Transport and Fate of Chloride from Road Salt within a Mixed Urban and Agricultural Watershed: Assessing the Influence of Chloride

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Background – Problems with Chloride (Cl^-)

- High chloride concentrations can have negative even fatal effects on stream organisms and surrounding vegetation (Panno et al., 1999; Environment Canada, 2001; Corsi et al., 2010; Findlay and Kelly, 2011)
- Chloride (Cl^-) is also highly corrosive to steel and pipes used in water treatment plants and local bridges, which contributes to high and frequent repair cost (Kelly et al., 2012).
- Secondary EPA drinking standard of 250 mg/L

Photo of Little Kickapoo Creek located in central Illinois.

Background – Road salt

- Compound containing Cl^- and either sodium, calcium, magnesium, or potassium
- Road salt (NaCl)usage has increased substantially due to growing population and urbanization since the 1950's (Figure 1)
- Application rates: 1 to 74 ton per road mile

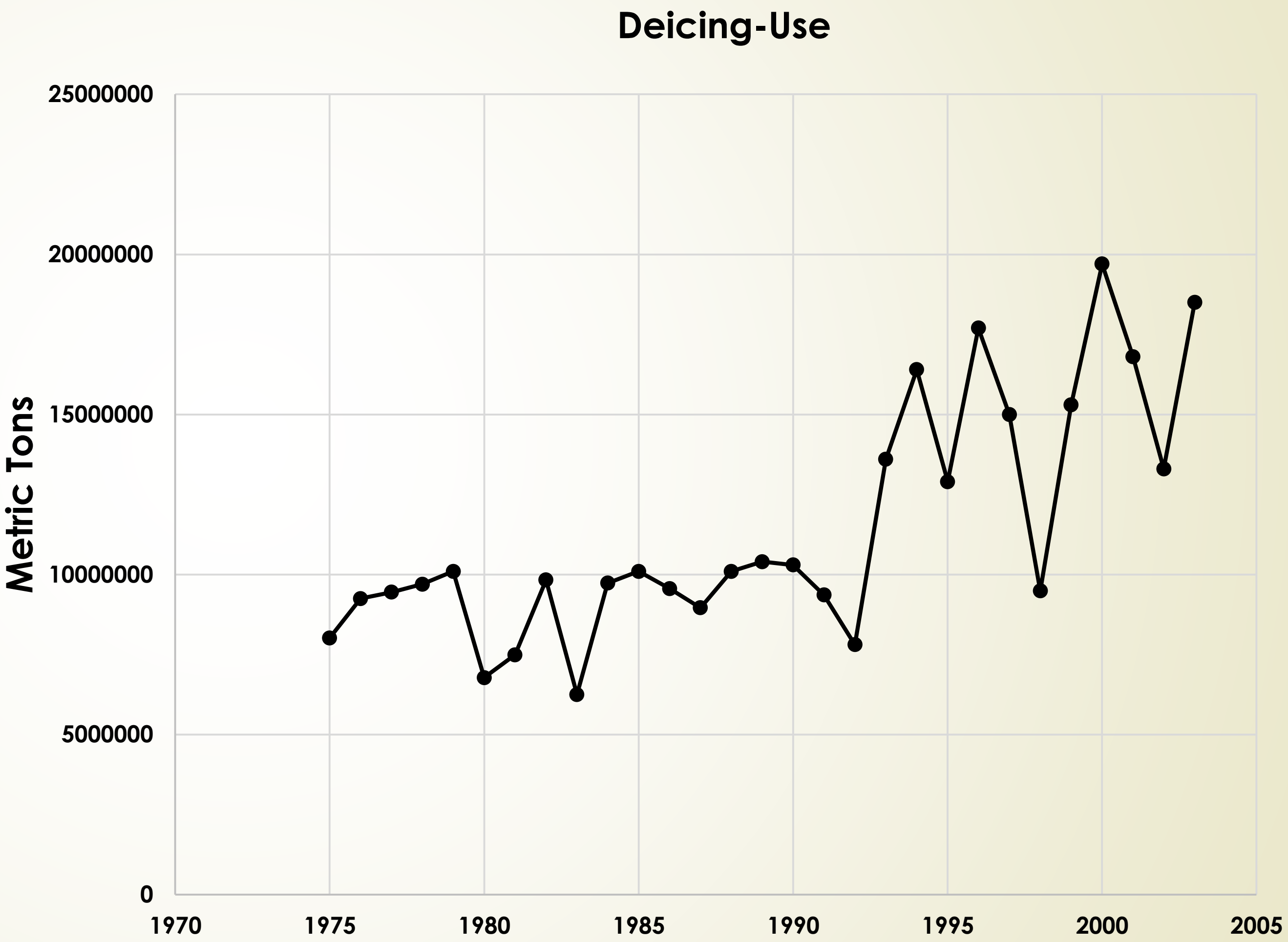
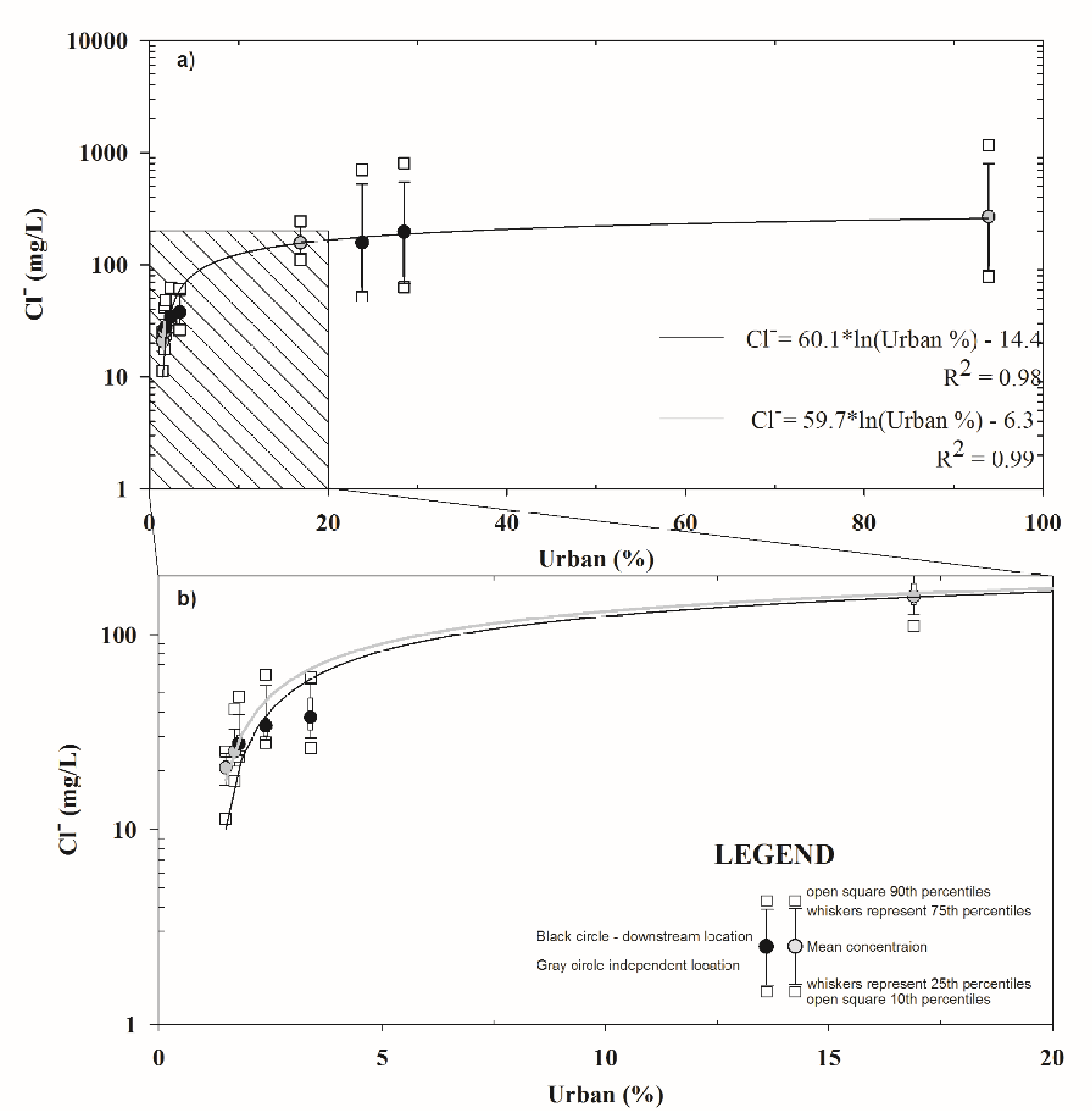


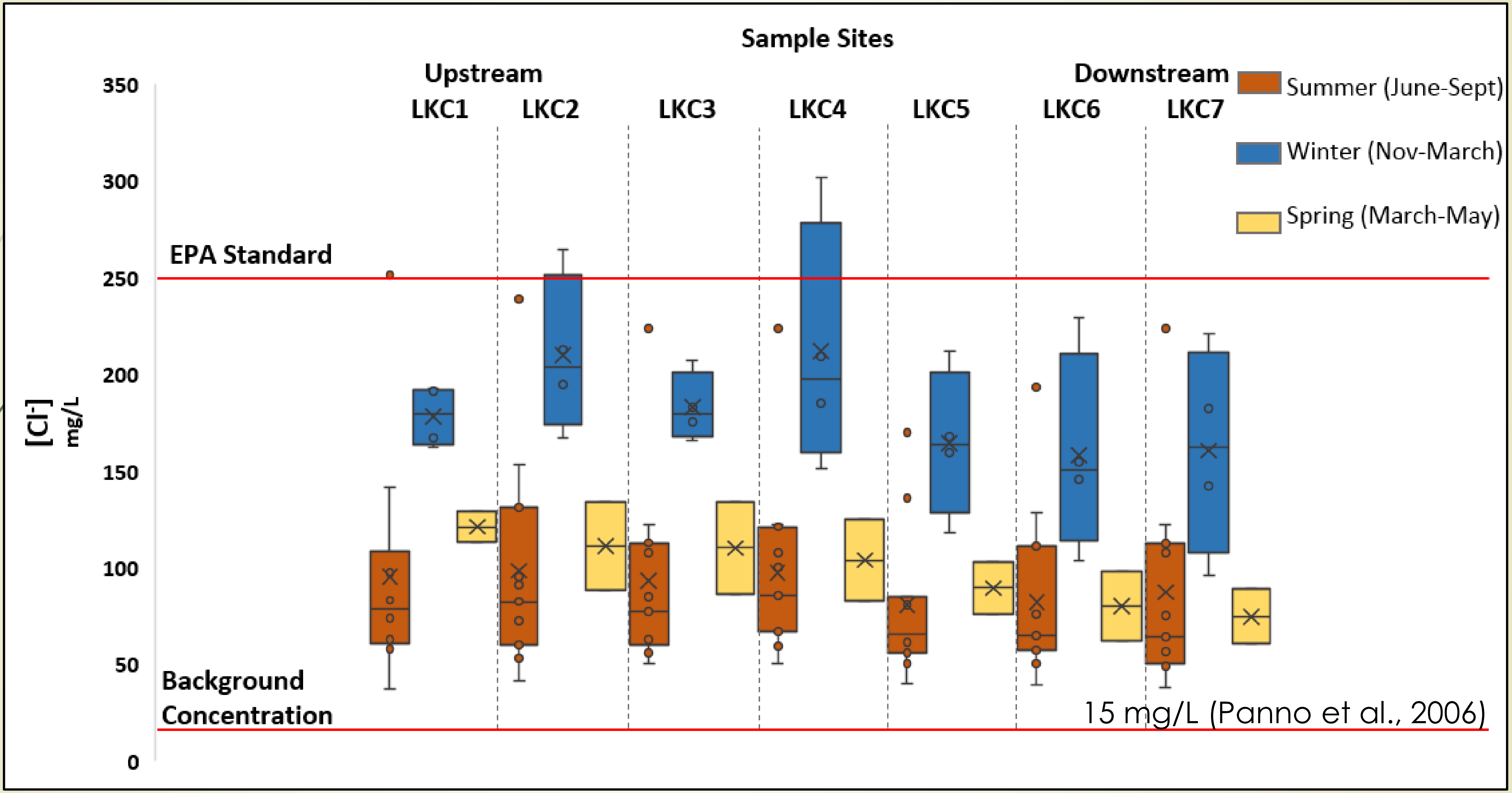
Figure 1: Road salt in End-Use from 1975-2003. Deicing data obtained online from the United States Geological Survey (2005).

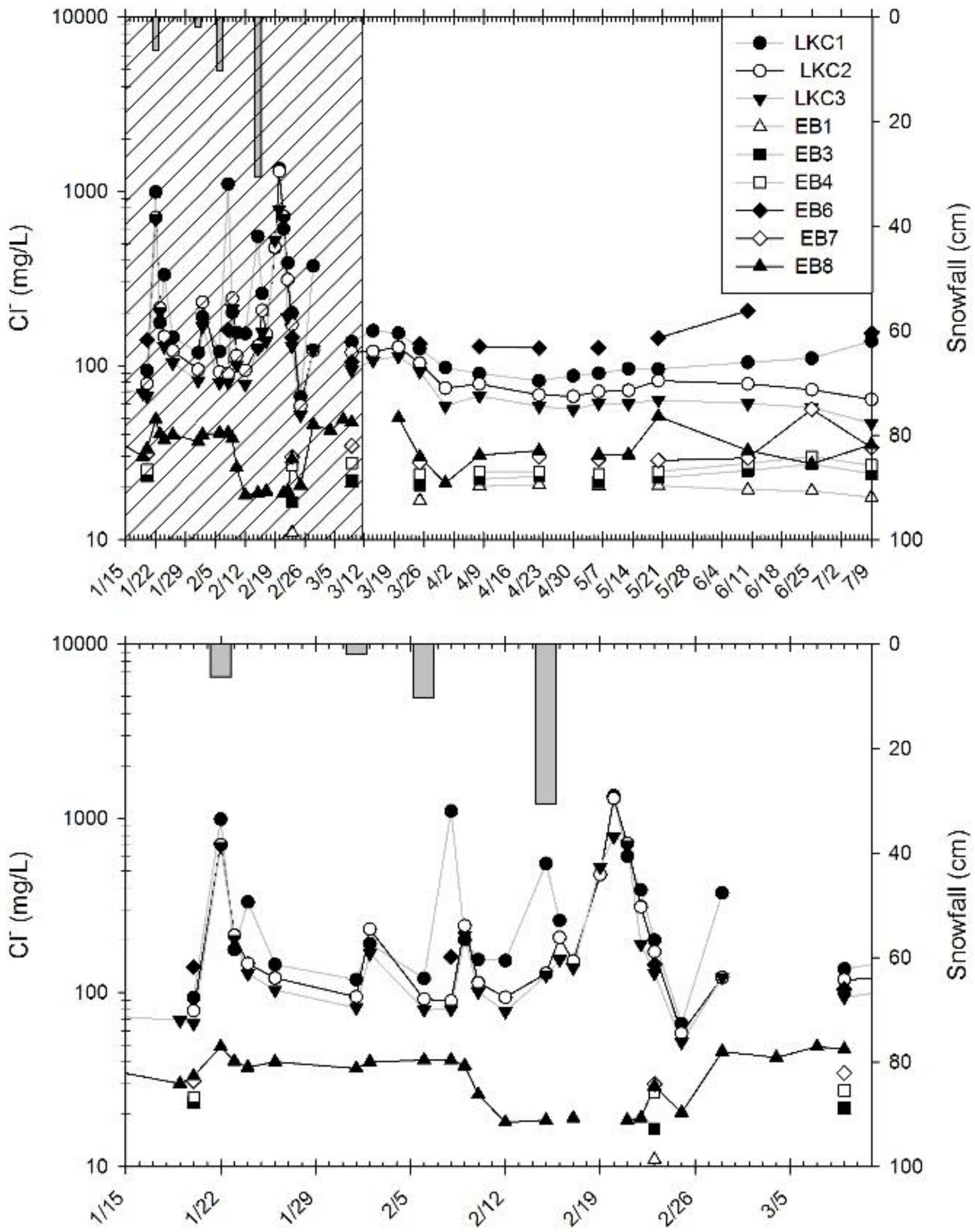
Land-use correlated to stream Cl^- concentration



(Herlihy et al.,1998; Poor et al., 2008; Cunningham et al., 2009; Lax et al., 2017)

Seasonal trends in Cl^- concentrations



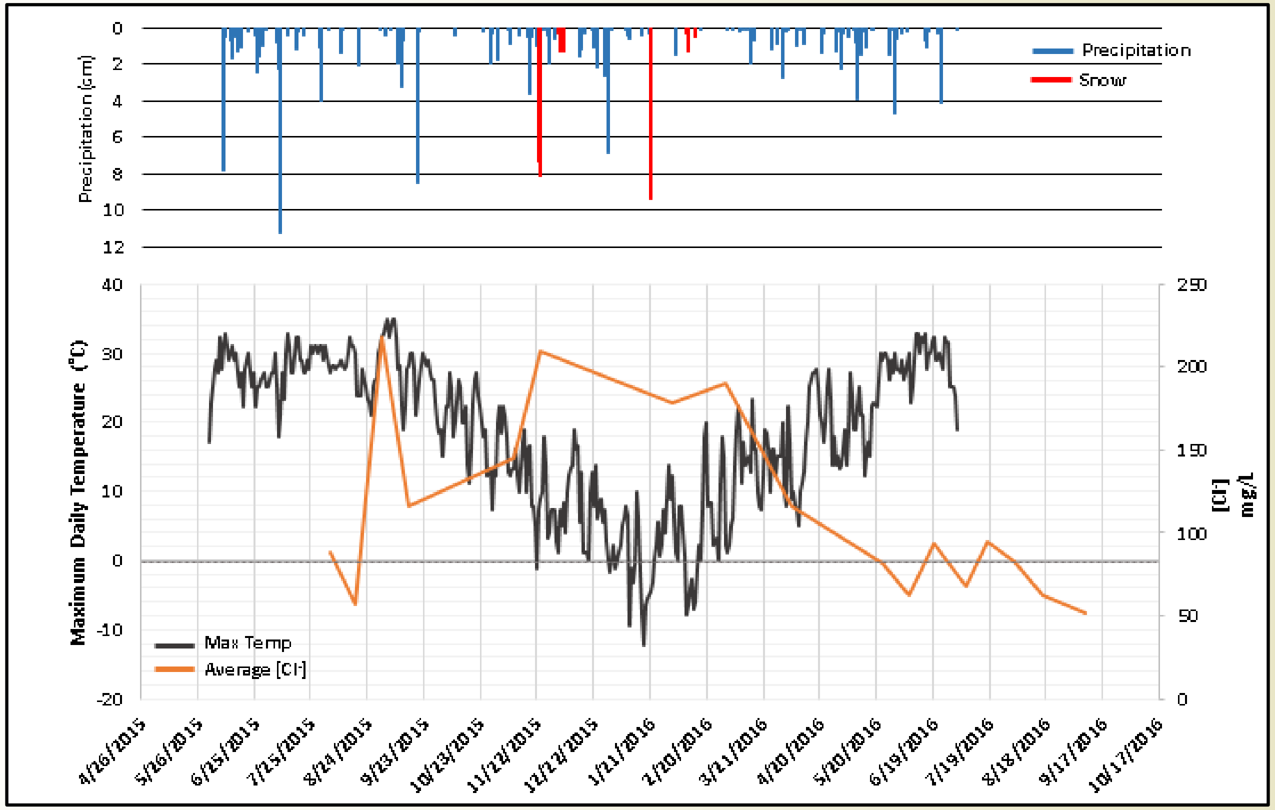


Cl^- in the environment

- Elevated concentrations associated with snowfall events
- Long-term, chronic concentrations observed year-round
- Source is groundwater (Lax and Peterson, 2008, Mason et al. 1999, Kelly et al., 2012, Corsi et al., 2014)
- 44% of freshwater lakes exhibit increases in Cl- concentrations (Dugan, et al., 2017).

Background – Cl^- storage

- In the urban area of Chicago, Il, Kelly et al. (2012) estimated about 14% of the road salt (Cl^-) is retained in the subsurface
- Bester et al. (2006) simulated chloride transport and found well Cl^- concentrations have not reached maximum concentrations after ~60 years
- Provides continual source of Cl^- to surface water

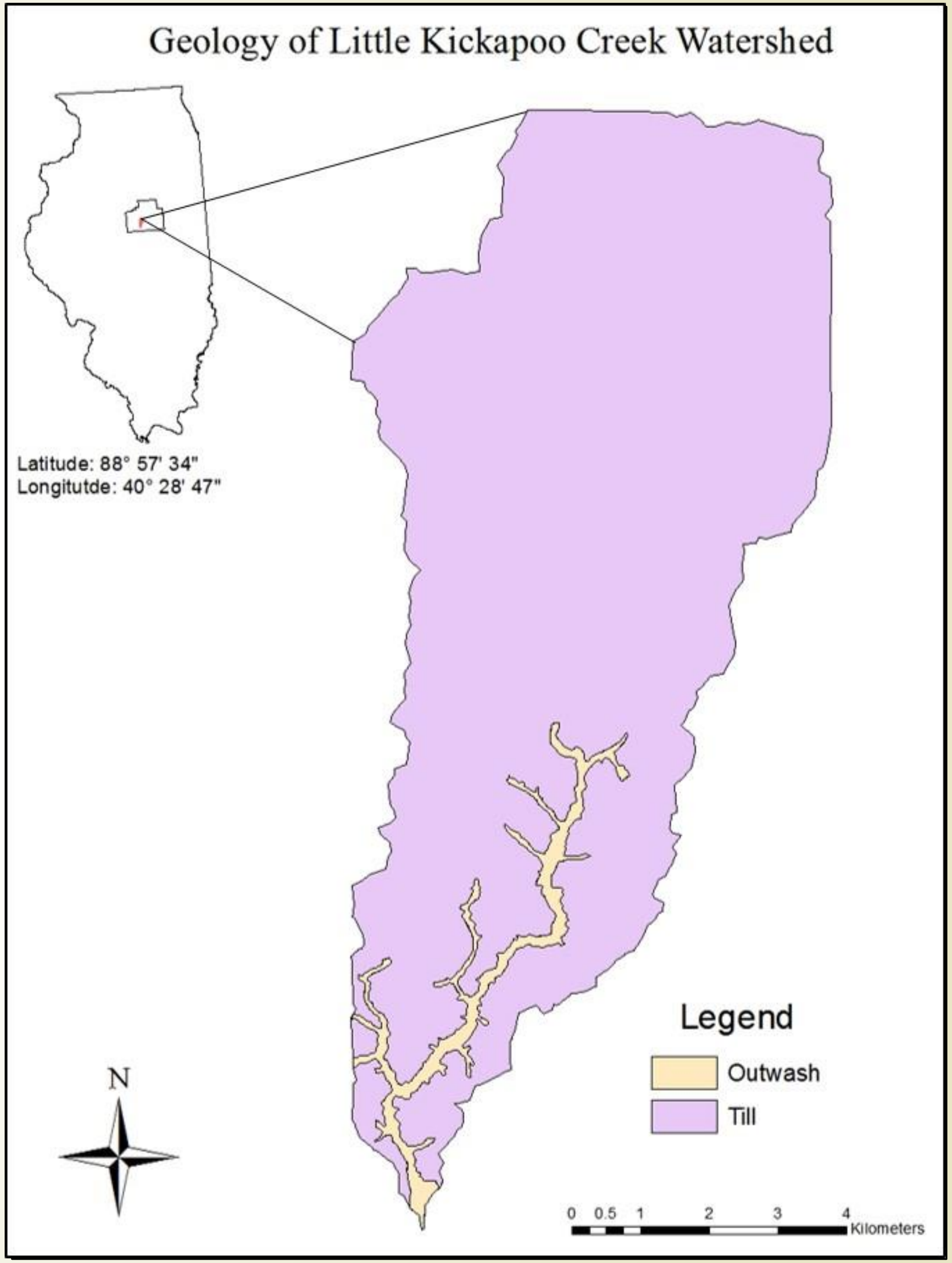


Purpose

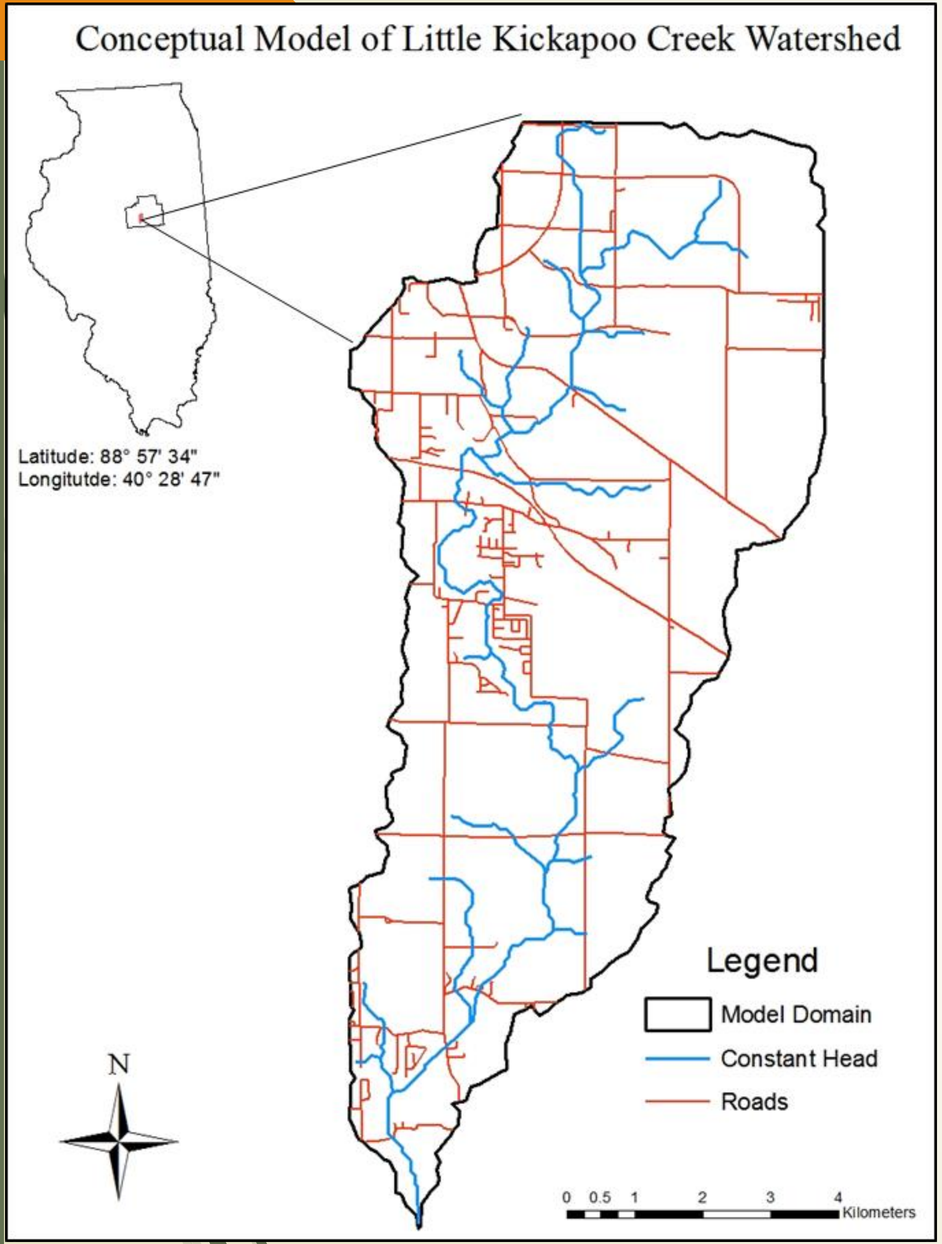
- Modeling of a watershed can be helpful in understanding chloride storage
- This project's purpose is to:
  - 1) Assess the relationship between the rate of road salt application and the residence time of Cl^- within a shallow aquifer.
  - 2) Assess the relationship between the rate of road salt application and the mass of Cl^- accumulating within a shallow aquifer.

Study Site

- Little Kickapoo Creek (LKC)
  - Low-gradient, perennial stream; 70 km^2
  - Background chloride concentration ~15 mg/L (Panno et al., 2006)
- Land use
  - 27% urban – primarily in headwater area
  - 69% agricultural
  - 4% forested/wetland/surface water areas (U.S Geological Survey, 2011)
- Geology
  - Till - K =1.0 x 10^{-8} m/s; thickness of 70 m (Hensel and Miller, 1991)
  - Outwash - K =1.0 x 10^{-4} m/s; thickness of 8 to 10 m (Ackerman et al., 2015)



Model Setup



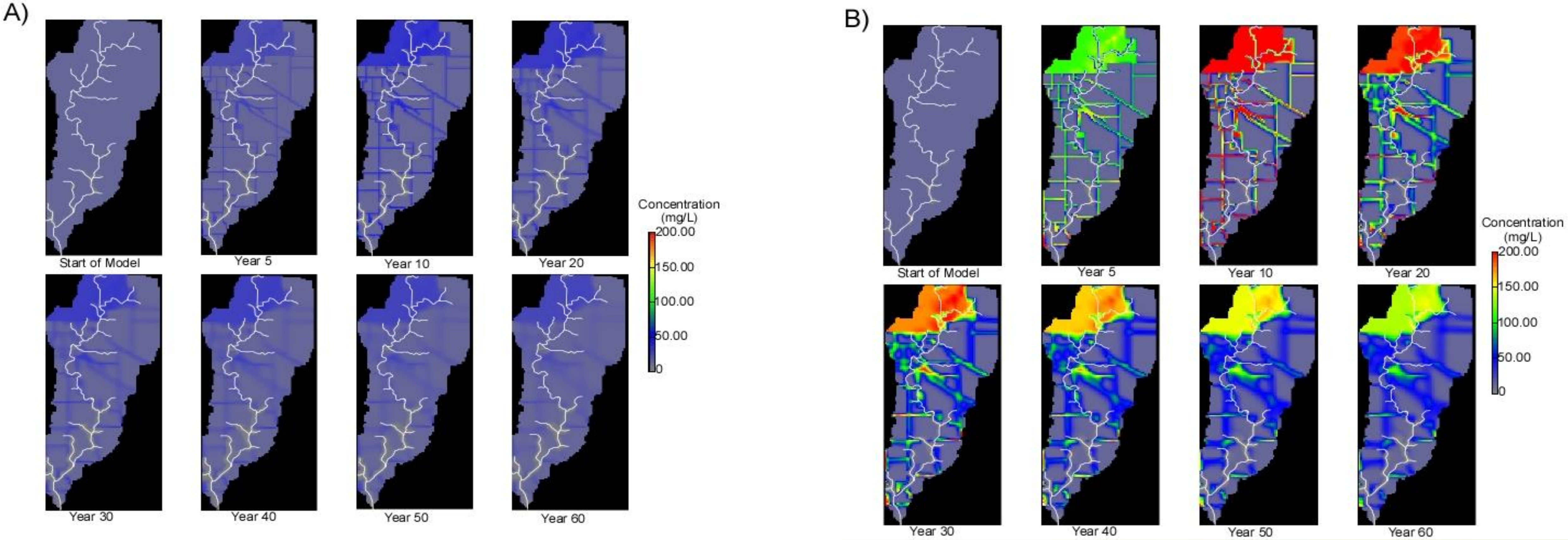
- Domain - Surface water drainage basin for LKC
  - 2D, 100 m x100 m cells
  - Geology
    - till and outwash, each is assumed to be isotropic-homogeneous
- Flow - Steady-State, MODFLOW (Harbaugh et al., 2000)
- Solute - Transient, MT3D (Zheng and Wang, 1999)
- Boundary conditions
  - No-Flow boundary – drainage basin, bottom of the domain
  - Surface Recharge
    - 0.026 cm/day
    - 10 mg/L Cl^- non-roadways
    - Roadways - sources of Cl^-
      - winter stress period 1,000 mg/L
      - summer stress period 10 mg/L

Scenarios

- "Flush Scenarios" - 10 cycles of winter and summer seasons (or 10 years) followed by 50 cycles of background levels
  - Scenario 1 - Cl^- application rates of 1,000 mg/L
  - Scenario 2 - Cl^- application rates of 10,000 mg/L.
- "Build-Up Scenarios" – 60 cycles of winter and summer seasons

Scenario	Winter Application Rate (mg/L)
3	1,000
4	2,500
5	5,000
6	7,500
7	10,000

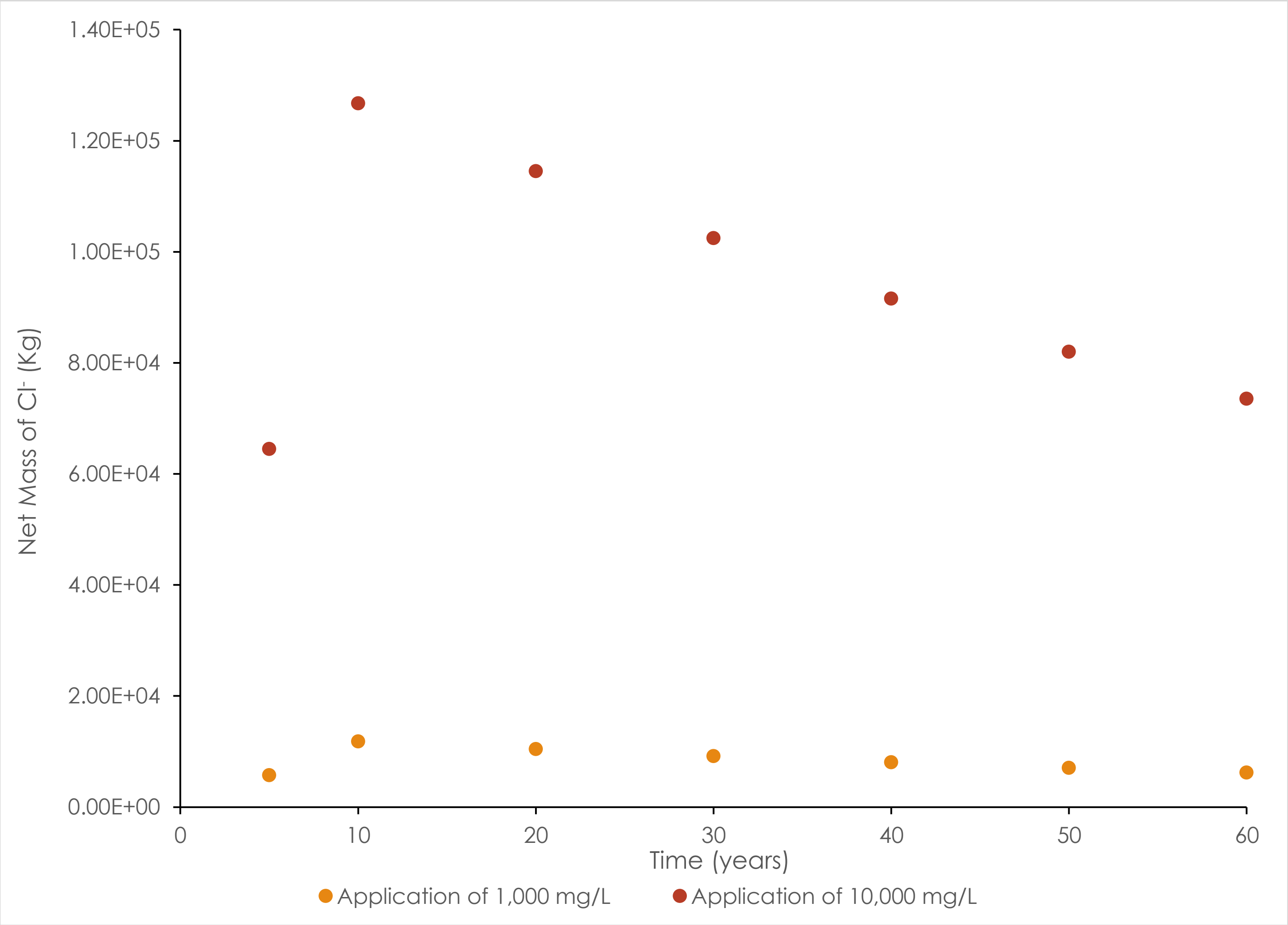
Distribution of Chloride



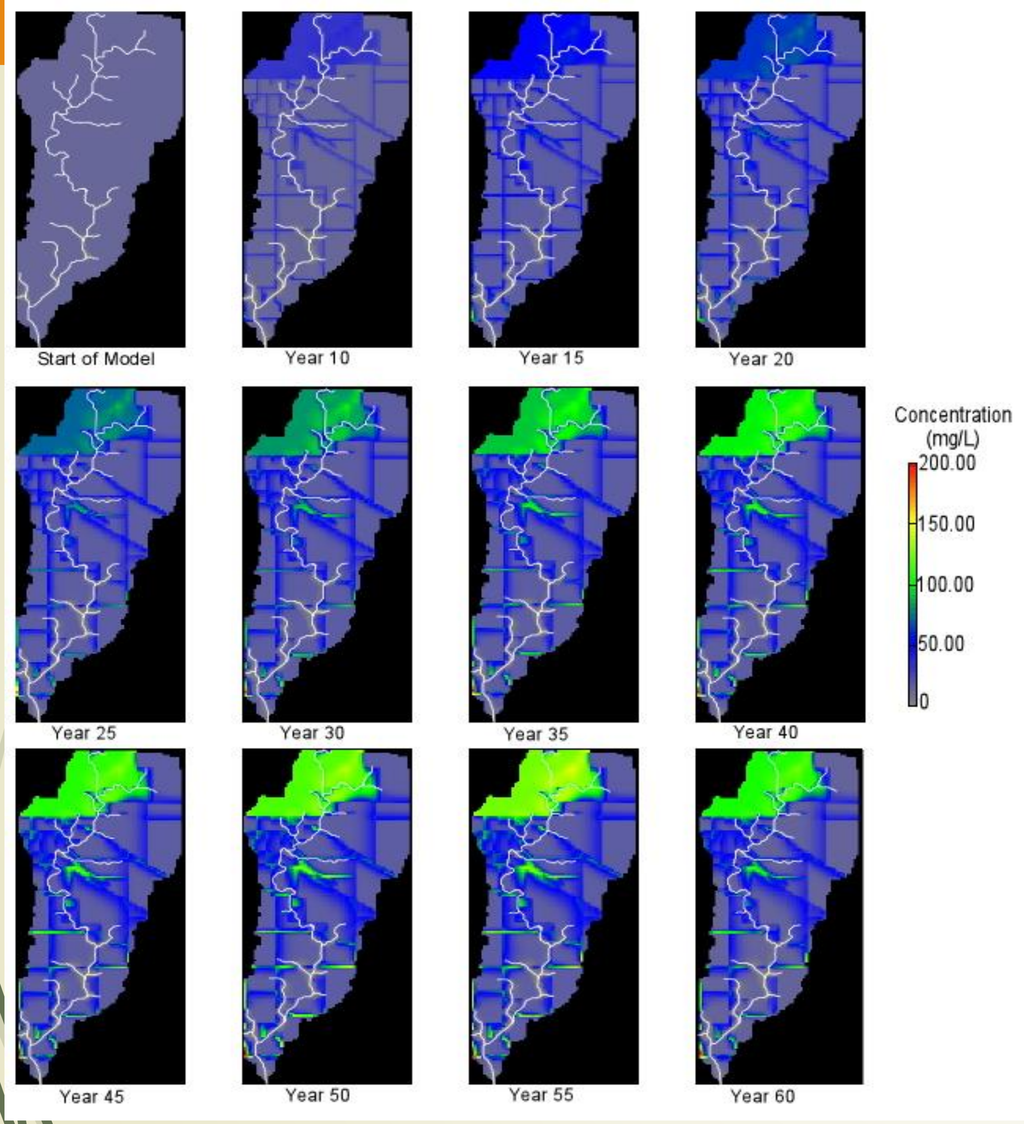
Scenario 1 **Scenario 2**

Results – Flush Scenario

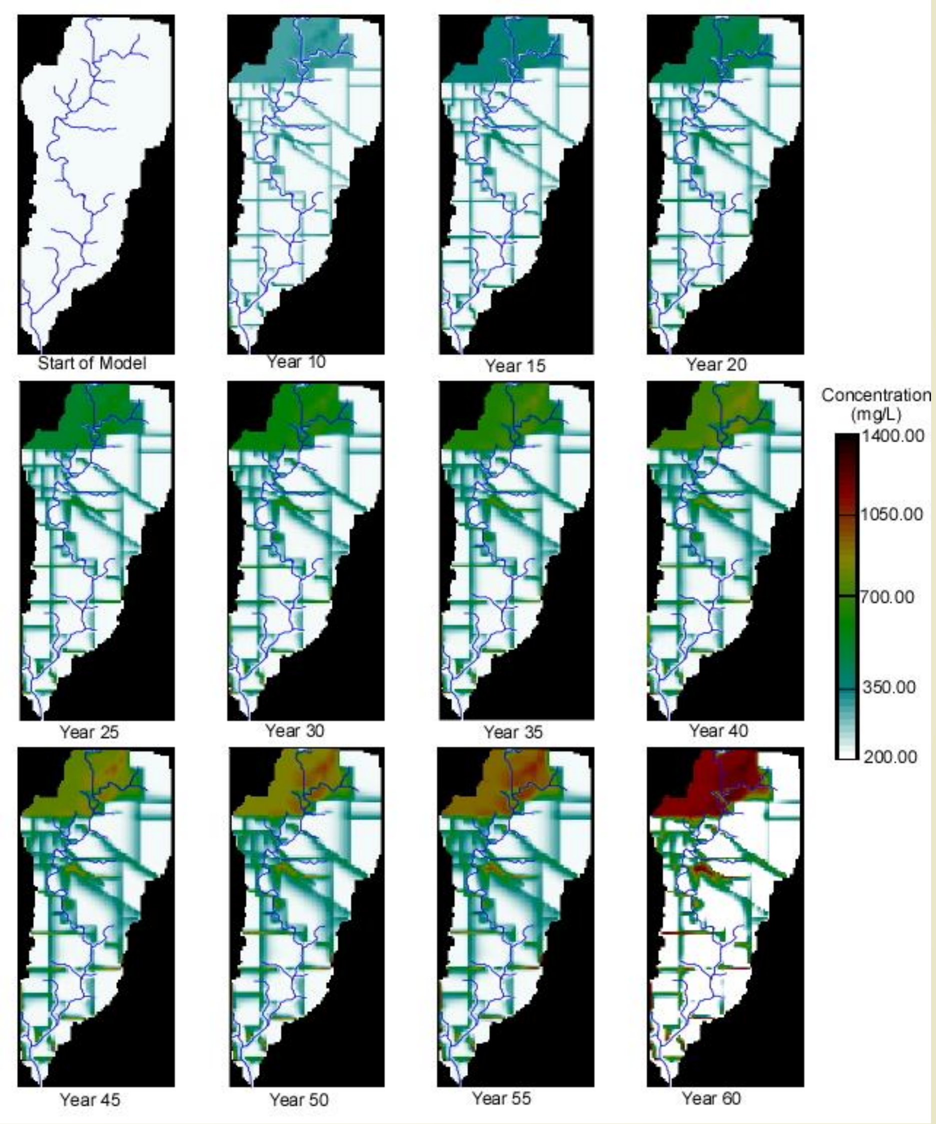
- Following 50 years of no application system still has elevated Cl^- concentrations
  - 25 mg/L – 1,000 mg/L application
  - 166 mg/L – 10,000 mg/L application
- Peak Concentrations
  - 85 mg/L – 1,000 mg/L application
  - 767 mg/L – 10,000 mg/L application
- Final Mass – after 50 years of no application
  - 6,200 Kg – 1,000 mg/L application
  - 73,500 Kg – 10,000 mg/L application
- Peak Mass
  - 11,800 Kg – 1,000 mg/L application
  - 127,000 Kg – 10,000 mg/L application



Distribution of Chloride

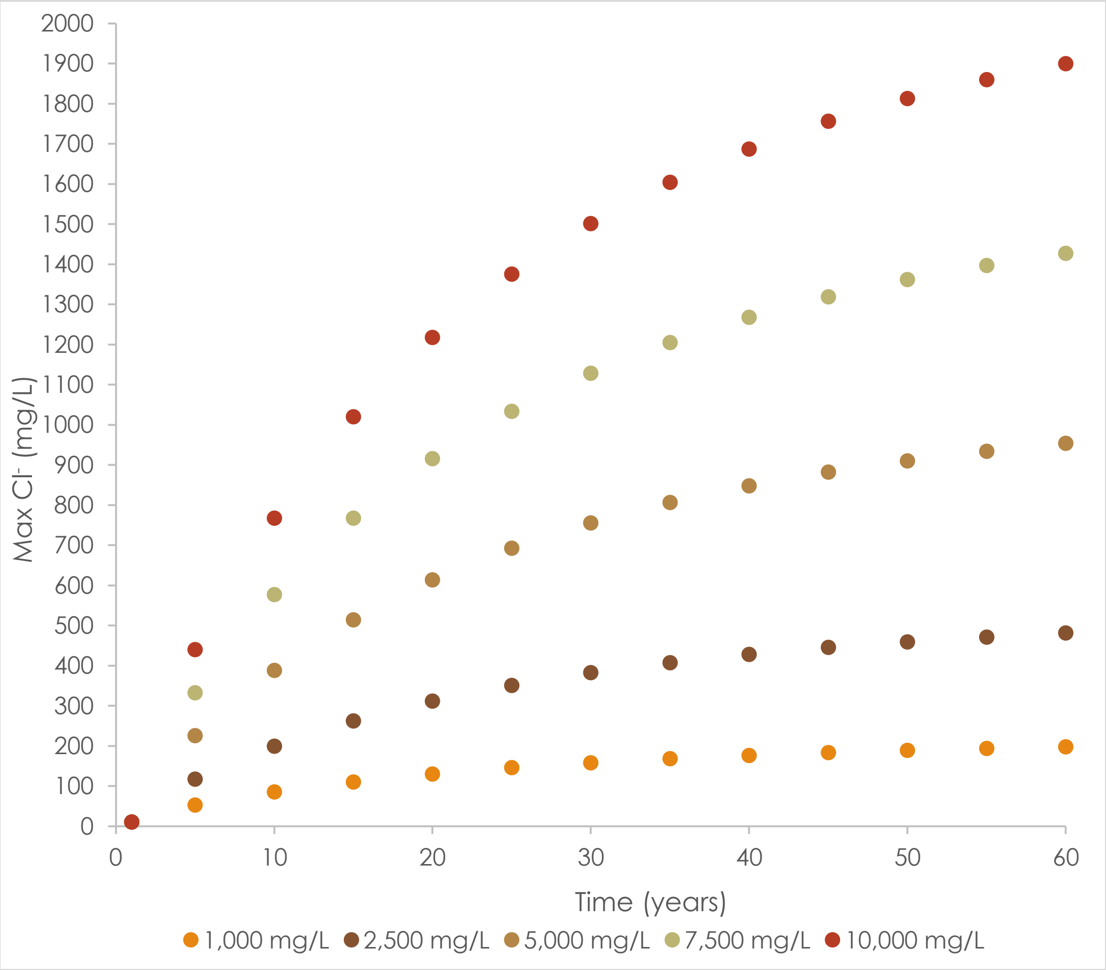


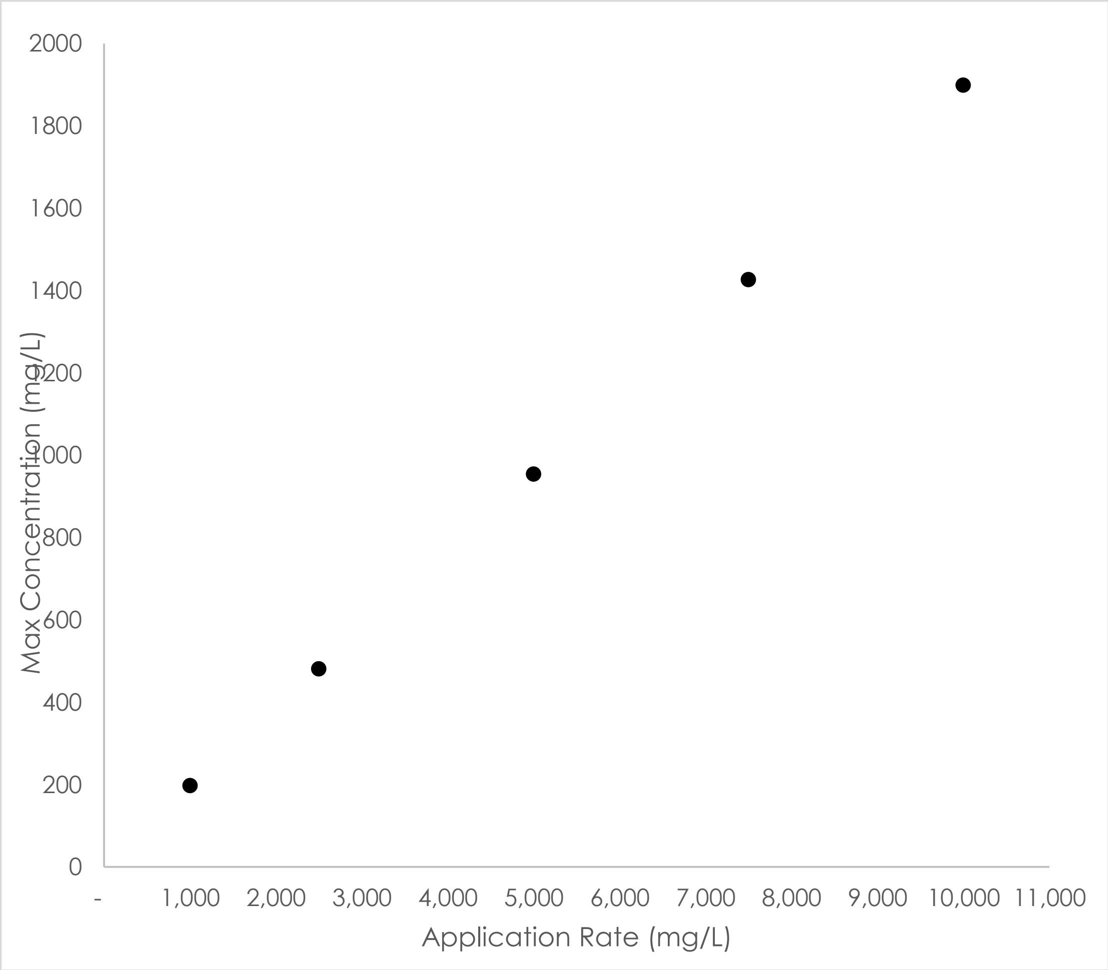
Scenario 3



Scenario 7

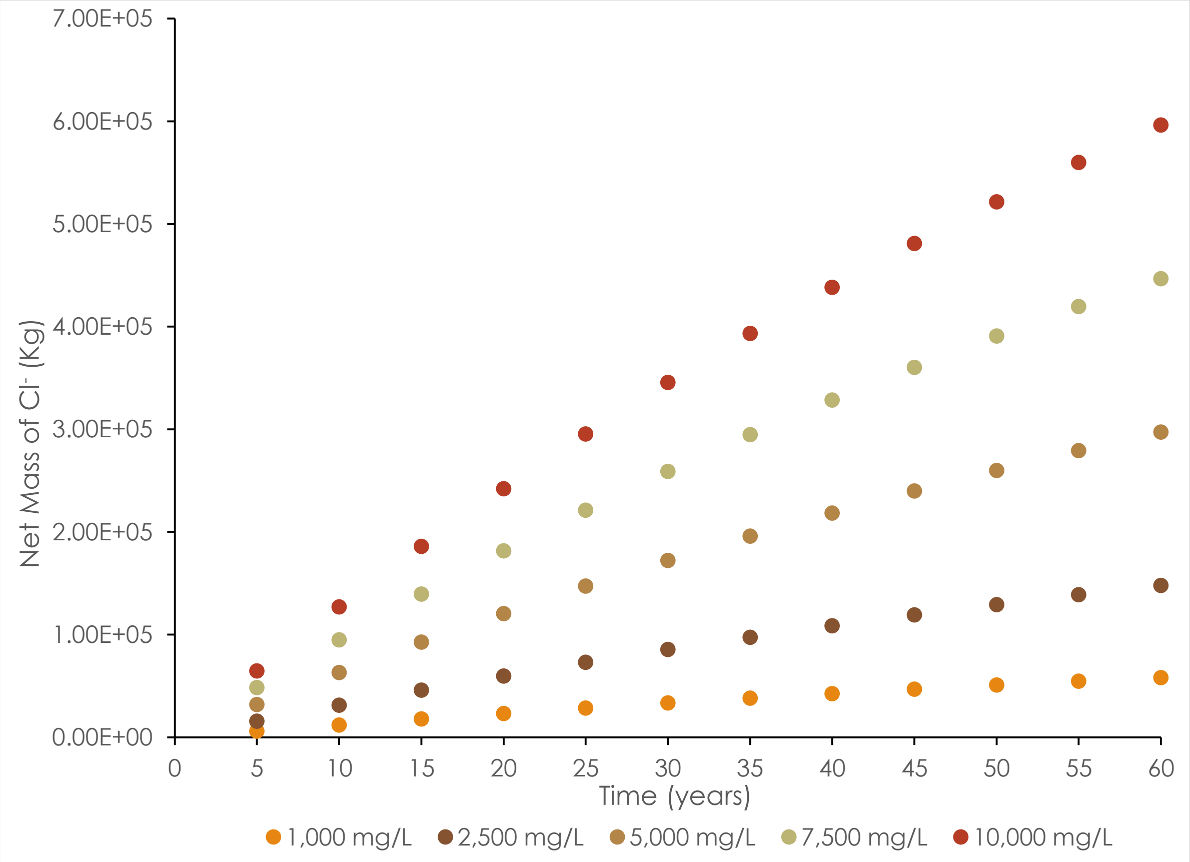
Results – Build Up Scenario

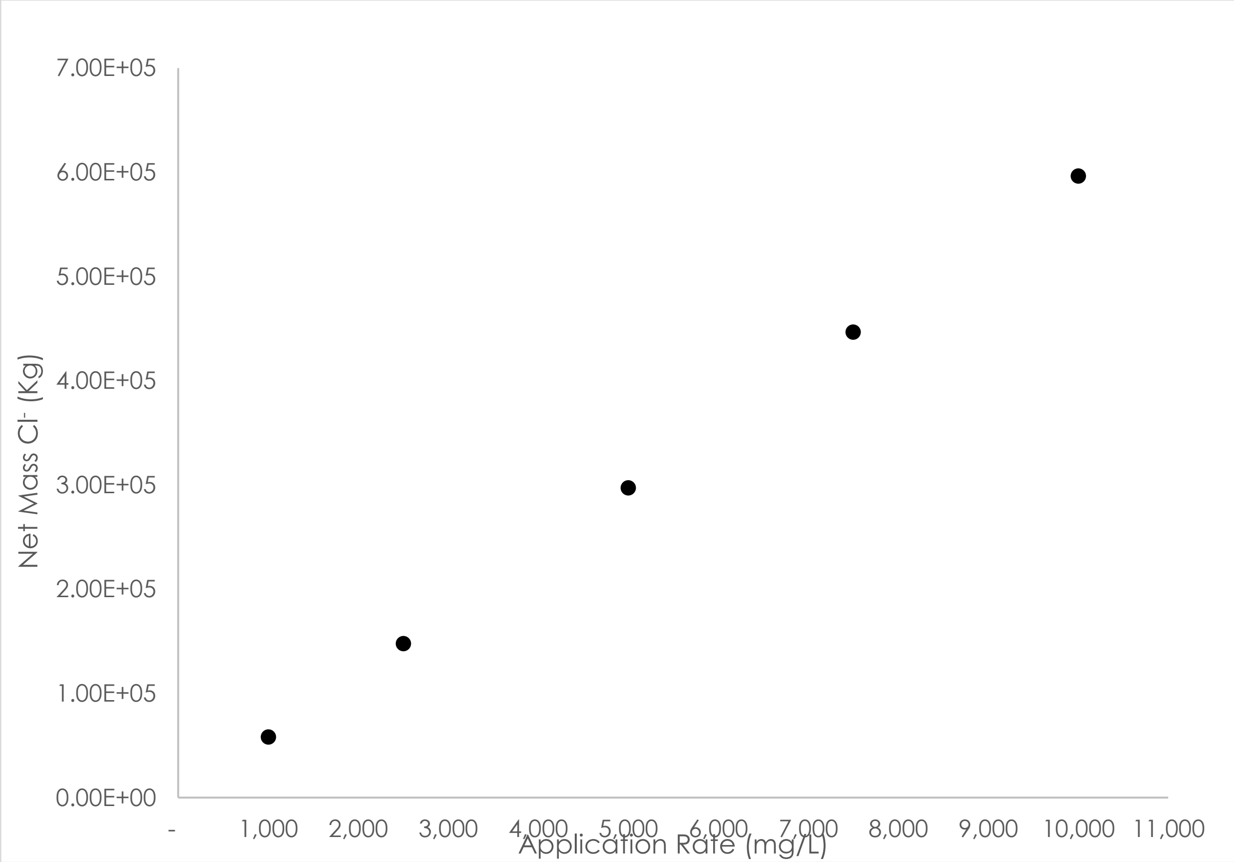




Positive linear relationship between application rate and maximum Cl^- concentration

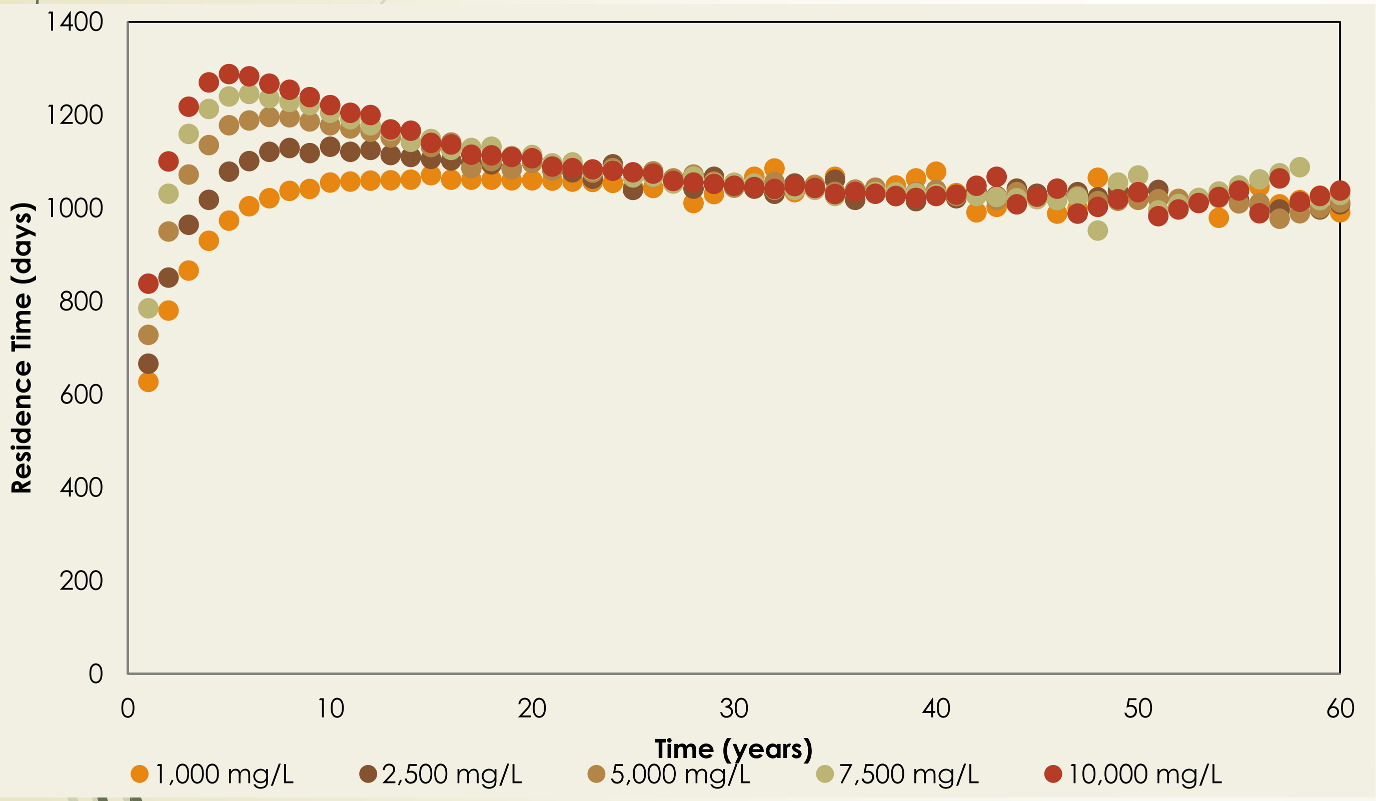
Results – Build Up Scenario





Positive linear relationship between application rate and accumulated mass of Cl^-

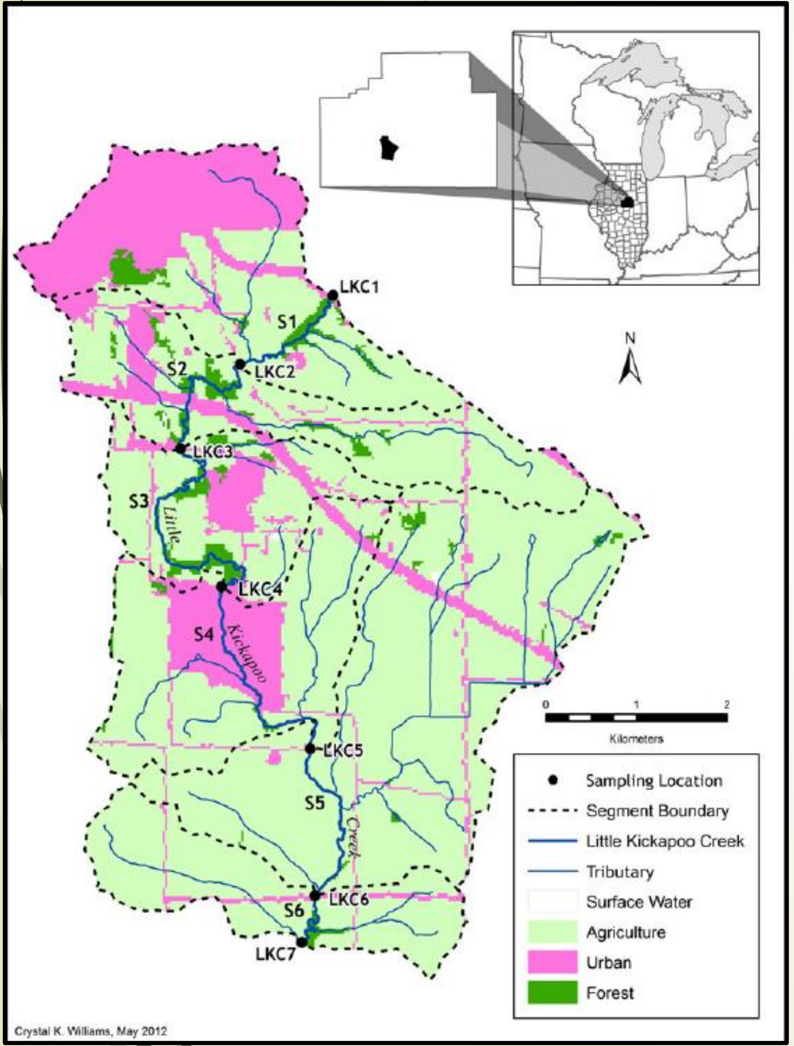
Residence Time

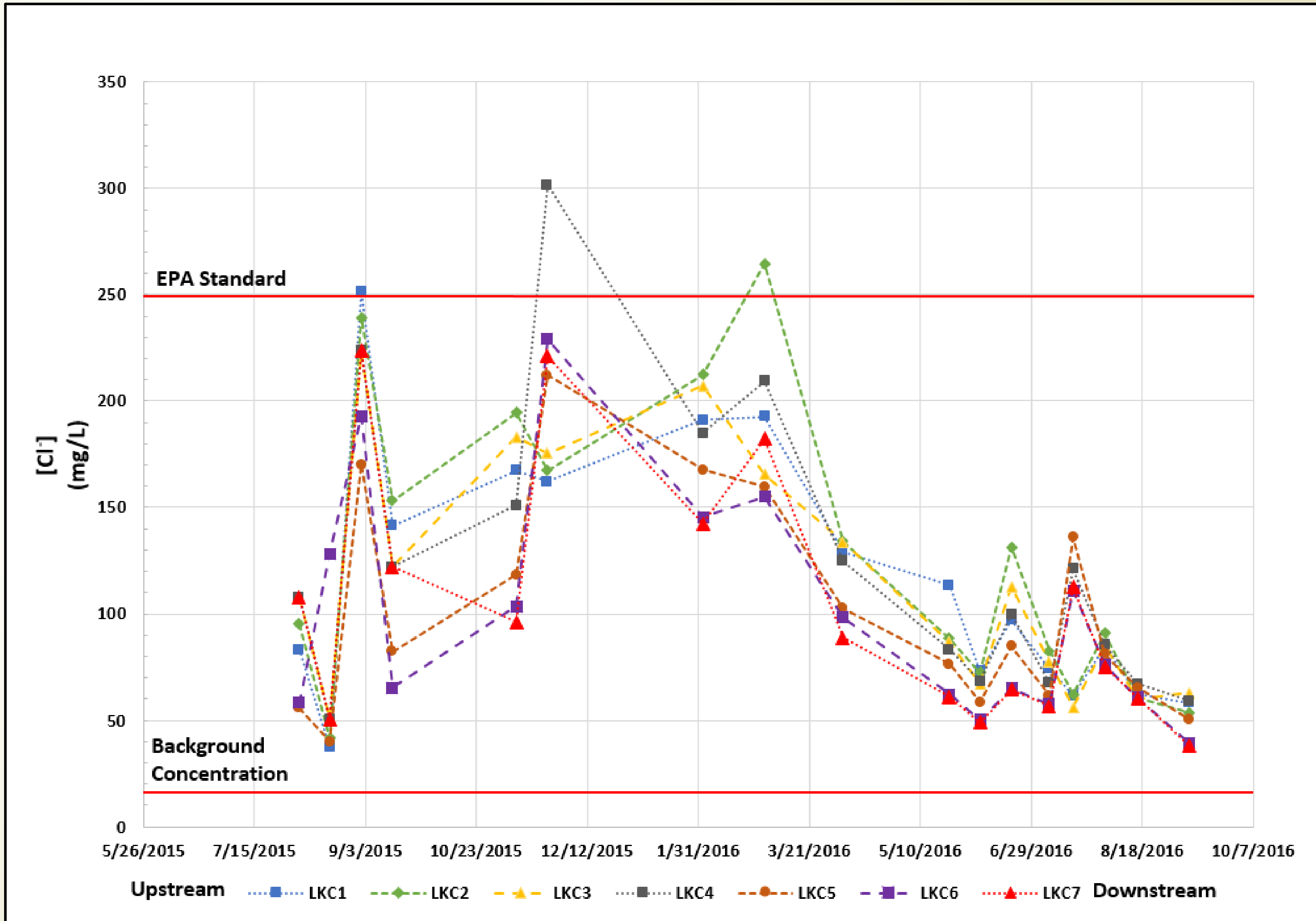


- Maximum residence time is a function of application rate
- System reaches steady-state – residence time ~1000 days for rates

Study Site/Methods

- 7 sample sites along LKC





Conclusions

- Cl^- remains in the system after 50 years of no application.
- Equilibrium between input and output results in a residence time of ~1000 days
- Application rate possess a liner relationship with accumulated Cl^- mass and maximum Cl^- concentration

Future Work

- Current Phase
  - Moved into Evergreen Lake Watershed
  - Examining role storm events on Cl^- load
  - Exploring agricultural role on Cl^- load

Acknowledgements

- Illinois Water Resources Center
- Student Field Workers
  - Joe Miller
  - Kyagaba "David" Lwanga

Results

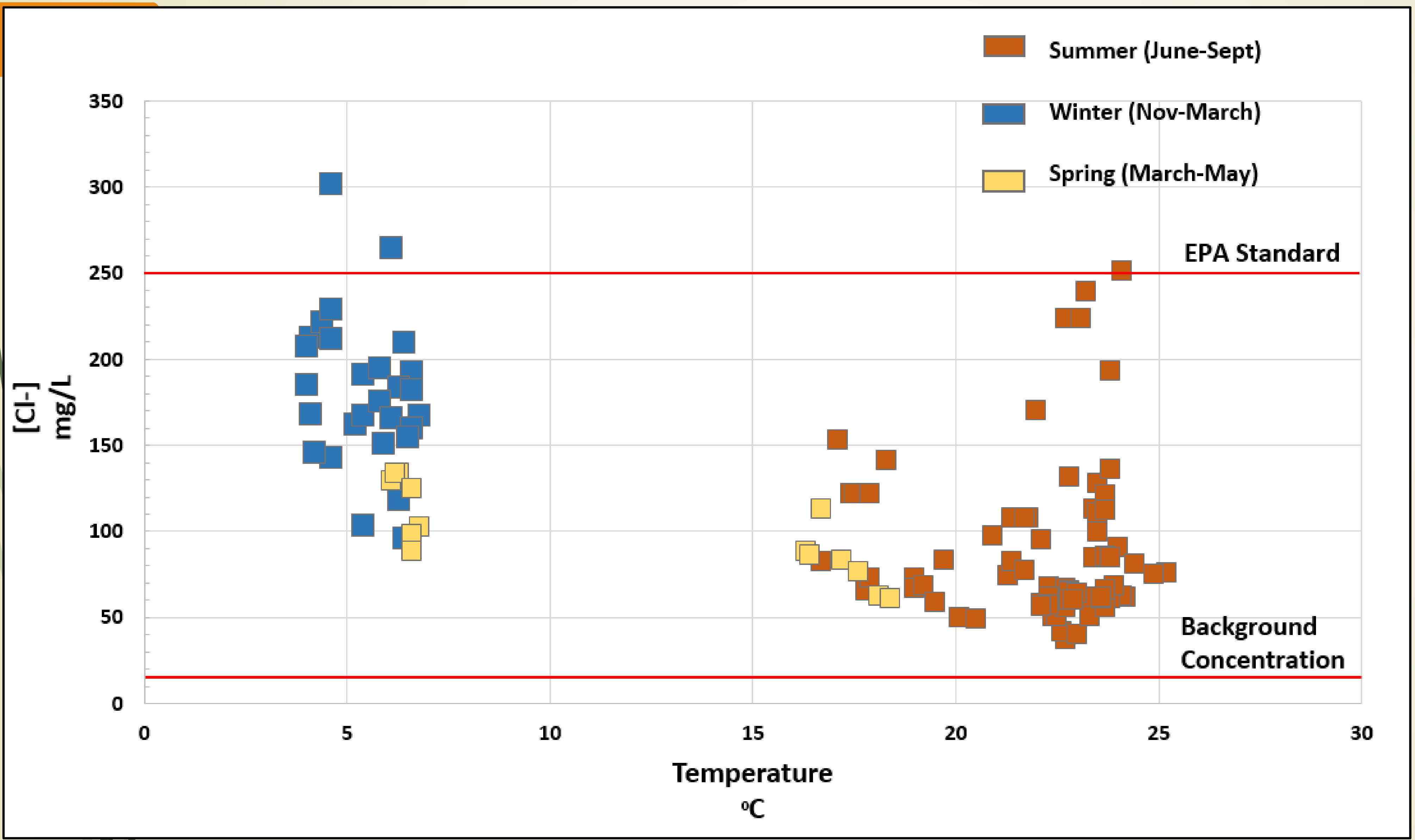


Figure 9: Scatter plot of seasonal chloride concentration plotted against temperature. The upper red line indicates the EPA secondary drinking standards of 250 mg/L and the lower red line indicates the background chloride concentration observed in the groundwater (Panno et al., 2006b).