

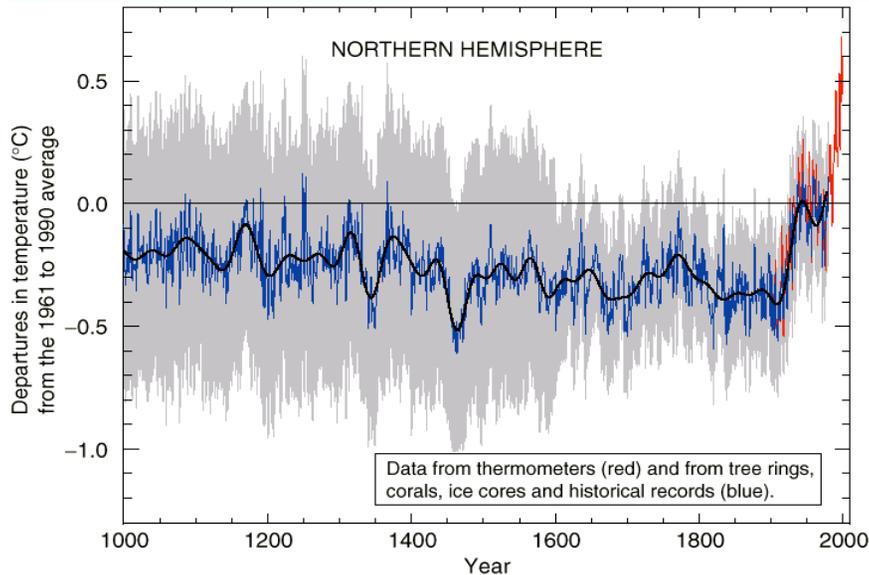
Managing for climate change in the Superior North Shore Tributaries: Can we maintain the flow?

Lucinda Johnson¹, William Herb²,
Ralph Garono¹, Meijun Cai¹, Kristen
Blann³, and John Jereczek⁴

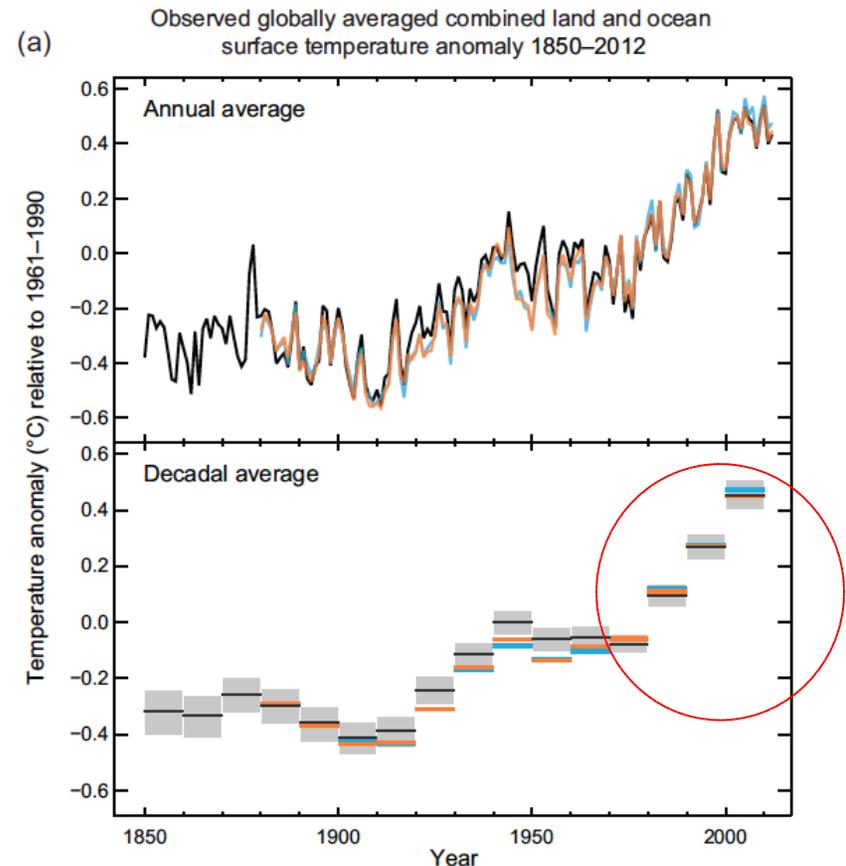
1. University of Minnesota, Duluth, Natural Resources Research Institute
2. University of Minnesota, St. Anthony Falls Lab
3. The Nature Conservancy
4. Minnesota Department of Natural Resources

The Impact of GHGs on Climate Increase in Global Air Temperature

Average global temperatures have increased by 0.85°C ($0.65\text{--}1.06^{\circ}\text{C}$ range). IPCC 2013



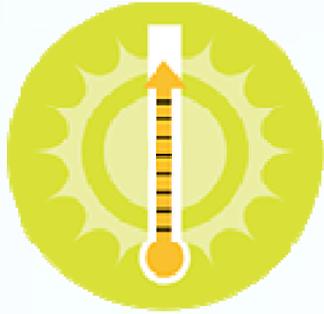
- In the Northern hemisphere, 1983-2012 was likely the warmest 30 year period of the last 1400 years. *IPCC 2013.*
- Globally, 2014 was the warmest year on record, based on 4 different data sets. NOAAnews, noaa.gov.
- 2015 global temperatures exceeded 2014; 6th warmest for Minnesota.



Recent Significant Climate Trends for Minnesota

- **Warmer winters; higher minimum temperatures**
- **Earlier spring**
- **Shorter duration of ice cover**
- **Greater frequency of tropical dew points**
- **Greater annual precipitation**
 - More days with rain
 - More frequent heavy rains
 - Trend of increasing winter snowfall





Minnesota and Climate Change

Seven of Minnesota's 10 warmest years occurred in the last 15 years.

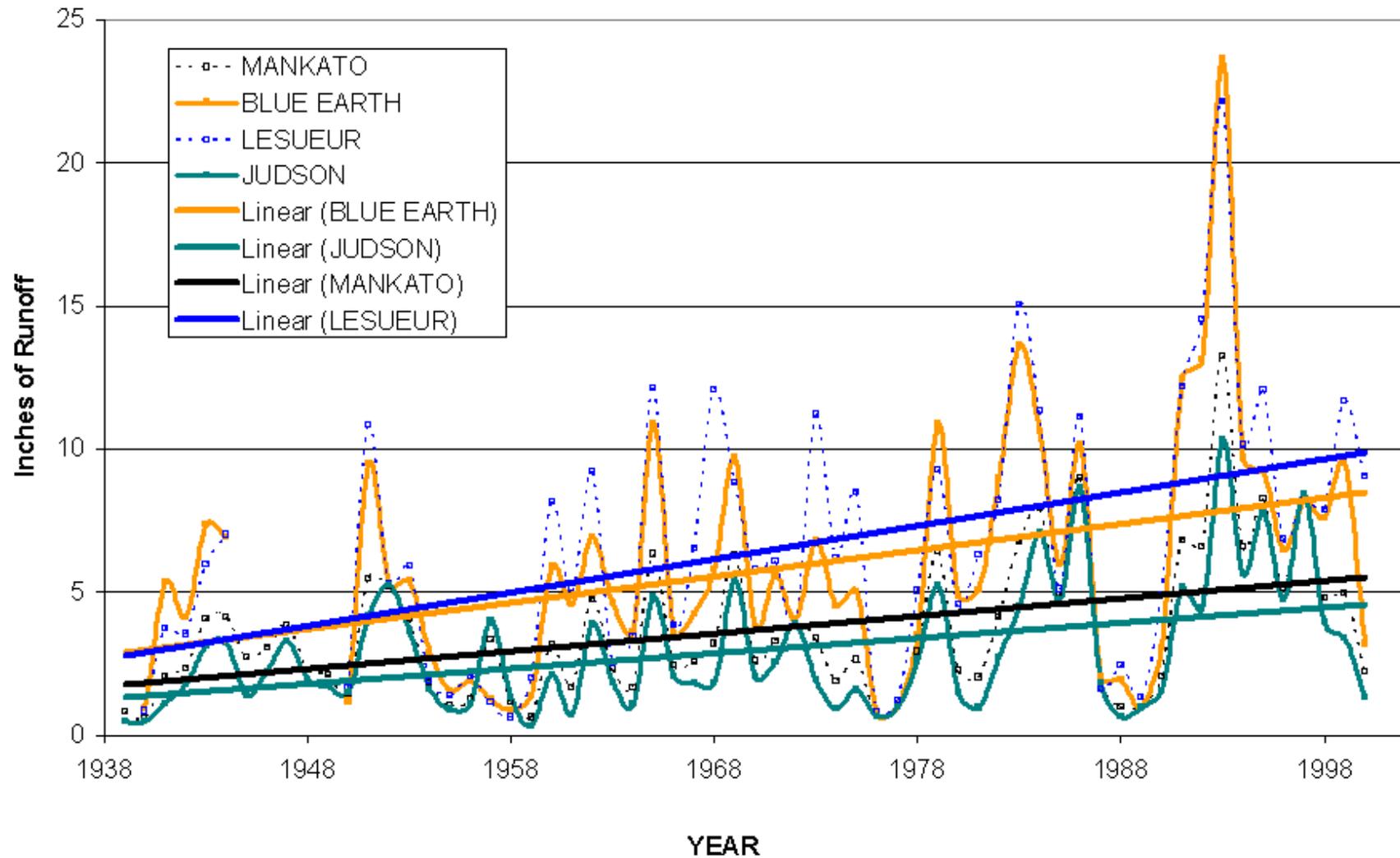


Since 2004, Minnesota has had three 1,000-year flash floods.



On July 19, 2011, Moorhead was the hottest, most humid spot on Earth. Its 88°F dew point and 134°F heat index eclipsed the Amazon Jungle.

Increasing Mean Annual Runoff



What we're seeing, what we expect, and how confident we are

Kenneth Blumenfeld- State Climatology Office

Variable	Recent & Current Observ.	Expectation	Confidence
Temperatures	Rapid warming of coldest temperatures (all seasons) has driven general warming	Coldest temperatures will continue to warm with fewer extreme cold events	Highest
Annual precipitation	General upward trend in annual precipitation on order of 1-1.5% per decade***; largest proport. increases in spring and fall	Continued increases, with annual and station-to-station variability expected	High
Extreme rainfall	Largest rainfall events becoming larger; frequency increasing	Unprecedented rainfall events expected	High
Snowfall	Decrease in frequency of both extremes of seasonal snowfall (snowy and snow-sparse); Largest snowfalls of season are increasing	Unclear as winters warm and as more precipitation falls as rain.	Moderate
Severe thunderstorms & tornadoes	Severe weather difficult to track, but evidence suggests fewer "days," but more events per day	Tendency towards more "super" events, even if frequency drops	Moderately low
Heat waves	Magnitude and frequency of excessive heat events is well within historical bounds	Heat waves may become more common as "bottom comes up"	Low
Drought	Drought frequency, areal extent have not increased in last 5, 10, and 50 years+	Some research indicating more late-season droughts, but <u>after</u> early-season heavy rainfall	Low

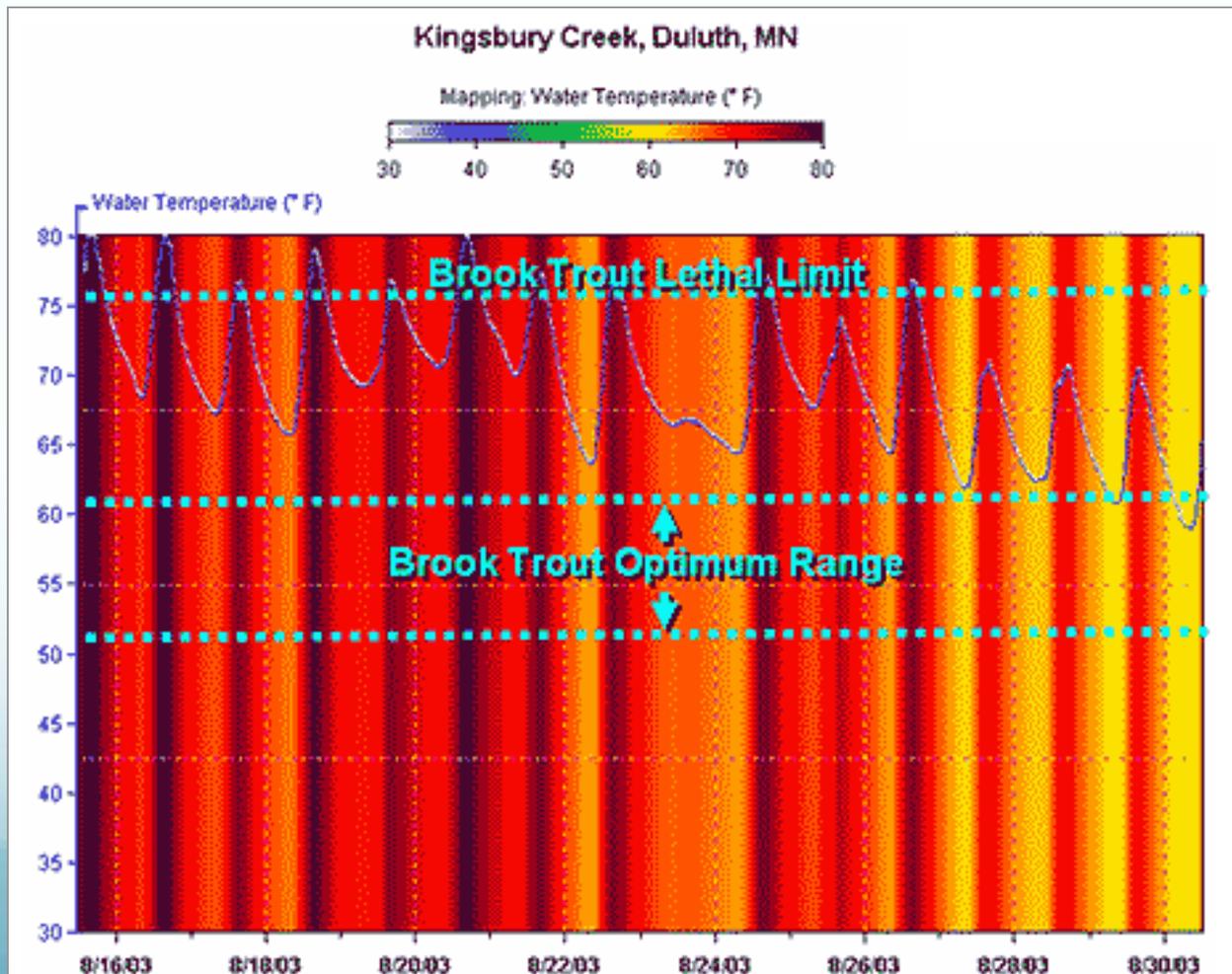
*** Except NE MN

Consequences?



Brook trout stress – Kingsbury Cr 2003

15 days continuously over the optimal temperature range for brook trout; exceeding upper limit 10 times

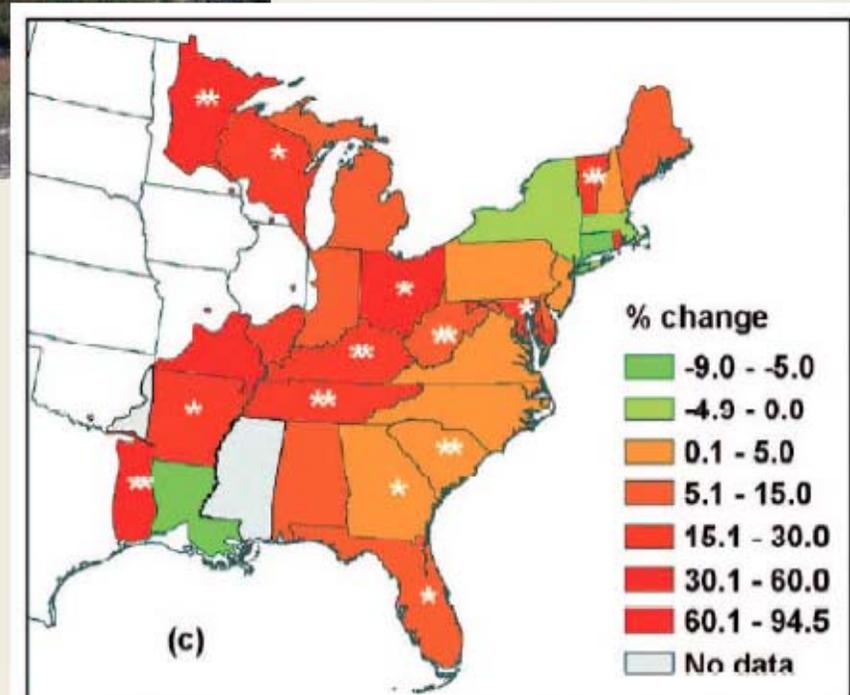




Minnesota's Northern Forests?

From Lee Frelich

Red maple taking over as birch die
(upper, Photo, Dave Hansen).
Red maple % change in abundance
1980-2005 (lower, from Fei, J. Forestry, 2007).



From: Lee Frelich <http://www.arboretum.umn.edu/userfiles/image/land-water%20summit/clean%20water-climate%20change%20summit/Lee%20Frelich.pdf>

NE MN Tree Response to Warmer Climate:

Decrease in abundance: jack pine, red pine, black spruce, white spruce, paper birch, aspen, balsam poplar, tamarack

Increase in abundance: sugar maple, red maple, white pine, basswood, red oak, bur oak, green ash, yellow birch

Migrate in: Hemlock, white oak, black cherry



Bud Heinselmann

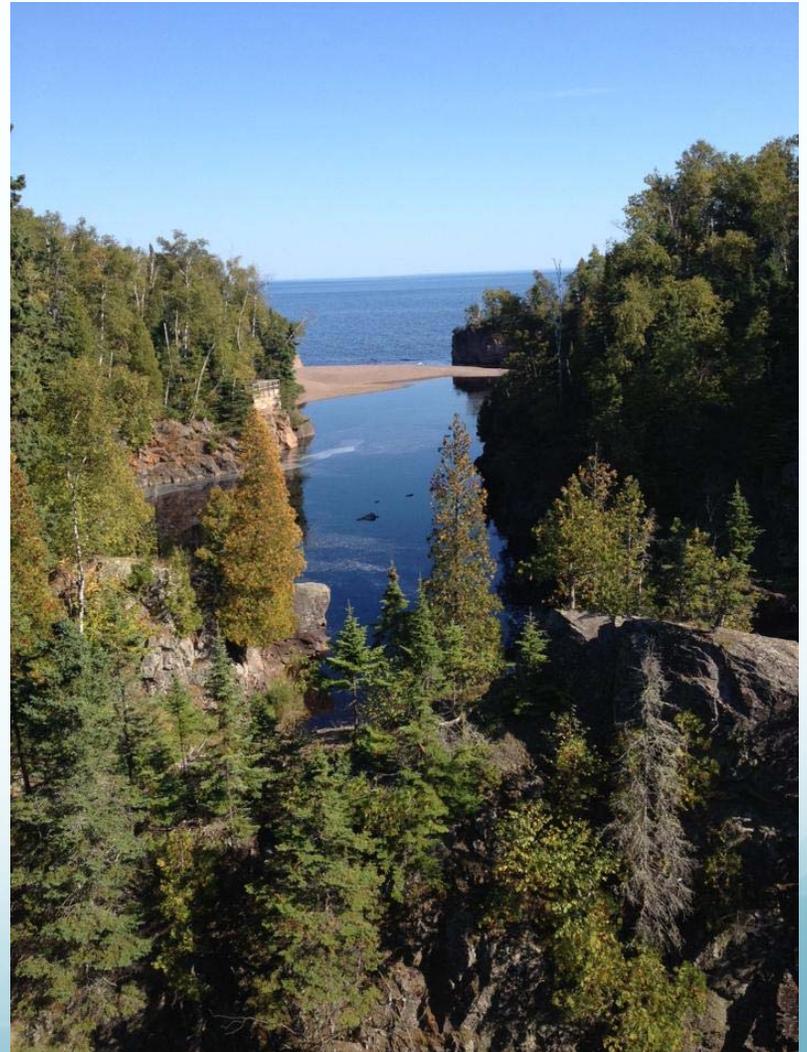


Sustaining Healthy Aquatic Ecosystems in a Changing Climate

- Understand how ecological communities relate to flow regime
- Anticipate/predict ecological response to flow alteration
- Develop strategies and priorities based on stream resilience

Overview:

- What do we already know?
- Modeling flow and predicting ecological implications
- What can we do ?



Project Partners

- William Herb: U of MN, St Anthony Falls Lab;
- Lucinda Johnson, Ralph Garono, Meijun Cai: NRRI, University of Minnesota Duluth
- Kristen Blann and Mark White: The Nature Conservancy
- John Jereczek and Amber Westerbur: Minnesota Dept. of Natural Resources – Minnesota Lake Superior Coastal Program
- Hilarie Sorensen: MN Sea Grant
- Rachael Franks Taylor: NOAA Office of Coastal Resource Management

Funding is provided by the Great Lakes Restoration Initiative (GLRI) and NOAA

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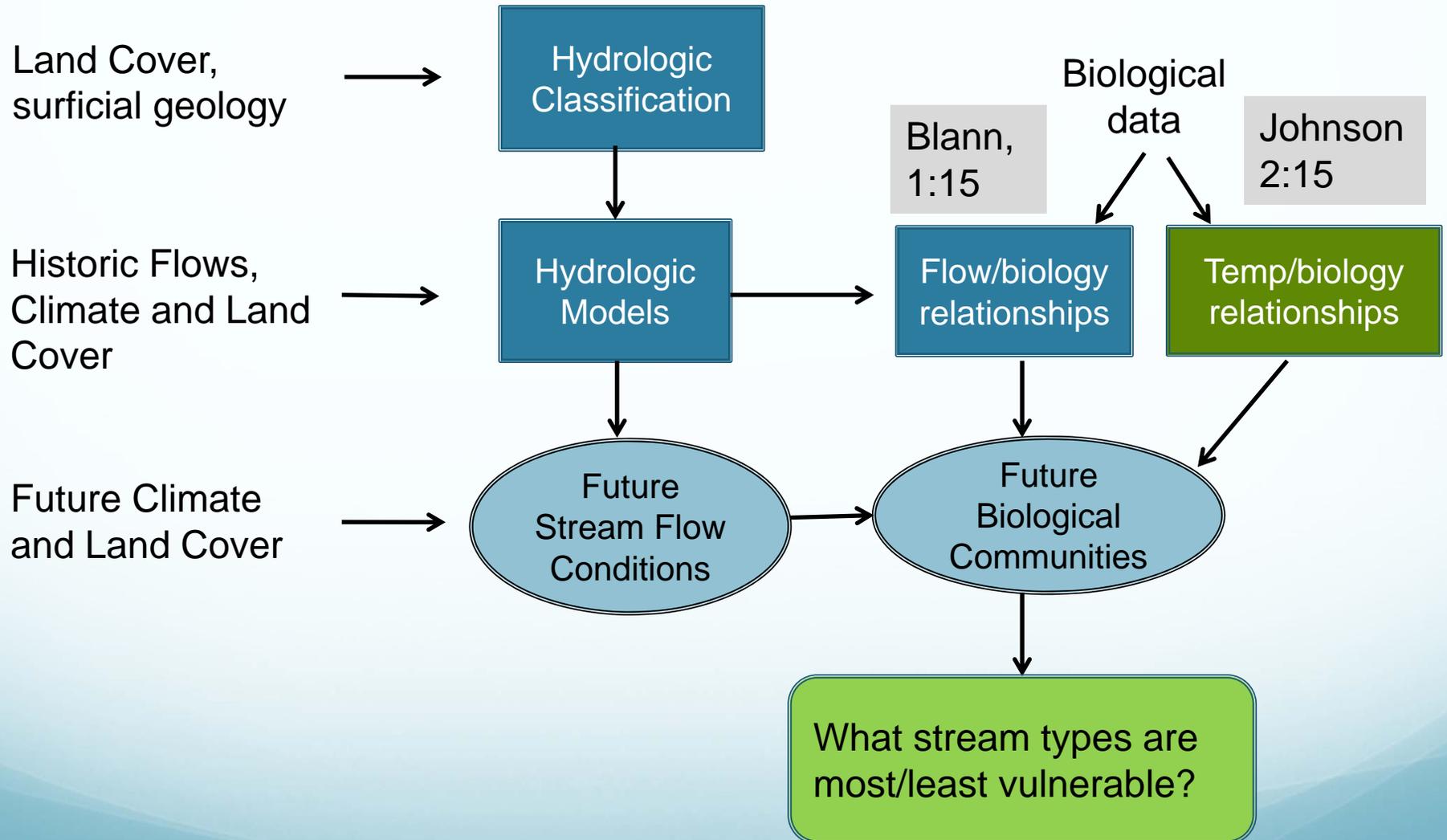
Slide 13

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I think there is some official wording that needs to be used.

Lucinda Johnson, 8/18/2015

Project Overview

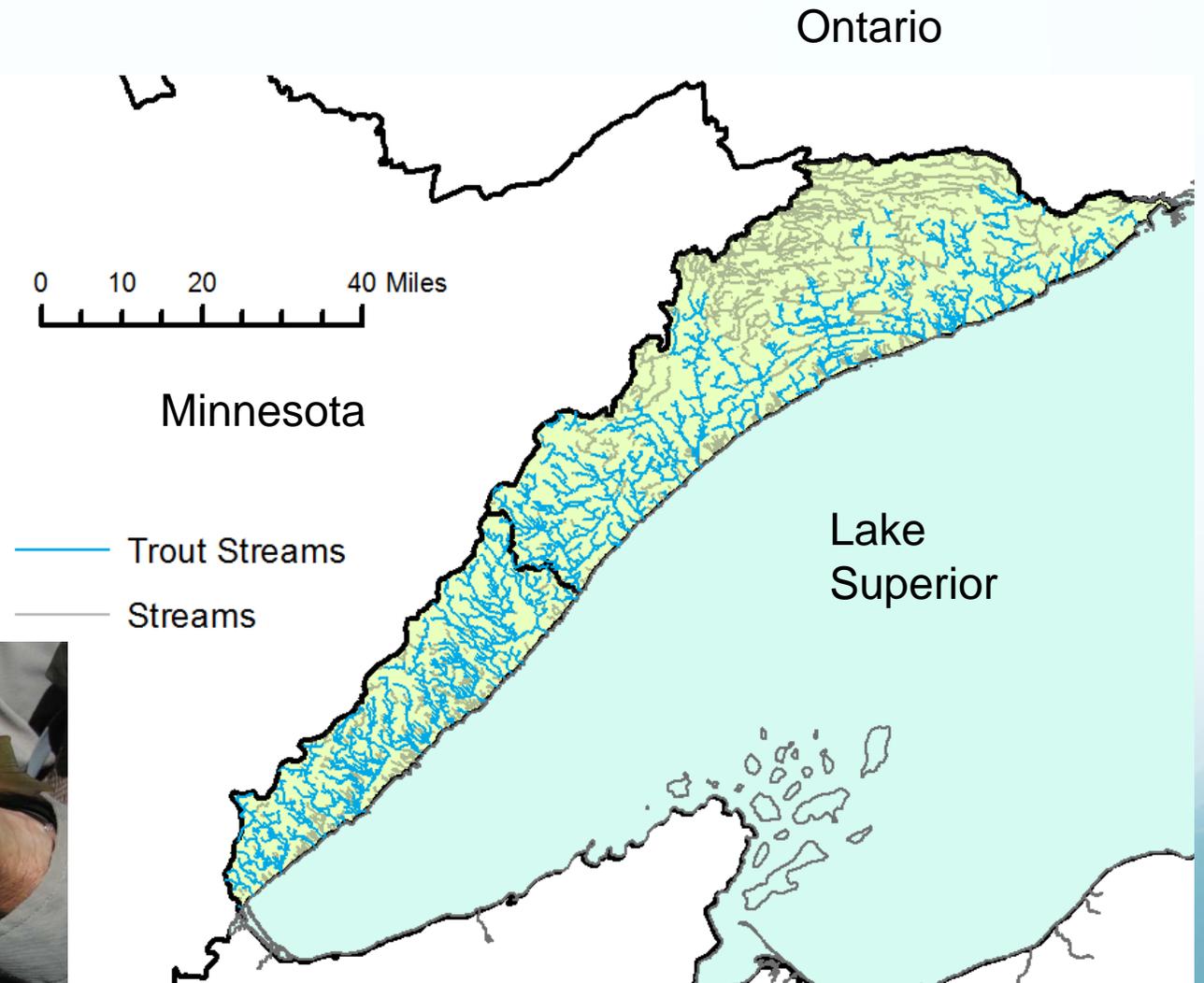


Goals and Motivation

- Goal: Develop management recommendations for maintaining stream resilience in the face of climate and land cover change
- Premises:
 - Improved understanding of flow-ecology relationships will help identify the vulnerabilities of aquatic communities with respect to land cover and climate change.
 - N.S. streams are responsive (flow and temperature) to changes in climate compared to, e.g., groundwater-fed trout streams in southeast Minnesota
- Previous work (Johnson, Herb, Cai) identified vulnerable streams with respect to flow and temperature; lack of groundwater information and future land cover identified as gaps.

The Study Area: Minnesota's North Shore Of Lake Superior

- Highly valued regional coldwater fishery
- >150 designated trout streams
- Brook trout are native
- Steelhead, salmon, and brown trout also present

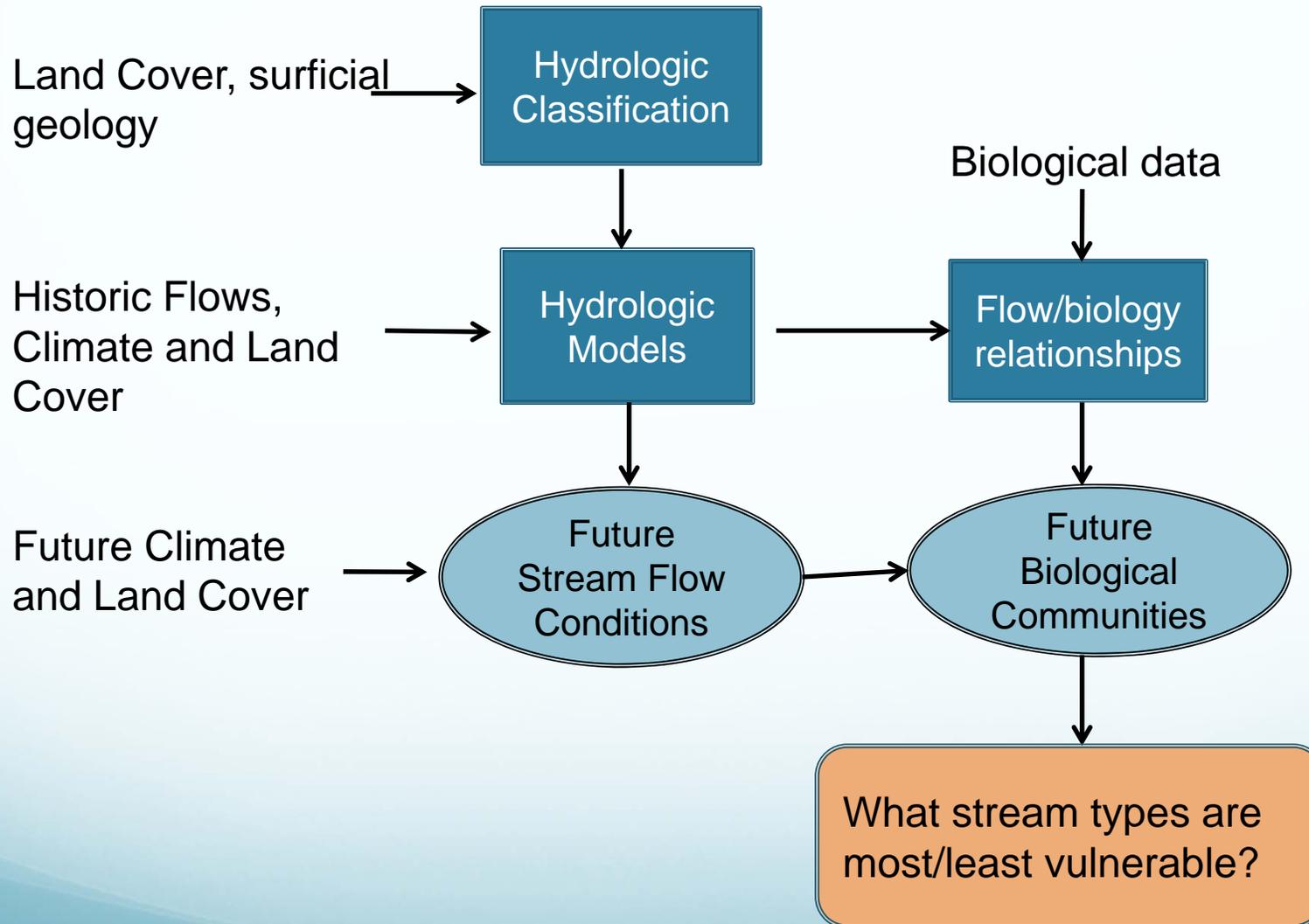


Minnesota's North Shore of Lake Superior

- Low impervious area from development, except in Duluth area
- But, still flashy because of exposed bedrock, thin soils, high slopes and few groundwater aquifers
- Baseflow partially supplied by wetlands



Methods Summary



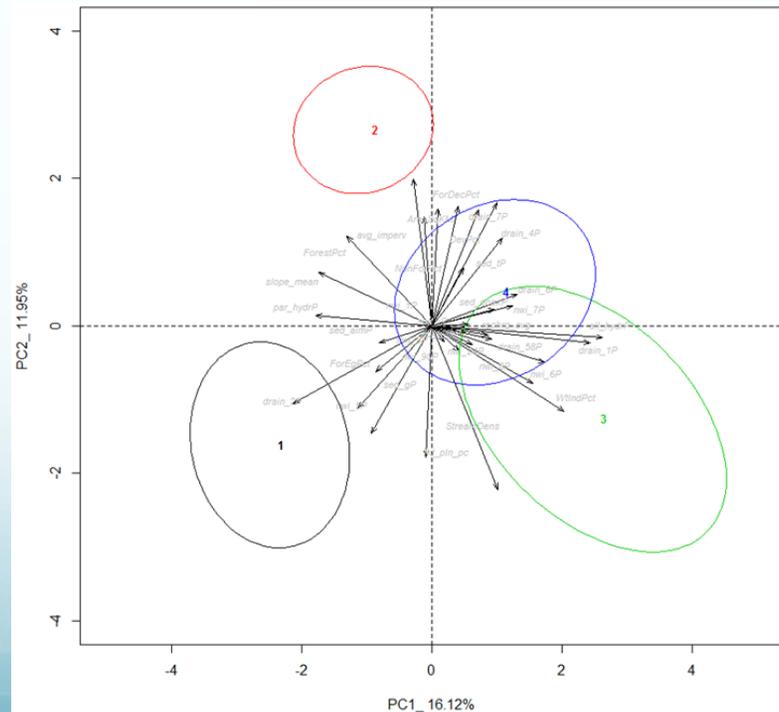
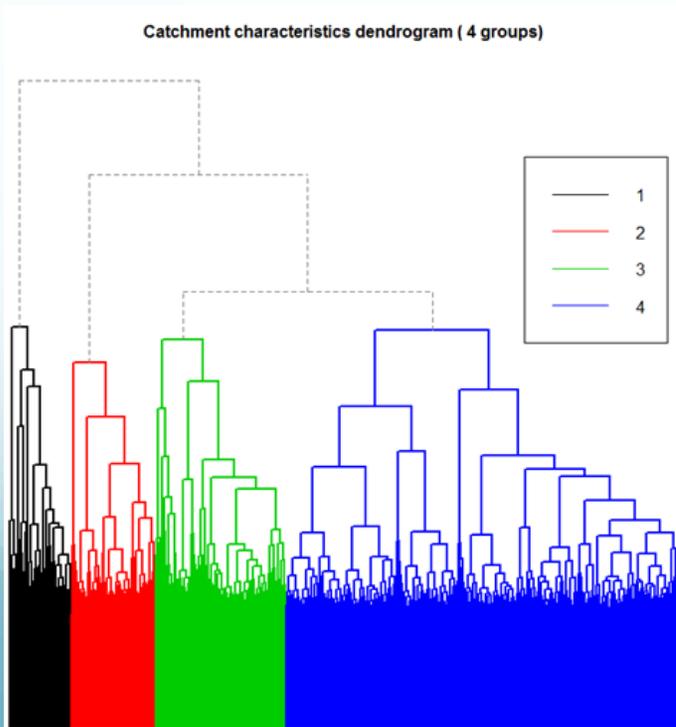
Stream Classification

Goal: Classify the North Shore tributaries into distinct hydrologic types, to understand their response to stressors and to refine regional hydrologic models.

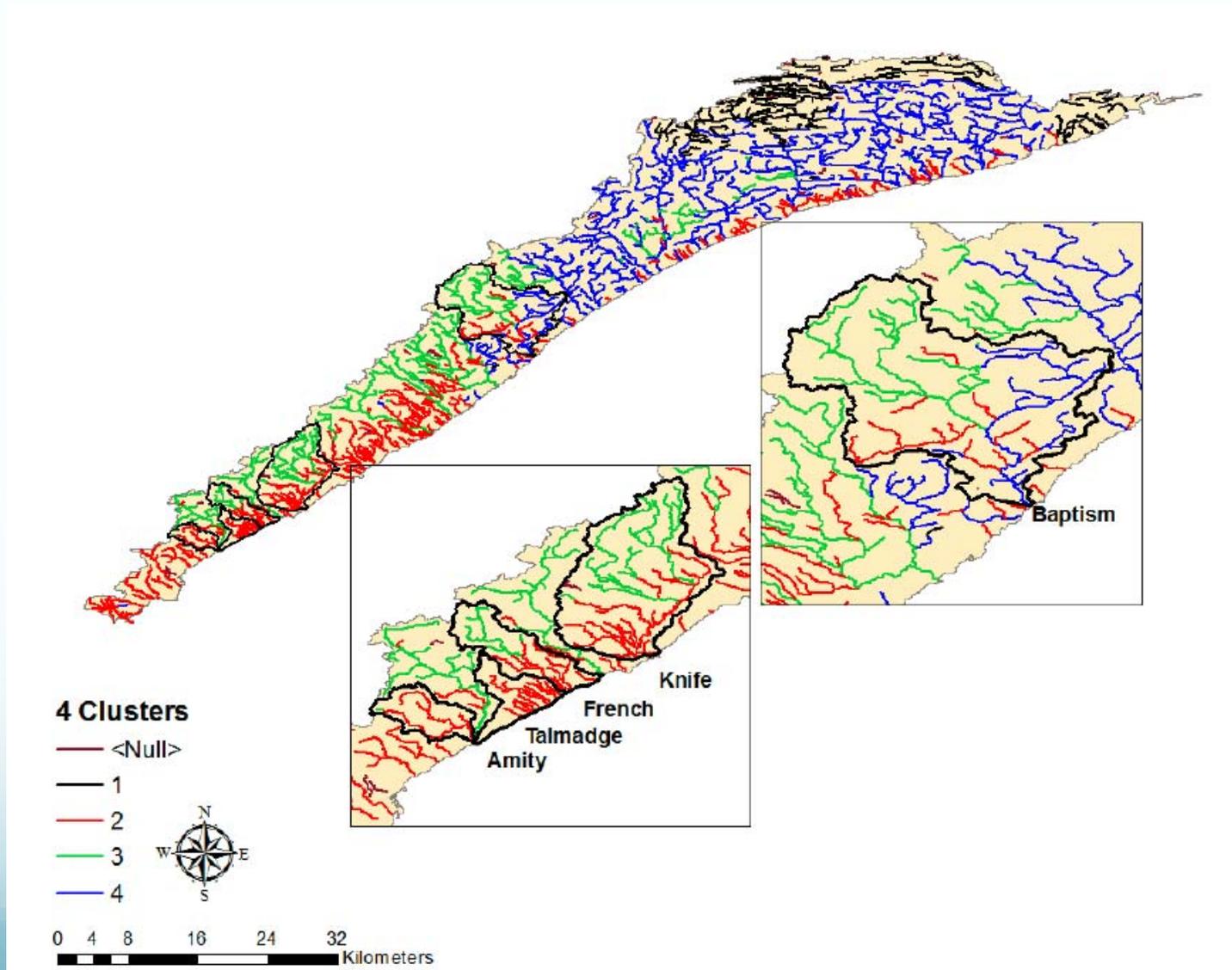
- Classification variables include soil types, drainage class, surficial geology, slope, land cover, wetland and lake coverage, drainage density
- Based on NHDplus hydrography

Stream Classification

1. Classification variables attributed to catchments
2. Principal component analysis (PCA) used to pre-treat the variables, e.g. reduce total number of variables
3. Cluster analysis was performed for 3 – 10 clusters
4. PCA used again to evaluate the overlap between clusters

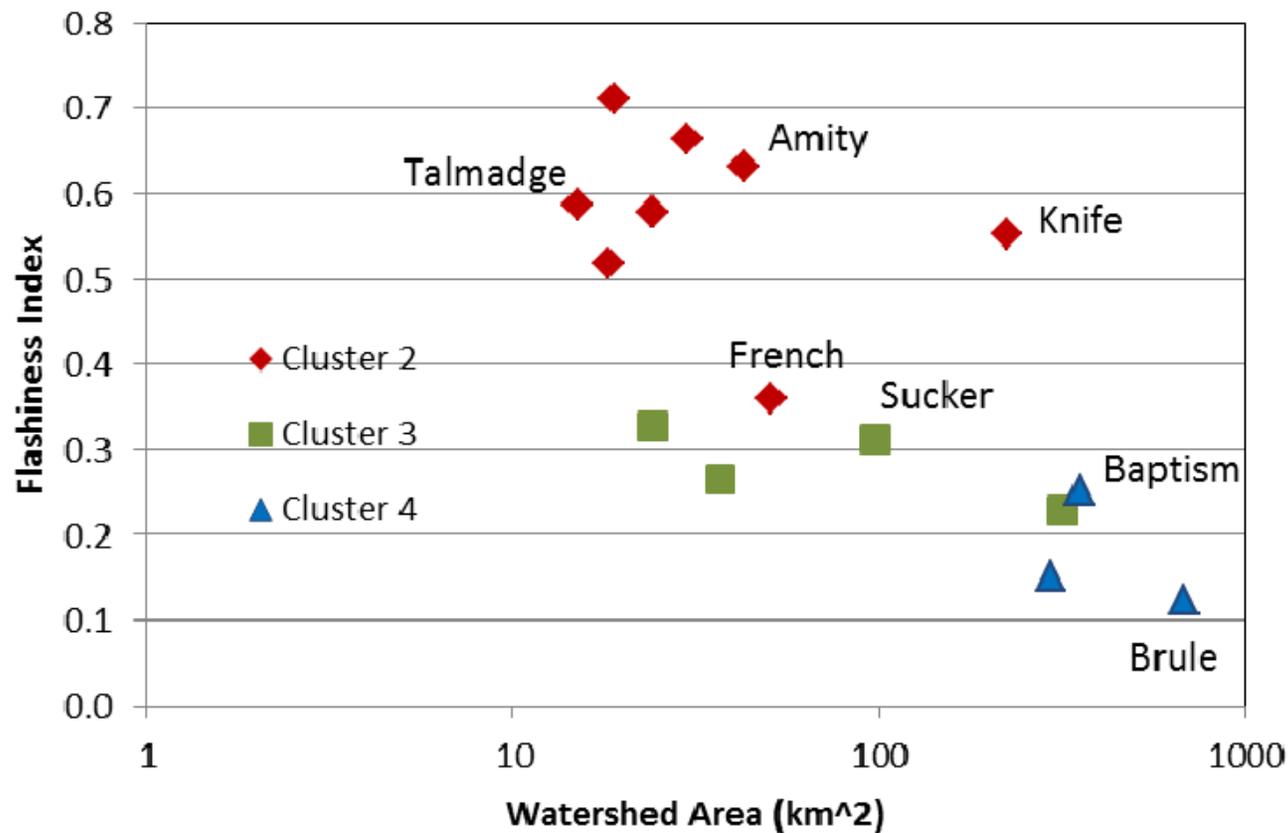


Stream Classification



Stream Classification

Are the classifications capturing hydrologic differences?
Use the stream gage data to check.



Hydrologic Modeling Summary

1. HSPF models: Calibrated models for Baptism, Knife, and Poplar

Strength: good for determining response of stream flow to land cover and climate change

Weakness: not good (yet) for extrapolating flows to ungaged watersheds.

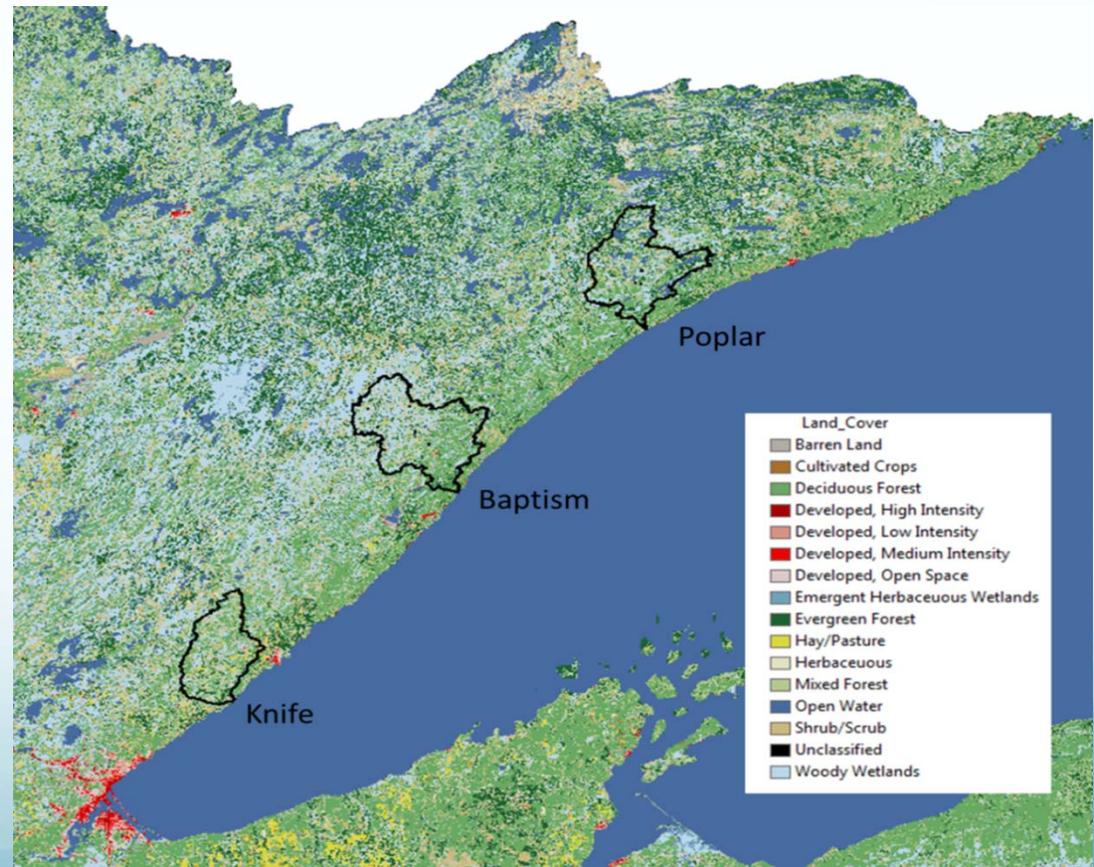
2. Regional Empirical Models: Relationships established between flow, catchment area, land cover, and geology using gage data (not stream class).

Strength: Best method to predict historical flows in ungaged catchments.

Weakness: Does not give a direct means to predict future flow based on land cover and climate changes.

HSPF Hydrologic Models

- HSPF models for the Baptism, Knife, and Poplar rivers
- Representative of the major hydrologic classifications
- Sub-catchments based on NHDplus hydrography
- Calibrated based on available gaging and climate data
- Simulates flow year-round at 1 hour time step

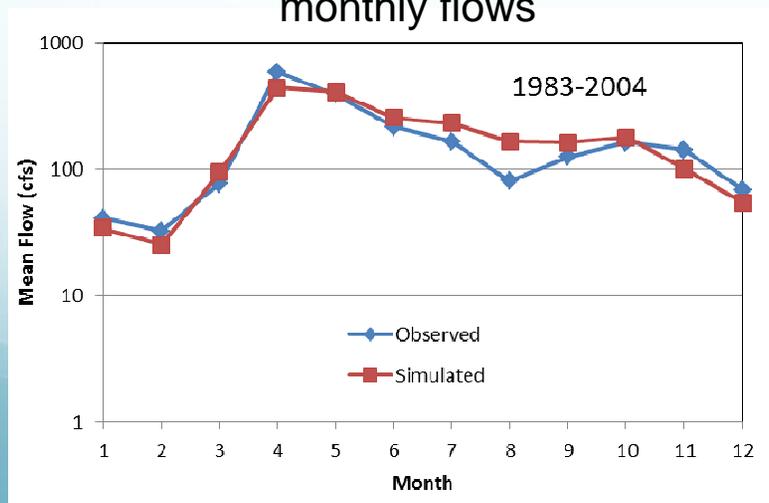


HSPF Model Calibration

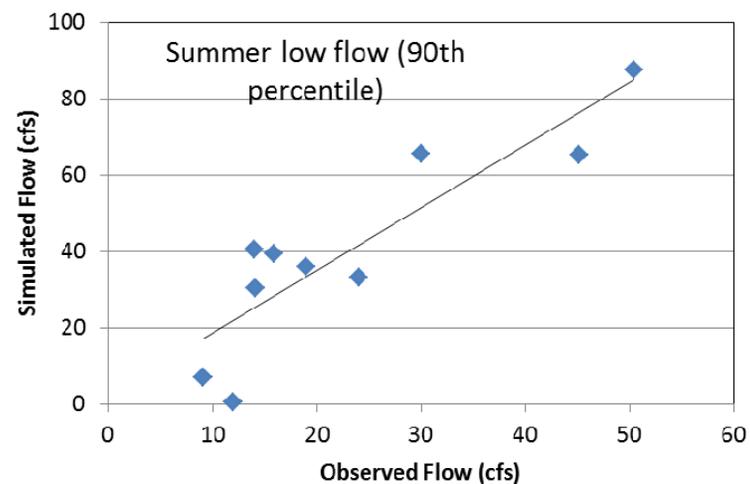
- HSPF models were calibrated to match observed flow statistics.
- Output: 20+years of continuous flow at any point in the watershed



Simulated and observed mean monthly flows



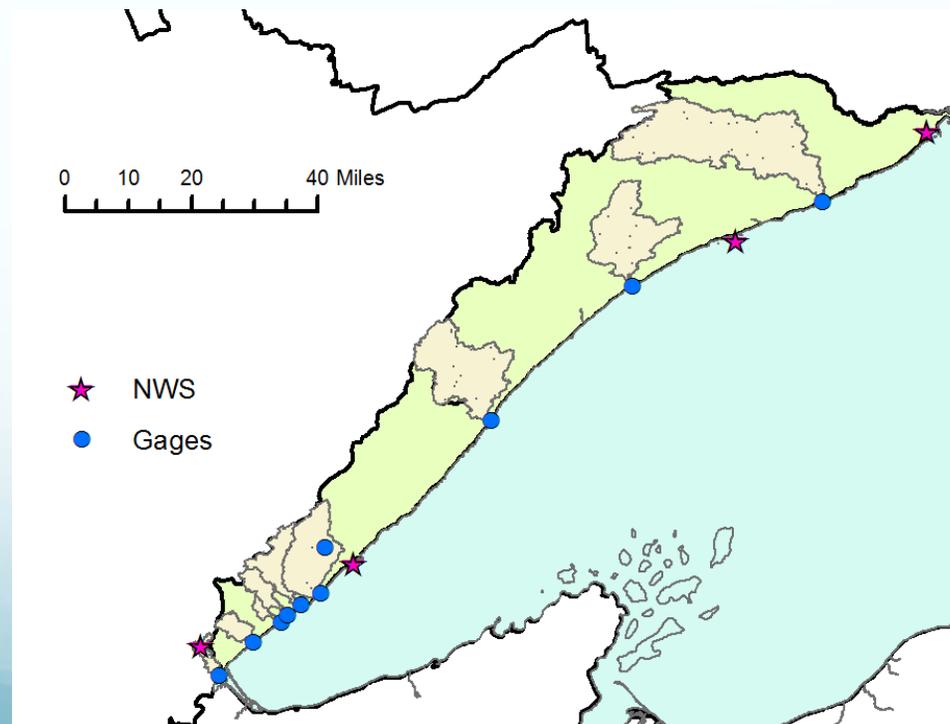
Simulated and observed summer low flow, by year



Regional Hydrologic Models

Purpose: extrapolate stream gage data to ungaged catchments

- Use regression analysis to relate specific stream flow parameters (flow metrics) to catchment area, land cover, and surficial geology types
- Target stream statistics we believe will be useful for flow-ecology relationships



Regional Hydrologic Models

Modeled Flow Metrics: Seasonal low/high/median flows, baseflow index, flashiness index, annual max/min

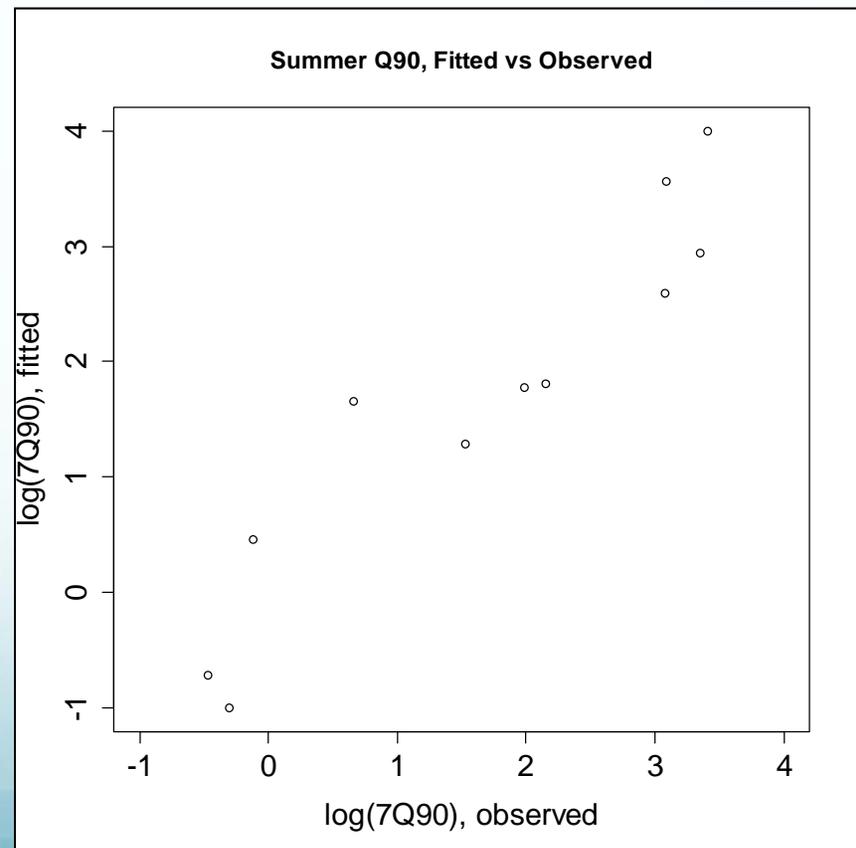
Predictor variables: catchment area, wetland fraction, surficial geology, forest cover, depression storage, slope

Typical regression relationship form:

$$\log(Q90) = c_0 + c_1 \cdot \log(\text{Catchment Area}) + c_2 \cdot \log(\text{Wetland Fraction})$$

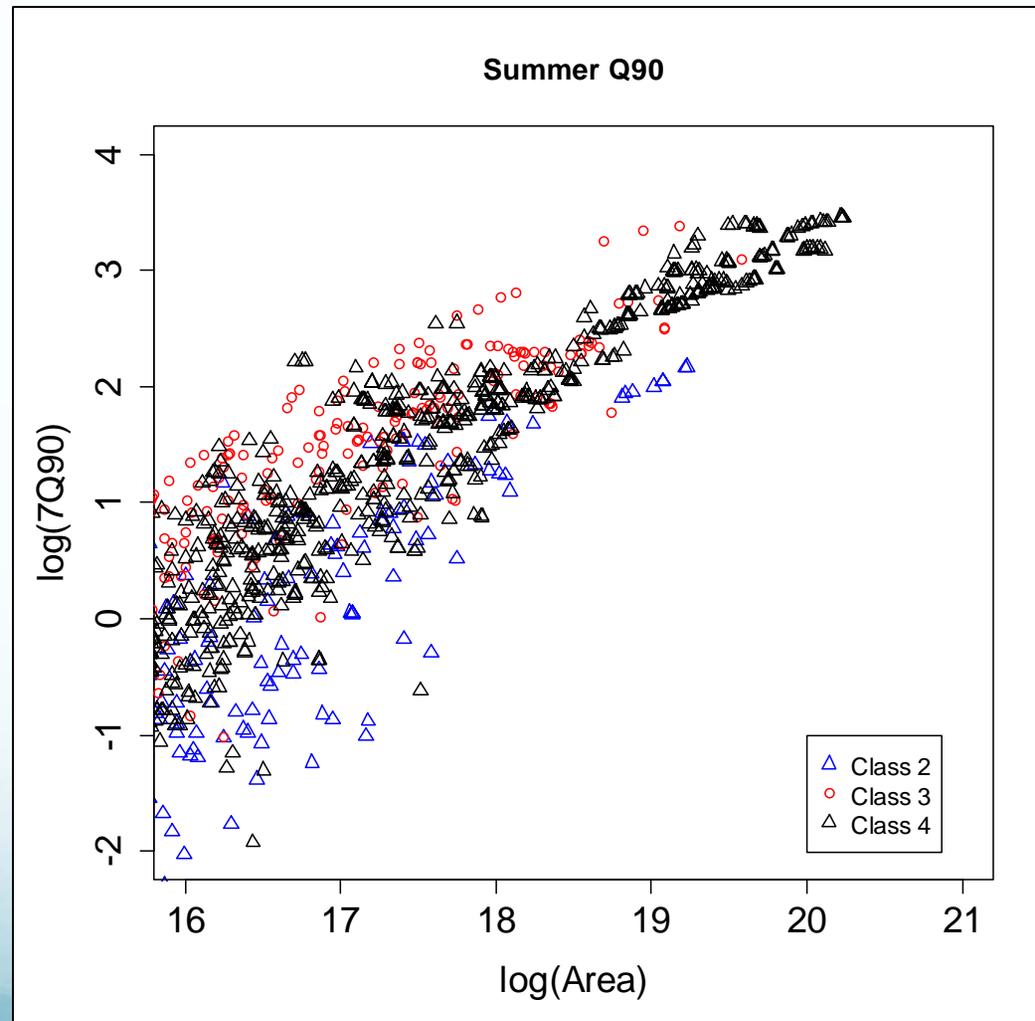
Using PRESS and predictive R^2 statistics to check for overfitting and extraneous variables.

Predictive R^2 is in the range of 0.62 to 0.98.



Do predicted flow metrics vary by stream class?

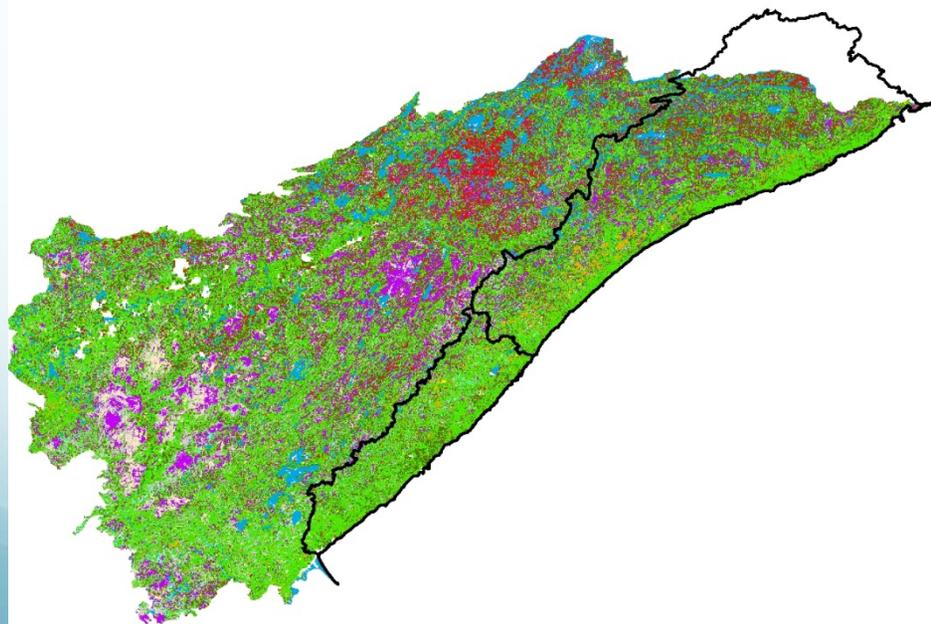
Summer low flow vs. catchment area, by stream class



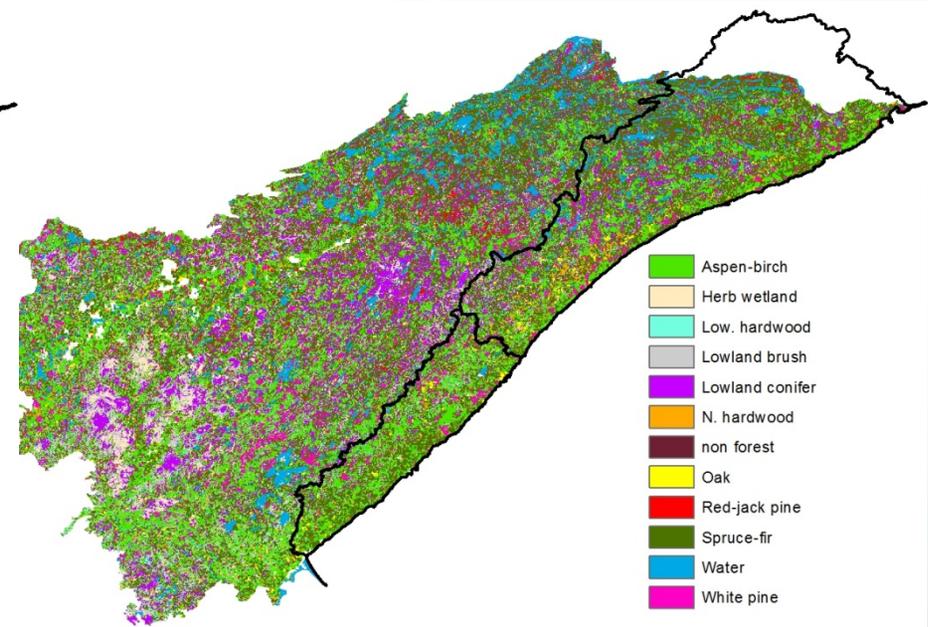
Land Cover Projections

- Minimal changes in urbanization and agriculture expected
- Use forest change projections from Landis II model (Ravenscroft et al. 2010), with help from Mark White (Nature Conservancy)
- Based on projected changes in forest cover and type, adjust evapotranspiration, canopy interception, etc. in models

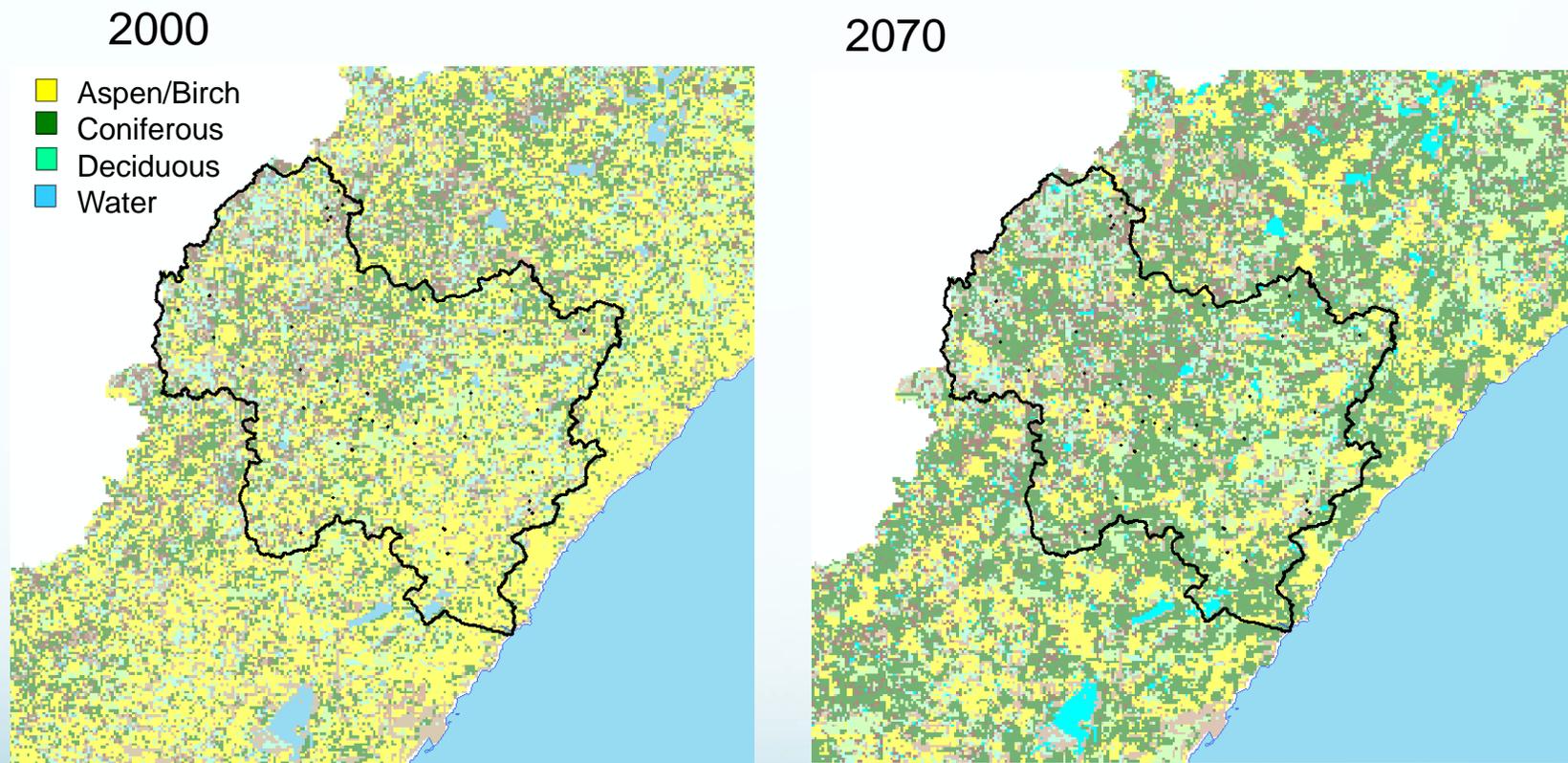
Baseline Land Cover 2000



2070, Modified Silviculture



Projected Shifts in Forest Type



Water Budget changes due to shifts in Forest Type

- Different forest types have different amounts of canopy interception, transpiration rates, etc.
- Coniferous forests have significantly more canopy interception than deciduous
- Aspen may have higher summer transpiration rates

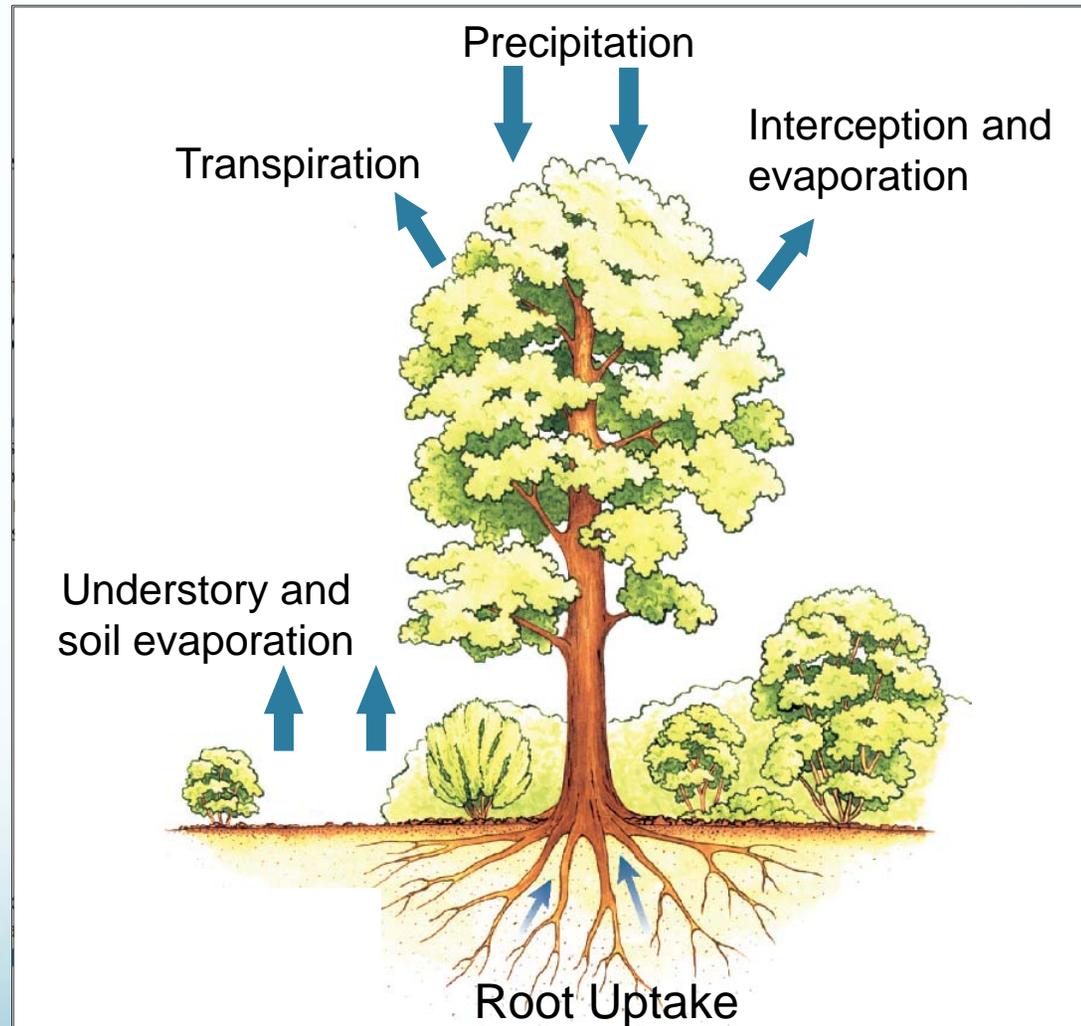
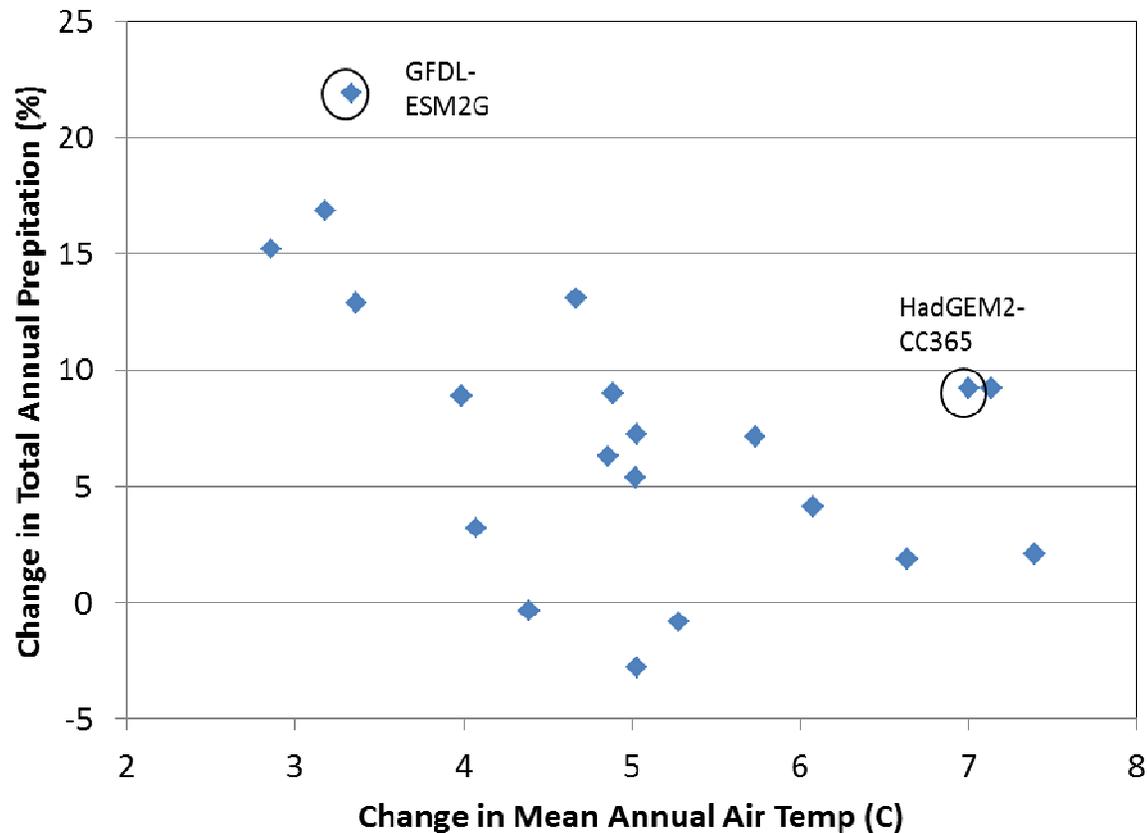


Figure adapted from Nisbet 2005, Water Use by Trees

Climate Projections

- Use available downscaled GCM data (several options available)

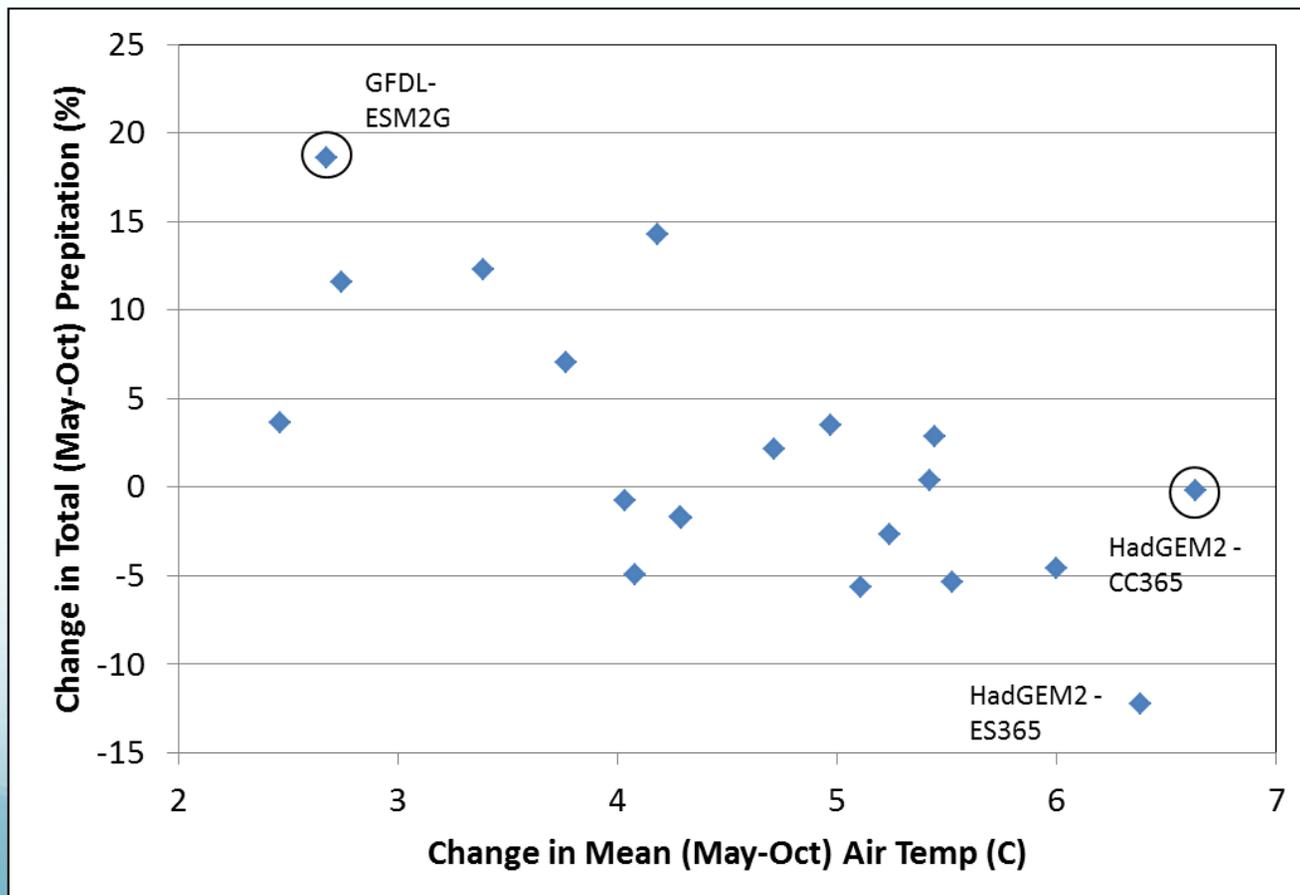
Changes in mean annual precipitation from 1970-99 to 2061-80, CMIP5, RCP85 (high emissions)



Climate Projections

- Seasonal variability important, annual average precip (+), summer precip (-)

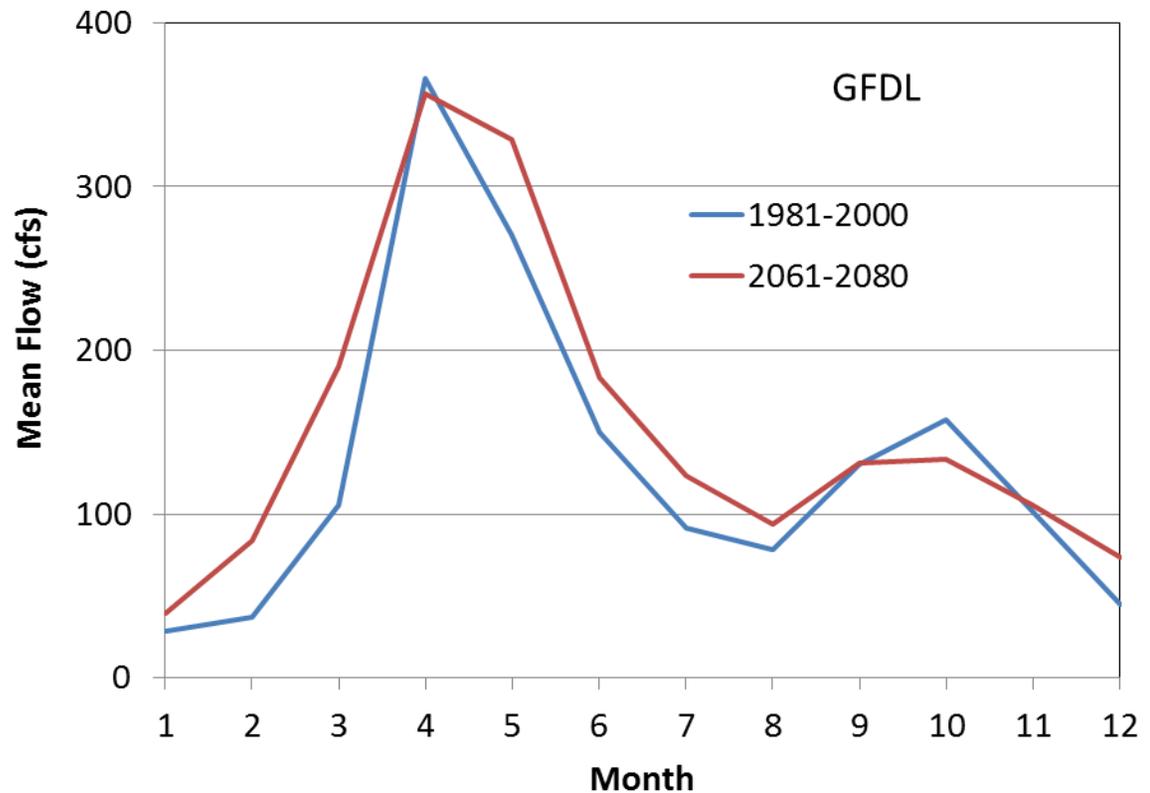
Changes in mean air temperature and precipitation,
May-Oct, from 1970-99 to 2061-80



Climate Time Series Analysis: GFDL

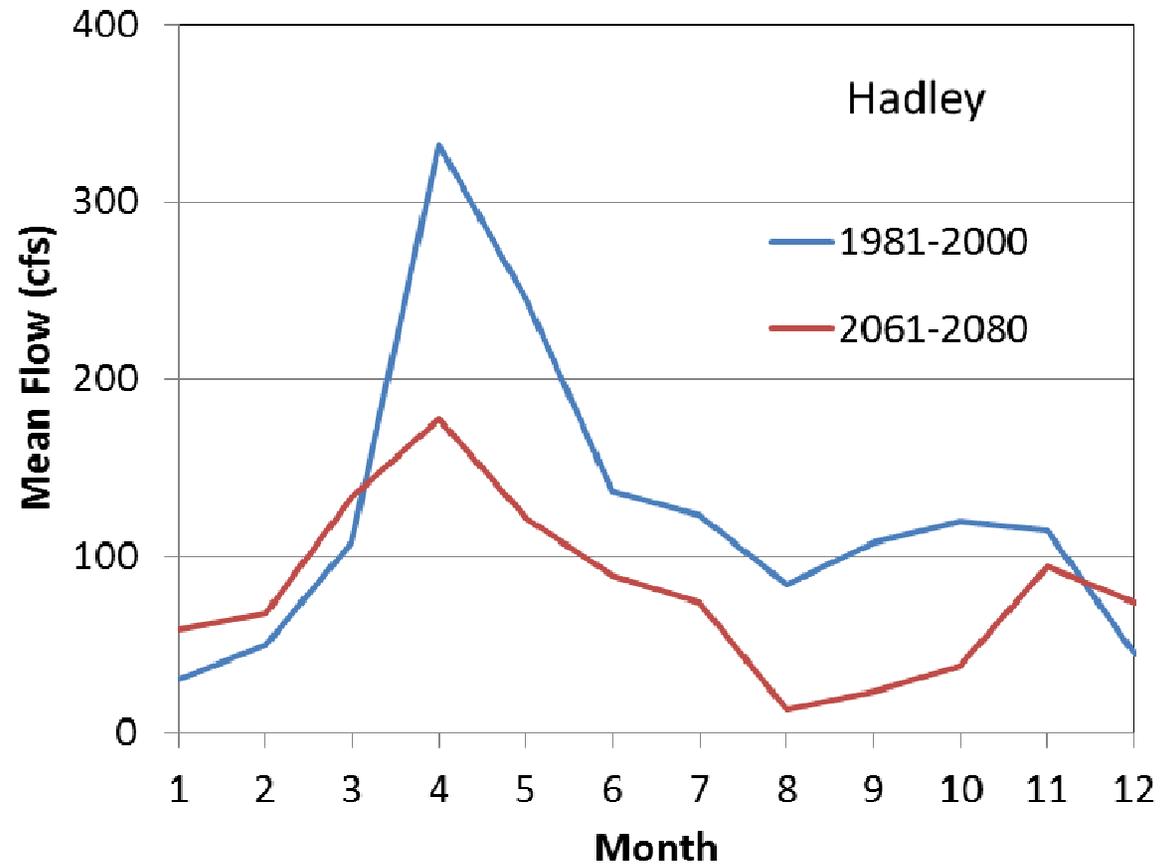
- Run historical and future climate time series through HSPF models, find response
- Includes change in precipitation and estimated change in ET

Month	GFDL-ESM2G	
	Change in Mean Air Temperature (°C)	Change in Mean Precipitation (%)
Jan	5.2	17.7
Feb	5.2	-10.1
Mar	4.4	61.3
Apr	2.0	66.3
May	2.1	35.2
Jun	1.9	28.3
Jul	2.0	28.1
Aug	3.4	5.3
Sep	3.3	9.2
Oct	3.3	1.1
Nov	3.8	3.8
Dec	3.3	16.0



Climate Time Series Analysis: Hadley

Hadley GEM2-CC365		
Month	Change in Mean Air Temperature (°C)	Change in Mean Precipitation (%)
Jan	8.2	29.4
Feb	8.9	20.7
Mar	5.1	36.1
Apr	4.2	30.1
May	4.9	7.4
Jun	4.7	-4.3
Jul	7.3	-23.6
Aug	7.3	-41.2
Sep	7.2	-11.6
Oct	7.0	12.5
Nov	6.1	47.4
Dec	9.0	46.2



Summary

- Hydrologic models are being used to generate historical and future flow statistics for the NHDplus stream segments in the region
- The future stream statistics will include the effects of forest change on hydrologic processes
- These flow statistics are an intermediate product of the project, which will be used for flow-ecology analysis to project future changes in regional stream ecology



Summary

- Although most GCMs project increases in mean annual precipitation, summer precipitation and streamflows may be reduced (preliminary results)
- Still work to do, incorporating forest changes into future scenarios

