

### Using Natural Flow Classes to Estimate Hydrologic Alteration by Dams across Canada, *a HydroNet Study*



## Research Aims

Examine how natural flow regimes differ across HydroNet study regions.

Identify how flow regimes of regulated HydroNet rivers compare to unregulated flow class norms.

At select sites, determine the timing and duration of river bed mobility events using field data.



Bull River Dam B.C. (Summer 2011)

## **Background & Constraints**

Dams do not always homogenize flows (McManamay et al. 2012):

• The altered regime is dependent on dam operation, dam type, & historical flow conditions.

Historically, hydrologic alteration has been quantified by comparing pre and post-dam flow data.

- But little pre-dam data exists for the HydroNet rivers
- Alternatives?

## **Regional Flow Classes**

Instead of pre-dam discharge data we use **Regional Flow Classes** to approximate past flow conditions:

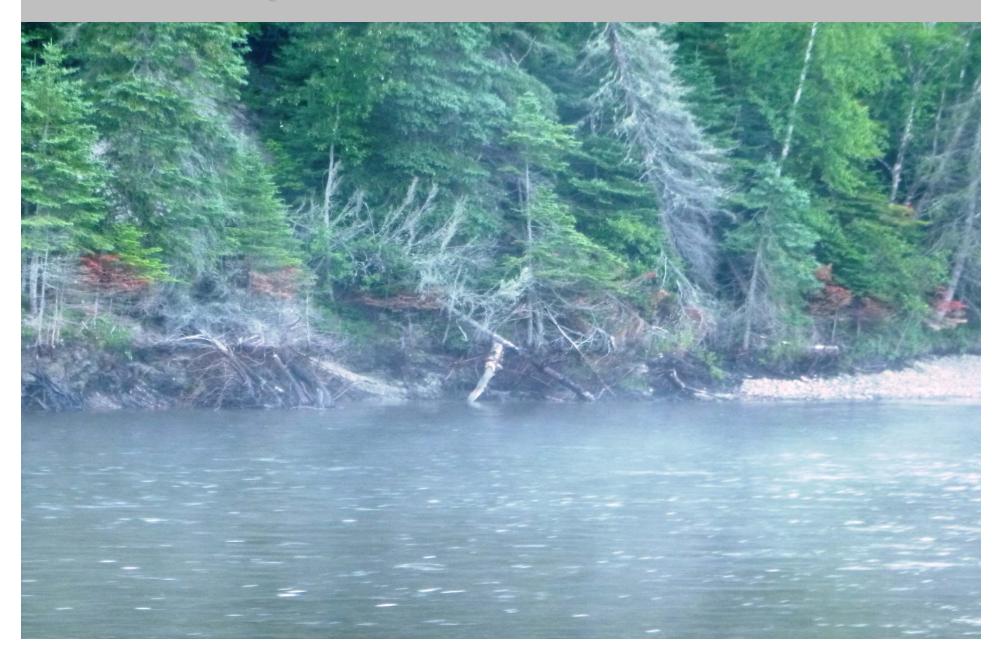
- Defined as groups of streams that share similar natural hydrology. They
  provide a stratified approach to evaluate hydrologic alterations (departures
  from natural baseline conditions) (McManamay et al. 2012)
- Classes membership will differ based on the scale of analysis (e.g. local vs. across Canada).

What is the natural **Range of Variability** within these classes? Do the regulated systems fall within this range?

## Data and Indices used in the Analysis

- About 15 years of concurrent mean daily flow data for 98 unregulated rivers across the country, of similar size and in proximity to regulated HydroNet rivers.
- Using discharge data (from HYDAT or CEHQ), flow Indices have been calculated that characterize the five ecologically important components of the hydrograph.
  - USGS Hyrologic Index Toolkit (HIT), Indicators of Hydrologic Alteration (IHA) and others (Olden and Poff, 2003; Richter et al. 1997).
- All magnitude metrics were divided by the median flow so that rivers with different watershed areas are comparable.
- Correlation matrix used to discard highly correlated Indices (163 → 70 Indices)
- Flow classes of rivers sharing similar hydrology were identified with K-Means clustering using remaining 70 flow Indices.
  - Minimize within group sum of squared differences

# Methods/Results



# K-Means Clustering & PCA Results

#### National Unregulated Analysis:

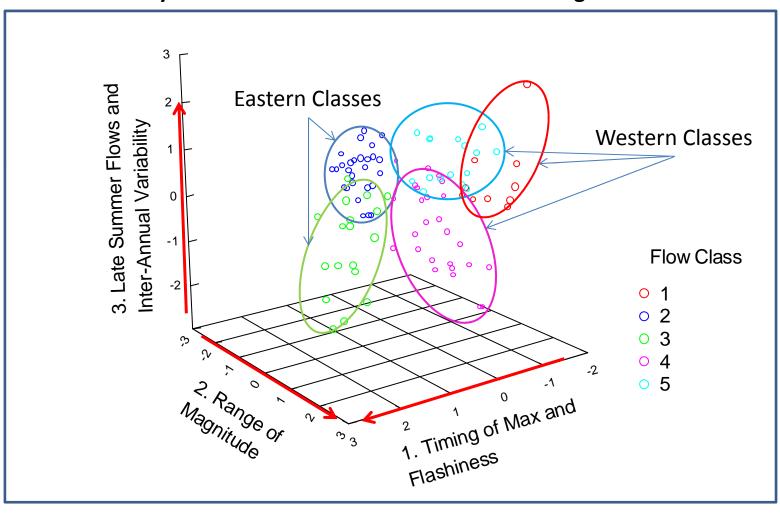
Identification and characterization of 5 Unregulated flow classes across the country in proximity to the regulated HydroNet systems.

Flow Class 2 Analysis: North Shore Eastern Rivers Insight into how regulated systems differ from class norms



#### 5 Unregulated Flow Classes in Multivariate Space

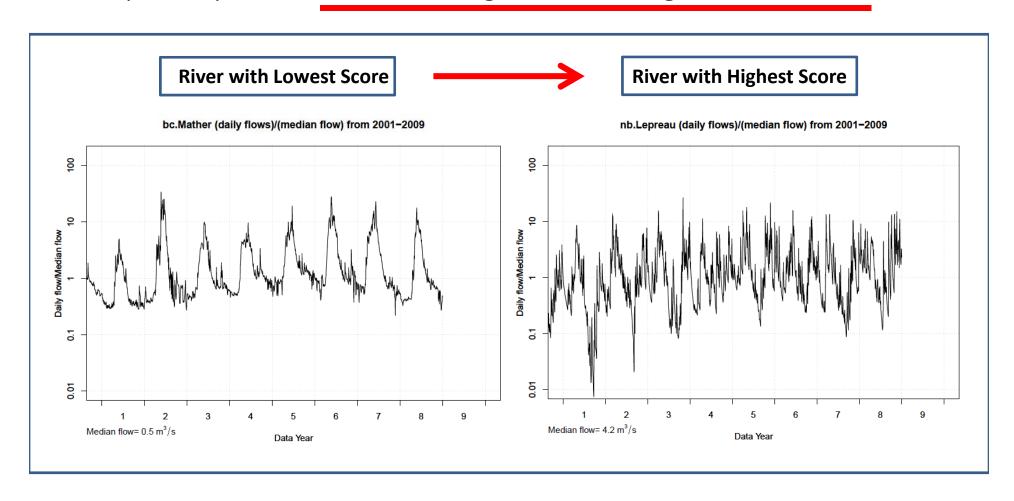
#### PCA Analysis of 70 Indices across 98 Canadian Unregulated Rivers



3 axes explain about 50% of total variance

# National Unregulated Analysis: PC1

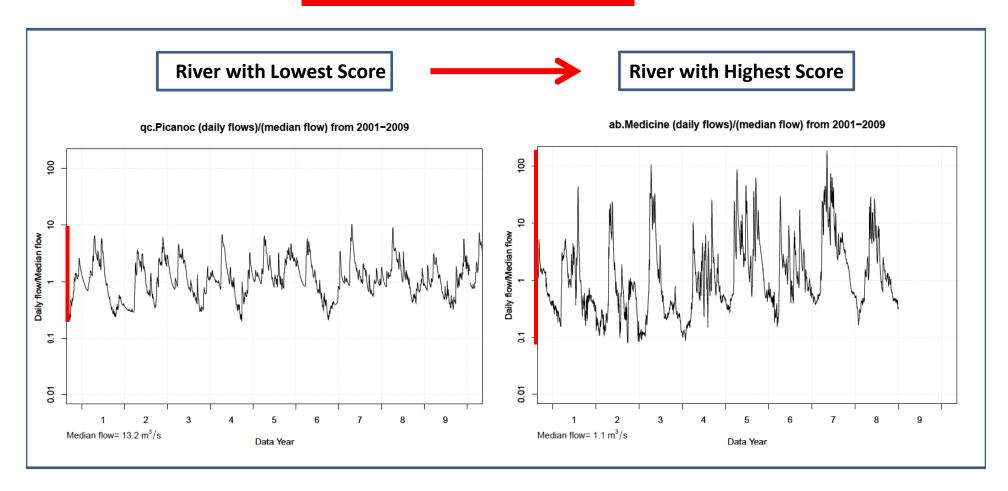
Principal Component 1: Index of Timing of Max and Degree of Flashiness



High score indicates that annual flood is early in the year, and that the system is quite flashy.

# National Unregulated Analysis: PC2

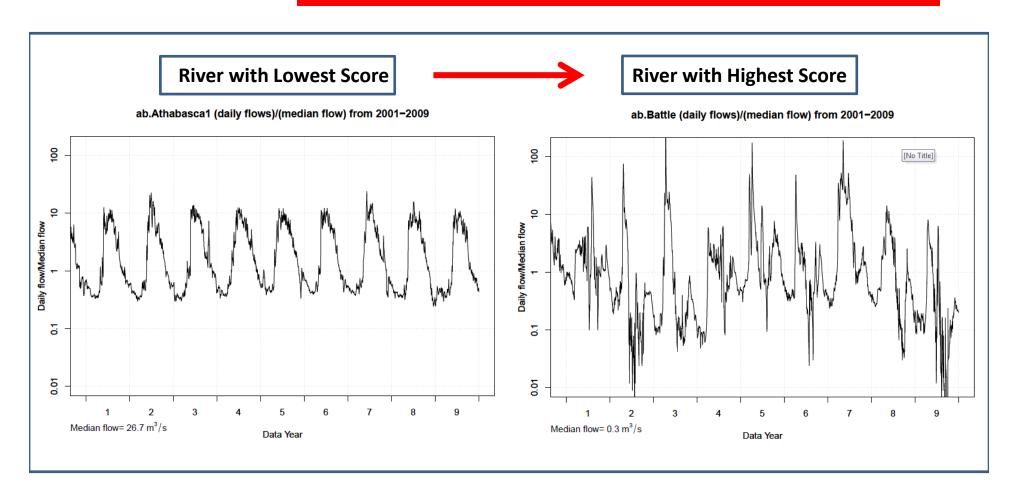
Principal Component 2: Index of Range of Magnitude



High score indicates a large range of flow magnitude: low baseflows & severe floods.

# National Unregulated Analysis: PC3

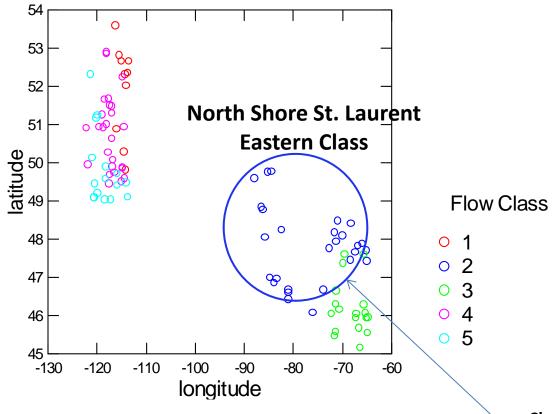
Principal Component 3: Index of Late Summer Flows and Inter-Annual Variability



High score indicates few/no high flows in September, and high inter-annual variability

### **Historic Class Membership of Regulated Sites**

#### **Distribution of Unregulated Flow Classes Across Canada**



- Based on quite clear-cut geographic class boundaries, most rivers can be assigned to classes based on location.
- In B.C. & Alberta, class overlap is largely explained differences in relief.

Class 2 includes all unregulated sites in On, on North Shore Qc, and flowing towards Gaspe in N.B.

## **Results Continued**

#### National Unregulated Analysis:

Identification and characterization of 5 Unregulated flow classes across the country in proximity to the regulated HydroNet systems.

Flow Class 2 Analysis (North Shore Eastern Rivers): Insight into how regulated systems differ from class norms

A New PCA of Class 2 regulated and unregulated rivers (for 70 flow indices).



## Flow Class 2 Analysis: PC1

Principal Component 1: Index of Range of Magnitude

Named based on an analysis of the top loading flow indices: top 3 shown here.

Index	Interpretation of a High Factor Score	PC 1 Loading
Days with flow above	Many days per year with flow	0.05
3x median	above 3x median	0.95
90 day max. moving		
average	High 90 day max moving average.	0.92
	A large range in magnitude	
Range of daily flows	(10 <sup>th</sup> % / 90 <sup>th</sup> %)	-0.87

**Explains 25% of total variance** 

High score indicates a large range of flow magnitude.

# Flow Class 2 Analysis: PC2

Principal Component 2:

**Index of Winter Flows and Flashiness** 

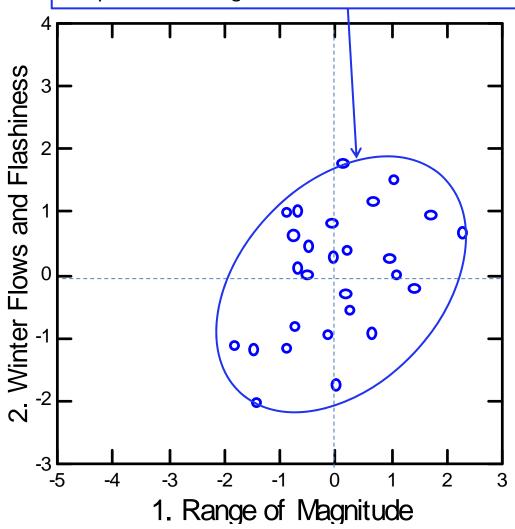
Index	Interpretation of a High Factor Score	PC 2 Loading
Relative rise rate	Fast flow rise rate	0.89
Mean minimum Jan. flow	Low minimum January flow	-0.83
Variability in low pulse duration	Low variability in low pulse duration	-0.70

**Explains 15% of total variance** 

High score indicates increased flashiness and low winter flows.

## **Unregulated Class 2 Norms in PCA Space**

**Natural range of variability** seems to be 2 standard deviations away from the unregulated class mean for the first two PCs

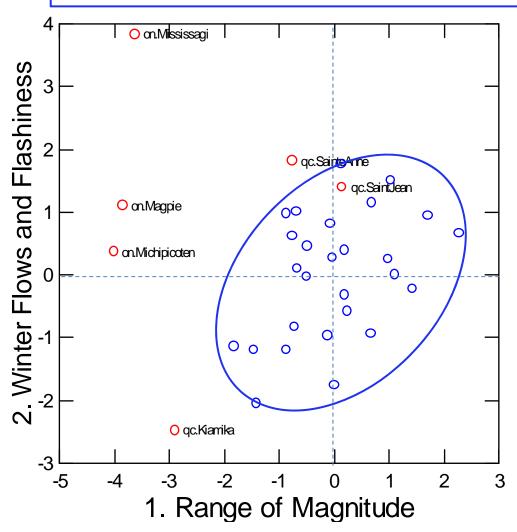


Where do the Class 2 Regulated Rivers plot in this multivariate space?

Unregulated

### Regulated Divergence from Class 2 Norms

**Natural range of variability** seems to be 2 standard deviations away from the unregulated class mean for the first two PCs



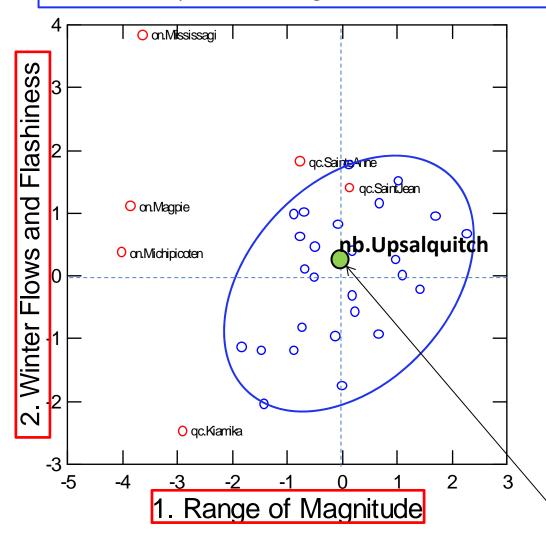
Where do the Class 2 Regulated Rivers plot in this multivariate space?

Type

- Regulated
- Unregulated

### Regulated Divergence from Class 2 Norms

**Natural range of variability** seems to be no more than 2 standard deviations away from the unregulated class mean for the first two PCs.



The maximum unregulated range of variability along these two axes is +/- 2 standard deviations from the class centroid. Regulated rivers scored:

Regulated Site	PC1 zScore	PC2 zScore
on.Magpie	-3.9	1.1
on.Michipicoten	-4.0	0.4
on.Mississagi	-3.6	3.8
qc.Kiamika	-2.9	-2.5
qc.SainteAnne	-0.8	1.8
qc.SaintJean	0.1	1.4

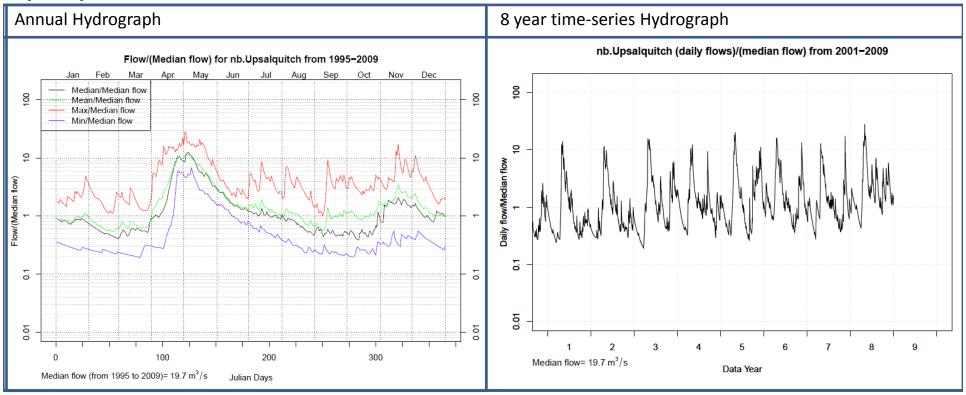
- Regulated
- Unregulated

**Central Class 2 Hydrograph** 

# Central Class 2 Hydrograph

Plotting the Class 2 rivers in multivariate space also allows for identification of the unregulated river closest to the Class Centroid.

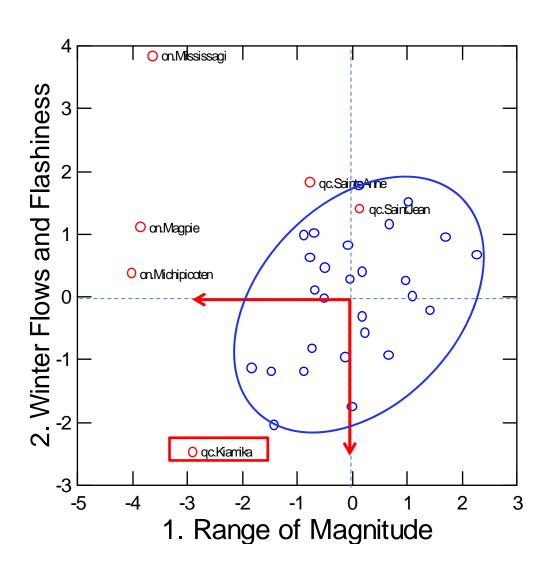
#### **Upsalquitch River, New Brunswick**



**Spring flood in late April/early May** 

Note the range of magnitude and flashiness

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- Regulated
- Unregulated

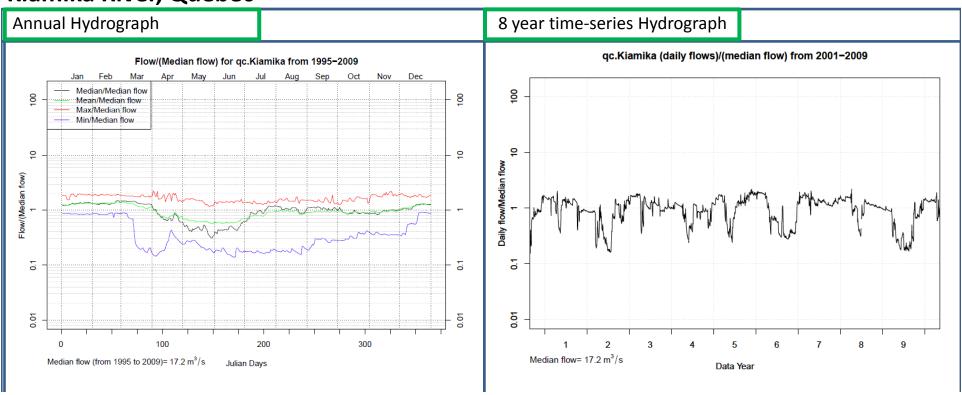
## Index Divergence: Kiamika River, Qc

#### 3 of the most divergent indices (of potential ecological interest)

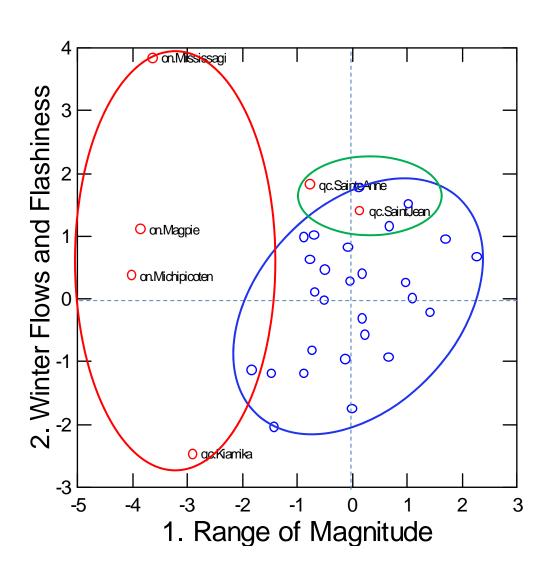
	Index	PC1 Loading	PC2 Loading	Standard Deviations from Class Mean
Low	Variability in Daily Flows	0.86	0.24	- 4.2
High	Mean Minimum Jan. Flow	- 0.11	- 0.83	4.0
Early	Date of Maximum Flow	0.29	0.35	-5.5

#### Implications?

#### Kiamika River, Quebec



## Regulated Divergence from Class 2 Norms



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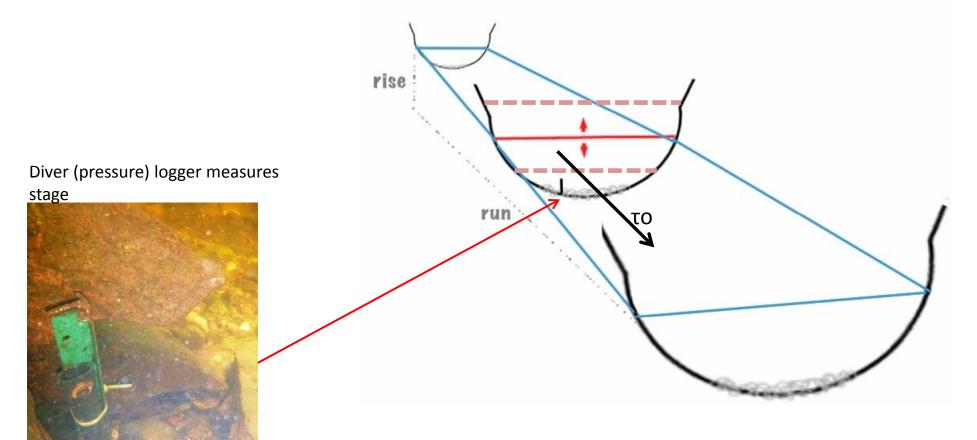
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- Regulated
- Unregulated



## **Time Series of Thalweg Shear Stress**

# $\tau o = \gamma RS \cong \gamma dS$



Installed Summer 2011-Summer 2012 in these systems. Stage data used to calculate Hydraulic Radius (R) or mean depth (d)

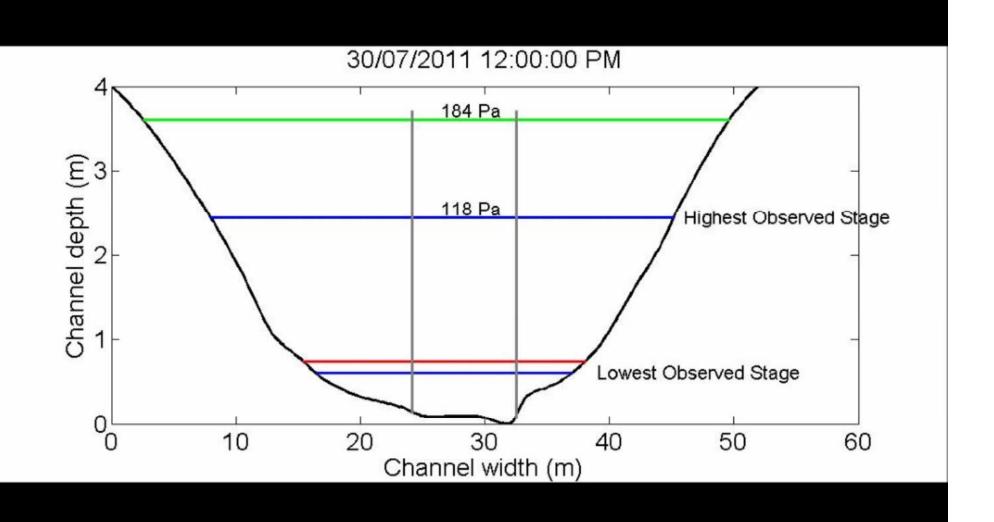
# Calculating Critical Shear Stress (Pa) in the Thalweg

If we know the distribution of Thalweg grain sizes, we can predict the shear stress required for mobilization.

The following cross section is located on the Mississagi river





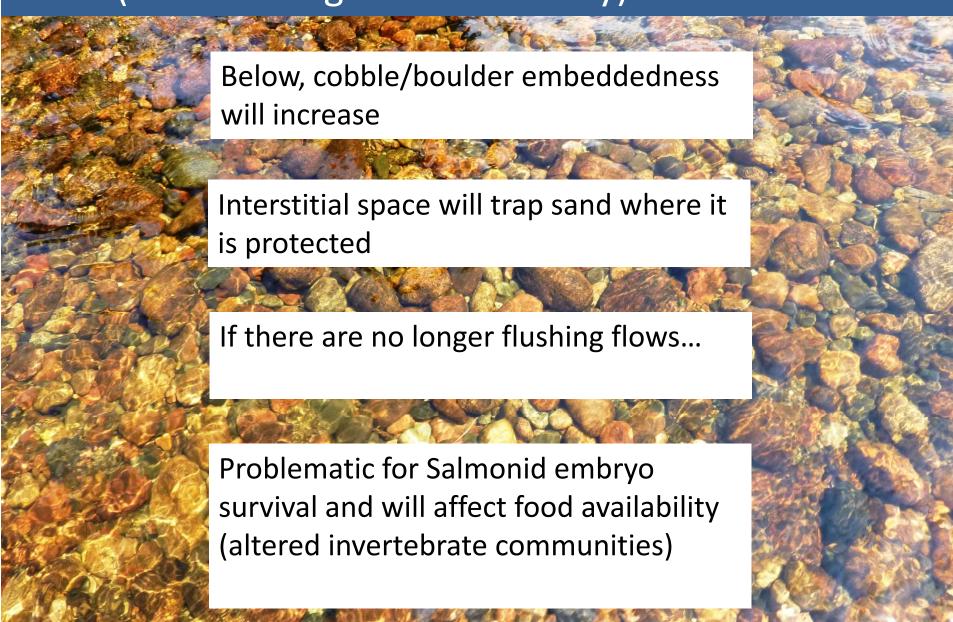


## **No Observed D50 Mobility**

(Summer 2011- Summer 2012)

Cross Section	Max Recorded Shear Stress/Critical Shear Stress (%)
Magpie 1	11 %
Magpie 2	40 %
Michipicoten 1	74 %
Mississagi 1 Result from video	64 % on previous slide
Mississagi 2	12 %





## Conclusion

- For each regulated river, we can present a small set of the ecologically relevant indices (selected from a set of almost 200) that are most divergent from the natural variability within a flow class.
- Visualization in multivariate space is useful to identify either cases of similar alteration (location in PCA Euclidian space) or extreme cases of alteration (flag as priorities for managers).
- Characterizing flow alteration provides important context to the ecological and geomorphological phenomena observed by other HydroNet researchers.

#### Thank you to all of the HydroNet collaborators!







## Sources

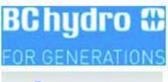
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- Richter, B. D., Baumgartner, J., Wigington, R., & Braun, D. P. (1997). How much water does a river need? *Freshwater Biology*, *37*, 231-249.





















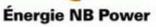
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