

An Ecological Response Model for the Cache la Poudre River, Colorado

Arizona Riparian Council, Urban Rivers Conference



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Outline

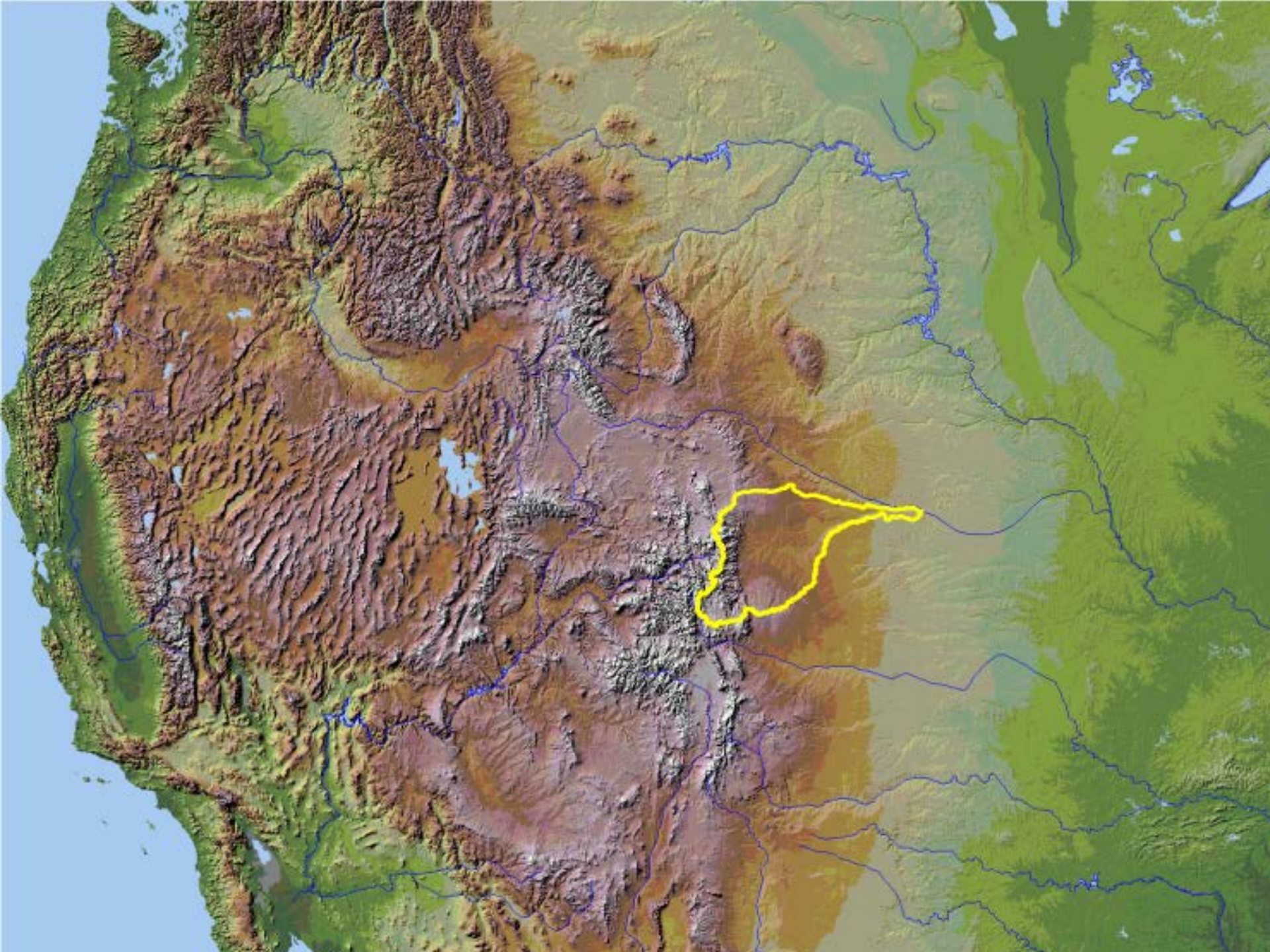
Cache La Poudre River history and future

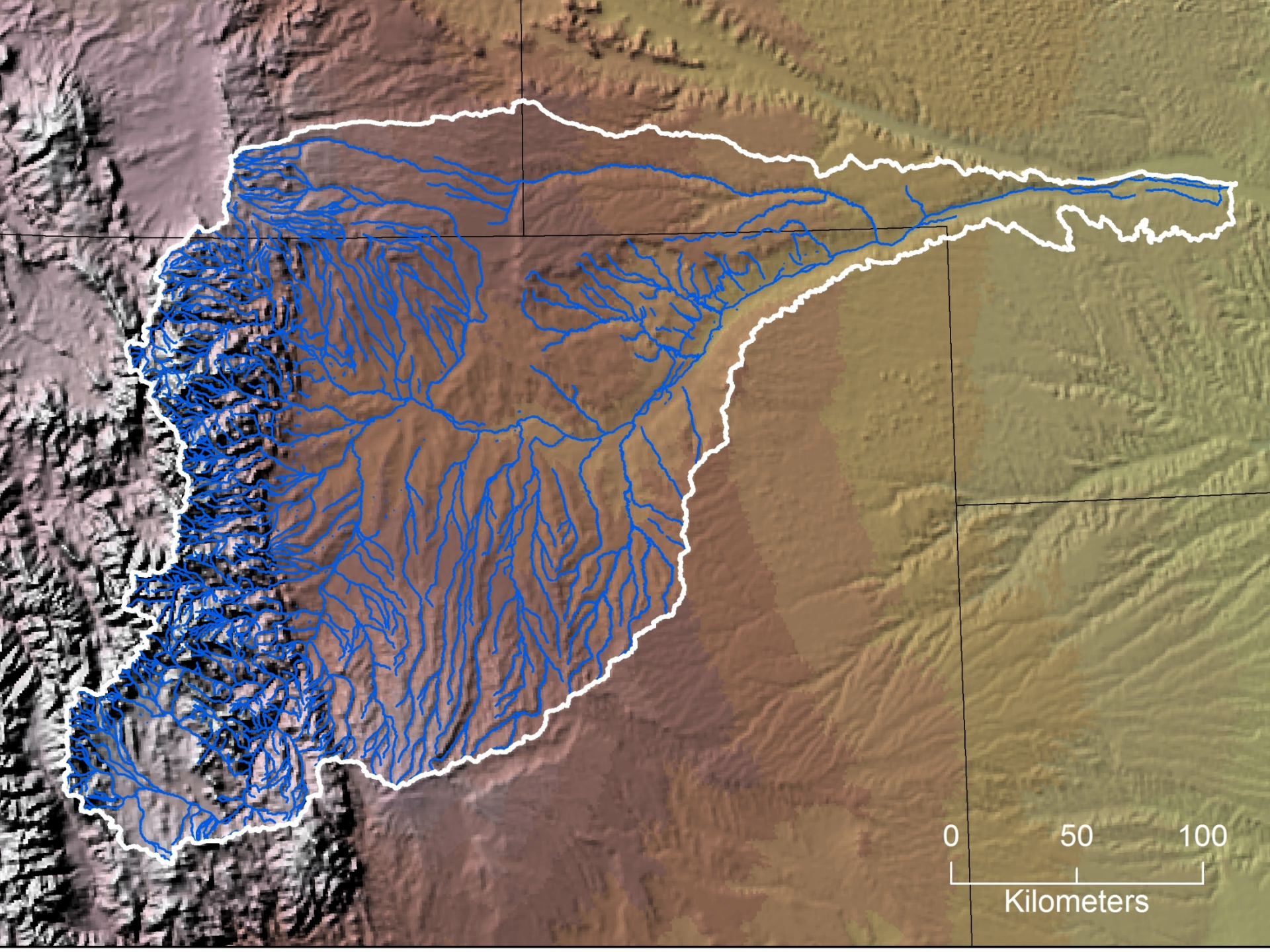
Ecological Response Model (ERM)

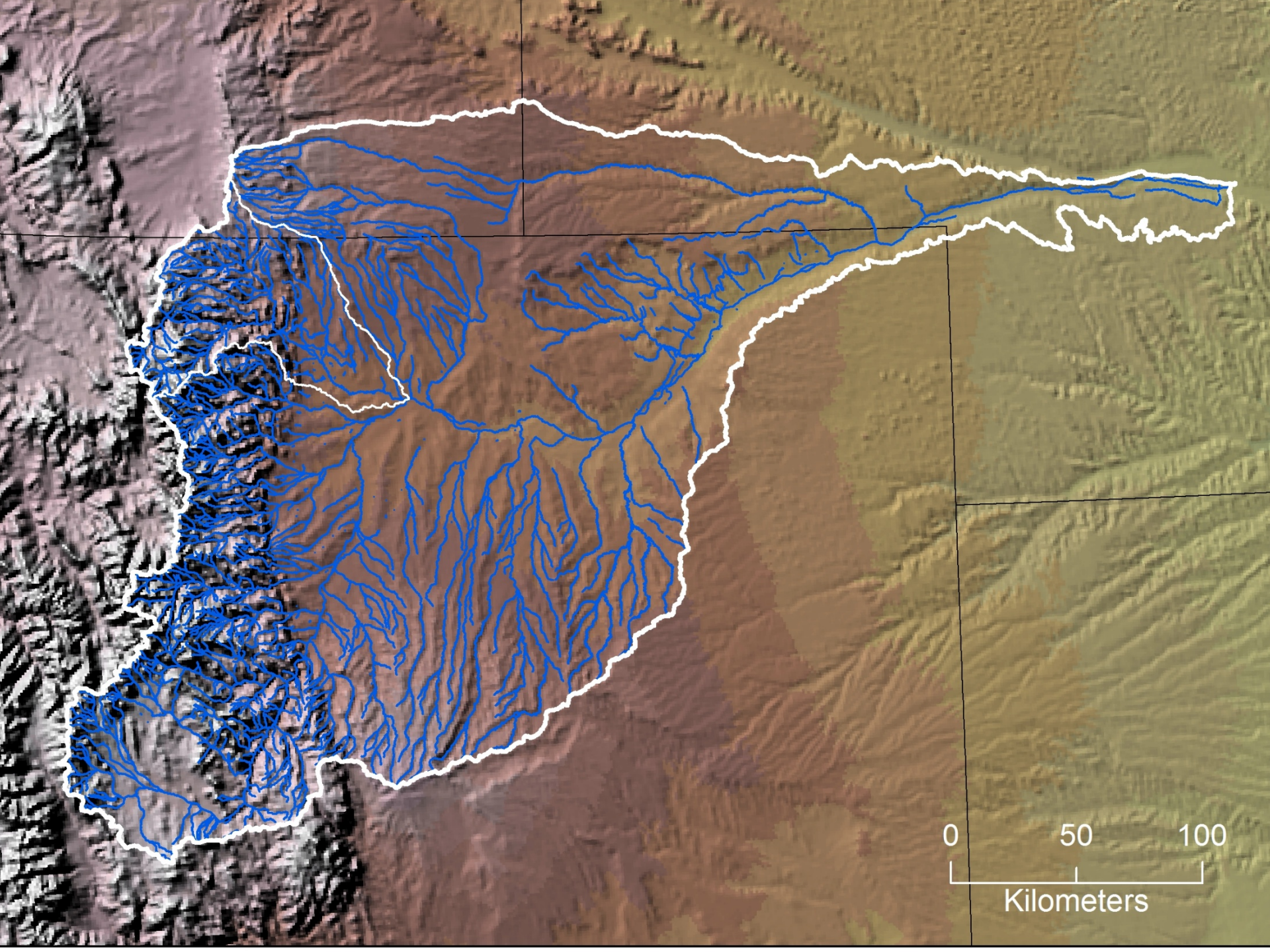
Conclusions



Cache la Poudre River history and future





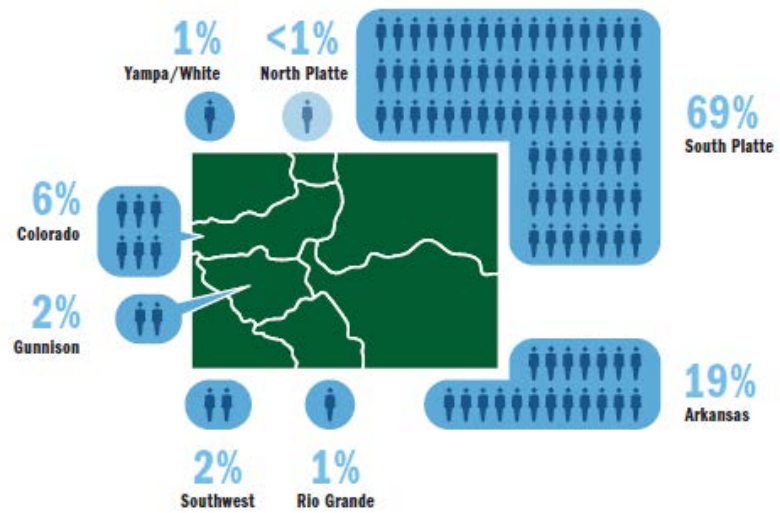


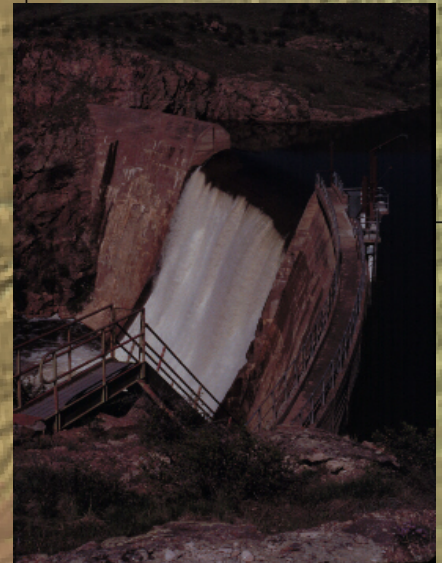
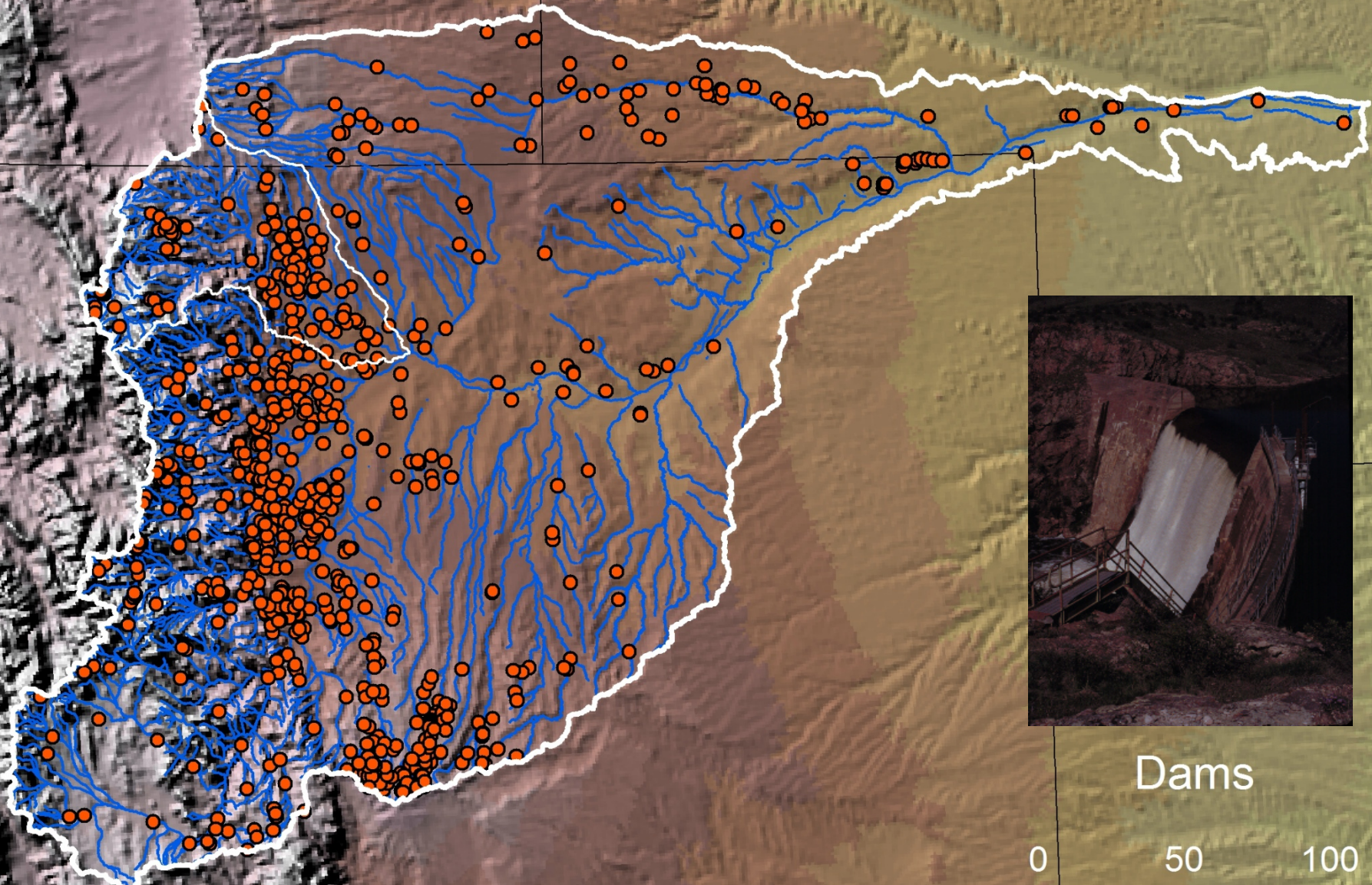
0 50 100
Kilometers





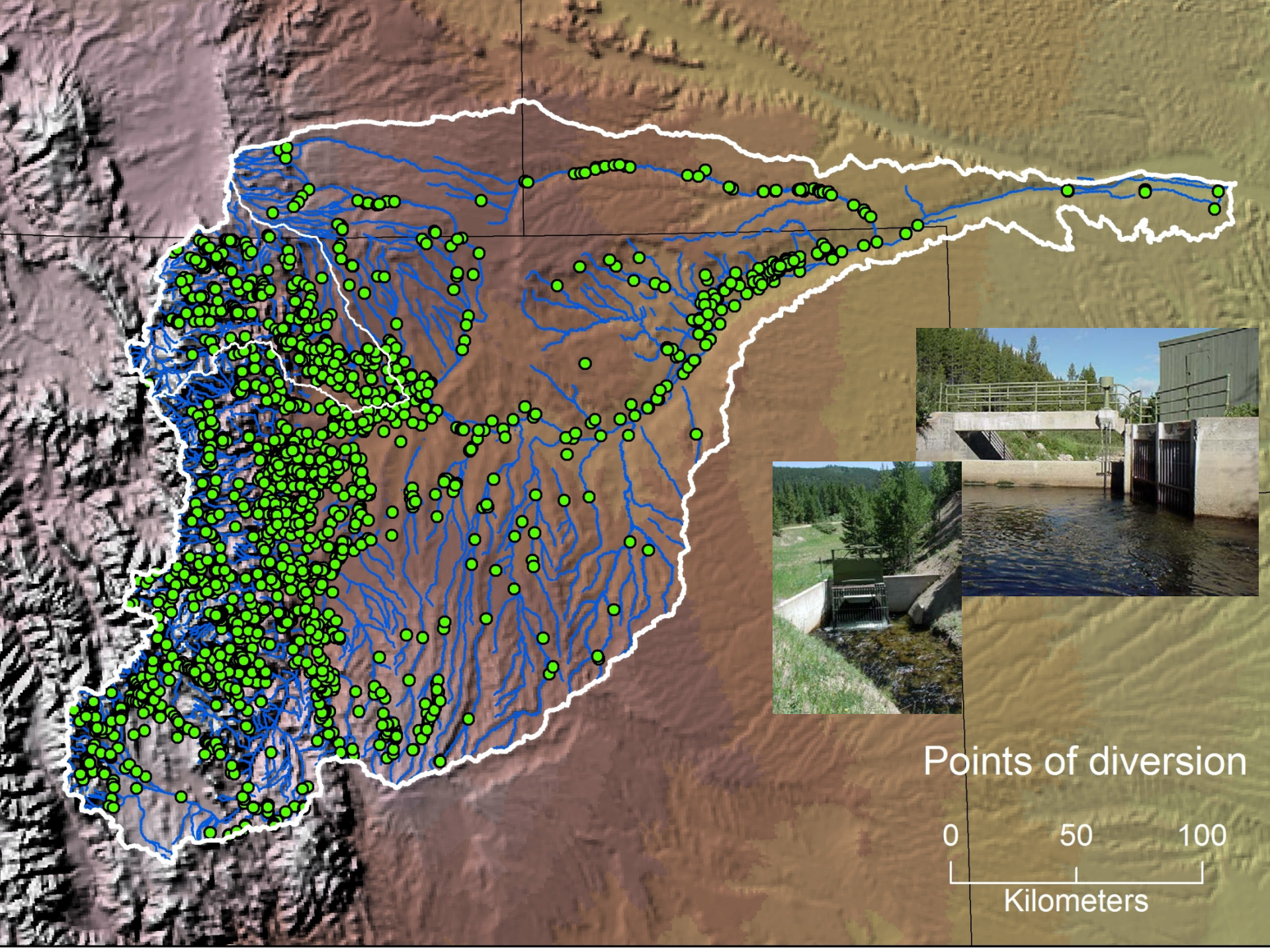




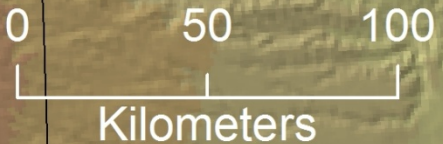


Dams



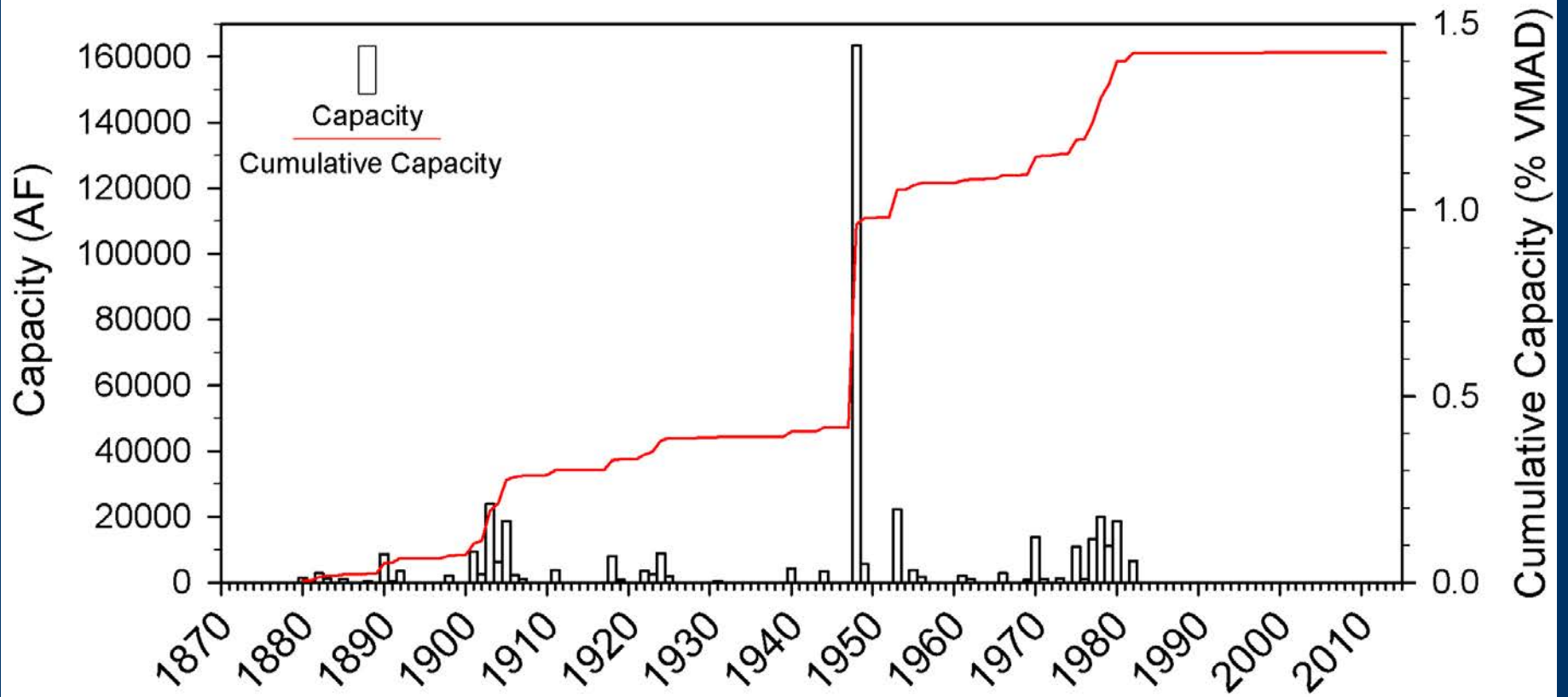


Points of diversion

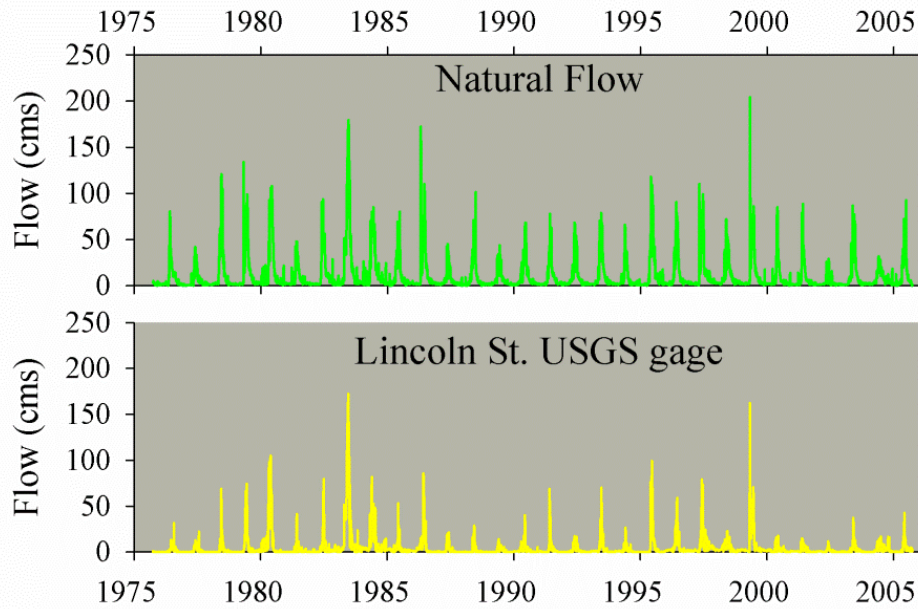




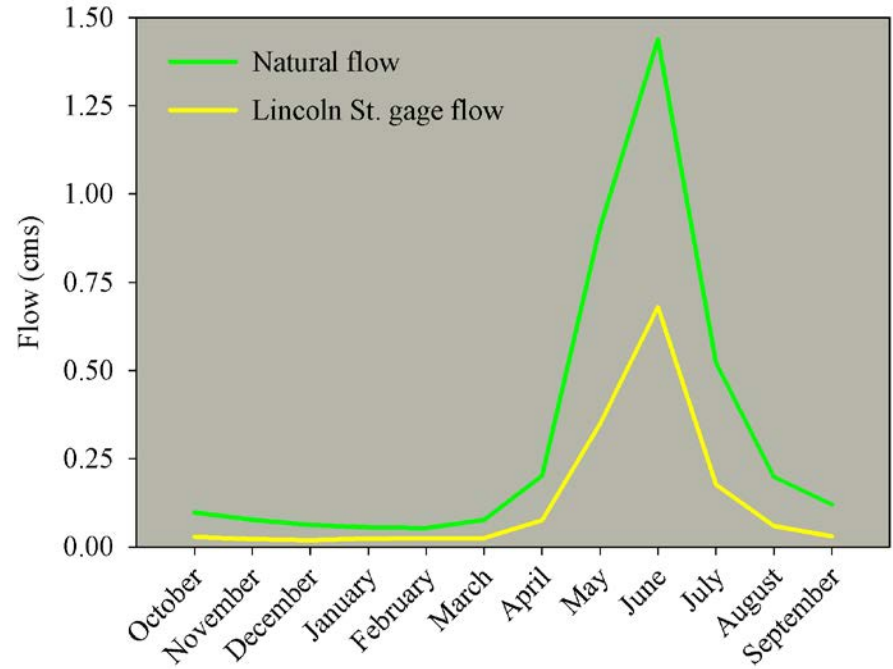
Cache la Poudre



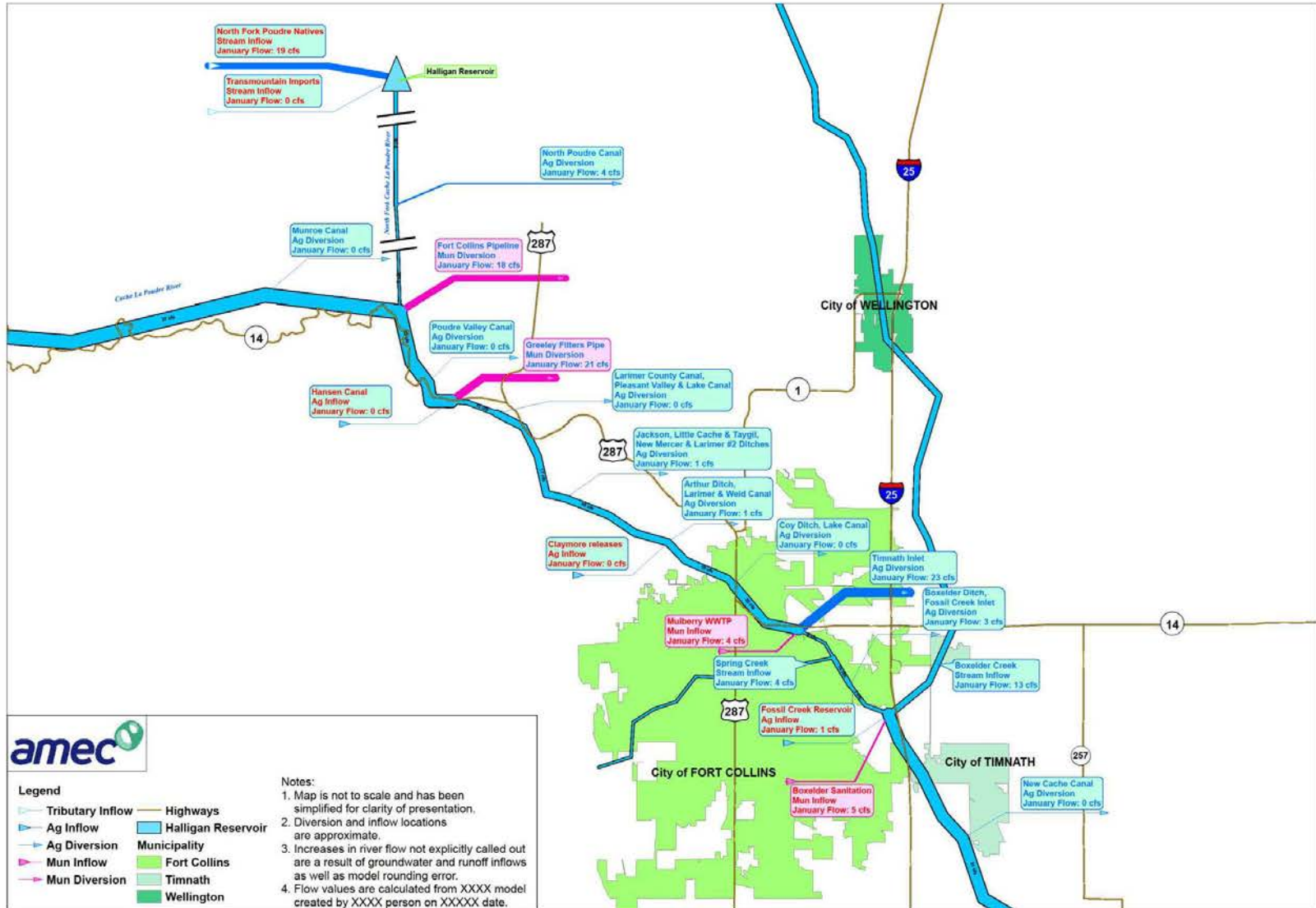
Cache La Poudre River



Cache La Poudre River: mean annual flow

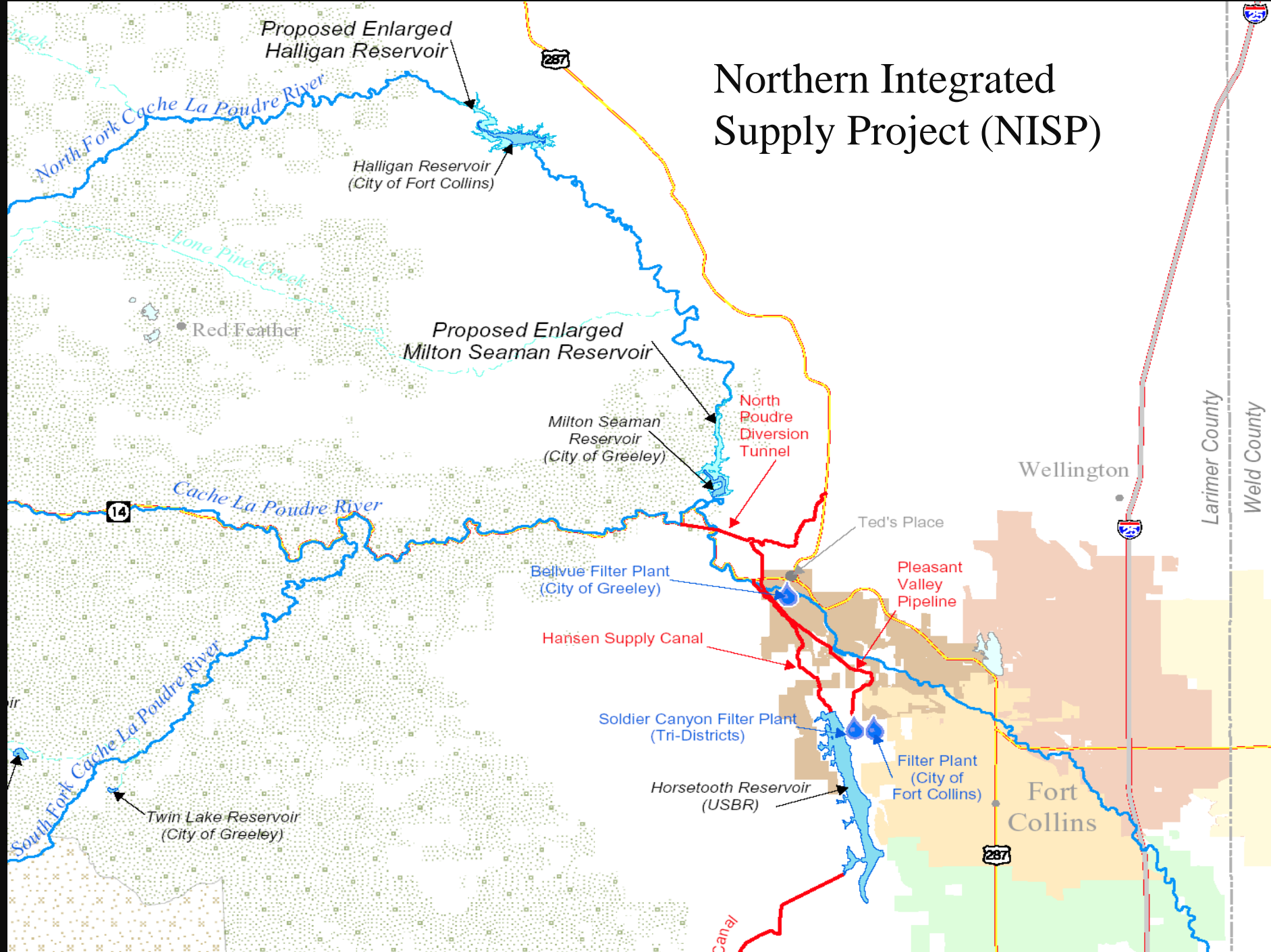


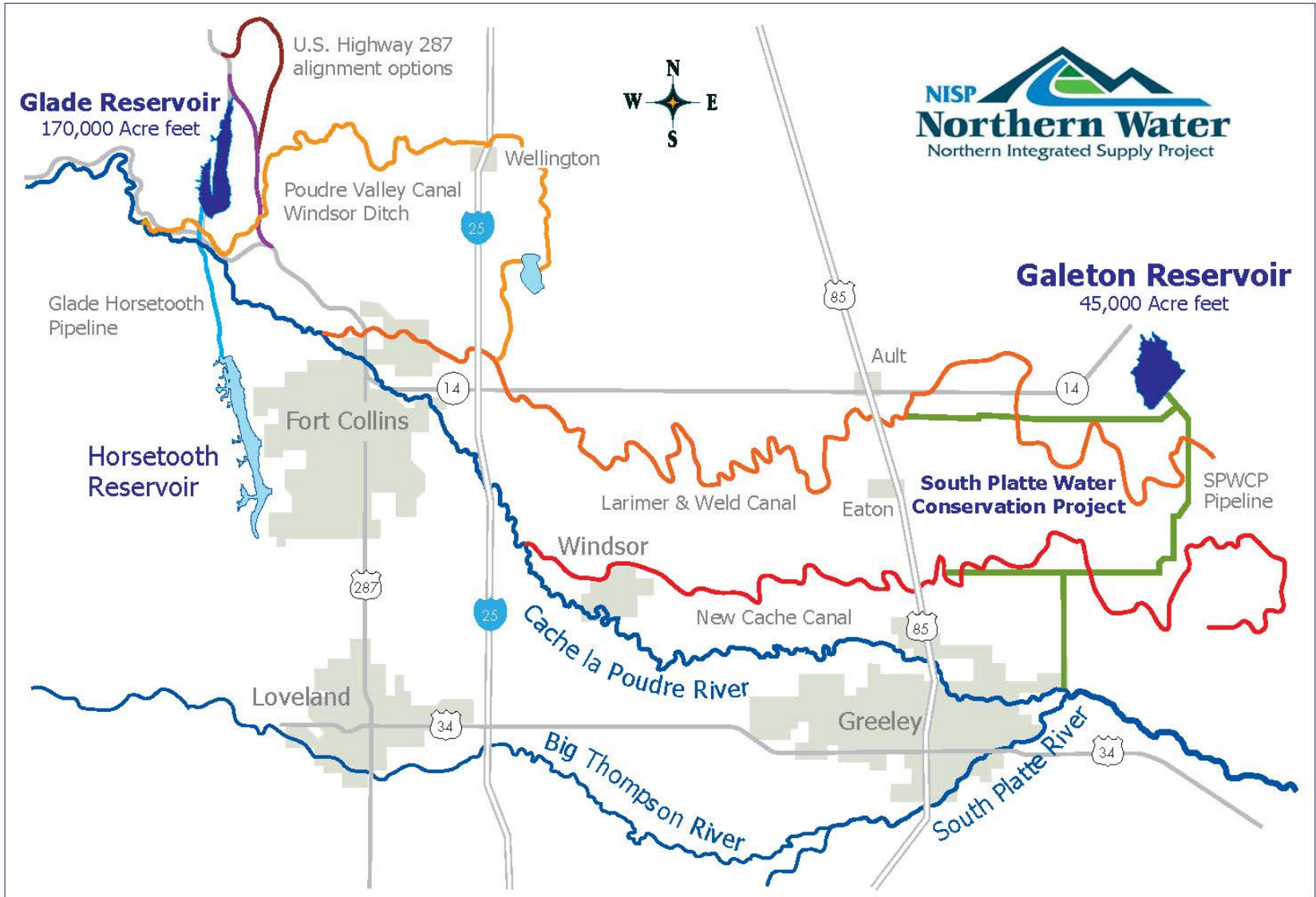
Conceptual Flow Diagram of the Cache La Poudre River in January





Northern Integrated Supply Project (NISP)







farmers for NISP
ood grow here water flows

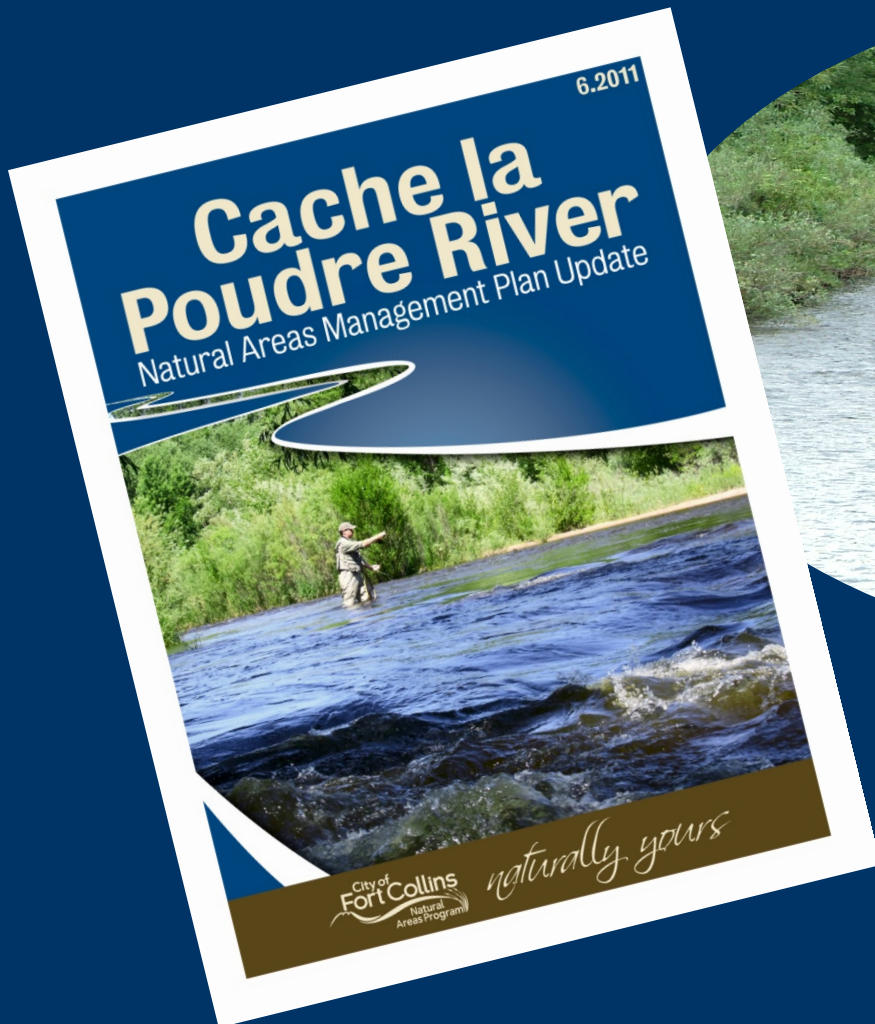


Save the Poudre
Store it in Glade





Poudre Natural Areas Management Plan



The City will support a healthy and resilient Cache la Poudre ecosystem and protect, enhance, and restore the ecological values of the River

Healthy?

- Clean water, abundant wildlife, and flourishing riparian forests
- Functioning ecological processes – e.g., dynamic interactions between flow patterns and physical habitat
- Self-sustaining – the river can maintain habitats and riparian forest itself
- Supports biodiversity through habitat diversity











Ecological Response Model Cache la Poudre River

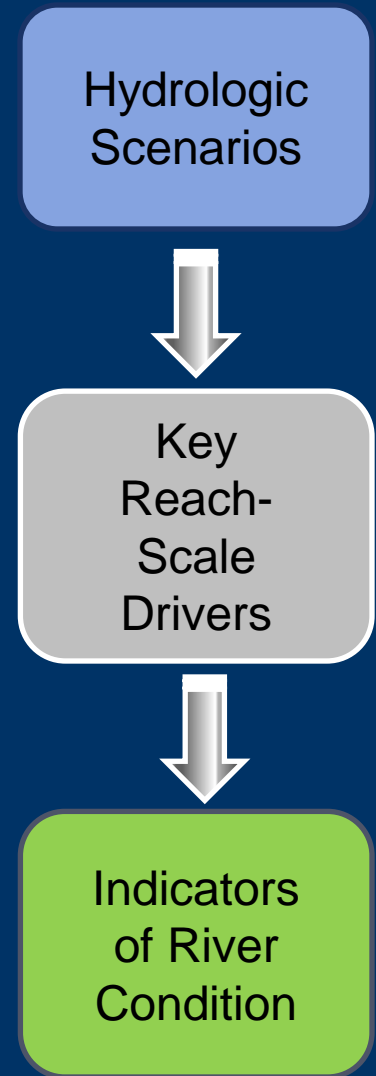
The Ecological Response Model

- To create an integrated science-based, formal understanding of Poudre River ecology and an improved understanding of ecological response to flow regime
- To reveal patterns of long-term trends associated with societally important biological attributes
- To use model to project ecological outcomes of future climate change, population growth, and water development
- To provide decision-makers and the community with a decision support tool intended to help inform management efforts to achieve the community's aspirations for a healthy and resilient Poudre River

The Ecological Response Model

Bayesian network (or probabilistic network)

- Integrates across multiple ecosystem components
- Synthetic, integrated evaluation of cause and effect among ecosystem elements
- Incorporates different sources of data and information (e.g., output from other models and expert judgment)
- Explicit about uncertainty (output is probability of various states)
- Allows for scenario testing



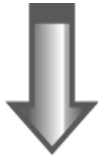
Hydrologic Scenarios

*CLP Basin Hydrology
Water Administration
Climate*



Key Reach Scale Drivers

*Geomorphology, Hydraulics,
Urban Channel and Bank Alteration,
Water Quality*



Indicators of River Condition

Channel
Structure

Algae

Aquatic
Macro-
invertebrates

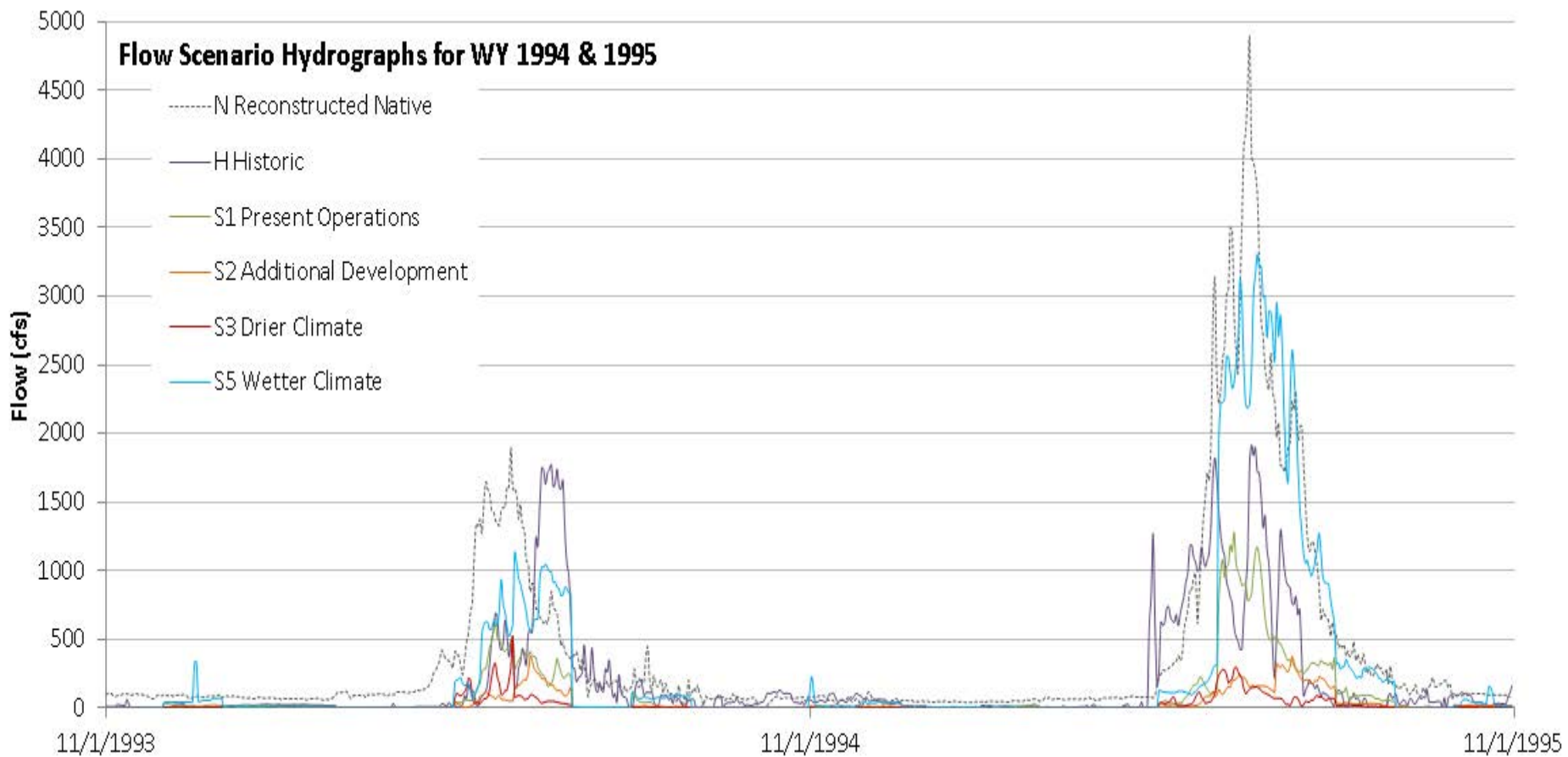
Native Fish

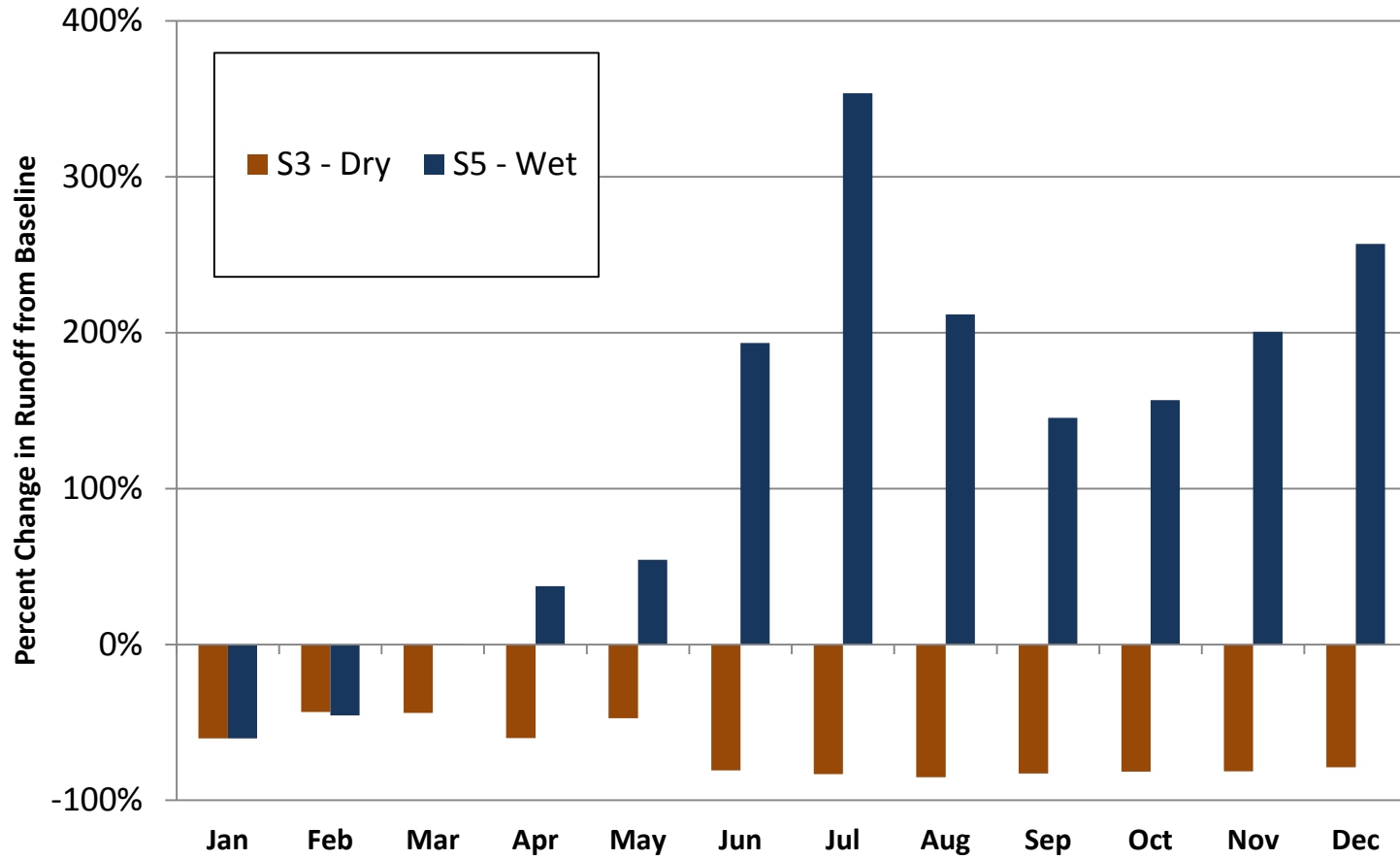
Trout

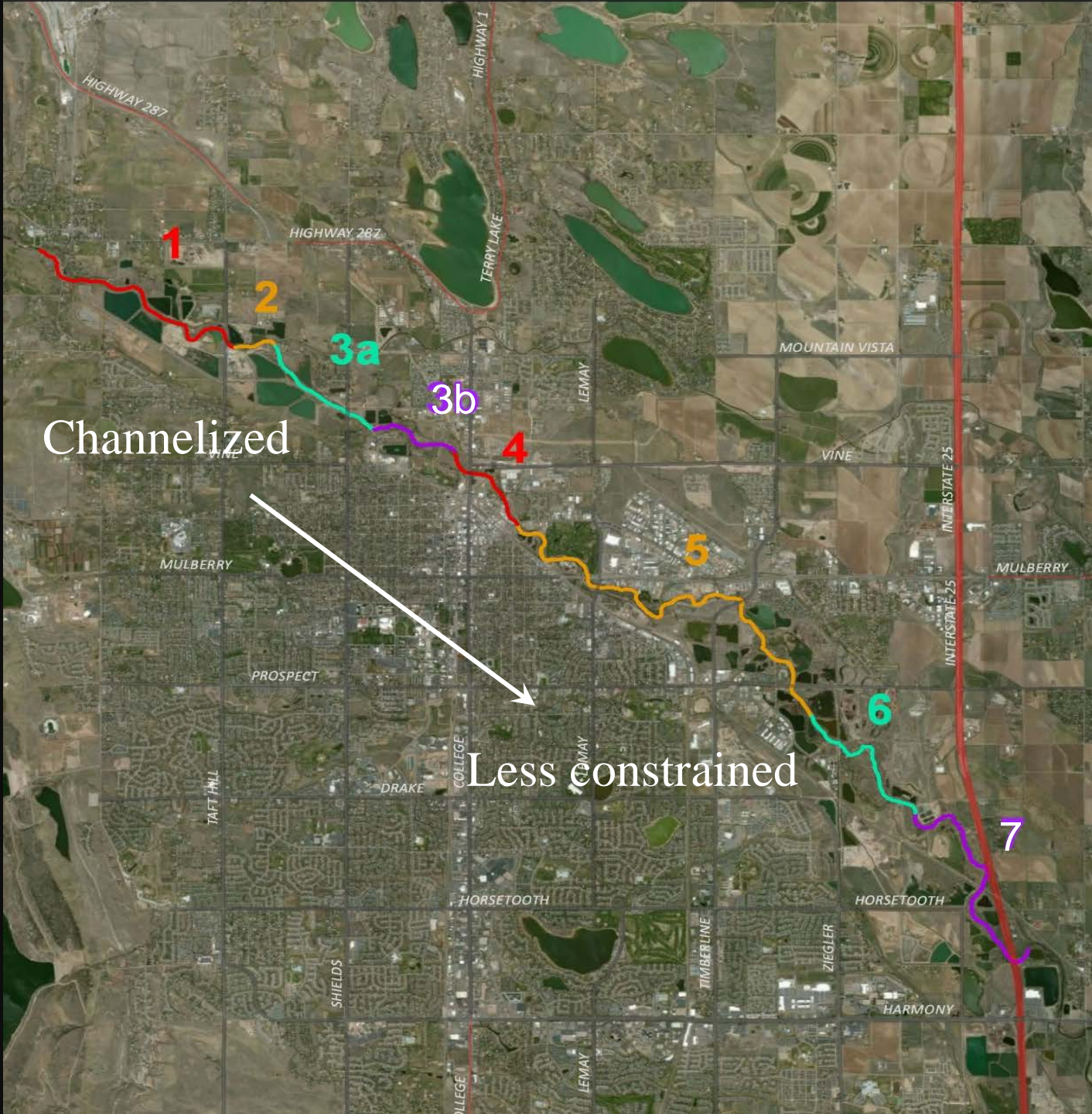
Rejuvenating
Mosaic

Riparian
Wetlands





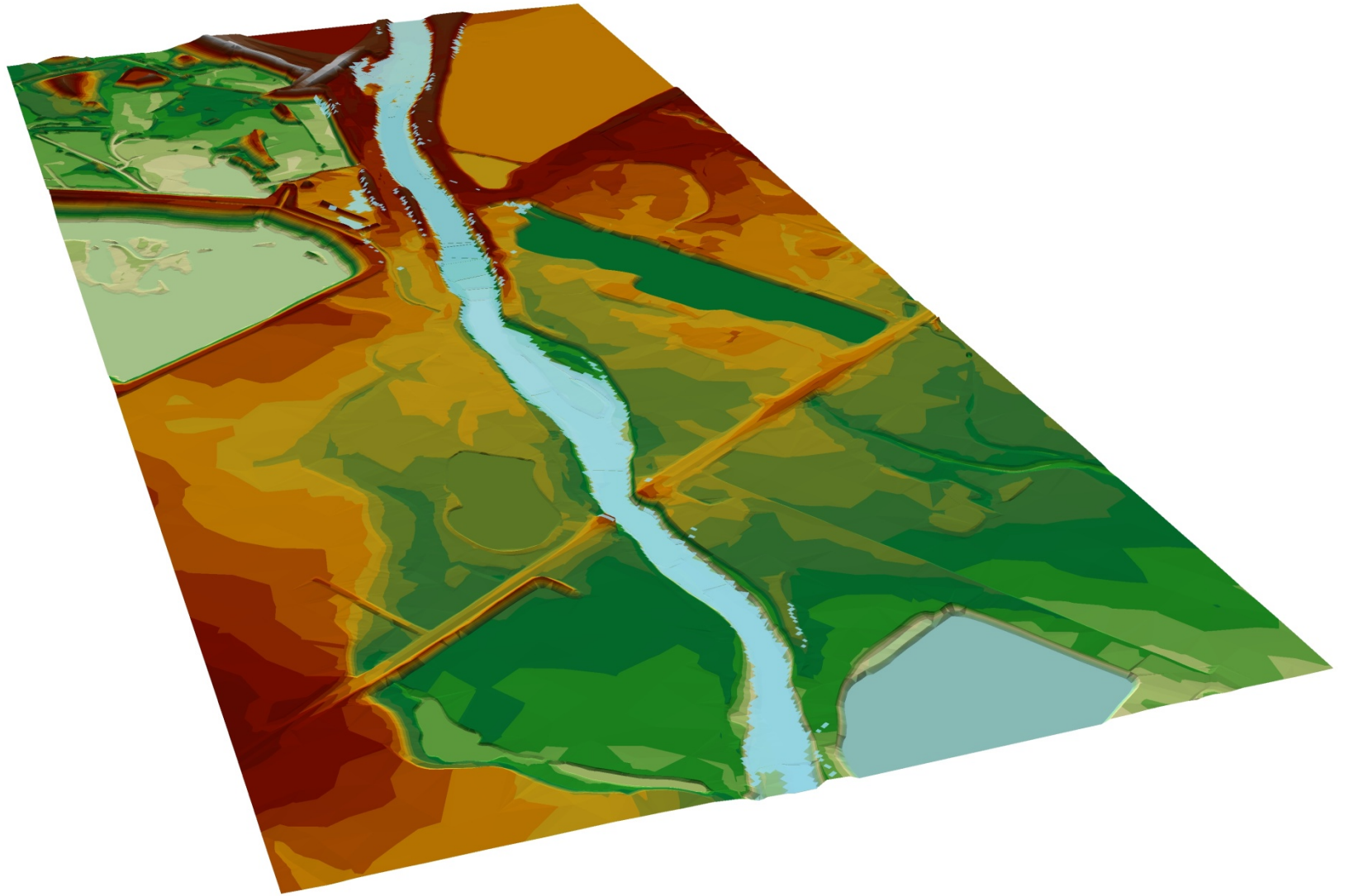


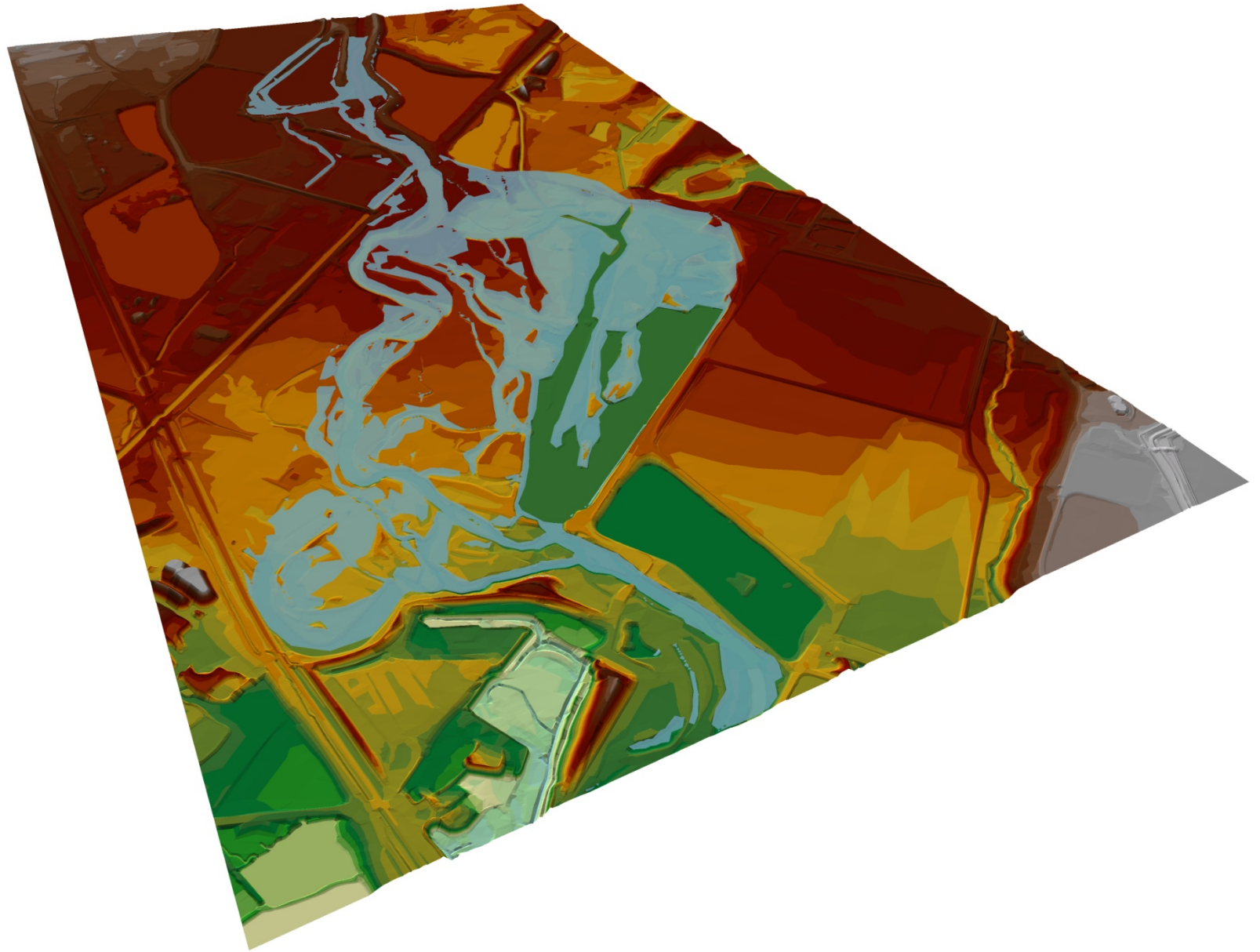


Channelized

Less constrained

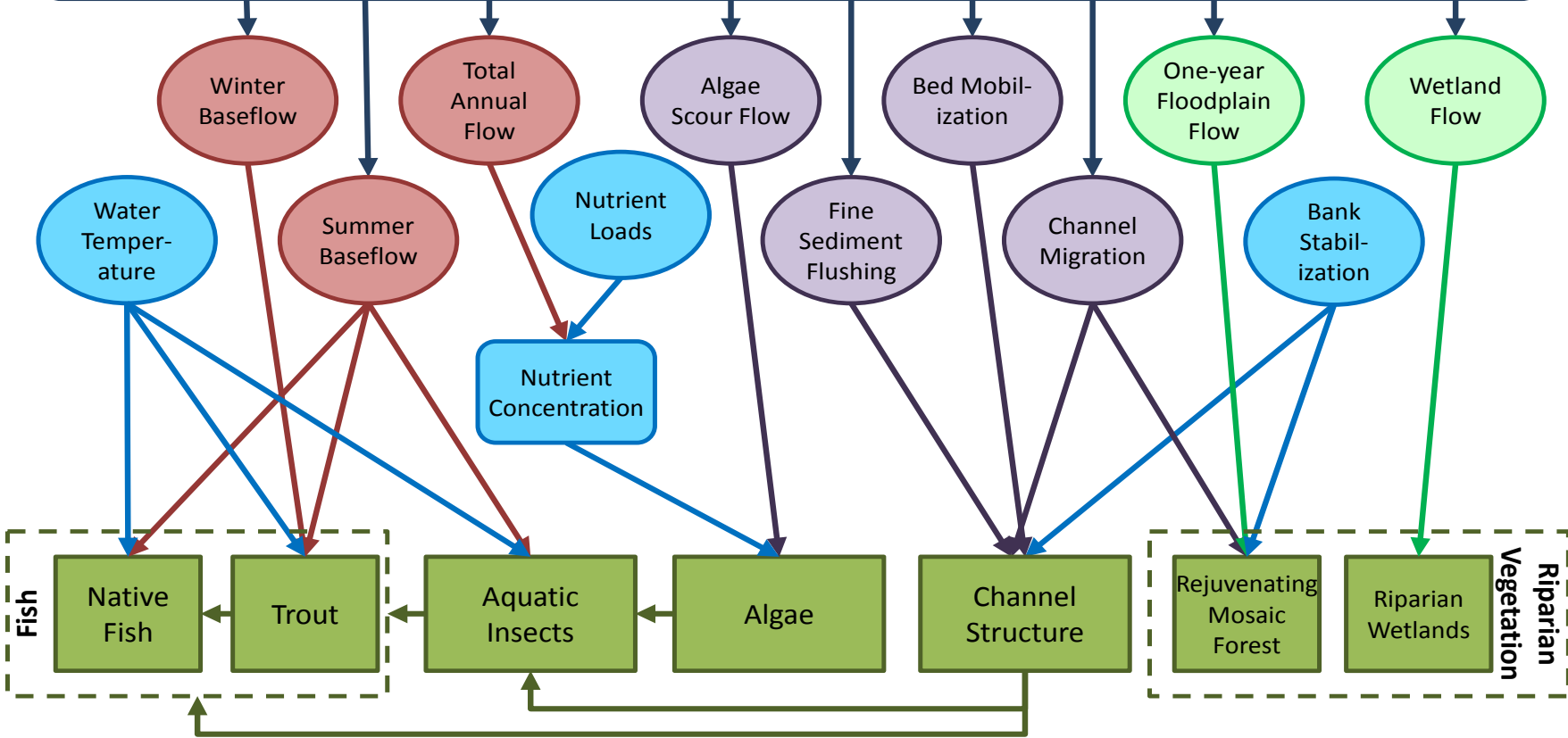
- 1
- 2
- 3a
- 3b
- 4
- 5
- 6
- 7





H = Historic
 N = Reconstructed Native
 S1 = Present Operations Continued

S2 = Additional Water Development
 S3 = Drier Climate
 S5 = Wetter Climate



Legend

- Hydrologic scenarios
- General flow metrics
- Riparian functions
- Drivers not derived from hydrologic scenarios
- High flow functions
- Indicators or river condition

Four possible *states* for brown trout

- + Multiple age classes; successful annual reproduction; high total biomass; resilient to multiple detrimental events; viable recreational fishery; many adult fish
- 0 Three age classes; more variability across years in terms of biomass and reproduction; variable as a recreational fishery from year to year; occasional years with moderate numbers of adult fish
 - Dominated by a single age-class - others may be present; reproduction minimal; recovery from stressor events would take several years; generally poor fishery; inconsistent from year to year
 - Single age-class present; very sporadic reproduction; low abundance, population vulnerable to one detrimental event/year; poor fishery in danger of collapse; many years of good condition required for recovery.



Trout States

Channel Structure	--	-	0	+
Clean and diverse	0	0	0.25	0.75
Partially mobile and diverse	0	0.25	0.5	0.25
Largely immobile and homogeneous	0	0.5	0.5	0
Entrenched	0.75	0.25	0	0

Trout States

Winter Baseflow	--	-	0	+
Adequate flow-cool water (<23°C)	0	0.15	0.15	0.7
Adequate flow-cool water (>23°C)	0	0.25	0.5	0.25
Inadequate flow-cool water (<23°C)	0.25	0.5	0.25	0
Inadequate flow-warm water (>23°C)	0.75	0.15	0.15	0

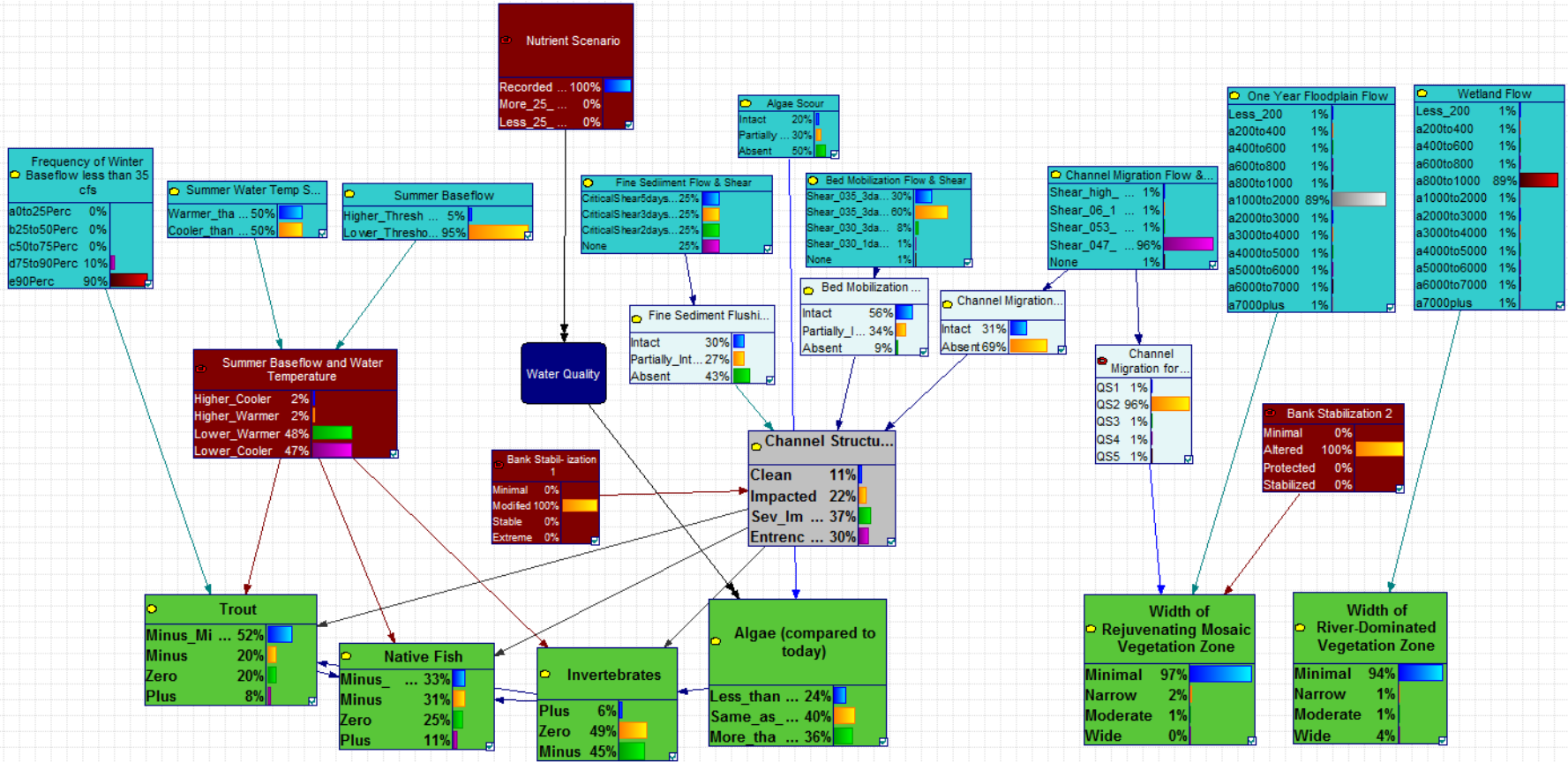
Channel
Structure

Winter Base
Flow

Aquatic
Macroinvertebrates

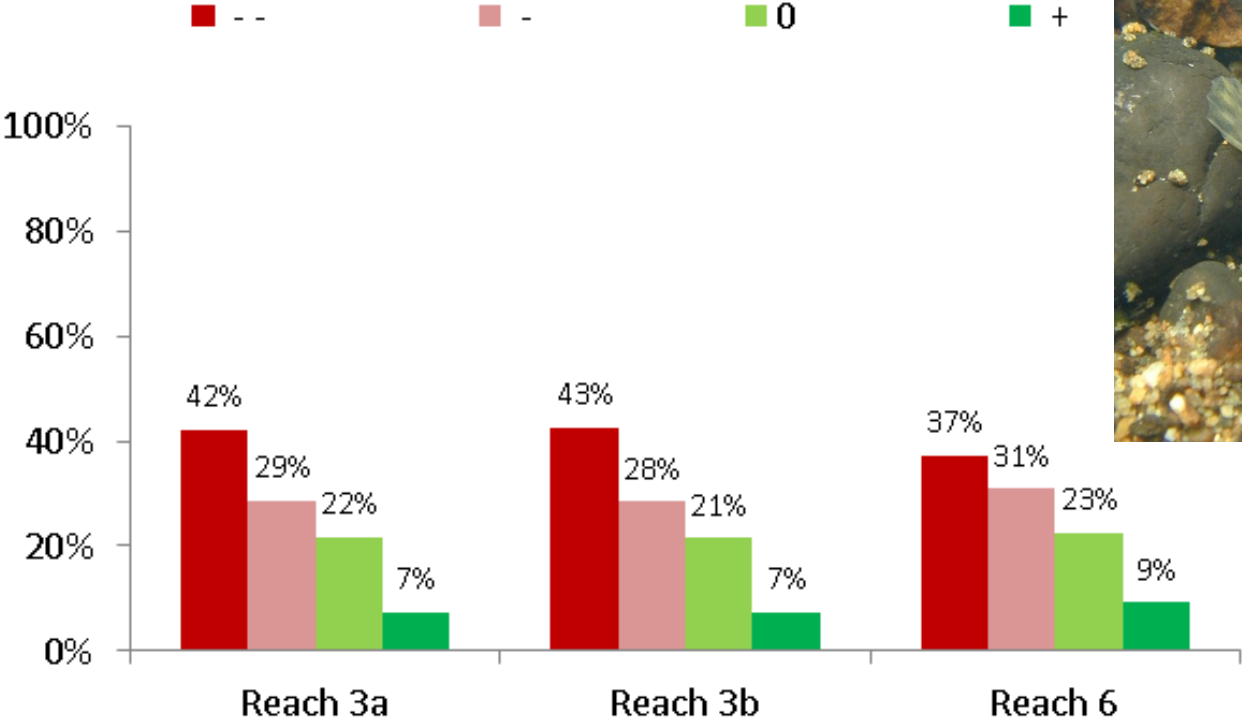
Trout
Population





Flow scenario: Historic flows

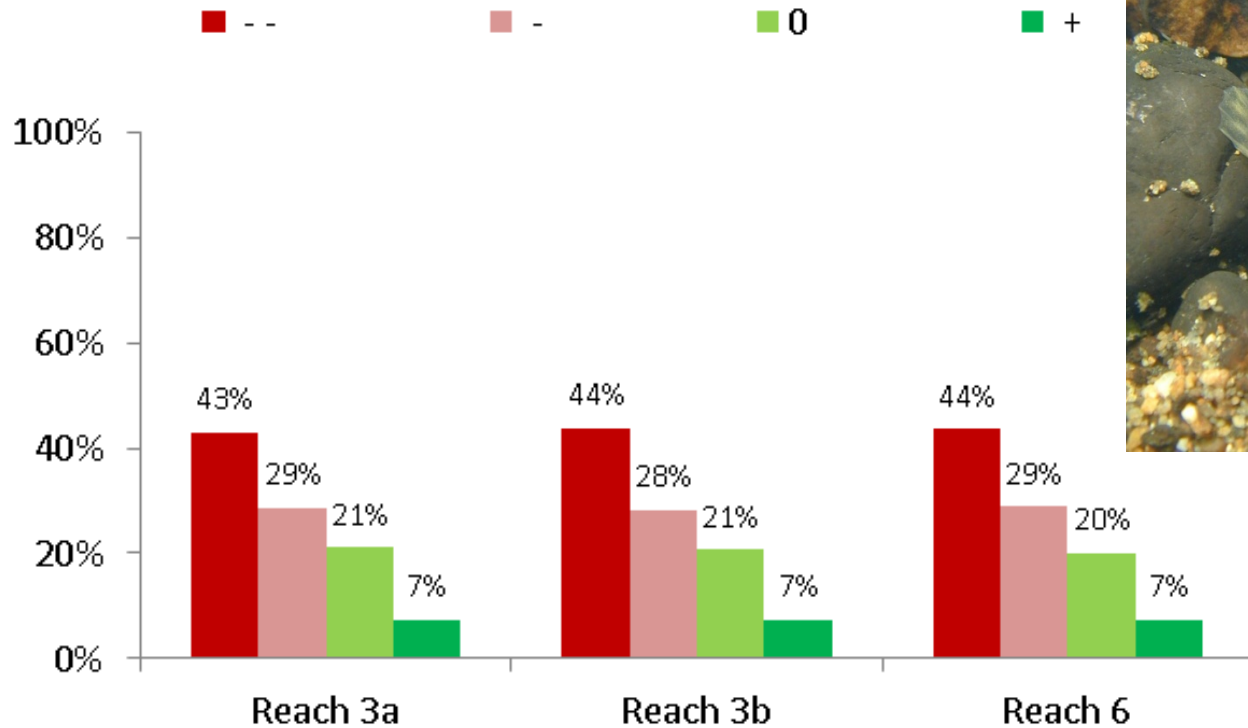
Response variable: Native fish



Channelized \longrightarrow Less constrained

Flow scenario: Present operations

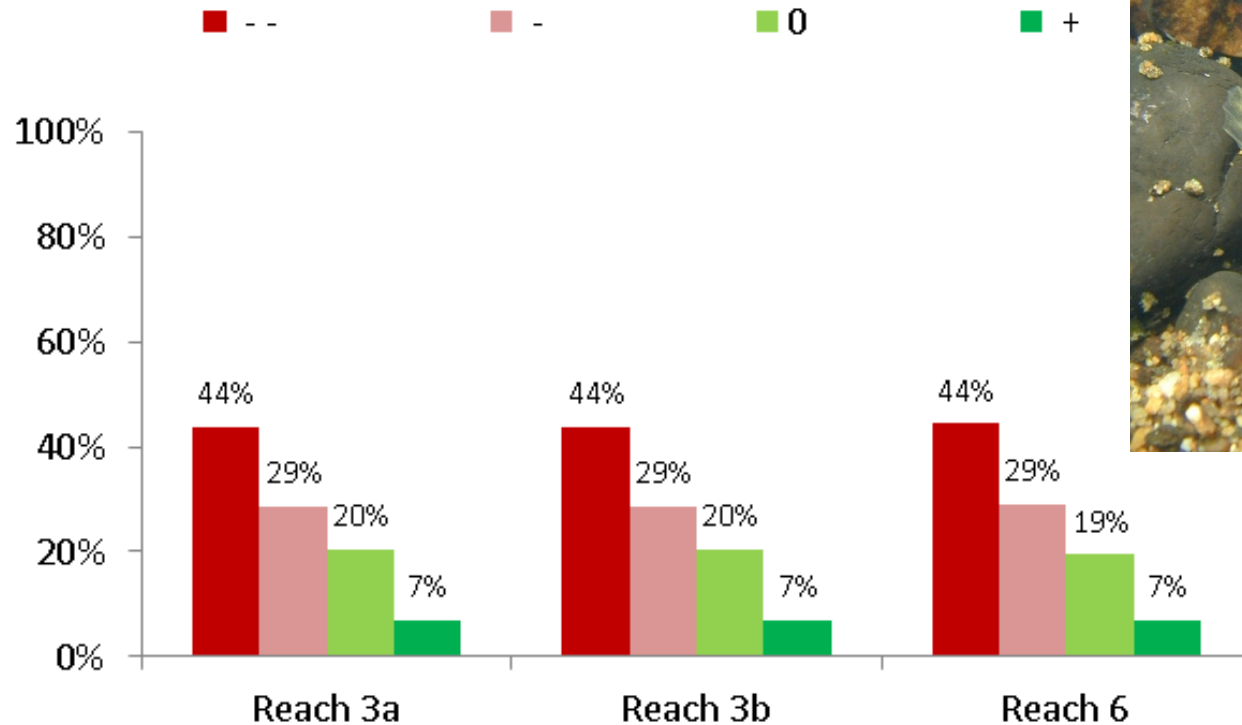
Response variable: Native fish



Channelized \longrightarrow Less constrained

Flow scenario: Additional water development

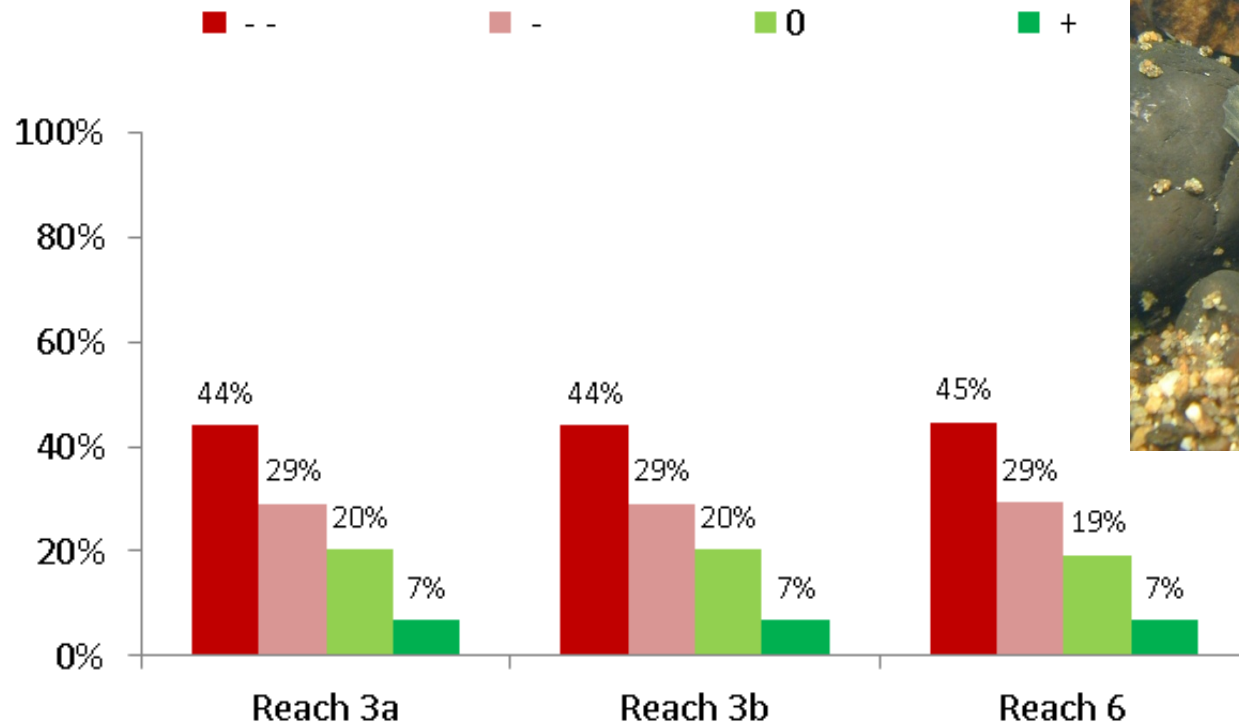
Response variable: Native fish



Channelized \longrightarrow Less constrained

Flow scenario: Present operations-drier climate

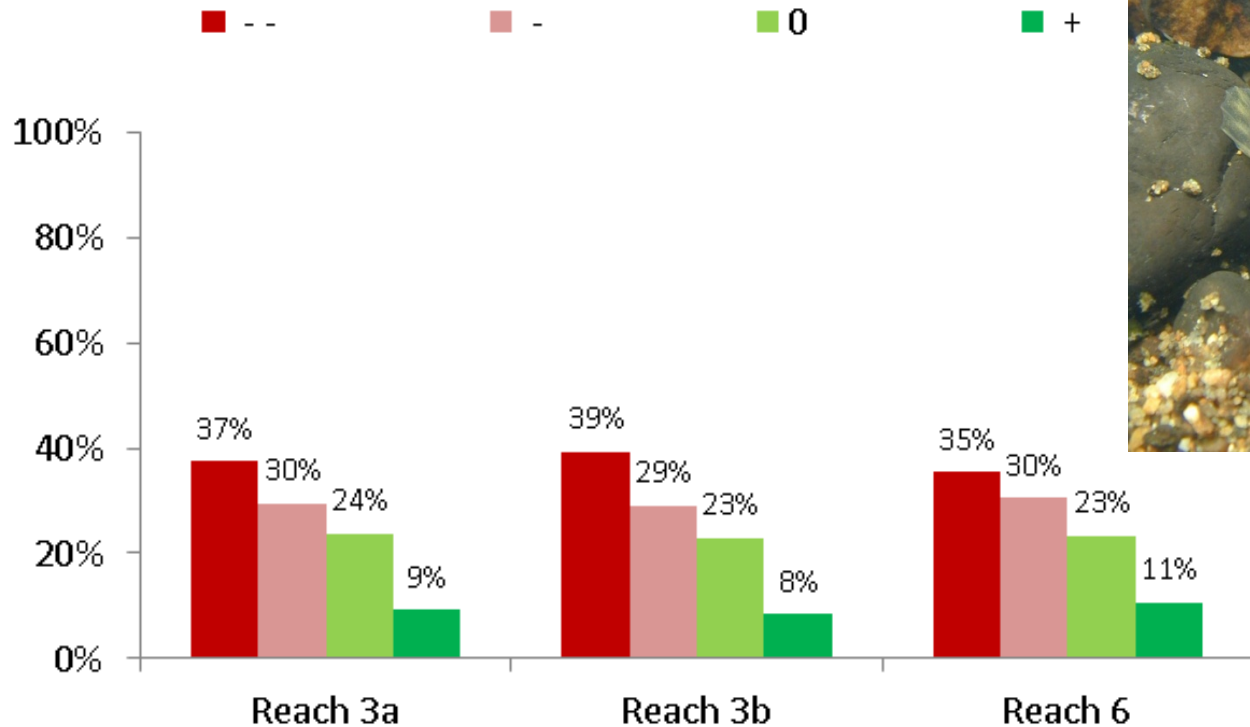
Response variable: Native fish



Channelized \longrightarrow Less constrained

Flow scenario: Present operations-wetter climate

Response variable: Native fish

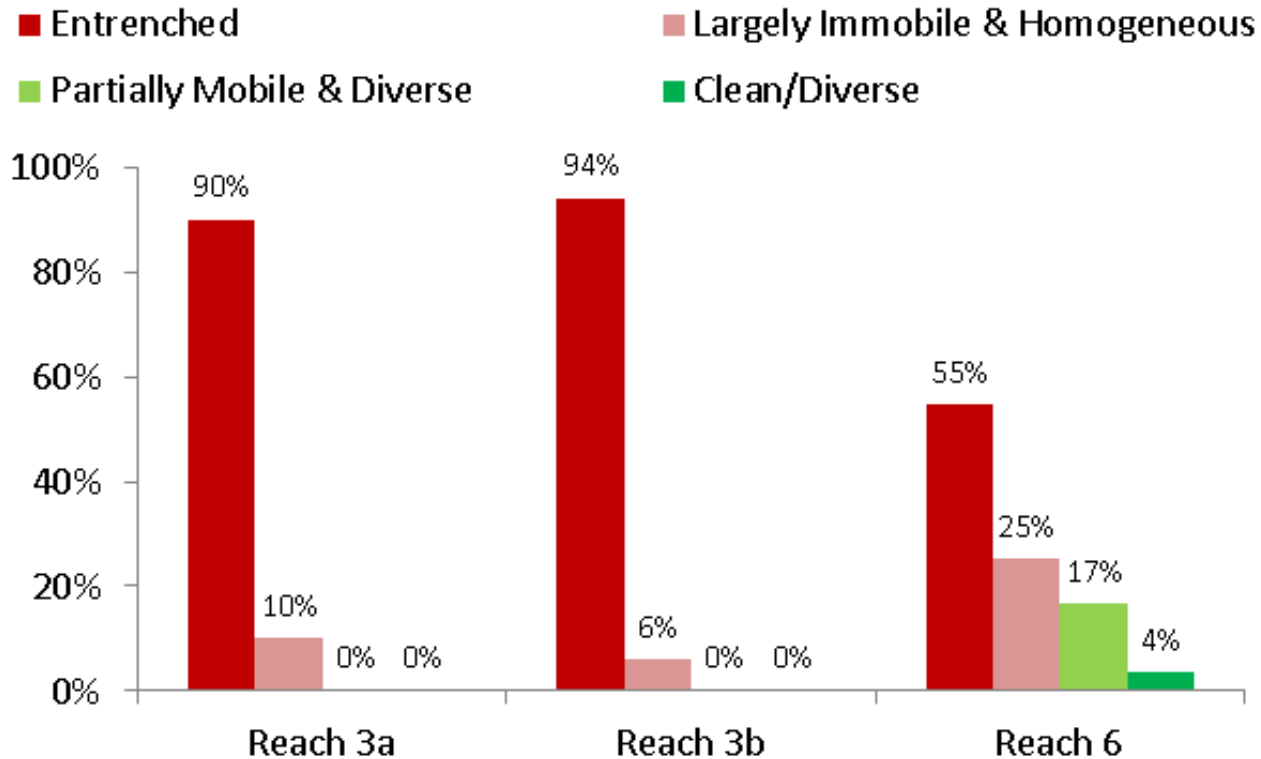


Channelized \longrightarrow Less constrained



Flow scenario: Historic flows

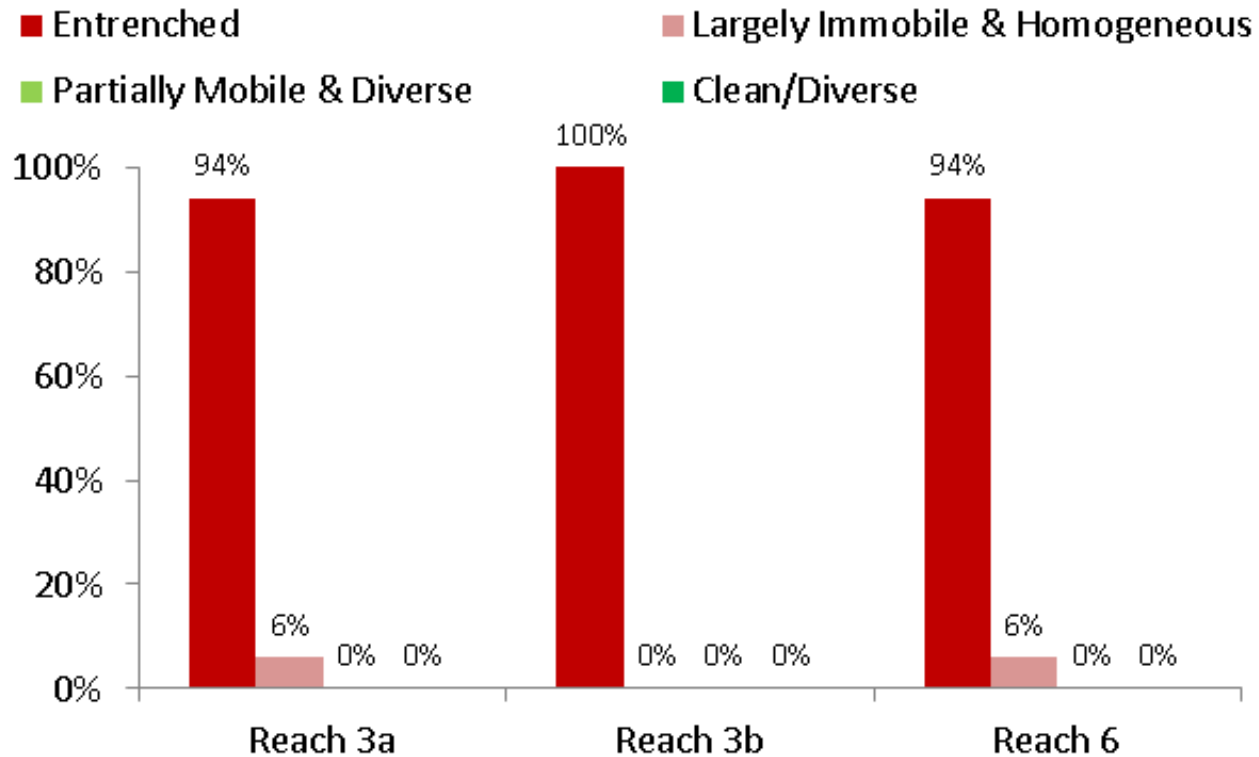
Response variable: Channel and substrate



Channelized \longrightarrow Less constrained

Flow scenario: Present operations

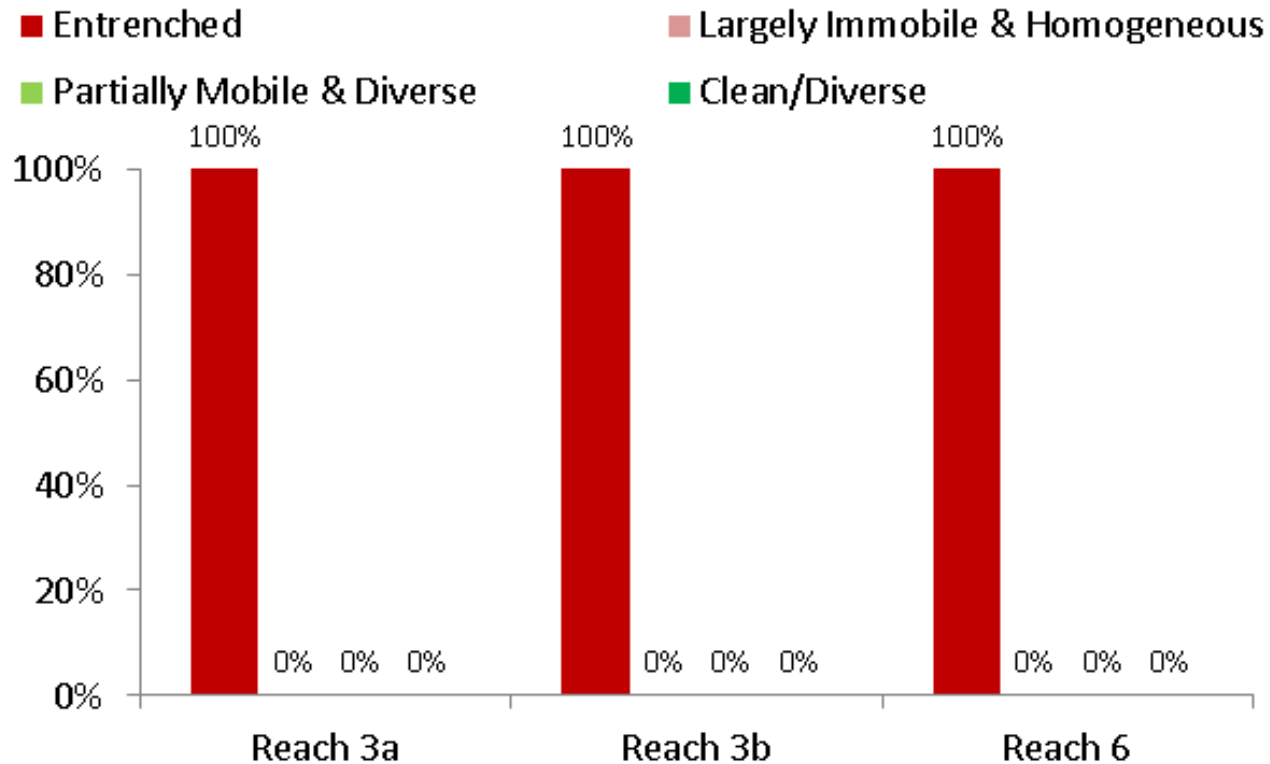
Response variable: Channel and substrate



Channelized \longrightarrow Less constrained

Flow scenario: Additional water development

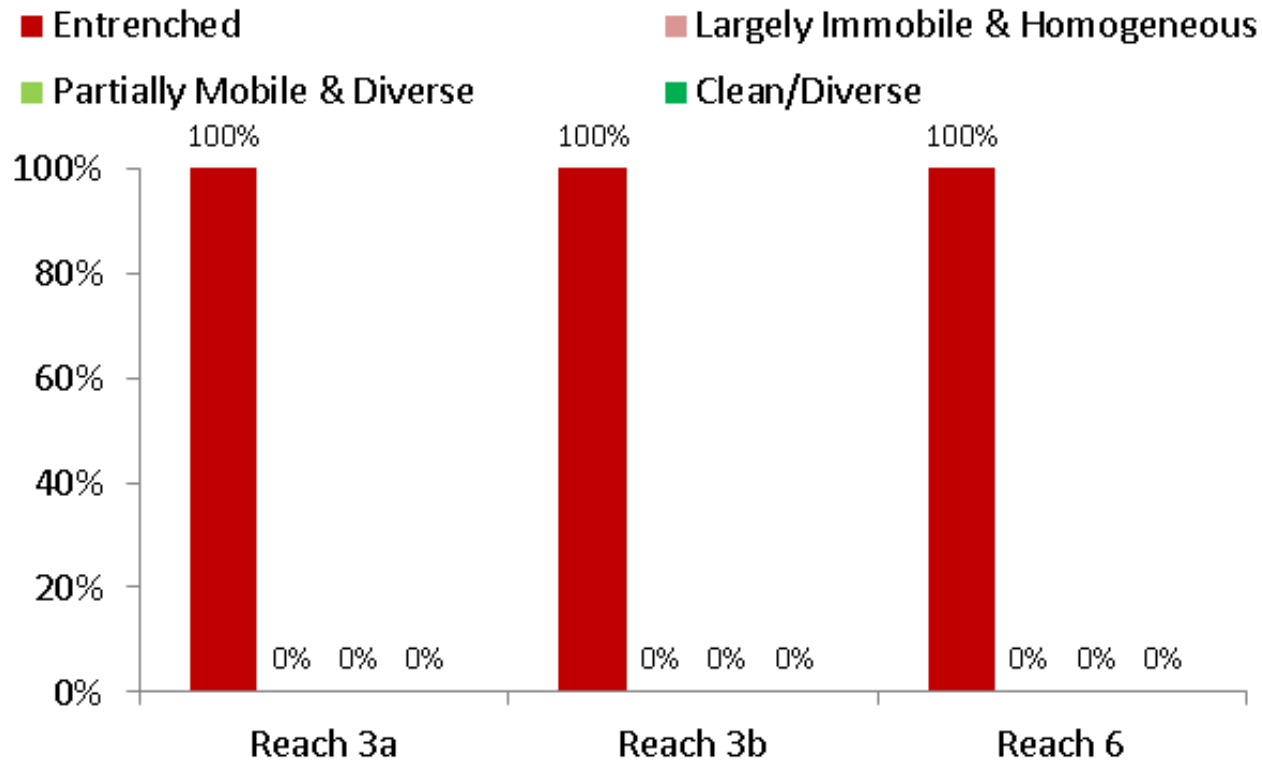
Response variable: Channel and substrate



Channelized → Less constrained

Flow scenario: Present operations-drier climate

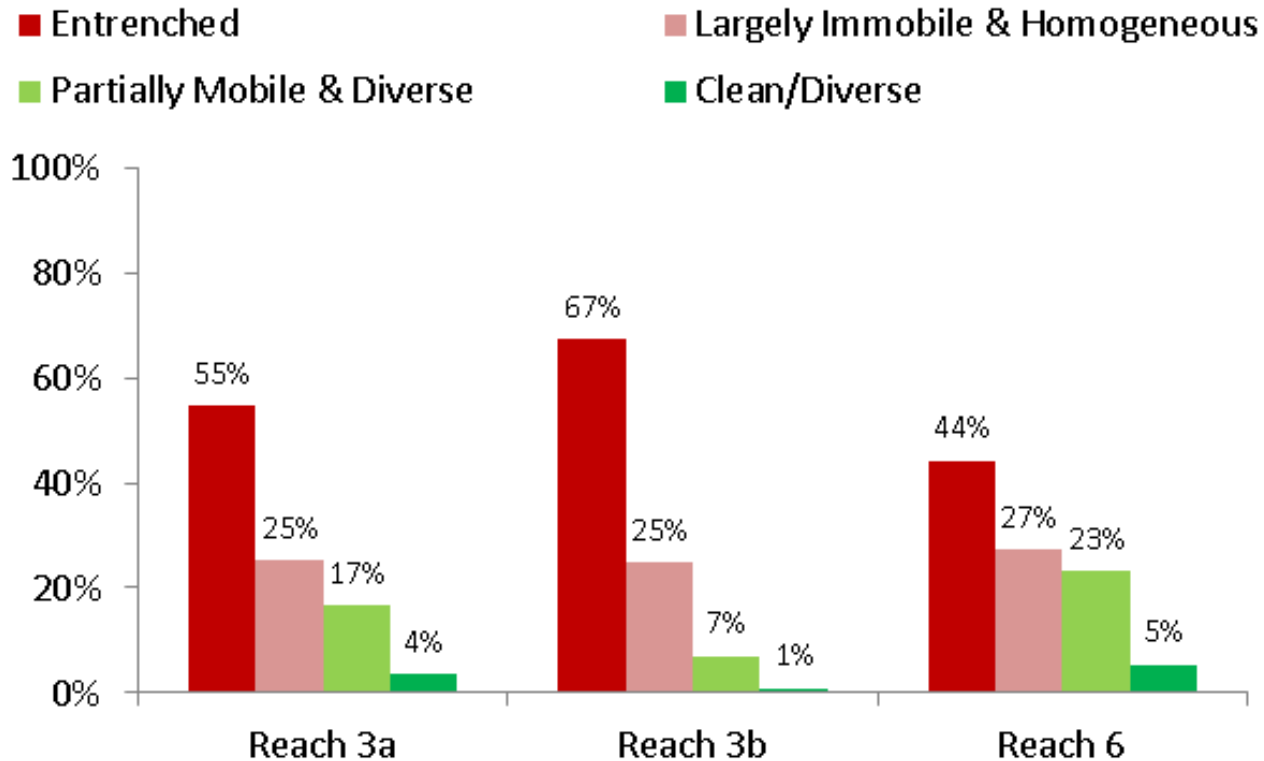
Response variable: Channel and substrate



Channelized \longrightarrow Less constrained

Flow scenario: Present Operations-wetter climate

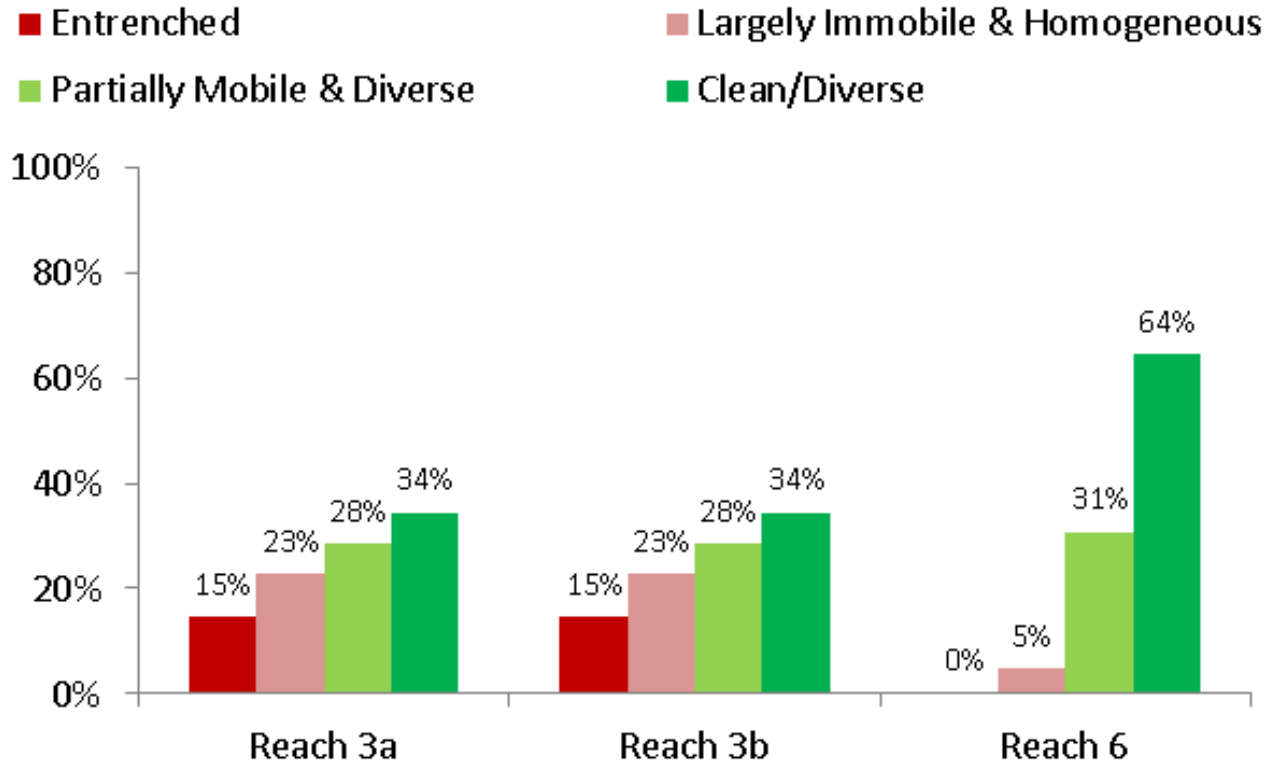
Response variable: Channel and substrate



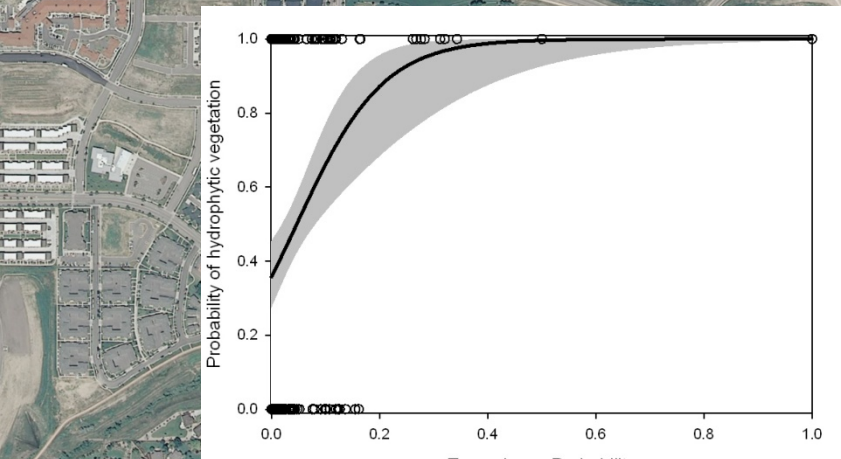
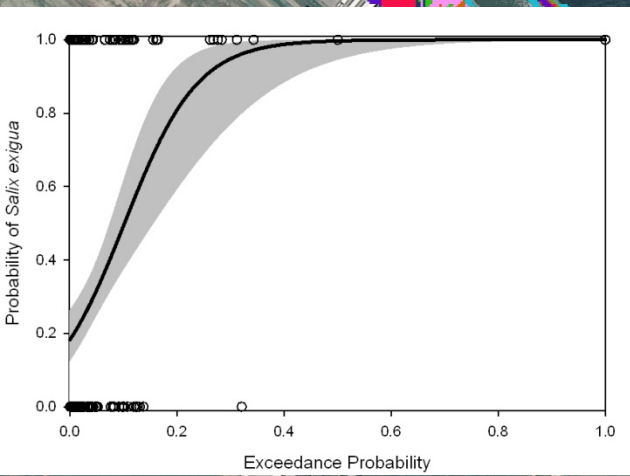
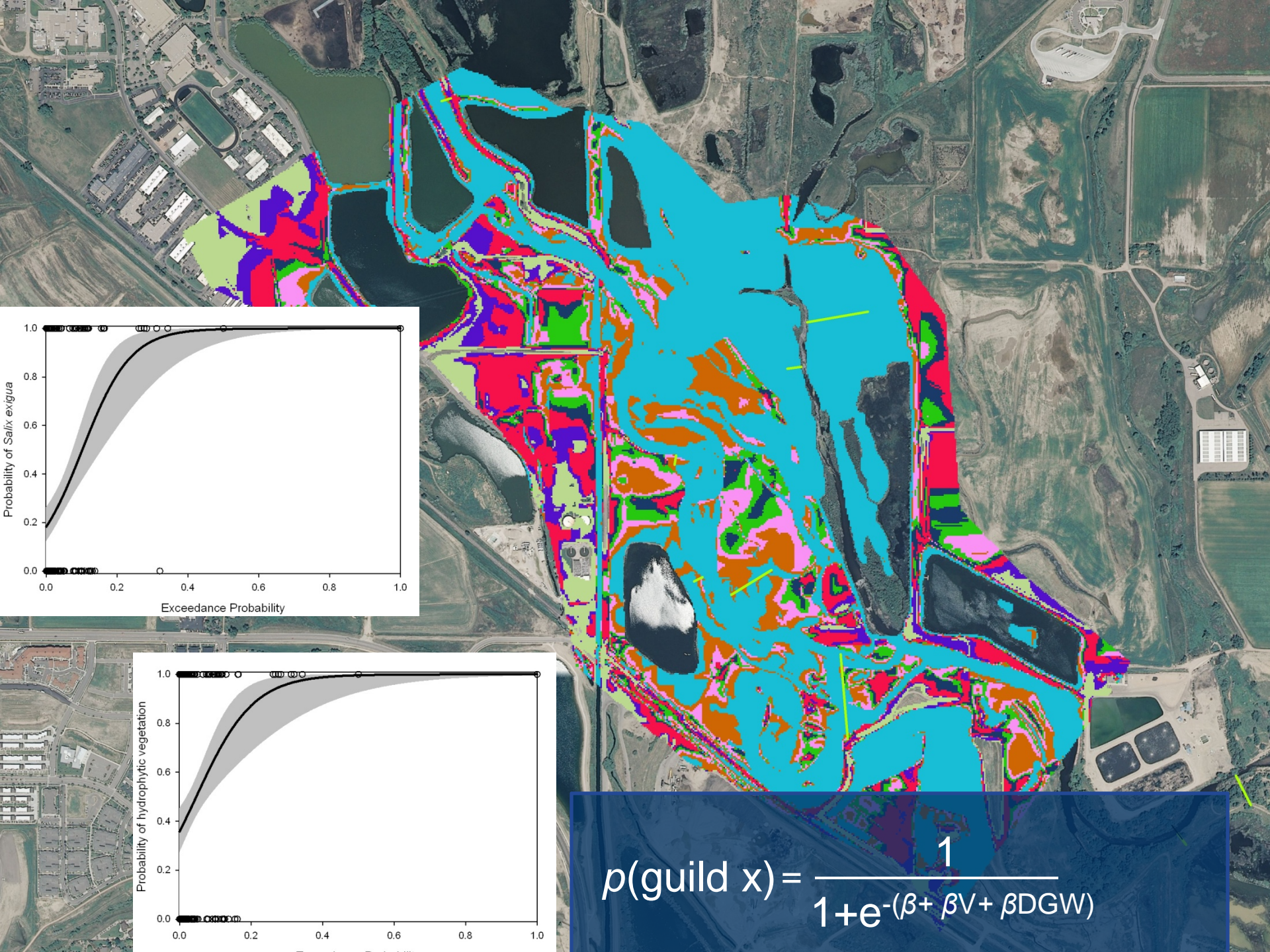
Channelized \longrightarrow Less constrained

Flow scenario: Reconstructed natural flows

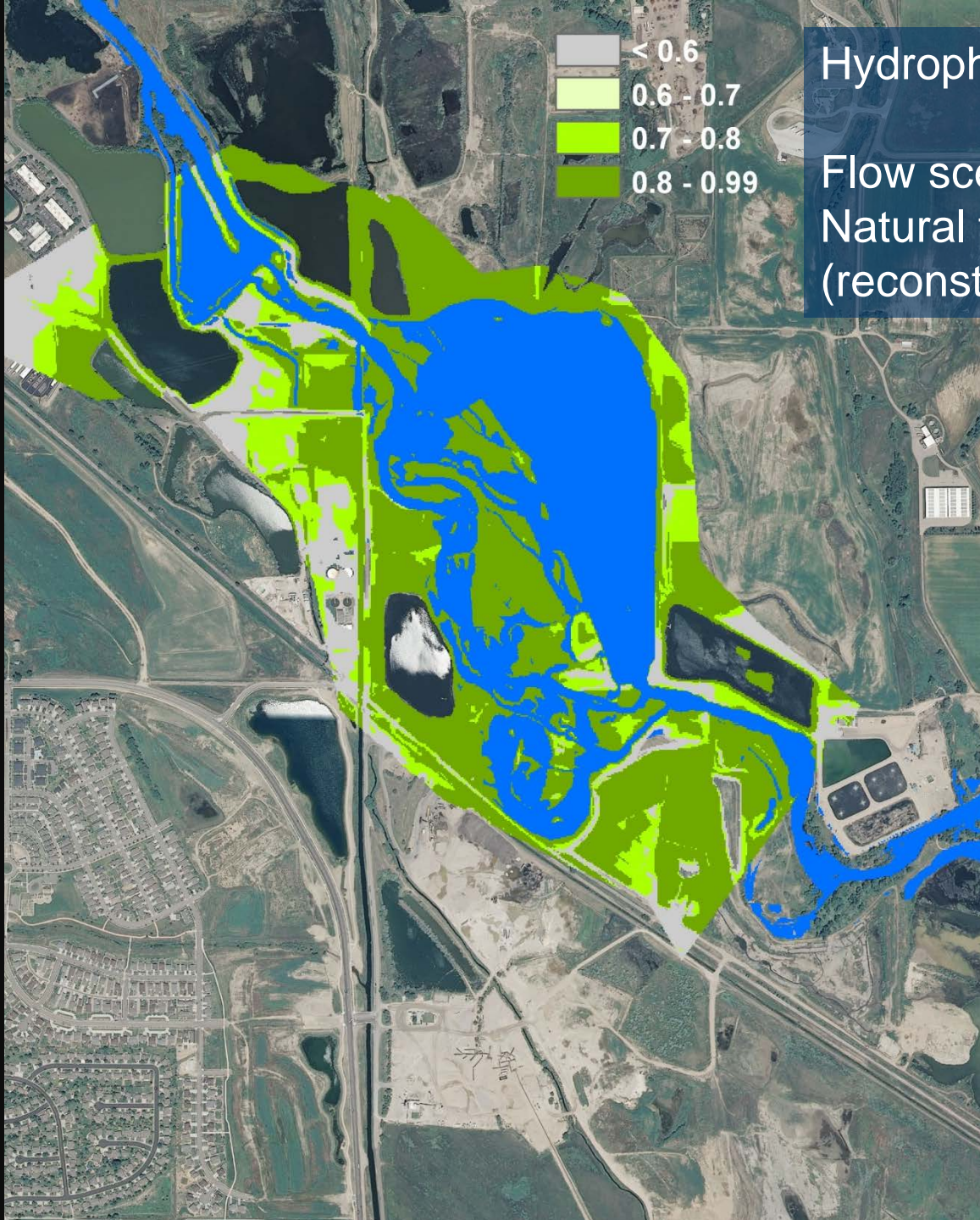
Response variable: Channel and substrate



Channelized \longrightarrow Less constrained

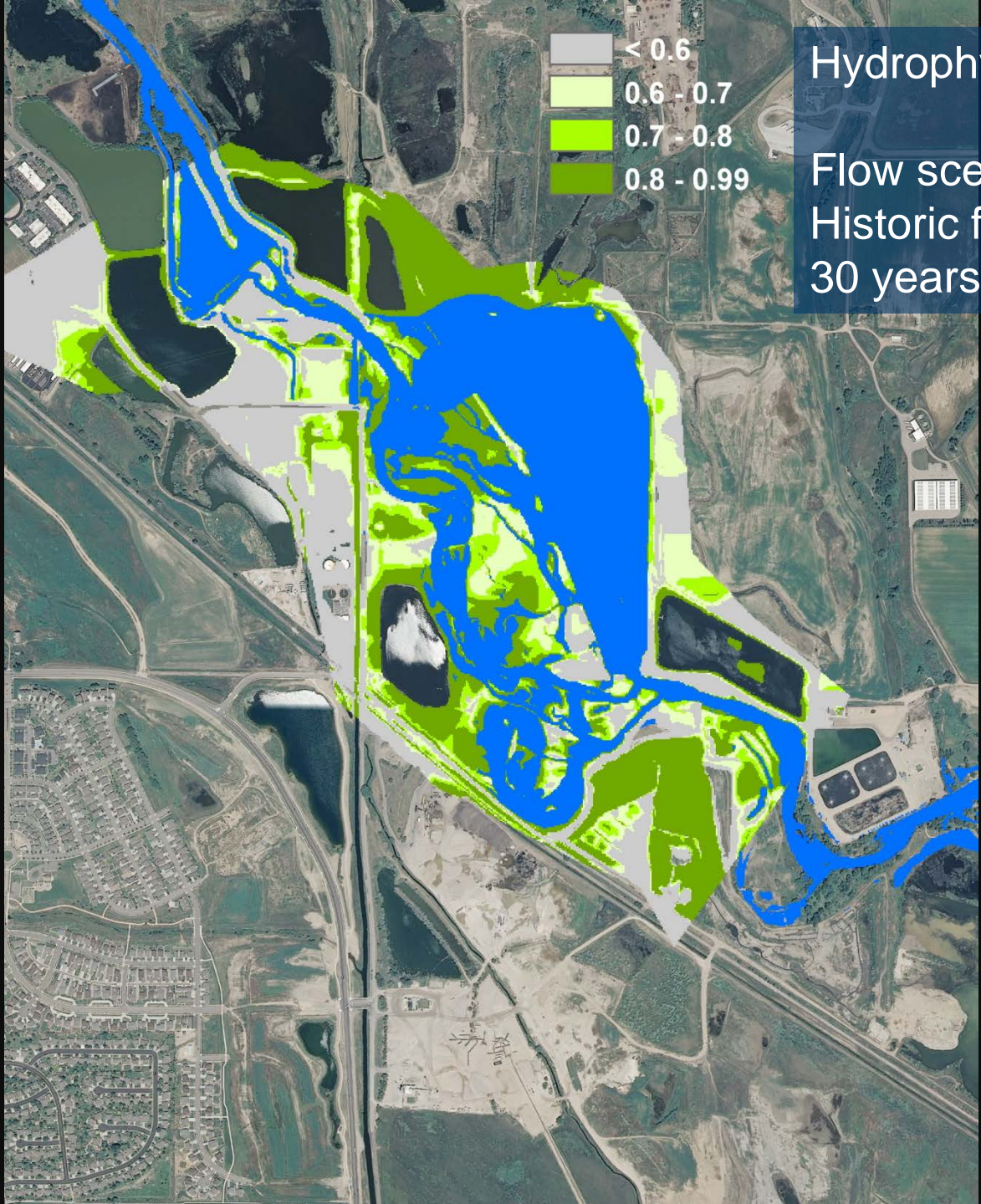


$$p(\text{guild } x) = \frac{1}{1 + e^{-(\beta + \beta V + \beta DGW)}}$$

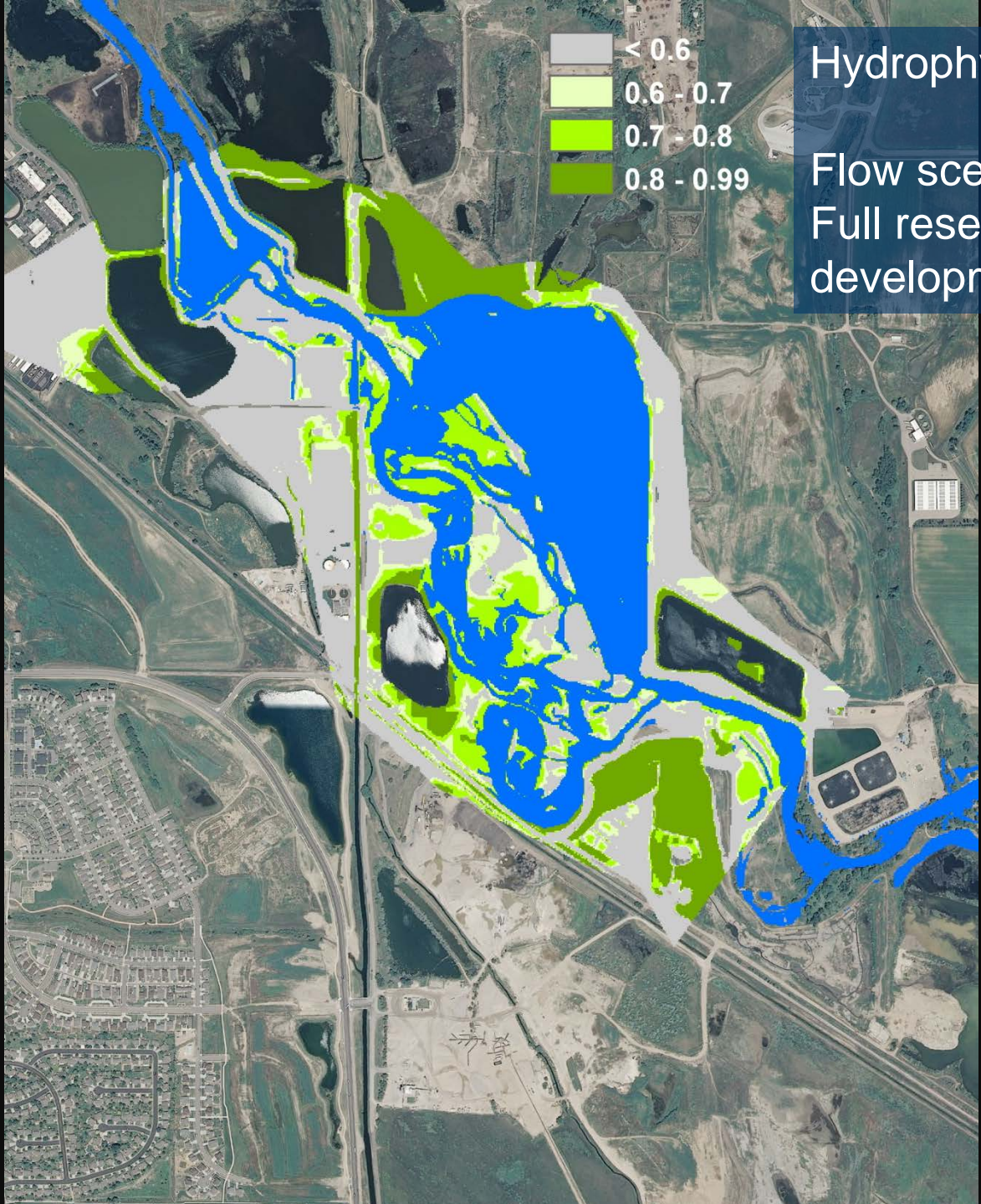


Hydrophytic guild
Flow scenario:
Natural flow regime
(reconstructed)

- < 0.6
- 0.6 - 0.7
- 0.7 - 0.8
- 0.8 - 0.99

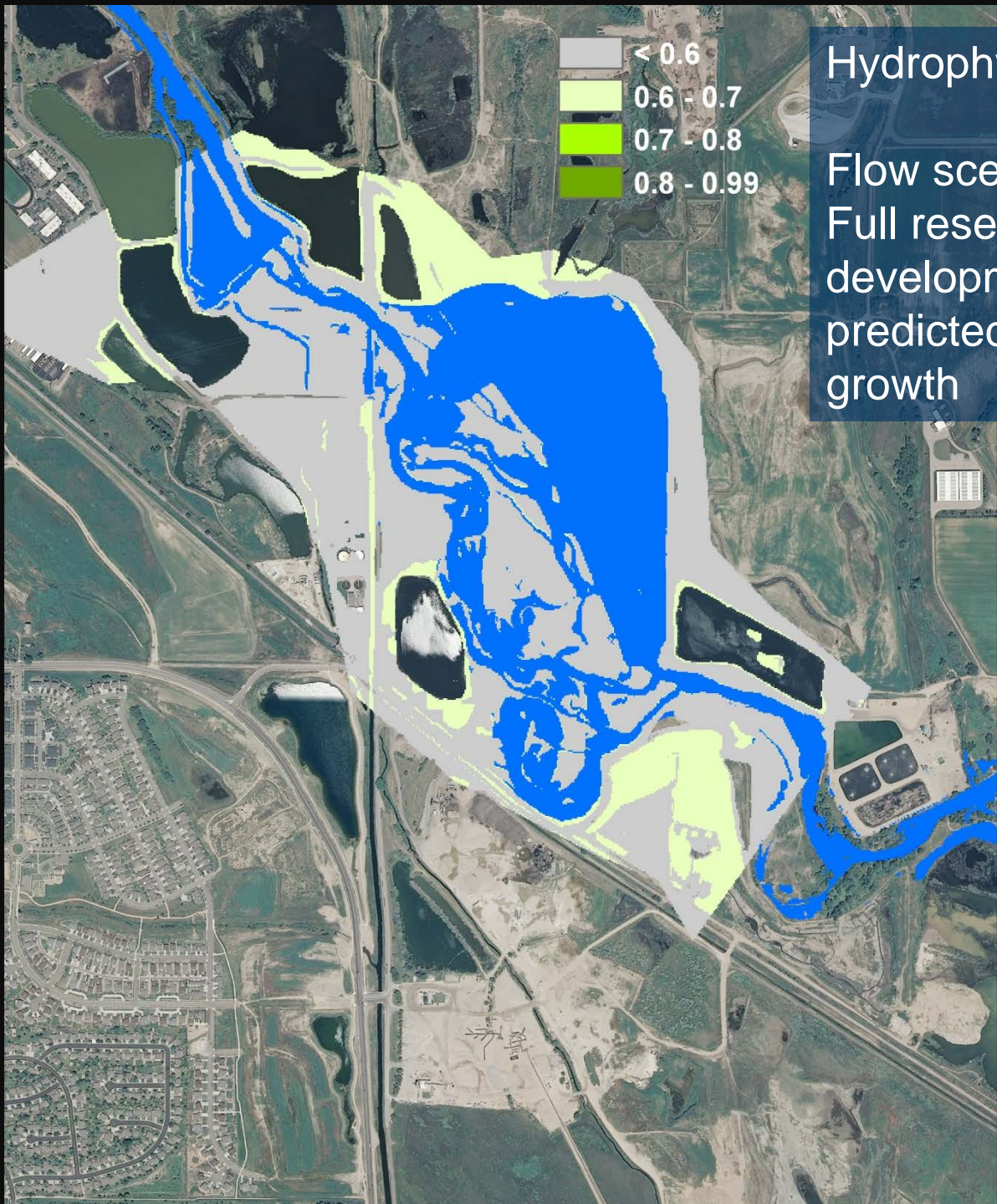


Hydrophytic guild
Flow scenario:
Historic flow (past
30 years)



Hydrophytic guild

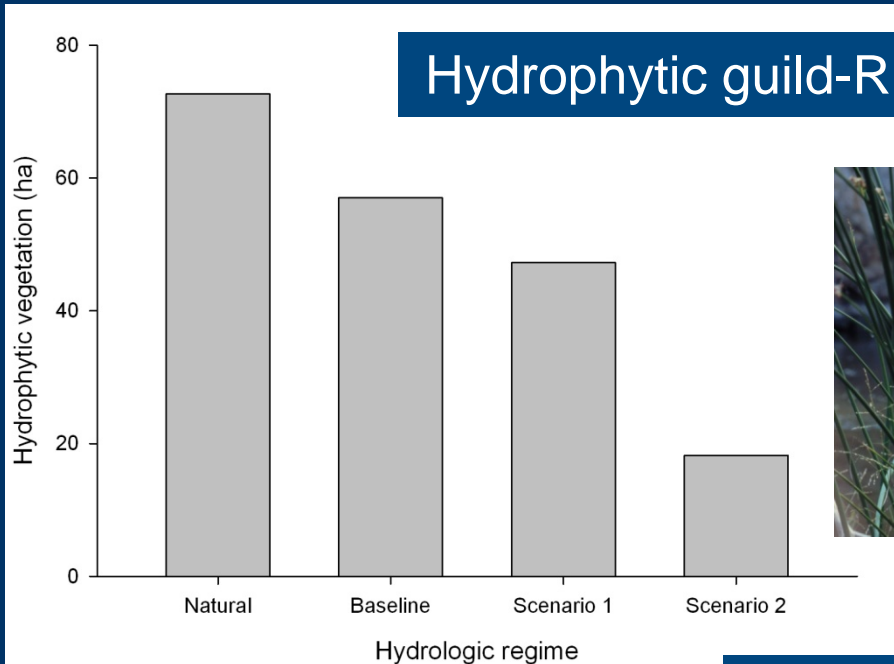
Flow scenario:
Full reservoir
development



Hydrophytic guild

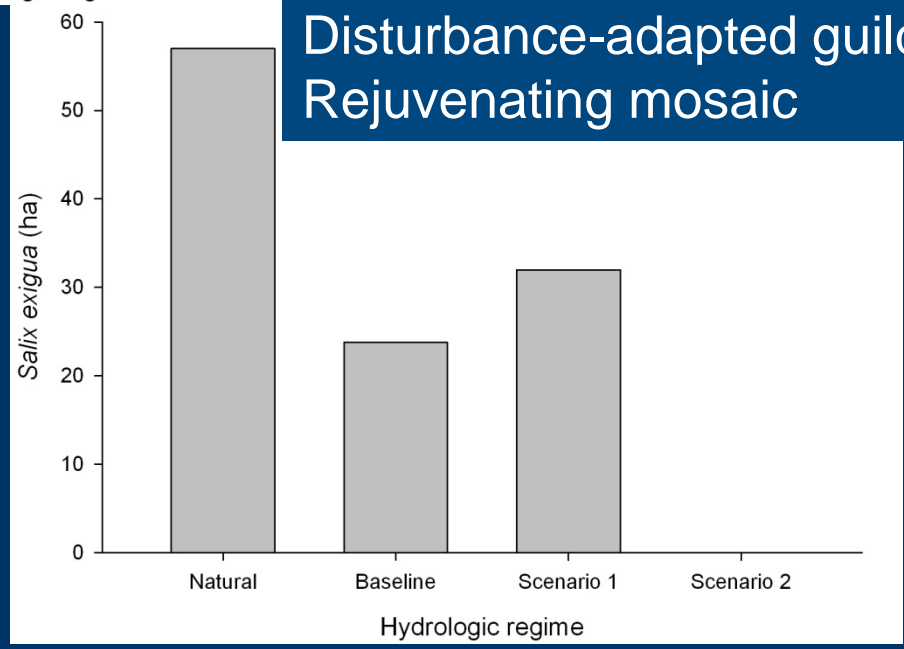
Flow scenario:
Full reservoir
development;
predicted population
growth

Hydrophytic guild-Riparian wetland



- Hydrologic regime
Natural (reconstructed)
Baseline (previous 30 yr)
S1 - Current
S2 - Reservoir Exp.
S3 - S1 + Hotter, drier
S4 - S2 + Hotter, drier
S5 - S1 + Wetter, cooler
S6 - S1 + Wet, cool
S7 - S1 + Wet, cool, early
S8 - S2 + Wetter, cooler, early

Disturbance-adapted guild-Rejuvenating mosaic



Channel
Mobility

Inundation
duration

Flow exceeds
critical shear 1 in
30yr and rigid
structures
minimal

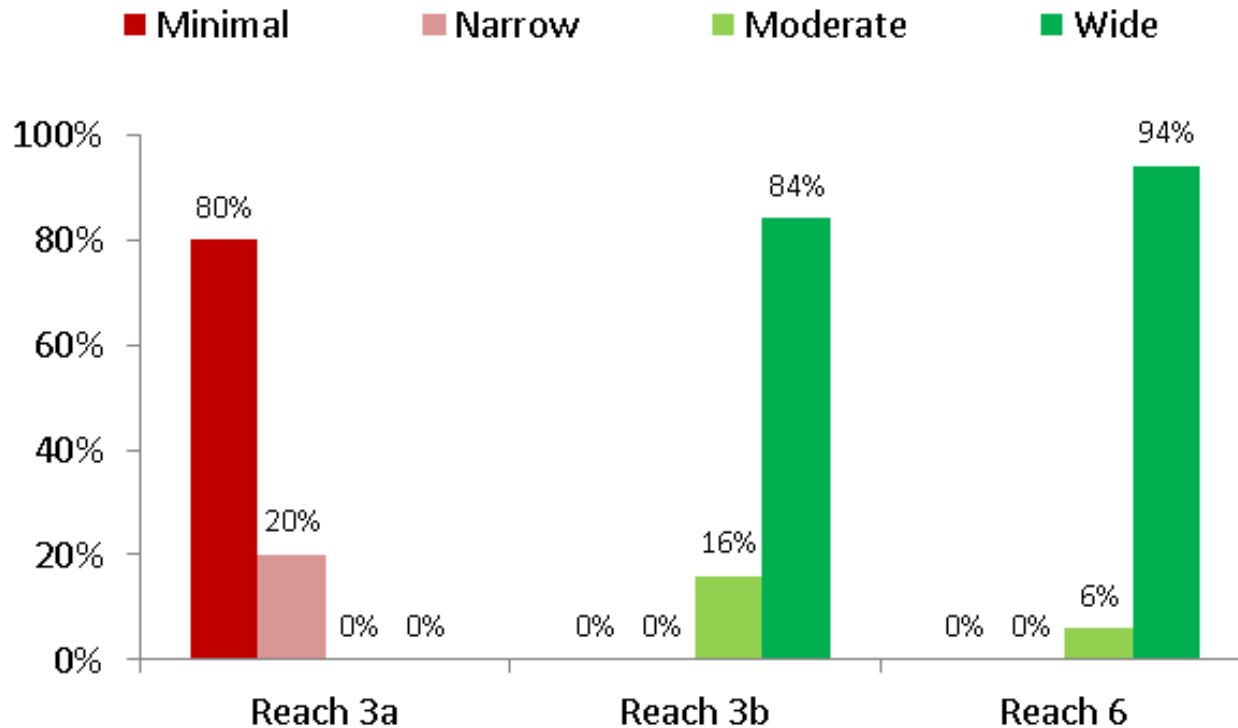
Rejuvenating
Mosaic

Riparian
Wetland

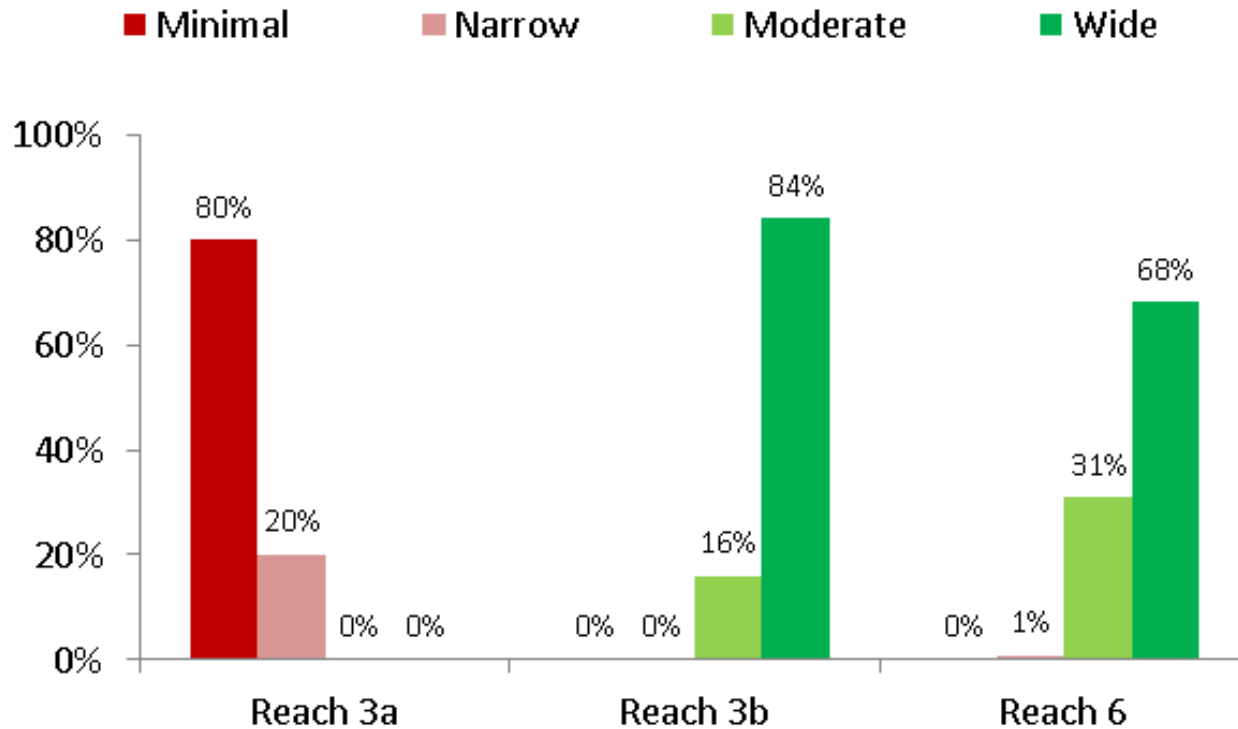


Flow scenario: Historic flows

Response variable: Riparian wetlands

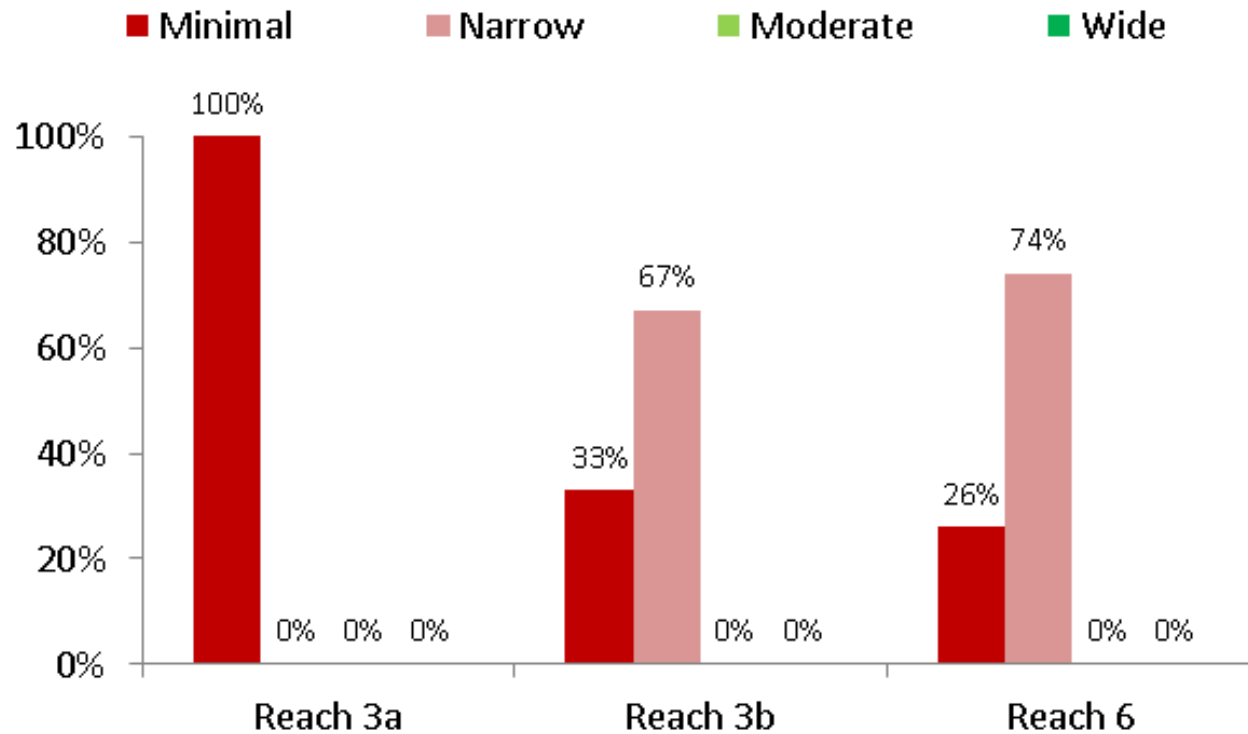


Flow scenario: Present operations
Response variable: Riparian wetlands



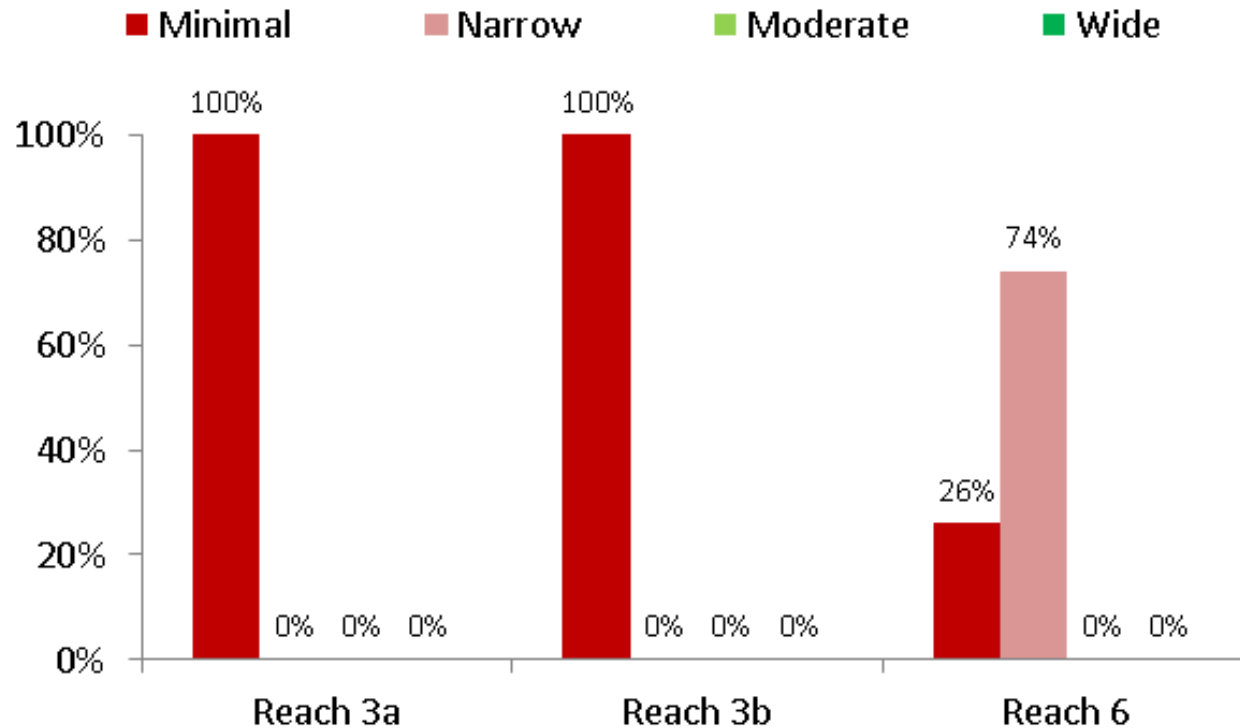
Flow scenario: Additional water development

Response variable: Riparian wetlands



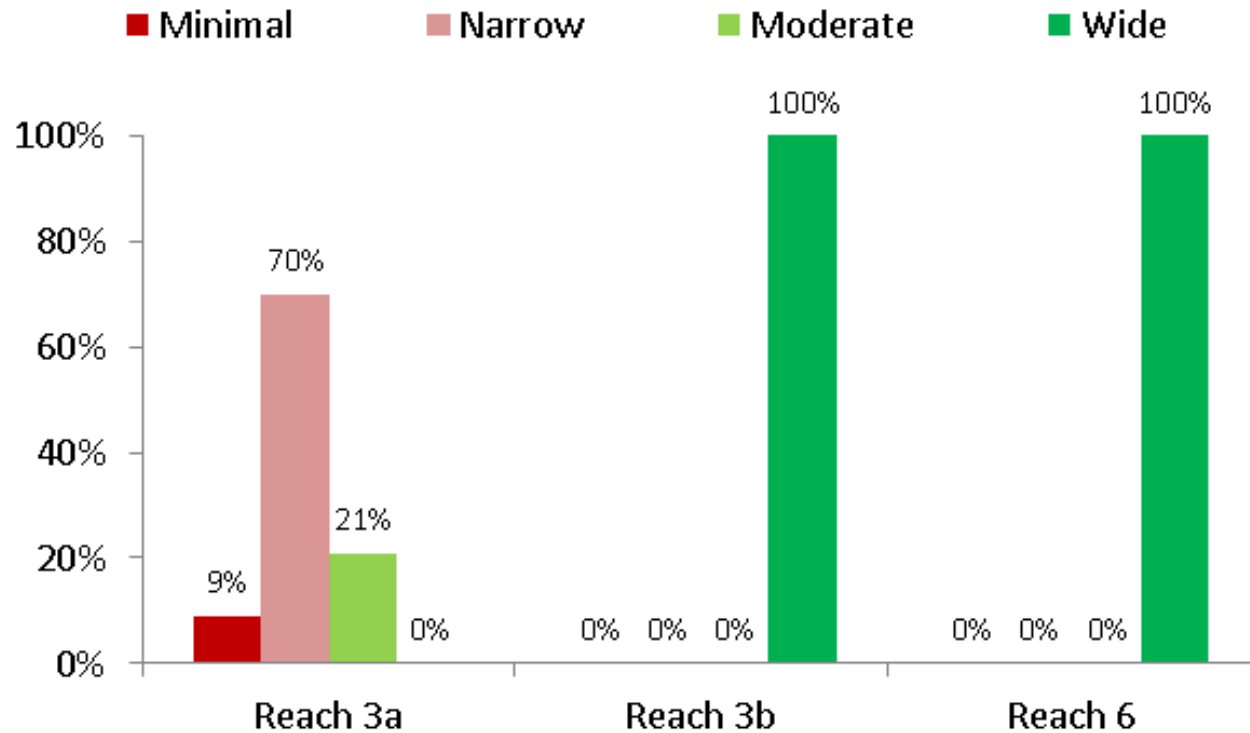
Flow scenario: Present operations-drier climate

Response variable: Riparian wetlands



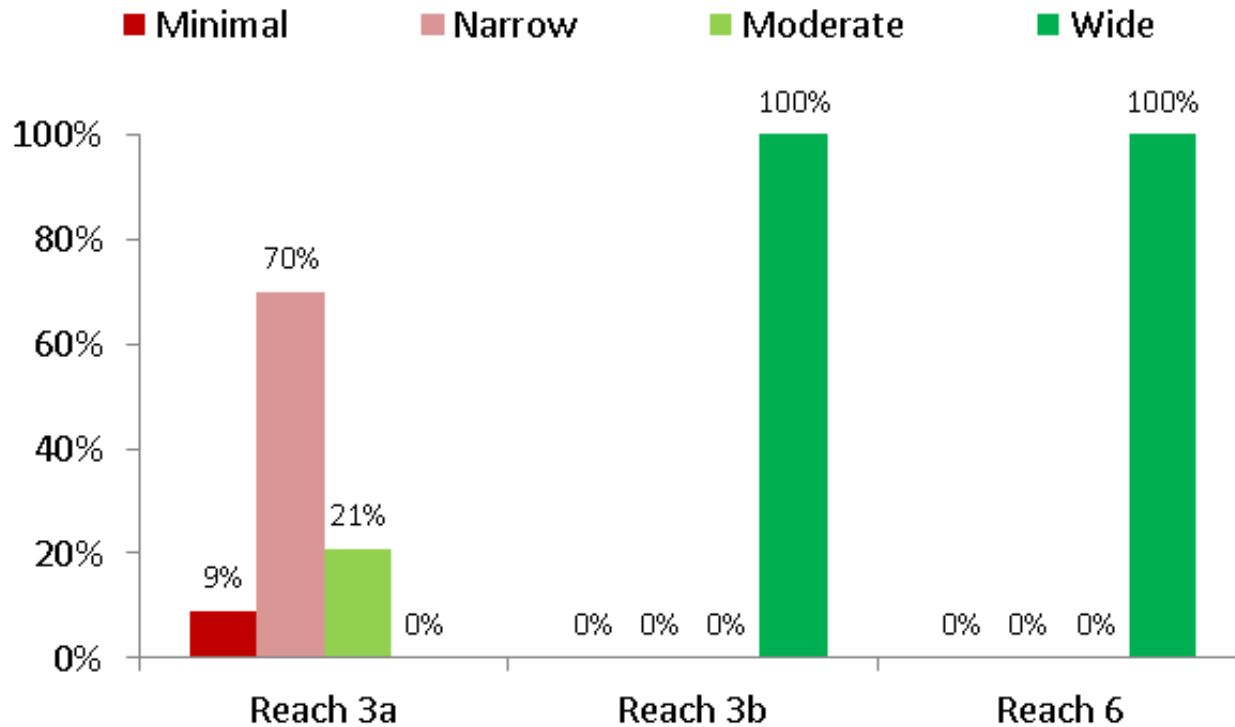
Flow scenario: Present operations-wetter climate

Response variable: Riparian wetlands



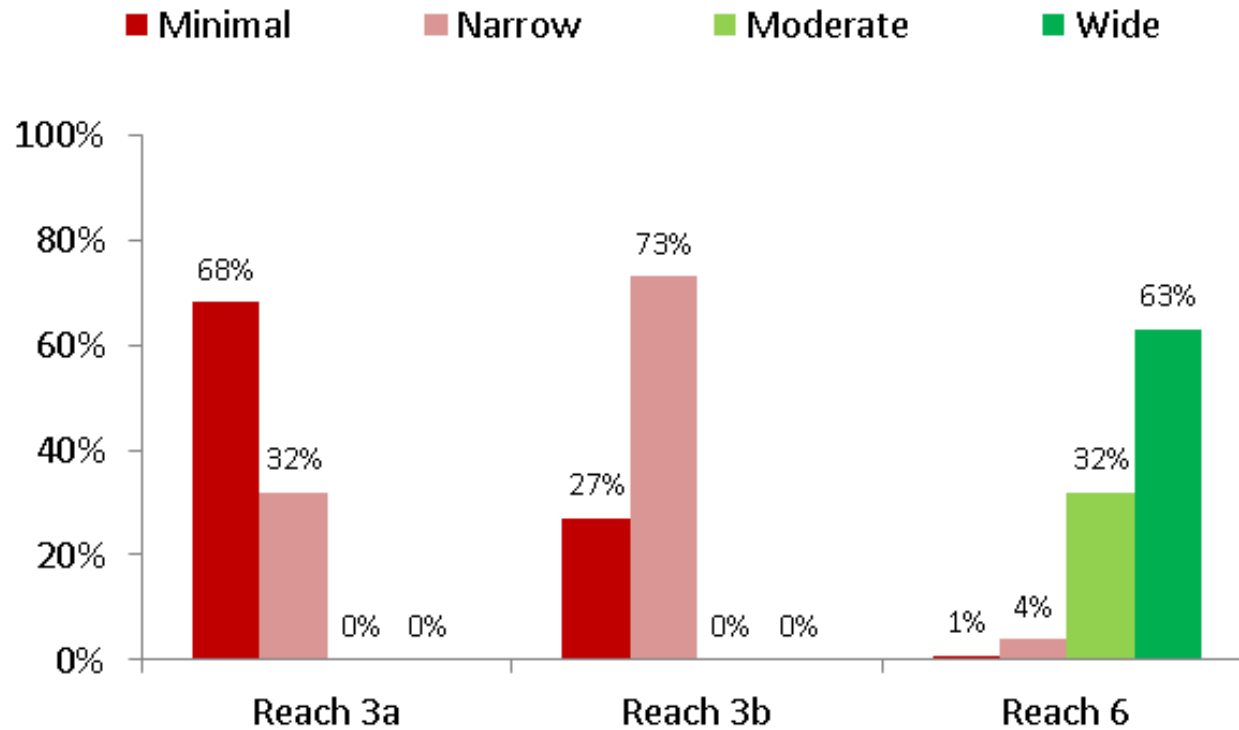
Flow scenario: Reconstructed natural flows

Response variable: Riparian wetlands



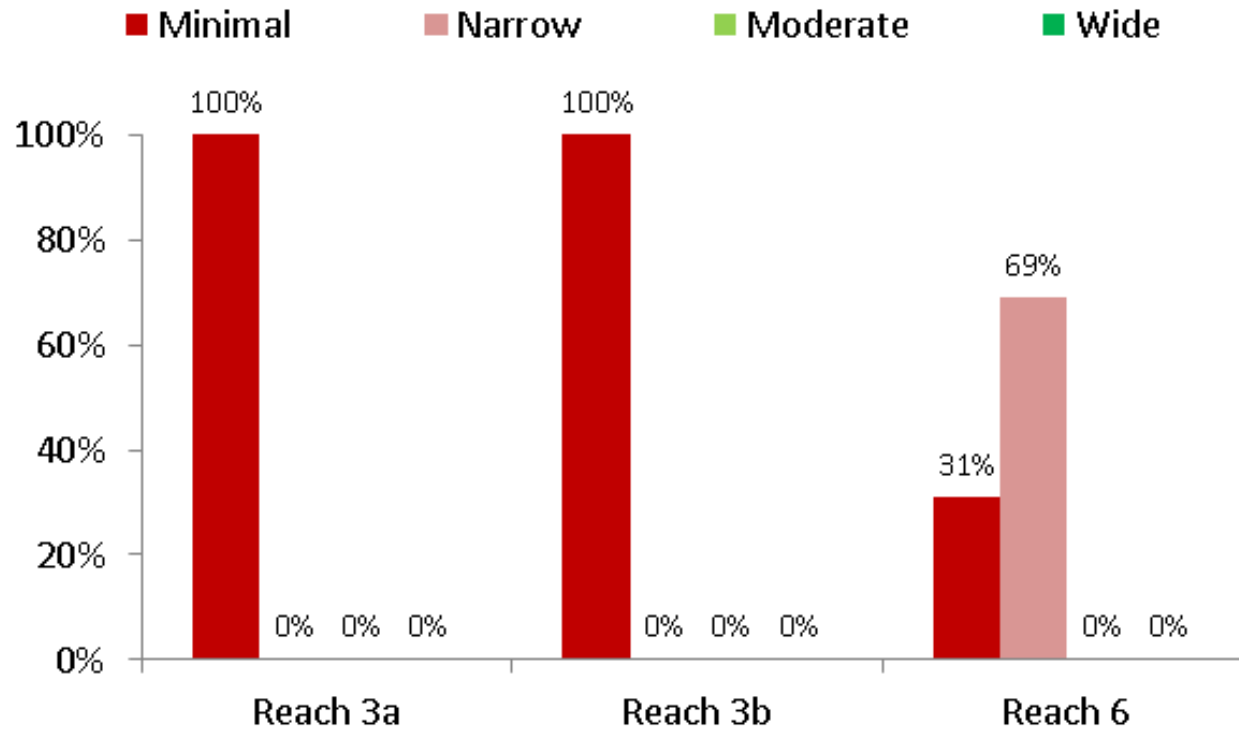
Flow scenario: Historic flows

Response variable: Rejuvenating mosaic



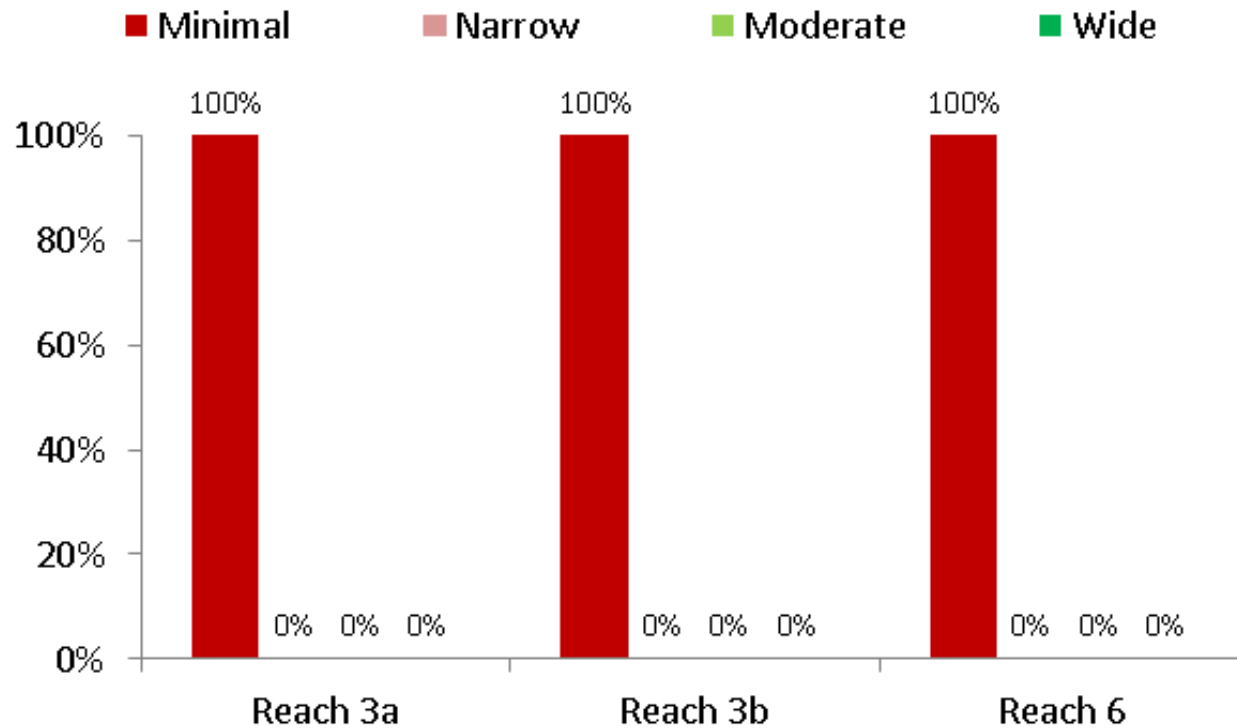
Flow scenario: Present operations

Response variable: Rejuvenating mosaic



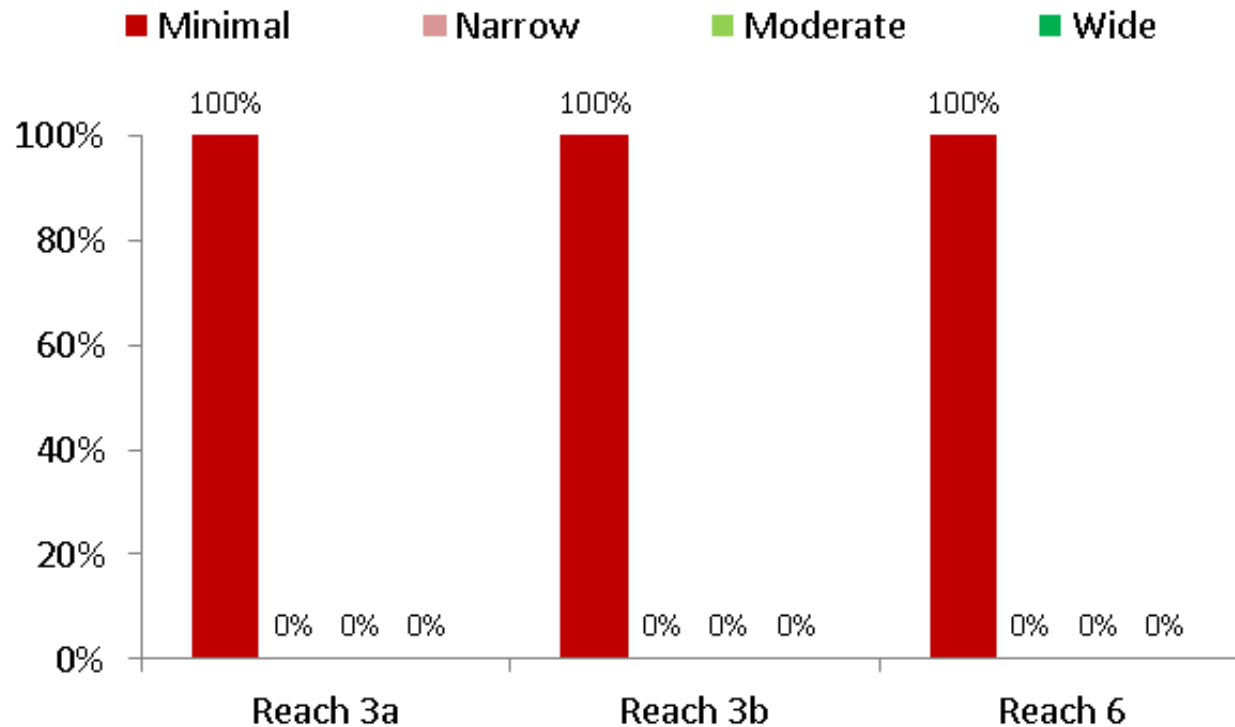
Flow scenario: Additional water development

Response variable: Rejuvenating mosaic



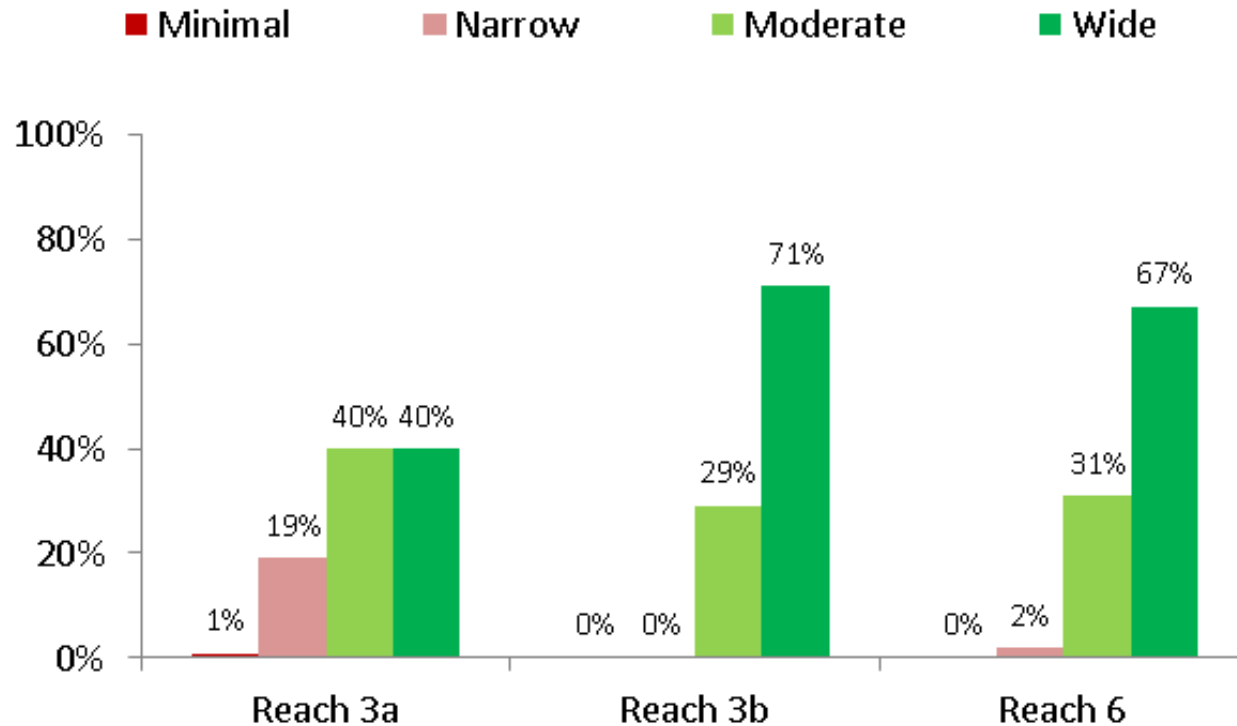
Flow scenario: Present operations-drier climate

Response variable: Rejuvenating mosaic



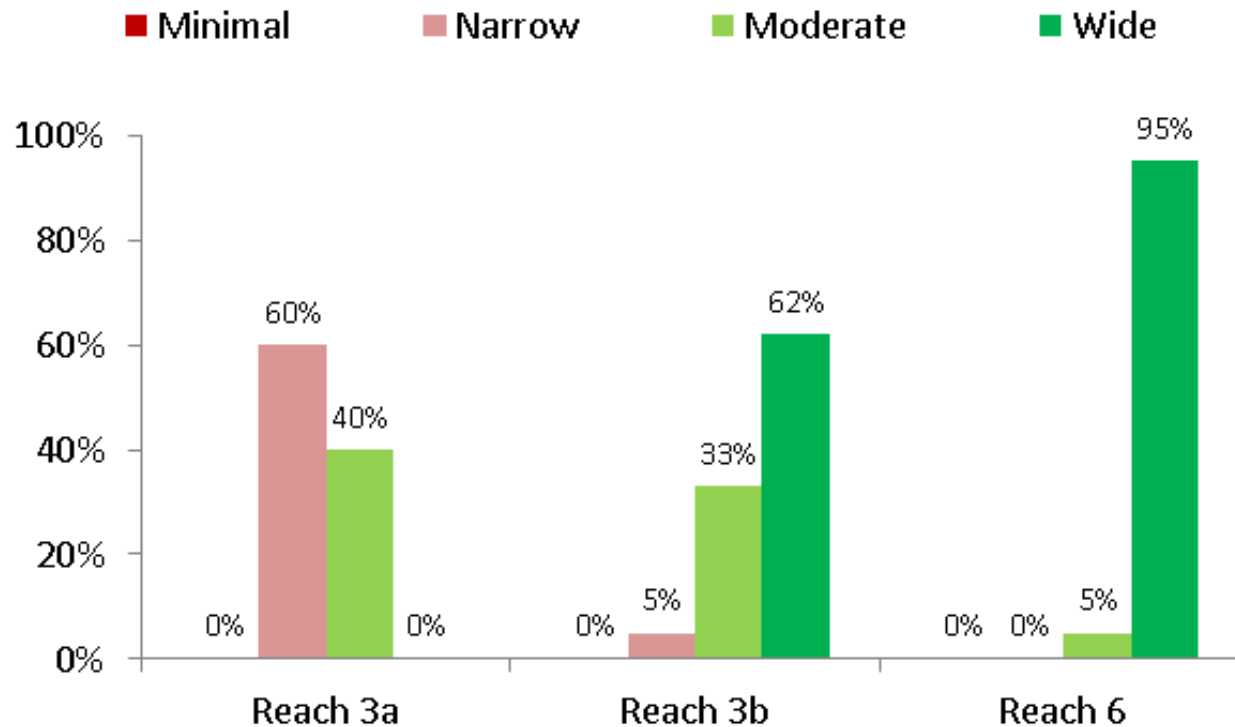
Flow scenario: Present operations-wetter climate

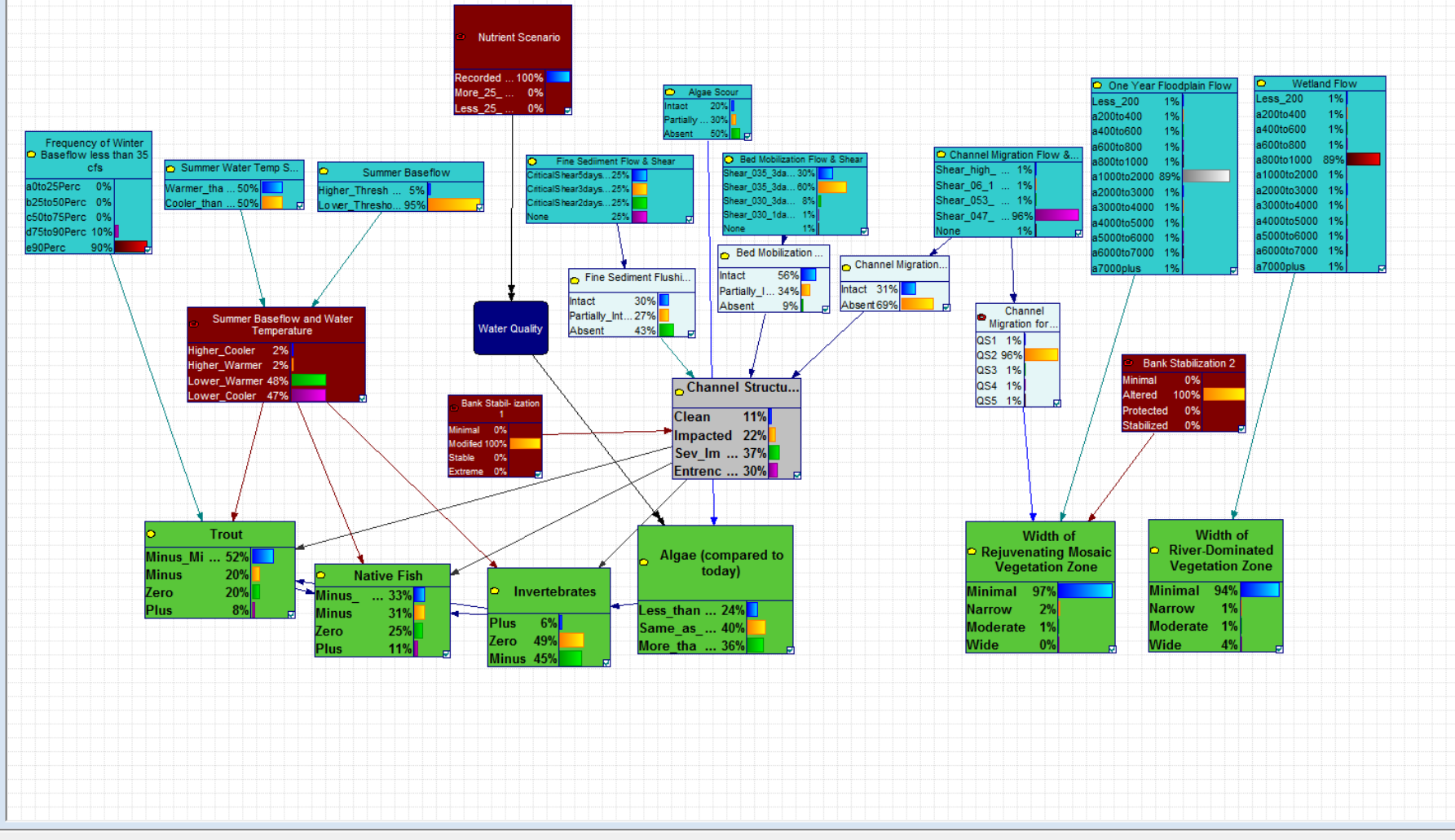
Response variable: Rejuvenating mosaic

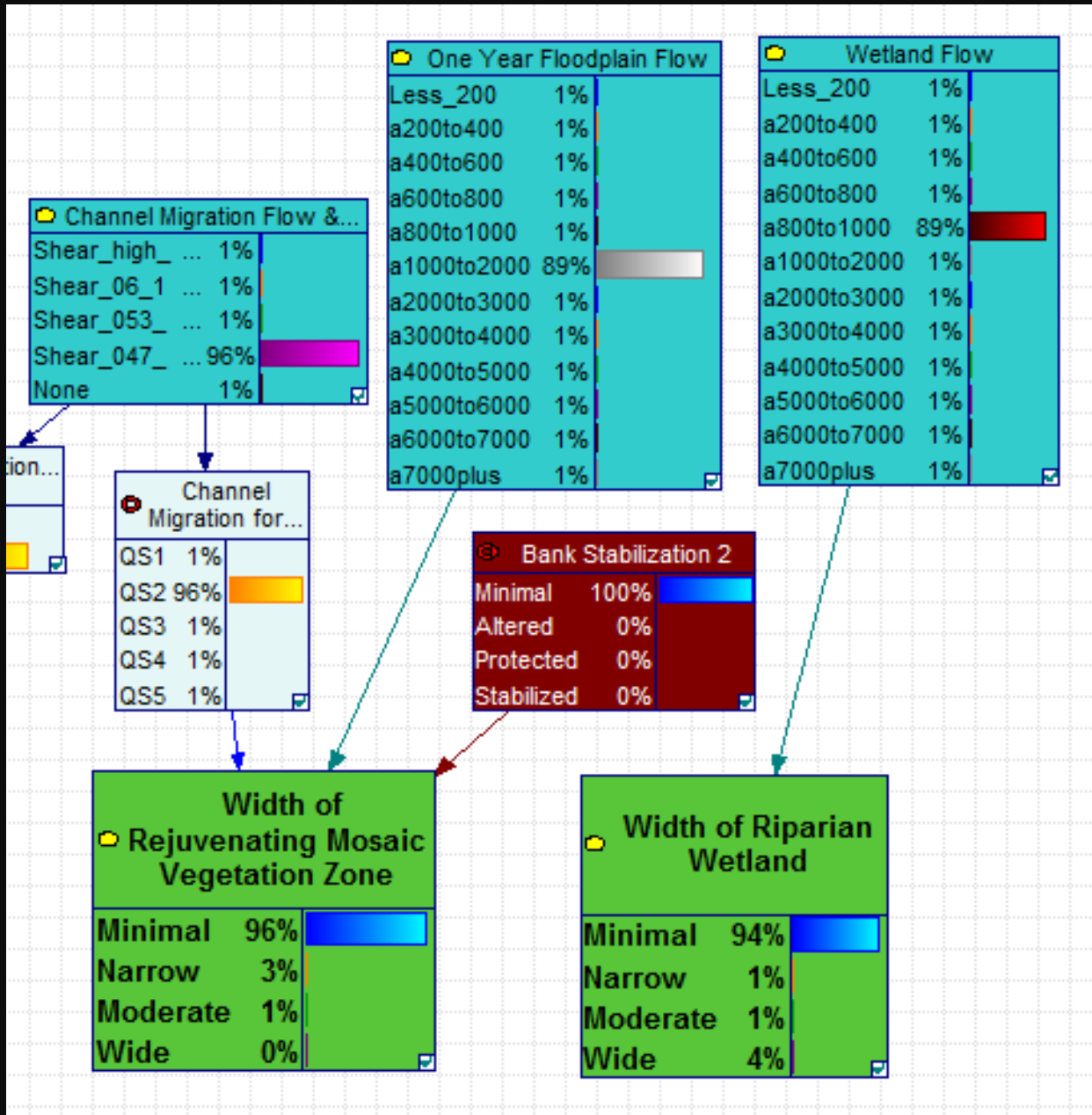


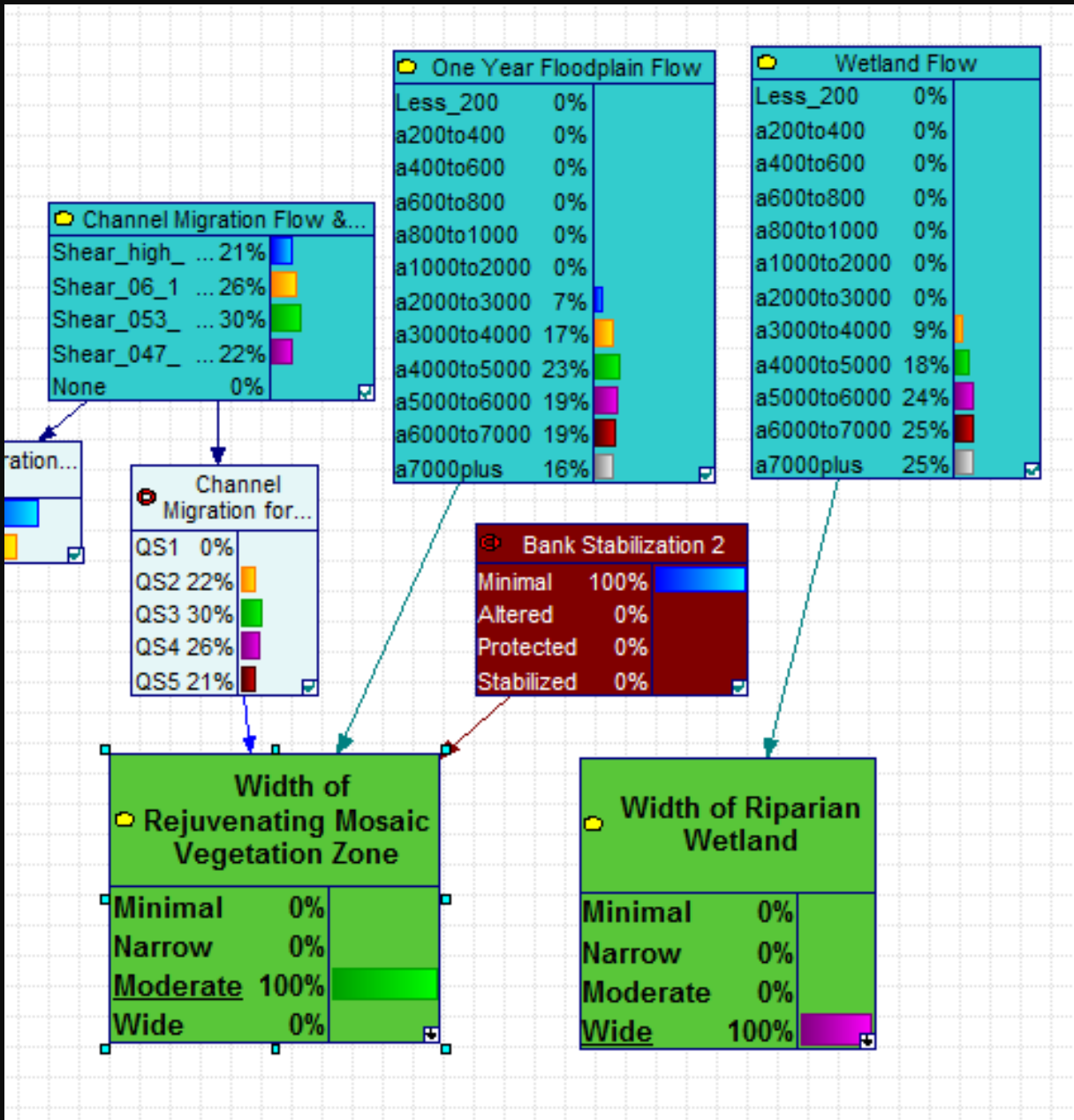
Flow scenario: Reconstructed natural flows

Response variable: Rejuvenating mosaic

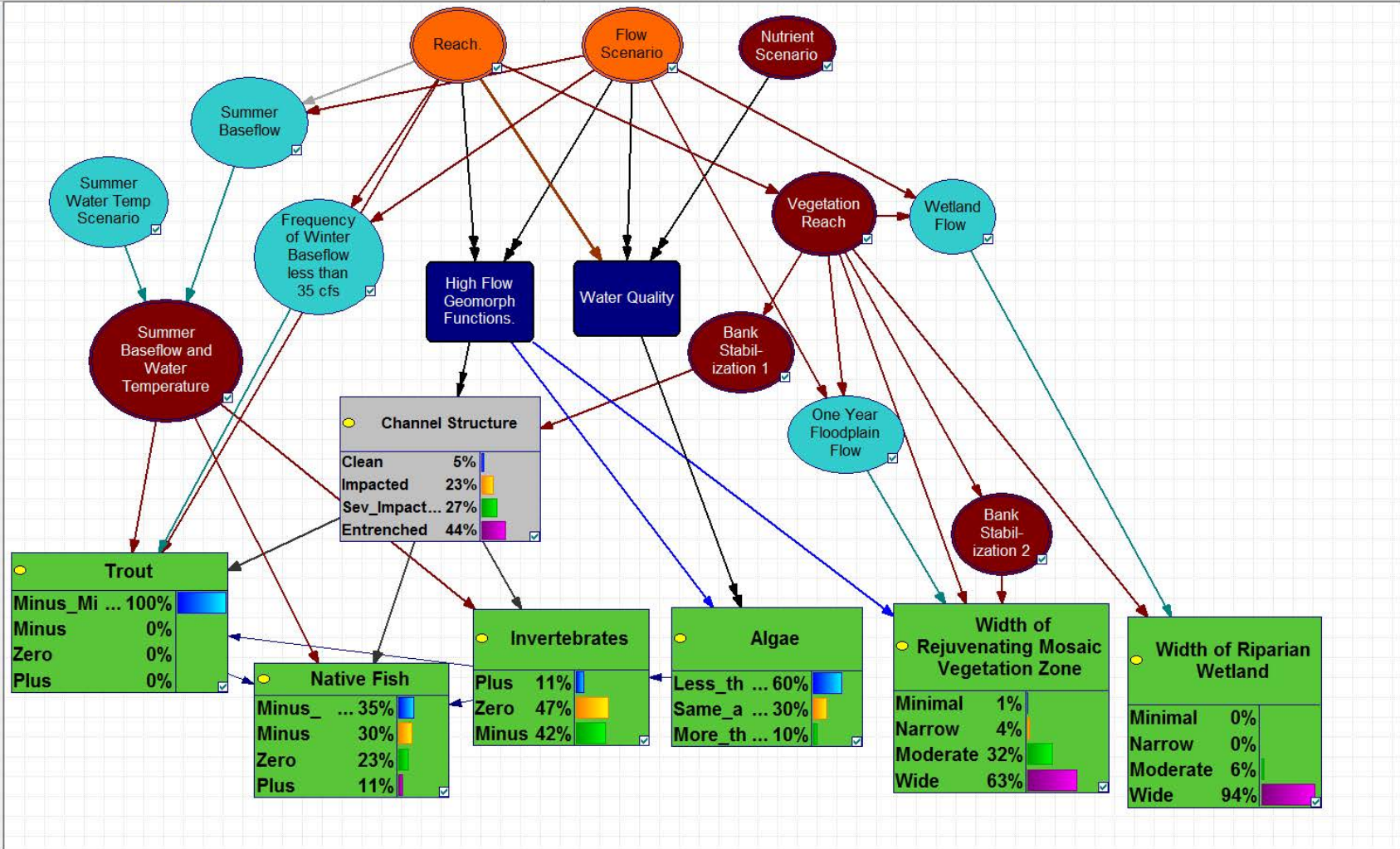






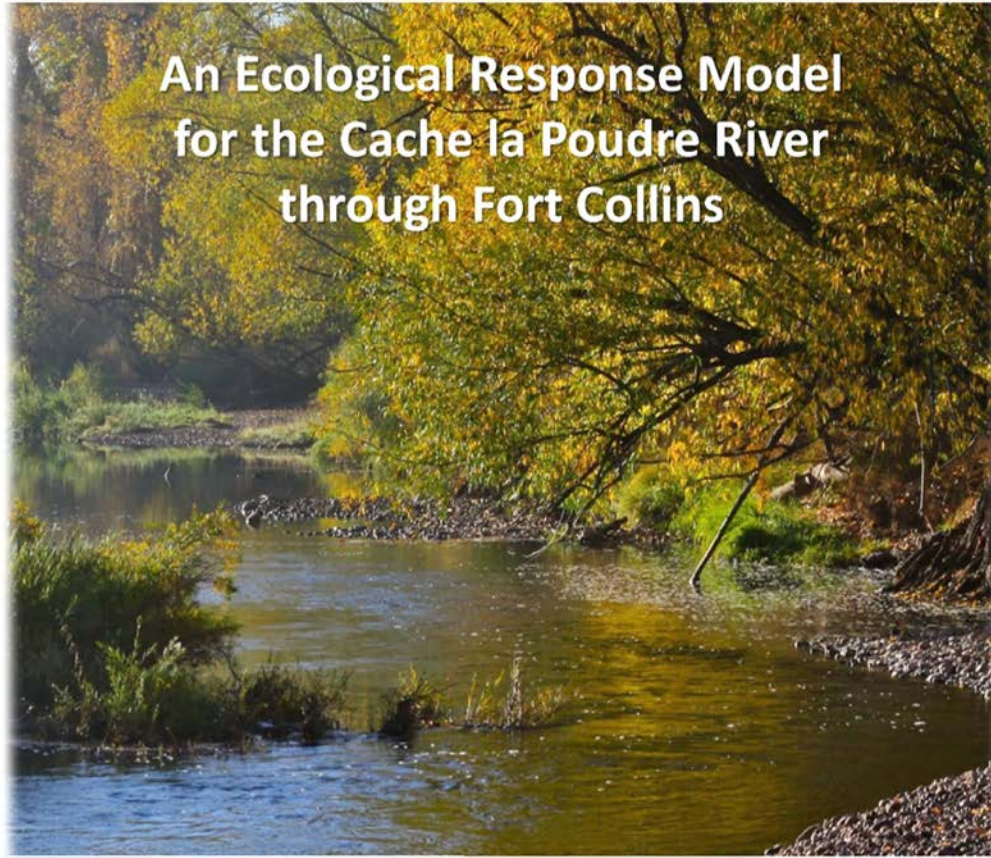


- Tree View
- PoudreVision (Poudre BE)
 - High Flow Geomorph
 - Water Quality
 - Width of Rejuvenating
 - Algae
 - Bank Stabilization 1
 - Bank Stabilization 2
 - Channel Structure
 - Flow Scenario
 - Frequency of Winter
 - Invertebrates
 - Native Fish
 - Nutrient Scenario
 - One Year Floodplain
 - Reach.
 - Summer Baseflow
 - Summer Baseflow an
 - Summer Water Temp
 - Trout
 - Vegetation Reach
 - Wetland Flow
 - Width of Riparian We
 - PoudreVision (Poudre BE)
 - Water Quality
 - Width of Rejuvenating
 - Algae (compared to 1
 - Algae Scour
 - Bank Stabilization 1
 - Bank Stabilization 2
 - Bed Mobilization Flo
 - Bed Mobilization Fur
 - Channel Migration Fl
 - Channel Migration F
 - Channel Migration f
 - Channel Structure
 - Fine Sediment Flow
 - Fine Sediment Flushi
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 - Wetland Flow



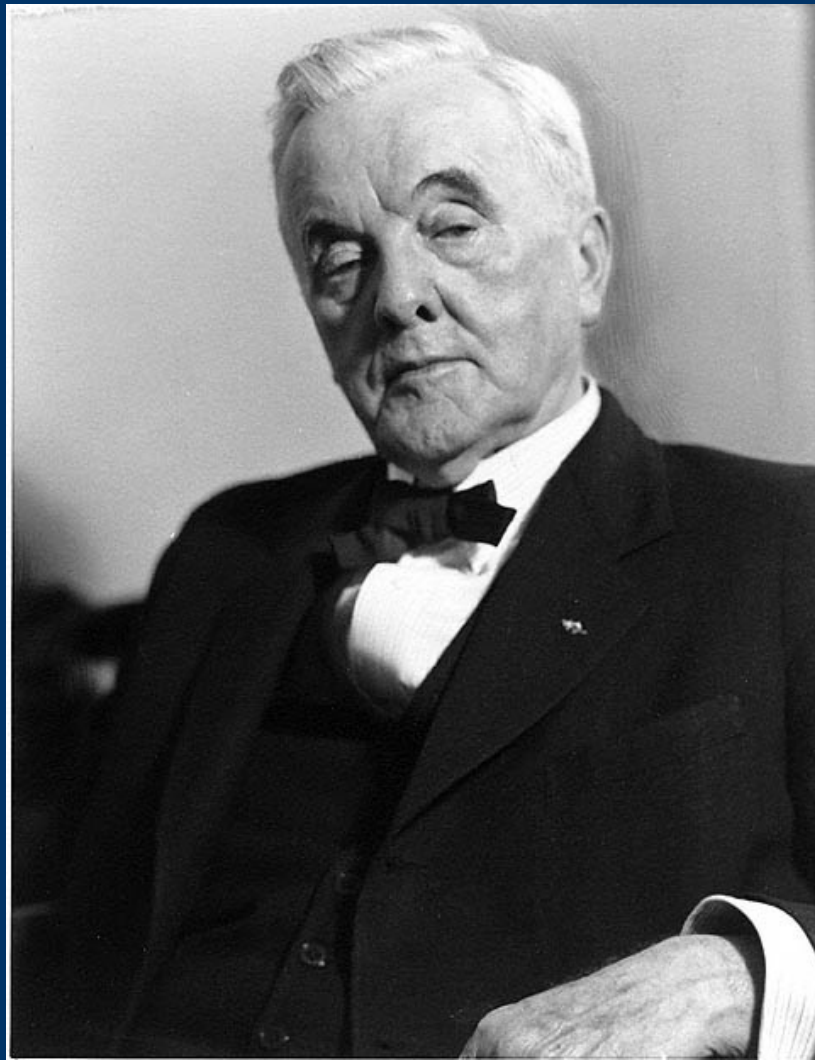


An Ecological Response Model for the Cache la Poudre River through Fort Collins



ERM Preliminary Results

- Present operations will result in long, slow decline in the riverine and riparian ecosystems
- Both trout and native fish populations could decline, and both populations could become more vulnerable
- The corridor of riparian vegetation and forest along the river is likely to become narrower, and lack regeneration of native species
- Further reductions in abundance and diversity of aquatic invertebrates (insects)
- Elevated nutrient levels, poor water quality



“...the dawning of that day when every rippling stream that flows down the mountain side and winds its way through the meadows to the sea shall be harnessed and made to work for the welfare and comfort of man.”

-Senator George Norris (1933)

ERM Preliminary Results

- Present operations combined with active restoration could significantly improve riverine and riparian ecosystems
- Future operations that include some enhanced flood flows and maintained winter baseflows could improve riverine and riparian ecosystems
- Both trout and native fish populations could be maintained and improved
- The corridor of riparian vegetation and forest along the river could be maintained or improved → Maintenance of low flows and enhanced regeneration of native species

Ecological Response Model

- Formalization of ecological interactions forces critical thought and science application
- Provides a formal view (based on best expert judgment) of consequences of management decisions
- Provides the public and managers with management options and outcomes and long-term view
- Connects with other management activities such as active restoration and engineering (demonstrates value added)

Useful resources

References

- Stewart-Kioster, et al. 2010. The use of Bayesian networks to guide investments in flow and catchment restoration for impaired river systems. *Freshwater Biology* 55.
- Uusitalo, L. 2007. Advantages of Bayesian networks in environmental modeling. *Ecological Modeling* 203.
- Said, A. 2006. The implementation of a Bayesian network for watershed management decisions. *Water Resources Management* 20.

Bayesian Network Modeling Software

GeNIe – genie.sis.pitt.edu

Hugin -- www.hugin.com

Netica – www.norsys.com

Samlam – reasoning.cs.ucla.edu

WinBUGS -- www.mrc-bsu.cam.ac.uk/bugs/winbugs/

R -- www.r-project.org/