The Influence of Green Infrastructure Practices on Groundwater Quality

Douglas Beak, Steven Acree, Michael Borst, Randall Ross, Jessica Brumley

Office of Research and Development
National Risk Management Research Laboratory\ Groundwater, Watershed, and Ecosystem Restoration Division

September 17, 2019

United States Environmental Protection Agency

Introduction

- Urbanization has been linked to declining water quality
  - Disruption of natural hydrologic cycle
  - Abnormally high volumes of stormwater
    - Increased flooding
    - Increased erosion
    - Increased sediment loads in surface water bodies
    - Increased stress to waste water systems
    - Increased combined sewer overflows (CSO)
    - Decreased subsurface storage

Introduction

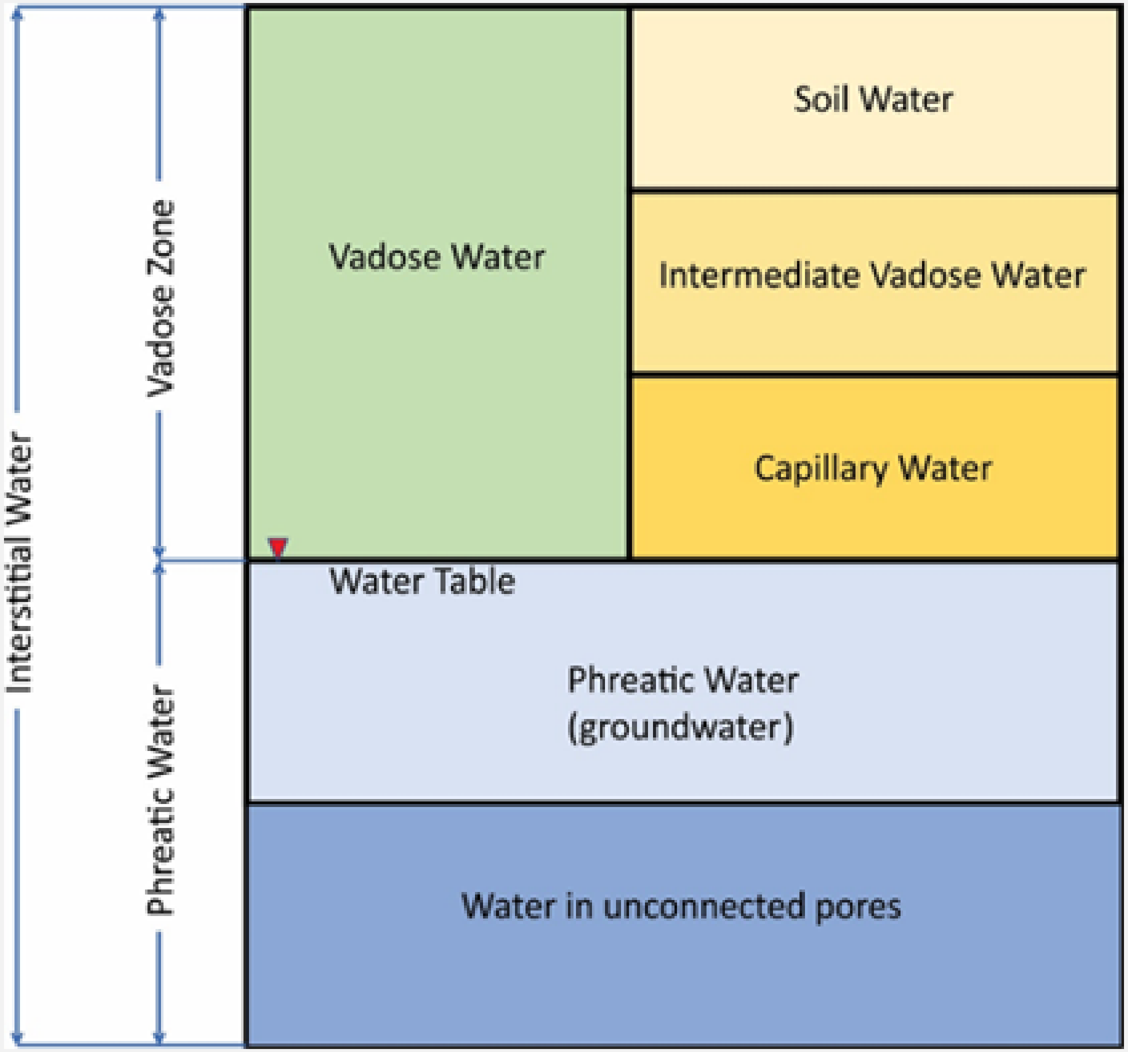
- What is Green Infrastructure (GI)?
  - GI is a water management approach that protects, restores, or mimics the natural hydrologic cycle
- Potential benefits of GI:
  - Infiltration of stormwater
  - Groundwater recharge
  - CSO reductions
  - Flood mitigation
  - Reduces stress on wastewater or sewer systems
  - Reduced sediment loads in surface water bodies.

United States Environmental Protection Agency

USEPA Green Infrastructure Strategy, 2013

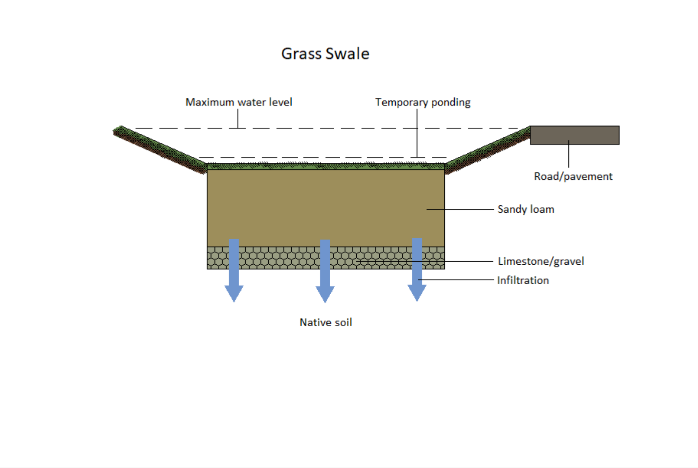
- This Strategy emphasized:
  - Reducing the volume of stormwater runoff
  - Reducing pollutant loadings
  - Creating a sustainable and resilient water infrastructure that supports and revitalizes urban communities
- Goal:
  - Increase the use of constructed and natural GI in stormwater management plans and watershed/ sewershed sustainability goals

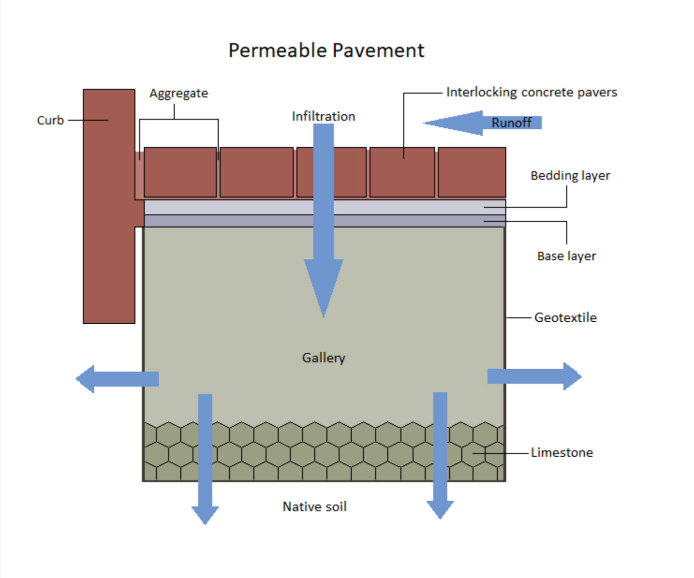
Subsurface Model



Types of GI

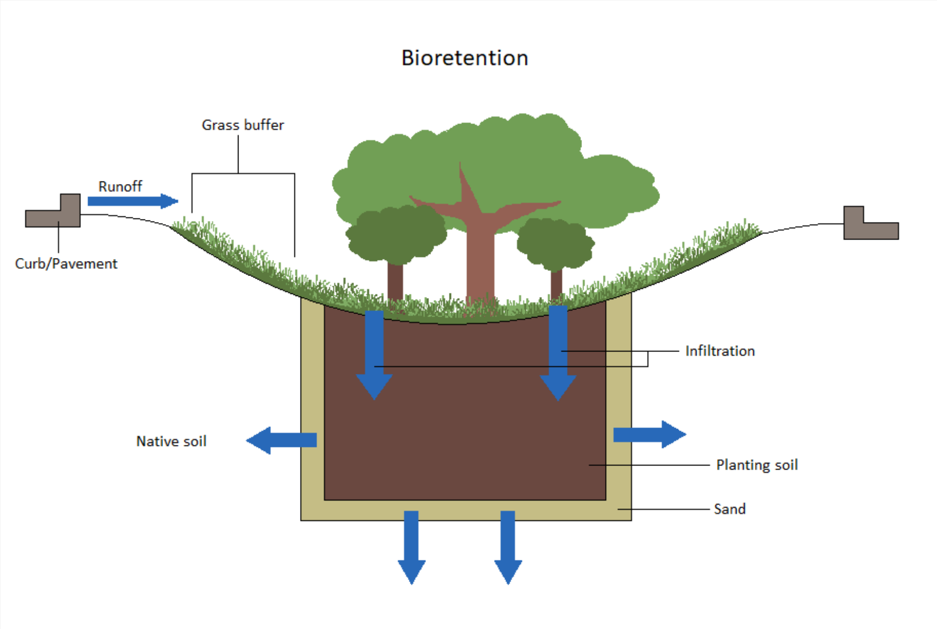
- Two broad categories (Pitt et al. 1999)
  - –Surface infiltration
  - –Subsurface infiltration





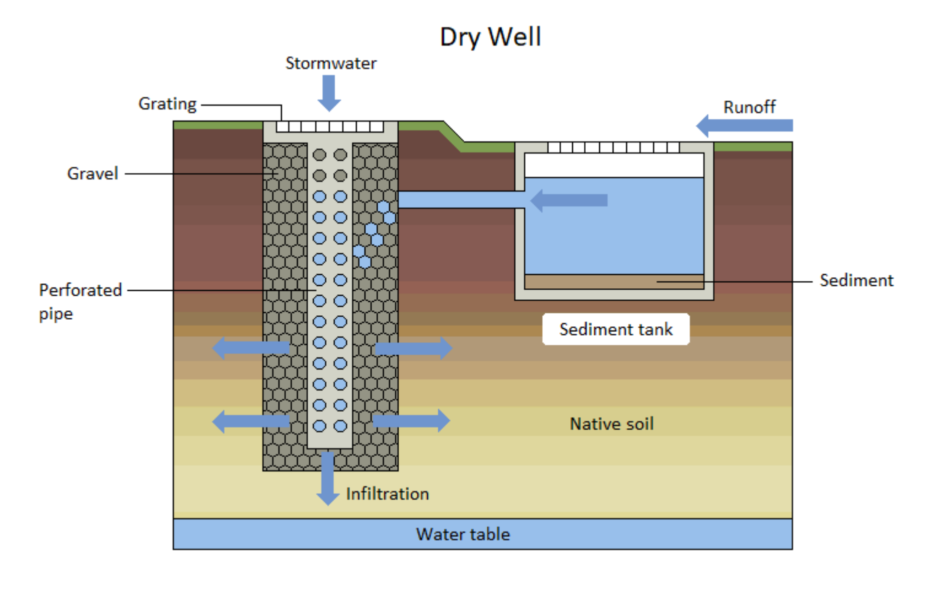
Surface Infiltration

- Relies on natural infiltration processes to move water from the surface through the vadose zone to groundwater.
- Mimics natural processes.
- Examples
  - –Infiltration basins
  - –Bioretention basins
  - –Bioswales
  - –Riparian Buffers



Subsurface Infiltration

- Engineered systems that directly infiltrates water into the vadose zone to groundwater.
- Examples:
  - –Permeable pavement
  - –Dry wells
  - –ASR technologies



Effect of GI on Groundwater Quality

- Few studies address groundwater quality
- Infiltration could create new pathways for contaminants transport
- Is GI a source or sink for stormwater contaminants?
- Does GI pose a risk to groundwater Quality?

Literature Review- State of Science Report

- Contaminants: nutrients, metals, anions, organic compounds, and pathogens.
- Sources of contaminants: automobiles, lawn treatments, industrial activities, deicing agents, native geology, etc.
- Literature Review findings:
  - no impacts were found during the study.
  - In some cases there were potential impacts.
  - Impacts were found.
- There is a risk to the vadose zone

Literature Review Problems/ Research Gaps

- Most studies did not monitor the aquifer or deeper in the vadose zone.
- When groundwater monitoring was included
  - Unknown if sampling strategies or monitoring network would detect groundwater quality changes
    - Groundwater flow direction was not known
    - Was the groundwater monitoring network robust enough to detect changes?
  - Lag time was not considered in many studies.
- Study duration

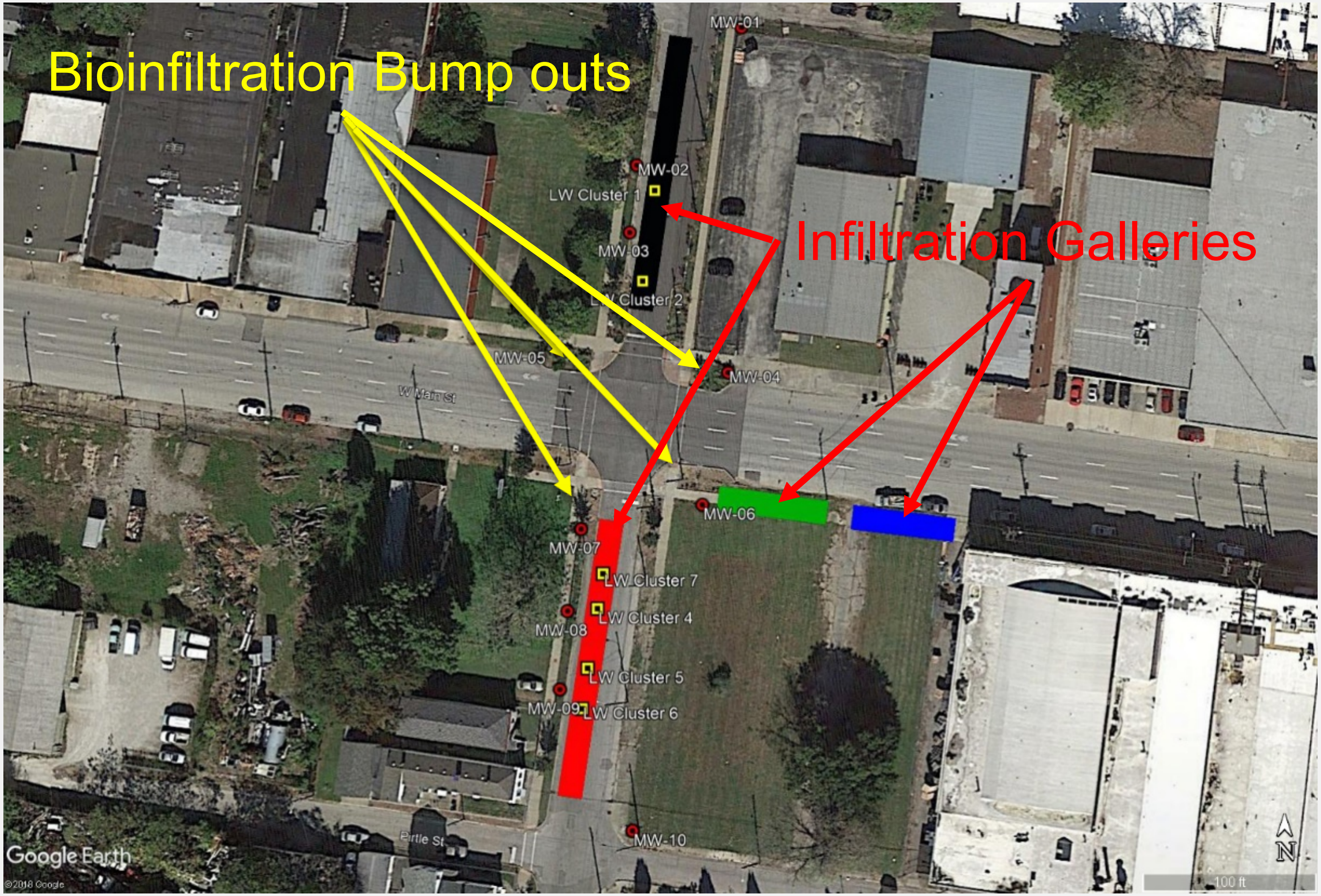
EPA
United States
Environmental Protection
Agency

Louisville, Kentucky

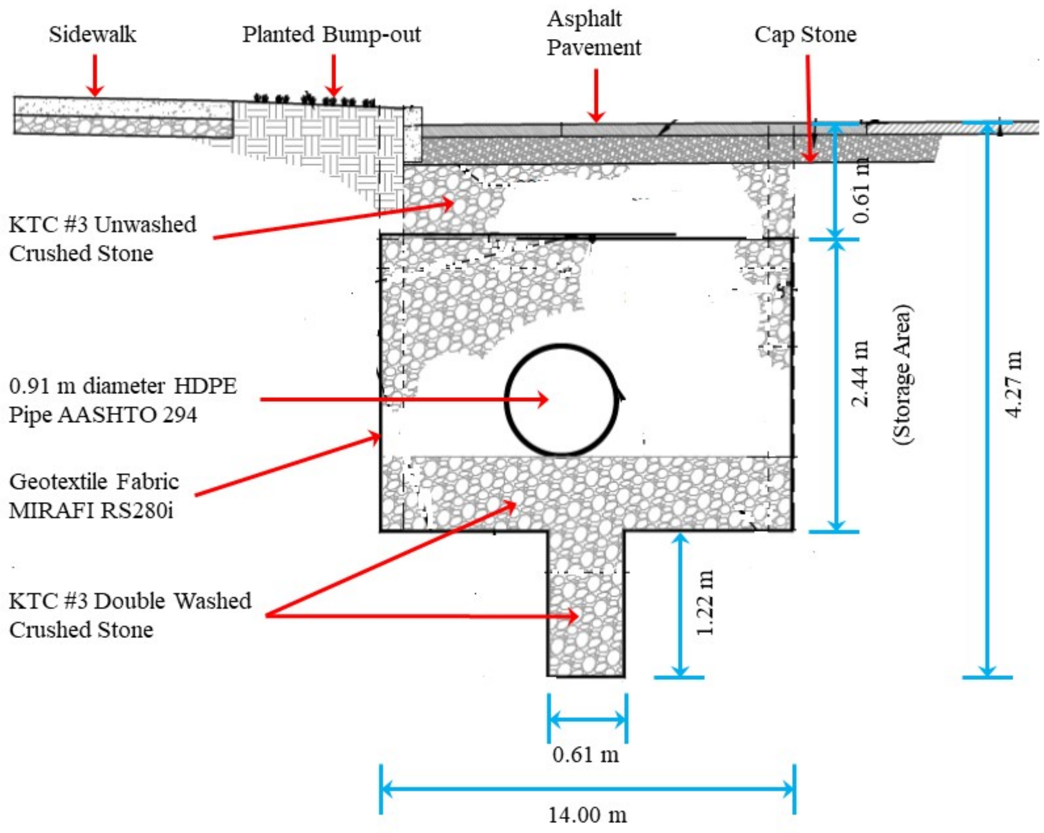
Louisville Study Site

- Located in the Portland neighborhood
  - 58.7 hectare sewershed
  - Residential, light industrial, and commercial
- Consent Decree
  - Reduce the annual overflow frequency from 54 to 8
  - Reduce overflow volume from 136 ML to 13.8 ML
- Type of GI is a combination of
  - Bioinfiltration areas (bump outs) intercept stormwater runoff
  - Underground infiltration galleries

Louisville Study Site

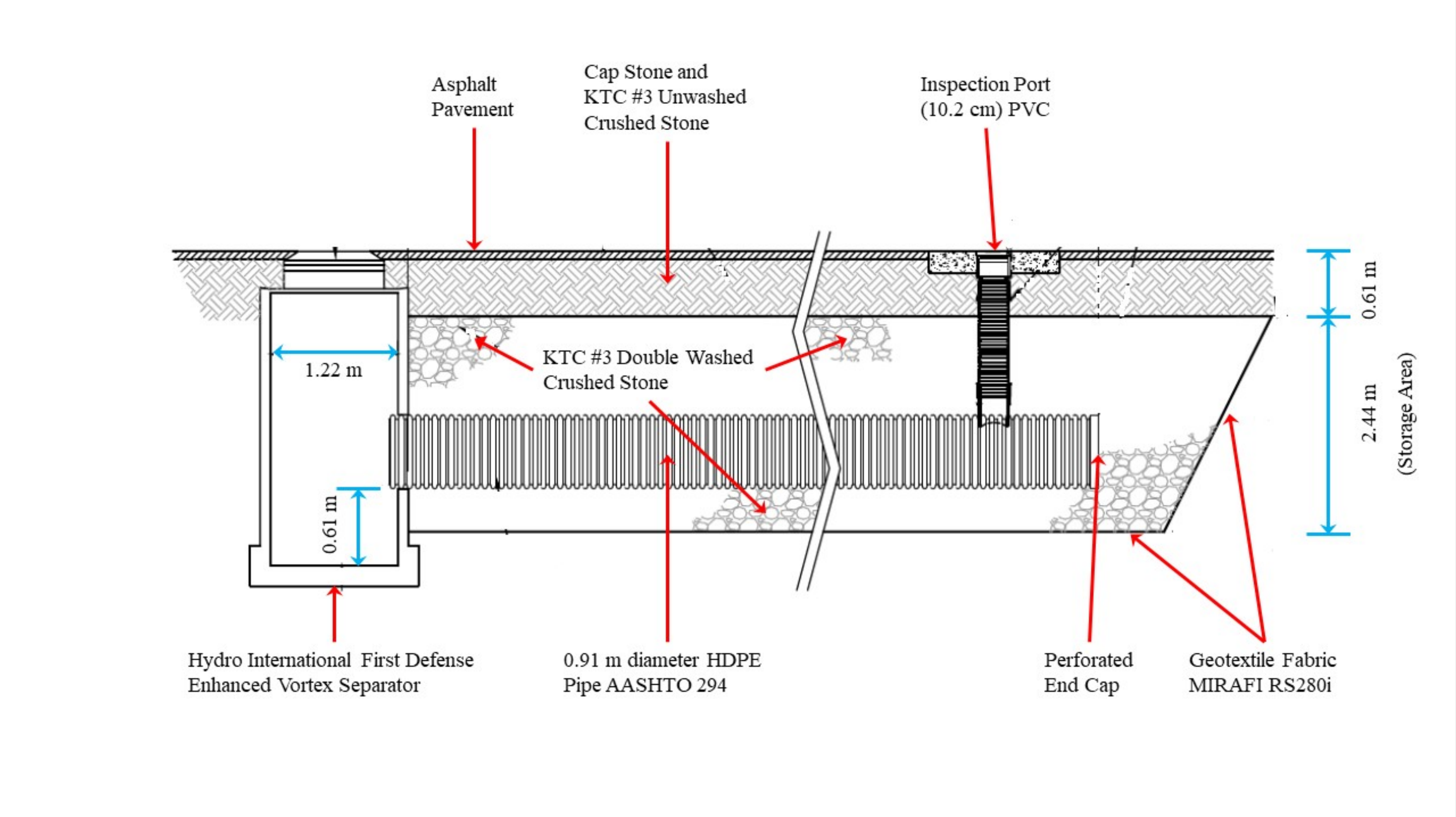


Infiltration Gallery Cross Section

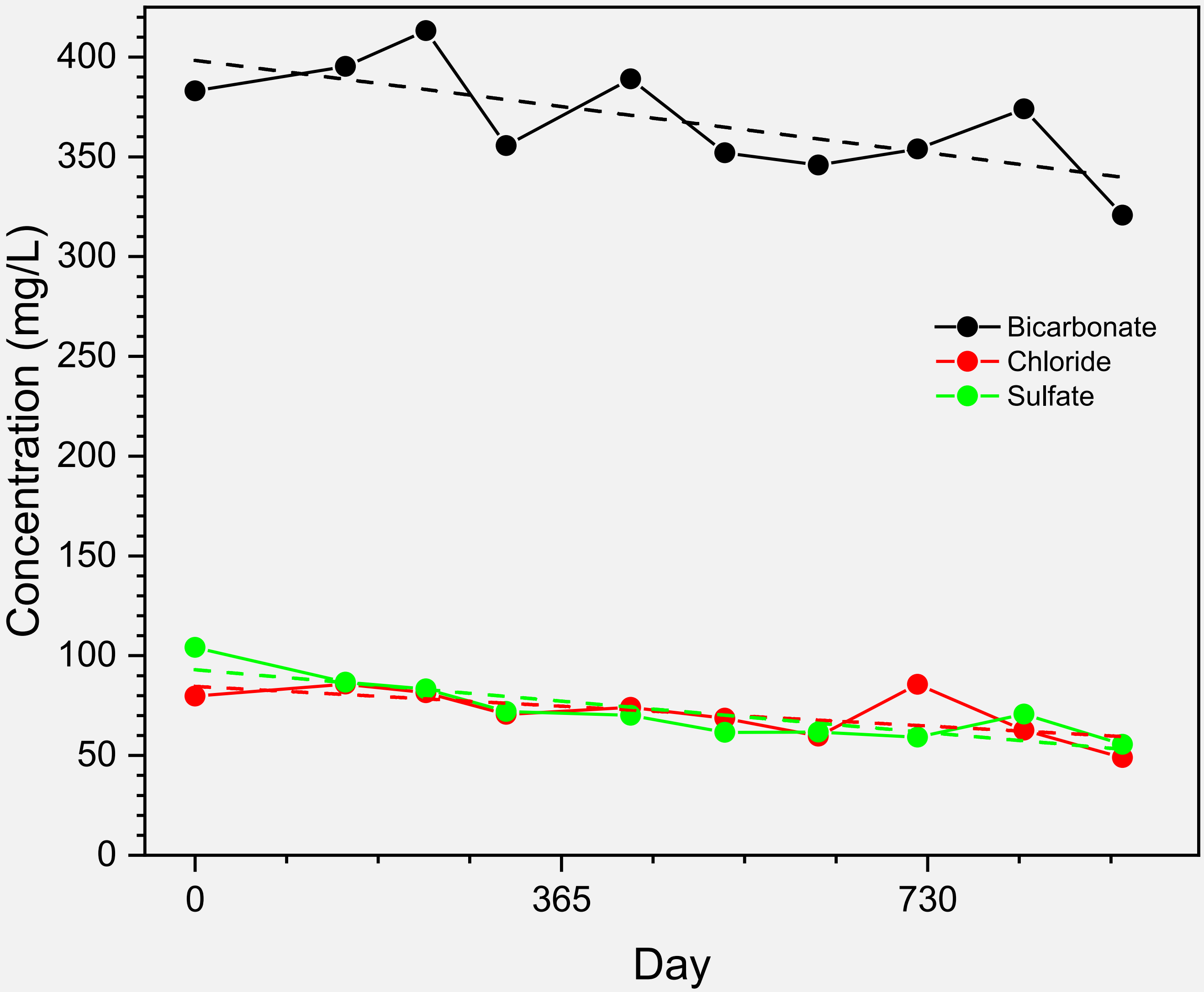


United States Environmental Protection Agency

Infiltration Gallery Transverse Section



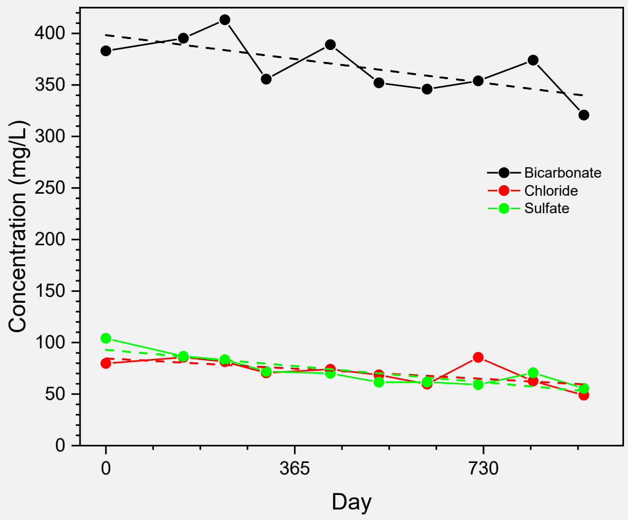
Major Anion Trends



EPA United States Environmental Protection Agency

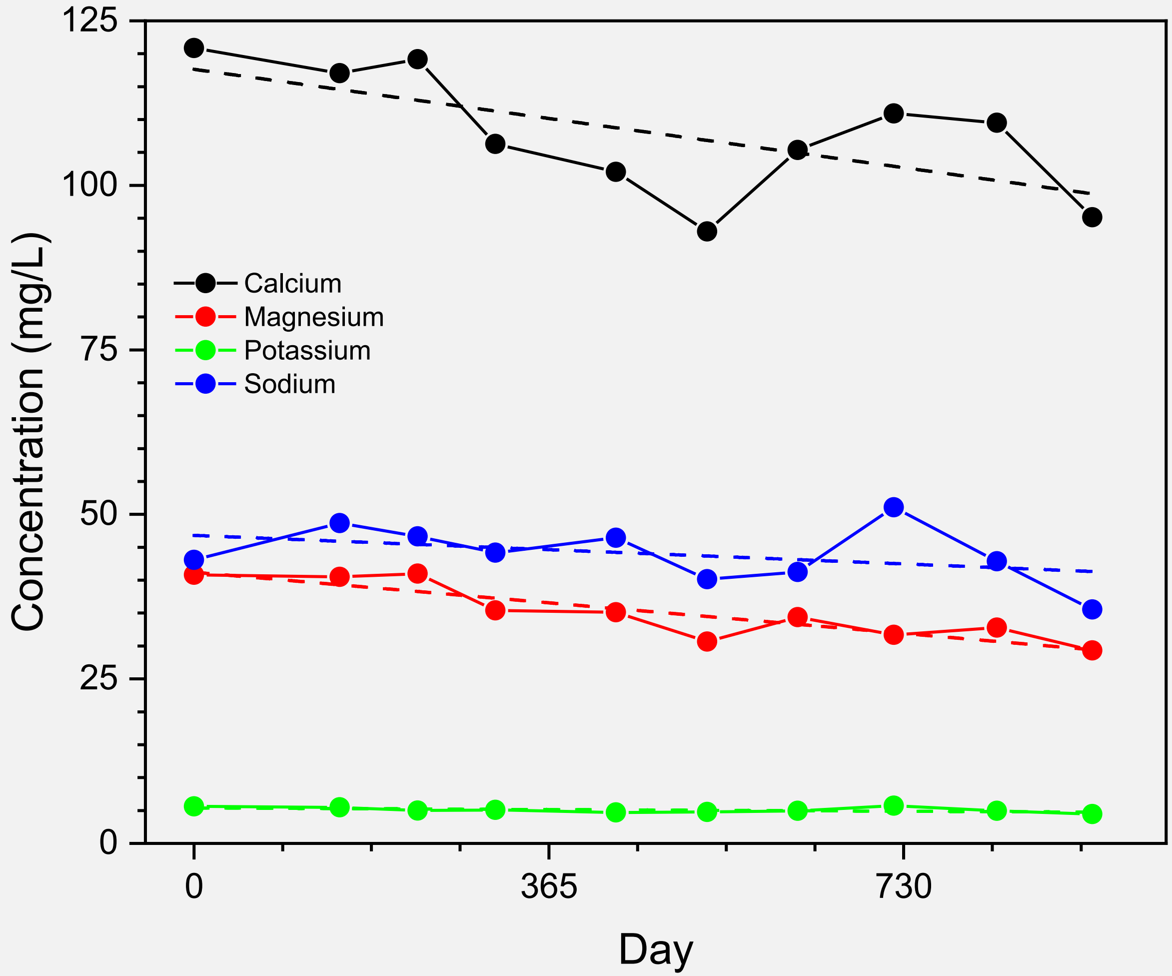
Major Anion Trends

- Bicarbonate
  - Significantly decreasing $p < 0.001$
  - Rate= -23.1 mg/L/yr
- Chloride
  - Significantly decreasing $p = 0.023$
  - Rate= -9.93 mg/L/yr
- Sulfate
  - Significantly Decreasing $p = 0.014$
  - Rate= -5.11 mg/L/yr



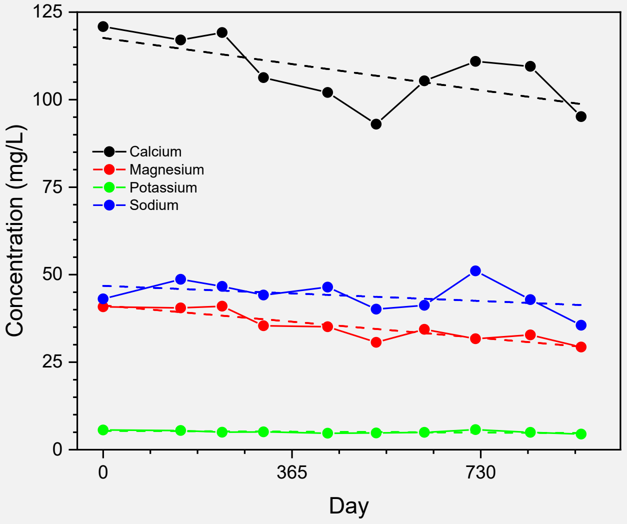
United States Environmental Protection Agency

Major Cation Trends



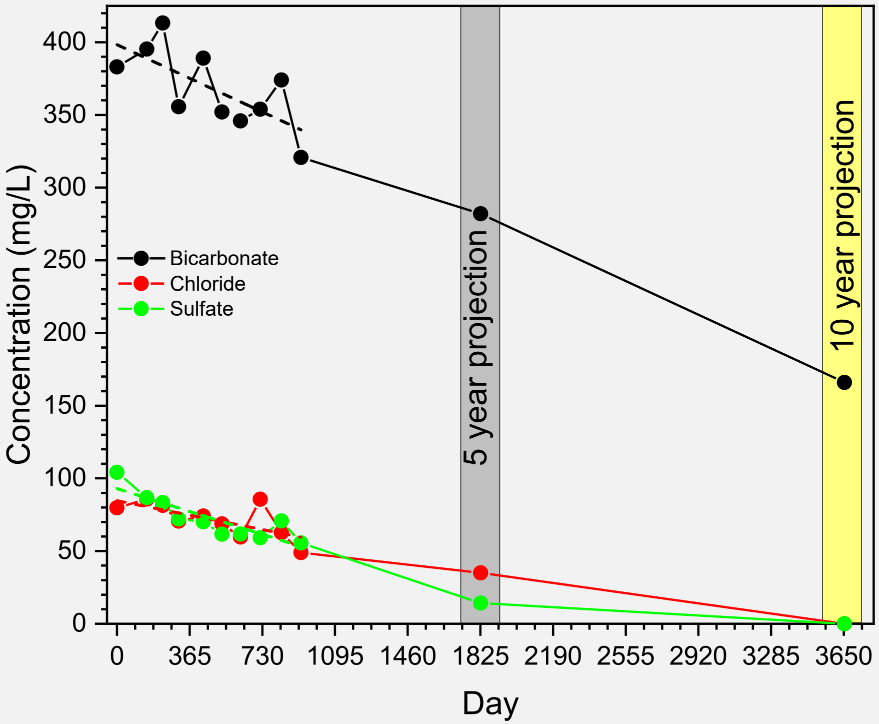
Major Cation Trends

- Calcium
  - Significantly decreasing p= 0.036
  - Rate= -7.48 mg/L/yr
- Magnesium
  - Significantly Decreasing p= 0.001
  - Rate= -4.65 mg/L/yr
- Potassium
  - Decreasing p= 0.054
  - Rate= -0.25 mg/L/yr
- Sodium
  - Slightly decreasing/ Stable p= 0.108 (not significant)
  - Rate= -2.16 mg/L/yr



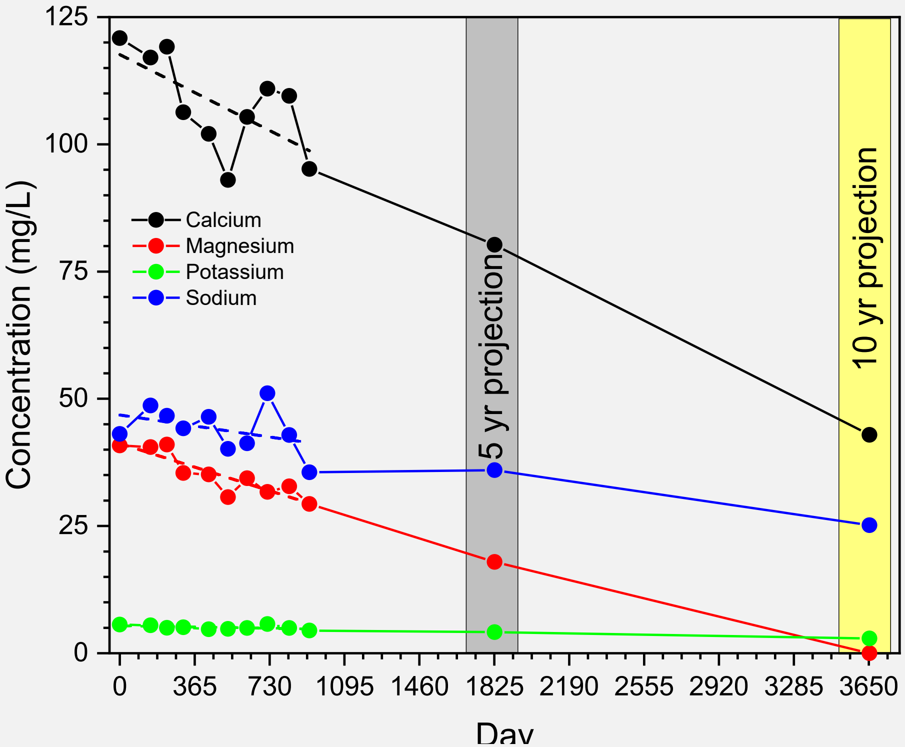
Major anions 5 year and 10 year Extrapolations

- Assumptions
  - Current rate of change is constant (?)
  - No other geochemical process will modify concentrations (?)
- Dilution of all anions



Major Cations 5 Year and 10 Year Extrapolations

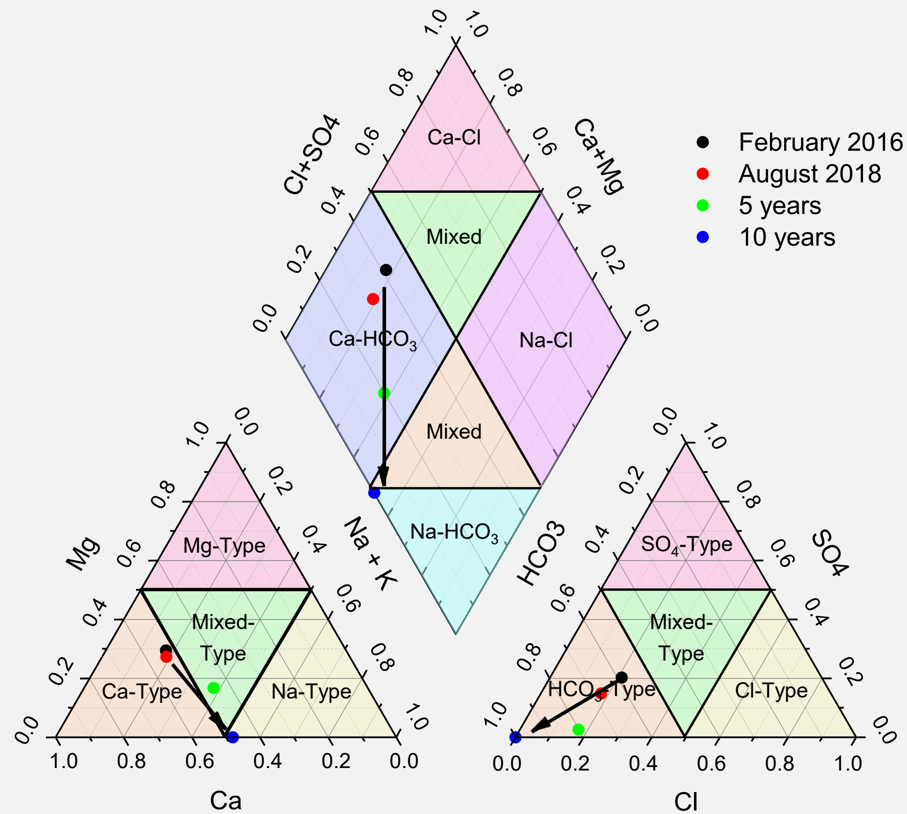
- Assumptions
  - Current rate of change is constant (?)
  - No other geochemical process will modify concentrations (?)
- Rate of change Mg & Ca> Na & K
- Dilution of cations
- Ca concentrations becoming more similar to Na concentrations



EPA
United States Environmental Protection Agency

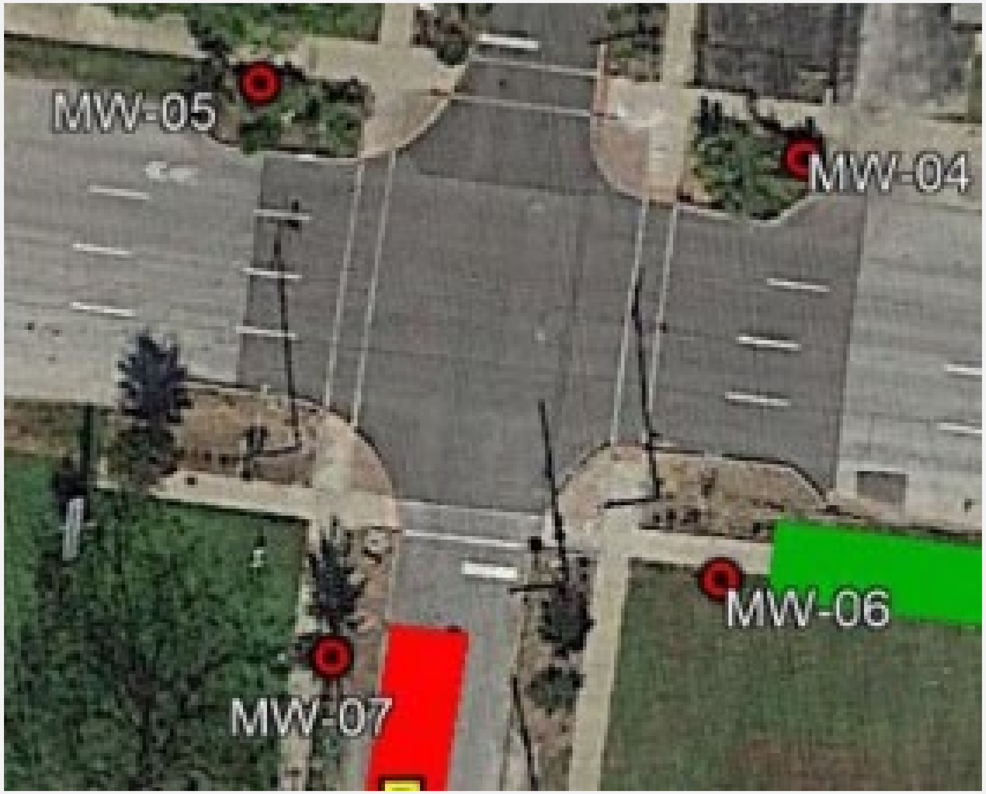
Water Quality Changes- Major Anions and Cations

- Water is shifting from a Ca-HCO_3 water to a more Na-HCO_3 type water.
- Cations- Ca dominant → Na dominant
- Anions- HCO_3 is becoming even more dominant



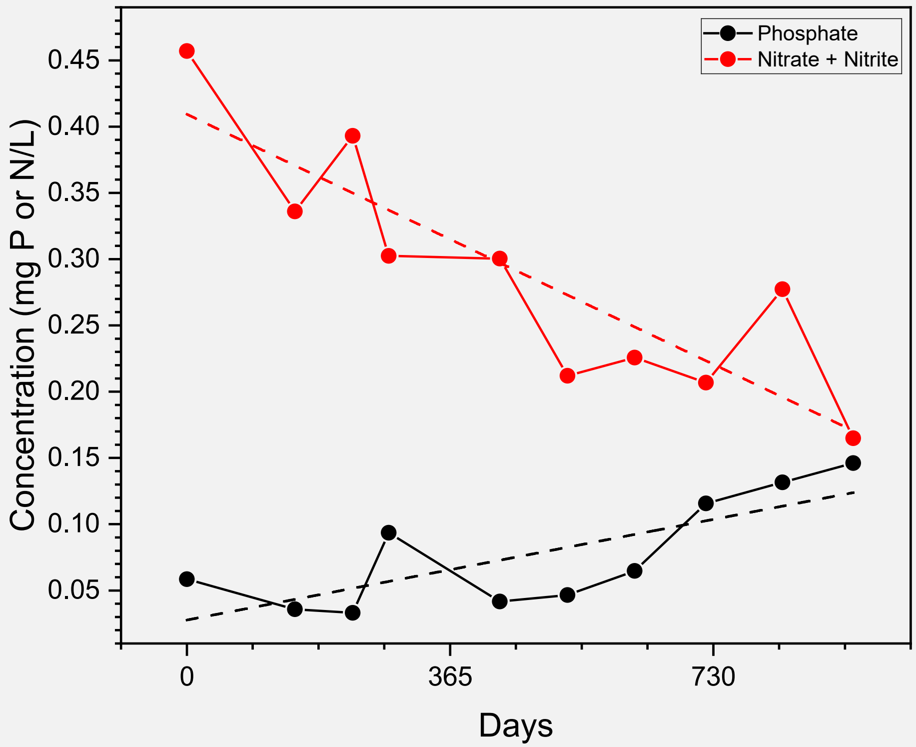
Other Trends in Groundwater

- Phosphate and Nitrate
- Chromium, Copper, and Nickel in groundwater near Main St.



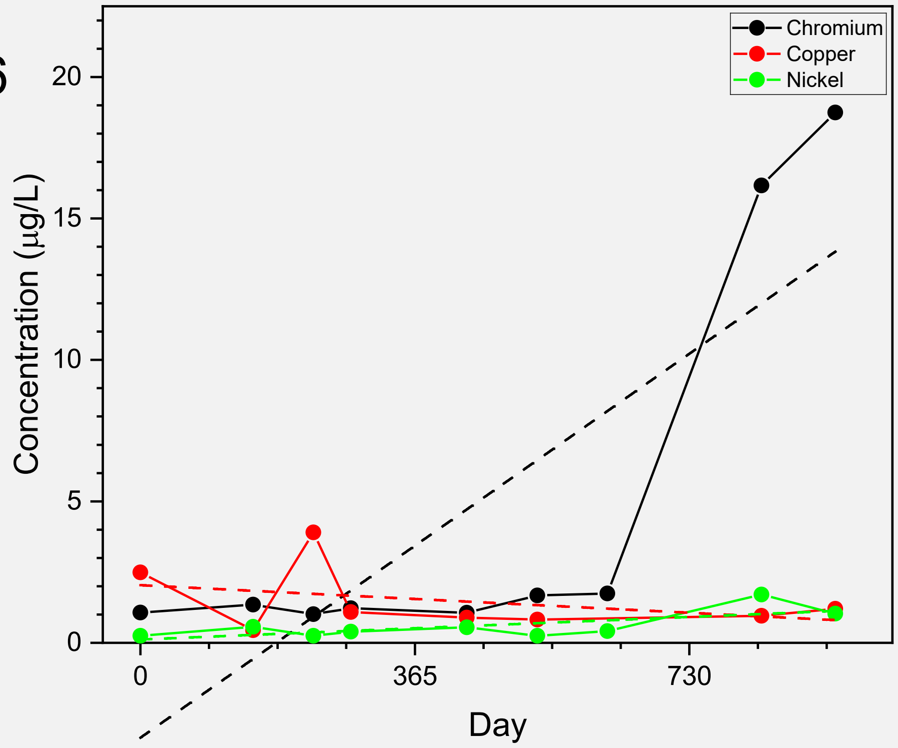
Phosphate and Nitrate + Nitrite

- Phosphate
  - Significantly increasing p= 0.005
  - Rate= 0.038 mg P/L/yr
- Nitrate + Nitrite
  - Significantly decreasing, p<0.001
  - Rate= -0.094 mg N/L/yr



Chromium, Copper, and Nickel

- Chromium
  - Significantly increasing p= 0.006
  - Rate= 6.79 µg/L/yr
- Copper
  - Stable p= 0.452
  - Rate= -0.49 µg/L/yr
- Nickel
  - Increasing p= 0.075
  - Rate= 0.69 µg/L/yr



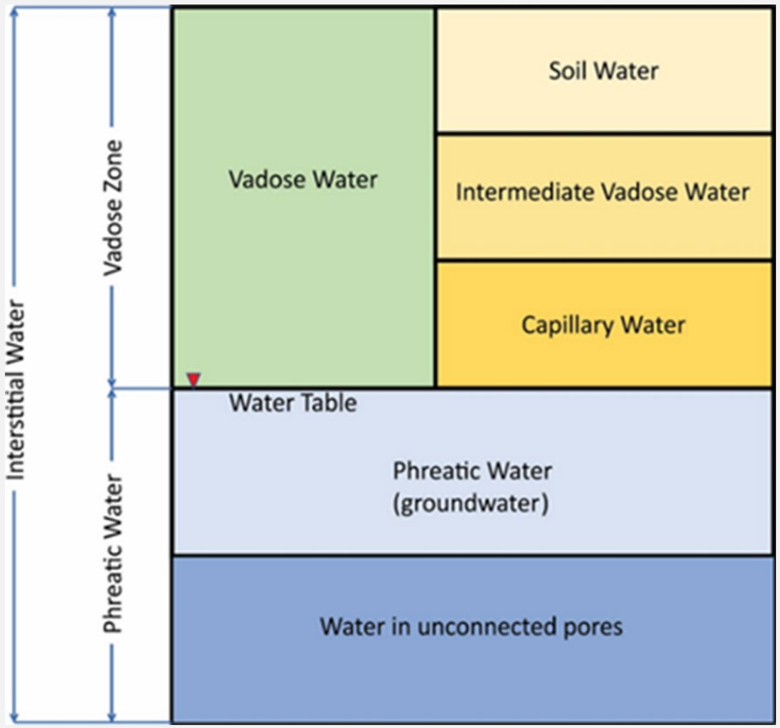
Phosphate, Nitrate + Nitrite, Chromium, Copper & Nickel Extrapolations

Analyte	August 2018	5 years	10 years
Phosphate	0.146 mg P/L	0.218 mg P/L	0.408 mg P/L
Nitrate + Nitrite	0.16 mg N/L	BDL	BDL
Chromium	18.8 µg/L	30.6 µg/L	64.6 µg/L
Copper	1.20 µg/L	BDL	BDL
Nickel	1.03 µg/L	2.11 µg/L	4.10 µg/L

- Chromium anomaly
- Need to monitor chromium concentrations

Vadose Zone

- Can alter stormwater chemistry during infiltration
- Types of reactions
  - Ion exchange
  - Sorption
  - Precipitation/Dissolution



United States Environmental Protection Agency

Ion Exchange Reactions

- Ion Exchange

$$Ca^{2+}_{(aq)} + 2Na - Solid = 2Na^{+}_{(aq)} + Ca - Solid$$

  - Ca replaces Na bound to solids

- Reverse Ion Exchange

$$2Na^{+}{}_{(aq)} + Ca - Solid = Ca^{2+}_{(aq)} + 2Na - Solid$$

  - Na replaces Ca bound to solids

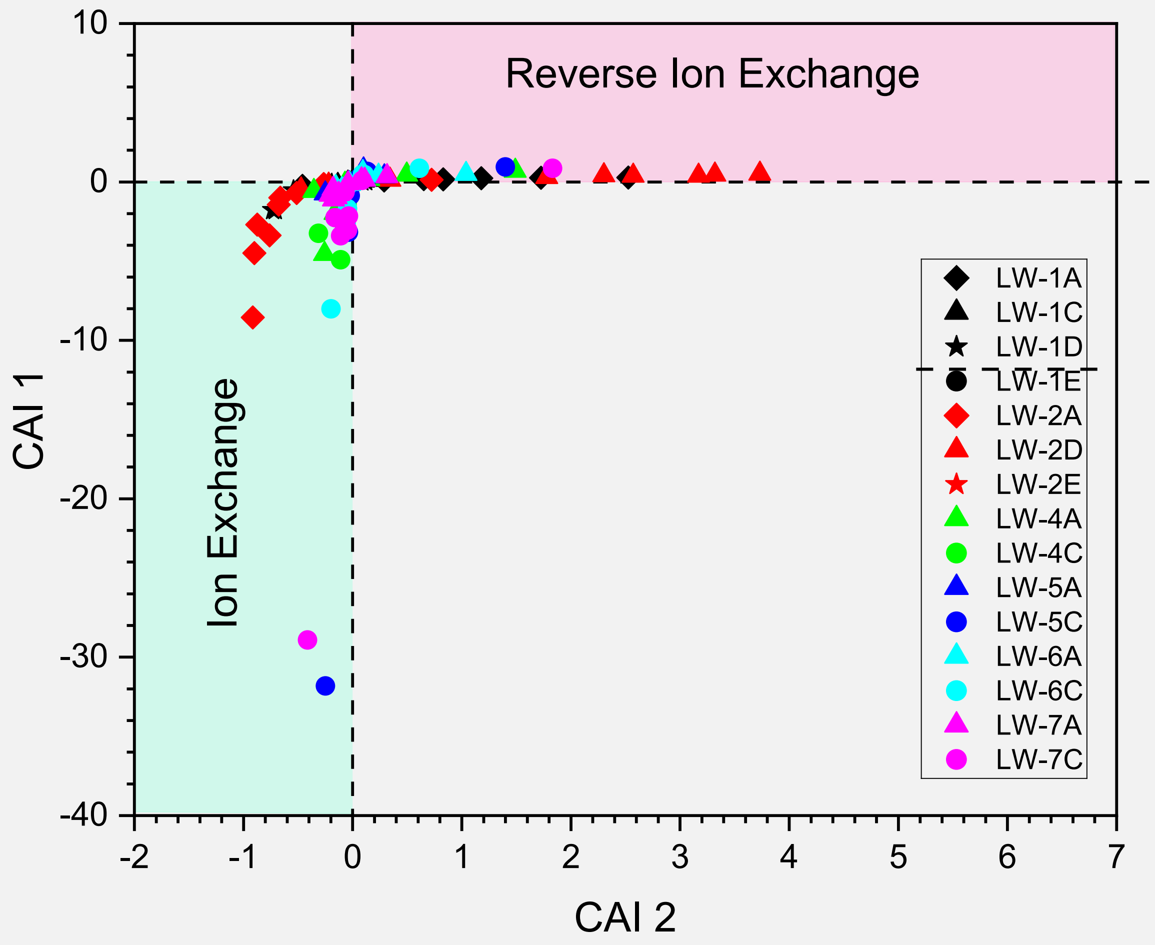
- Chloro-Alkaline Index can be used to distinguish between these ion exchange reactions (Schoeller, 1965, 1967; Zaidi et al., 2015)

Chloro-Alkaline Index (CAI)

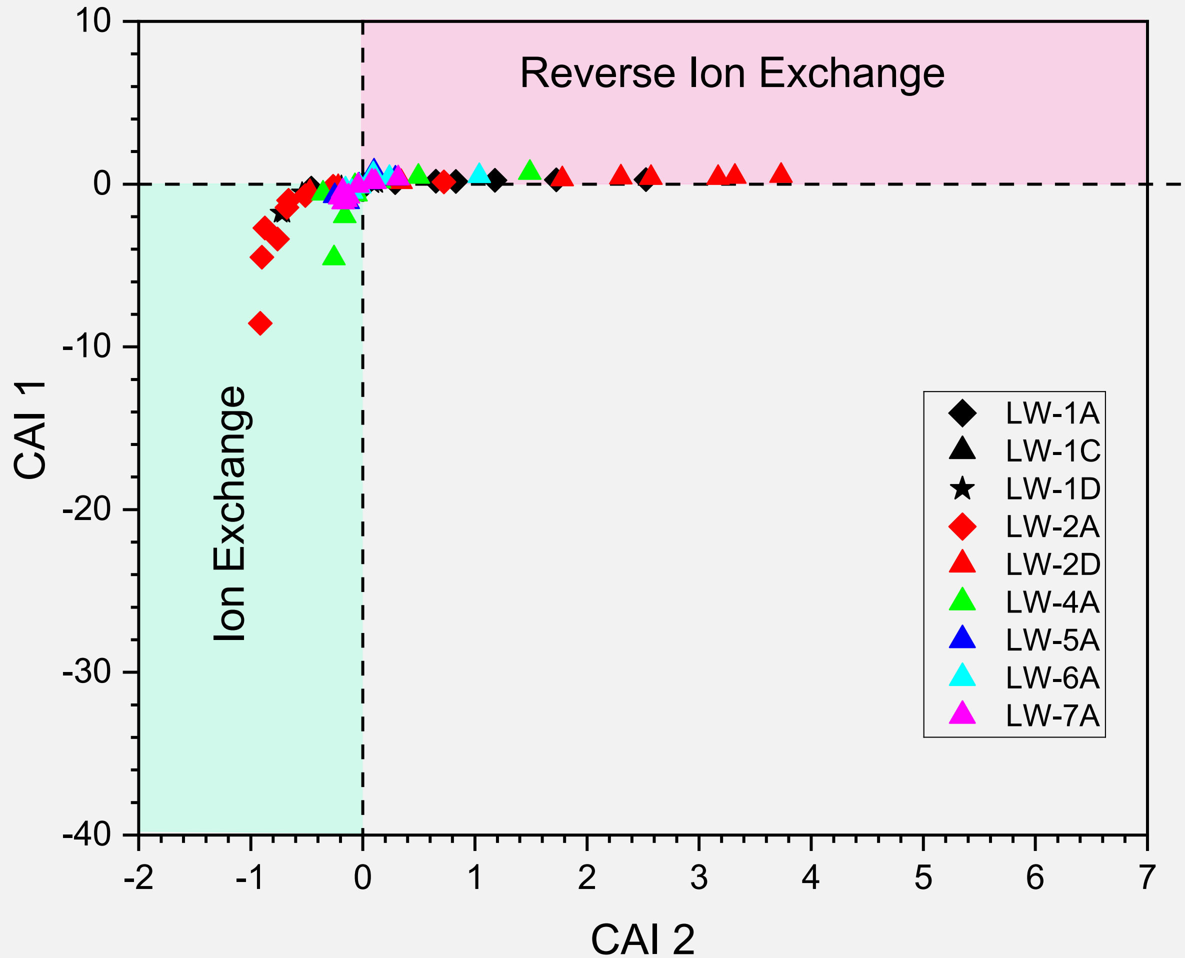
$$\text{CAI 1} = \frac{\text{Cl}^- - (\text{Na}^+ + \text{K}^+)}{\text{Cl}^-}$$

$$\text{CAI 2} = \frac{\text{Cl}^- - (\text{Na}^+ + \text{K}^+)}{\text{Cl}^- + \text{HCO}_3^- + \text{SO}_4^{2-} + \text{NO}_3^-}$$

Soil Porewater



Soil Porewater (>130 m-msl)



Potential Problems With Reverse Ion Exchange

- Reverse ion exchange loads sodium on the surface of vadose zone particles
- Excess sodium on particles can causes dispersion of the particles in the matrix
  - Slows or prevents infiltration
  - Clogging is undesired in a GI system
- Some samples collected in August 2019
  - Filtering with 0.45 μm filters
  - Significant sediment passed through the filters in some samples
  - Not previously seen

United States Environmental Protection Agency

Conclusions State of Science Report

- Results from the literature review report were mixed
  - Results ranged from no Impacts to potential impacts to impacts to water quality
  - There are gaps in knowledge
- Issues raised by the report
  - Experimental design, sampling strategies, monitoring duration
- More research is needed!

Conclusions Louisville Study Site

- Major anion/ cation chemistry impacts
  - Dilution of most major anions and cations were observed with time
  - It is unknown how long this dilution trend will continue
  - Dilution is causing a gradual shift for a Ca-HCO_3 type water towards a Na-HCO_3 type water.
- Nutrients
  - Phosphate concentrations are significantly increasing with time
  - Nitrate + nitrite concentrations are significantly decreasing with time

United States Environmental Protection Agency

Conclusions Louisville Study Site

- Metals near the bioinfiltration areas
  - Chromium concentrations are increasing
    - Unknown if the current rate of increase will continue
  - Copper concentrations are decreasing with time
  - Nickel concentrations are increasing with time
- Trace metal concentrations away from the bioinfitration areas are stable and have low concentrations

United States Environmental Protection Agency

Conclusions Louisville Study Site

- Potentially a sodium build up in the vadose zone
  - Infiltration changes in future??
  - Clogging??
- Future impacts??
- Study needs to be continued!

Questions