Chloride impairment of the Merrimack River through 2100: the interactive roles of climate, development, and management

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Errin Volitis, Ashley Hyde, Dan Demers

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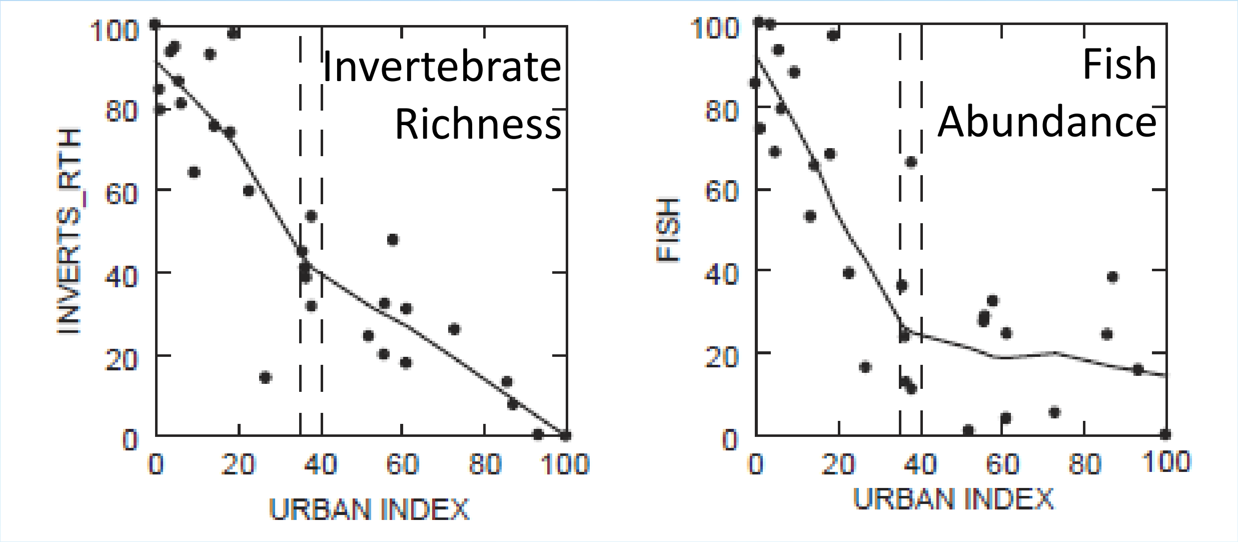
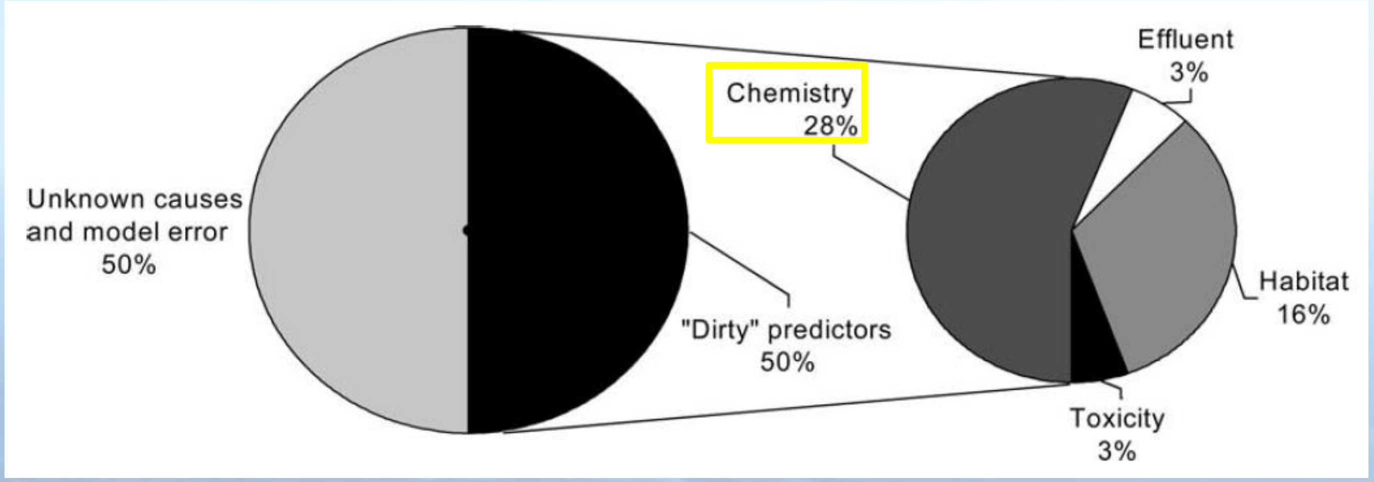
Aquatic impairment increases in lock step with development and impervious cover



Richness and fish abundance declines with increased urbanization

Chemical factors are greatest known cause (declining fish richness)

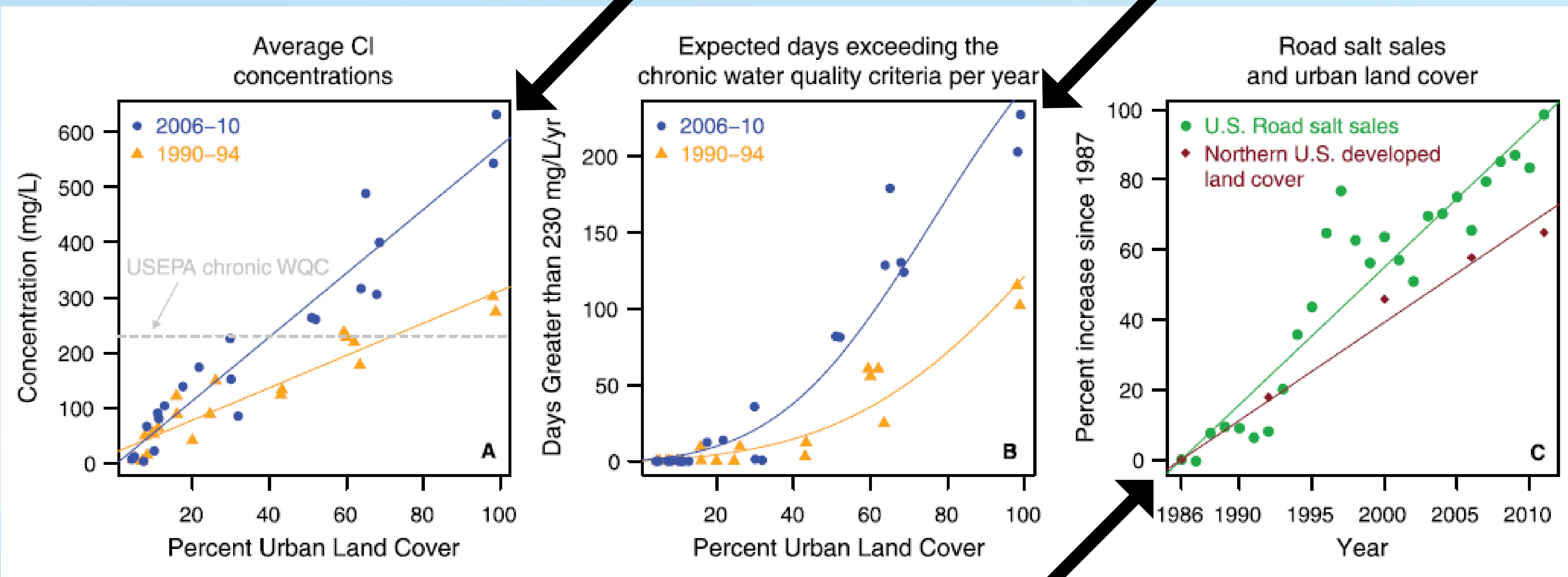


Coles et al. 2004
de Zwart et al. 2006

17
Cl
35.453

Chloride also increases with development and impervious cover

- Increasing concentrations and impairment



- Road salt is primary source in NE and Urban areas

Corsi et al. 2015

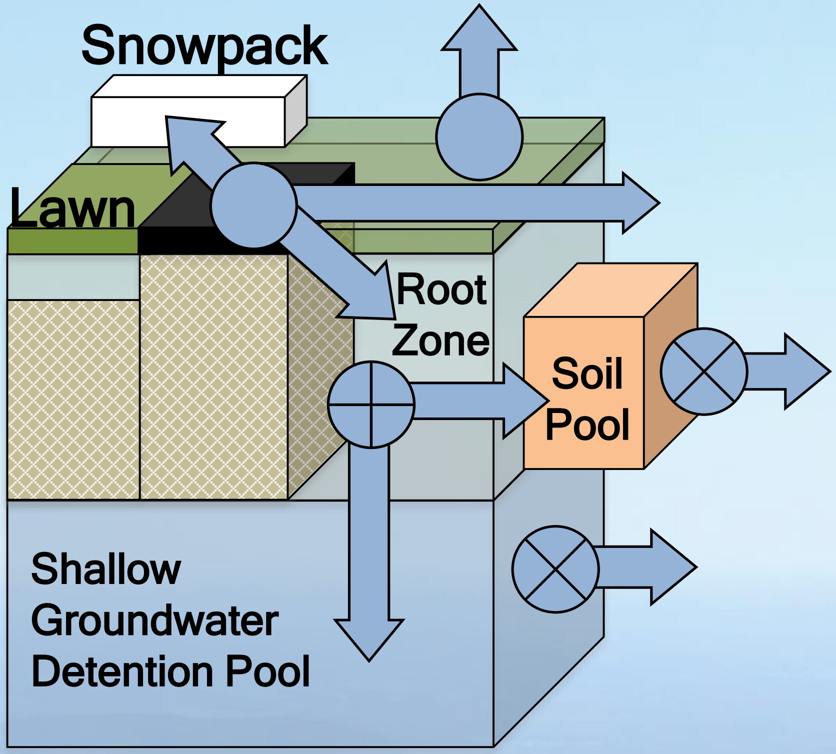
The Road to a Low Salt diet: How resilient is the Merrimack?

- Chloride sources and loading
  - Infer from stream chloride data
- Chloride impairment ([Cl^-] above target)
  - Spatial extent of impairment
  - Interannual variability driven by climate
- Projecting future impairment
  - Warming winters ultimately decrease loading
  - But, increasing development may offset
  - And, long history from groundwater storage

Coupled hydrologic and chloride loading

Coupled hydrologic and chloride loading

FrAMES:
Vertical and Horizontal
Water Routing

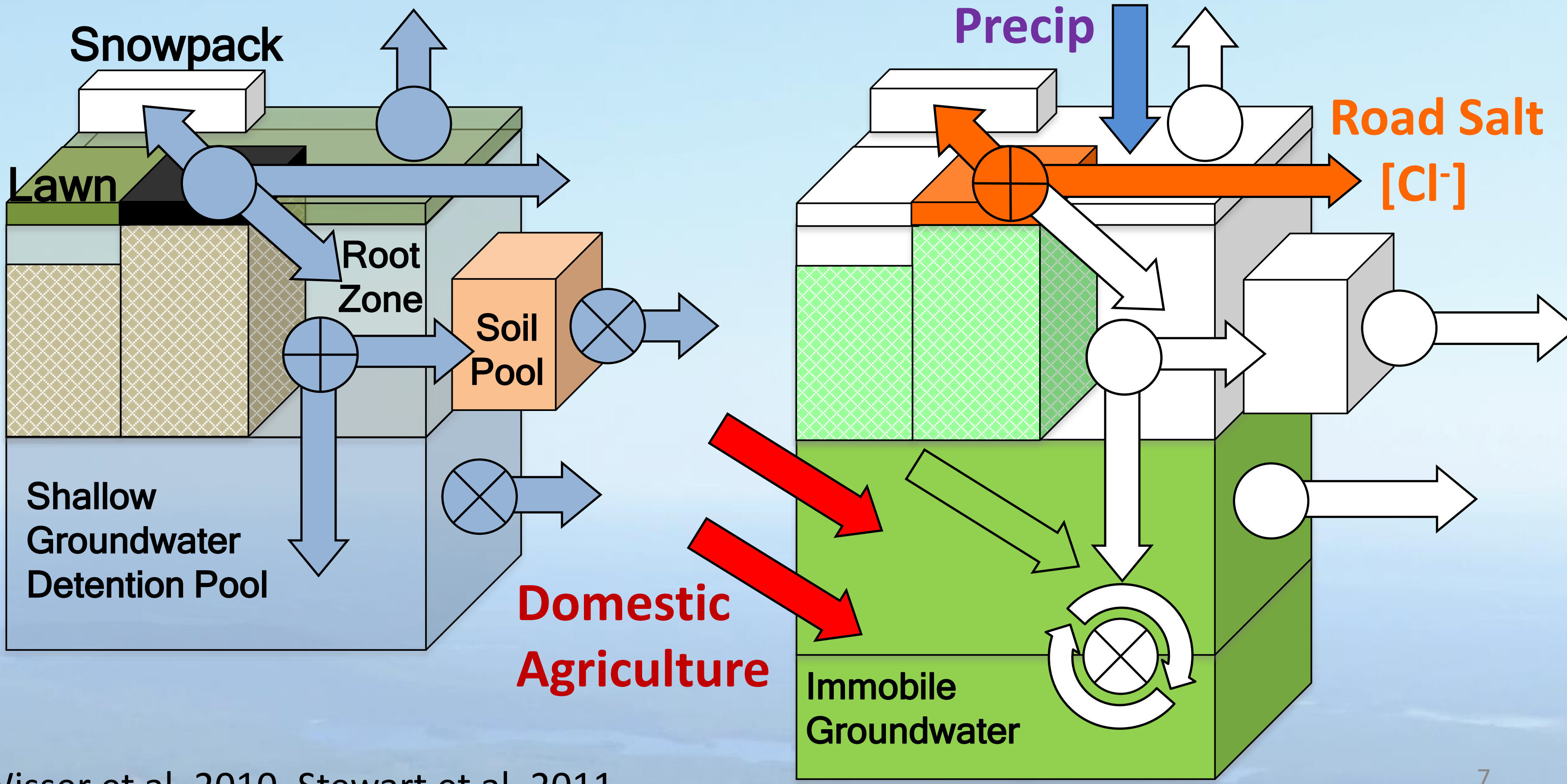


Wisser et al. 2010, Stewart et al. 2011

Coupled hydrologic and chloride loading

FrAMES:
Vertical and Horizontal
Water Routing

NACL:
Non-point Anthropogenic
Chloride Loading



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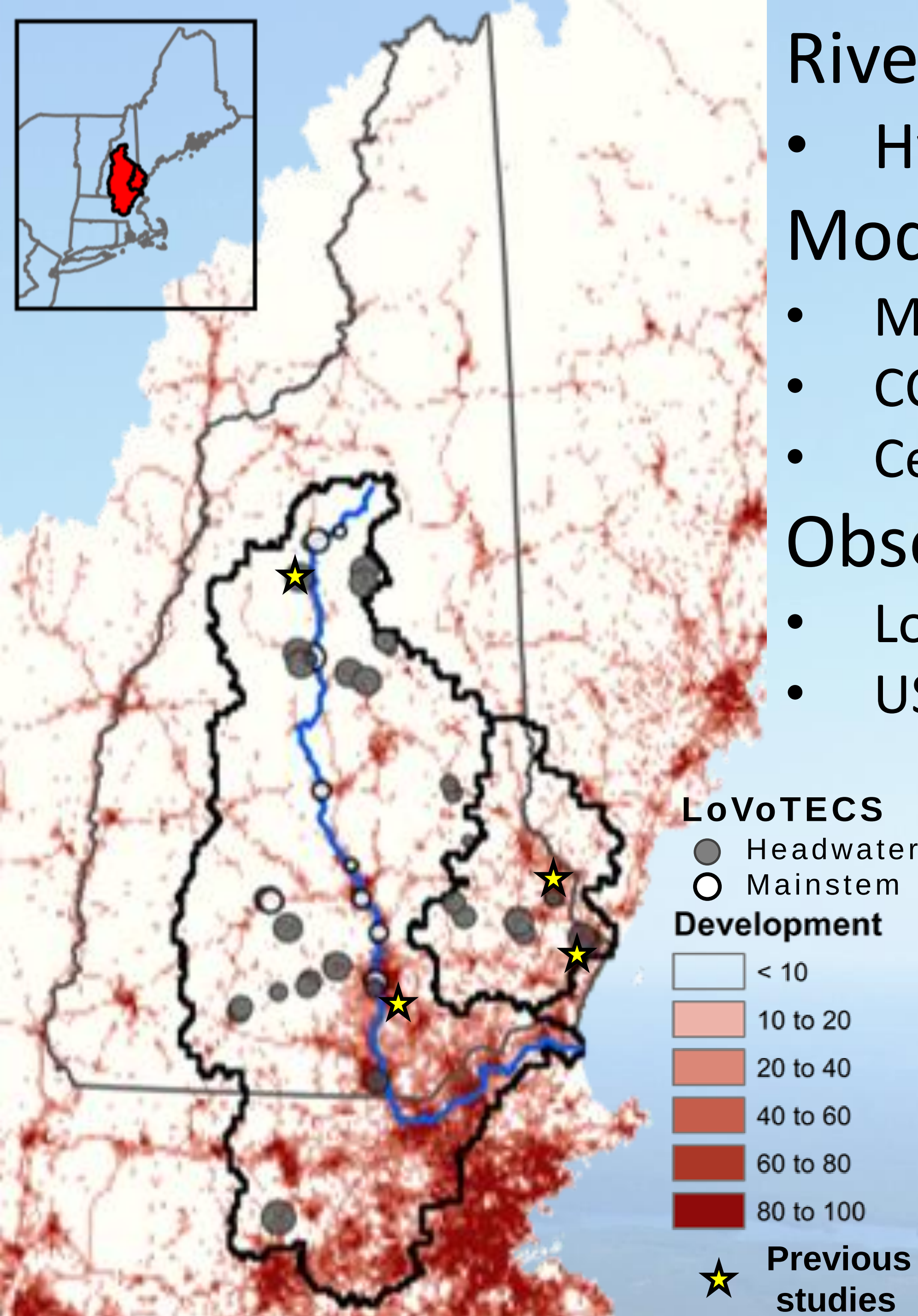


River Network

- HydroSheds (45” ≈1.5 km)

Model Drivers

- MERRA (NASA) + GHCN (NWS)
- CCAP+NLCD (NOAA/USGS)
- Census Data (USCB)

Observation Data

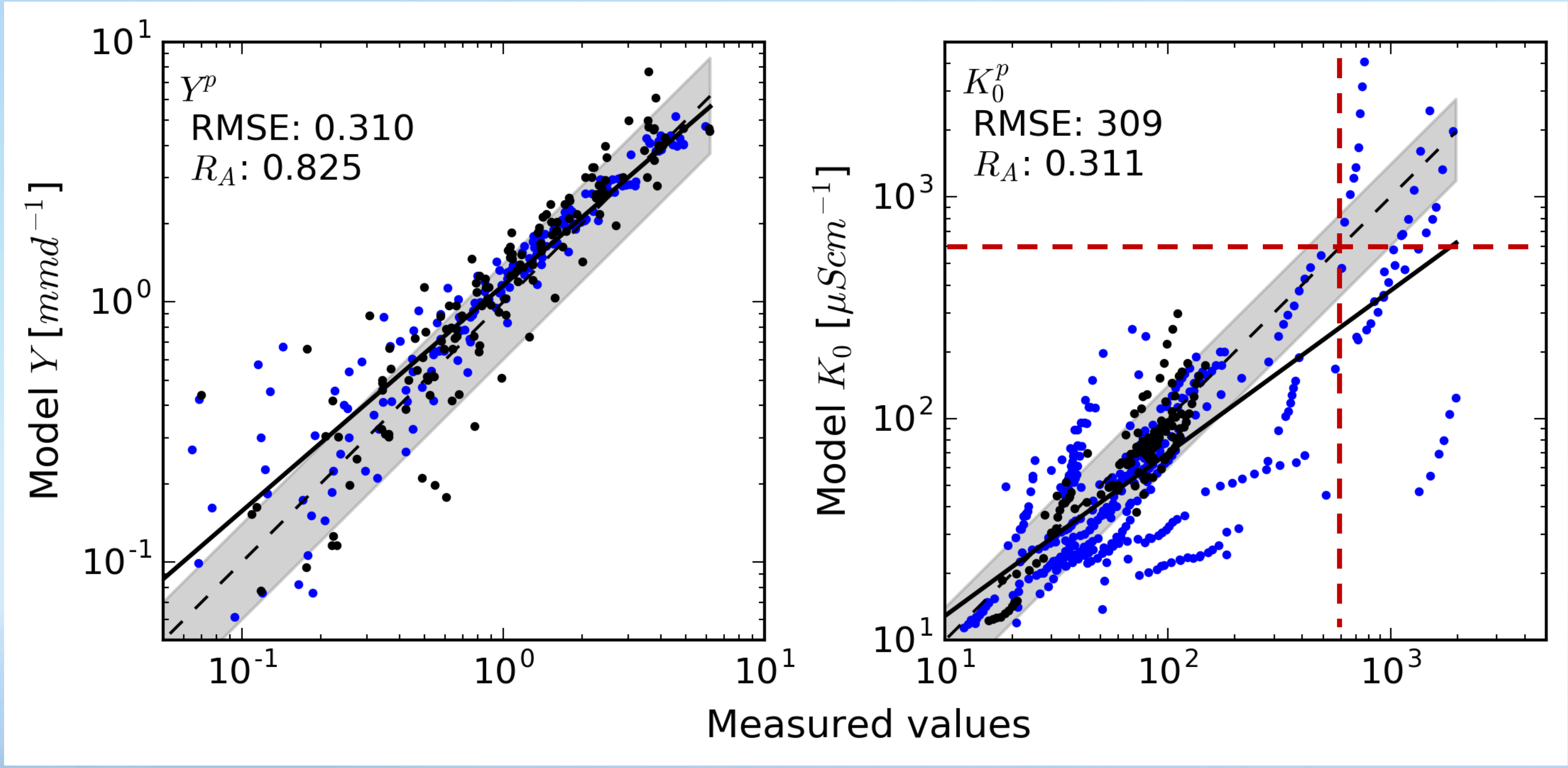
- LoVoTECS (*n*=54 k_0)
- USGS (*n*=35 Q, 1 k_0)

Methodology

- Calibrate 6 and 10 parameters
- Markov-Chain Monte Carlo
  - Runoff + Conductance
- Impaired Reaches

Thorn et al. In Prep

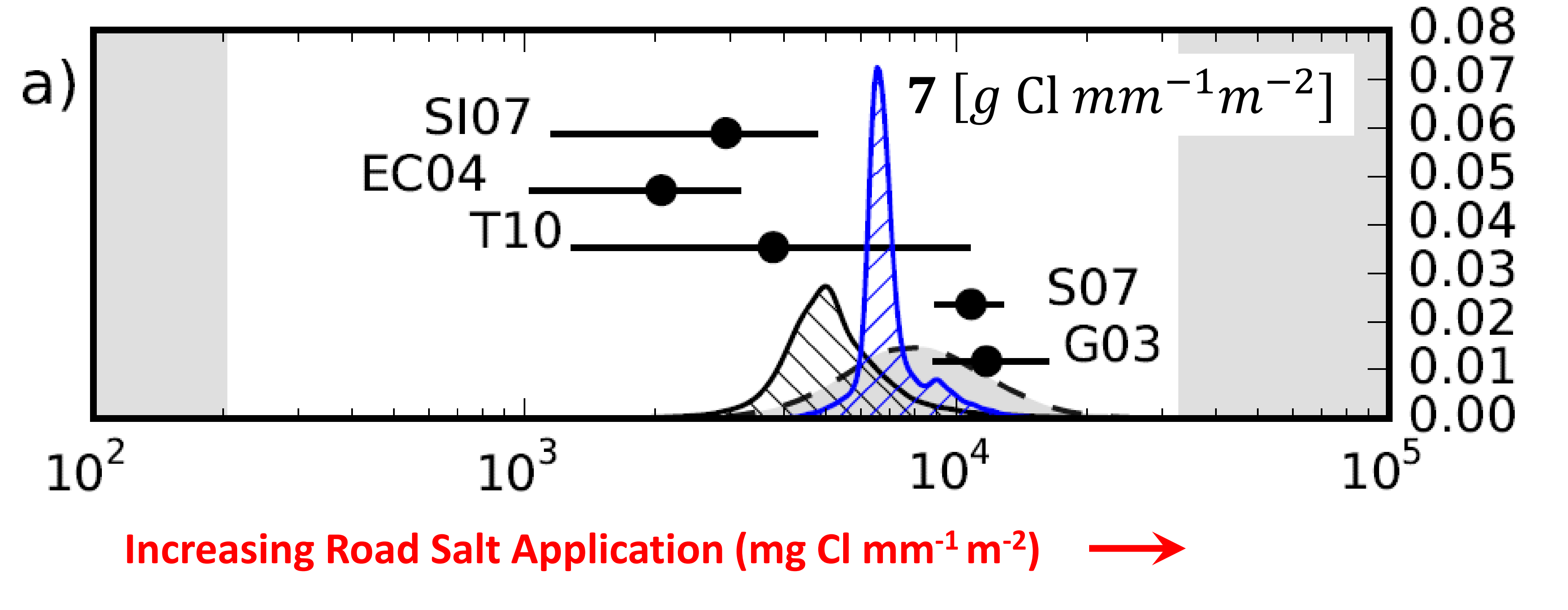
FrAMES-NACL recreates the probability distributions of daily runoff and specific conductance



Runoff

Specific Conductance

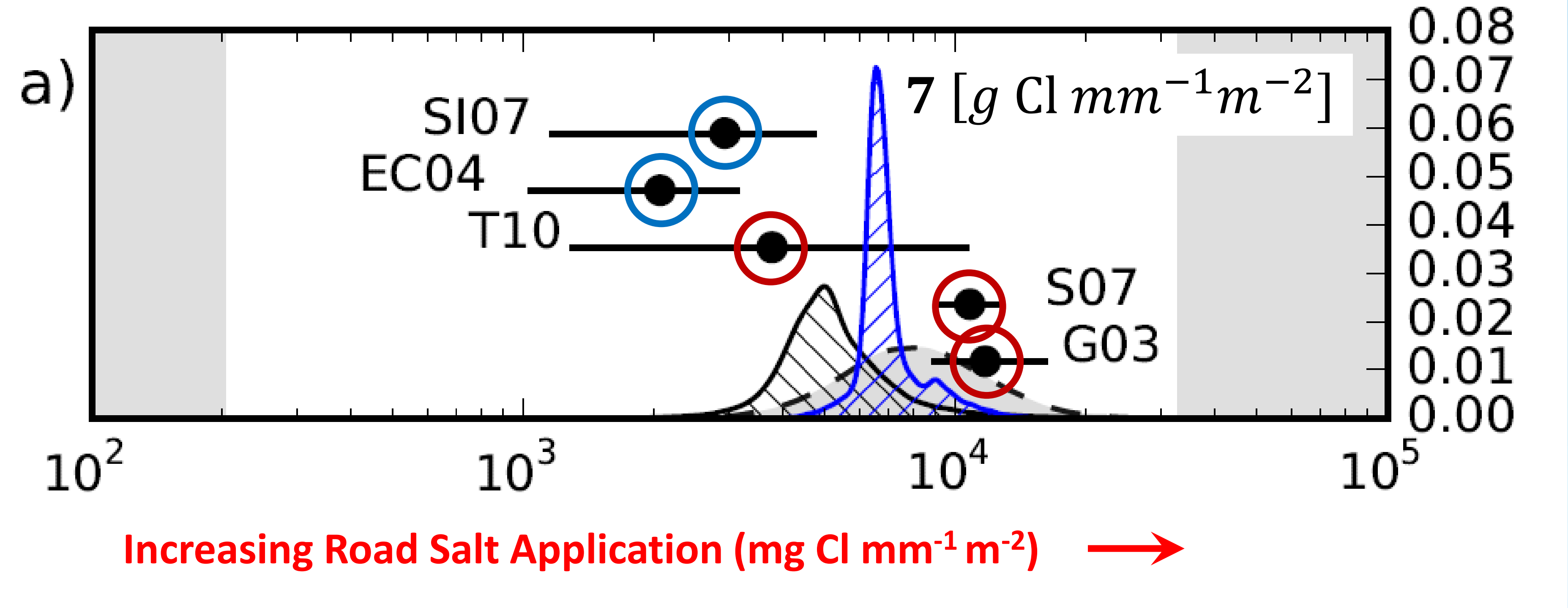
Road salt application similar to inventories and above recommendations



Mean road salt application (C_{DEI}) from stream $[\bar{Cl}]$.

- C_{DEI} close to empirical average, closest to I-93 study
- Values are probably twice recommendations

Road salt application similar to inventories and above recommendations



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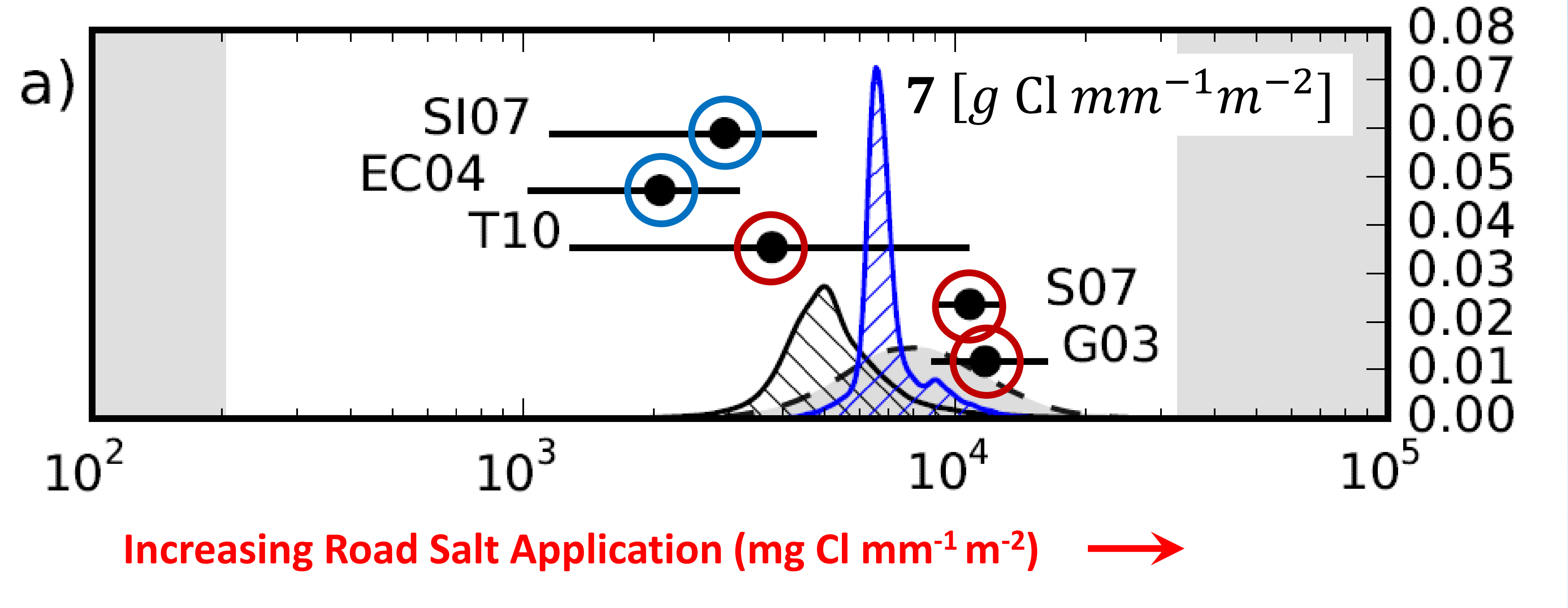


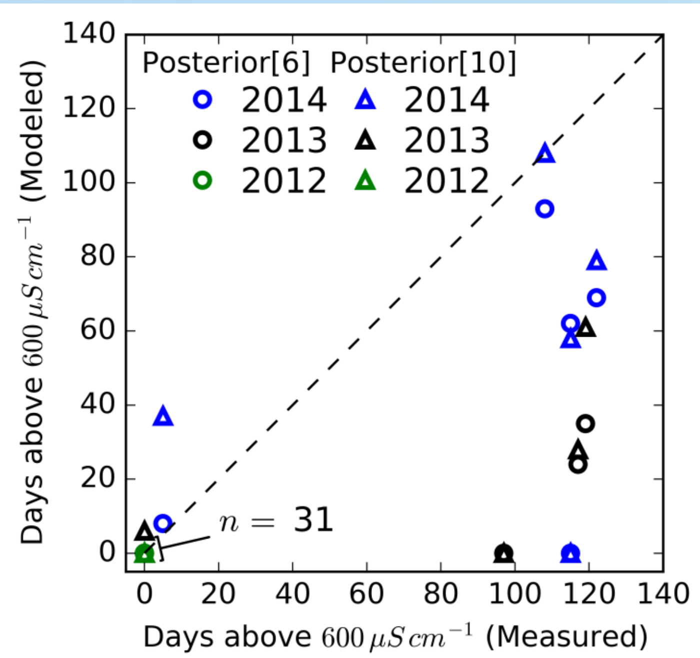
Values are probably twice recommendations: How?

- Includes historic road salt usage
  - Godwin 2003 indicative: >4 times recommended
  - Long memory of loading. Is the memory long enough?
- Potential management improvements

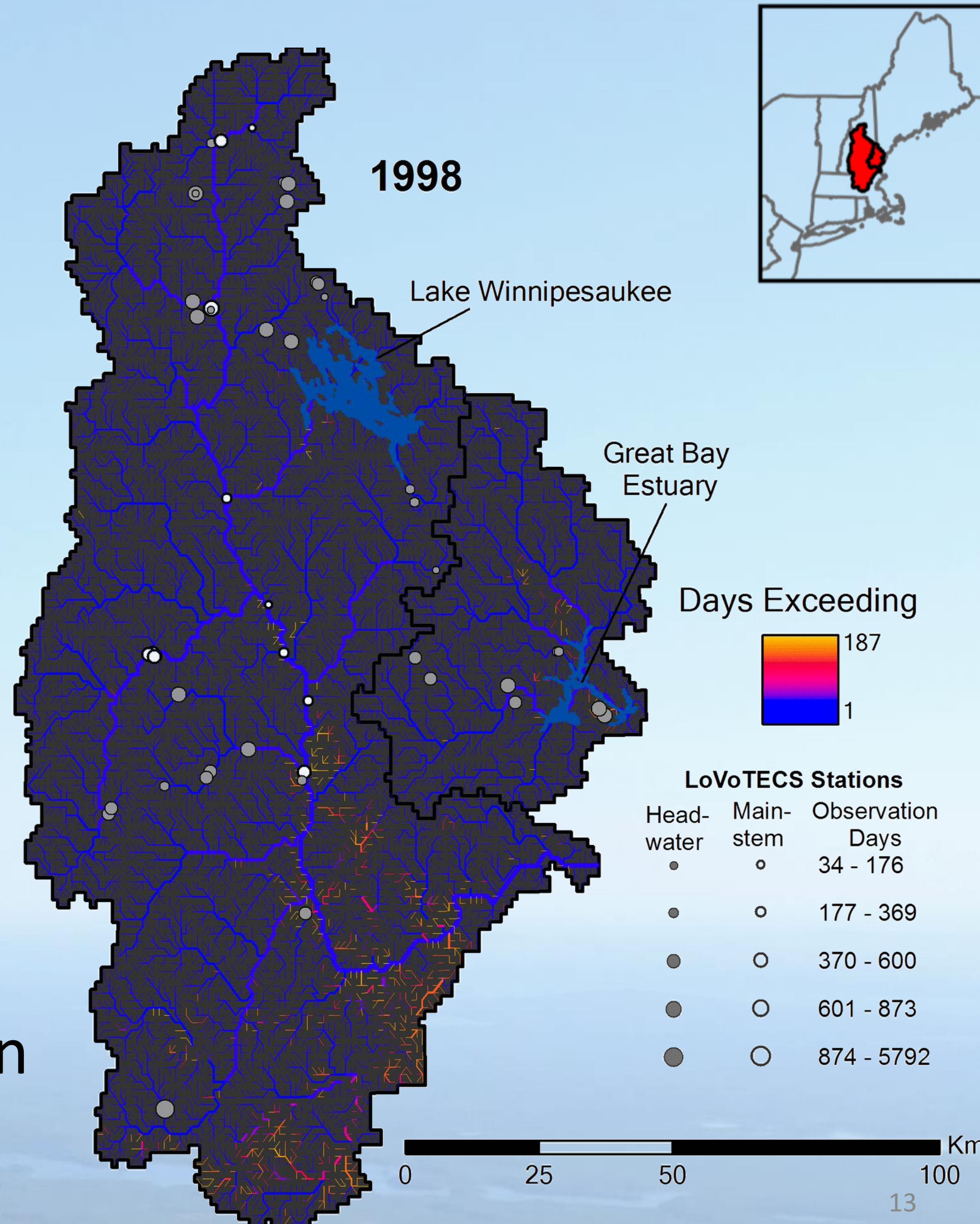
Impairment:

Defined as number days:

$$k_0 > 600\ [\mu S\ cm^{-1}]$$

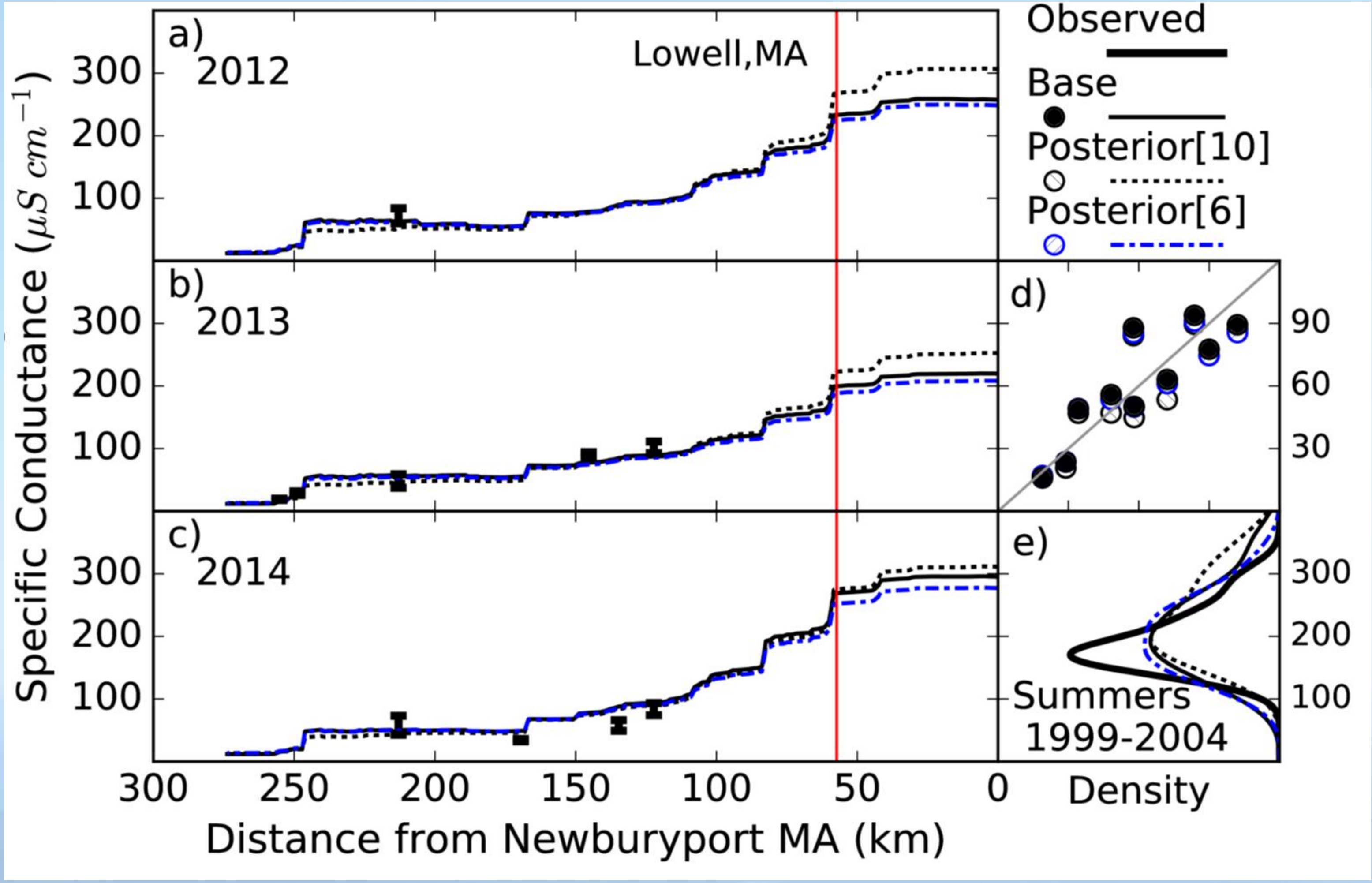


Predict ≈90% sites, underestimate duration



Σ Duration × Length

Outlet summer mean varies between 180 and 300 $[\mu S\ cm^{-1}]$

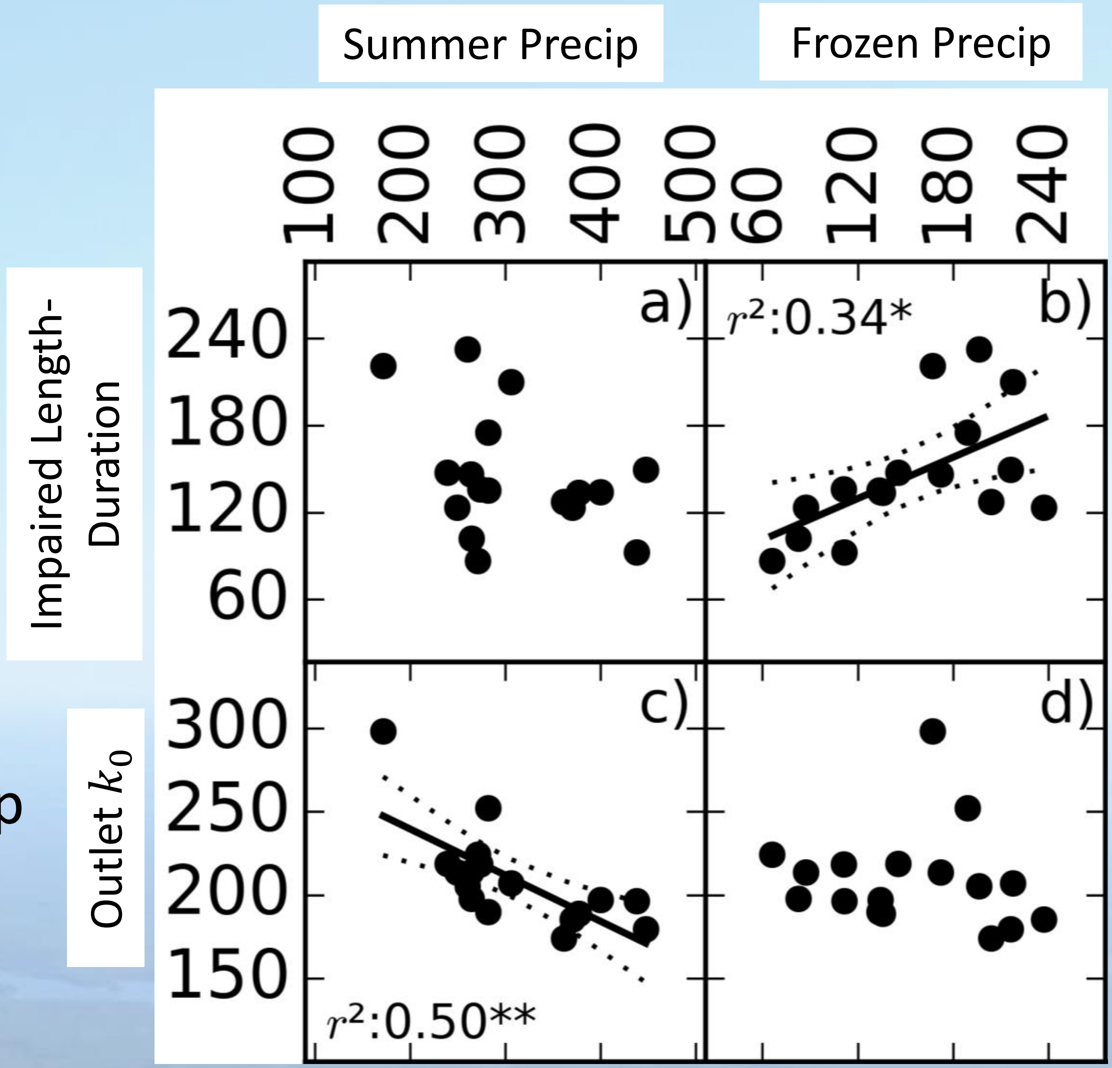


Within 20% along river profile and historic samples

Sensitivity of climate on impairment depends on stream size

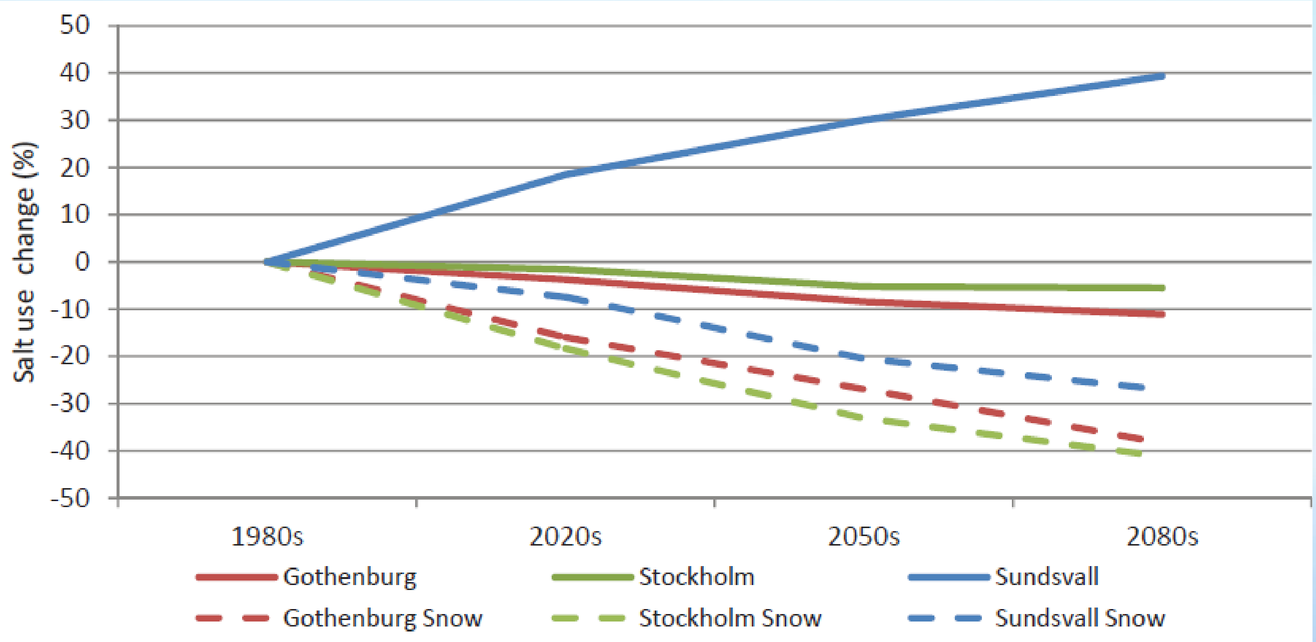
Considerable interannual variability

- Impaired Length-Duration
  - Headwaters
  - Loading – Snowfall
  - Suggests leverage
- Outlet Concentration
  - Large River
  - Dryness – Inverse precip
  - Suggests Drought concerns



What does the future hold?

- Surprisingly little work
- Sweden will lose snow, but a mixed bag



- In our region, we should expect less snow too

Arvidsson et al., 2012

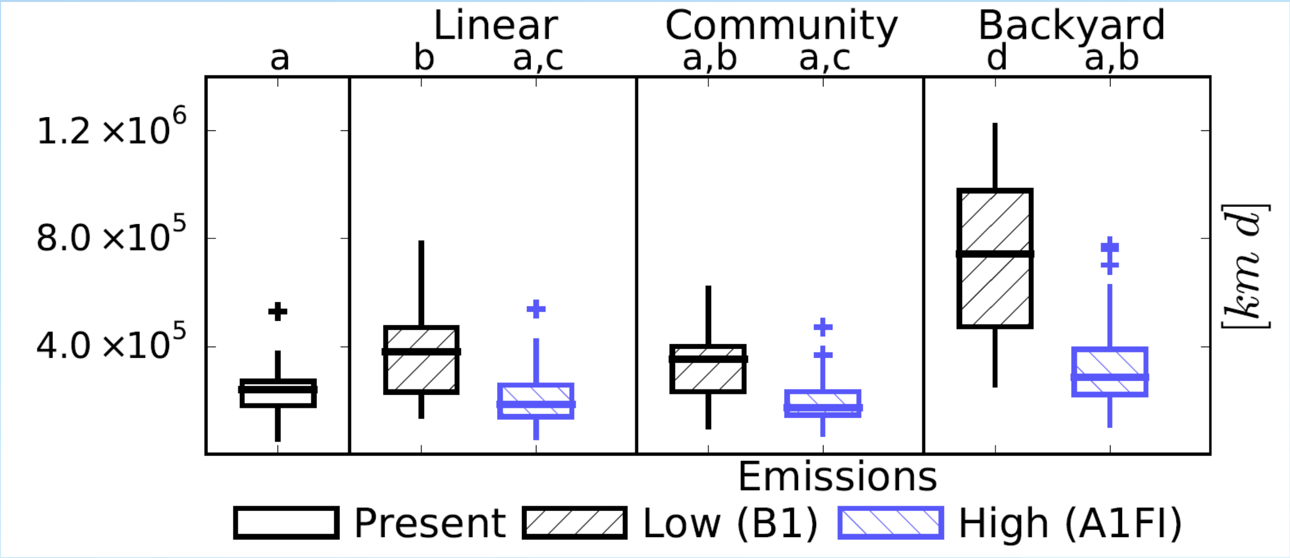
Less snow, less salt, less impairment …

TARGET VARIABLES			UNCERTAINTIES		
Emissions	Land Cover	Road Salt	AOGCM	Spinup (yr)	Subsurface Store
•High (A1FI) •Low (B1)	•Linear •Community •Backyard	•Status Quo •Recommended (2015 transition)	•GFDL •CCSM	•16 (1964) •30 (1950)	•Median Lag •High Lag
2	3	2	2	2	2
	6	12	24	48	**96**

- Modeled a suite of scenarios (96)
- Investigated Land-Cover, Road Salt, and Climate
- Considered key model uncertainties

Less snow, less salt, less impairment …, right?

Impaired River Length-Duration in 2100

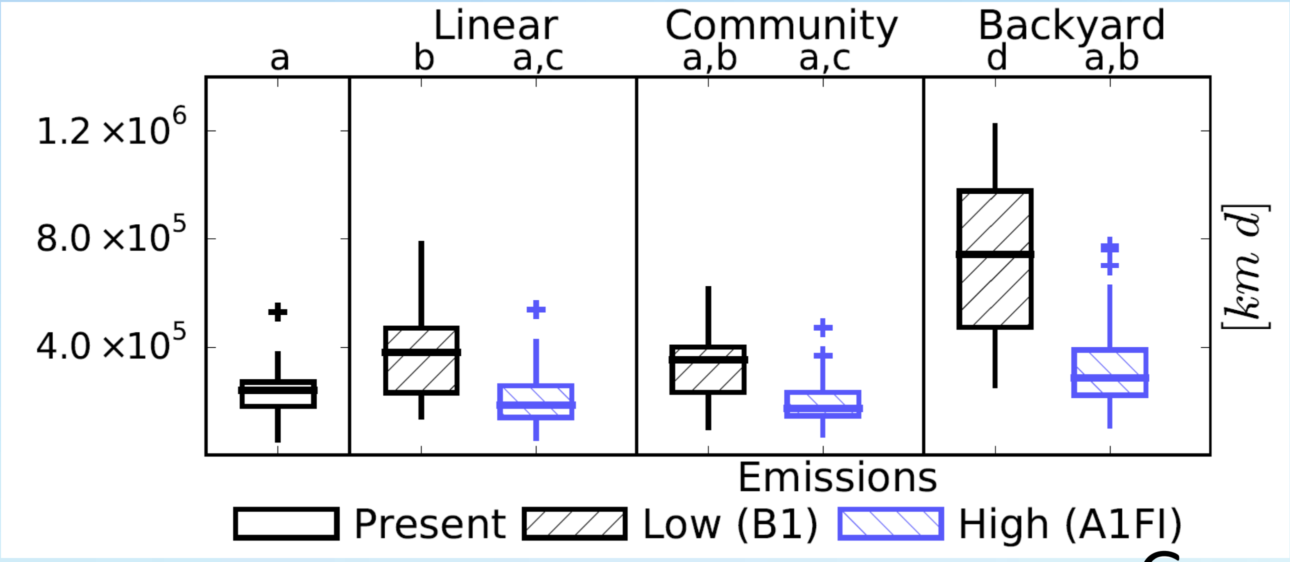


Status Quo Road Salt Application

- Snowfall doesn't change that much
  - Especially under low-emissions scenarios
- Continued development
- Continued accumulation in groundwater

Less snow, less salt, less impairment …, right?

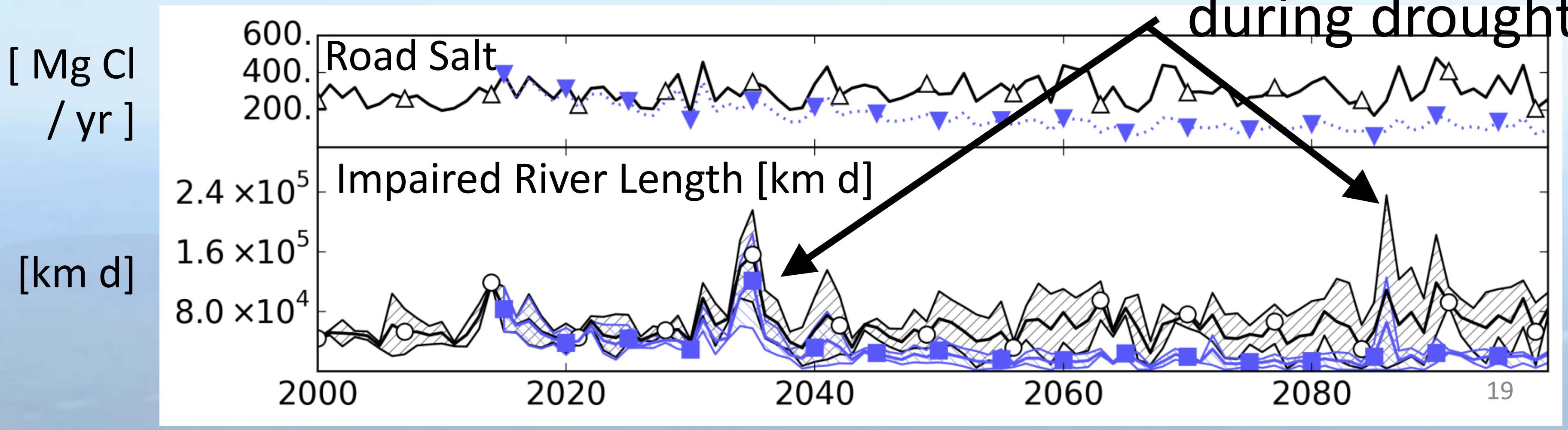
Impaired River Length-Duration in 2100



Status Quo Road Salt Application

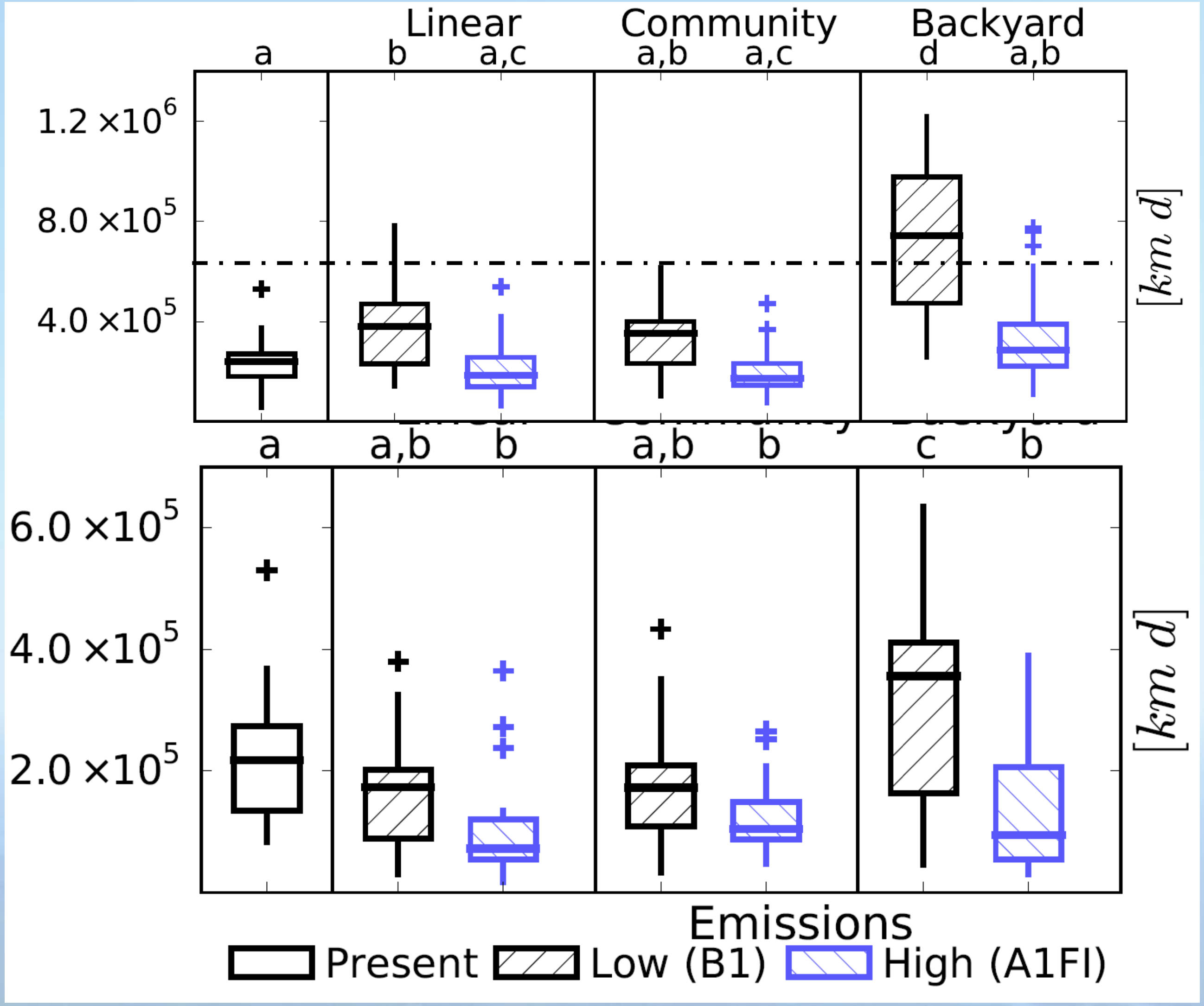
Impaired River Length-Duration through time

Groundwater release during drought



Less snow, less salt, less impairment …, right?

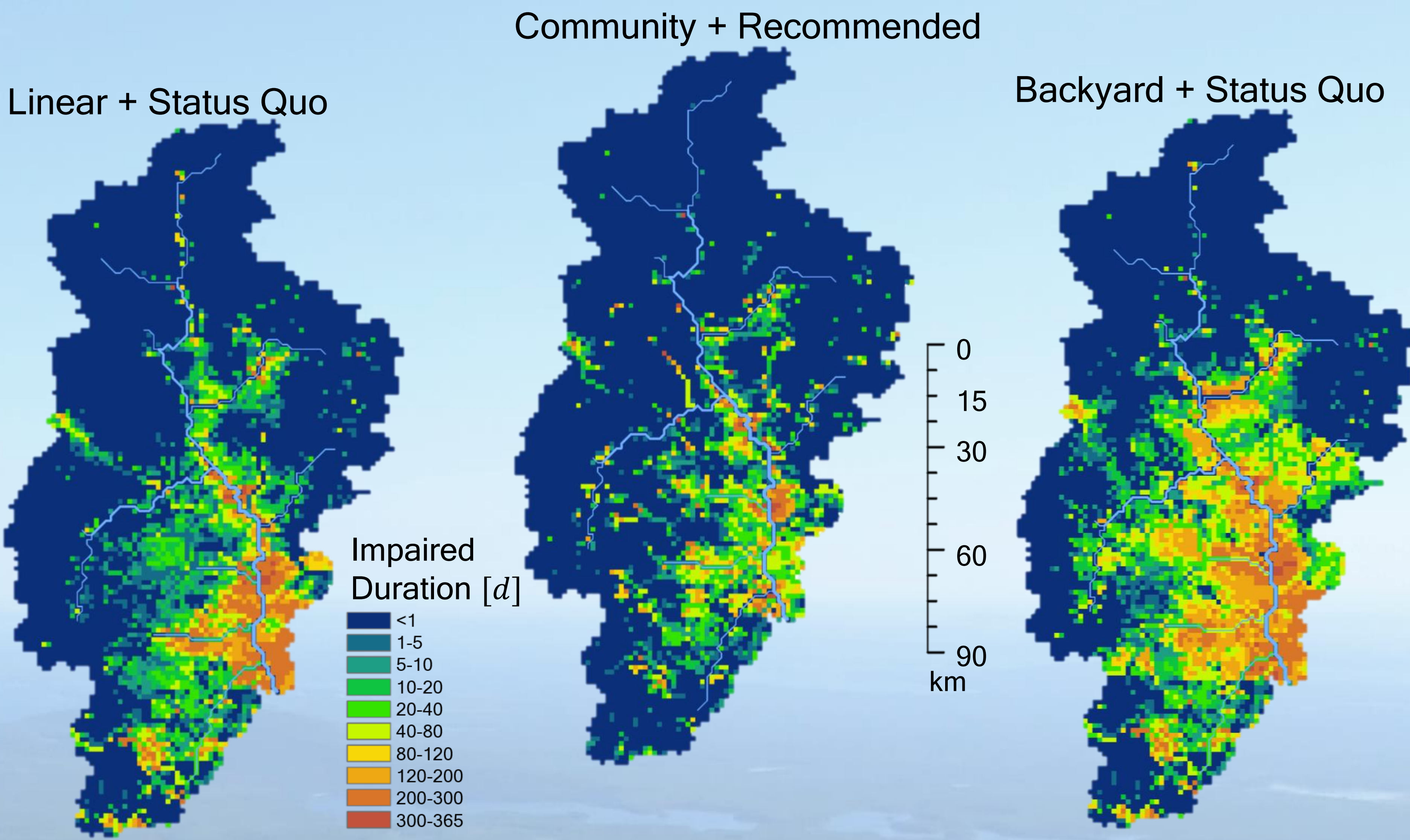
Impaired River Length-Duration in 2100



Status Quo Road Salt Application

Recommend Road Salt Application

Extent of impairment in 2100



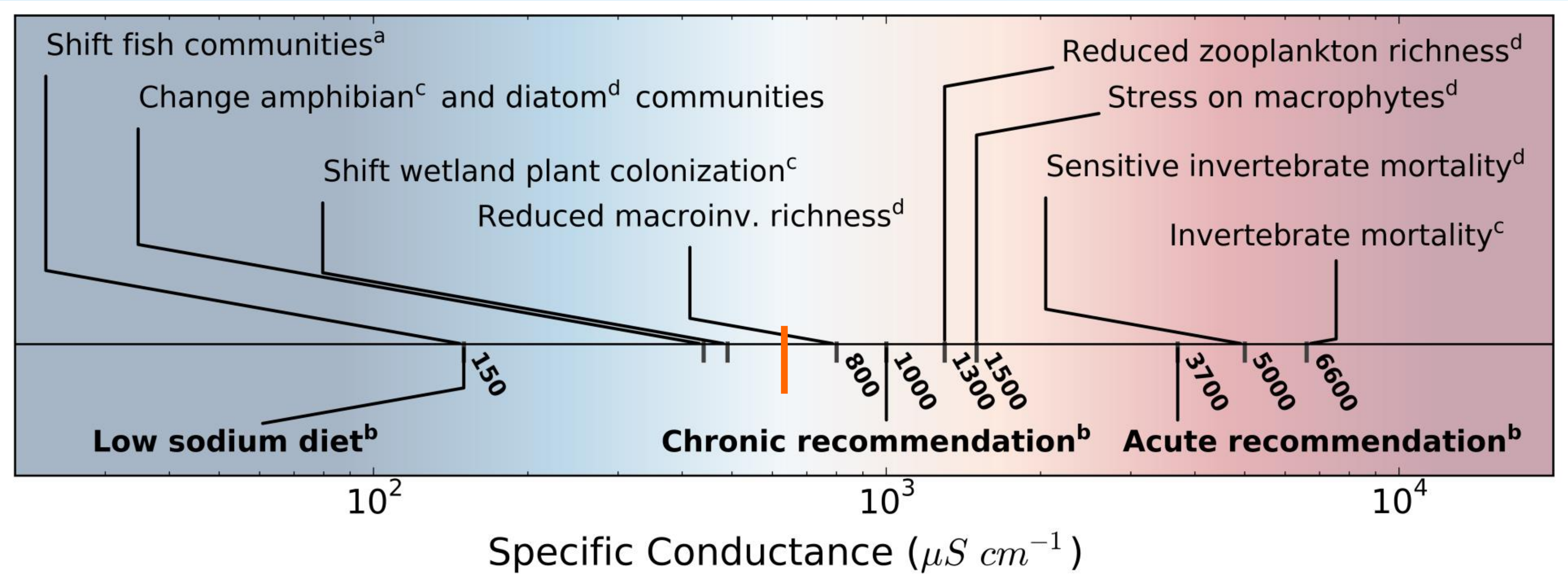
Leverage points for management, and definite causes for concern

- Stream chloride shows greater than recommended road salt loading
- Chloride impairment up to 23% of watersheds
  - Dry summers bigger driver downstream
  - Climate variability expected to increase
- Projecting future impairment
  - Warming will not improve impairment (Temperature)
  - Maintaining current practice (road salt and build out) Greatly increases impairment from present

Leverage points for management, and definite causes for concern

- Projecting future impairment
  - Road salt management and build-out can
    - Reduce chloride impairment in a warmer climate
    - Maintain current impairment for greater population
- Leverage points
  - Happening already
  - Green SnowPro
  - Coverage Indication Technology

Selecting the 600 uS cm^{-1} Threshold



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