Road Salt and Groundwater: Monitoring, Management and Mitigation Strategies

http://imgc.allpostersimages.com/images/P-473-488-90/65/6591/KUV2100Z/posters/christopher-weyant-plow-truck-salts-highway-from-giant-salt-shaker-on-back-of-truck-new-yorker-cartoon.jpg

Presented at the NGWA Groundwater Summit, April 26, 2016

John Jansen, P.G., Ph.D., Frank Getchell, P.G., and Thomas P. Cusack, CPG

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What's the problem?

- Road salt use continues to rise in spite of efforts to reduce application rates.
- Road salt run off is a problem in surface water is a problem for a few weeks every year
- Road salt in groundwater is a problem that lasts for decades

Why should I care?

- Elevated sodium in drinking water can affect people with high blood pressure
- High chloride levels give water an unpleasant flavor
- Chloride is expensive and often impractical to treat
- Many areas could lose the use of their shallow aquifers
- Elevated chloride levels increase corrosion in the distribution system
- The lead problem in Flint was caused by switching to a higher chloride source water and failing to address the higher corrosivity of the water

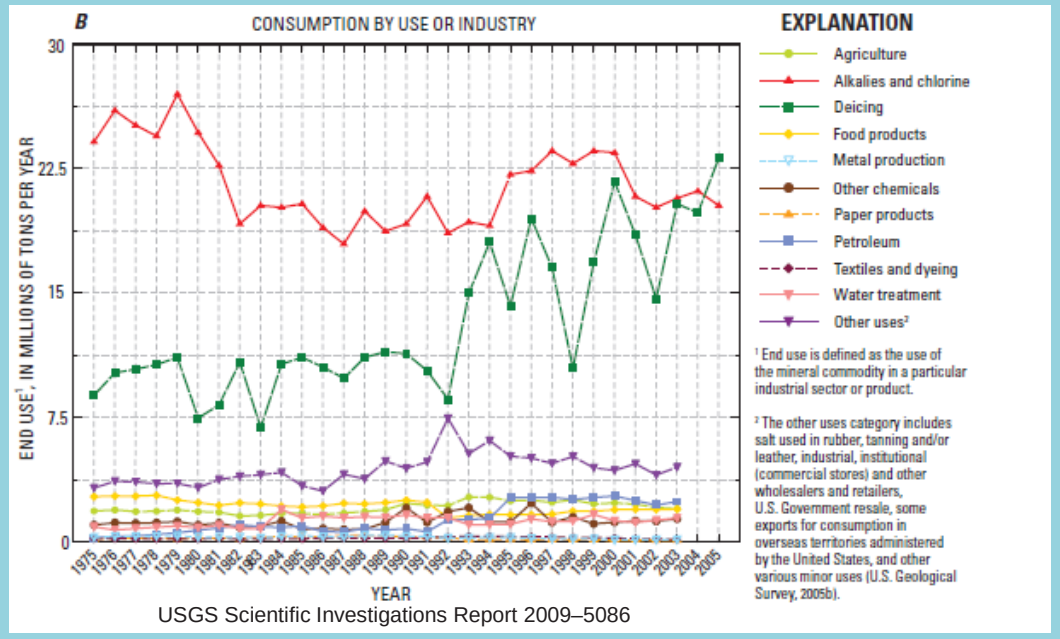
Environmental and Health Risks of Road Salt Contamination

Area of Impact	Examples of Impacts
Human health	• Hypertension from excess sodium in drinking water • Ferrocyanide, added to chloride salts to prevent clumping, can release 25% cyanide ions in presence of sunlight
Infrastructure	• Corrosion of concrete reinforcing rods in road, bridges, parking structures, etc. • Corrosion costs estimated at $3.5 to $7 billion per year in the U.S. • Corrosion protection practices increase the cost of auto manufacturing by nearly $4 billion/year • Corrosion protection costs estimated at $8.3 billion/year for highway bridges, and $109 billion for epoxy coating;
Vegetation	• Osmotic imbalance in plants, inhibiting water absorption and reducing root growth • Inhibition of seed germination and root growth for grasses and wildflowers (for NaCl as low as 100 ppm in soil) • Competition to native species from salt-tolerant invasive species
Soil	• Inhibition of soil bacteria (for NaCl concentrations as low as 90 ppm), compromising soil structure and increasing erosion • Accumulation of salt, particularly sodium, in soil over time, reduces soil fertility and affects soil chemistry
Groundwater	• Remediation of salt contamination in drinking water estimated at $10 million nationally
Wildlife	• Compromised health in birds ingesting salt at 266 mg/kg; median lethal dose in birds and mammals is 3,000 mg/kg
Aquatic life	• Decreased dissolved oxygen and increased nutrient loading, promoting eutrophication • Release of toxic metals from sediment into the water column • Reduction of number and diversity of macroinvertebrates • Critical tolerance values in 10% of aquatic species exceeded for prolonged exposure to chloride concentrations >220 mg/L • Median lethal dose (7 days exposure to salt) for 17 species of fish, amphibians, crustaceans ranges from 1,440 – 6,031 mg/L (mean value of 3,345 mg/L)

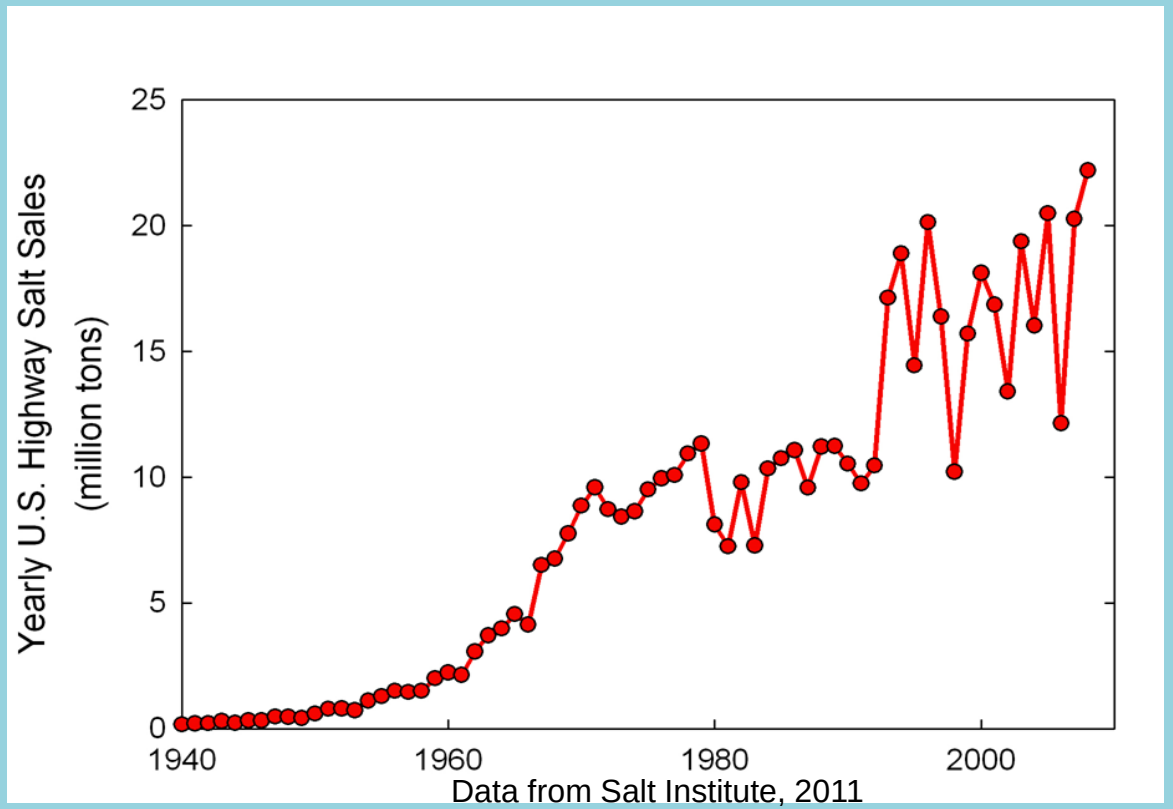
From City of Madison Salt Report 2006

- Secondary Drinking Water MCL for Chloride is 250 ppm (Based on Aesthetic Issues)
- USEPA Drinking Water Equivalency Guideline for Sodium is 20 ppm (Based on Sensitivity of People With Hypertension)
- USEPA Cl Surface Water Standards; Acute 860 ppm and Chronic 230 ppm (Based on Toxicity for Fish)
- Infrastructure corrosion costs $3.5B to $7B/yr
- Car corrosion costs $4B/yr
- Remediation of chlorides in drinking water estimated at $10M/yr in 2006

Application Rates of Road Salt are Still Going Up



USGS Scientific Investigations Report 2009–5086



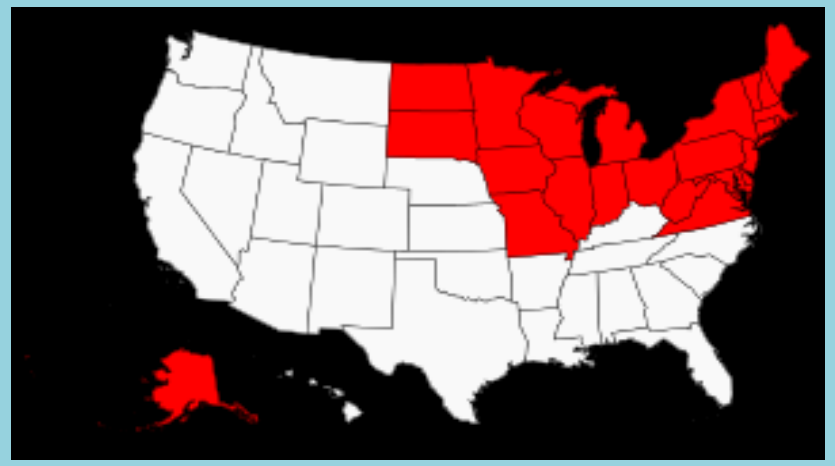
Data from Salt Institute, 2011

- Salt use for most uses flat since the 1970s
- Road salt is the only use showing significant increase
- US Road Salt Use Over 22 Million Tons in 2010
- National Application Rates Have Tripled Since 1980 Despite Aggressive Reduction Efforts

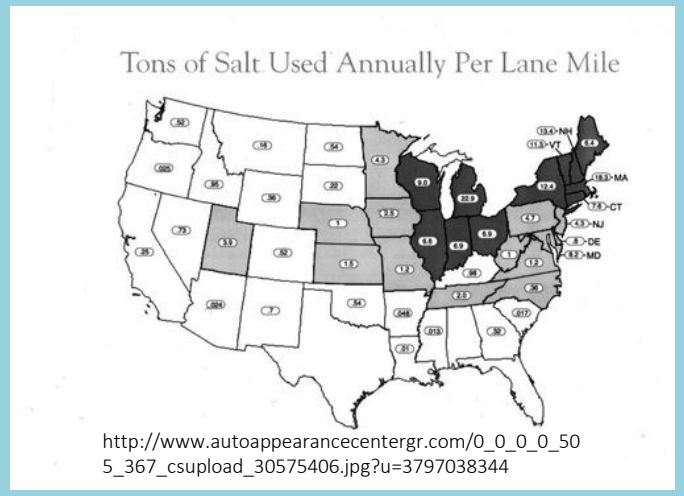
The Salt Belt

(The States That Apply Large Amounts of Salt to Their Roads)

The Salt Belt



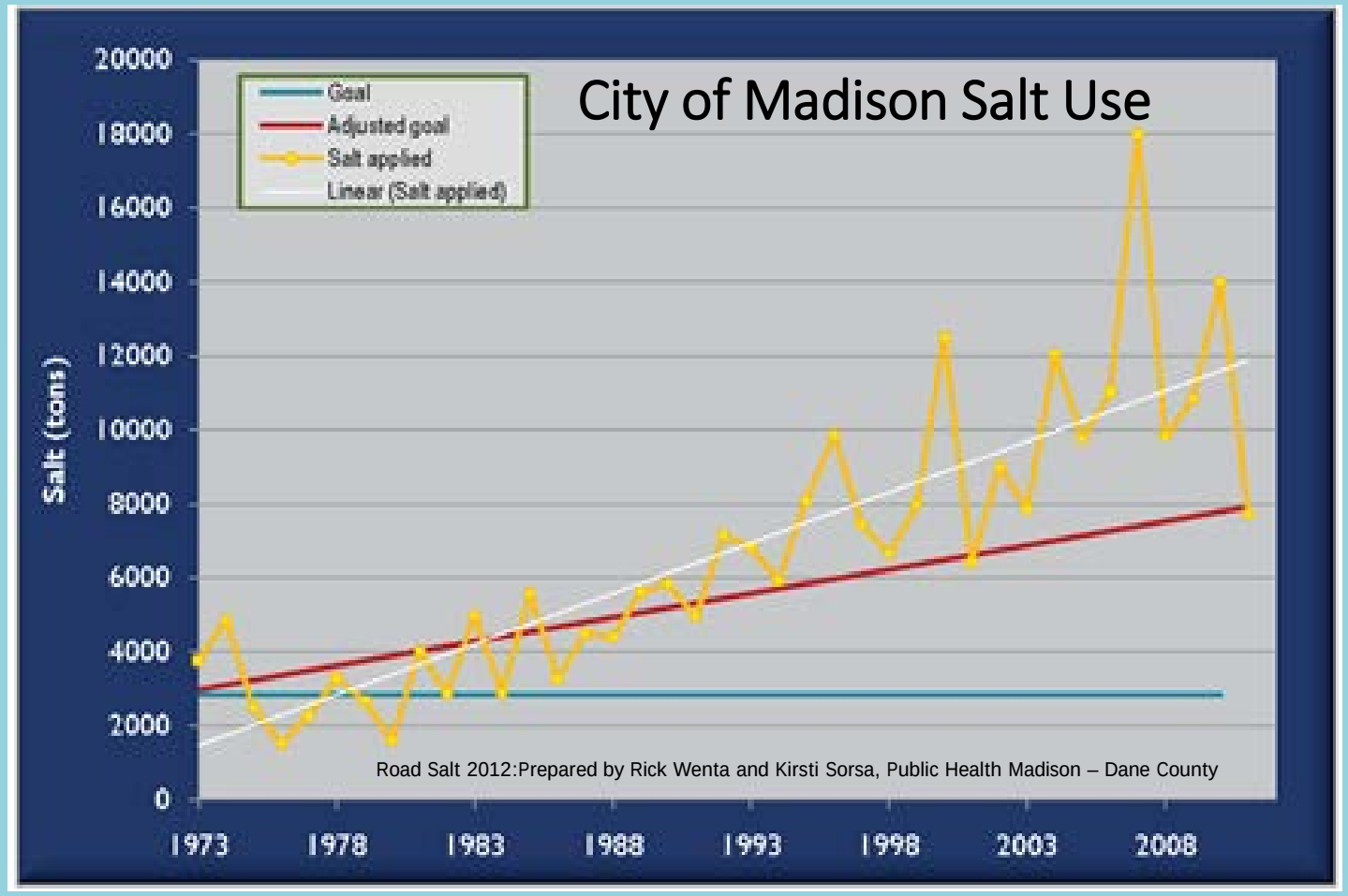
https://en.wikipedia.org/wiki/Salt_Belt



http://www.autoappearancecentergr.com/0_0_0_0_505_367_csupload_30575406.jpg?u=3797038344

- State Average Applications Rates as High as 22.9 Tons/Mile in Michigan
- As high as 298 Tons/Mile on I84 in New York
- Most states in the 5 to 10 Tons/Mile Range
- Parking Lots Can Have Much Higher Rates; Up to 40 Tons/Acre (one acre is about one lane mile)

Application Rates Are Rising Despite Efforts to Limit Use



- Despite Intense Efforts to Reduce Salt Use, Total Use Continues to Rise
- Public Expectations and Increasing Miles of Roadway Overwhelming Reduction Efforts
- Typical for Most of Salt Belt

Chloride Levels Rising in Streams Across the Salt Belt

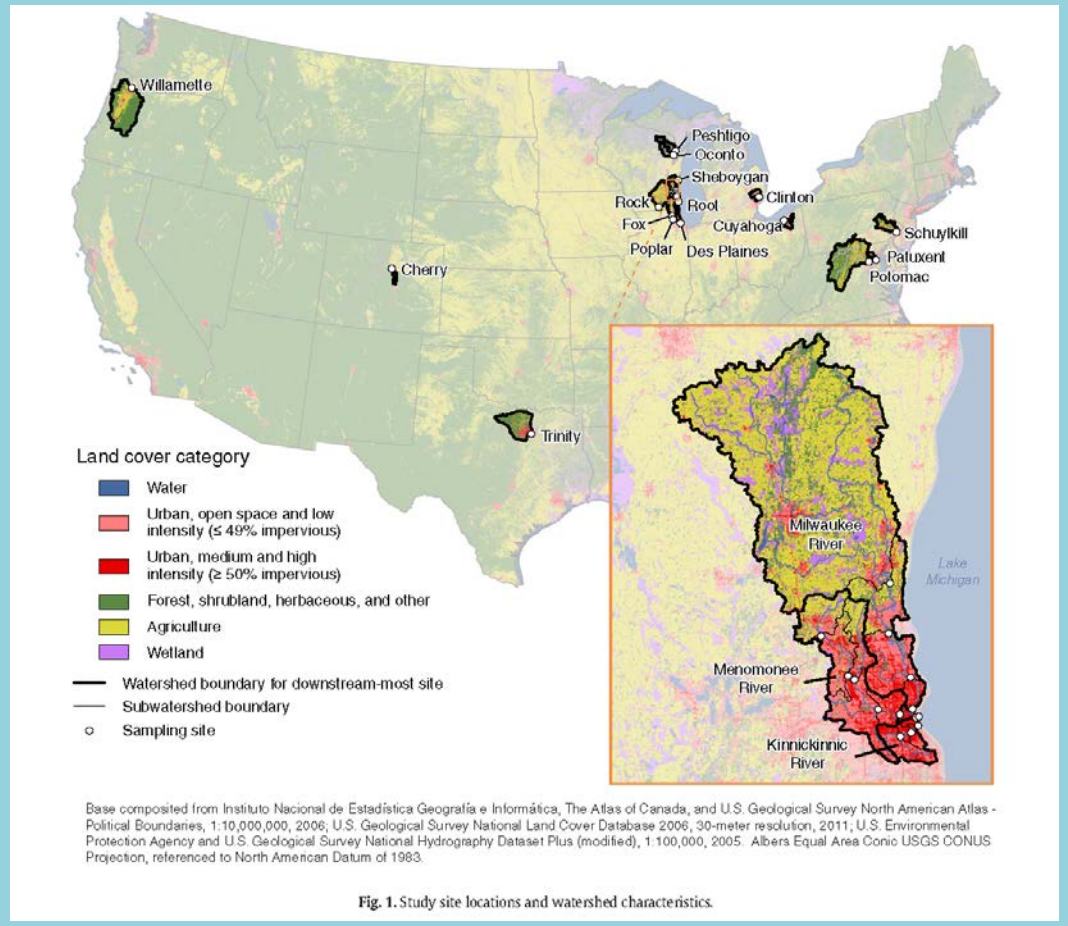
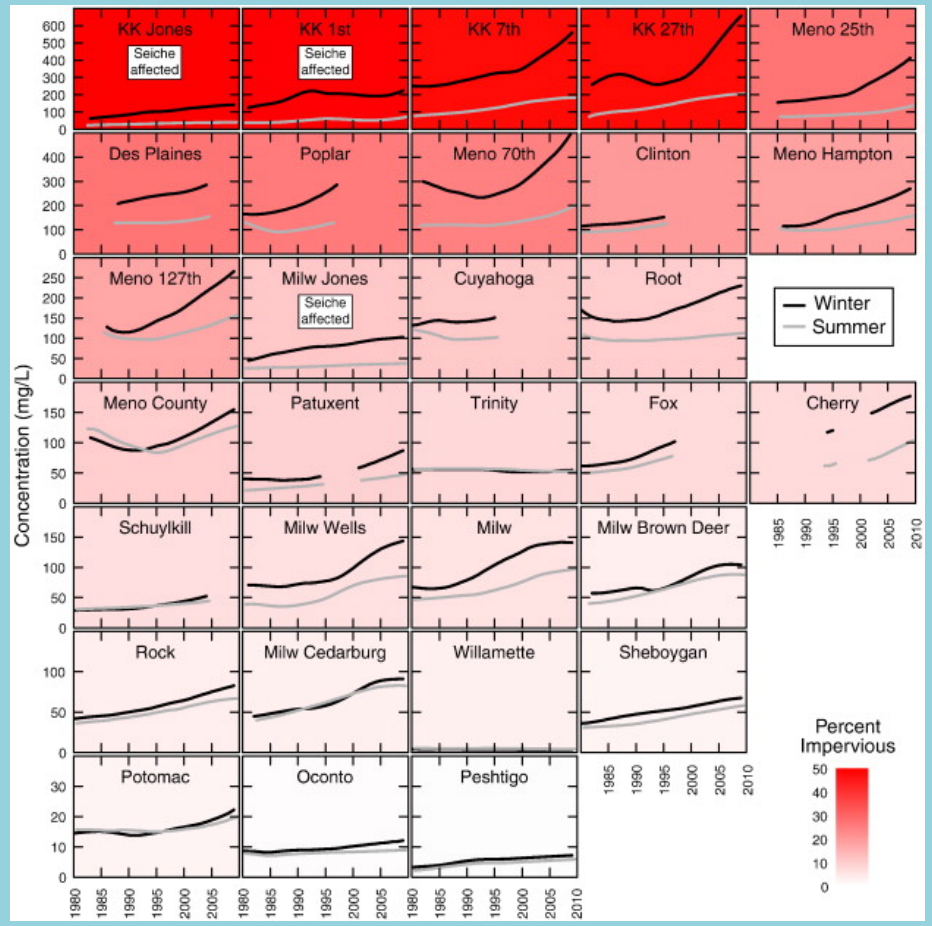


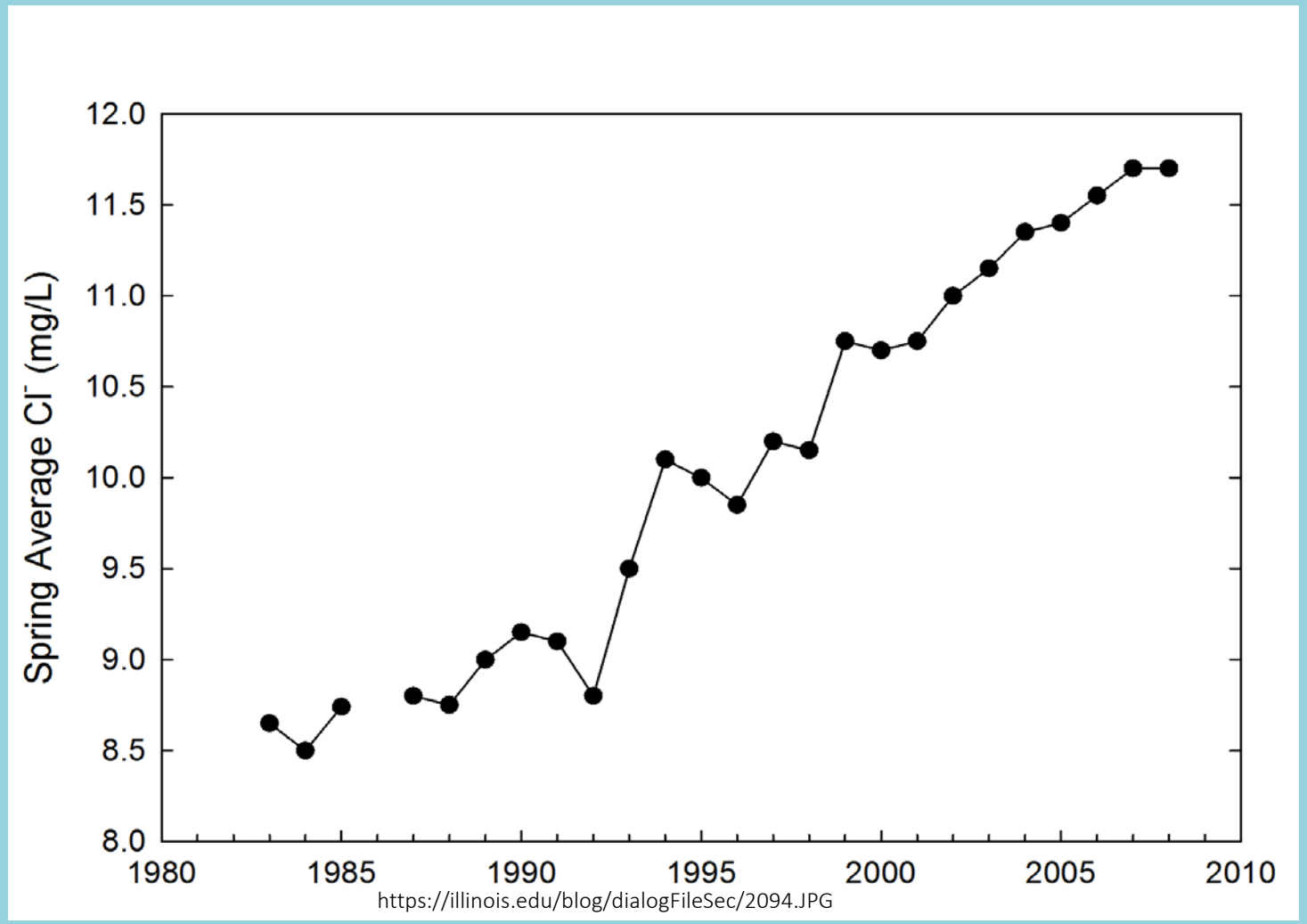
Fig. 1. Study site locations and watershed characteristics.



Winter (black line) and summer (gray line) flow-normalized chloride concentration trends for 30 sites in 19 streams across the United States. The background color represents watershed percent imperviousness.

http://dx.doi.org/10.1016/j.scitotenv.2014.12.012

Chloride Concentrations in Lake Michigan



https://illinois.edu/blog/dialogFileSec/2094.JPG

- Chloride Levels Are Still Low But Have Risen 38% in 25 years

Chloride Levels Rising In Wells In The Upper Midwest and Northeast

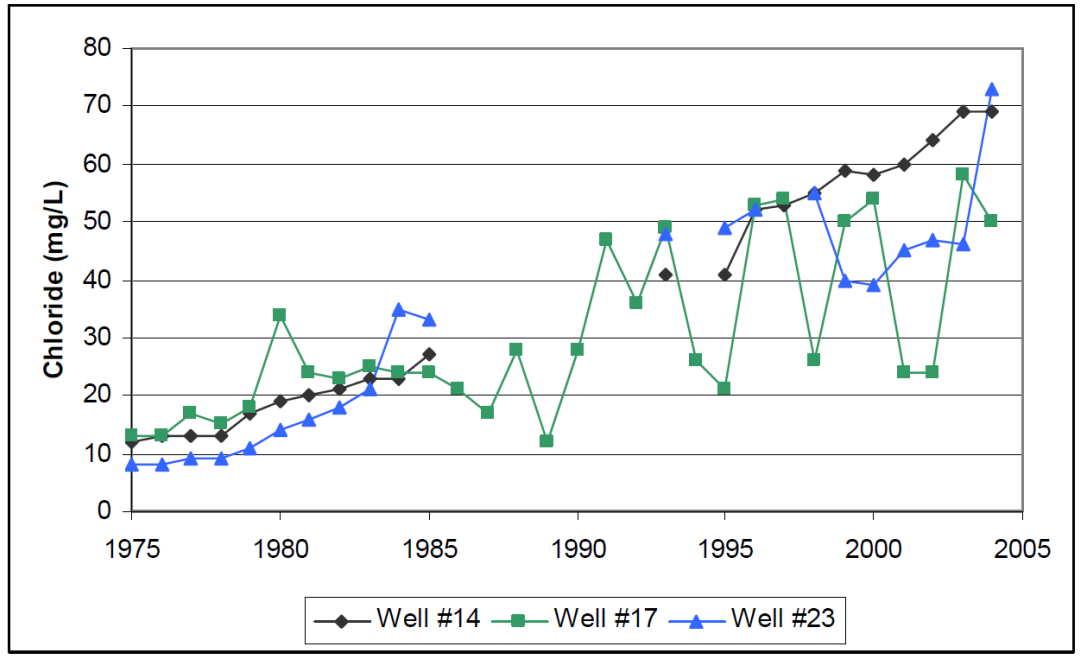
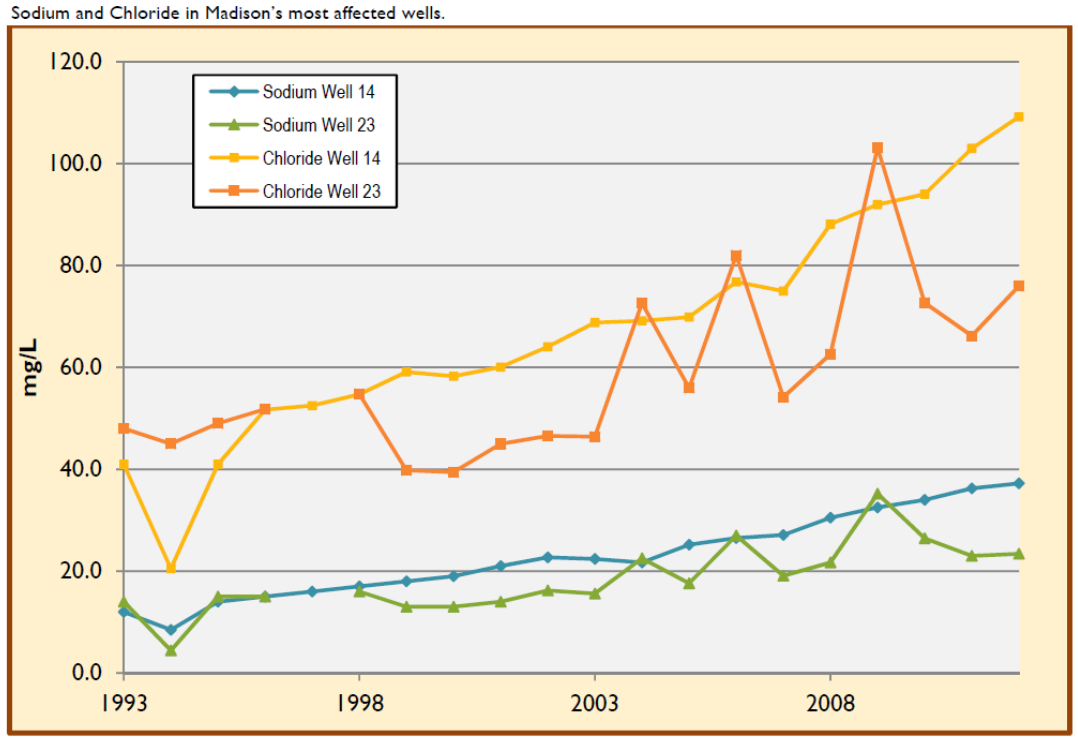


Figure 2: Chloride Levels in Three Madison Water Utility Drinking Wells

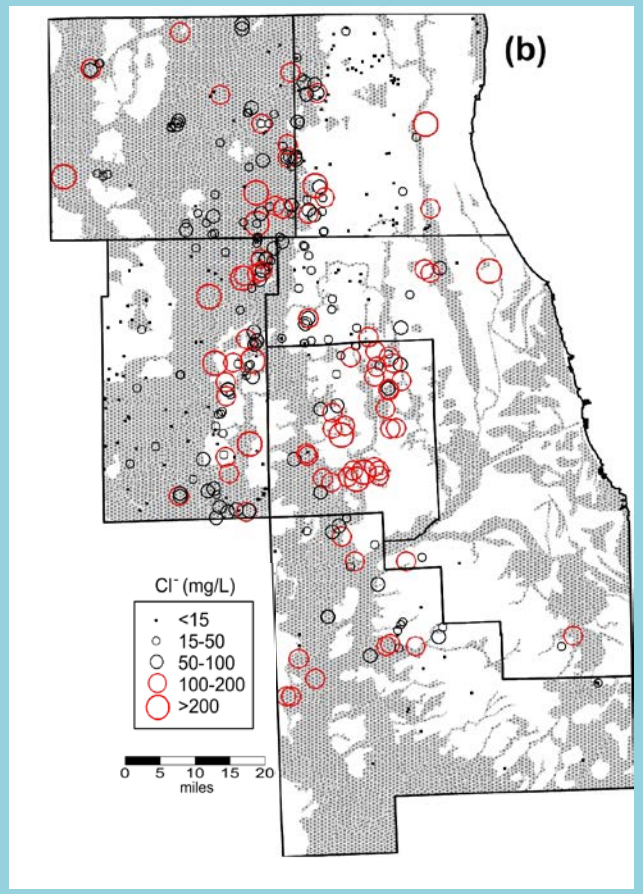
Chloride levels in three Madison Water Utility drinking water wells , 1975-2004. (Source: City of Madison 2004-2005 Road Salt Report, prepared by the Madison Public Health Department.)



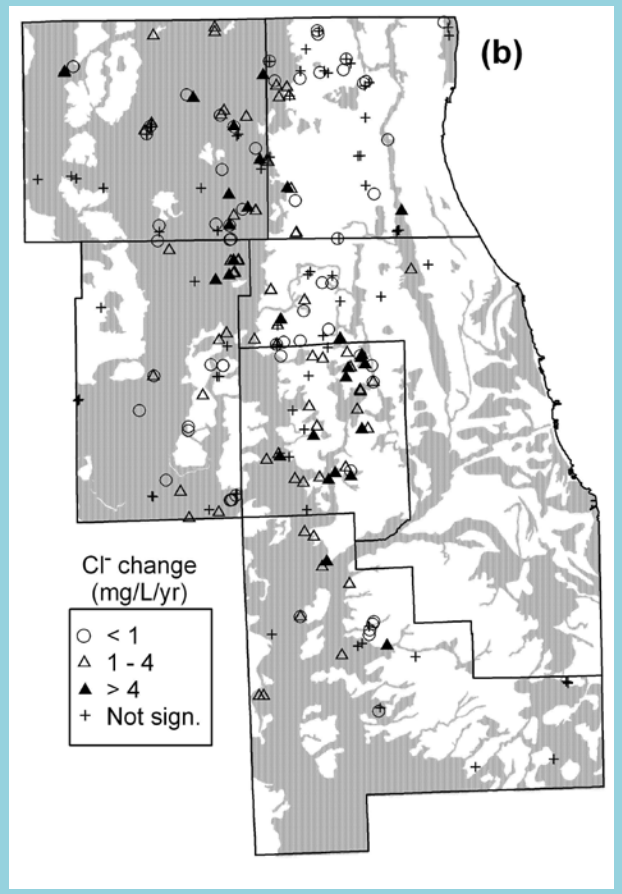
From City of Madison Salt Report 2012

- Chloride levels up 246% to 551% in three of Madison's Wells from 1975 to 2004
- Chlorides up ten fold in Well 14 from 1975 to 2012
- Sodium levels doubled in Well 14 from 1993 to 2012
- These are Sandstone wells 600 to 800 feet deep

Chloride Levels in Groundwater, Northeastern Illinois



Chloride levels in shallow aquifer



Rate of increase

Shaded Area: sand and gravel aquifer within 50 feet of surface

Problem most significant where sand and gravel aquifer within 50 feet of surface

Kelley 2011

Road Salt Contamination Still Happens in Low Salt States

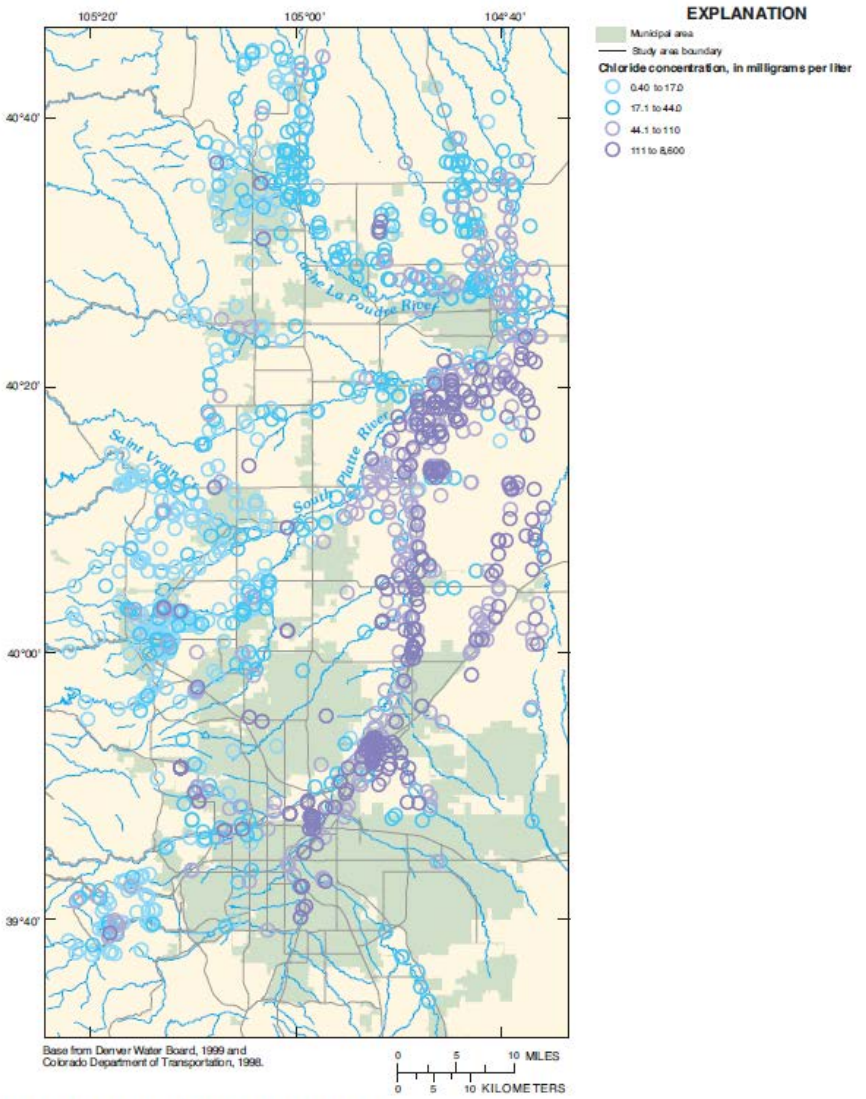
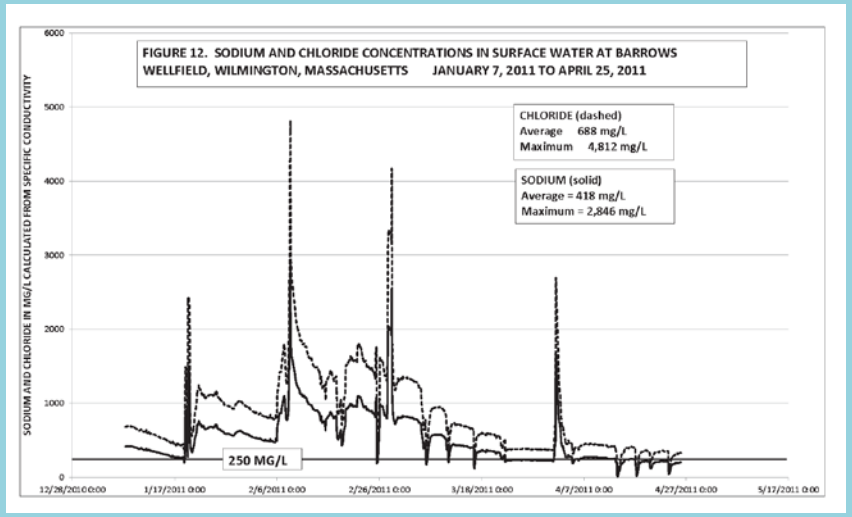


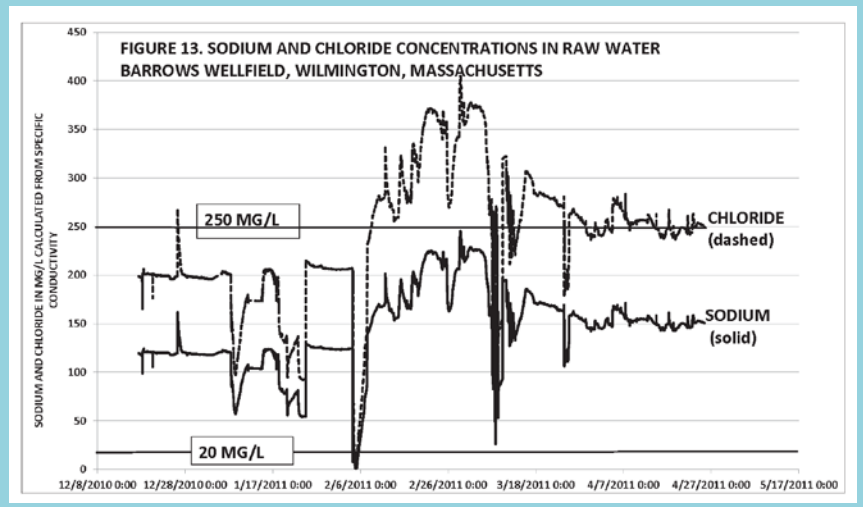
Figure 9. Spatial distribution of chloride concentrations.

http://pubs.usgs.gov/wri/wri02-4247/pdf/wri02-4247.pdf

- Chloride concentrations in Colorado Front Range 1954-1998
- Chloride levels elevated along transportation corridors (Hwy 85)

Salt Levels Can Spike Quickly in Some Wells

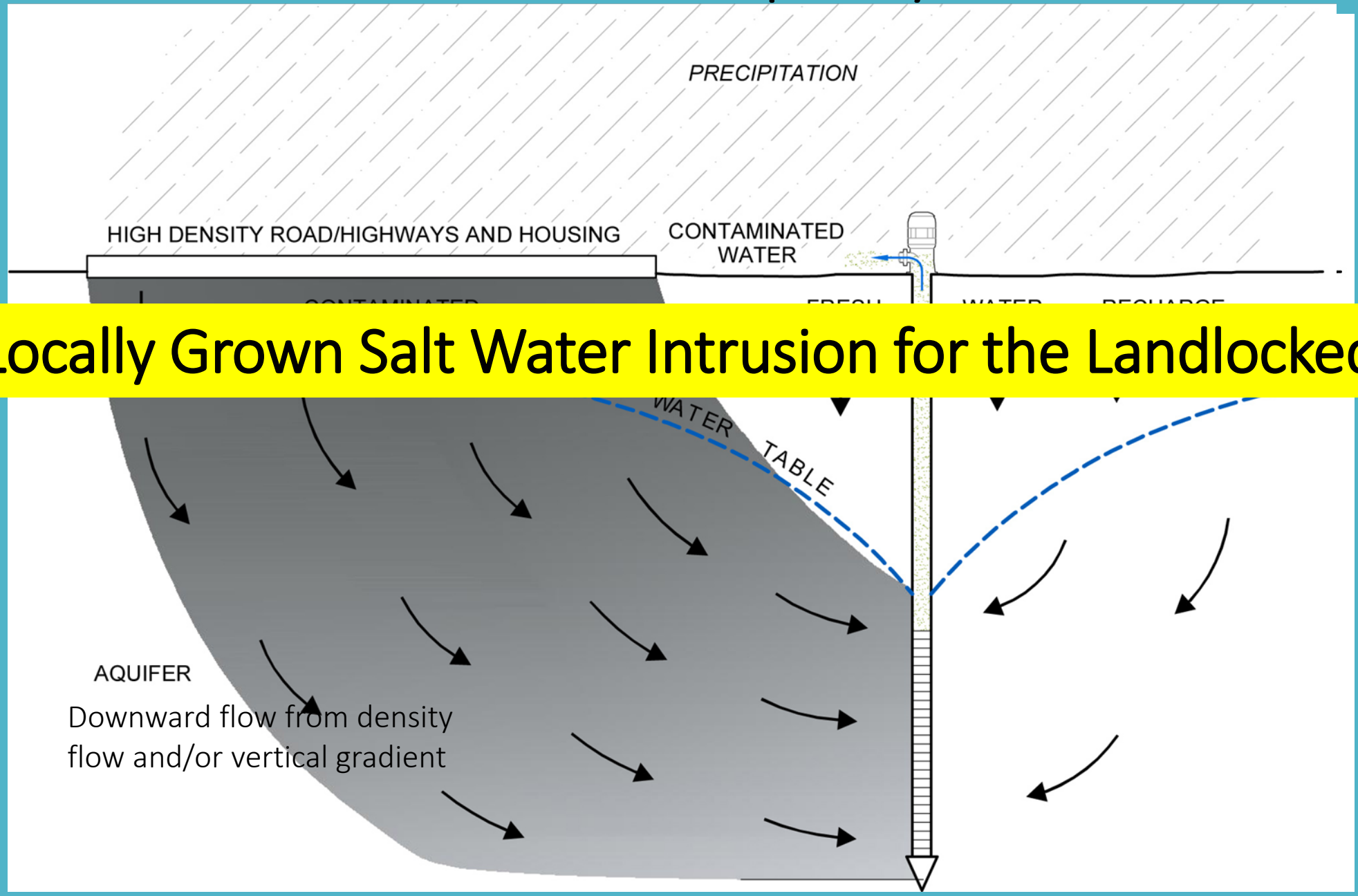




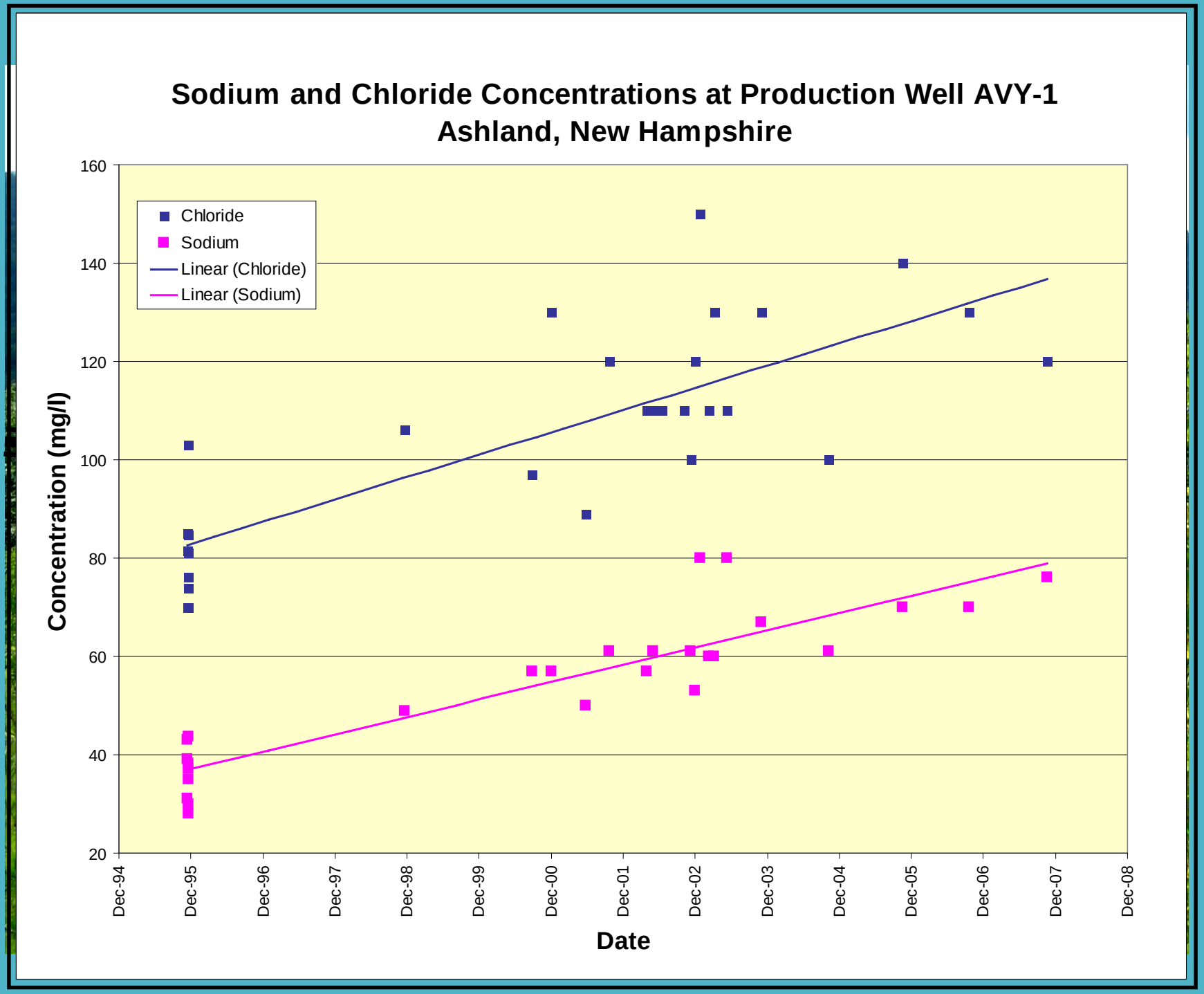
Heath and Morse, 2013

- Barrows Wellfield in Wilmington, MA
- 43 wells between 18 and 37 feet deep
- 800 feet from I-93 near a stream channel running from I-93 through well field.
- EPA installed conductivity meters and data loggers in Wilmington, MA wells and adjacent stream
- On 2/18/11 Chloride levels spiked to nearly 8,200 ppm in surface water near interstate and 4,800 ppm near wellfield
- 20 days later Chloride levels reached 400 ppm in wells
- Sodium reached nearly 250 ppm
- Annual sampling would miss these types of events
- Most wellfield show slower, more continuous increases

Multiple or Large Sources Can Generate Fully Penetrating Plumes



Locally Grown Salt Water Intrusion for the Landlocked


Sodium and Chloride Concentrations at Production Well AVY-1
Ashland, New Hampshire
Chloride
Sodium
Linear (Chloride)
Linear (Sodium)
Concentration (mg/l)
160
140
120
100
80
60
40
20
Dec-94
Dec-95
Dec-96
Dec-97
Dec-98
Dec-99
Dec-00
Dec-01
Dec-02
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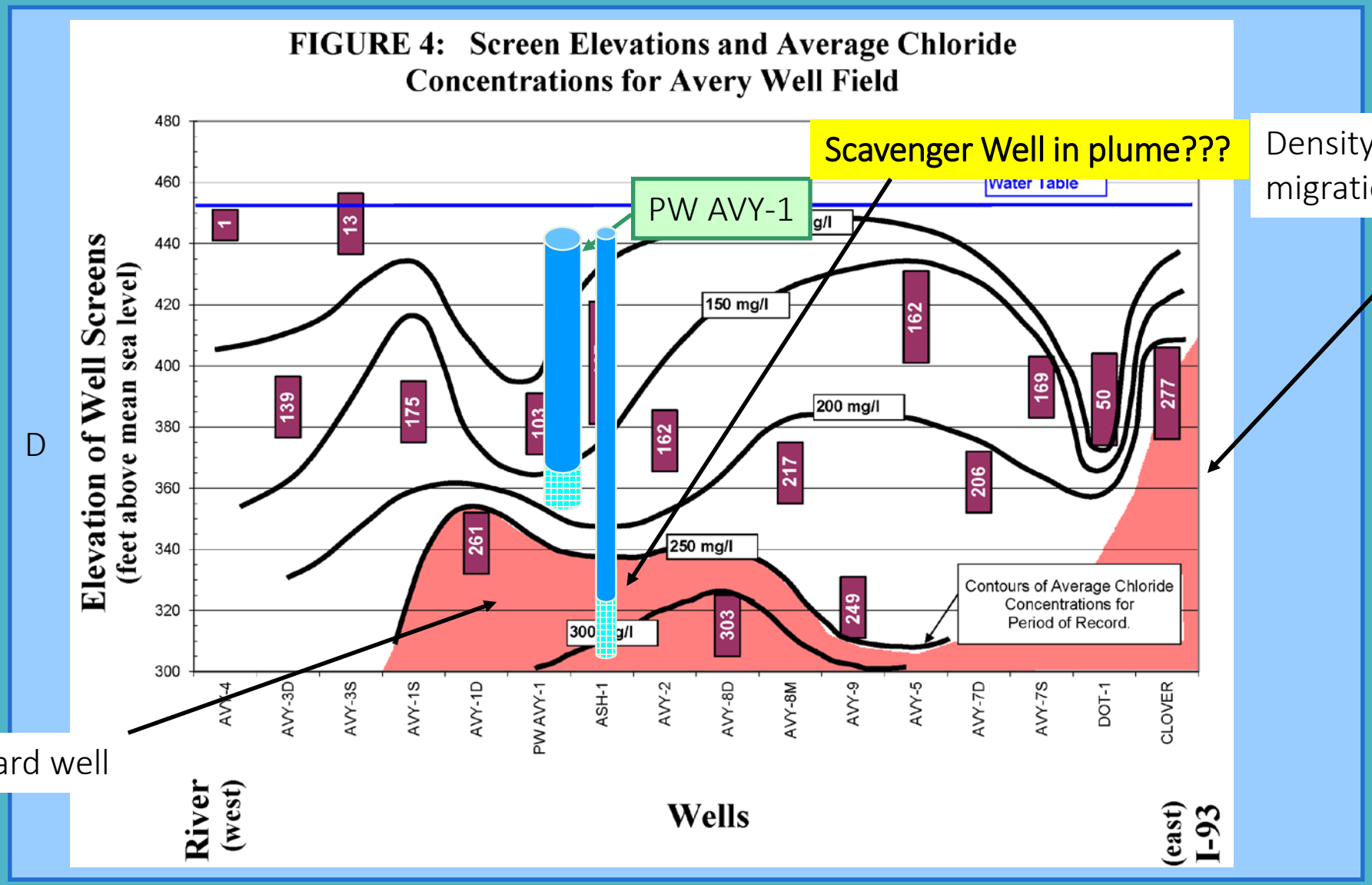
Dec-08
Date

Screen Elevations and Average Chloride Concentrations



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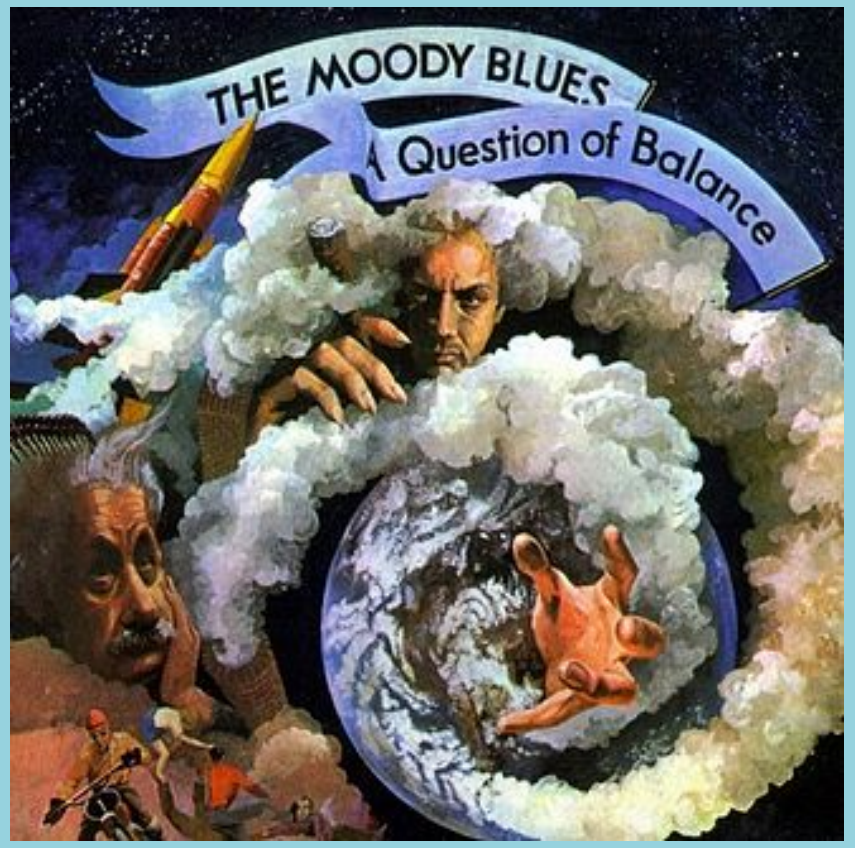
Upwelling toward well

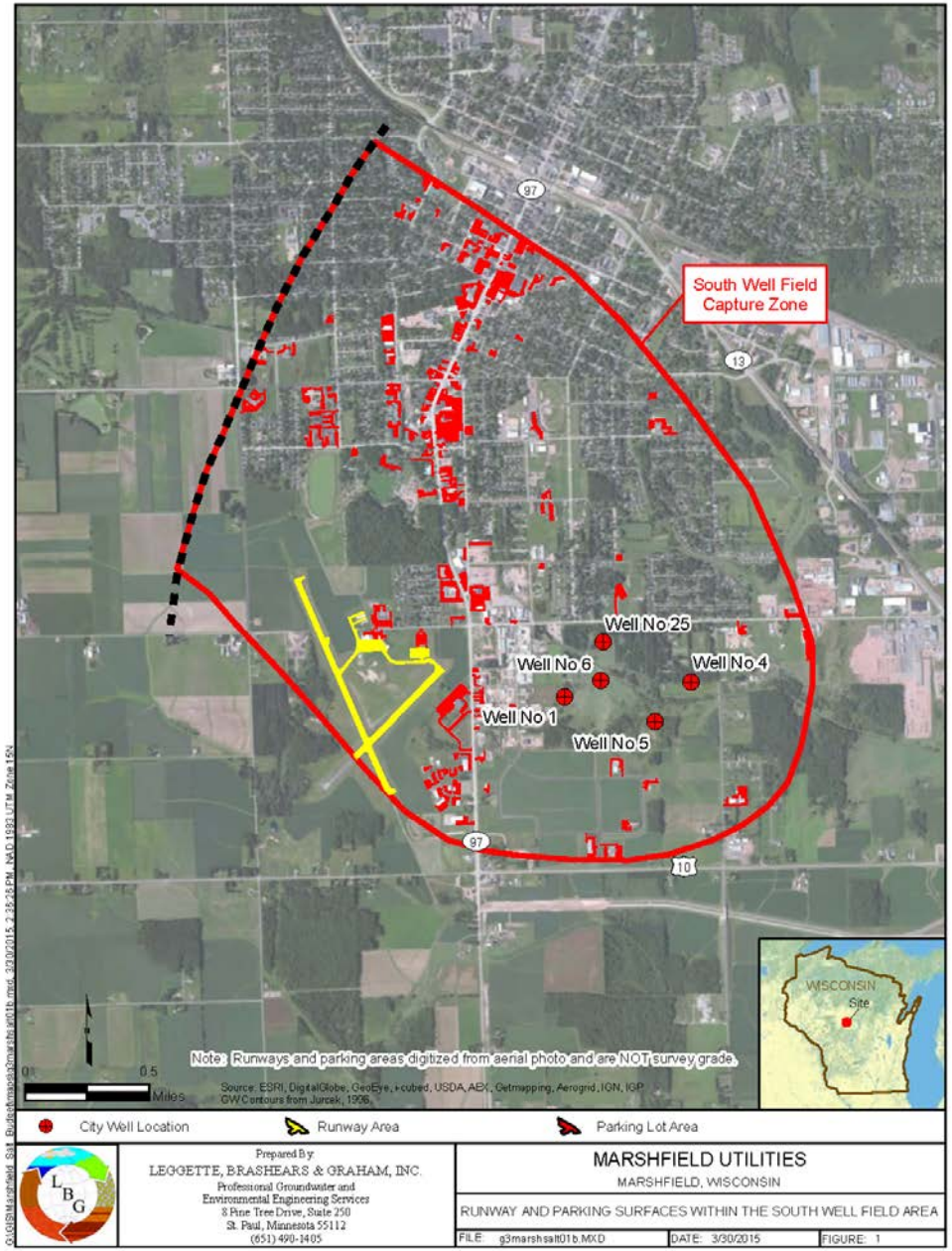
A Question of Balance:
Developing a Salt Budget for a Wellfield



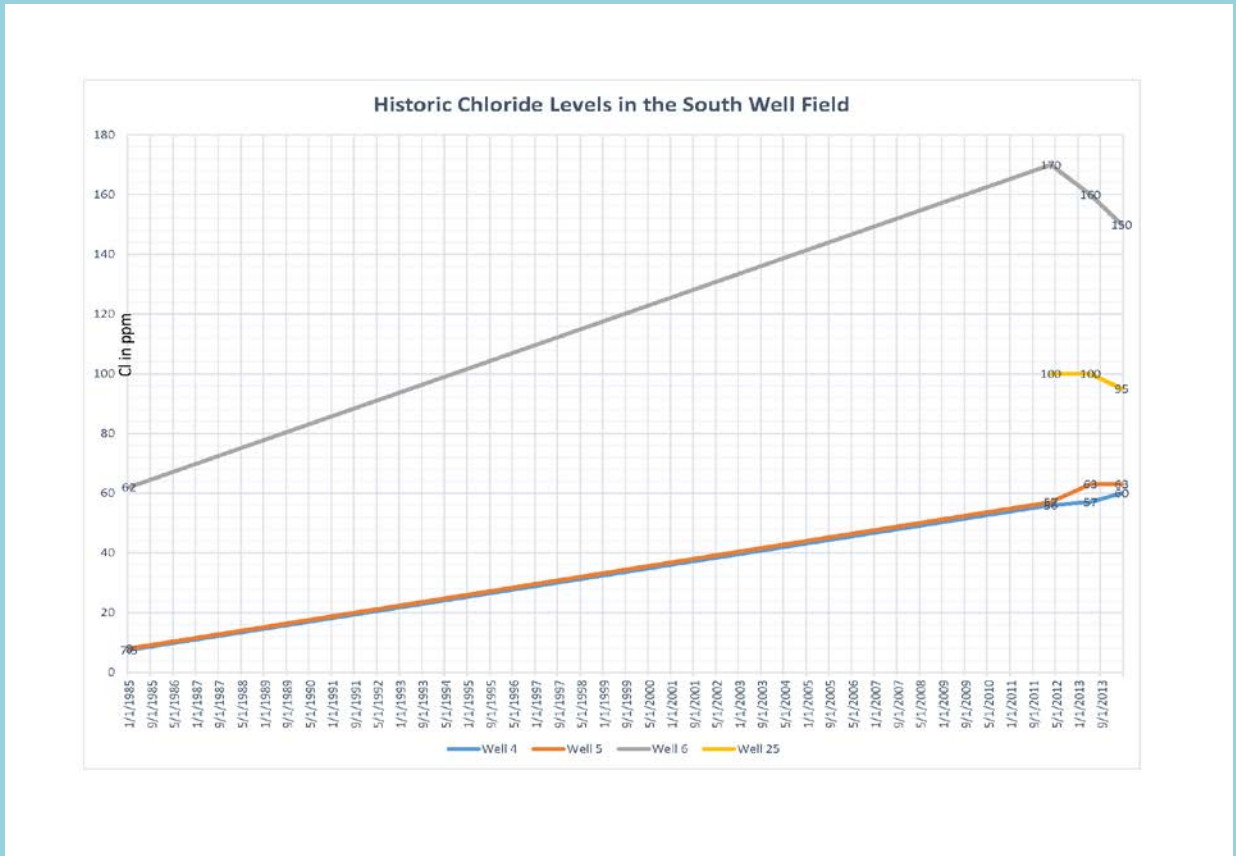
- How Much Salt Can the Groundwater System Handle?
- Is the Safe Level Enough to Keep the Roads Clear?
- Loading Limits Depend on Soil Type, Recharge Rate and Groundwater Flow Pattern
- Salt Balance Estimates Loading and Future Salt Levels
- Level of Effort Can Be Matched to the Need For Accuracy – Start Simple and Increase Level of Effort if Needed
- Target Values Can Be Fit to Sensitive Receptors

South Well Field
City of Marshfield, WI

- Oldest Well Field Still in Use By City
- Currently 5 Active Wells, 2 Abandoned
- 4 Wells Several Decades Old
- Located in an Area With a State Highway, an Airport, and Many Parking Lots
- Capture Zone Delineated By Two Previous Studies



South Well Field Chloride Trends



- Cl levels Doubled to Tripled From 1985 to 2011
- Apparent Declining Trend in 2 of 5 Wells From 2011 to 2013
- Data Sparse So Trends From 1985 to 2011 are Speculative
- Sodium Levels Exceed 30 ppm in Wellfield (58 ppm in 1998)

Salt Loading in Capture Zone

- Salt Load Calculated Using Lane Miles and Average Salt Loading Rate From WDOT and City Road Department
- Lower Application Rates Used for Runways
- Used Capture Zone From Both Wellhead Studies
- Estimated Loading Rate 926 to 1575 Tons/Yr

Table 1
Salt Loading Calculations

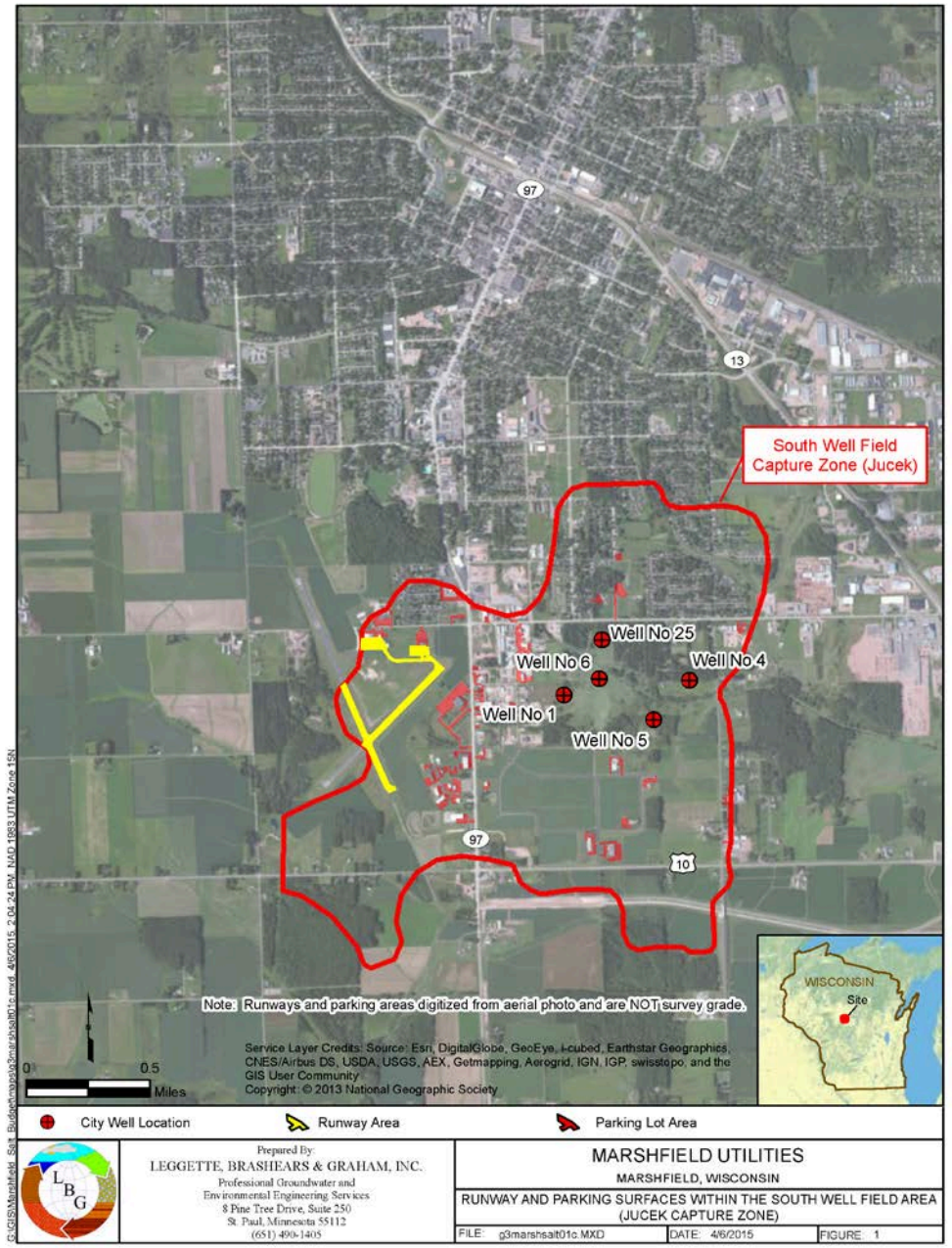
1994 Capture Zone

	Area	Application rate	Salt Load (tons/yr)
Roads	109.9 ln. mi.	12 tons/ln. mi.	1318.6
Parking lots and runways	28.4 acres	9 tons/ acre	256
Total			1574.6

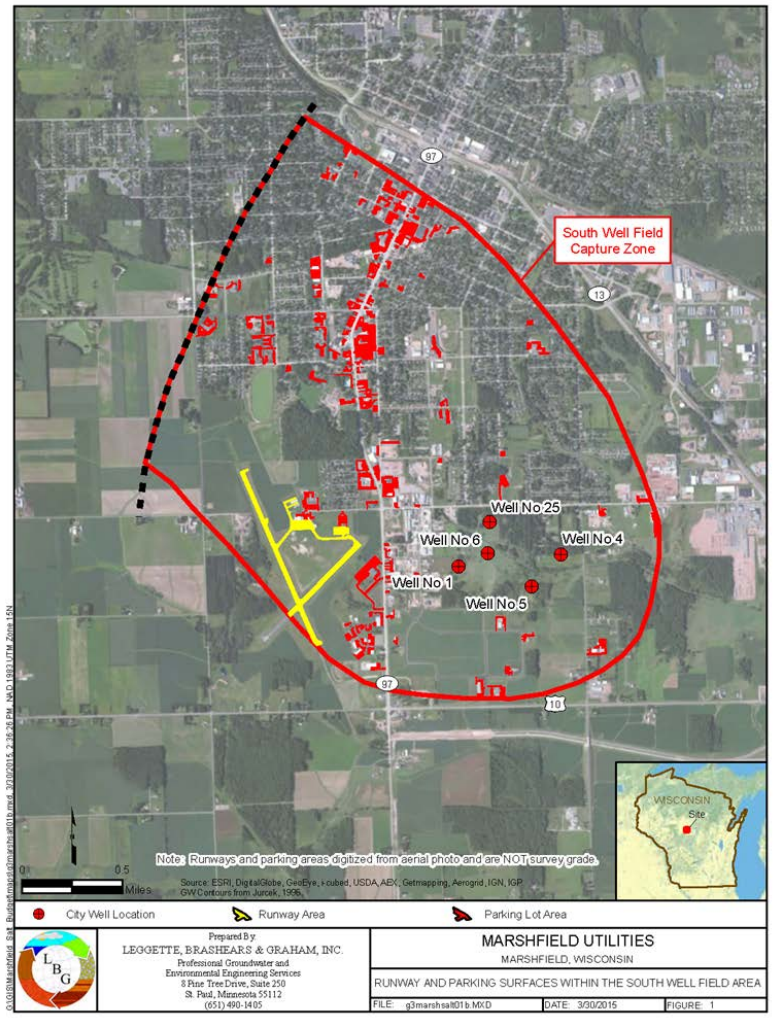
1996 Capture Zone

	Area	Application rate	Salt Load (tons/yr)
City Streets	37.1 ln. mi.	12 tons/ln. mi.	445.2
Parking lots and runways	53.4 acres	9 tons/acre	480.6
Total			925.8

ln. mi.= lane miles



Calculating Maximum Groundwater Chloride Concentrations



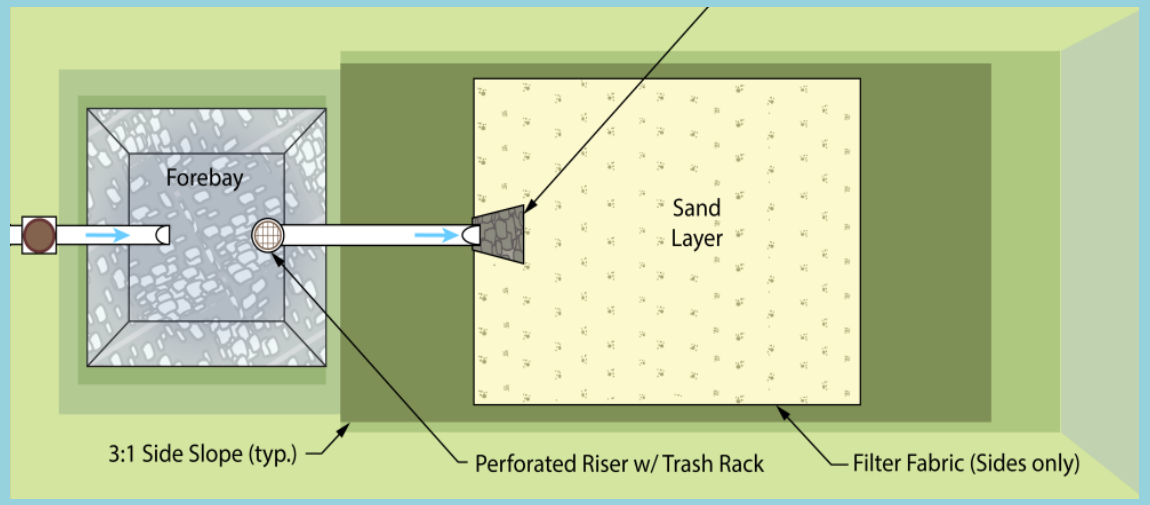
- Average Chloride Levels Could Exceed 2,500 ppm for 100% Recharge (Not Realistic)
- Infiltration of About 25%, the Average Chloride Would Be 360 ppm (Not Implausible Given Concentrations in Other Wells)
- 10% Infiltration Estimate Predicts Average Chloride Concentration of Recharge of About 130 ppm (Similar to Recent Values in Wells)
- Low Infiltration Rates Consistent With Heavy Clay Soils
- Capture Zone for the Well Field Indicates That the Bulk of the Water in the Aquifer is Probably Less Than 5 or 10 Years Old
- Chloride Levels Have Reached Equilibrium for Current Application Rates
- No Large Increases Likely If Loading Rate Does Not Rise
- Any Reductions in Loading Will Result In Improvements Within a Few Years
- City is Currently Reducing Salt Loading and Rerouting Parking Lot Runoff to Continue Decreasing Trends
- Well Fields With More Critical Problems May Require Monitoring Wells, Transport Models, Extraction Wells, and More Aggressive Follow Up Work
- Budget Approach is Inexpensive Screening Tool

Living With Road Salt:
Can We have Safe Roads and Safe Wells?

- Obviously We Need Both!
- We are Not Going to Stop Salting Our Roads
- Salt Reduction Efforts May only Slow the Rate of Growth
- Sitting on Our Hands or Throwing in the Towel May Cost Us Our Shallow Aquifers
- Hope is Not a Strategy
- With Proper Management and Proactive Steps We can Have Both
- What Will Work?

http://caveviews.blogs.com/.a/6a00d8341bffd953ef0133ece0e79e970b-800wi

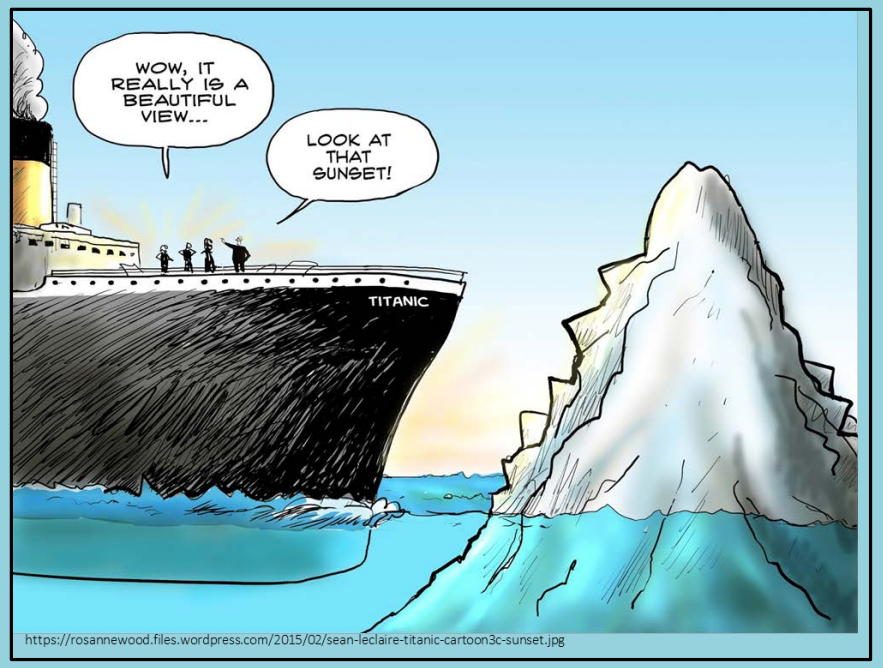
Rethinking Storm Water Infiltration



http://www.njstormwater.org/bmp_manual/NJ_SWBMP_9.5.pdf

- Putting Storm Water in the Ground is Good
- Putting Road Salt in the Ground is Bad
- We need to Rethink How We Recharge Storm Water
- One Suggestion: Sequester Run Off in Detention Basins
- Low Conductivity Water Goes to Infiltration Basin
- High Conductivity (Salty) Water Gets Slowly Released to Surface Water

Know What is Headed Your Way



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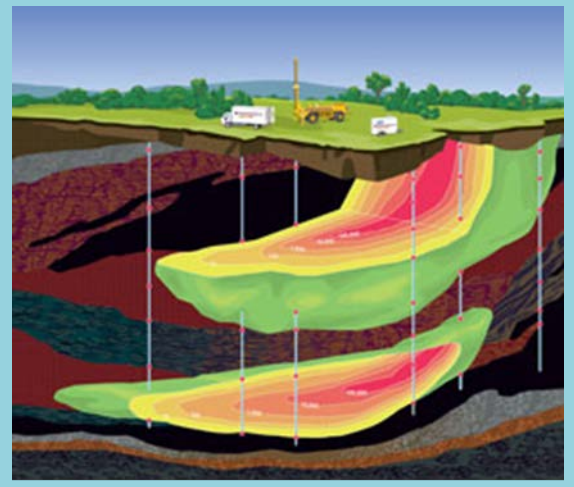
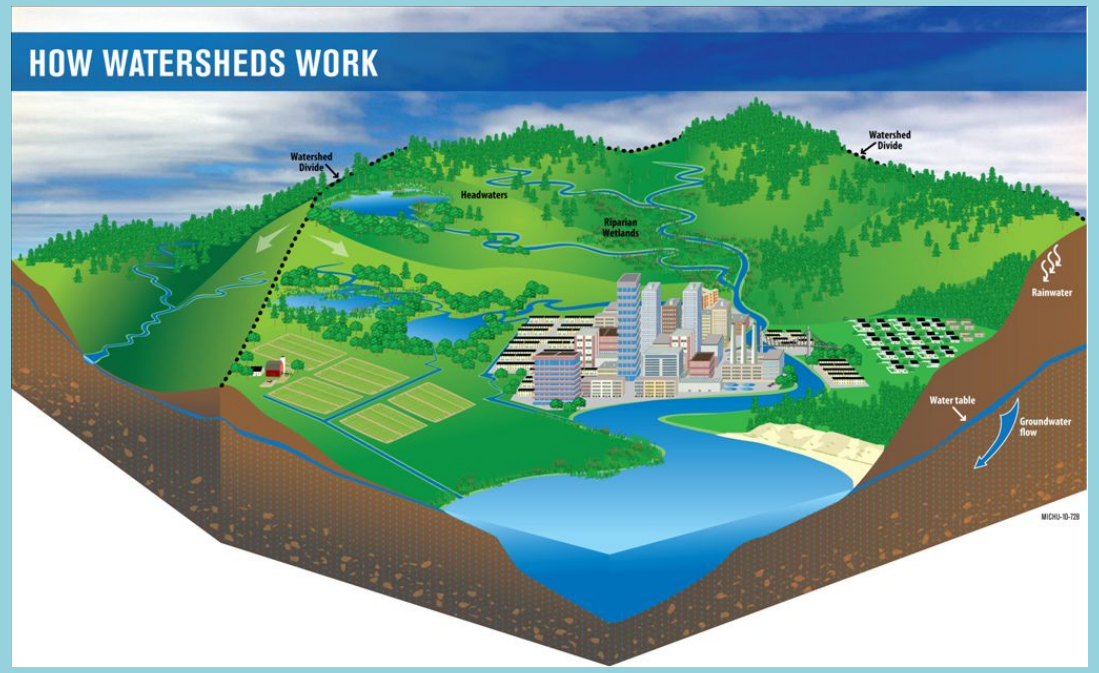

http://www.stone-env.com/images/prostratigraphy.jpg

- Inventory salt sources and sinks in capture zone
- Water sampling and monitoring
- Calculate loading to groundwater
- Salt budget to look at potential concentrations
- Inventory Salt Sources and Sinks in Capture Zone
  - Geoprobe Grab Water Samples
  - Vertical Water Profiling
  - Monitoring Wells for Long Term Monitoring
  - Soil Samples in Storm Water Ponds and Drainage Swales
- Dig Up Contaminated Soils
- Pump Out “Hot Plumes”
- Create Freshwater Mounds With Recharge Basins
- Use Scavenger Wells as Appropriate

Consider Road Salt Contamination Potential When Siting New Wells



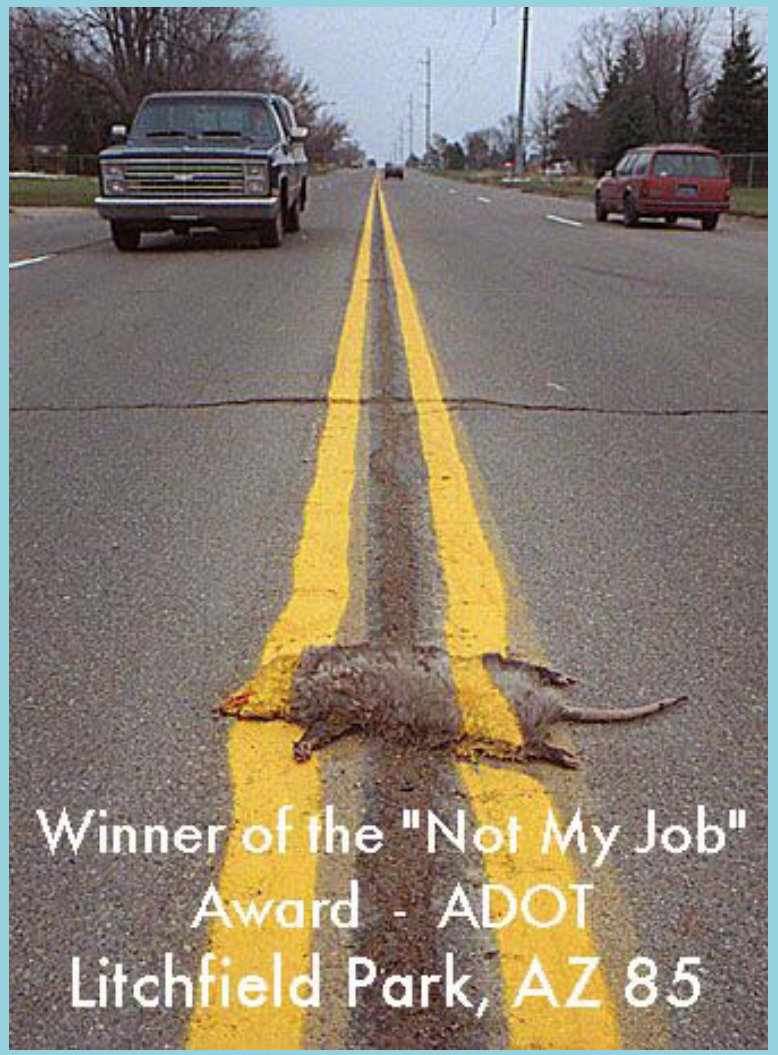
http://www.northeastmichiganwatersheds.org/media/pages/10728howawatershedworks_1.jpg

- Road Salt is Turning Out to be One of the Biggest Threats to Wells
- In Many Ways This is One of the Most Predictable Contamination Problems
- Not a part of Most Well Siting Investigations
- We Need to Start Screening New Well Sites for Salt Loading in Capture Zone
- Look For Ways to Protect Capture Zone and Minimize Salt Loading or Improve Salt Management

Summary

- Road salt has been recognized as a problem since the late 60's to early 70's
- Decades of study and reduction programs have not worked
- Road salt use is rising in spite of efforts to manage its use and find alternative deicers
- The historic use is impacting the environment and reaching harmful levels
- Sodium and chloride levels in streams are approaching toxic levels for plants and fish
- Sodium and chloride levels are reaching limits for drinking water in many aquifers
- Road salt is the major source of Chloride to the environment in the "salt belt" states
- Groundwater systems have long storage times so we will be dealing with the impacts of past actions for decades
- The cost of road salt use includes the cost of salt and application but also infrastructure and environmental damage
- We don't know how much salt most places can tolerate. Salt budgets are needed
- The full cost has not been calculated, but it is many times just the cost of direct use
- The true cost of road salt may make other alternatives much more attractive

End of the Road For Me



Note: not caused by road salt