DILUTION IS NOT A SALT SOLUTION

Case Studies: Assessment, Containment and Recovery of Two Produced Water Spills into Domestic Use Aquifers in Central Alberta

AUTHORS

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  Combined assessment and remediation experience of more than 30 years and 300 sites.

  More than 25 operating groundwater interception and recovery systems.

THIS PRESENTATION

- This presentation explores the assessment and remediation of two sites where produced water spills affected domestic use aquifers.
  - overview of salinity issues and regulatory requirement
  - assessment and remediation methods and options

PRODUCED WATER - THEN AND NOW

- There have been literally billions of cubic metres of saline water produced from oil and gas formations in Alberta since the 1940s.
- This produced water is often highly saline and may contain up to 150,000 mg/L chloride.
- Historical practices did not always manage this water in a responsible manner.
- A lot of old surface and subsurface facilities still used to transport, store and dispose of produced water.
- Corrosion, metal fatigue and physical damage continue to result in large one time or cumulative releases of produced water.

REGULATORY GUIDELINES & CRITERIA

- Alberta Tier 1 Soil and Groundwater Remediation Guidelines (2009)
- AENV Salt Contamination Assessment & Remediation Guidelines (2001)
- Alberta Agriculture: Soil Quality and Salt Tolerance (soil ratings)
- CCME: Soil and Water Quality Criteria

REGULATORY GUIDELINES & CRITERIA

- Regulations under the Environmental Protection and Enhancement Act and the Water Act require aquifer protection.

- Current remediation criteria for chloride vary dependent on land use and receptors:
  - Irrigation: 100 mg/L
  - Aquatic: 230 mg/L
  - Drinking Water: 250 mg/L

- Other surface water chloride criteria:
  - 35 mg/L no observed effects - Fathead Minnow [EC]
  - 100 mg/L irrigation of sensitive crops [AENV]
  - 140 mg/L no observed effects – Daphnia [EC]
  - 230 mg/L four day average [USEPA]
  - 500 mg/L runoff water release criteria [ERCB / AENV]
  - 860 mg/L one hour every three years [USEPA]

SALTS RELATIVE TO BACKGROUND

- Significant salt concentrations in soil and water can be naturally occurring
  - sodic soils in the Southern Prairies
  - groundwater discharge areas
  - evaporative concentration
  - bedrock of marine origin

- Naturally saline soils may have limited or no potential to mitigate added salts

- Due to sensitive receptors, remediation to background conditions may often be necessary to restore fully equivalent land use

ADVERSE EFFECTS - VEGETATION

- Vegetation stress / death, poor crop yield with a decrease in planting options for trees and other horticultural species

Dead and Stressed Aspen

Leaf Stress – Brown Margins

ADVERSE EFFECTS - IRRIGATION / AQUATIC ECOSYSTEMS

- Decline in water quality for human drinking or irrigation (livestock watering impairment is relatively rare)

- Aquatic ecosystem stress

IMPACTS TO AQUIFERS

- Saline water is dense, and when released into a fresh water aquifer, it will quickly sink to the base.
- Long lasting salinity stratification in the aquifer will occur where the release is large and there is sufficient difference in density.
- Once at the base of the aquifer, dense saline plumes will flow by gravity down slope on the top of a lower permeability layer.
- This movement can be in a different direction than groundwater flow.
- These characteristics must be considered when designing assessment and remediation plans.

CASE STUDIES

SITE 1: SITE DESCRIPTION

- Agricultural land (hay crop)
- Surficial sand aquifer 4 – 5 m thick underlain by silty clay
- Low permeability clay layer sloped to east
- Water table depth ~1.5 m
- Hydraulic conductivity of ~1x10^{-4} cm/s
- Large wetland receptor to northeast

SITE 1: SPILL

- Produced water spill from flow line due to gasket/joint failure
- Reported spill volume of 120 m^3 with no recovery
- Flow line likely leaked for many months prior to fluid coming to surface
- Mounding of water table occurred, resulting in rapid migration of plume

SITE 1: ASSESSMENT TOOLS – METHODS AND LIMITATIONS

- Geophysical surveys
  - EM 31 and EM 38 instrument
  - magnetometer
  - multiple surveys completed to track rapidly migrating plume in groundwater
  - accurately mapped thick saline plume, less accurate where plume thins out
  - interference from metal objects and geologic changes

- Soil sampling
  - advancement of boreholes using truck/track mounted drill rig
  - field and laboratory analysis
  - saturated flowing sands difficult to sample, risk of cross contamination
  - multiple sampling events to delineate affected area

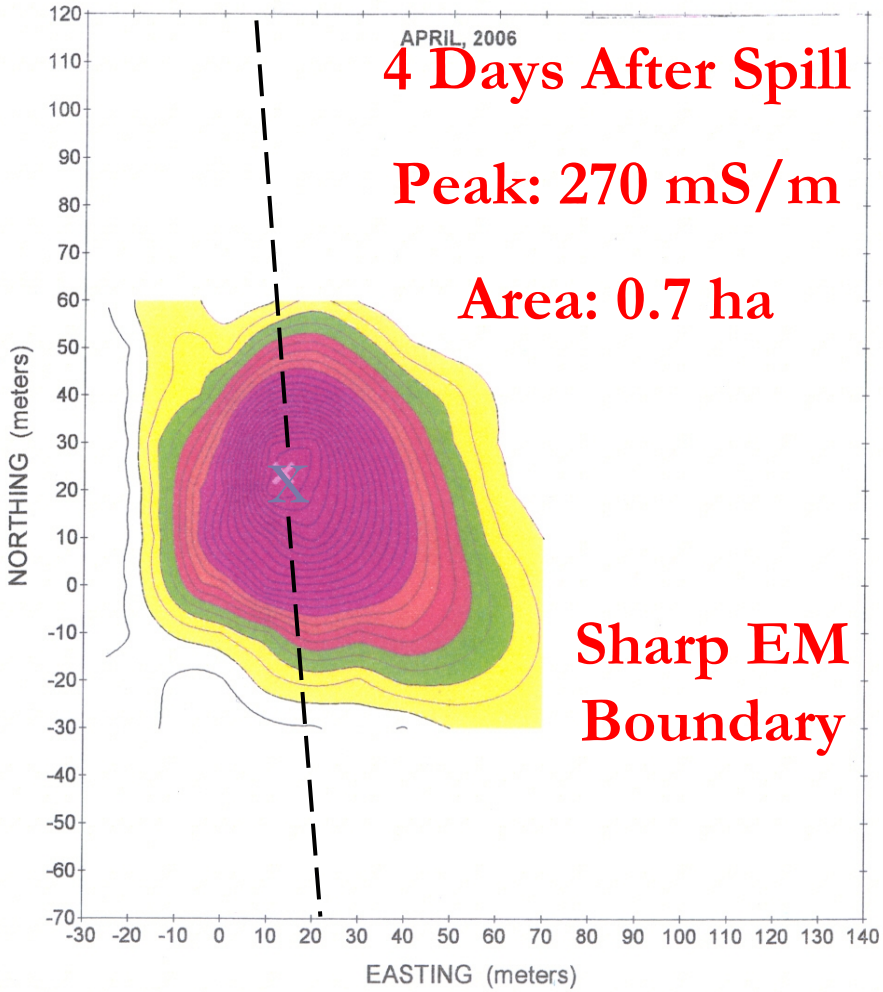
SITE 1: ASSESSMENT TOOLS – METHODS AND LIMITATIONS (CONTINUED)

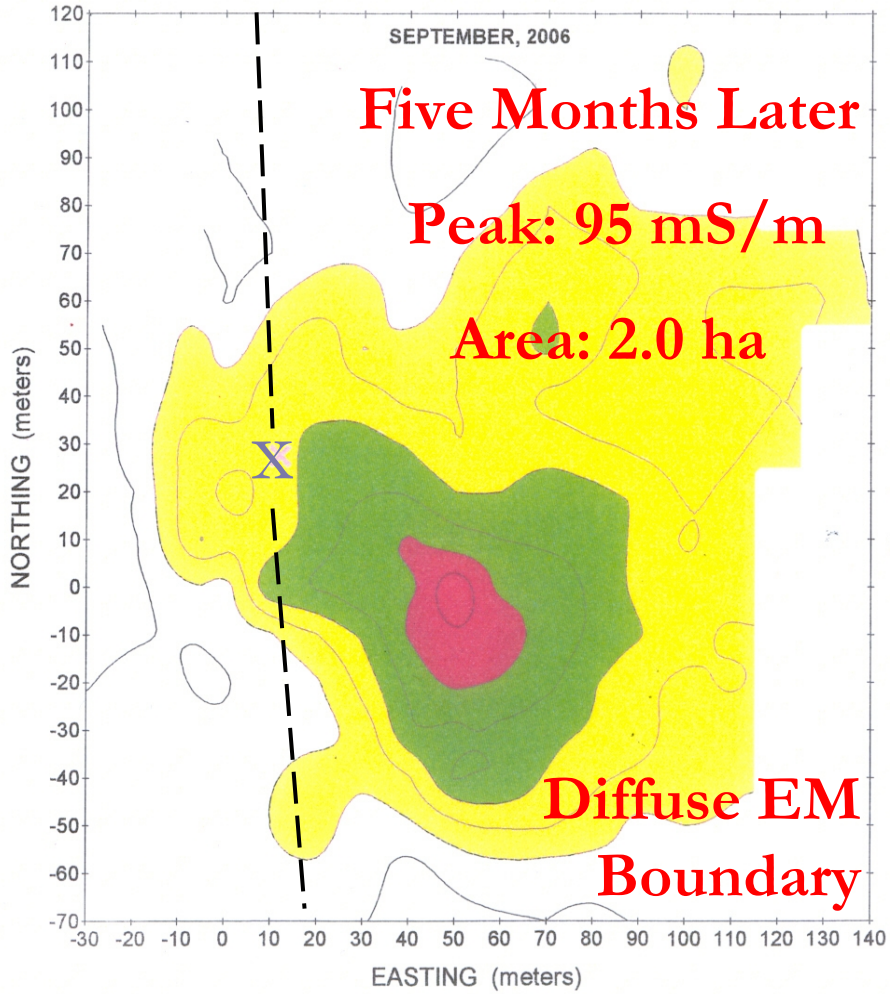
- Groundwater monitoring:
  - monitor wells installed as sand points screened across the base of the aquifer
  - slow flow purging technique used to sample dense saline plume at bottom of aquifer
  - analysis for indicator parameters to reduce analytical costs
  - multiple sampling events required to assess rapidly migrating plume and evaluate effectiveness of remediation

SITE 1: SELECTING CONTAINMENT AND REMEDIATION OPTION

- Excavation of Soil
  - volume of contaminated soil >40,000 m^3
  - not practical to excavate saturated sand
  - perimeter saline groundwater plume would remain
  - replacement soil difficult to source
- Groundwater Recovery
  - series of bored wells to intercept plume selected as preferred option
  - separate forcemain and power required for each well
  - initial recovery of ~100 m^3/day/well

SITE 1: GEOPHYSICAL SURVEY FINDINGS

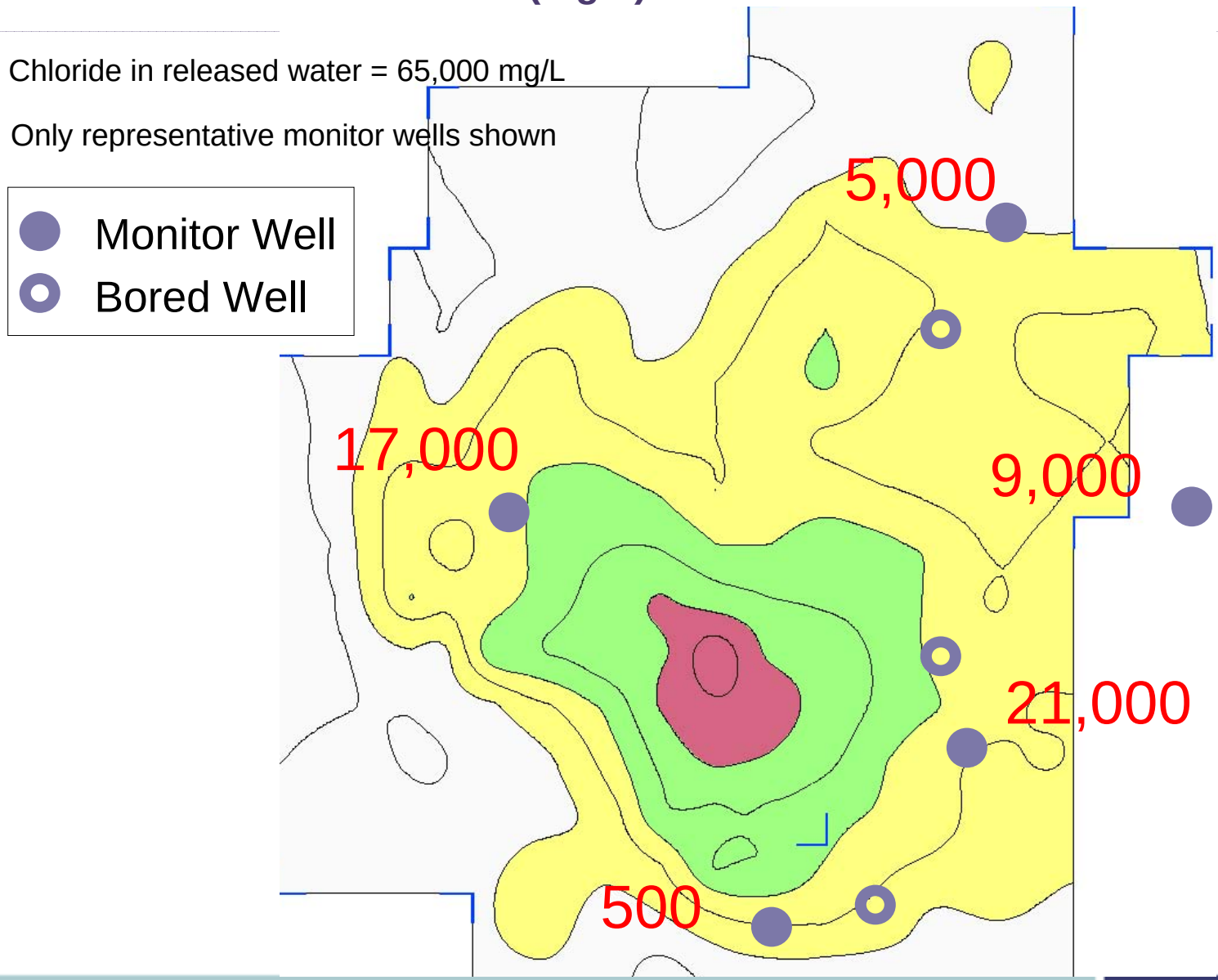




SITE 1: INITIAL CHLORIDE CONCENTRATIONS (mg/L)

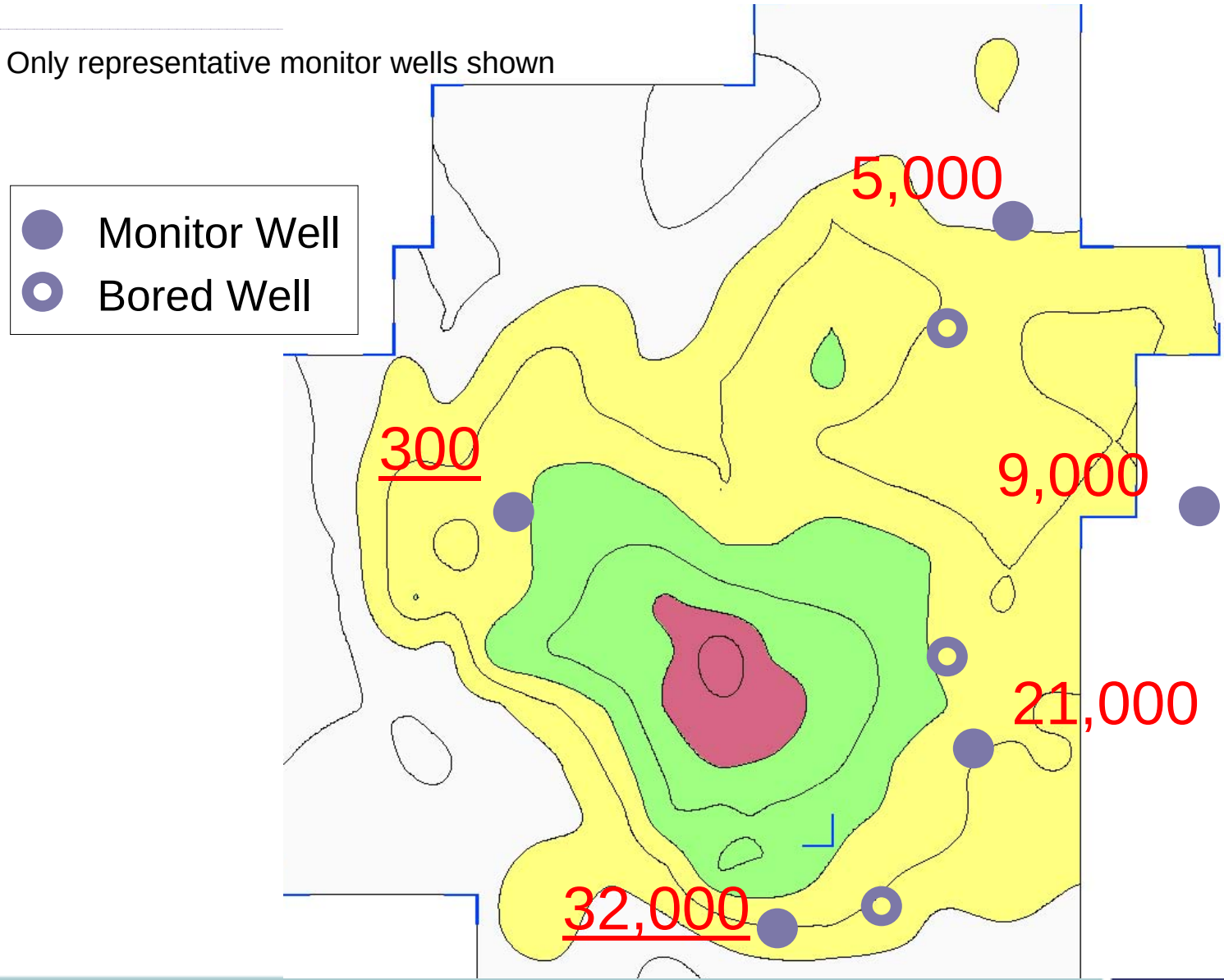
Chloride in released water = 65,000 mg/L

Only representative monitor wells shown



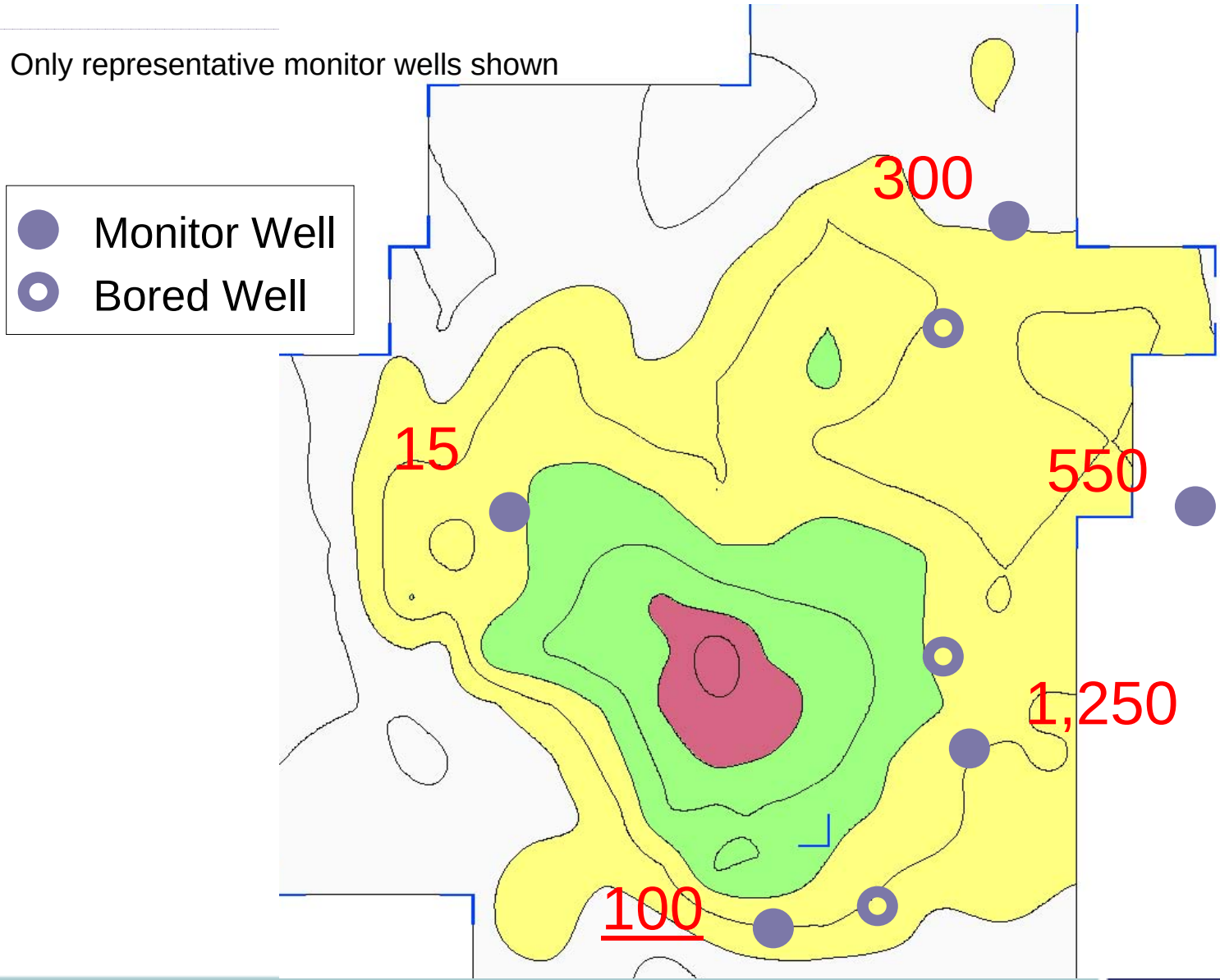
SITE 1: GROUNDWATER CHLORIDE PRIOR TO PUMPING

Only representative monitor wells shown



SITE 1: GROUNDWATER CHLORIDE THREE YEARS LATER

Only representative monitor wells shown

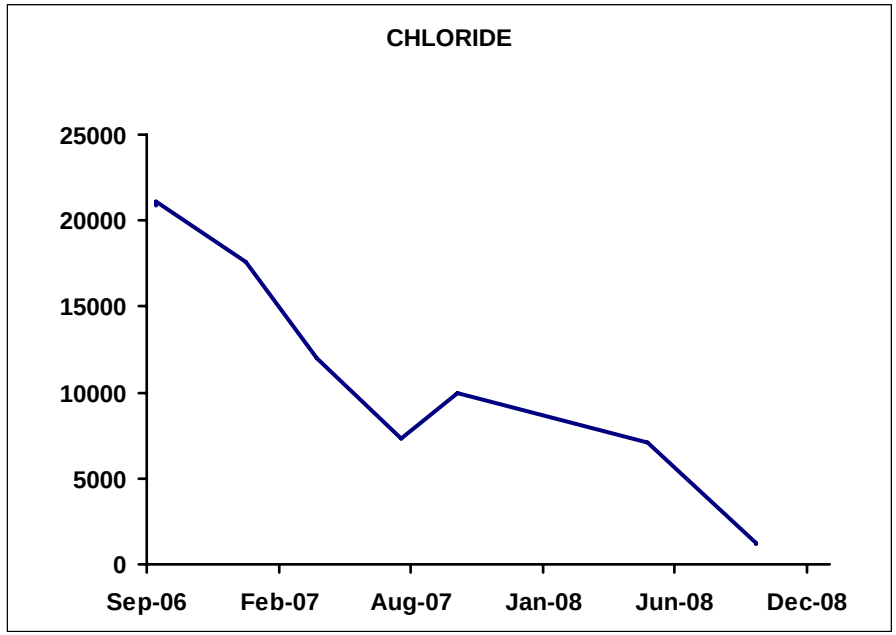


SITE 1: SUMMARY OF REMEDIATION

- Area of saline plume prior to pumping was >2.0 ha
- Area of saline plume after 3 years of remediation was ~ 1.3 ha
- Chloride maximum declined from 32,000 to 1,250 mg/L
- Total volume of recovered water: 100,000 m^3
- Total volume of produced water equivalents: 3,000 m^3
- Anticipated time line remaining to reach closure: ~5 years
- Construction cost: $150,000
- Annual cost of operation/monitoring and maintenance: ~$50,000

SITE 1: PERFORMANCE ASSESSMENT

- Decreasing chloride trend across the site
- Downgradient salinity plume drawn back to recovery wells
- Adjacent wetland receptor was protected
- Substantial removal of primary salt mass
- Site closure likely possible within 10 years of the spill



SITE 1: MANAGEMENT, MAINTENANCE AND MONITORING

- Recovered water pumped into forcemain – no tanks used
- Nearby injection well resulted in low water disposal costs
- Regular acid treatments reduced scale problems
- Heat trace required to prevent freezing of header
- Regular inspection of ensure pump and meter system
- Groundwater monitoring

SITE 2: SITE DESCRIPTION

- Partially forested agricultural land (pasture), with oil and gas facilities
- Site split by provincial highway
- Bedrock aquifer, clay till with sand units over shale bedrock ~ 3 m below ground
- Water table depth ~1.5 m
- Hydraulic conductivity of ~$1x10^{-4}$ to $1x10^{-7}$ cm/s

SITE 2: SPILL

- Numerous releases from a produced water handling facility, well site and pipelines
- Releases occurred between 1950 and 1985
- Volume of released fluid unknown – slowly migrating salt plume
- Landowner complained of change in water quality and many stressed trees
- Chloride in drinking supply well increasing
- Hundreds of trees eventually died

SITE 2: ASSESSMENT TOOLS – METHODS AND LIMITATIONS

- Geophysical surveys
  - EM 31 and EM 38 instrument
  - magnetometer
  - accurately mapped soil salinity
  - limited interference from metal objects and geologic changes

- Soil sampling
  - advancement of boreholes using auger drill rig and air rotary rig
  - field and laboratory analysis
  - non-homogeneous distribution of salts, vertically and horizontally
  - multiple drill events to delineate affected area
  - natural salinity/sodicity in till and bedrock complicated assessment

SITE 2: ASSESSMENT TOOLS – METHODS AND LIMITATIONS (CONTINUED)

- Groundwater monitoring
  - slow groundwater recovery in tight clay till and shale
  - analysis for indicator parameters to reduce analytical costs
  - multiple sampling events required to assess plume migration and evaluate effectiveness of remediation
  - wide seasonal and annual variations in chloride concentrations, difficult to evaluate trends
  - sampling of residential well to assess quality for consumption

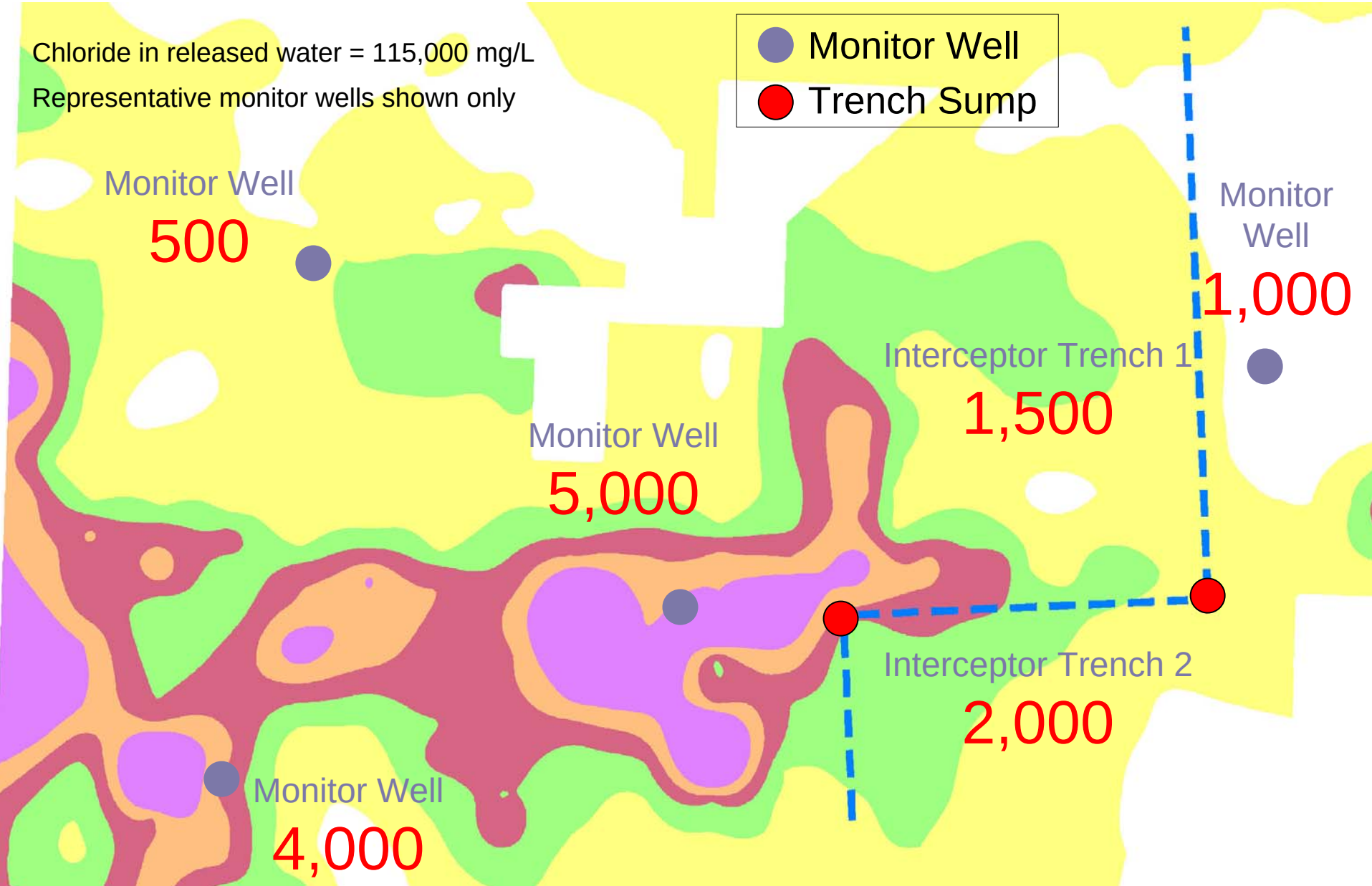
- Vegetation Sampling
  - analysis of leaf tissue was used to identify accumulation of chloride
  - leaf tissue chloride correlated with visual stress
  - effective for determining the leading edge of the groundwater plume

SITE 2: CONTAINMENT AND REMEDIATION MEASURES

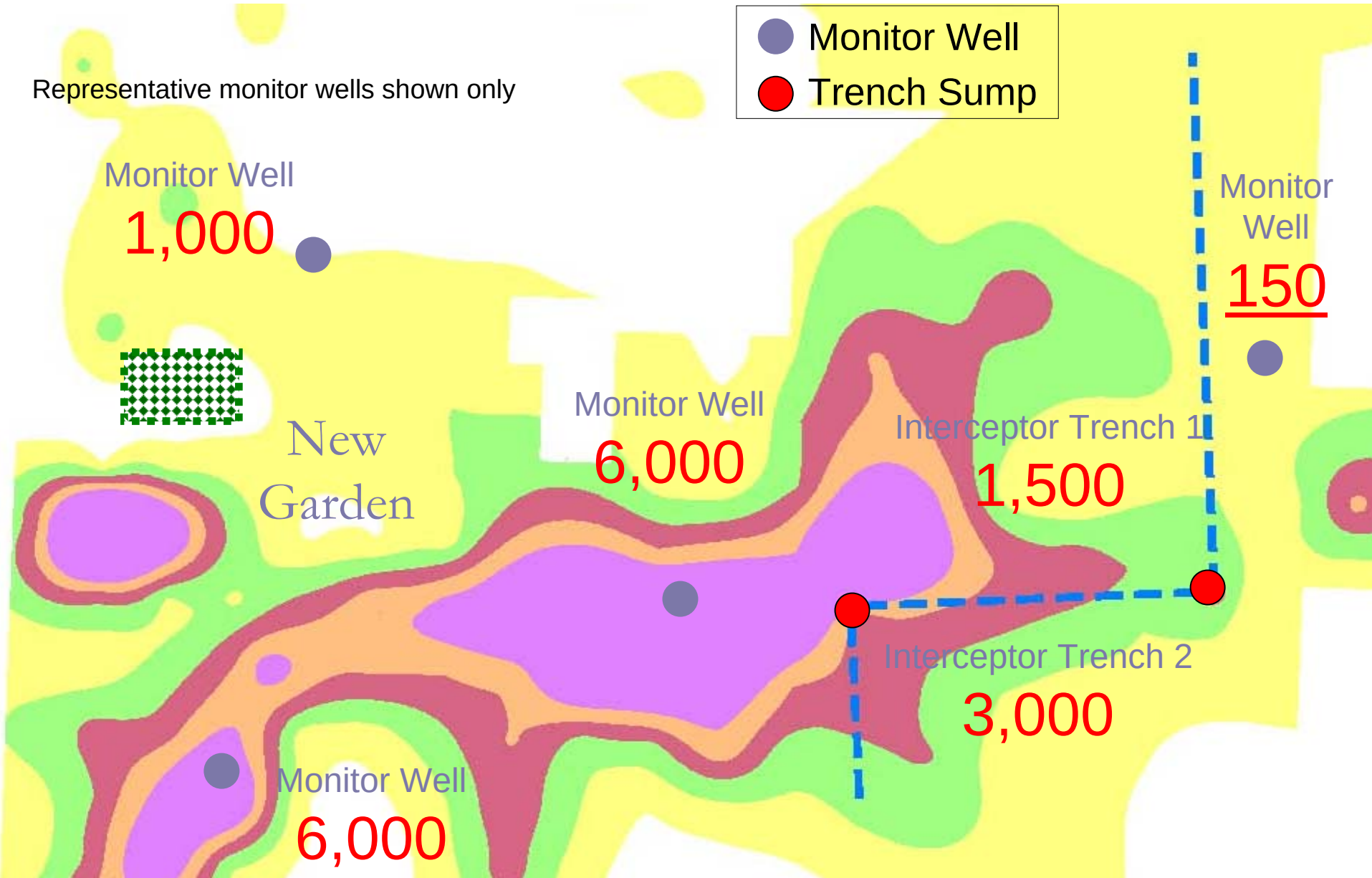
- Excavation of Soil
  - potential volume of saline soil above criteria >100,000 m^3
  - would not address all groundwater issues
  - replacement soil difficult to source
  - would impact adjacent residence/farm yard

- Groundwater Recovery
  - interceptor trench selected to cut off migration of groundwater and protect remaining trees
  - low hydraulic conductivity resulted in small recovery volumes

SITE 2: INITIAL EM SURVEY AND GW CHLORIDE (mg/L)



SITE 2: CHLORIDE (mg/L) TEN YEARS LATER



SITE 2: MANAGEMENT, MAINTENANCE AND MONITORING

- Recovered water pumped to 1949 vintage oil well converted for disposal
- Operating a disposal well for remediation purposes only can be expensive if casing fails [trucking is usually most expensive]
- Regular inspections of pump and meter system
- Groundwater monitoring

SITE 2: SUMMARY OF REMEDIATION

- Area of saline plume prior to pumping was ~4.0 ha
- Area of saline plume after 10 years of remediation is still ~4.0 ha
- Peak chloride in forested area decreased from 1,000 to 150 mg/L
- Total volume of recovered water: 18,000 m^3
- Total volume of produced water equivalents: 350 m^3
- Anticipated time line to closure: >50 years
- Construction cost: $200,000, disposal well costs: $1,000,000
- Annual cost of operation/monitoring and maintenance: ~$35,000

SITE 2: PERFORMANCE ASSESSMENT

- Effective protection of downgradient forest receptors
- Minimal removal of primary salt mass
- Landowner drinking supply well replaced with cistern with long term obligation to haul water
- Many decades of continued site management will be required

FUTURE ENHANCEMENTS AND LONG TERM OPERATIONS

- Irrigation to flush residual salt from soil
- Surface grading to minimize runoff and maximize infiltration/flushing
- Installation of additional recovery system components
  - $1,000 - $2,000 per linear metre – trench
  - $15,000 - $40,000 per bored well
- Excavation of highly saline source soil
- Periodic redevelopment of bored wells
- Jetting of trench gravel pack

THERE IS NO SALT FAIRY…
DILUTION IS NOT THE SOLUTION

QUESTIONS