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Proposed Metric For Measuring Shifts In Ecological Function Of Impaired Streams

ERIE *Ecosystem Restoration Through Interdisciplinary Exchange*

NSF

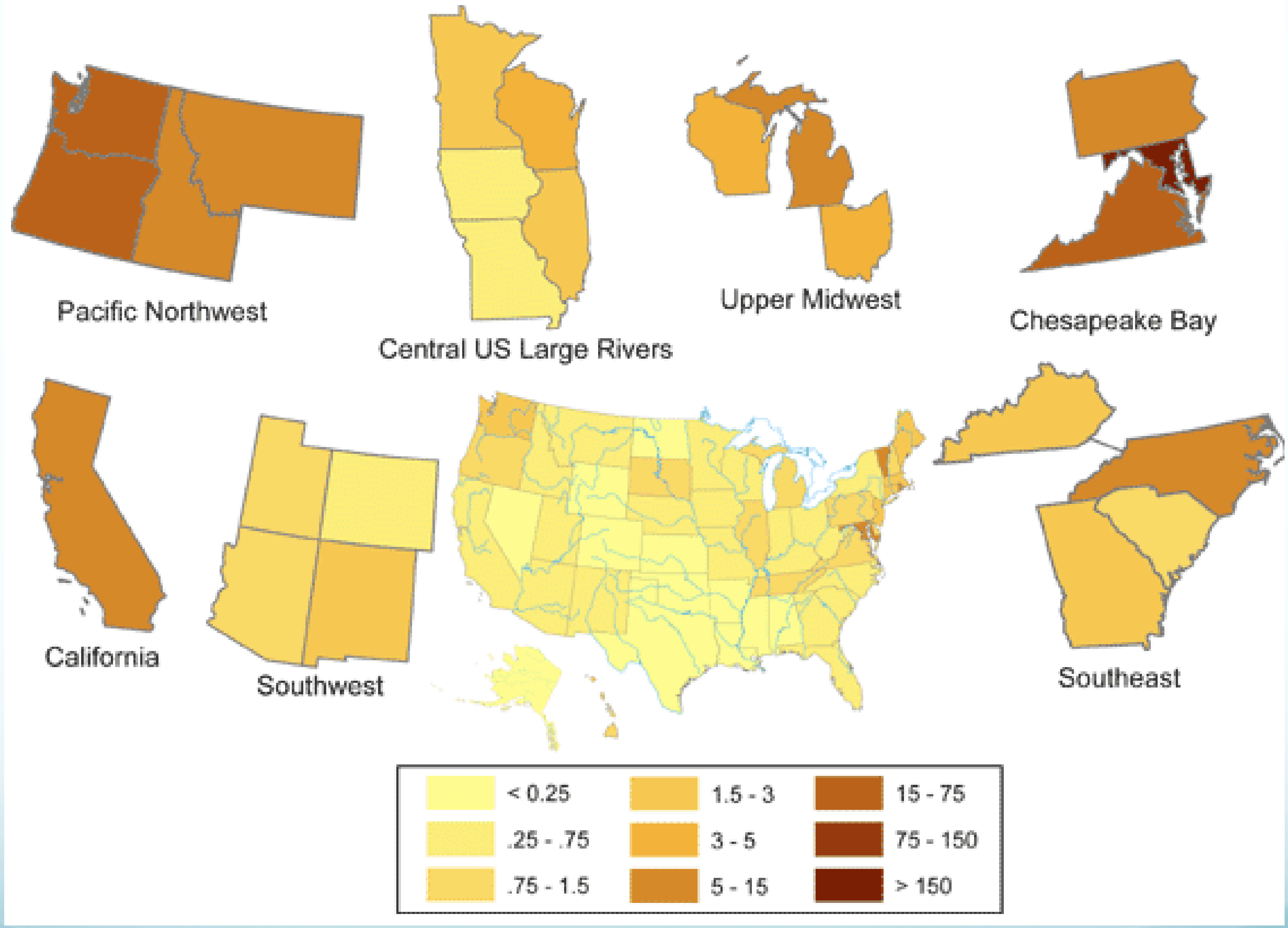
Overview

- Motivation for research
- Hypothesis and objectives
- Methods
  - Conceptual framework
  - Field experiments
  - Lab Experiments
  - Hydraulic Models
- Results and Outcomes

Motivation for Research

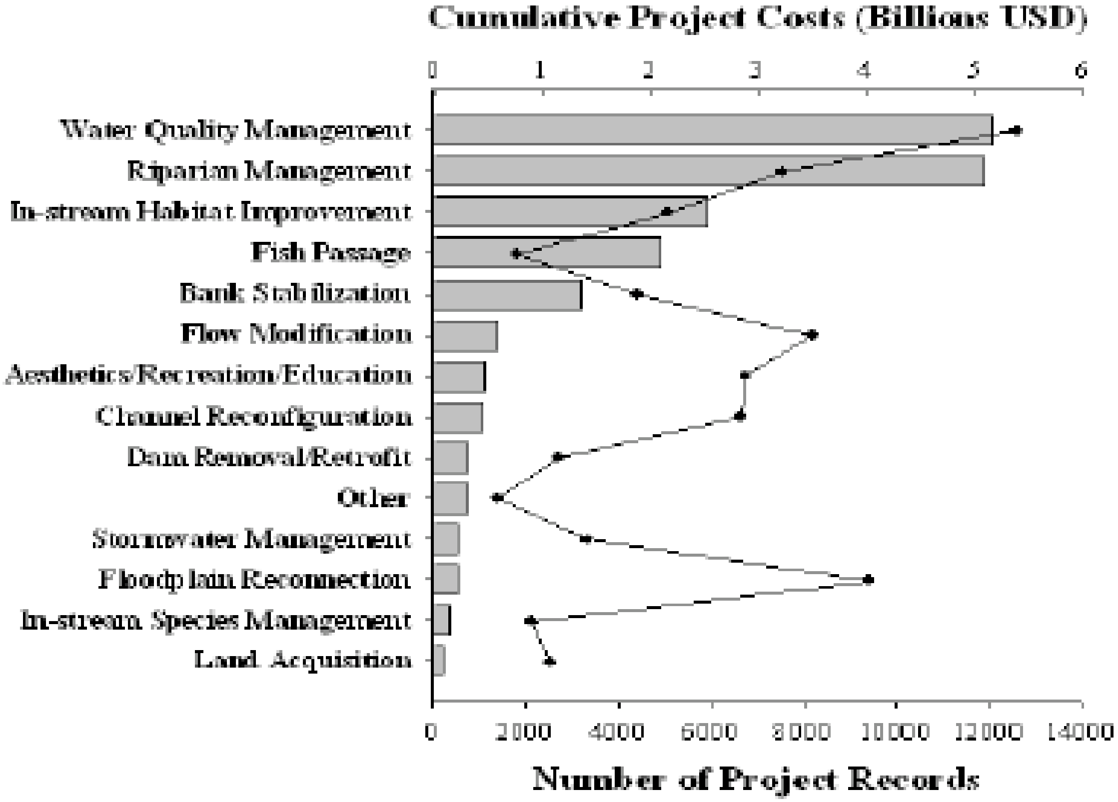
Tensaw River Delta, 1977

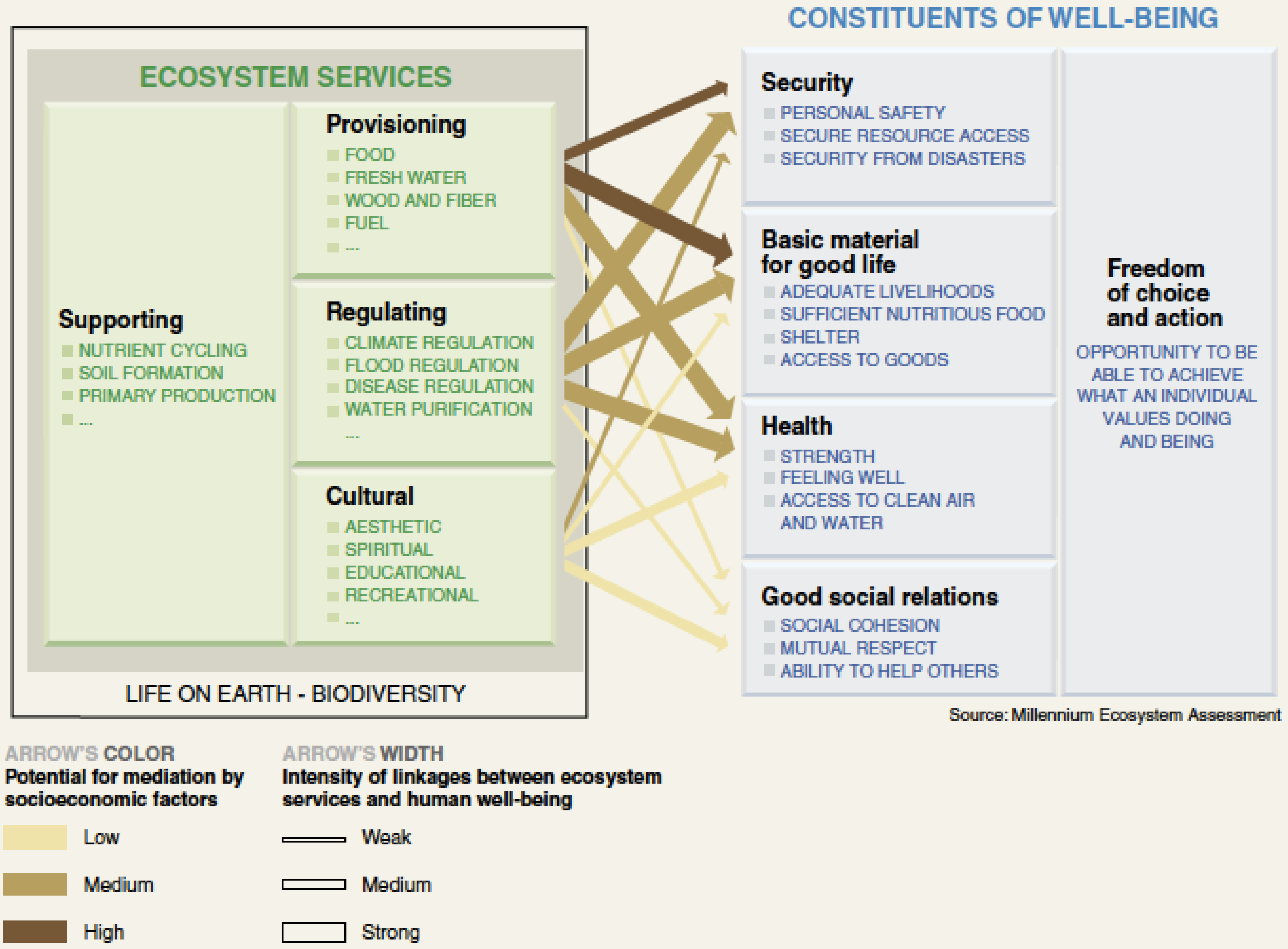
Bernhardt et. al. 2005. *Synthesizing U.S. River Restoration Efforts*,



How much is being spent?

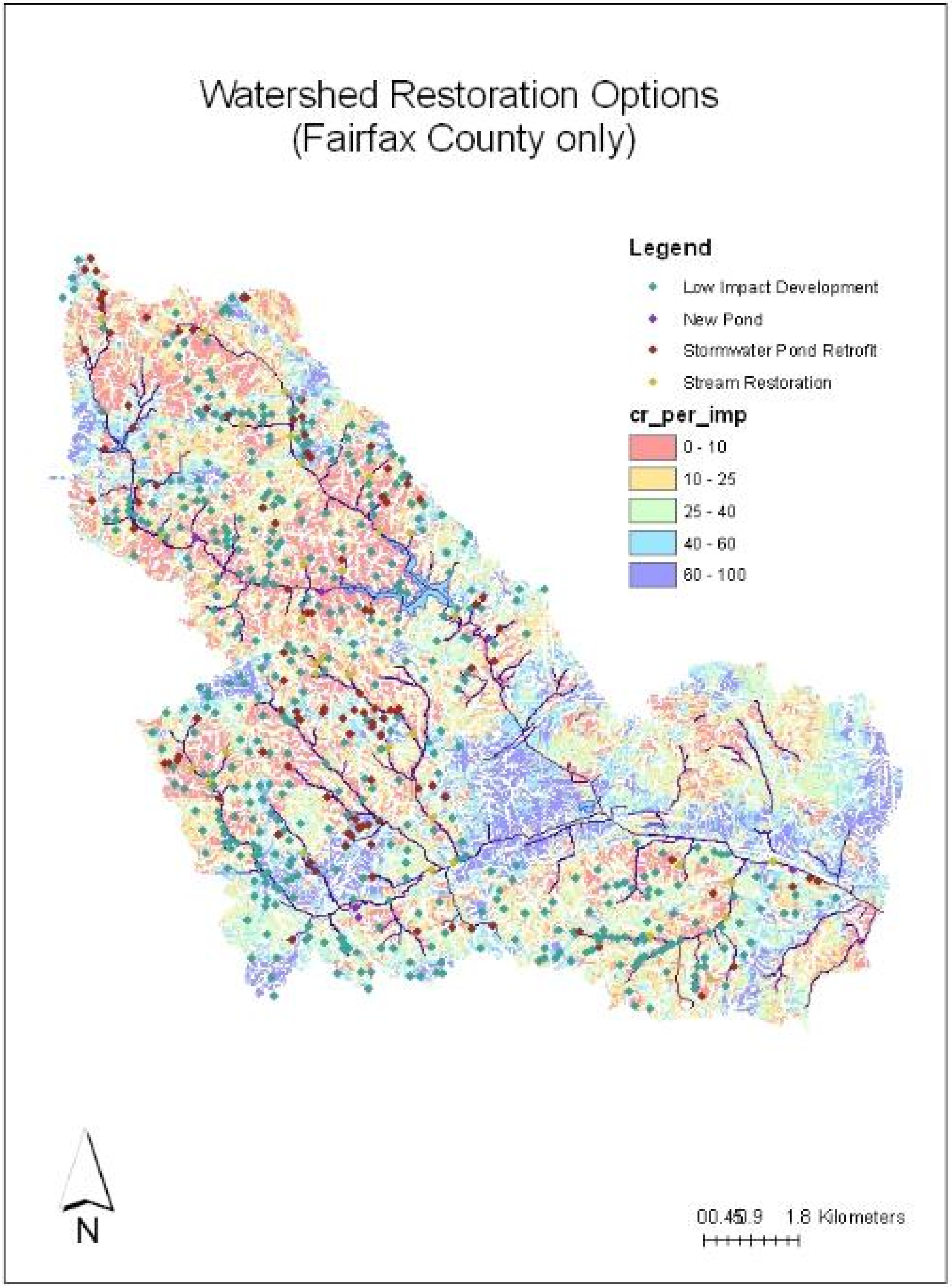
Total expenditures 1996- 2003 > $14 billion
(ca. $1B per year)
Average cost per project $380,000



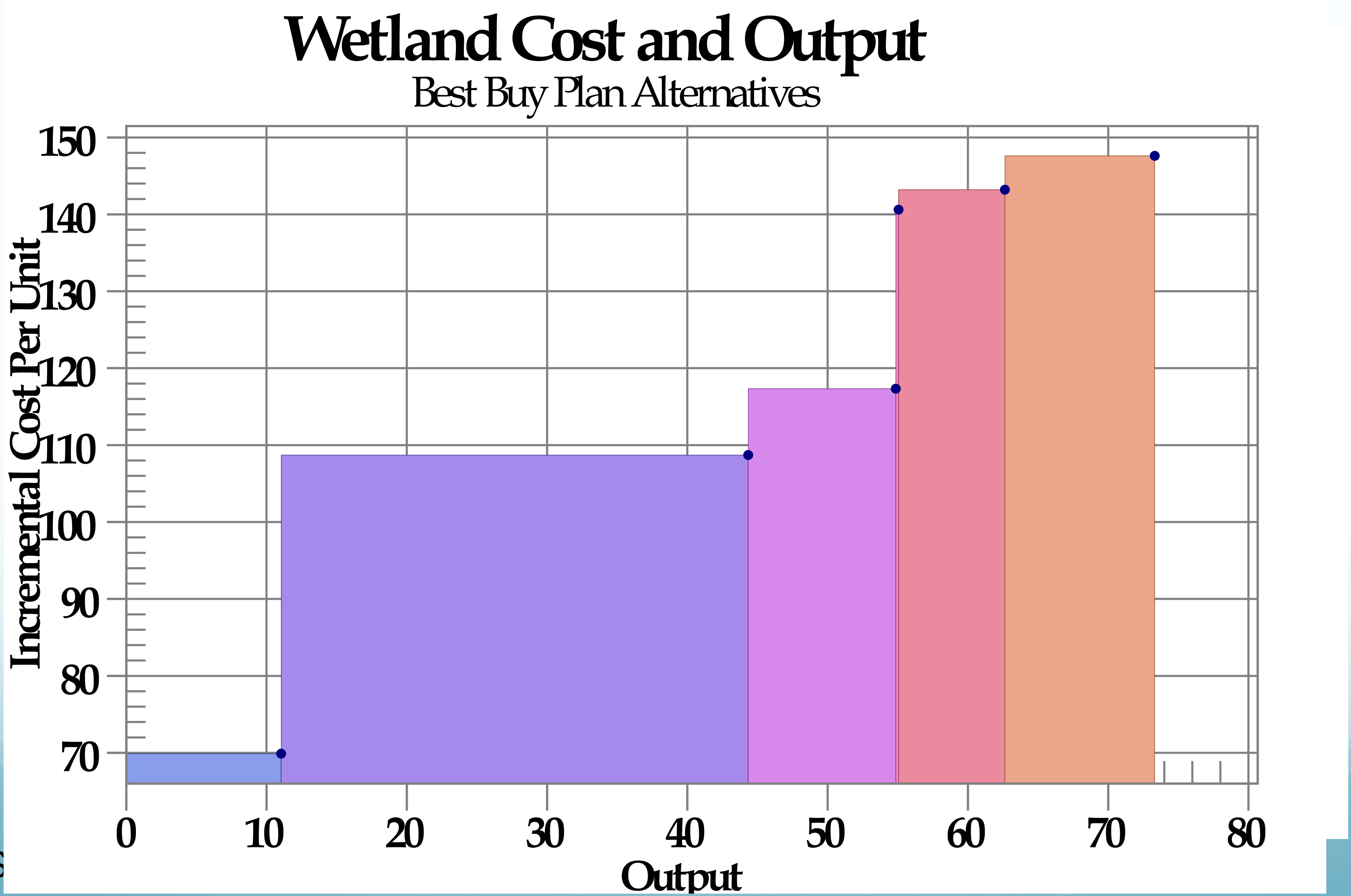


CONSTITUENTS OF WELL-BEING
ECOSYSTEM SERVICES
Provisioning
FOOD
FRESH WATER
WOOD AND FIBER
FUEL
...
Supporting
NUTRIENT CYCLING
SOIL FORMATION
PRIMARY PRODUCTION
...
Regulating
CLIMATE REGULATION
FLOOD REGULATION
DISEASE REGULATION
WATER PURIFICATION
...
Cultural
AESTHETIC
SPIRITUAL
EDUCATIONAL
RECREATIONAL
...
LIFE ON EARTH - BIODIVERSITY
Security
PERSONAL SAFETY
SECURE RESOURCE ACCESS
SECURITY FROM DISASTERS
Basic material for good life
ADEQUATE LIVELIHOODS
SUFFICIENT NUTRITIOUS FOOD
SHELTER
ACCESS TO GOODS
Health
STRENGTH
FEELING WELL
ACCESS TO CLEAN AIR AND WATER
Good social relations
SOCIAL COHESION
MUTUAL RESPECT
ABILITY TO HELP OTHERS
Freedom of choice and action
OPPORTUNITY TO BE ABLE TO ACHIEVE WHAT AN INDIVIDUAL VALUES DOING AND BEING
Source: Millennium Ecosystem Assessment
ARROW'S COLOR
Potential for mediation by socioeconomic factors
Low
Medium
High
ARROW'S WIDTH
Intensity of linkages between ecosystem services and human well-being
Weak
Medium
Strong

hed


Watershed Restoration Options
(Fairfax County only)
Legend
Low Impact Development
New Pond
Stormwater Pond Retrofit
Stream Restoration
cr_per_imp
0 - 10
10 - 25
25 - 40
40 - 60
60 - 100
N
00.450.9 1.8 Kilometers

Cost/Benefit Analysis



Stream Restoration is….

- the intentional act of recreating or repairing the **structure** and **function** of a stream ecosystem so that **natural processes** can operate **unimpeded**.

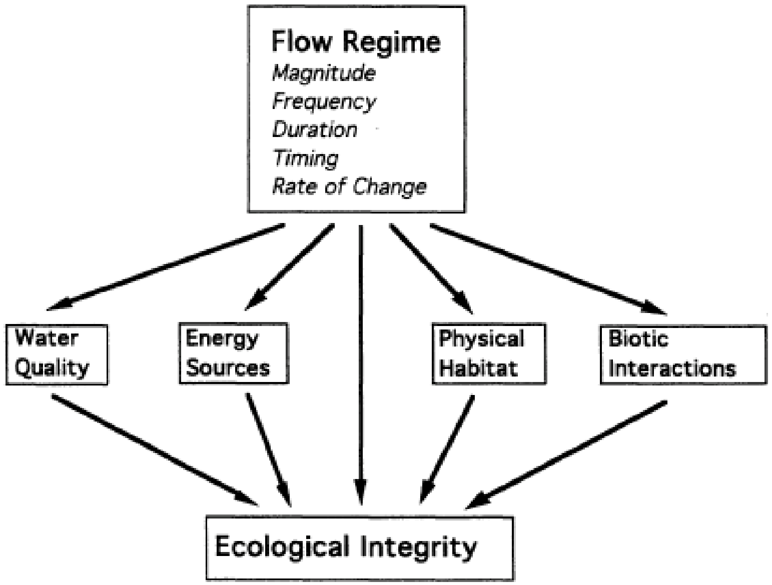
(National Research Council 1992, McCandless and Bisland 1995, Brookes and Shields, Jr. 1996, Williams *et al*., 1997, Stream Corridor Restoration Handbook, 1998, Palmer et al 2005.)

Ecological Structure vs. Function

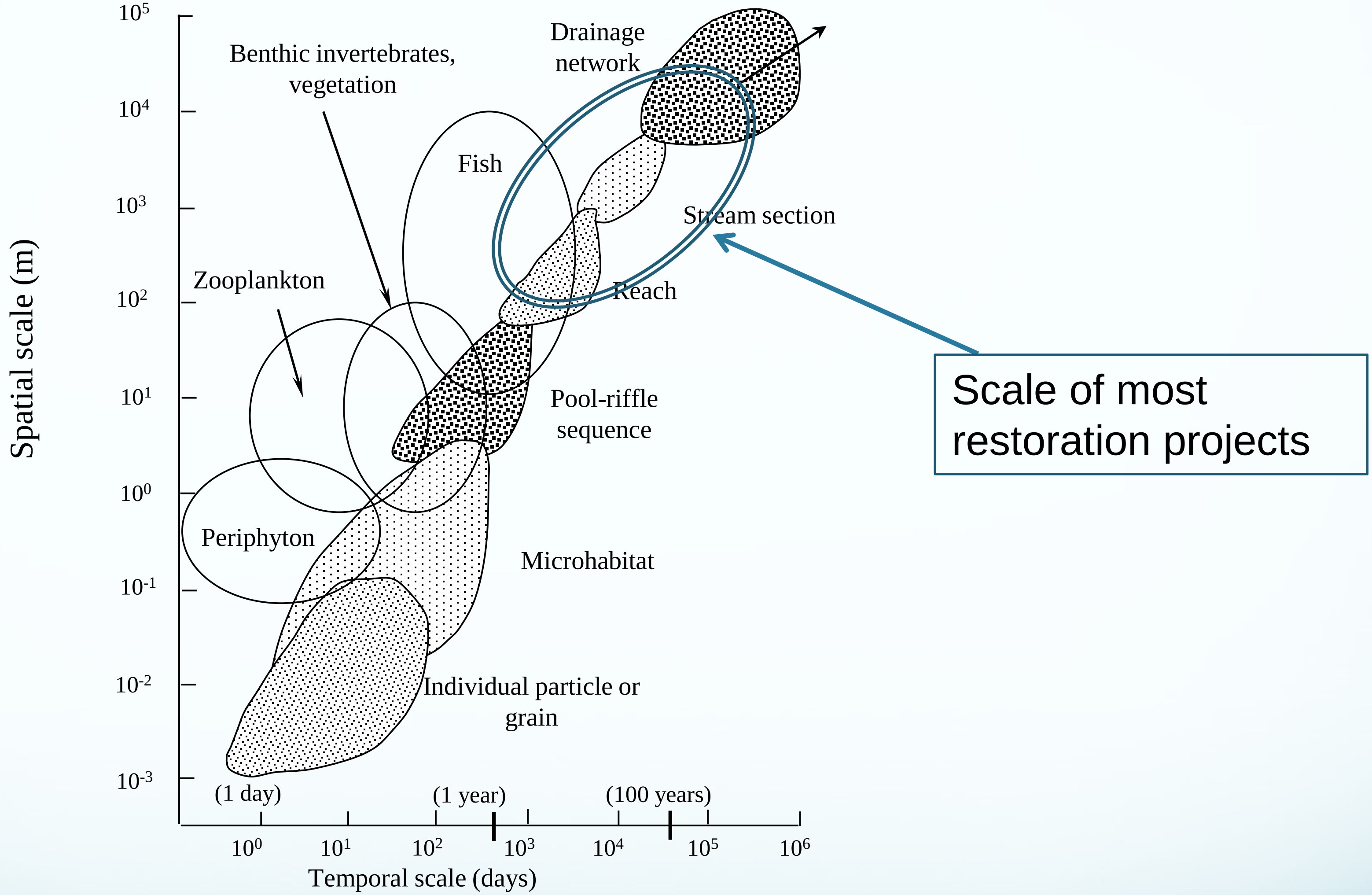
- Structure
  - Channel configuration (dimension, pattern, profile)
  - Focal habitat types (e.g. pools and riffles)
  - Focal species (trout)
  - Functional group (game species)
  - Species diversity (IBI scores)
- Function
  - Food web interactions
  - Nutrient processing/uptake
  - Primary production
  - Sediment transport
  - Detoxification

What is the impact of restoration activities on ecosystem function in streams?

Stream Restoration often focuses on physical manipulation of structure.



(Poff et al., 1997)



Representative temporal and spatial scales of physical (redrawn from Allan 1995) and ecological changes in streams.

Issues

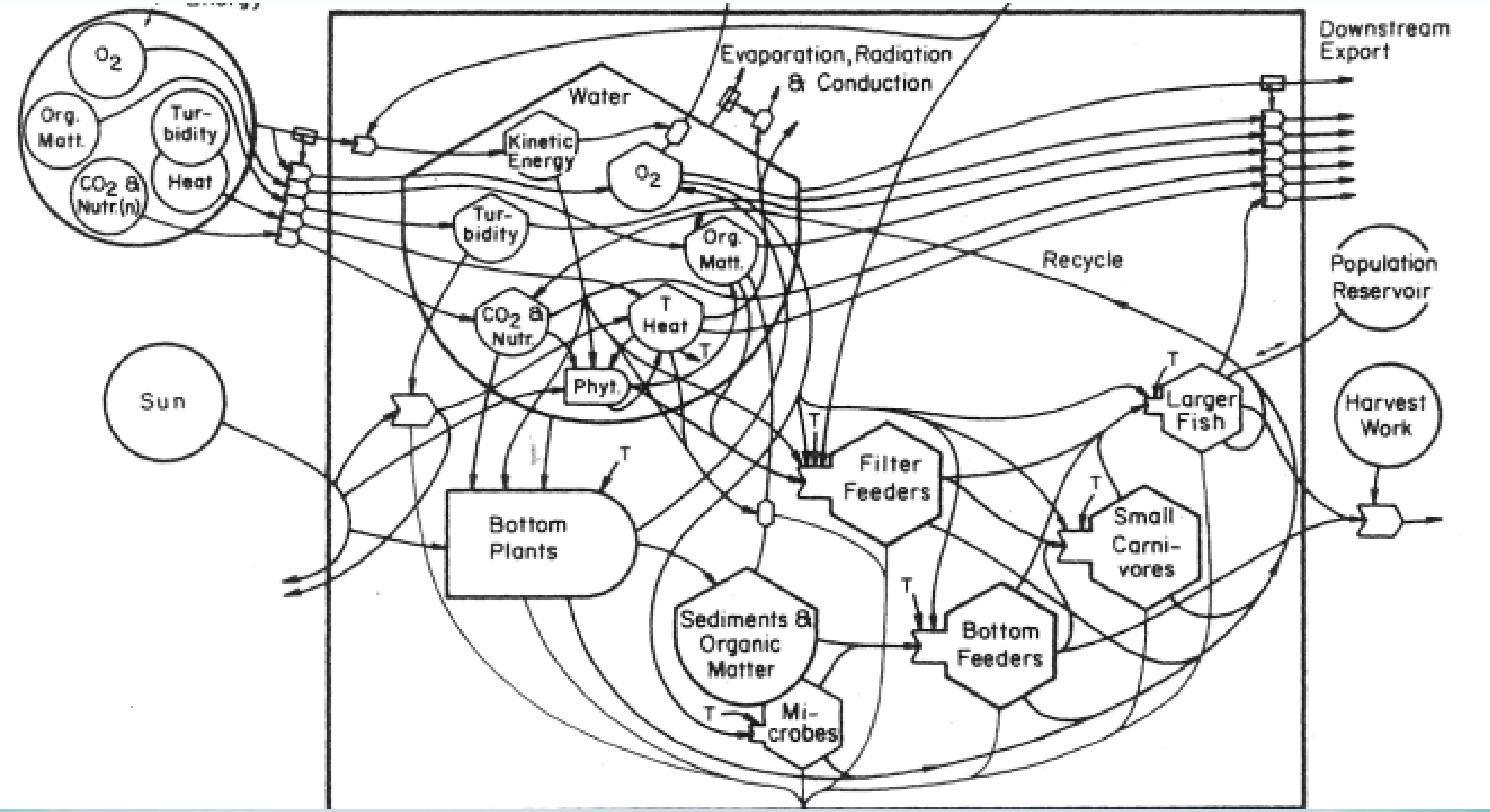
- Stream restoration practice has only a rudimentary sense of how to restore for function
- The demand for restoration is driven by valuation of ecosystem services.
- Ecosystem services are defined at the interaction between human perception and stream ecosystem function and structure.

Research Needs

- Science-based tools and guidelines that are practical for stream restoration practitioners.
- Tools should accurately assess and monitor ecosystem services at different spatial scales.
- Metric should be developed that allows decision-makers to differentiate the effects of different restoration scenarios (emerging properties key).

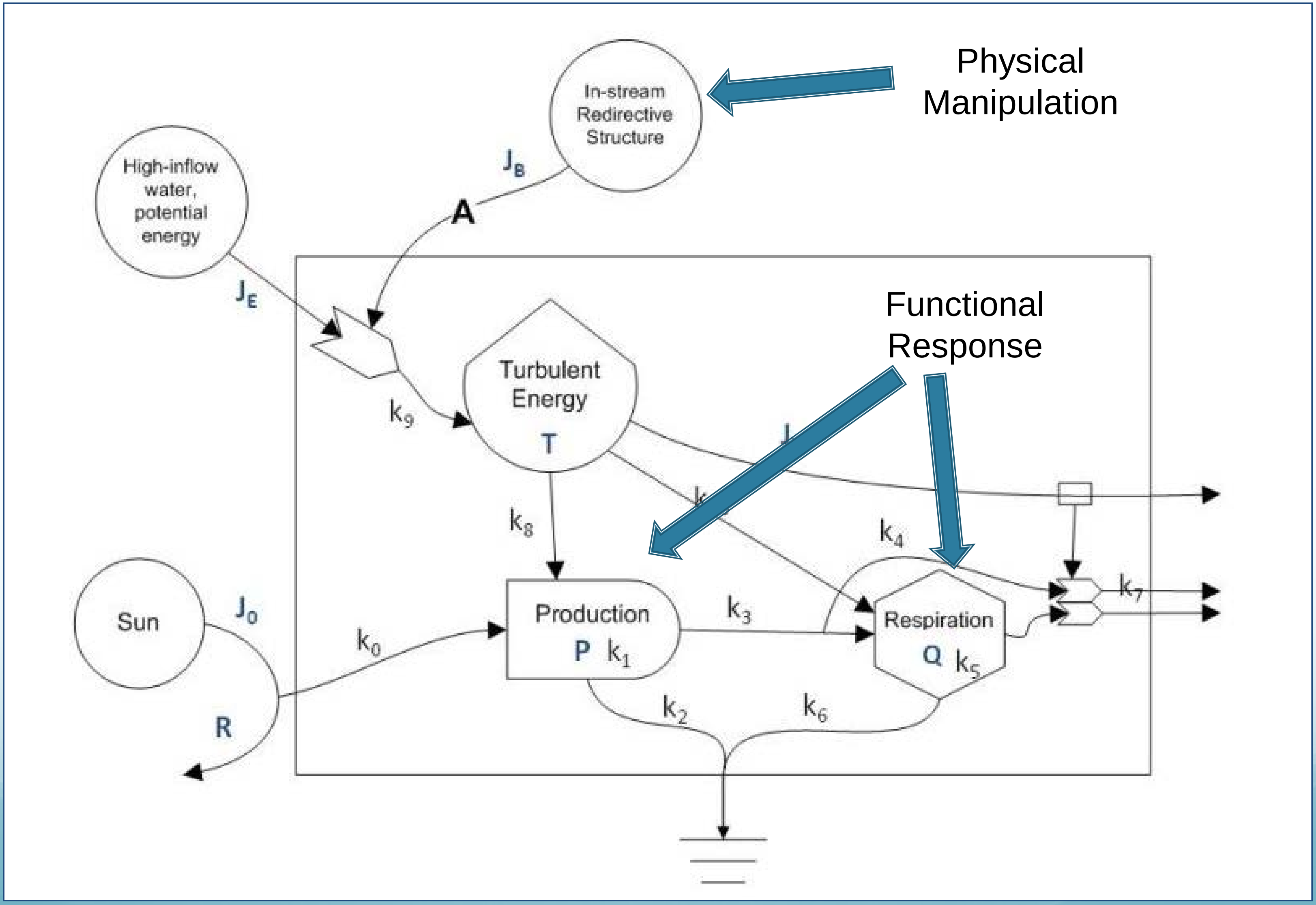
Hypothesis and Objectives

System diagram of a generic stream section



Odum (1994)

Guiding conceptual model for stream restoration activities in a generic reach

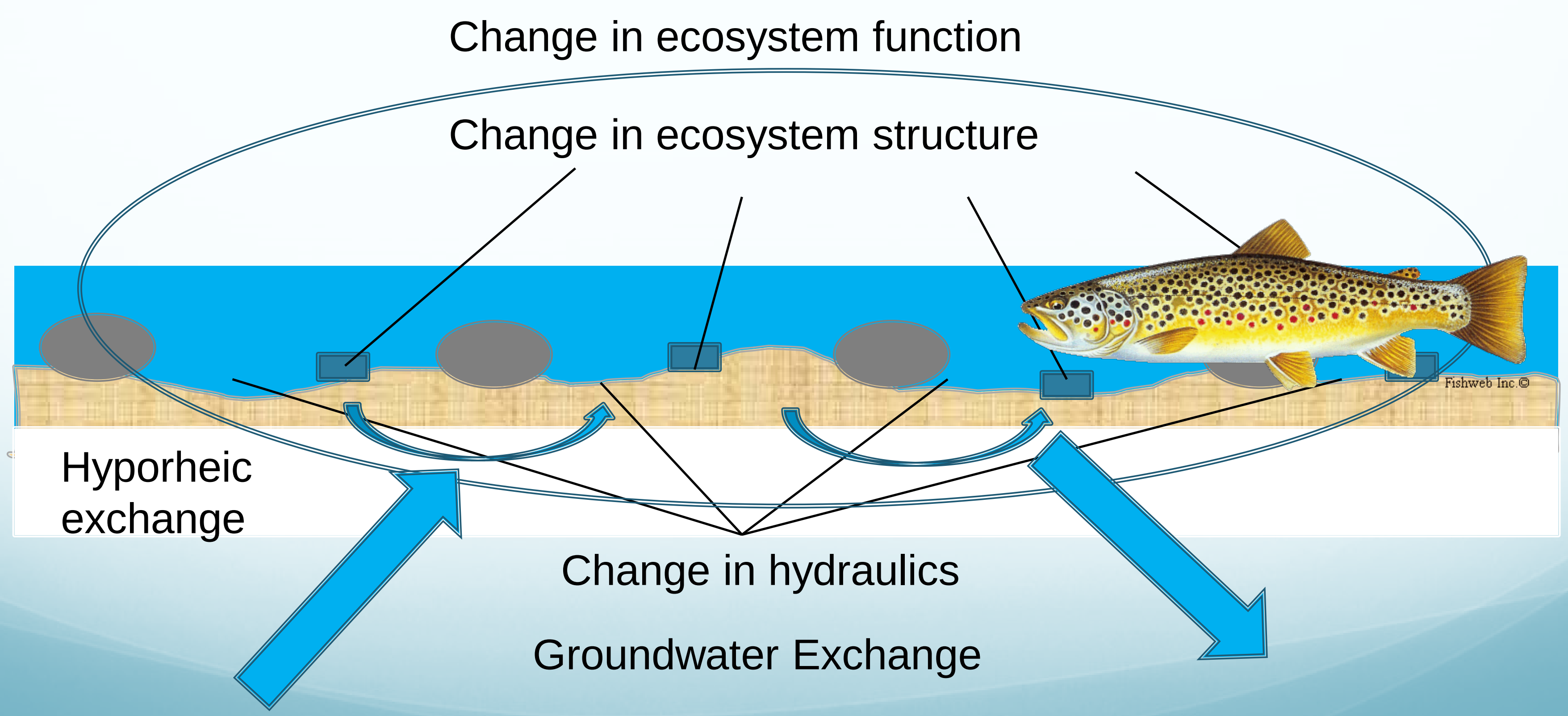


Proposed Hypothesis

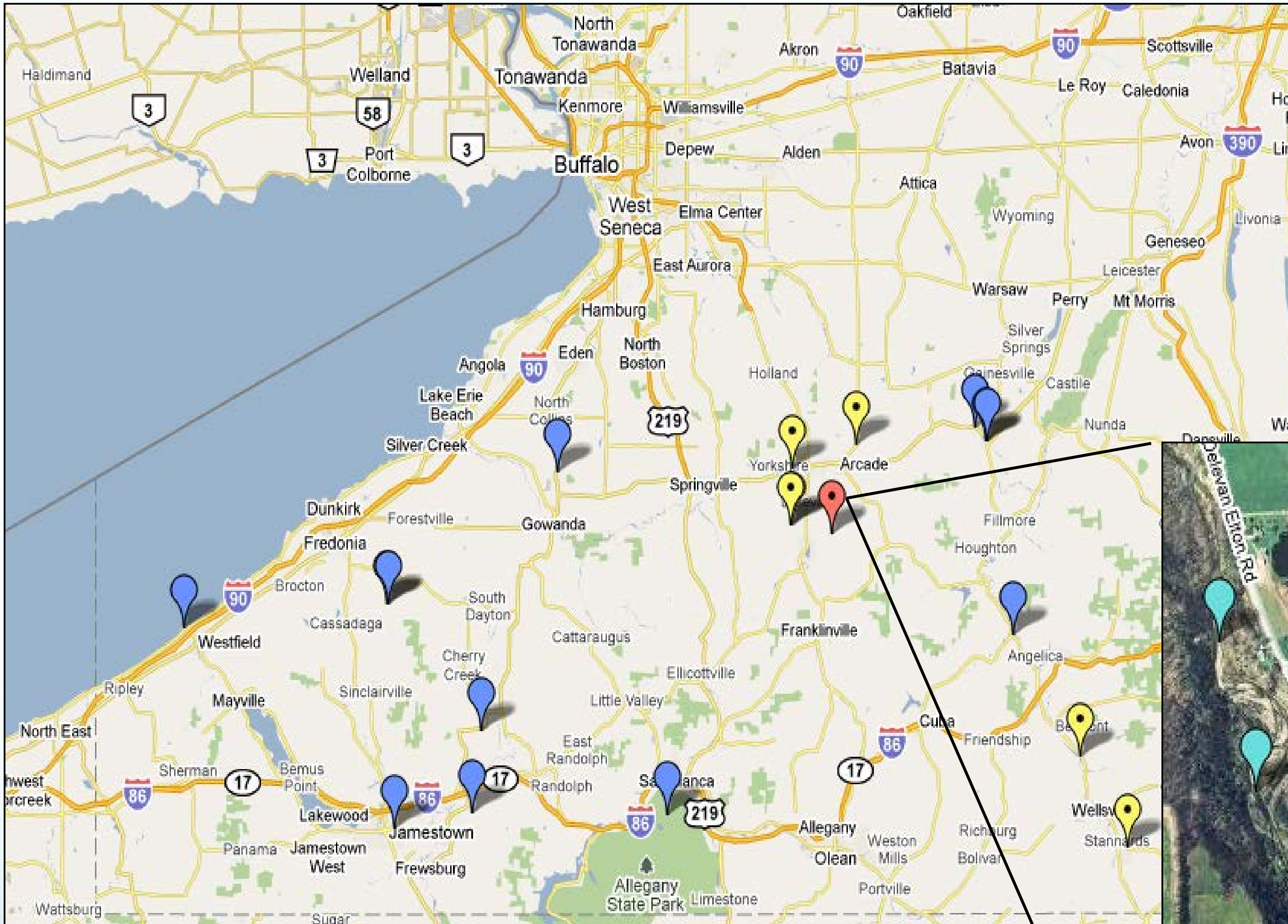
- *Modifications in the hydraulic signature of a stream will result in shifts of ecological structure and function* (supported by: Statzner and Higler 1986; ASCE 1992; Ernst et al. 2010; Baldigo et al. 2010).

- The goal is to determine whether the current dominant paradigm in stream restoration of installing a series of in-stream structures to increase habitat heterogeneity at the pool-riffle scale will indeed result in a correction to impacted ecological function and structure of the stream.

What’s expected.



Methods



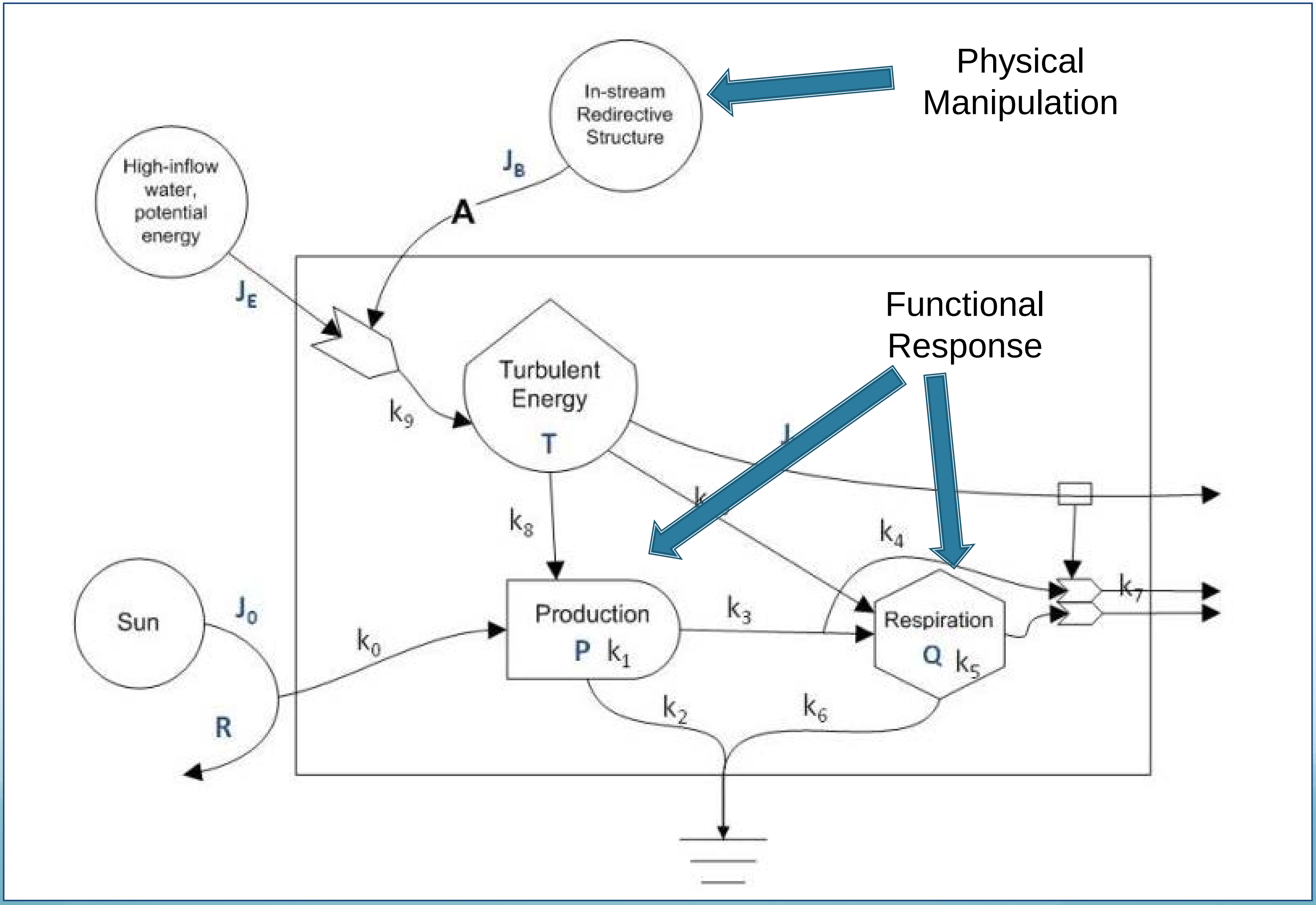
Field Site: Elton Creek (Delevan, NY)

LaFarge Natural Aggregates, Inc.

Problems

- Lack of riparian buffers
  - Hemlock forests
  - Willows
- Channelization
- Agricultural run-off
  - High productivity
- Instability
  - Flashy hydrograph
  - Massive bank erosion
  - Lateral migration
  - Head cuts (multiple)

Guiding conceptual model for stream restoration activities in a generic reach



Equation	Description	Variables	Source
$R = J_0 - k_0PRT \rightarrow \quad R = \frac{J_0}{1 + k_0PT}$	R is the remainder solar energy unused by primary producers; controlled by the rate of uptake (k0).	Jo =solar energy on stream surface	Hobo-tidbits (2012) Weather station at Machias another possible source Densi0meter measurements Elton (2010)
		Q=respiration or energy lost through plant respiration	DO measurements (dark metabolic chambers lab work 2011 and Sonde data at night 2011/2012)
$\frac{dP}{dt} = k_1PRT - k_4P - k_3QT - k_4J_TP$	The change in stream productivity.	P=Primary production, or rate at which solar energy is converted to chemical energy in units of mass area^{-1} time^{-1}	DO measurements (light metabolic chambers lab work 2011 and Sonde data during the day 2011/2012) Biomass of field samples (2011)
$\frac{dQ}{dt} = k_5QTP - k_6Q - k_8J_TQ$	The change in respiration, or consumers energy consumption within the system	T=turbulent energy affecting production and respiration rates J_T = outflow of turbulent energy exported down stream	Discharge measurements (2011/2012) Detailed stream survey (2011) Flowtracker measurements, ave-depthed velocity (2010/2011) Pebble counts reach 1 (2010) Geomorphic survey of reach 1(2012) x-section surveys (2010/2011/2012)
$\frac{dT}{dt} = k_9J_EJ_B - J_T - k_8PRT - k_{10}QPT$	The change in turbulent energy within the specified control volume	J_B = bedform affects on turbulent energy J_E =Potential energy of the stream reach	

Research Approach

- Measure stream ecosystem metabolism in restored and unrestored reaches of an impaired stream
- Measure at two scales
  - Stream reach scale (upstream-downstream oxygen diurnal method)
  - Stream benthos scale (sample substrate and light-dark chamber method)
- Model hydraulic characteristics of geomorphically distinct reaches
- Develop metric linking flow and stream metabolism

Hydraulic Signature: Pool-Riffle Scale

- Kinetic Energy: quantified the rate at which flow's of kinetic energy changed in the x-direction (downstream) between two points

$$\left|\frac{\frac{\partial}{\partial x}\frac{V^2}{2}}{\frac{V^2}{2}}\right| \cong \left|\frac{2V_{\mathrm{AVE}}\frac{V_2-V_1}{\Delta x}}{V_1^2}\right|$$

- Vorticity: equal to the twice the rate of the rotational velocity gradient difference (assuming 2-D flow)

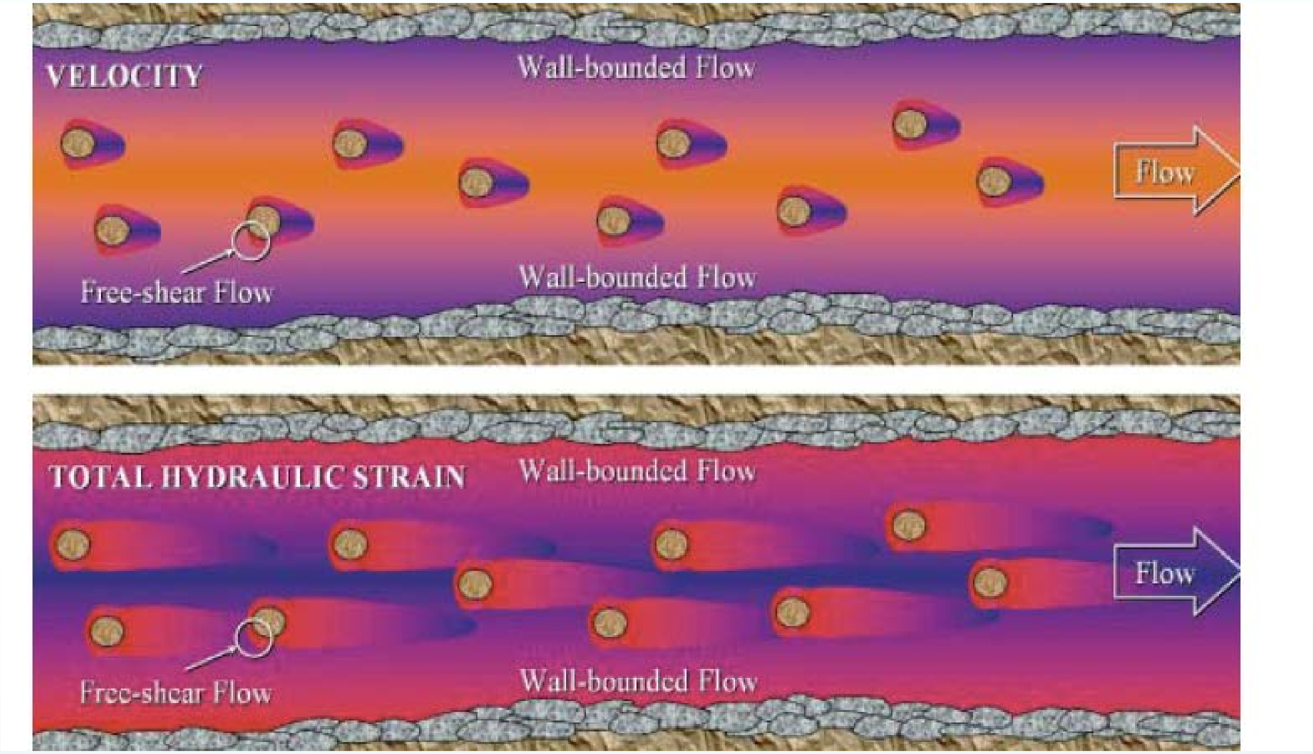
$$\xi = \left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right)\mathbf{k}$$

- Circulation of the vortex structures (based on Munson et al., 2002)

$$\Gamma = \int\int_{A_{tot}} \xi dA$$

Source: Crowder and Diplas, 2006

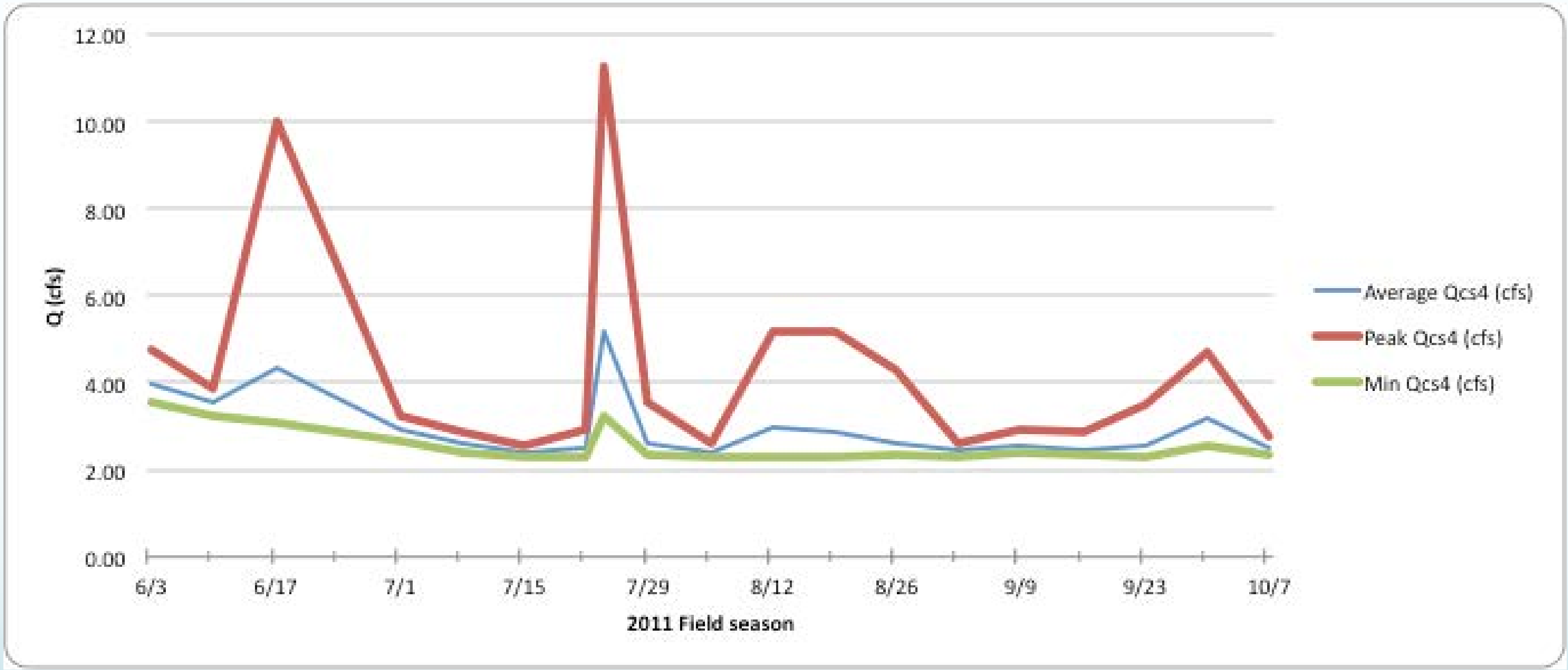
Hydraulic Signature: Reach Scale



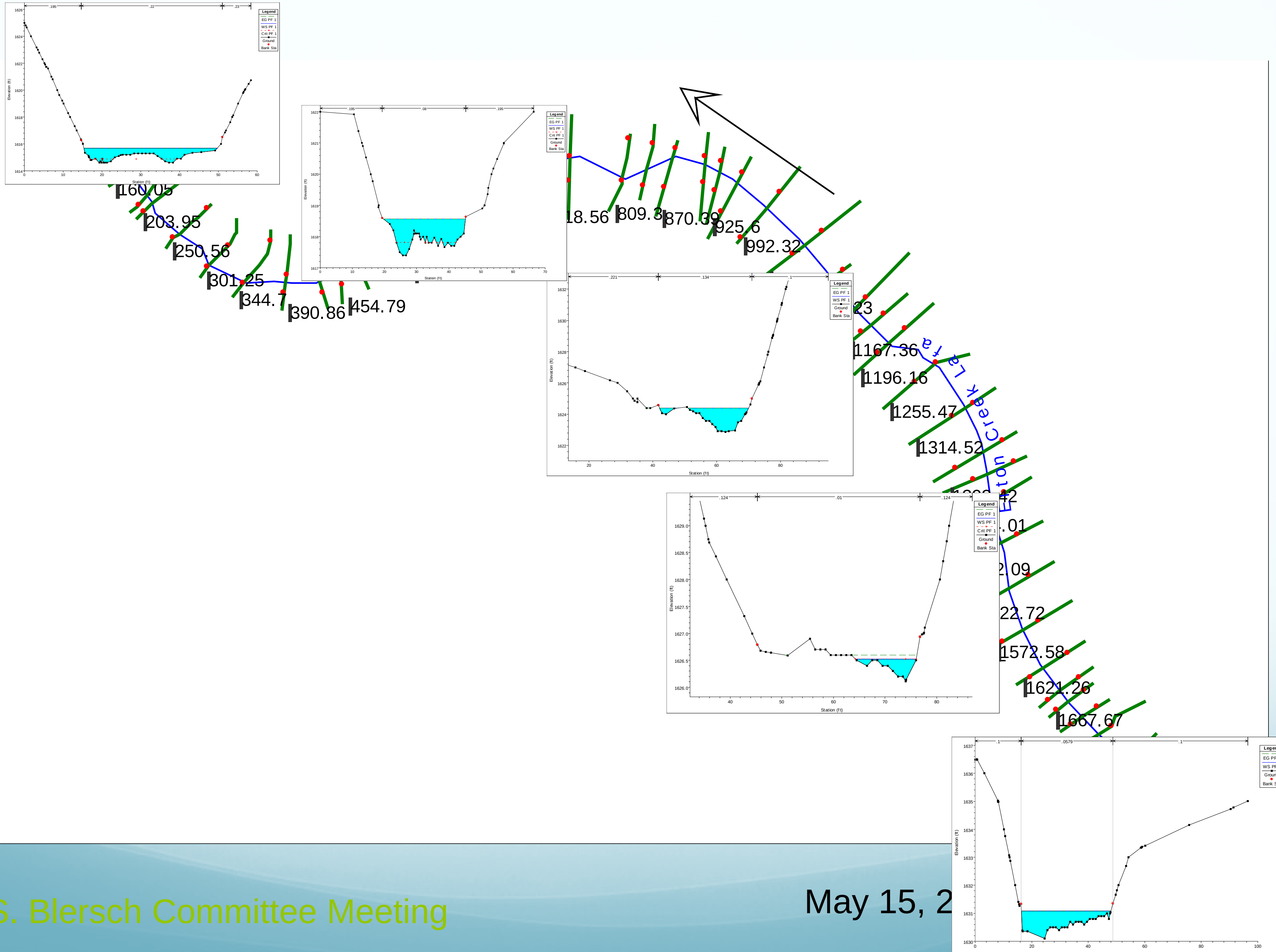
$$S_1 = \sum \left|\frac{\partial u_i}{\partial x_j}\right| = \left|\frac{\partial u}{\partial x}\right| + \left|\frac{\partial u}{\partial y}\right| + \left|\frac{\partial u}{\partial z}\right| + \left|\frac{\partial v}{\partial x}\right| + \left|\frac{\partial v}{\partial y}\right| + \left|\frac{\partial v}{\partial z}\right| + \left|\frac{\partial w}{\partial x}\right| + \left|\frac{\partial w}{\partial y}\right| + \left|\frac{\partial w}{\partial z}\right|$$

Source: Nester et al., 2005

Elton Creek Field Site



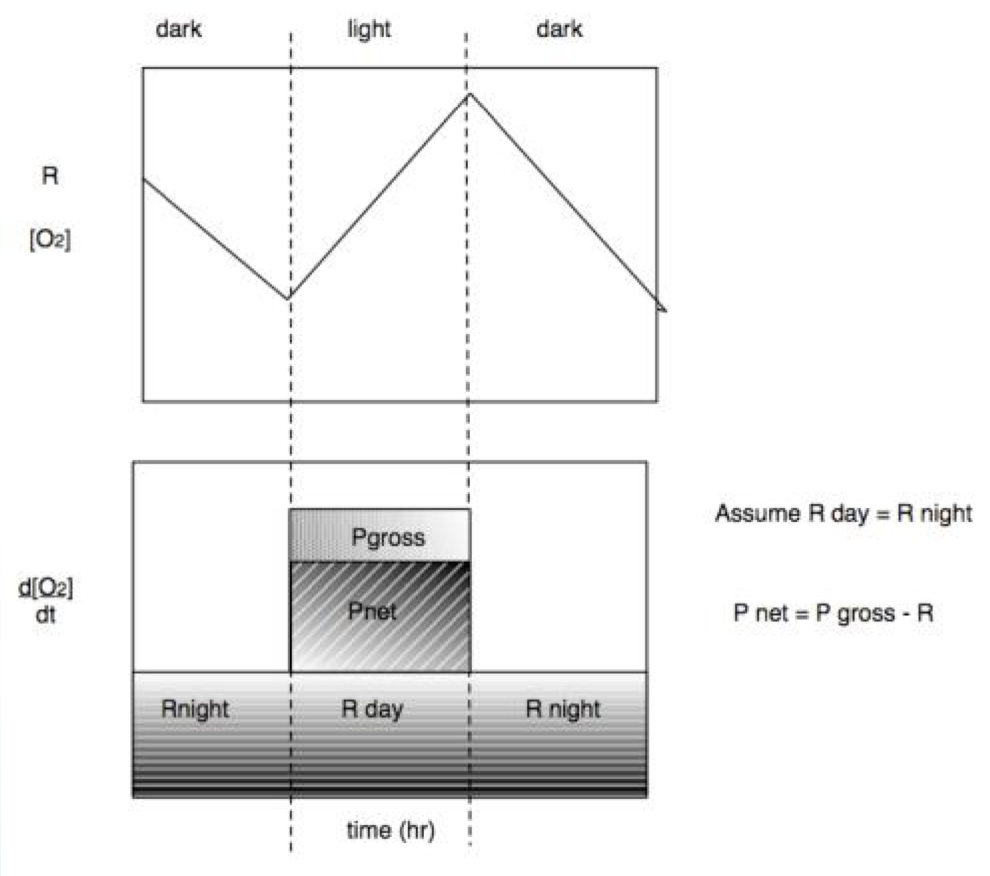
$$\mathrm{Fr} = \frac{U}{\sqrt{gd}}.$$



160.05
203.95
250.56
301.25
344.7
390.86
454.79
18.56
809.3
870.39
925.6
992.32
23
1167.36
1196.16
1255.47
1314.52
.01
2.09
22.72
1572.58
1621.26
1667.67
Creek
Legend
EG PF 1
WS PF 1
Crit PF 1
Ground
Bank Sta
Elevation (ft)
Station (ft)

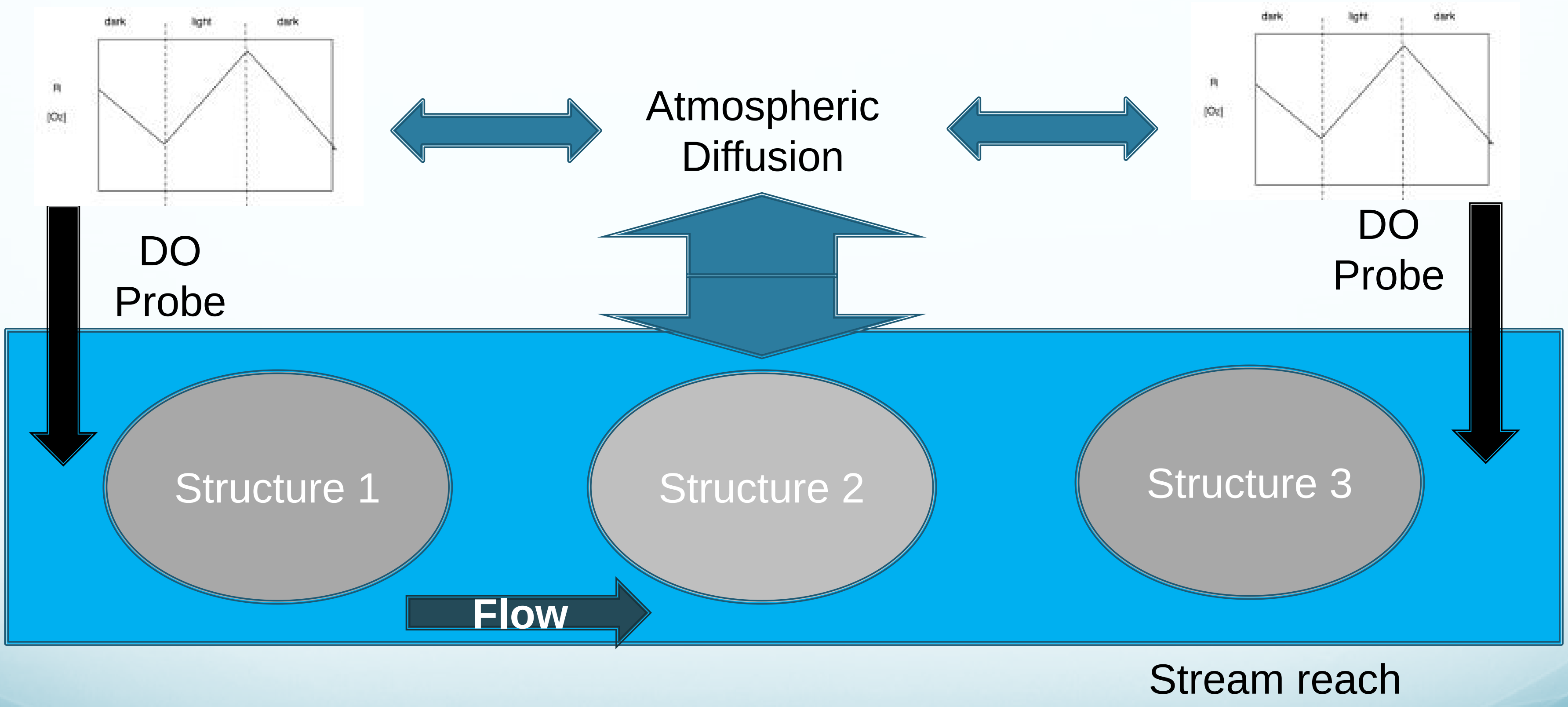
Background: Stream Metabolism

- Oxygen diurnal:
  - primary production (day) and community respiration (night)

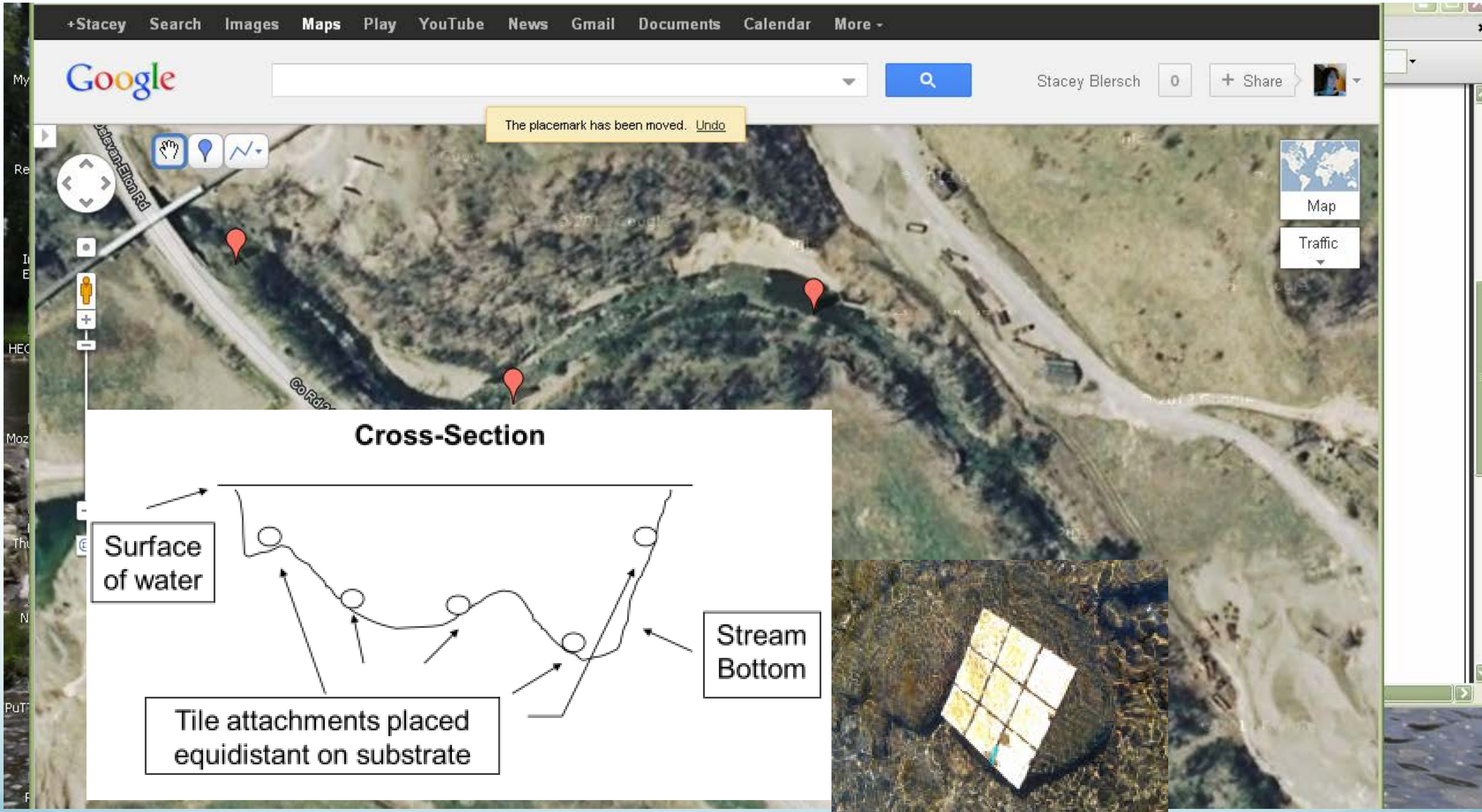


$6CO_2 + 12H_2O \rightarrow 6O_2 + C_6H_{12}O_6 + 6H_20$

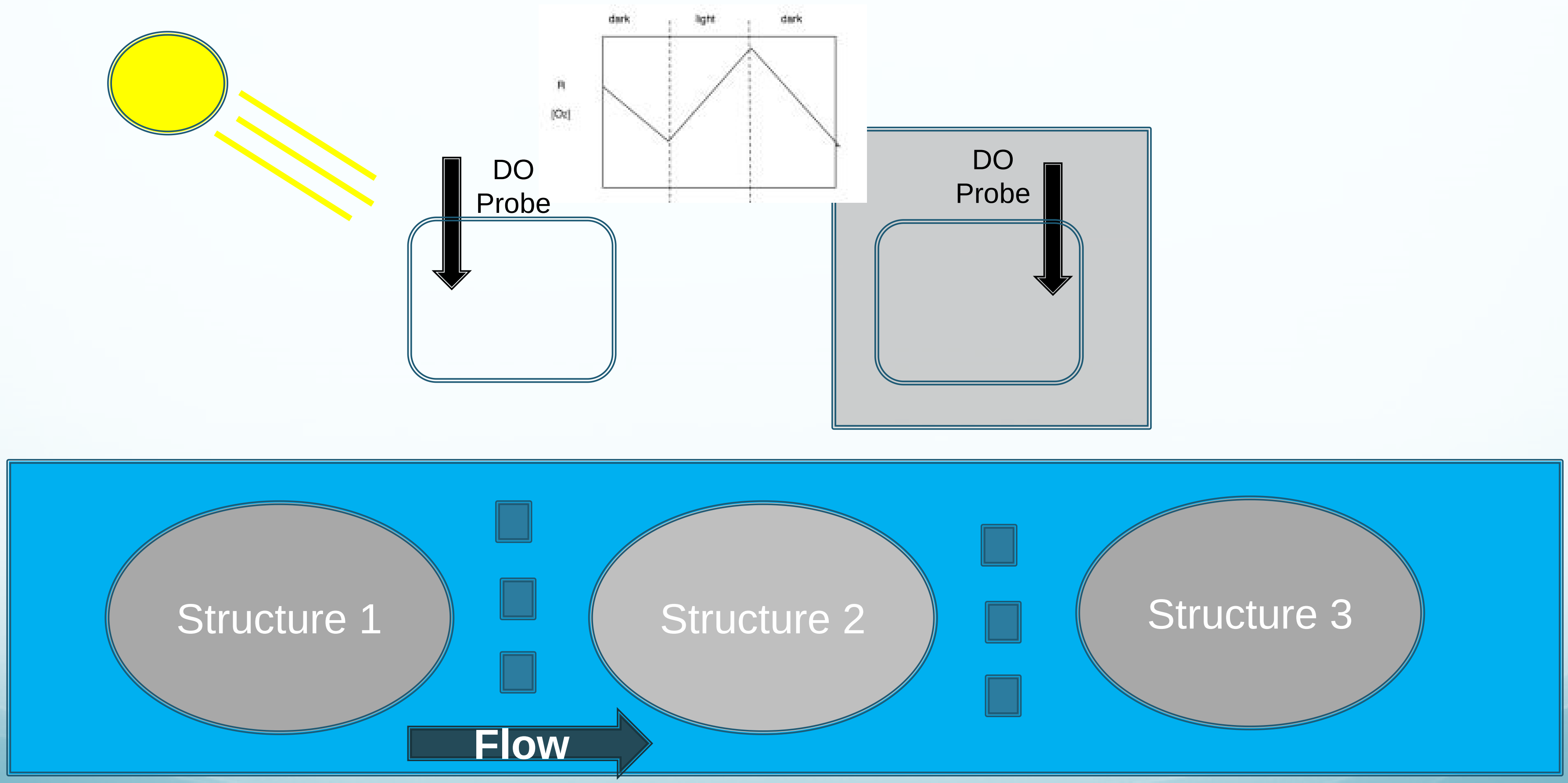
Stream ecosystem metabolism: Upstream-Downstream method



Stream Metabolism: Benthic substratum

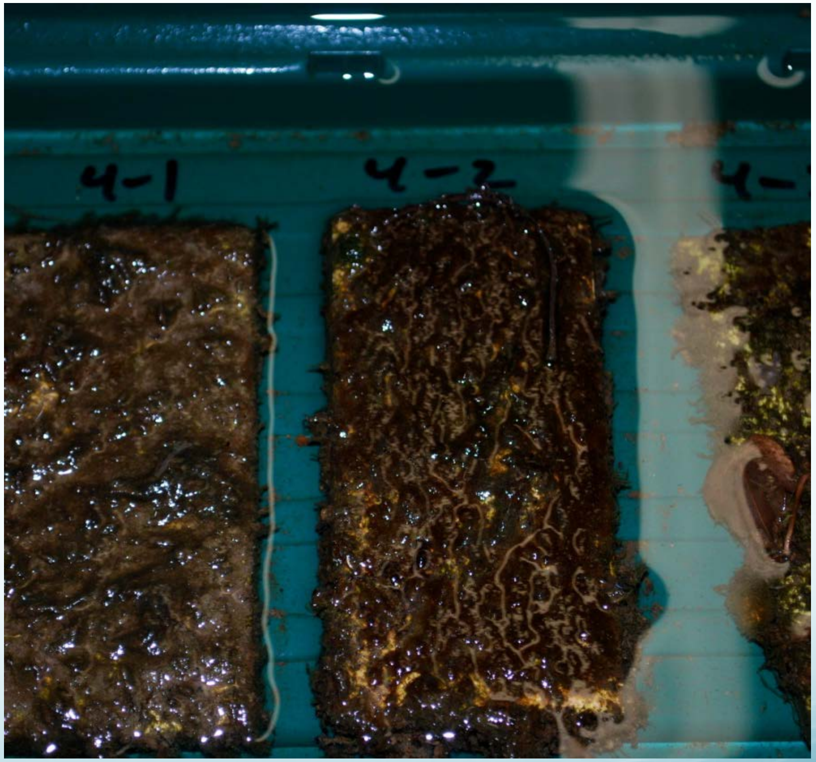


Stream ecosystem metabolism: Substrate-Chamber method



Stream reach

Field samples (16 weeks)



Experimental Setup

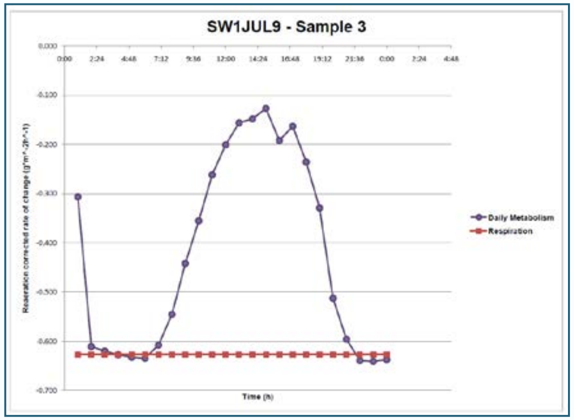

Light chamber

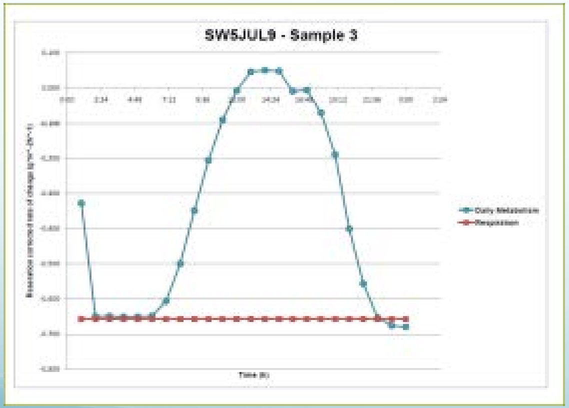

Dark chamber

Data acquisition

Results

Stream metabolism (reach scale)





Null Hypothesis H0: μ1 = μ2						
Alternative Hypothesis Ha: μ1 ≠ μ2						
Sonde Data	SW1	SW5	α	T-Test Result	α	T-Test Result
GPP	4.35	6.66	0.05	Reject	0.01	Reject
CR24	-14.45	-15.4	0.05	Accept	0.01	Accept
P/R	0.3	0.43	0.05	Reject	0.01	Reject

- GPP and P/R different for two reaches
- Net heterotrophic (P/R<1)

Macroinvertebrates

r

Figure 1: Map of Elton creek reaches and riffle location

Order	Riffle 1	Riffle 2
Crustacea	0.00	0.00
Odonata	0.00	0.00
Coleoptera	4.67	10.00
Diptera	114.67	81.33
Lepidoptera	1.00	2.33
Oligochaeta	0.00	0.00
Plecoptera	2.67	3.33
Ephemeroptera	17.67	11.67
Megaloptera	0.00	0.00
Hemiptera	0.00	0.00
Trichoptera	70.67	101.33

Table 2: Average number of macroinvertebrates found within riffle

Riffle	Family Biotic Index	Water Quality
Reach 1	4.40	Good
Reach 2	4.00	Very Good

Table 3: Family Biotic Index (FBI) based on average number or macroinvertebrates found in each riffle


P/R - Cross Section 5
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
5-1
5-2
5-3
5-4
Location within Cross Section
P/R (calc)
P/R - Cross Section 3
2
1.5
1
0.5
0
-0.5
3-1
3-3
3-4
3-5
Location within Cross Section
P/R (calc)
P/R - Cross Section 4
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
4-1
4-2
4-3
4-4
4-5
Location within Cross Section
P/R*(calc)
P/R - Cross Section 2
6
4
2
0
-2
2-1
2-2
2-3
2-4
2-5
Location within Cross Section
P/R (calc)
Flow
P/R - Cross Section 1
7
6
5
4
3
2
1
0
1-1
1-2
1-3
1-4
Location within Cross Section
P/R (calc)

Conclusions

- Differences in stream metabolism at the reach level are observed for different geomorphological conditions
- Chamber method could be used as a “bioassay” of a stream pre and post restoration to accurately shows shifts in ecological function and not just structure
- Flow fields are diverse for restored and unrestored reaches of Elton Creek and a hydraulic signature could be used to define a restored reach
- Froude number may not be sensitive enough to detect differences in stream metabolism at the stream segment level using two point method; however, chamber method does correlate with Froude number.

Questions?

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Tensaw River Delta, 9/6/15