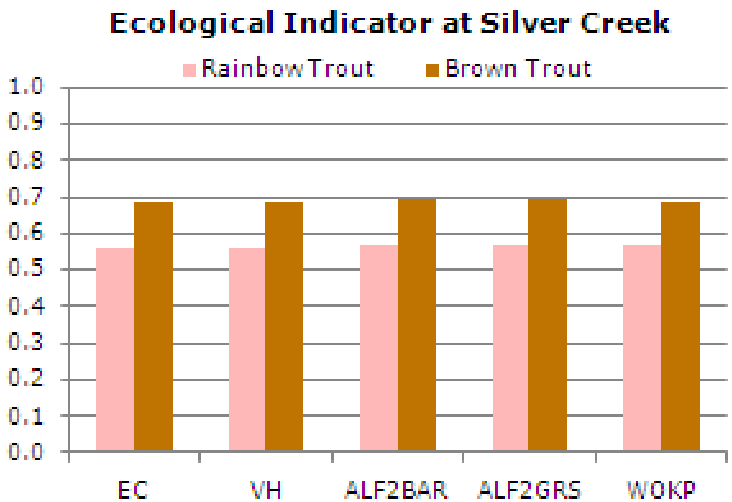
Average Temperature Change

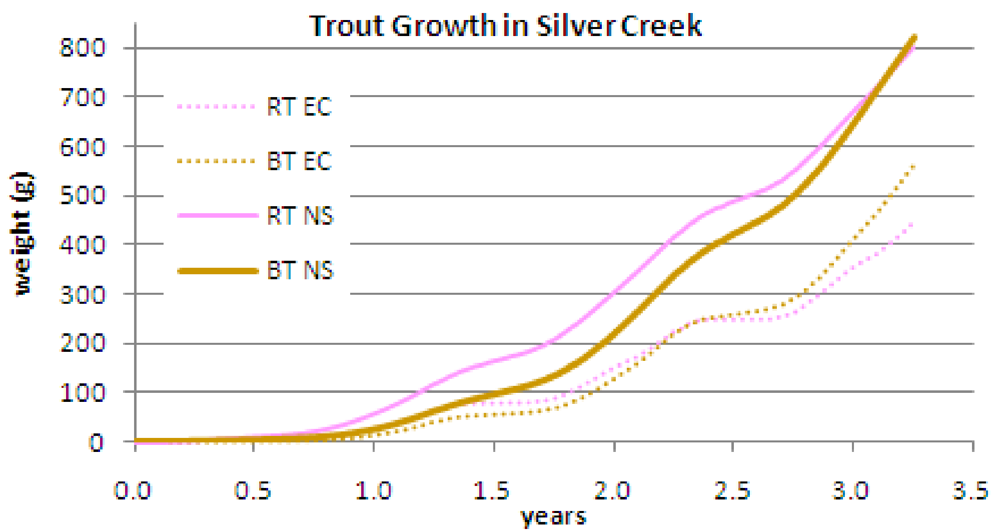
Seg	VH	WOKP	ALF2BAR	ALF2GRS	NS
1	0.0	0.0	0.1	0.6	-0.5
2	0.0	0.0	-0.2	-0.6	0.0
3	0.0	0.0	0.0	-0.3	-1.7
4	0.0	0.0	-0.1	-0.1	-1.2
5	0.0	0.1	-0.2	-0.6	-1.5
6	0.0	0.2	-0.1	-0.5	-1.6
7	0.0	0.1	-0.1	-0.3	-1.6
8	0.0	0.0	0.0	-0.2	-0.8
9	0.0	0.0	0.1	0.2	-1.0
10	0.0	0.0	0.0	0.0	-3.2
12	0.0	0.0	0.1	0.2	-0.6
13	0.0	0.0	0.0	-0.1	-1.0
15	0.0	0.0	-0.3	-0.9	-1.6
16	0.0	0.0	0.0	-0.2	-1.4
17	0.0	0.0	0.0	0.0	-1.3

Average Summer Water Temperature (deg C)

- 7 - 8
- 8 - 9
- 9 - 10
- 10 - 11
- 11 - 12
- 12 - 13
- 13 - 14
- 14 - 15
- 15 - 16
- 16 - 17

Ecological Model Results





	F3	T_M (d)
RT NS	2534	395
RT EC	1573	480
BT NS	2575	493
BT EC	1875	659

F3 = Potential fecundity at age 3

T_M = time to reach potential maturity (200 mm)

Conclusions

- All model scenarios cause a change stream temperatures from current conditions, but only scenario 3 (changing alfalfa crops for grass) was significant decrease in average summer temperatures. A combination of different restorations strategies needs to be further explored.

- Ecological model results imply that the current system is at approximately half of its potential.

- The bioenergetics model should also include habitat degradation conditions (p-value).

- Deviation from natural conditions seem to have less of an impact on brown trout than rainbow trout, which may explain the increasing numbers of brown trout in relation to rainbow trout.

Thank you