Spring Valley Sub-Watershed: Final Project Update

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Project Objectives

From the original proposal:

1) Characterize groundwater-surface water interaction and hydraulic connection within the watershed.
2) Assess the potential and seasonal timing of chloride concentrations in the Spring Valley Park impoundment.
3) Evaluate the potential for eutrophication in watershed.
4) Investigate possible connections between impoundment water and the deeper water-supply aquifer.

What We've Accomplished

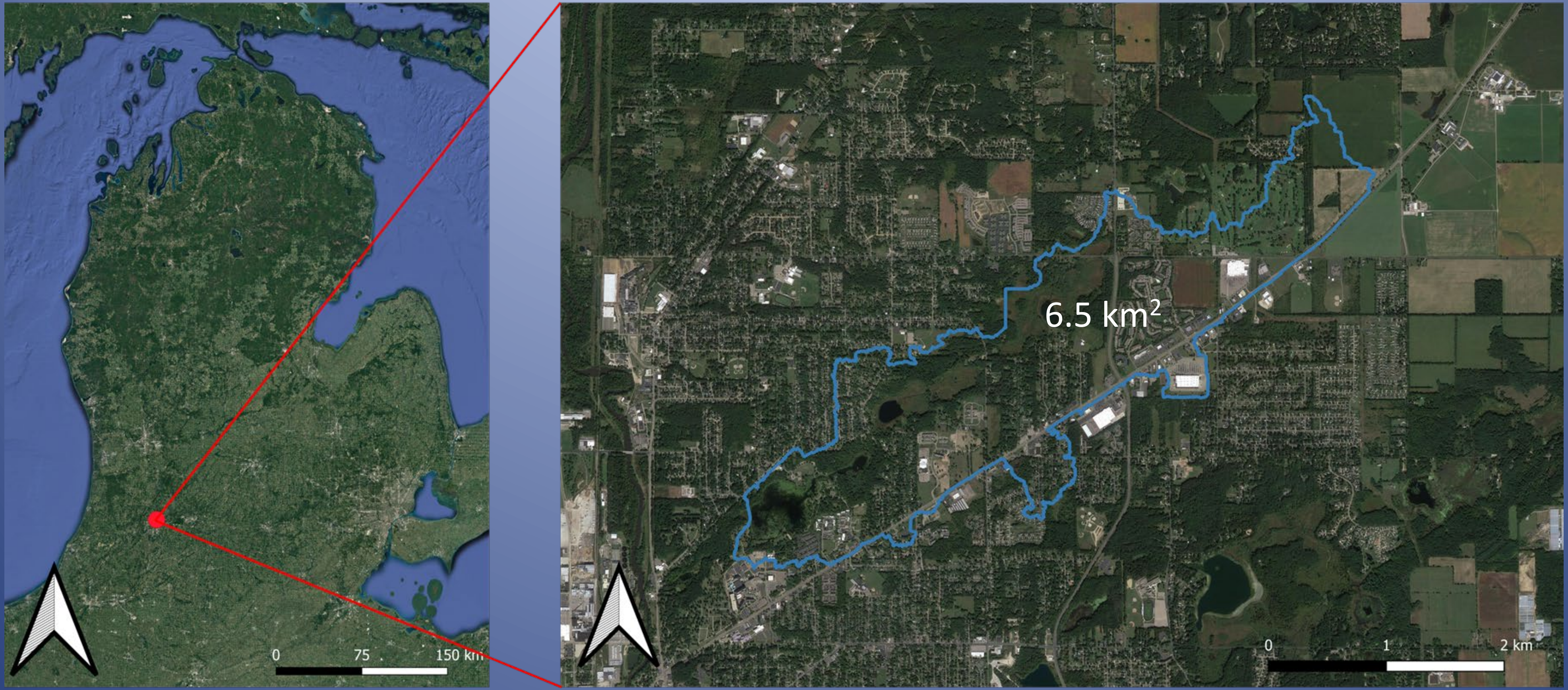
- The source of chloride is from winter road salt applications, directed along engineered outfalls to stream and lake.
- Defined spatiotemporal trends of chloride, major ions, and nutrients within the sub-watershed.
- Spring Valley lake is mesotropic, with occasional (low) eutrophic status solely based on phosphorus, not reflected in algal concentrations/mass; biogenic activity in the lake influences corrosivity due to alkalinity declines.
- Station 14 wells capture Spring Valley lake water, with capture estimates from three independent methods indicating a mutually defined range: 0.26-0.31 (26 – 31%).
- Helped discover an illicit discharge into the lake.

- Had a great time!!

Presentation Organization

- Spatiotemporal Trends of Road Salts and Major Ions
- Surface Water Capture
- Lake Water Quality

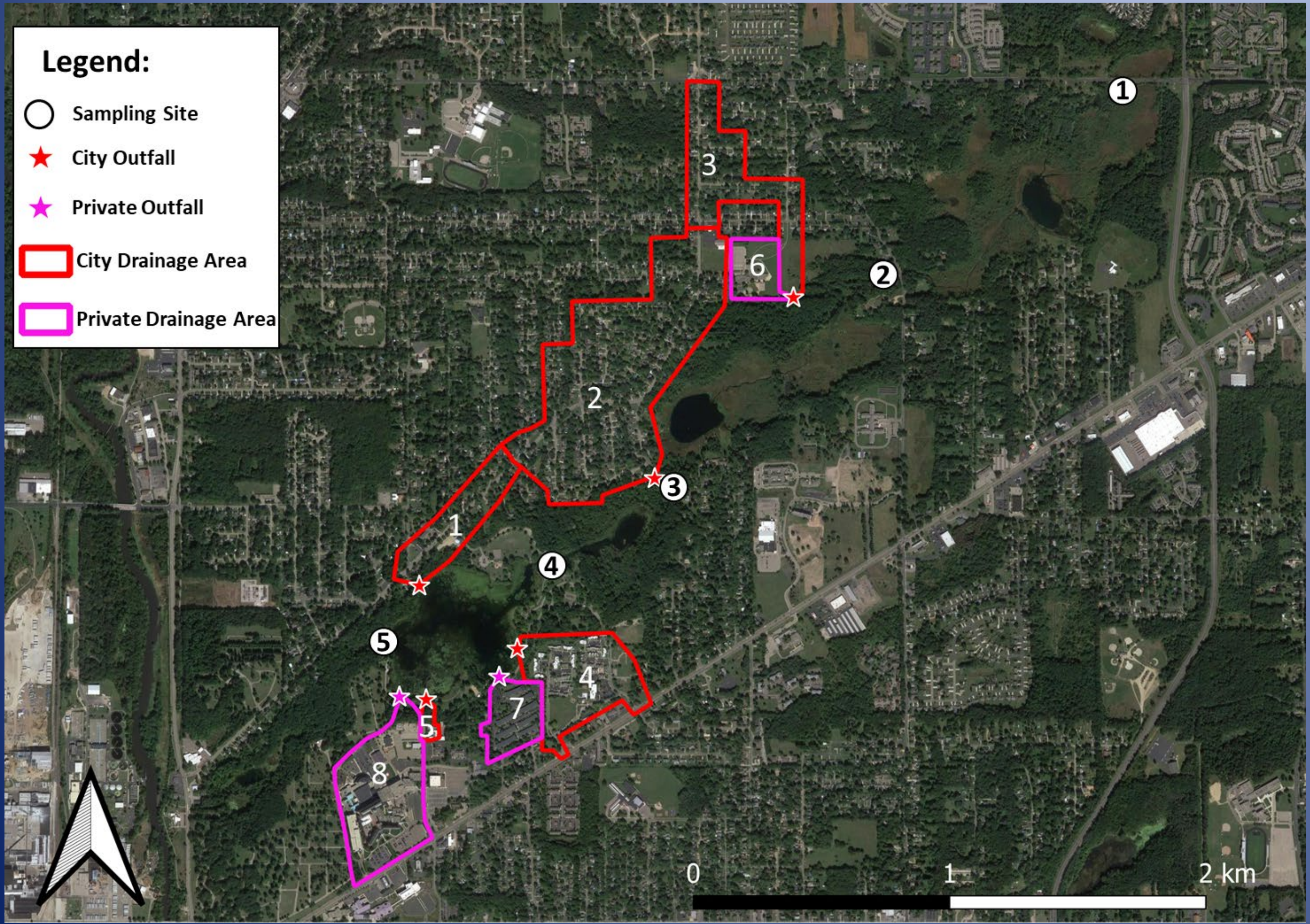
Watershed Delineation



Flow accumulation algorithm in GIS, modified to include engineered stormwater outfalls

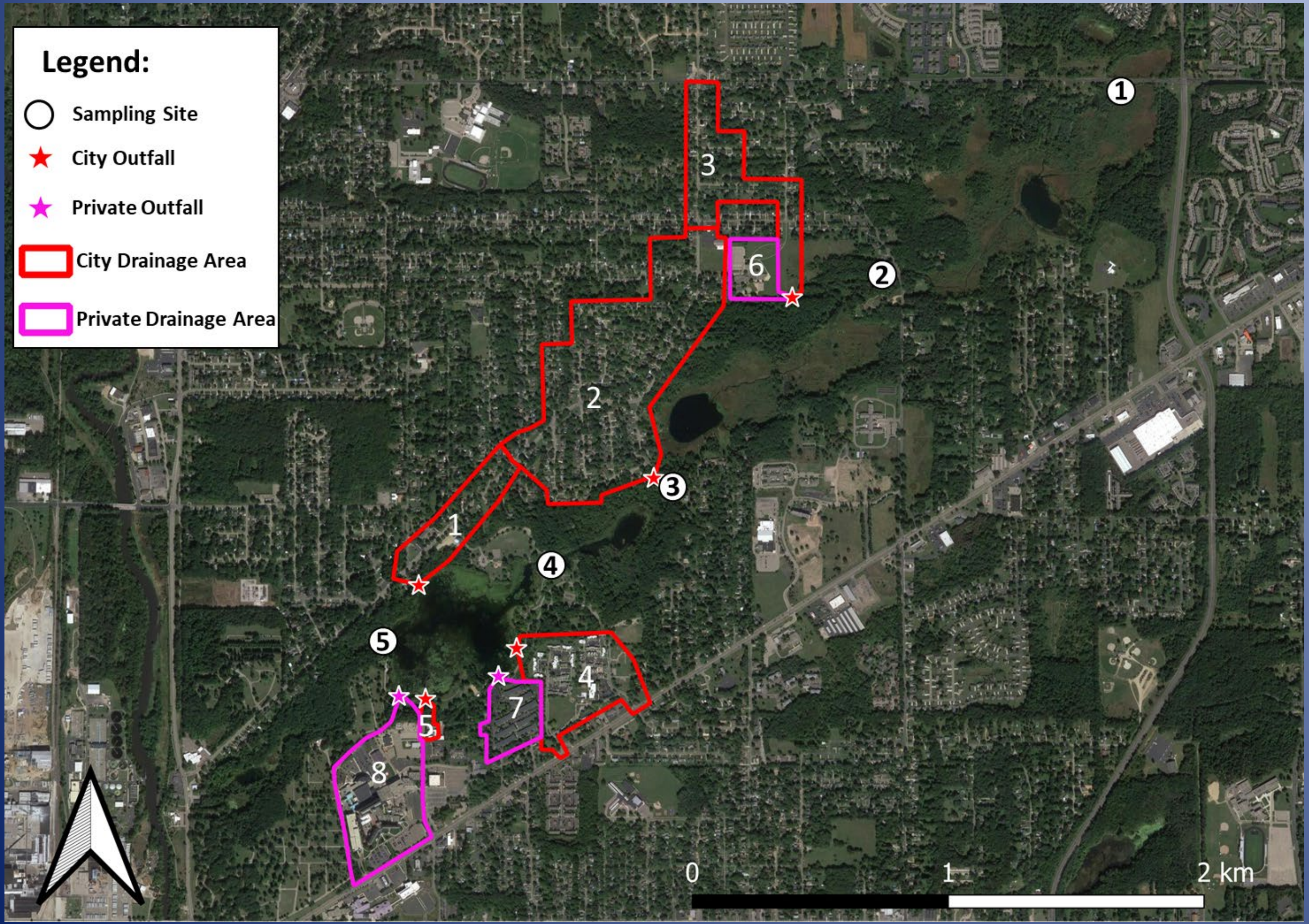
Provides basis for investigating road salt and nutrients within sub-watershed

Water Quality Monitoring and Sampling



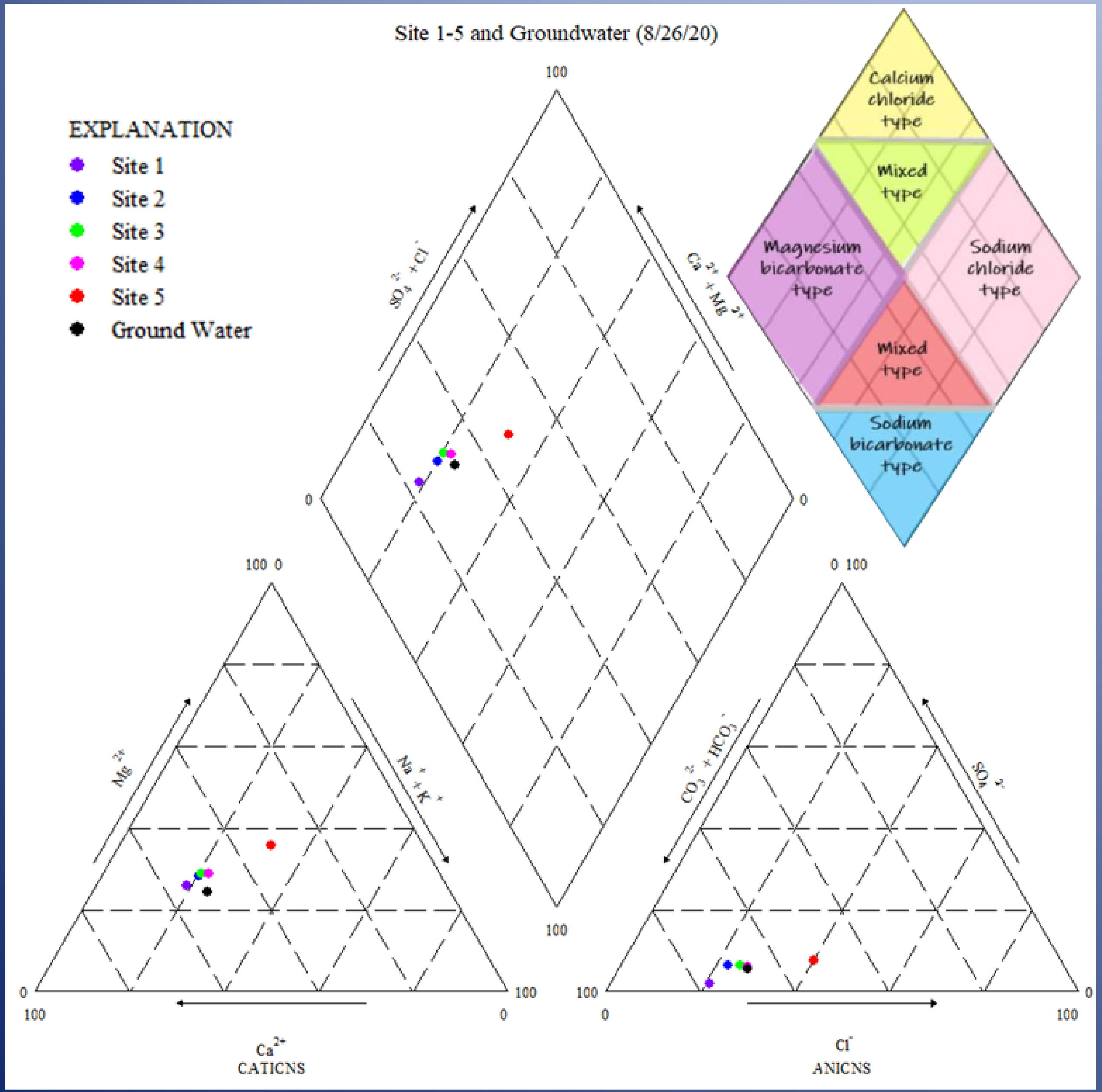
- Five sampling sites were established to monitor trends in major ions and nutrients
- Monthly sampling from March 2020 to December 2021
- Onset data loggers at sites 1-5 and outfalls (15-minute resolution) January-May, 2021
- Isotope sampling of wells and site 5 during summer 2020 and fall 2021
- Chlorophyll-a sampling at sites 4 and 5, and three 3 locations between sites 4 and 5 during summer 2020 and 2021

Stormwater Outfalls



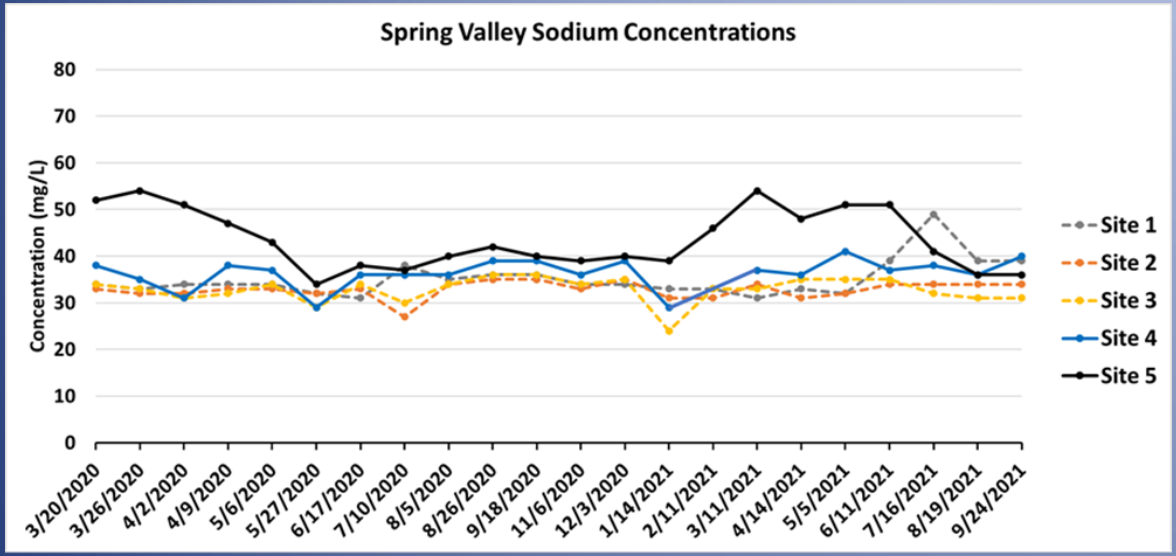
- Seven outfalls contribute runoff to the Spring Valley surface water system
- 5 public outfalls and 2 private outfalls
- Public drainage areas were provided by the City of Kalamazoo; private drainage areas estimated using GIS

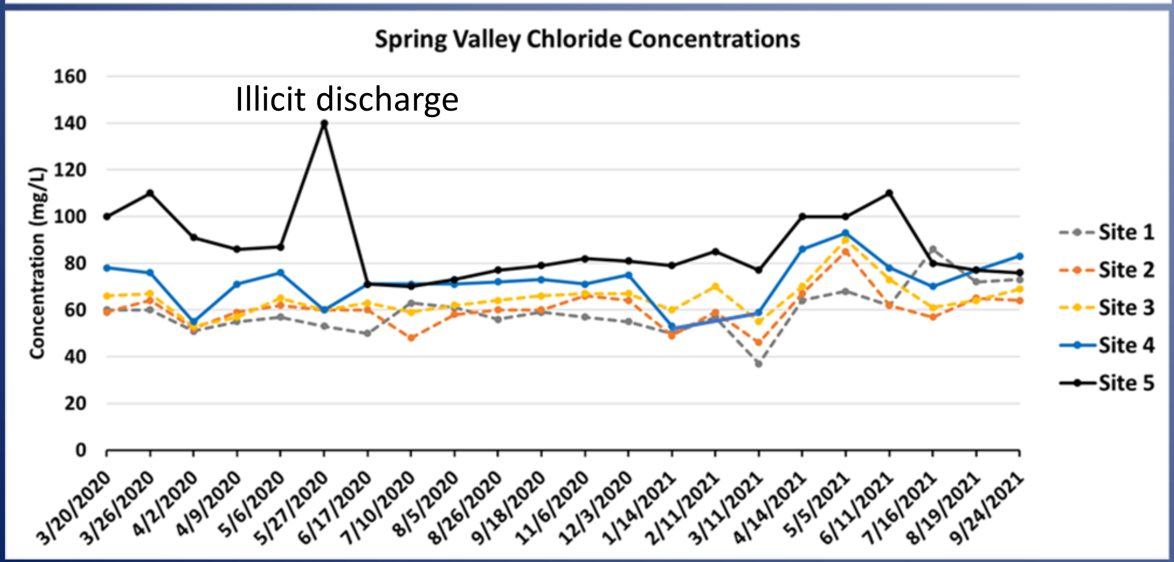
Water Quality



- Surface water at all sites is magnesium bicarbonate type.
- Major cation and anion concentrations generally increase from site 1 to 5.
- Exceptions to this general trend occur for bicarbonate, calcium, magnesium, and sulfate.
- Bicarbonate and calcium concentrations decrease from site 1 to site 5, while magnesium and sulfate concentrations tend to remain similar at all sampling sites.

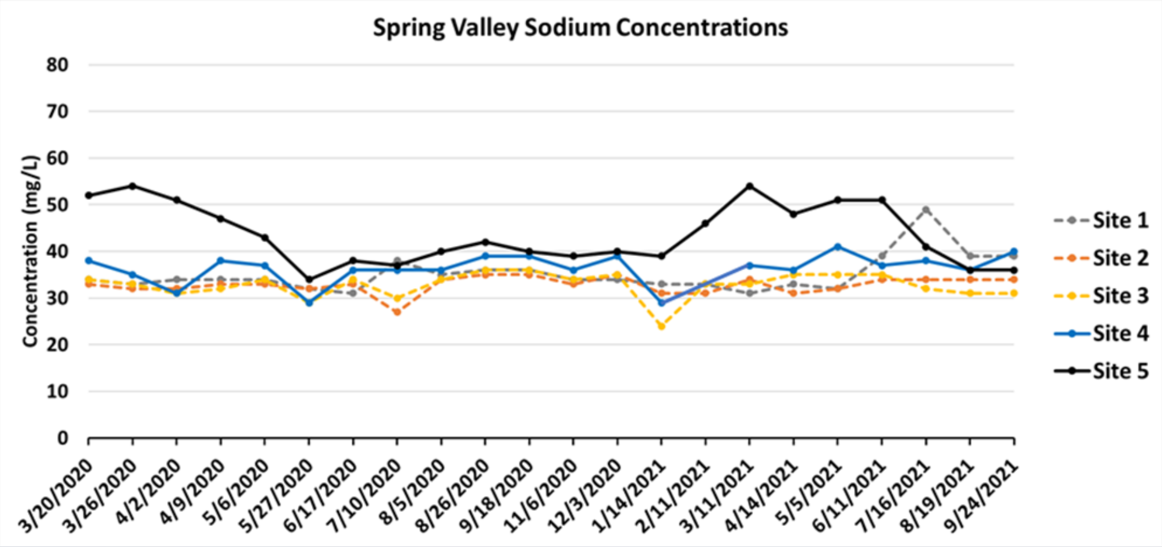
Road Salt Spatiotemporal Trends in the Watershed

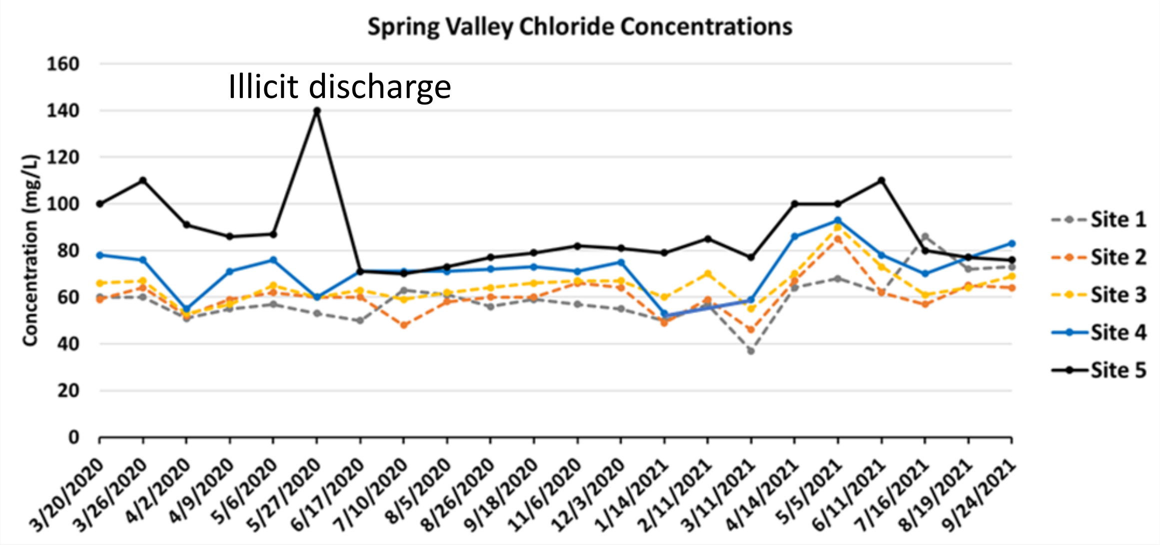




- Sodium and chloride concentrations generally increase downgradient froms site 1 to 5
- 2020: Maximum sodium and chloride concentrations (3/26) 53 mg/L and 110 mg/L, gradually decreased in the summer
- 2021: Maximum sodium and chloride concentrations 54 mg/L and 110 mg/L on 3/11 and 6/11, respectively
- 2021: Remained significantly elevated from 3/11 to 6/11 then returned to baseline concentrations

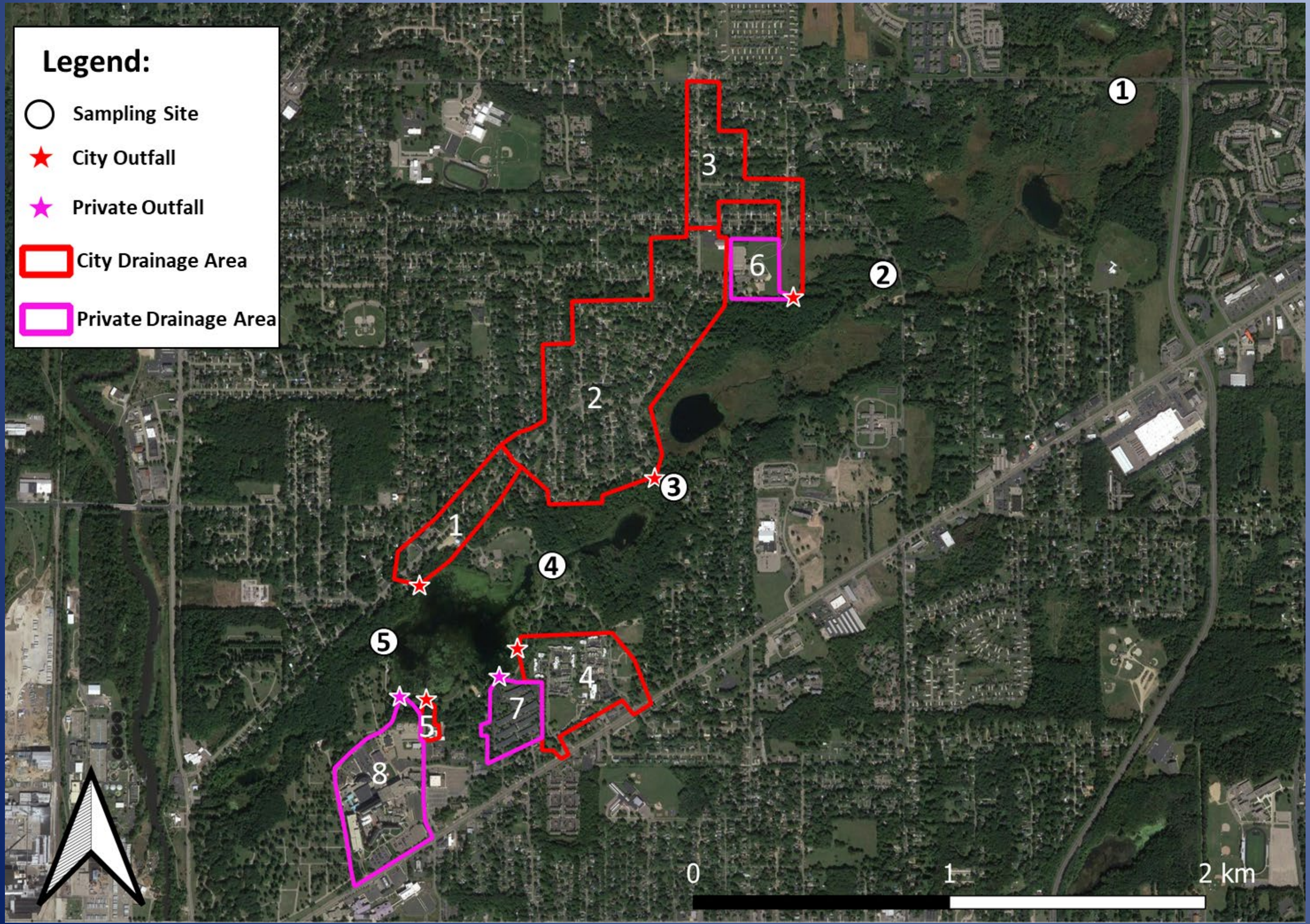
Road Salt Spatiotemporal Trends in the Watershed





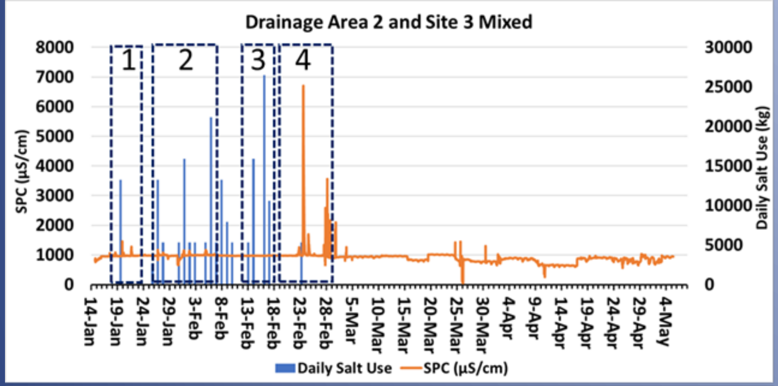
- Sodium concentrations for sites 1-3 generally similar
- Downgradient sodium enrichment between sites 3 and 4, most pronounced between sites 4 and 5
- Chloride enrichment in the stream occur incrementally from sites 1-3, notable increases from sites 3 to 4 and largest from 4 to 5
- Enrichment most pronounced from spring to early summer in 2020 and from spring to midsummer in 2021

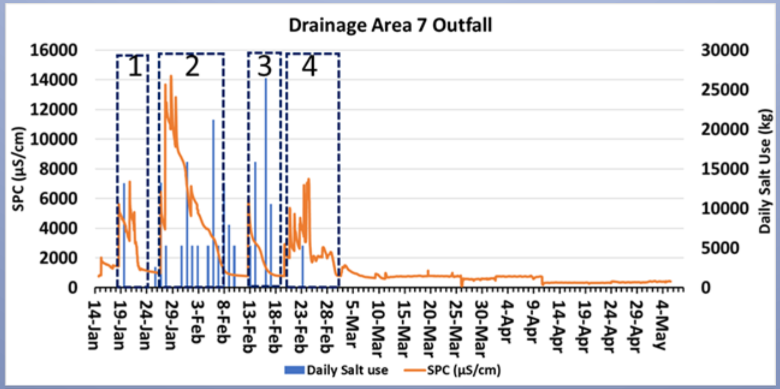
Road Salt Spatiotemporal Trends in the Watershed

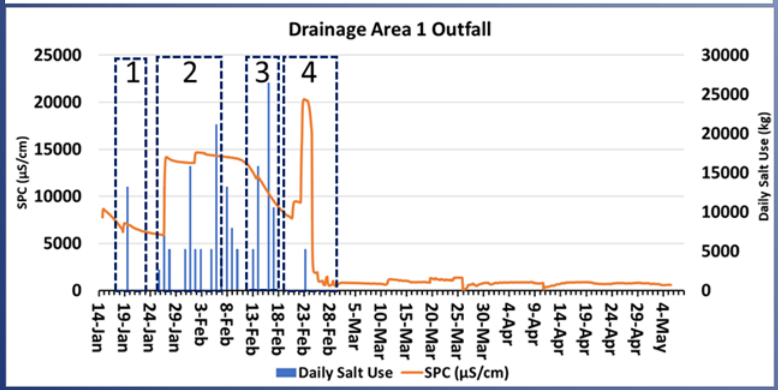


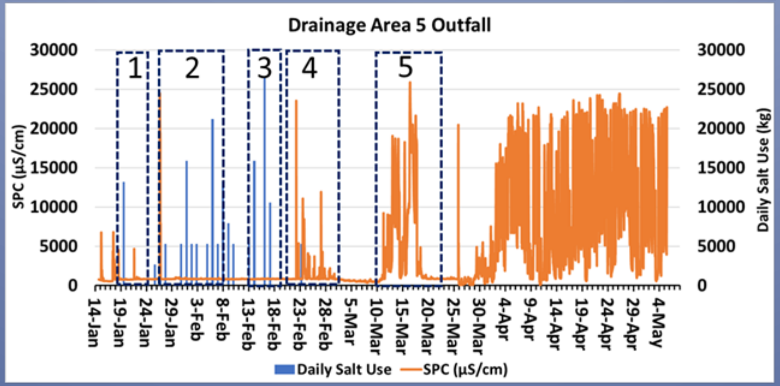
- Increases in sodium and chloride can be correlated to the presence of stormwater outfalls between sampling sites
- Between sites 2 and 3 sodium does not appreciably increase, chloride has an average increase of 4.6 mg/L
- 3 to 4: sodium and chloride increase 1.9 mg/L and 7.6 mg/L, respectively, on average
- 4 to 5: sodium and chloride increases of 8.9 mg/L and 15.6 mg/L, respectively, on average

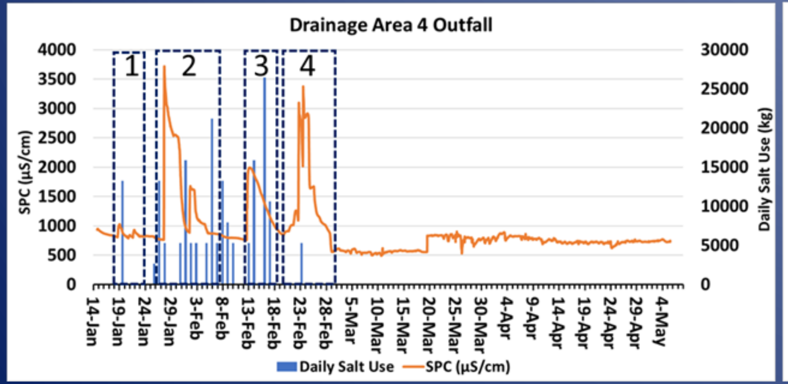
Road Salt Input to Spring Valley Lake

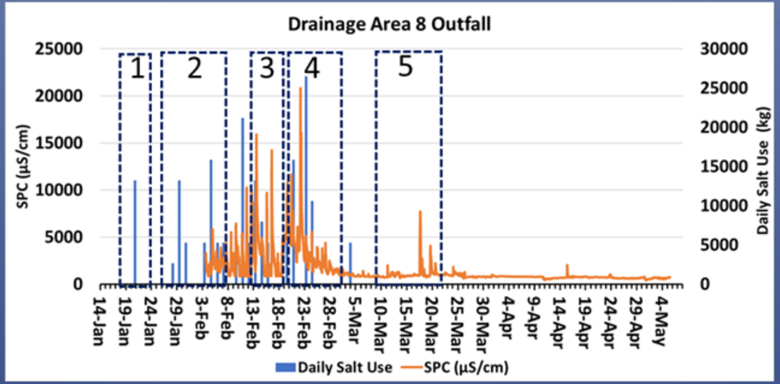






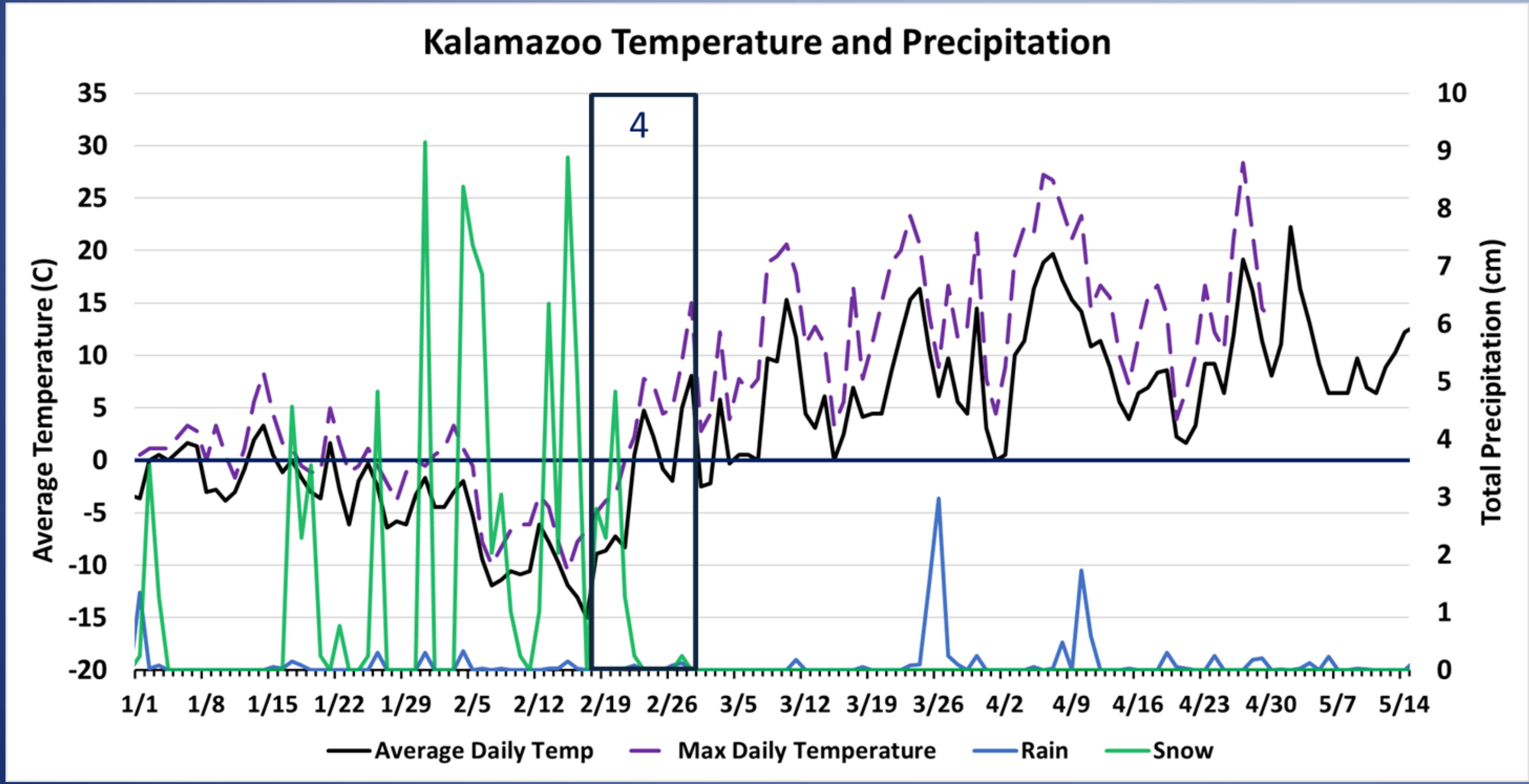






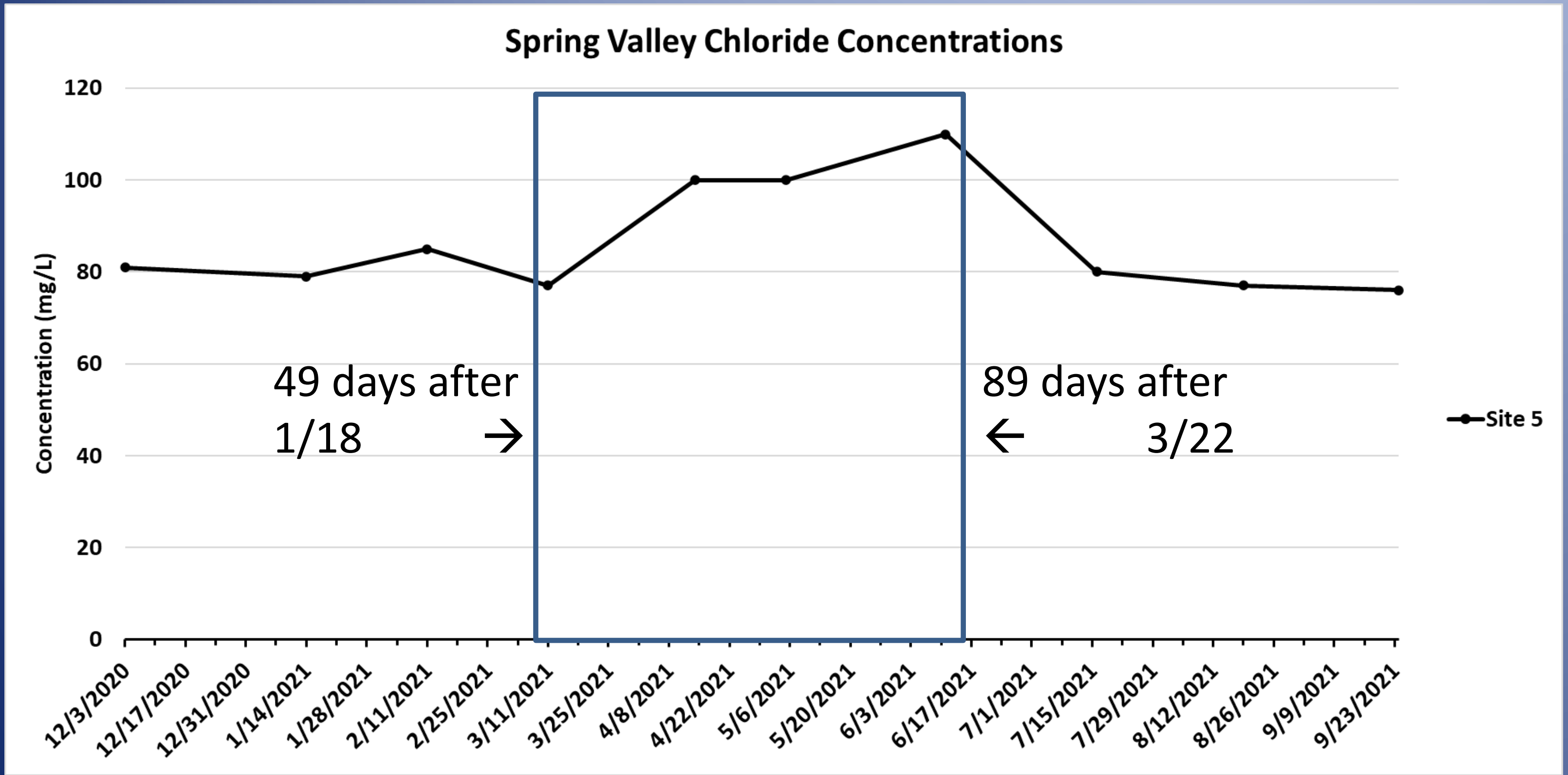
- 5 distinct SPC peaks observed from 1/14 to 5/4 of 2021
- Peak 1: 1/18 to 1/24
- Peak 2: 1/26 to 1/2/7
- Peak 3: 2/12 to 2/18
- Peak 4: 2/19 to 3/1
- Peak 5: 3/10 to 3/22, outfalls 5 and 8

Road Salt Input to Spring Valley Lake



- SC peak 4 likely represents largest melt event during 2021, only melt event detected by all stormwater outfall conductivity loggers
- Preceding peak 4, maximum daily temperatures never exceeded freezing leading to buildup of road salt on impervious surfaces
- After 2/22, significant snowmelt runoff and road salt transport to surface water outfalls would have occurred.

Residence Time and Road Salt Inputs to Spring Valley Lake



- 2021: Road salt runoff to Spring Valley lake: 1/18 to 3/22
- Residence time: 49 days to 89 days
- If chloride increases in lake from road salt runoff via outfalls, chloride should be detected at site 5 from 3/8-6/19
- Does not account for rain events after 5/14

Summary: Road Salt Spatiotemporal Trends

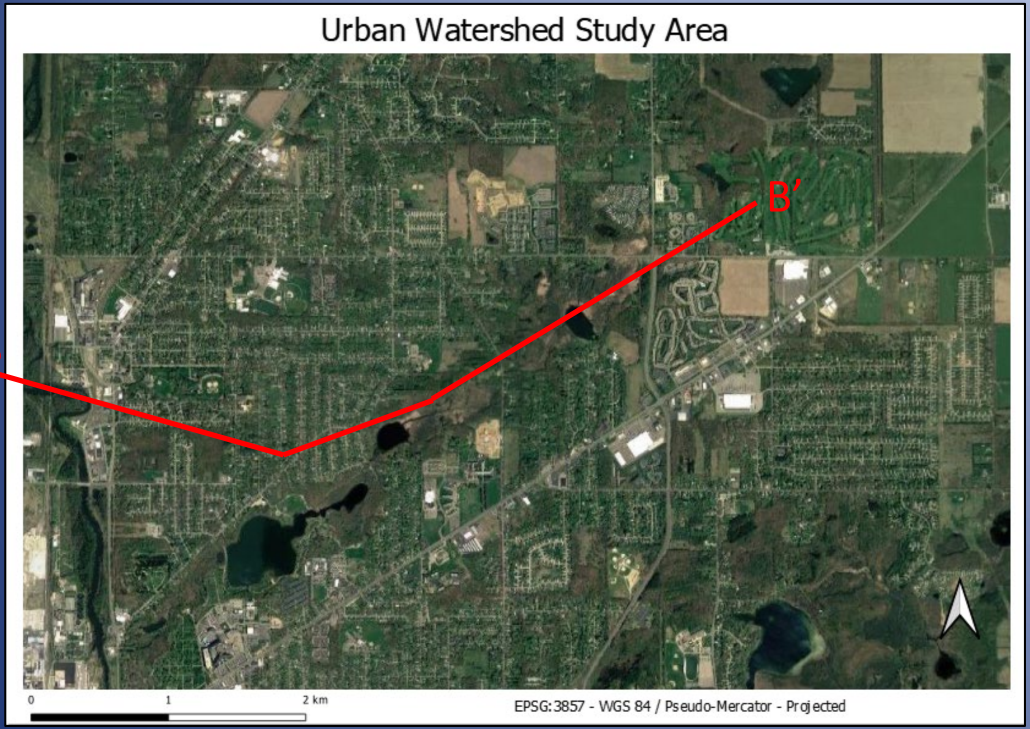
- Road salt is the primary source of sodium and chloride enrichment in the watershed
- Greatest sodium and chloride increases between outfalls occur from spring to summer after the application of road salts cease
- Increases in sodium and chloride are correlated with presence and drainage area of outfall structures, indicating surface water runoff is the dominant transport mechanism to stream and lake
- Pulses of road salt derived sodium and chloride are transported through the watershed in the spring and reside in the lake for months after direct runoff

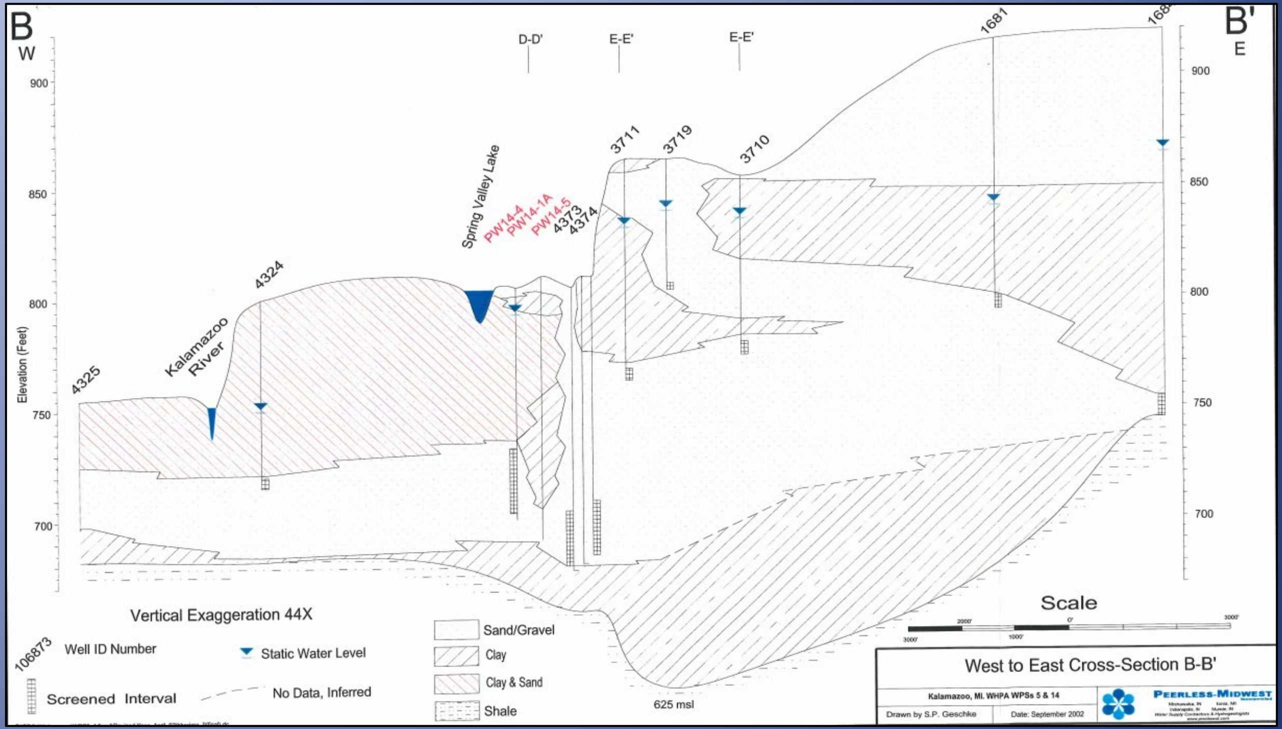
Surface Water Capture

Surface Water Capture Method Characteristics

- Water Balance: Lake-scale, temporal snapshot, physical measurements
- Isotope Tracer: Individual well scale, temporal snapshot, independent of physical lake measurements
- Mass Balance: Lake-scale, annual estimate based on water year, combines physical and chemical measurements

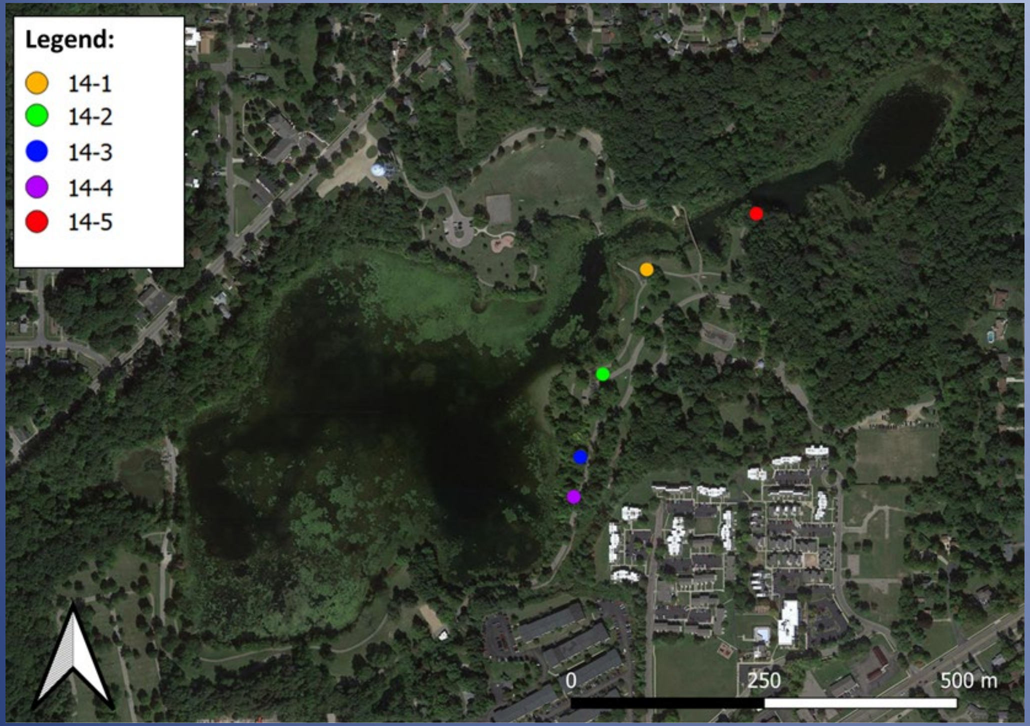
Spring Valley Lake Water Capture – Geological Basis

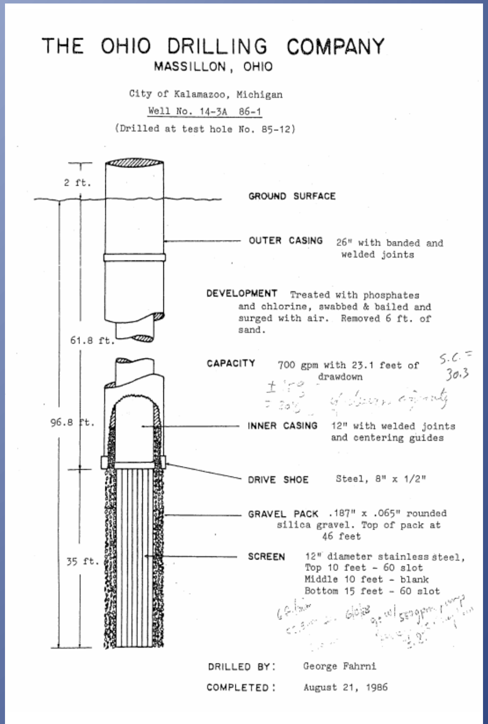




- Spring Valley sub-watershed contains surficial aquifer (0-2.5 m bgs) underlain by a semi-continuous clay aquitard (2.5-23 m bgs).
- Semi-confined sandy gravel aquifer (18 to 35 m bgs) serves as the supply aquifer for the municipal wells.
- Surficial aquifer and deeper aquifer are connected where aquitard is not present.

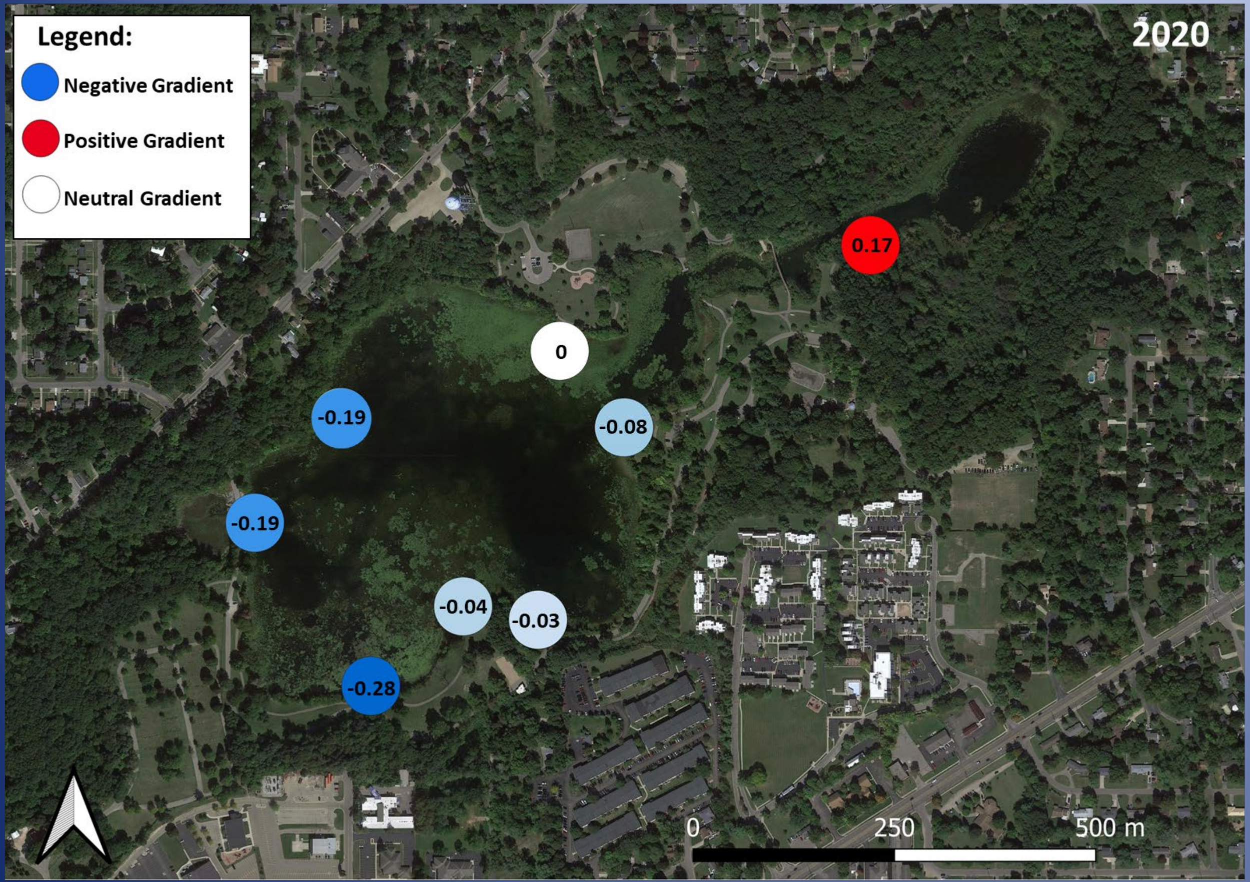
Station 14 Wells

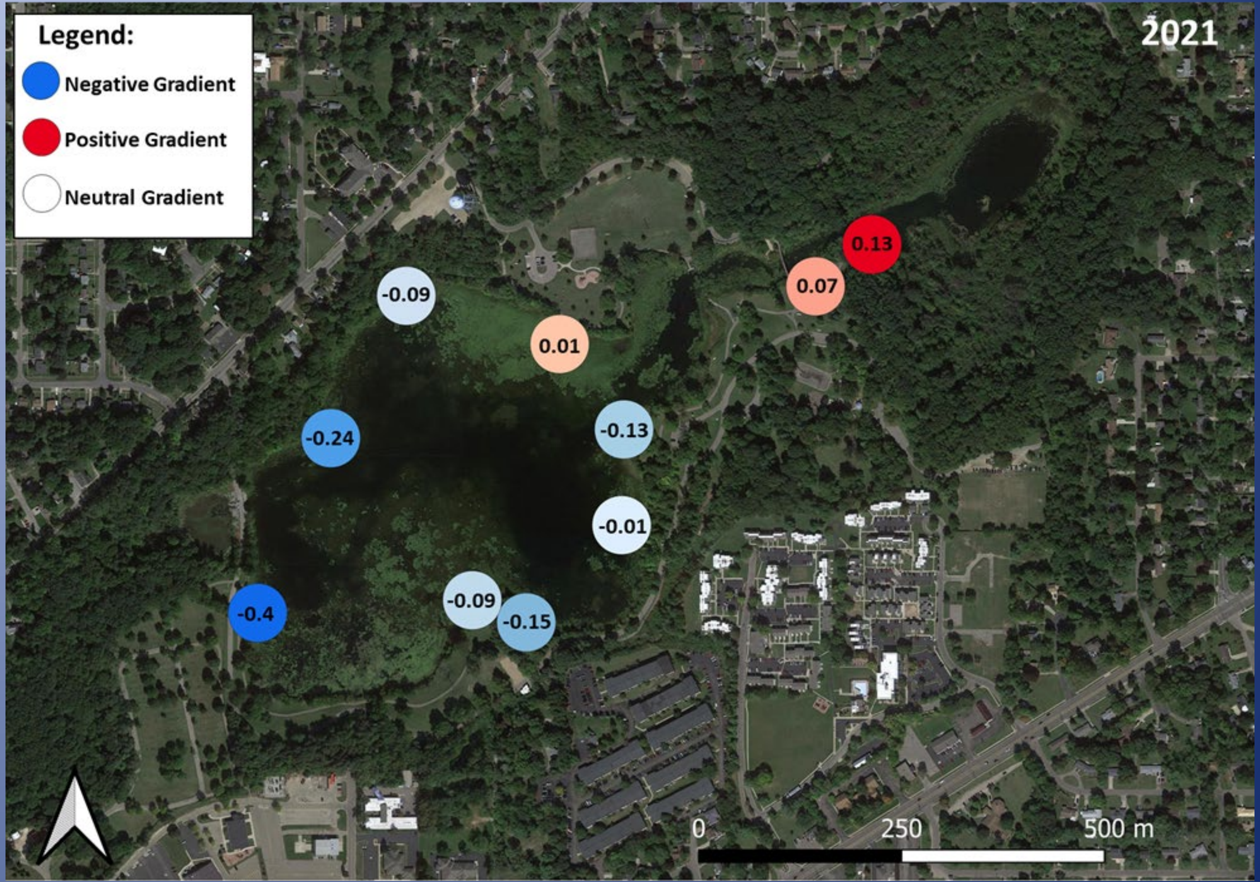




- Deeper sand and gravel aquifer transmits water to five pumping wells of the Station 14 wellfield
- Five pumping wells: average pumping rate for station 14 is 3765 m^3/d (670 gpm); screens 19 m to 31 m bgs, with lengths 8 to 11 m

Vertical Gradients





- 2020: mostly negative (-0.03 to -0.28), One positive upward gradient (0.17) observed near well 14-5, one neutral gradient
- 2021: mostly negative (-0.01 to -0.4), three positive upward gradients (0.01 to 0.13)

Isotope Mixing Model

Isotope Mixing Model

- Man-made impoundments represent surface water reservoirs, which have enriched δ^{18}O values due to evaporative fractionation of oxygen isotopes.

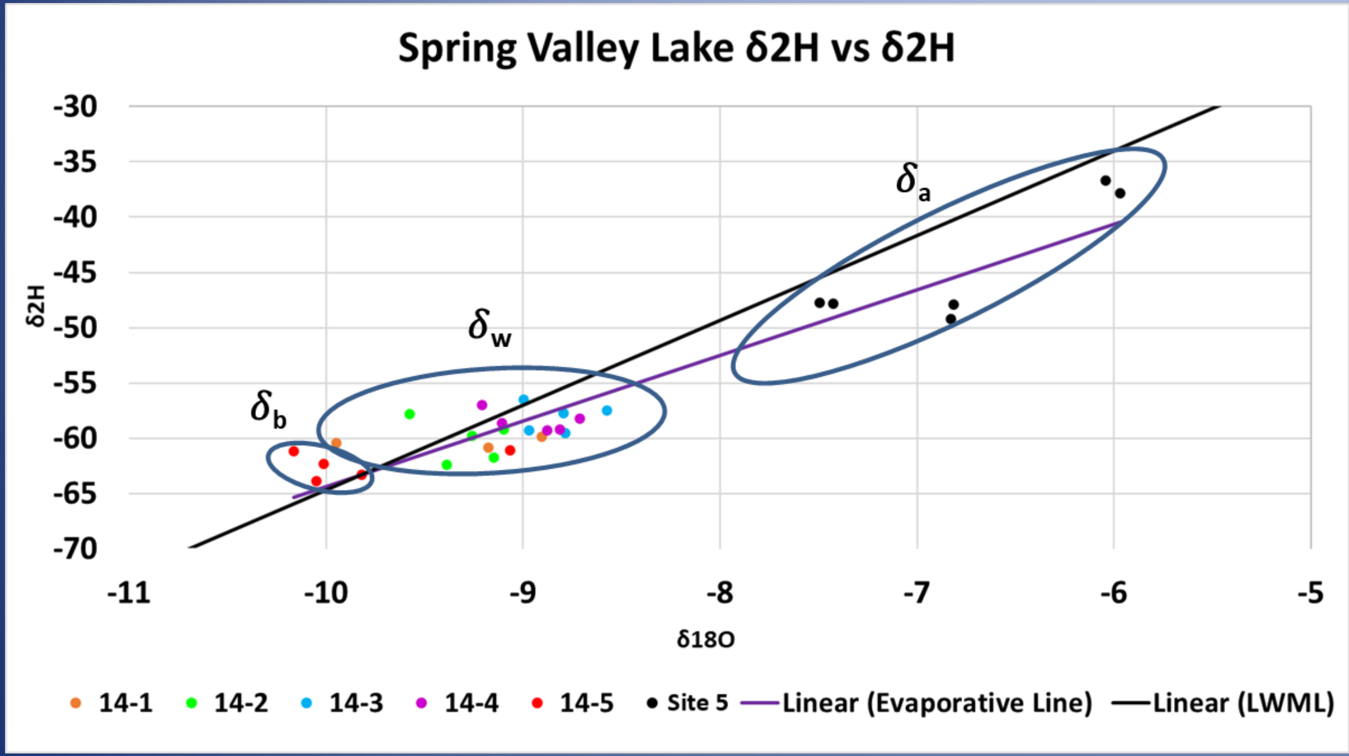
- The fraction of well water sourced from infiltrating lake water and ground water can be determined using a two-component mixing problem:

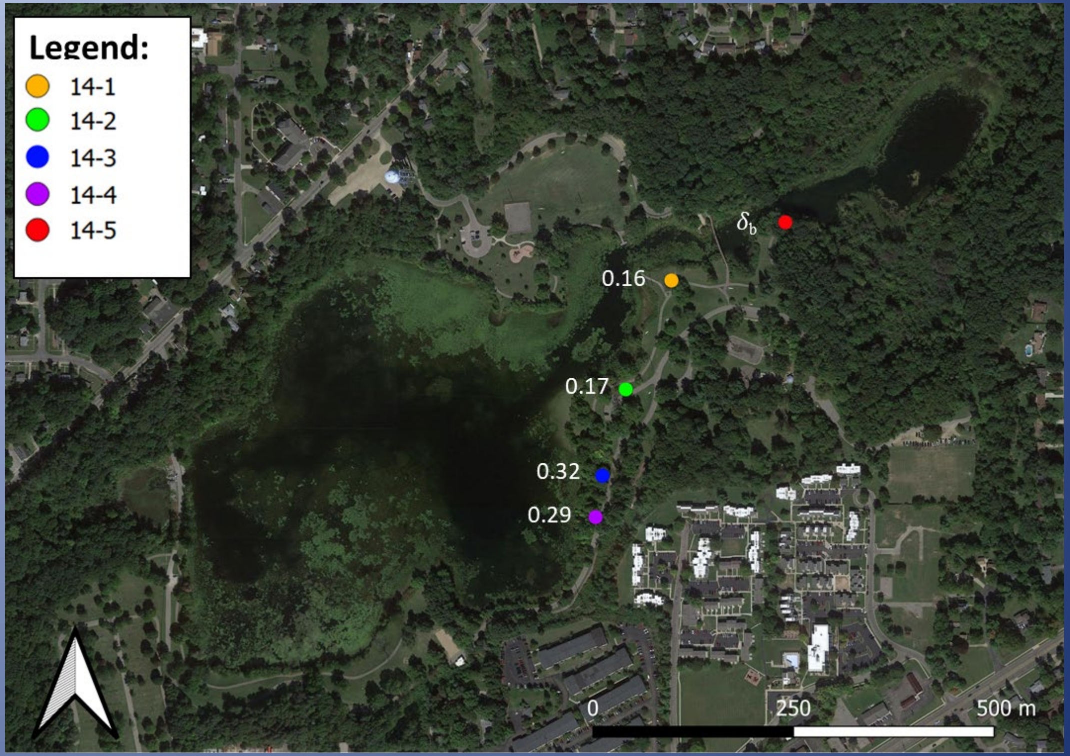
$$\delta_w = \delta_a f_a + \delta_b(1 - \delta_a)$$

$$SWC_{IMM} = f_a = \frac{\delta_w - \delta_b}{\delta_a - \delta_b}$$

- where δ_w is the δ^{18}O value of the produced well water, δ_a and δ_b represent the two δ^{18}O endmembers of lake water and ground water respectively, and f_a represent the fraction of lake water found in production well water (Clark 2015)

Stable Isotope Data – Lake and Wells



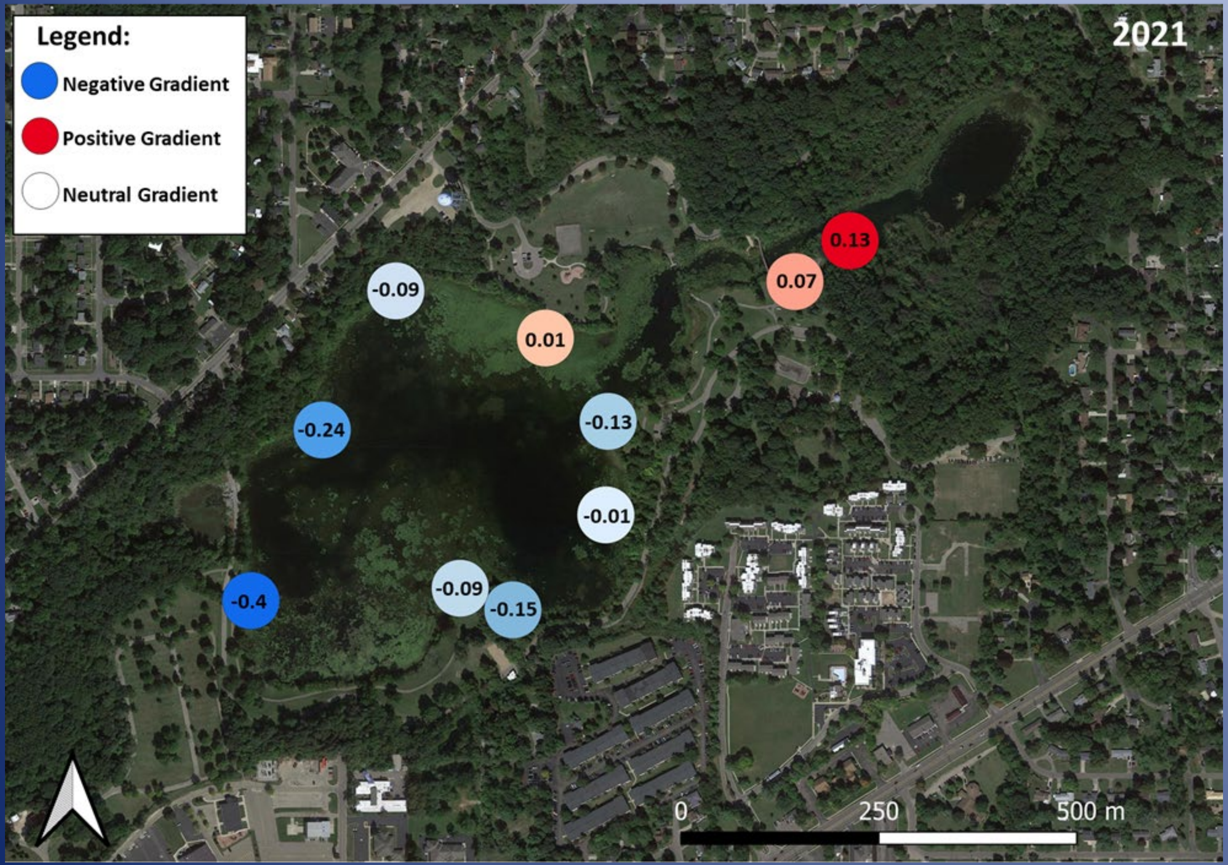


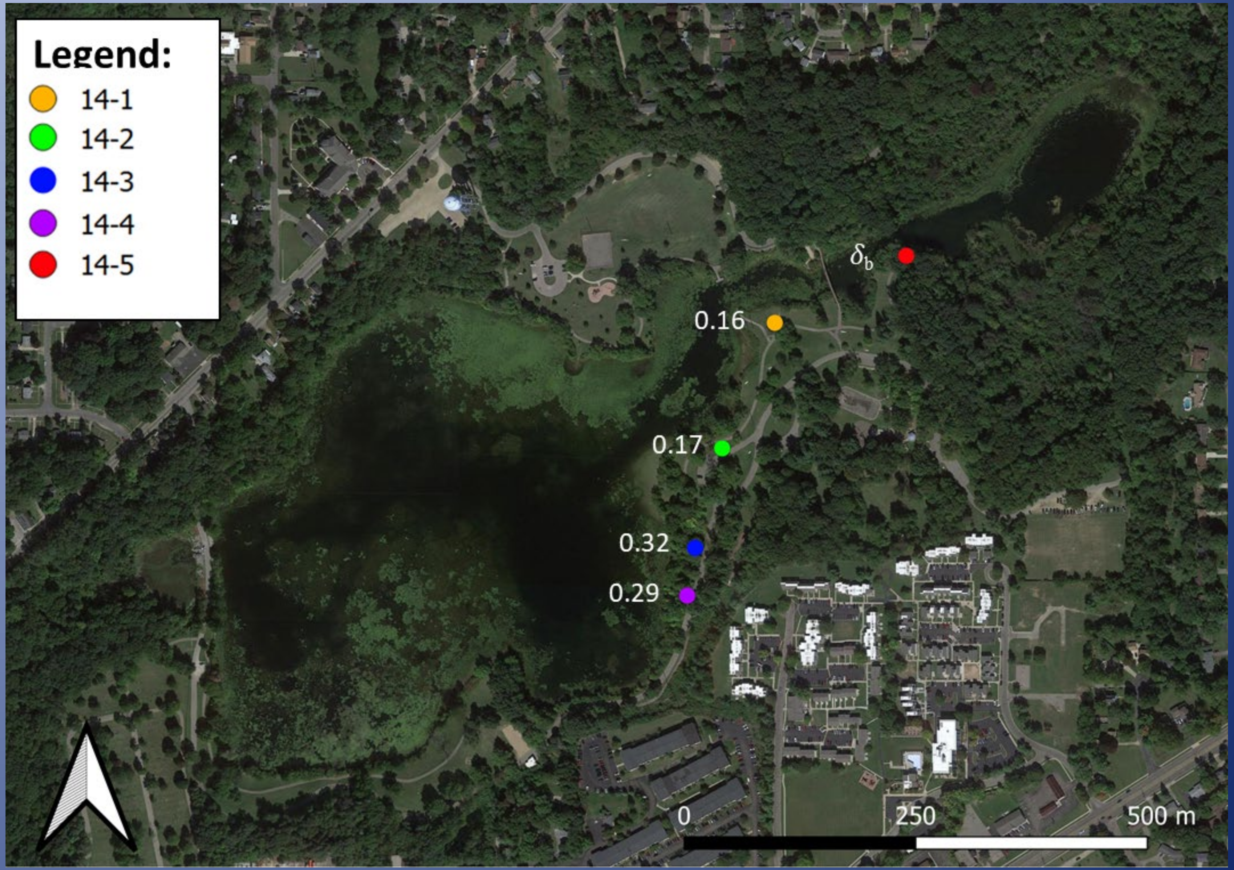
LMWL from Hurst S and Krishnamurthy R V. (2019)

Increasing surface water capture from wells 14-1 to 14-4 moving north to south, consistent with the trend of increasingly negative vertical gradient measurements

Differences in ^{18}O enrichment from summer 2020 to summer 2021 are likely a result of the significant increase in precipitation during summer 2021

Stable Isotope Data – Correlation of Wells and Vertical Gradients

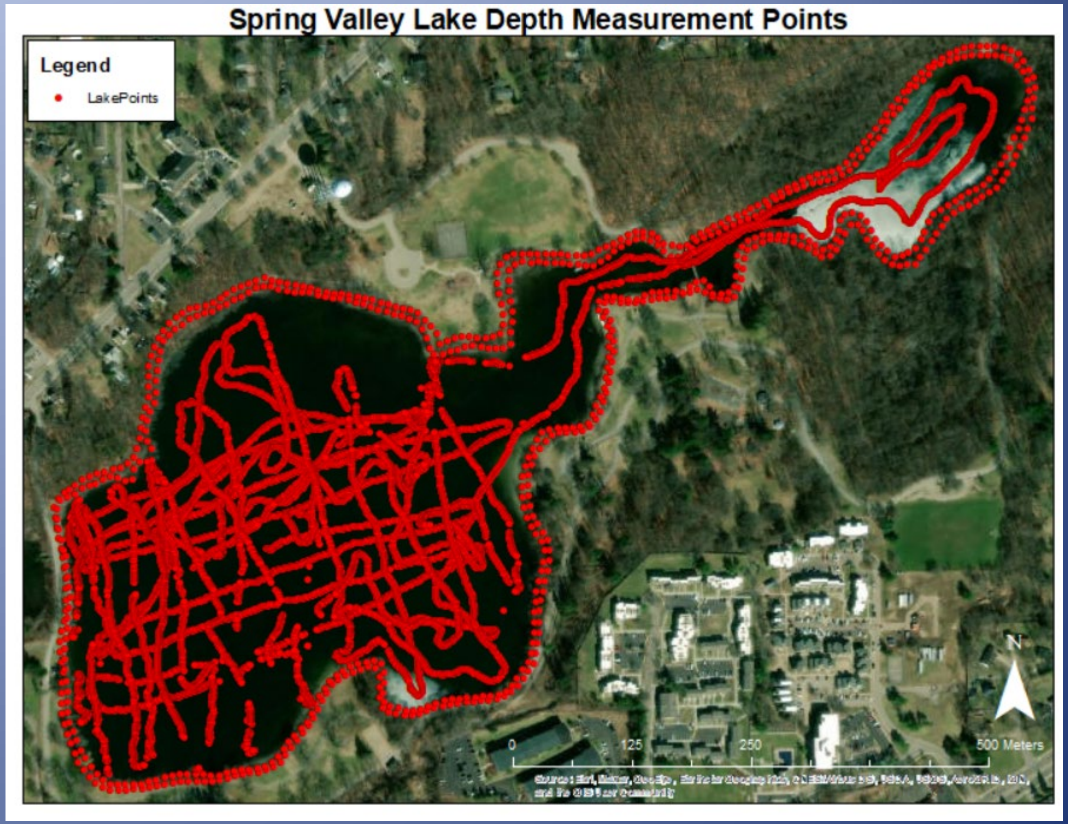




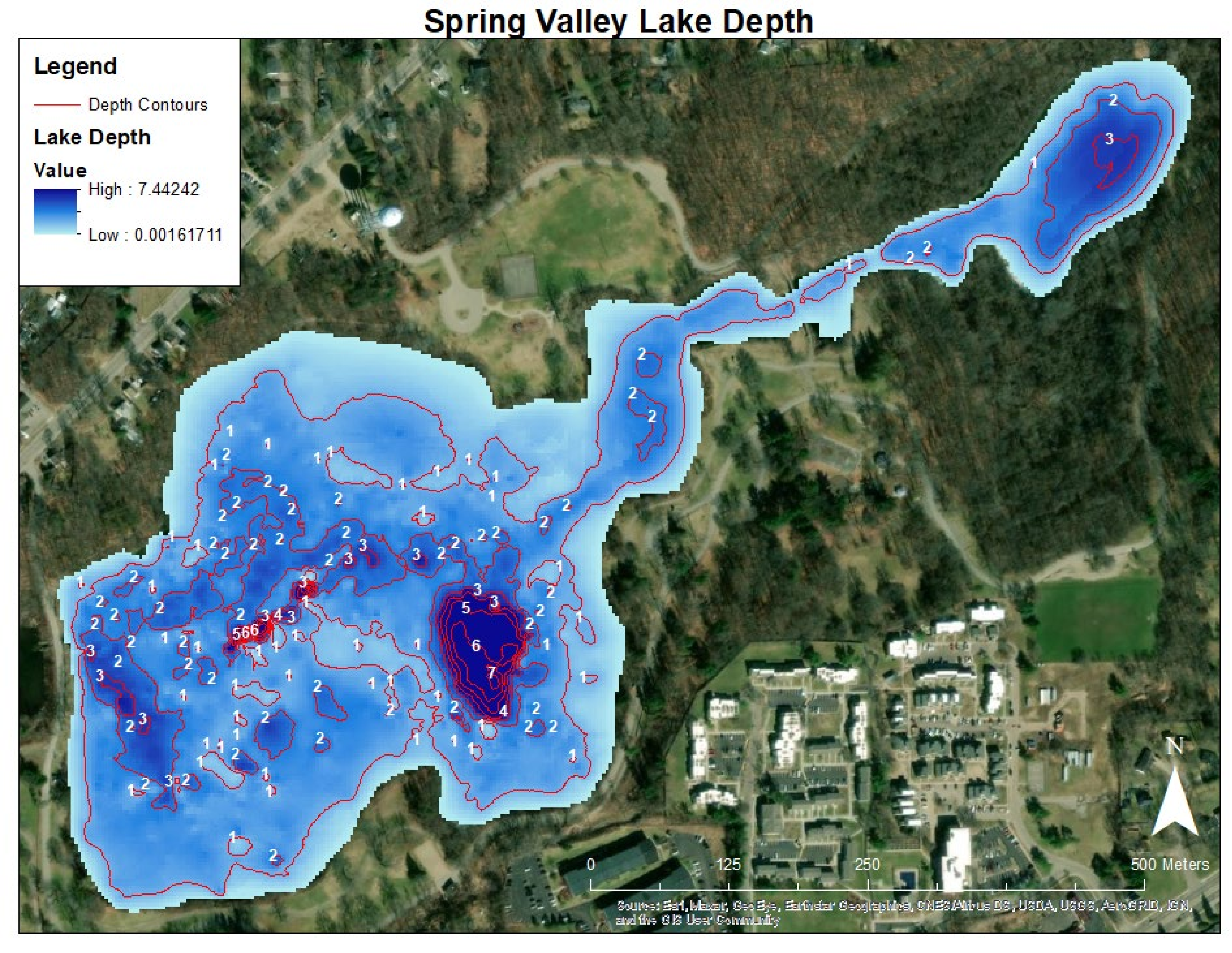
Average lake water capture ranges from 0% (14-5) to 32% (14-4); no composite estimates from blending station.

Lake Water Balance

Lake Bathymetry and Volume



- Bathymetry survey with sonar depth probe in September 2020: 12,984 spatial points
- These data were then used to interpolate depths throughout the entire lake to compute lake volume: essential for residence times and chloride mass in lake

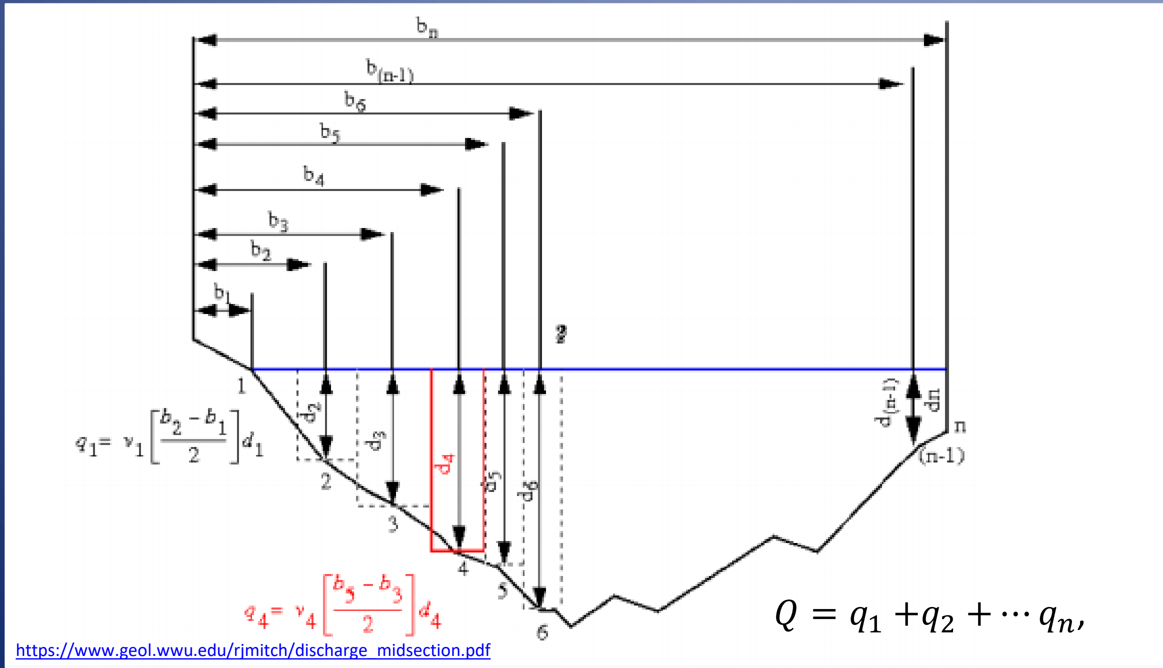


- Depth is 1 to 3 meters for most of the lake, max is 7.4 m
- Volume: 258,225 m^3
- Stage of the lake appears to fluctuate less than a 0.3 m (1 ft) throughout the year
- Residence time is approximately 49 to 89 days

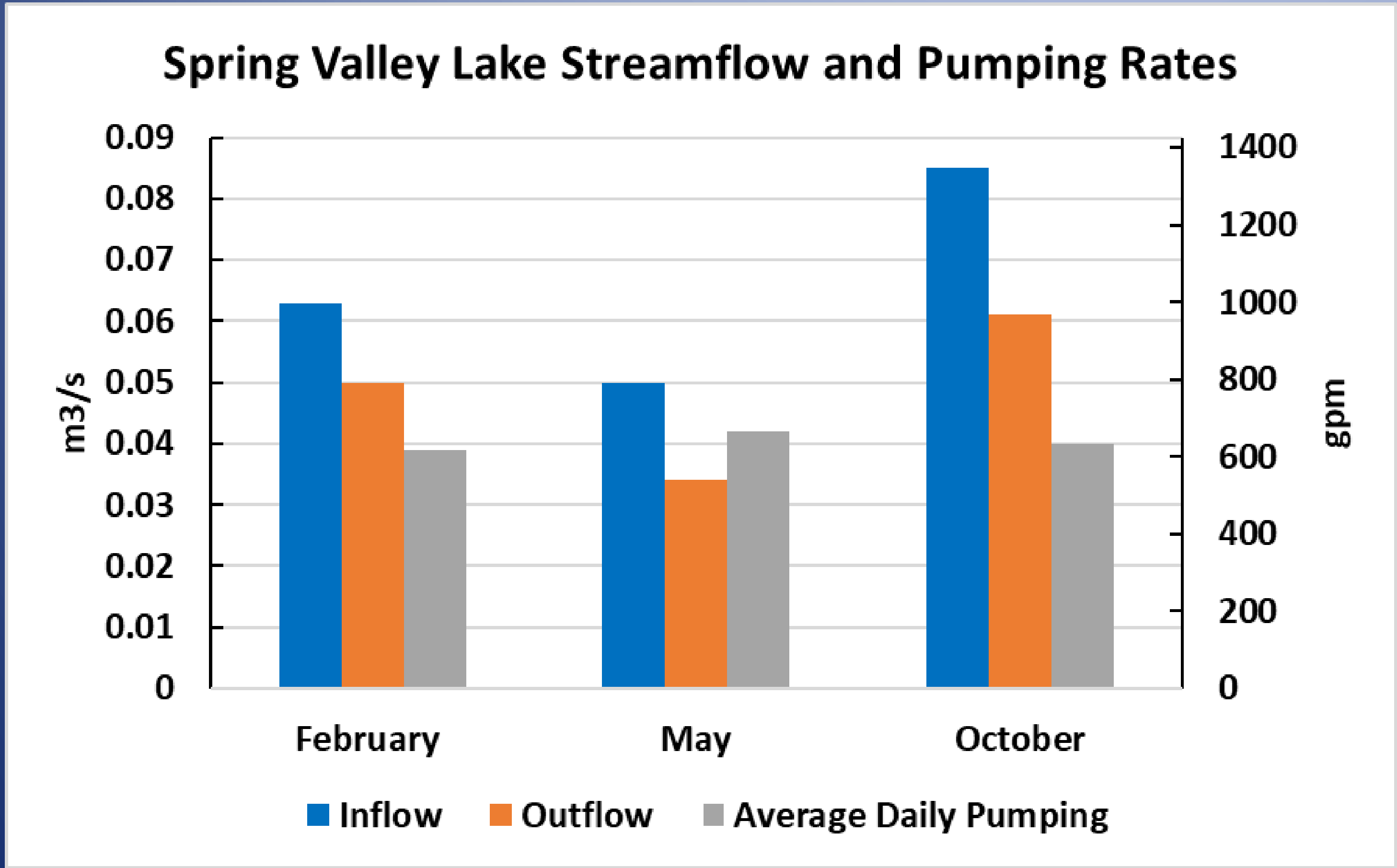
Lake Water Balance

- Stream gauging surveys during February, May, and October of 2021
- Surface water capture estimation was calculated using the computed inflow and outflow values by the equation:

$$SWC_{WB} = \frac{Q_i - Q_o}{Q_w}$$



Spring Valley Inflow, Outflow and Pumping



- Pumping rate of the wells is similar for all three stream gauging periods
- February represents best time to estimate surface water capture, no ET
- Water balance (Feb): 0.26 to 0.38 with 0.32 average
- SWC from water balance is biased high as not all lake water exiting system is captured by pumping wells

Chloride Mass Balance

Chloride Mass Balance

- While chloride can adversely impact aquatic ecosystems and infrastructure, it is beneficial for estimating surface water capture on an annual scale:

$$SWC_{MB} = \frac{M_w}{[Cl] * Q_w}$$

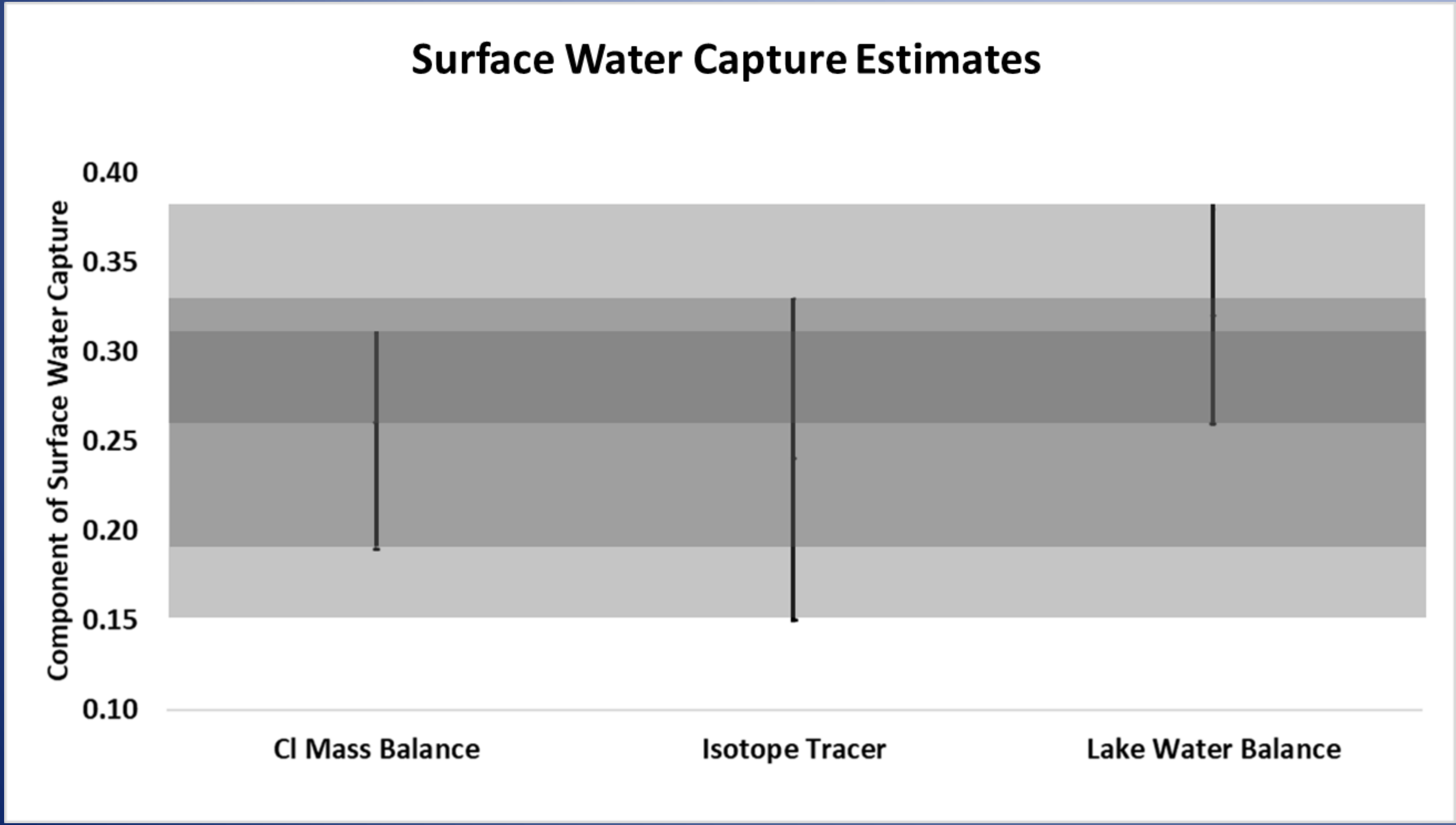
- M_w chloride mass captured by the pumping wells, [Cl] is average annual chloride concentration in the lake, and Q_w is the station 14 average annual pumping rate for the 2020-2021 water year

- Water chemistry at site 4 is assumed to be representative of the water chemistry captured by the pumping wells due to the proximity of site 4 to the pumping wells.

Chloride Mass Balance

- Chloride mass entering and exiting the lake annually: 153,332 kg and 130,755 kg, respectively.
- Annual chloride storage in the lake (increase from 72 to 74 mg/L): 1,033 kg
- Annual mass of chloride captured by the pumping wells : 23,610 kg
- Surface water capture: 0.19 to 0.31 with 0.26 average

Lake Water Capture by Municipal Wells



- Water balance (Feb): 0.26 to 0.38, 0.32 central tendency (biased high, temporal snapshot)
- Isotope mixing model: 0.15 to 0.33, 0.24 central tendency (no true composite, temporal snapshot)
- Chloride mass balance: 0.19 to 0.31, 0.26 central tendency (based on full water year)
- Overlap: 0.26 to 0.31, represents constrained estimate

Lake Water Quality

Water Corrosivity

- Chloride Sulfate Mass Ratio (CSMR): measure of corrosion potential for galvanic corrosion of lead soldered joints in copper and brass pipes

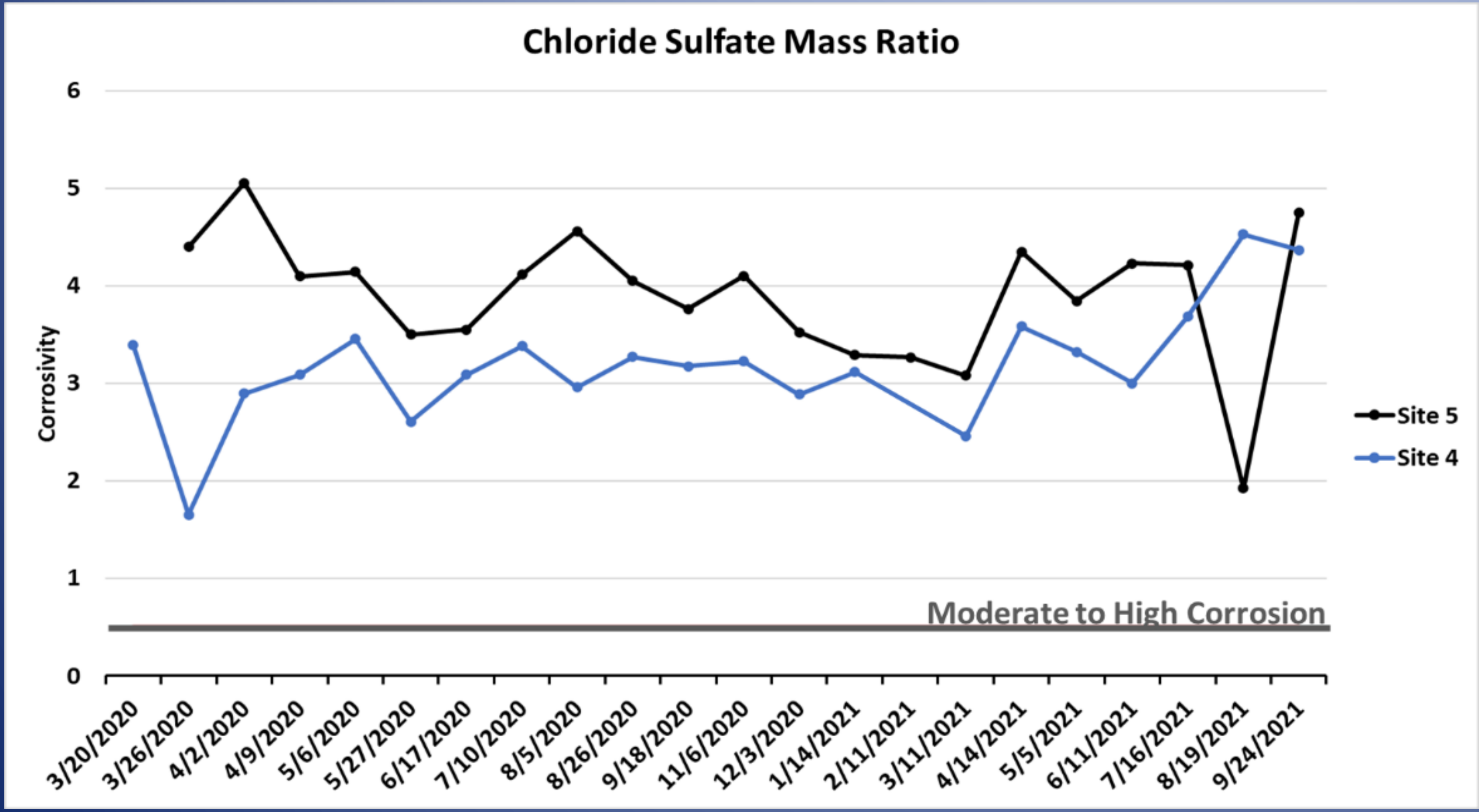
$$CSMR = \frac{CL^{-}}{SO_4^{2-}}$$

- Larson Index (LI): indicates corrosivity of water to iron and steel:

$$LI = \left(\frac{Cl^{-} + SO_4^{2-}}{HCO_3^{-} + CO_3^{2-}}\right)$$

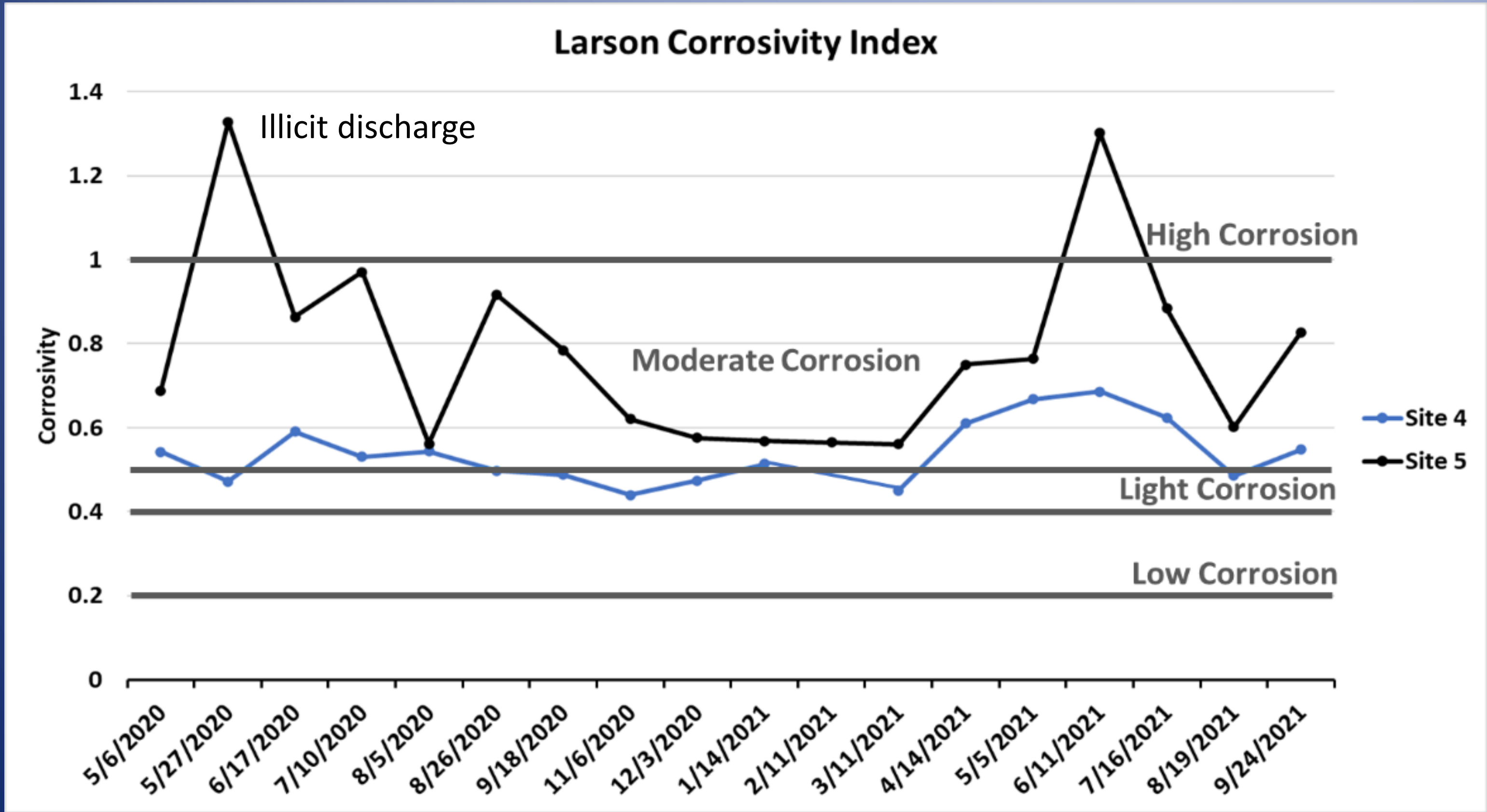
all values are in moles/L

Lake Water Corrosivity



- 2020: Max concentrations at site 5 during the spring (5) and fall (4.5)
- 2021: Max concentrations at site 5, during spring (3.8) and early fall (4.8)
- Spring Valley Lake is always moderately corrosive to lead
- Would be highly corrosive if lake alkalinity ever fell below 50 mg/L

Lake Water Corrosivity



- LI values 0.4 - 1.3, greatest during the summer
- Increases in LI during the summer 2020 can be attributed to reductions in lake alkalinity
- High LI values in the lake during summer of 2021 caused by low lake alkalinity and high chloride concentration

A list of possible changes that might be expected in a north temperate lake as the amount of algae changes along the trophic state gradient.

TSI	Chl(μg/L)	SD(m)	TP (μg/L)	Attributes	Water Supply	Fisheries & Recreation
< 30	< 0.95	> 8	< 6	**Oligotrophy:** Clear water, oxygen throughout the year in the hypolimnion.	Water may be suitable for an unfiltered water supply.	Salmonid fisheries dominate.
30 – 40	0.95 – 2.6	8 – 4	6 – 12	Hypolimnia of shallower lakes may become anoxic.		Salmonid fisheries in deep lakes only.
40 – 50	2.6 – 7.3	4 – 2	12 – 24	**Mesotrophy:** Water moderately clear; increasing probability of hypolimnetic anoxia during summer.	Iron, manganese, taste, and odor problems worsen. Raw water turbidity requires filtration.	Hypolimnetic anoxia results in loss of salmonids. Walleye may predominate.
50 – 60	7.3 – 20	2 – 1	24 – 48	**Eutrophy:** Anoxic hypolimnia, macrophyte problems possible.		Warm-water fisheries only. Bass may dominate.
60 – 70	20 – 56	0.5 – 1	48 – 96	Blue-green algae dominate, algal scums and macrophyte problems.	Episodes of severe taste and odor possible.	Nuisance macrophytes, algal scums, and low transparency may discourage swimming and boating.
70 – 80	56 – 155	0.25 – 0.5	96 – 192	**Hypereutrophy:** (light limited productivity). Dense algae and macrophytes.		
> 80	> 155	< 0.25	192 – 384	Algal scums, few macrophytes		Rough fish dominate; summer fish kills possible.

https://www.nalms.org/secchidipin/monitoring-methods/trophic-state-equations/

Trophic State

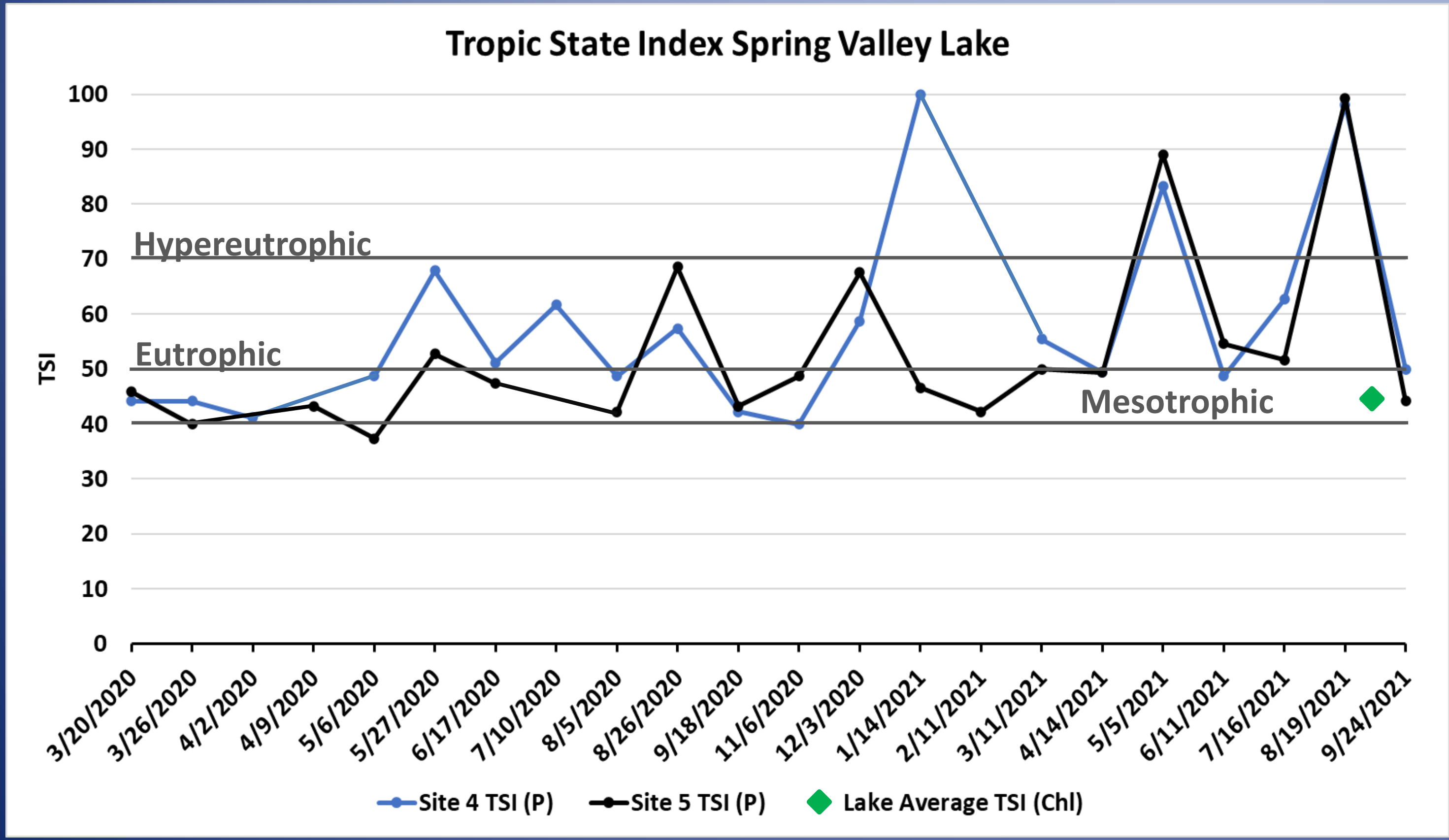
- The Trophic State Index (Carlson, 1977) uses algal biomass as the basis for trophic state classification.
- Chl-a and P can be used independently to find TSI values, as these variables are interrelated through linear regression models:

$$TSI\ (chl) = 10\left(6 - \frac{2.04 - 0.68(\ln chl)}{\ln 2}\right)$$

$$TSI\ (P) = 10\left(6 - \frac{\ln \frac{48}{P}}{\ln 2}\right)$$

- TSI (P) can be used to estimate summer TSI (Chl-a) during non-summer months

Seasonal Lake Alkalinity Declines



- Lakes with Alk > 1 meq/L, summer DIC depletion caused by biogenic calcite precipitation.
- In summer when algae are present in abundance, micro algae act as nucleation site for calcite precipitation.
- Release of 1 mole CO2 with net loss of 1 mol DIC and 2 moles total alkalinity (Khan et al. 2020).

$$Ca^{2+} + 2HCO_3^- \rightarrow CaCO_3 + CO_2 + H_2O$$

- Highest lake water corrosivity should occur in summers after road salt transport to Spring Valley Lake has persisted into March.

Recommended Future Work

Proposed Future Work

Unanswered Research Questions

1. What is the interannual variability of chloride in Spring Valley Lake, and is chloride accumulating over time?
2. How accurate is chloride mass balance and will estimates significantly change year-to-year?
3. How helpful will the quantification of ET be to resolve lake water balance and associated capture estimates?
4. What is the composite isotope estimate for station 14 wellfield?
5. What is the ratio of road salt in Spring Valley Lake to total applied road salt within watershed?
6. Should we be concerned about road salt accumulation and impacts to other wellfields? In other words, should the developed methodology be applied to other wellfields in Kalmazoo?

Proposed Activities

Proposed Activities (Spring Valley Lake)

- Continue to monitor for chloride and alkalinity at sites 4 and 5 (biweekly or monthly)
- Isotope sampling and analysis at blended station for composite value (4x year)
- Chloride sampling at blended station for chloride (biweekly or monthly)
- Stream gauging of inflows and outflows (biweekly or monthly)

Other Sites in Kalamazoo

- Similar methodology applied as Spring Valley Lake, modified to fit specific sites