REMEDIATING DIFFICULT SALT SPILL SITES:

NO MAGIC WAND - BUT WE HAVE A FEW TRICKS UP OUR SLEEVE

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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.
  - No magic show credentials what so ever

Magic Wands for Salt?

- Unfortunately there are no simple or inexpensive methods of dealing with large complex salt spill sites
- However there are several proven methods for removing salt mass (excavation, soil washing, electrokinesis, groundwater recovery, others)
- The focus today will be on groundwater recovery methods.

This presentation includes:

- a brief overview of salt issues in Alberta
- fast response to new spills – three examples
- methods to deal with old spills – three examples
- summary of effectiveness
- long term operating and closure issues

Naturally Occurring Salts in Alberta

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

Naturally Saline Soils Around a Prairie Slough

Salts From Human Actions

- Road deicing in Canada uses 5 million tonnes / year – extensive but diffuse impacts
- Transportation yards with outdoor pickled sand storage areas – localized intense impacts
- Solution mining of the Upper Lotsberg Formation in AB & SK provides salts for table use, industrial processes and creates storage caverns
- Oil and gas production byproduct – produced water

Seawater and Produced Water

Source	Mean Chloride (mgL)
Seawater	19,000
Medicine Hat PW	<500
Cold Lake PW	5,000
Redwater PW	65,000
Rainbow Lake PW	120,000

Regulatory Guidelines & Criteria

- AENV Alberta Tier I Soil and Groundwater Remediation Guidelines (2007) & Salt Contamination Assessment & Remediation Guidelines (2001)
- AB Agriculture: Soil Quality and Salt Tolerance (soil ratings)
- CCME: Soil and Water Quality Criteria
- Env. Canada [EC]: Environmental Management of Road Salts

AENV and BC Soil Criteria

- Conductivity:
  - 2 dS/m topsoil / 3 dS/m subsoil
  - 4 dS/m industrial
  - 6 dS/m G50 equivalent salinity
- SAR
  - 4 agricultural
  - 12 industrial or 10 G50 equivalent salinity
- B.C. [draft – No AB criteria] – Protects 75% of tested species
  - Chloride: 370 mg/kg
  - Sodium: 190 mg/kg

Water Criteria

- Drinking Water Criteria - aesthetic objectives
  - sodium: 200 mg/L
  - chloride: 250 mg/L
- Surface Water Chloride:
  - 35 mg/L no observed effects - Fathead Minnow [EC]
  - 100 mg/L irrigation of sensitive crops [CCME]
  - 140 mg/L no observed effects – Daphnia [EC]
  - 230 mg/L four day average [USEPA]
  - 500 mg/L runoff water release criteria [EUB / AENV]
  - 860 mg/L one hour every three years [USEPA]

Salts Relative to Background

- 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 stress / death, poor crop yield with a decrease in planting options for trees and other horticultural species
- Decline in water quality for human drinking or irrigation (livestock watering impairment is relatively rare)
- Aquatic ecosystem stress

Dead and Stressed Aspen

Leaf Stress – Brown Margins

Surficial Salt Crust

Bare Soil in Pasture

Difficult Salt Spill Sites

- Includes some or all of:
  - concentrated salt release
  - large total salt mass
  - large area affected
  - limited or ineffective spill recovery
  - multi-decade plume migration
  - density driven flow / segregation in granular aquifers
  - structural changes to fine grained soils
  - one or more sensitive receptors

Tools to Delineate Salt Impacts

- Indirect Tools
  - Historical records - often poor or incomplete
  - Geophysical tools - EM and / or Resistivity
  - Vegetation stress assessment – seasonal
- Direct Tools - Required for Remediation
  - Soil sampling and analysis
  - Hydrogeologic investigation with groundwater sampling and analysis

Removal of Salt Mass

- For large highly saline salt spills, removal of salt mass is required to prevent migration and begin the path to closure.
- Options include: dig and dump; electrokinesis; soil washing; phytoremediation and others.
- If there is a significant impact to groundwater, then interception and recovery can be very effective.

Operating GW Recovery Systems

- Pipeline to disposal well is lowest cost
- Year round operation preferred, frost protection is necessary
- Water Act Approval is required for diversions or more than **1,250 m3 / year**
- Maintenance and monitoring is crucial to optimize recovery and contain the plume

Produced Water Equivalents

- For Oil & Gas related releases, salt recovery and system performance can be related back to the volume of spilled produced formation water

- Produced water equivalents =

  (chloride concentration of recovered water / chloride concentration of the produced water) x the recovered volume

Fast Response Sites

- Recent spills with detailed assessment within weeks or months of the release
- Usually some degree of removal of highly saline shallow soils at the source – to landfill
- Rapid design and installation of groundwater recovery system

Site 1: Spill Into Sand Aquifer

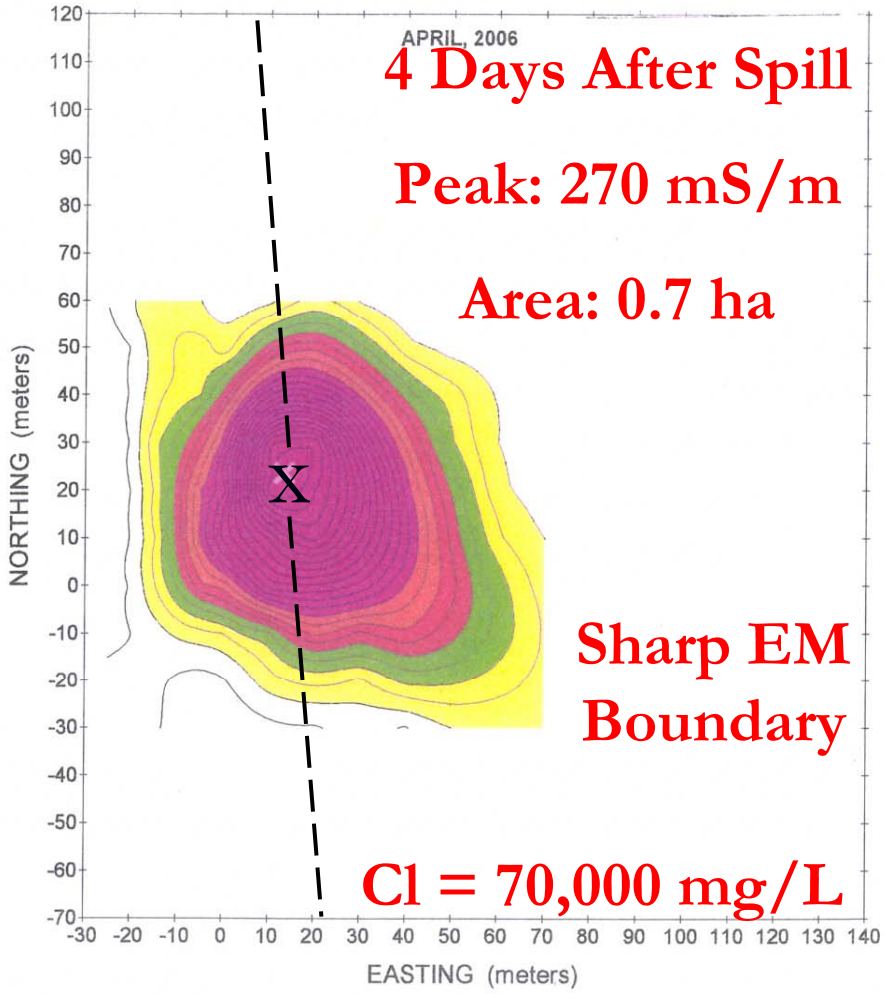
- Large subsurface release of produced water due to sudden pipeline joint failure
- Extensive shallow sand aquifer with near surface water table
- Private agricultural land with downgradient residence and drinking water well

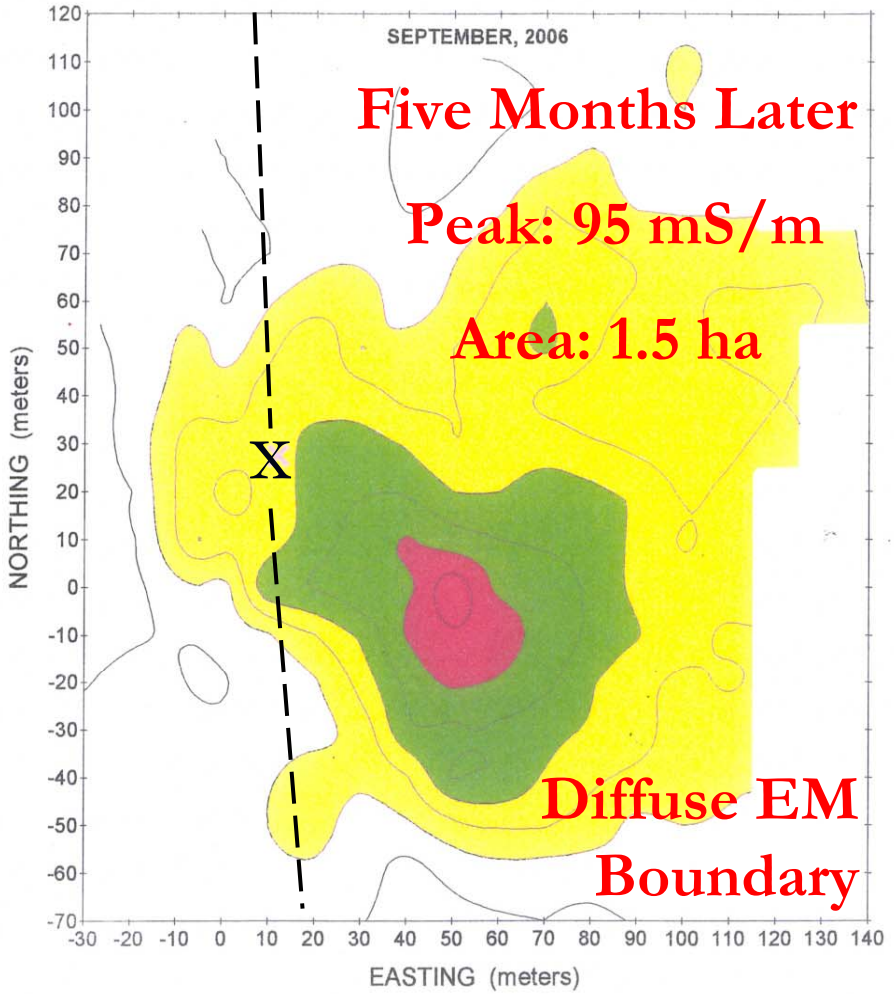
Remediation Actions

- Rapid response included:
  - installation of three groundwater recovery wells once access agreements were in place
  - commissioning of a pumping and water management system tied to disposal well
  - monitoring of operating system and groundwater

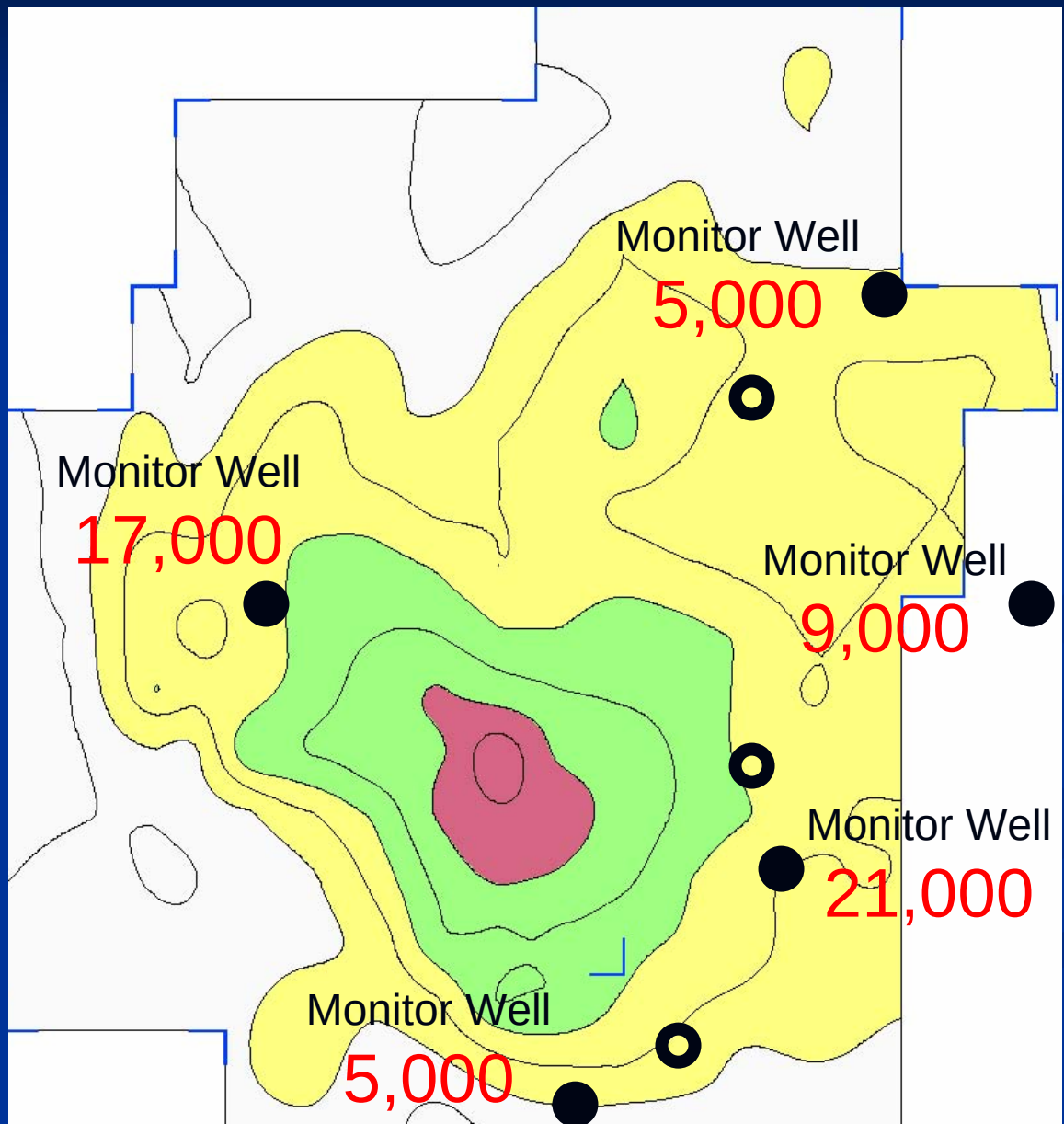
Bored Recovery Well

High Plume Migration Rate

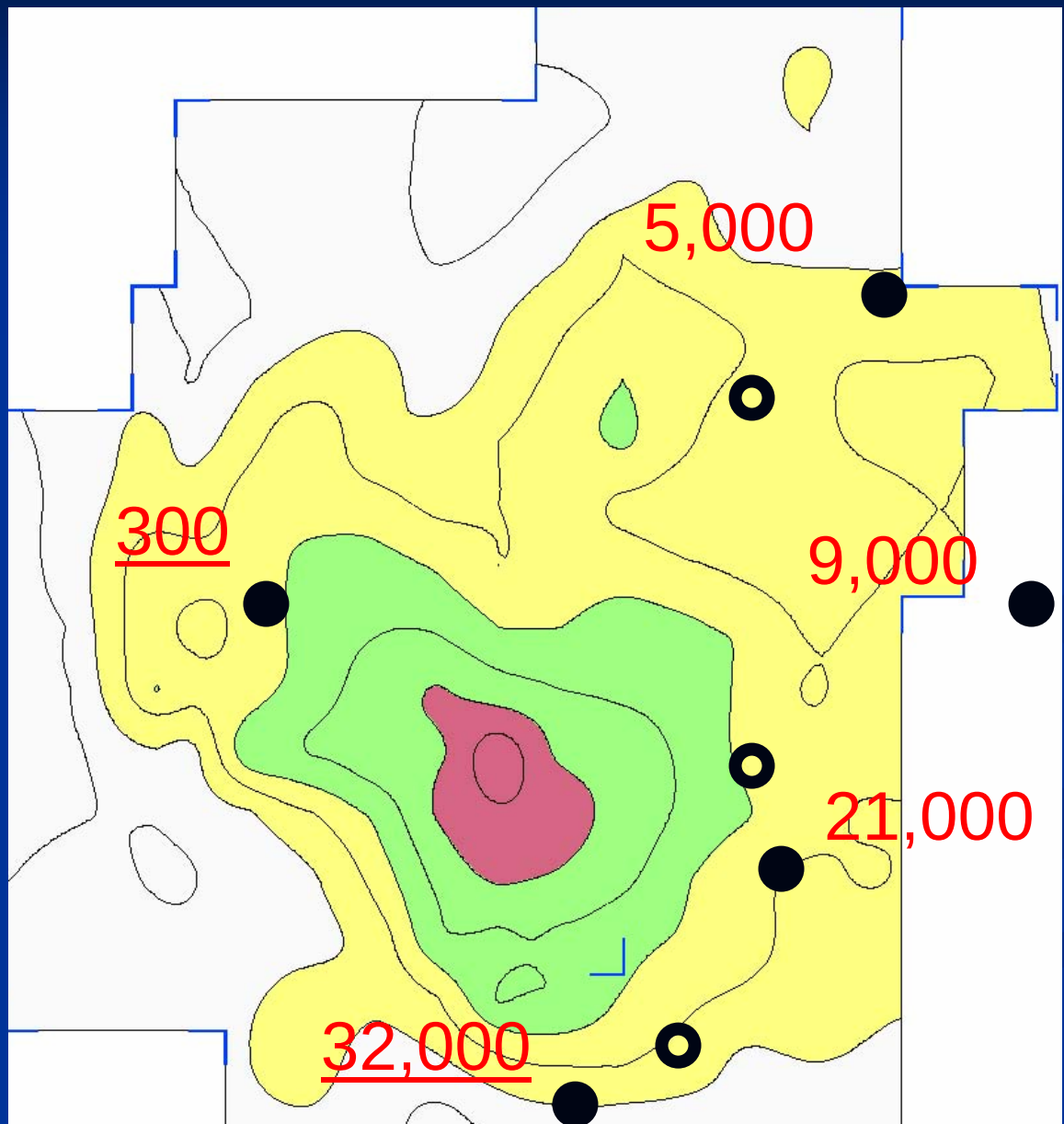




Initial Chloride Concentrations (mg/L)

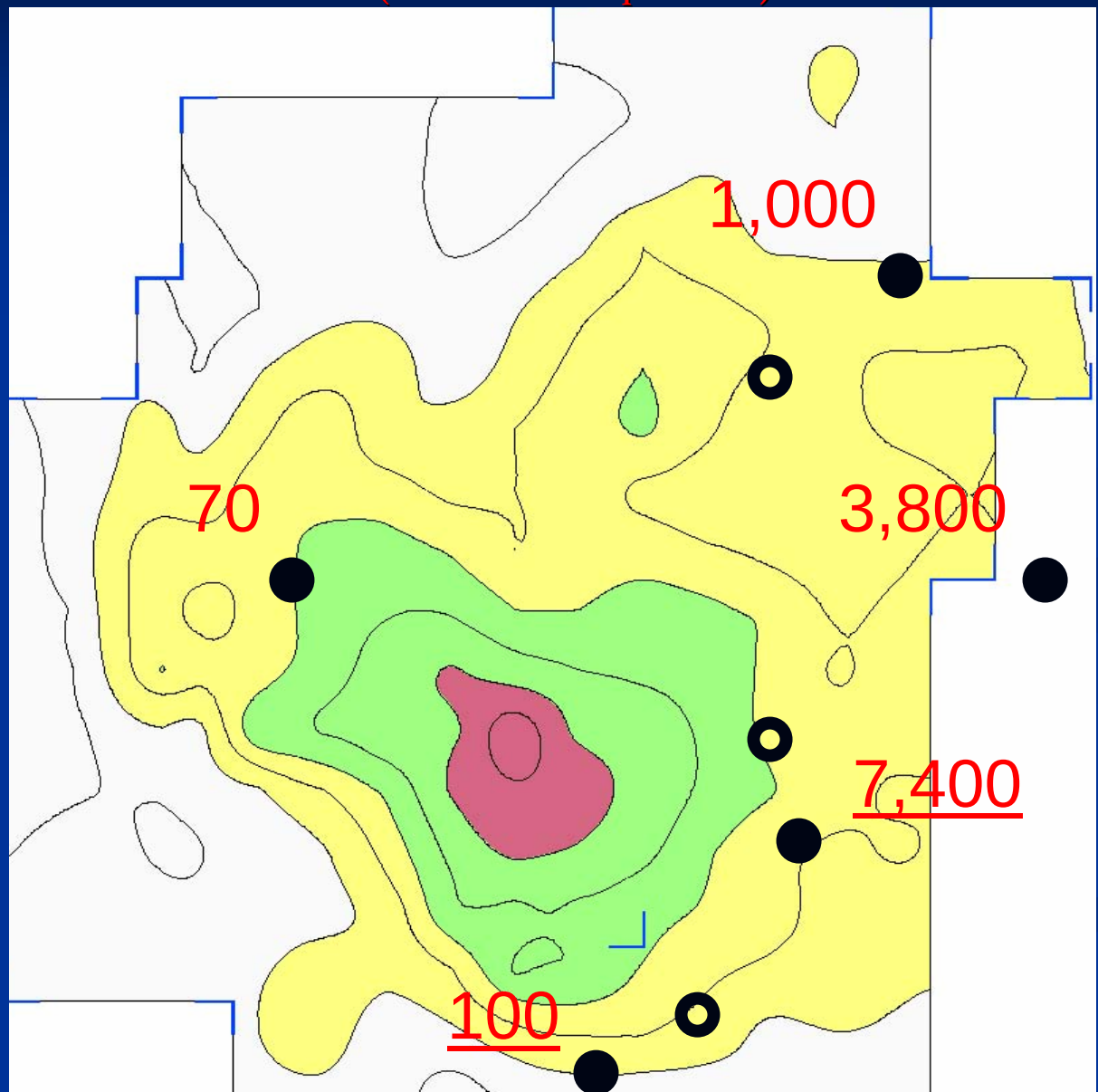


Chloride Prior to Pumping (mg/L)



Chloride (mg/L) 7 Months After Pumping

(~2500 m3 PW equivalents)



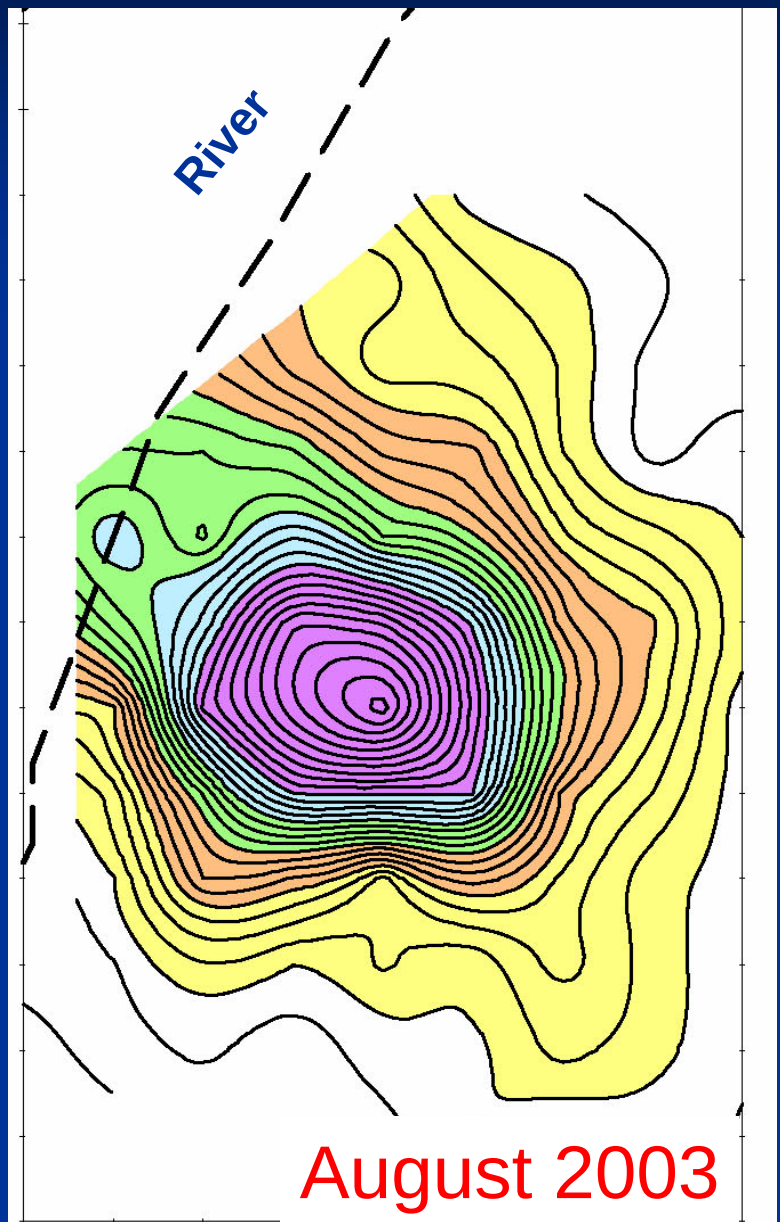
Site 2: Spill Adjacent to River

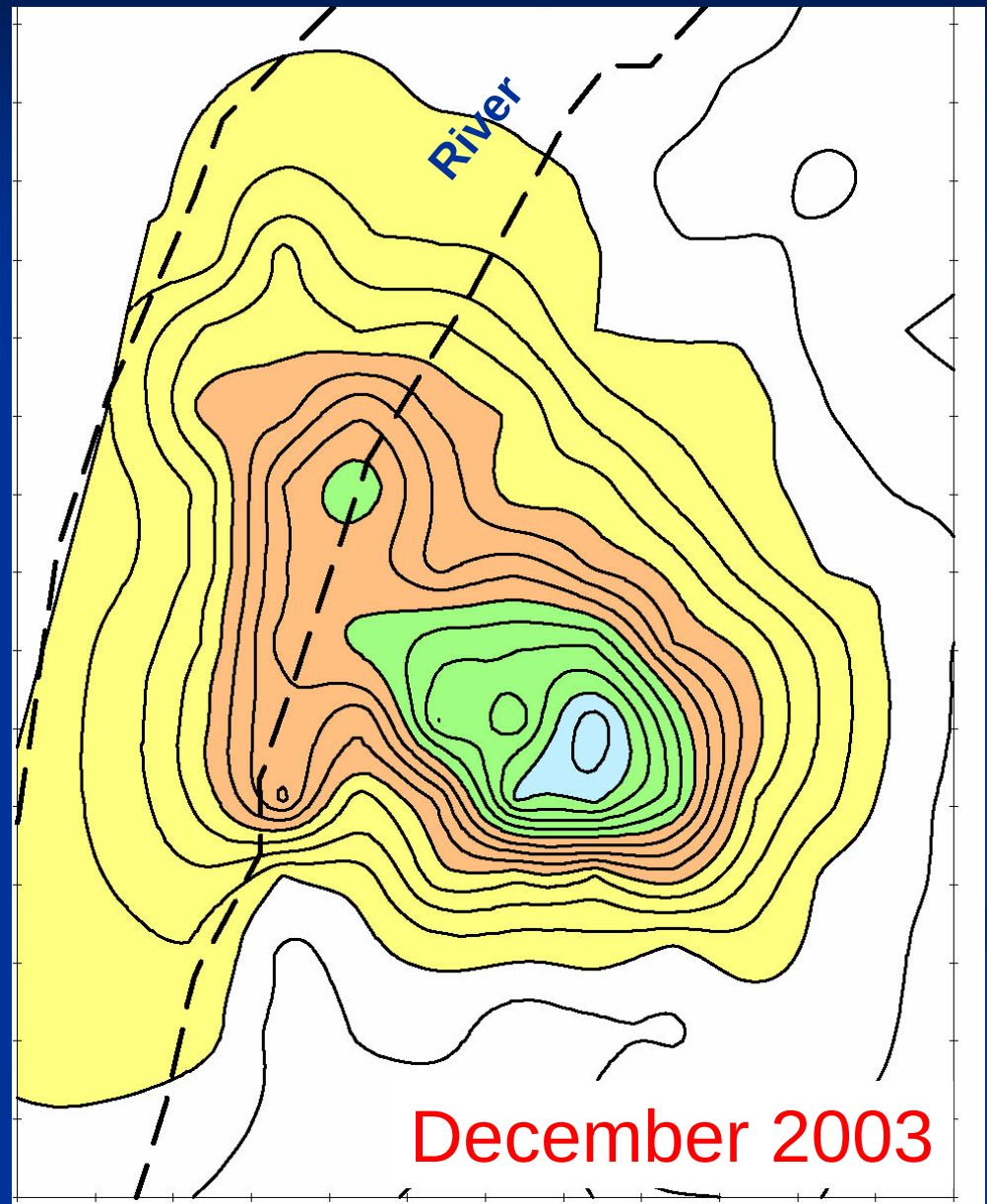
- Large subsurface produced water release due to long slow leak from a pipeline
- Failure point was ~10 m from major river into complex recent sediments
- Approximately 1 hectare salinized – mostly subsurface
- Groundwater plume extended under the river but no measurable increase in Cl in the flowing surface water

Remediation Actions

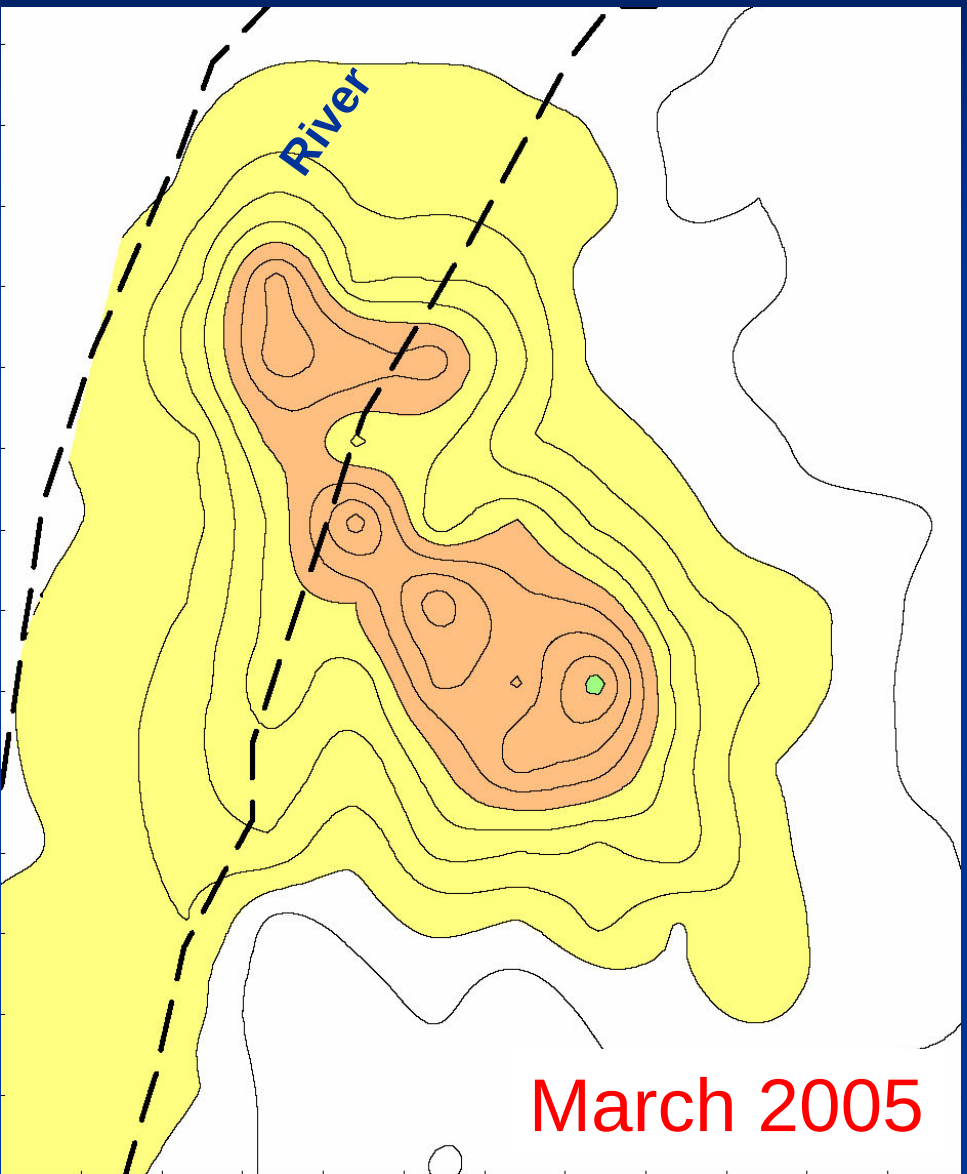
- Rapid response included:
  - removal of source soils near pipeline
  - installation of a groundwater recovery well
  - commissioning of a pumping system to an AST – higher cost than disposal well due to trucking
  - monitoring of operating system and groundwater

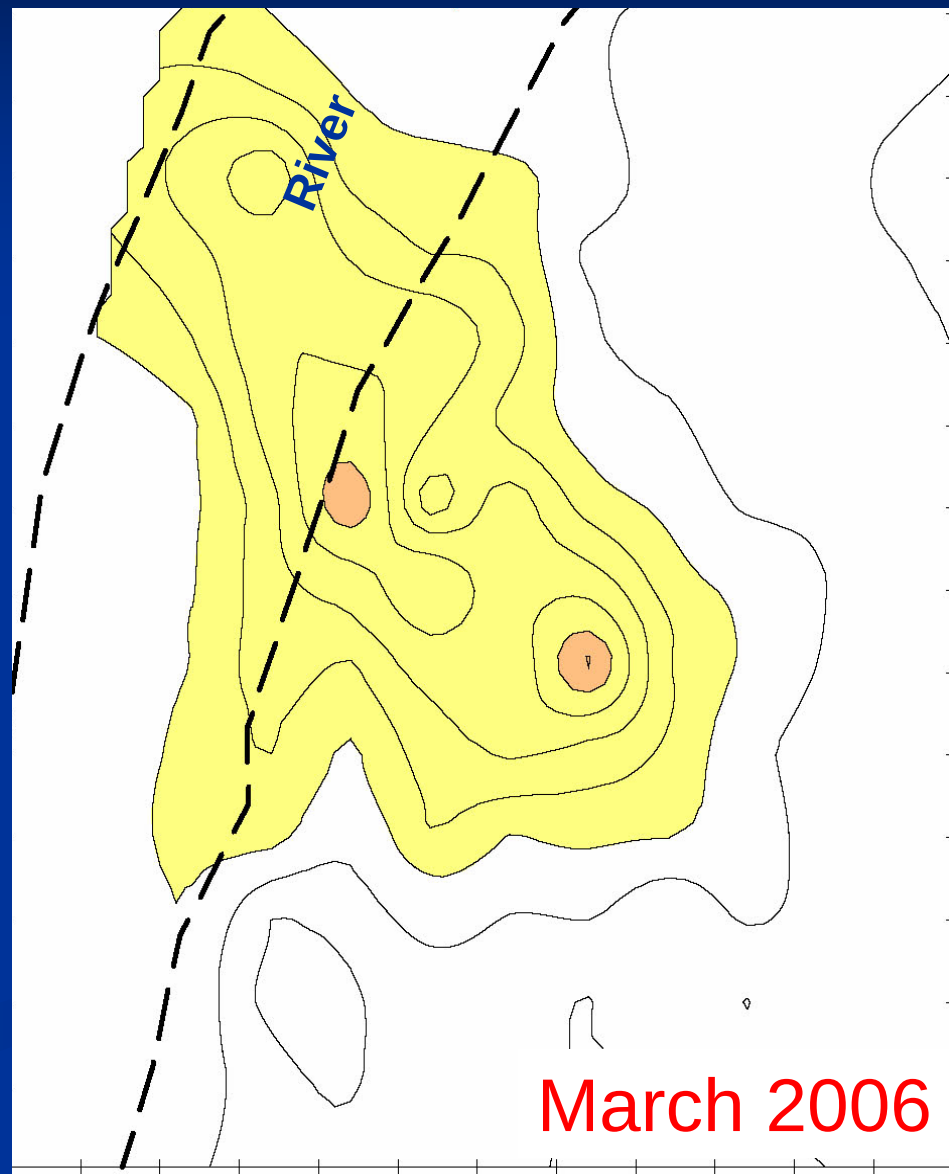
Decreasing EM Intensity Year 1



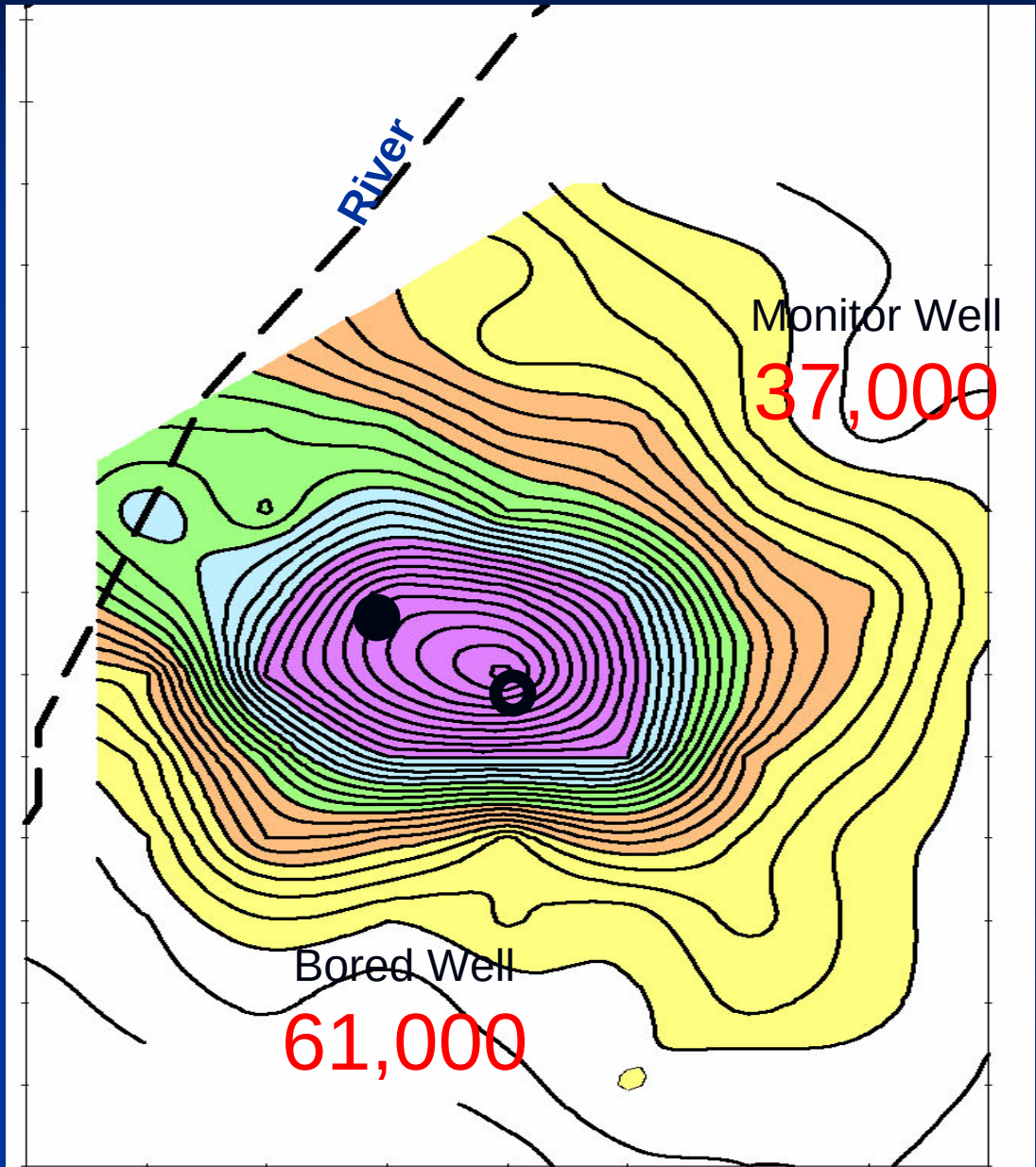


Decreasing EM Intensity – Year 2 & 3



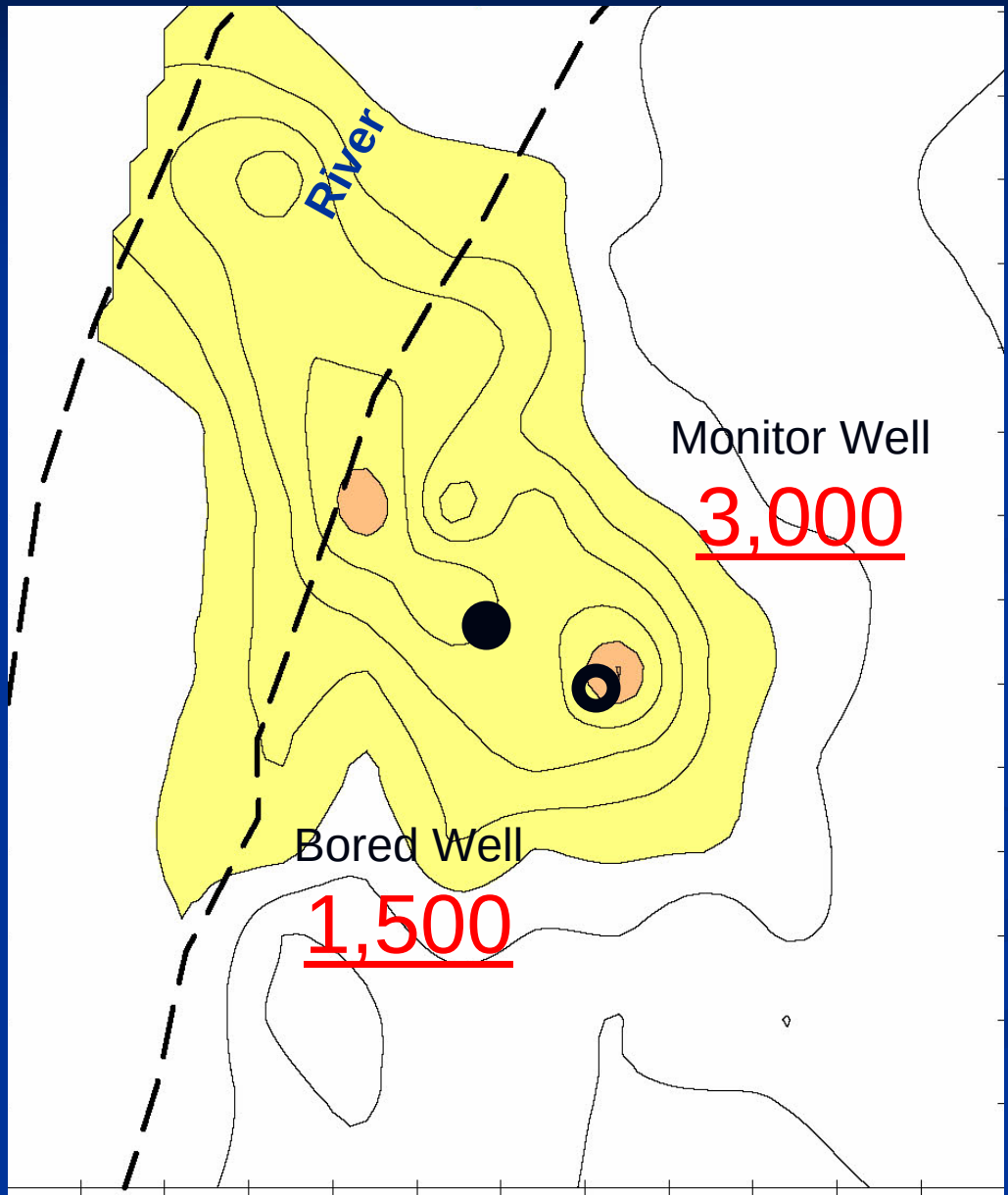


Initial Chloride Concentrations (mg/L)



Chloride (mg/L) After 3 Years

(~440 m3 pw equivalents)



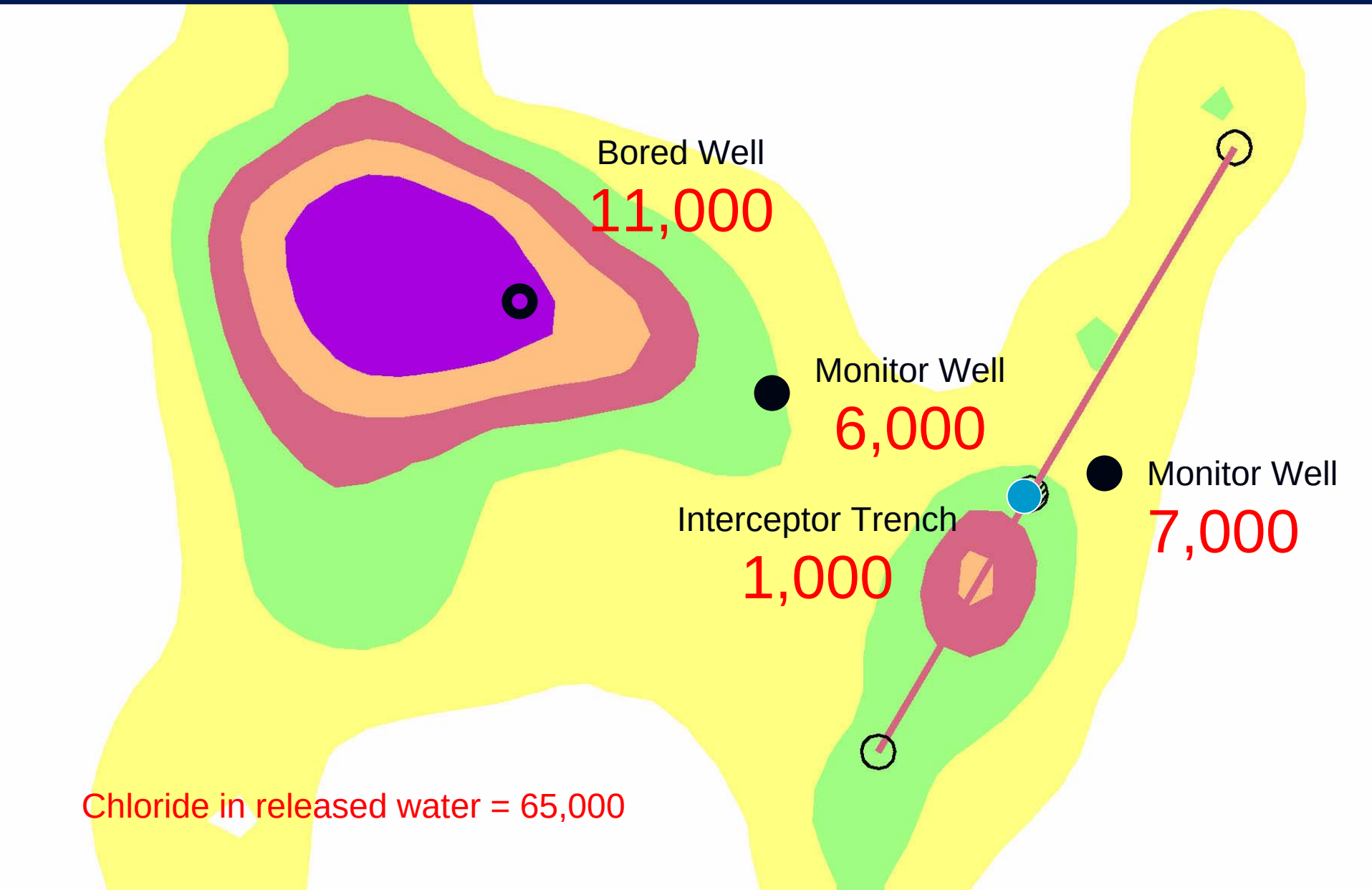
Site 3: Spill at Edge of Valley

- Large subsurface and surface release of produced water due to joint failure following pipe modification
- Failure point was ~ 50 m from edge of major valley – high gradients and sensitive plant species
- Approximately 1 hectare soil and gw salinized
- Complex lacustrine sand, silt and clay deposits

Remediation Actions

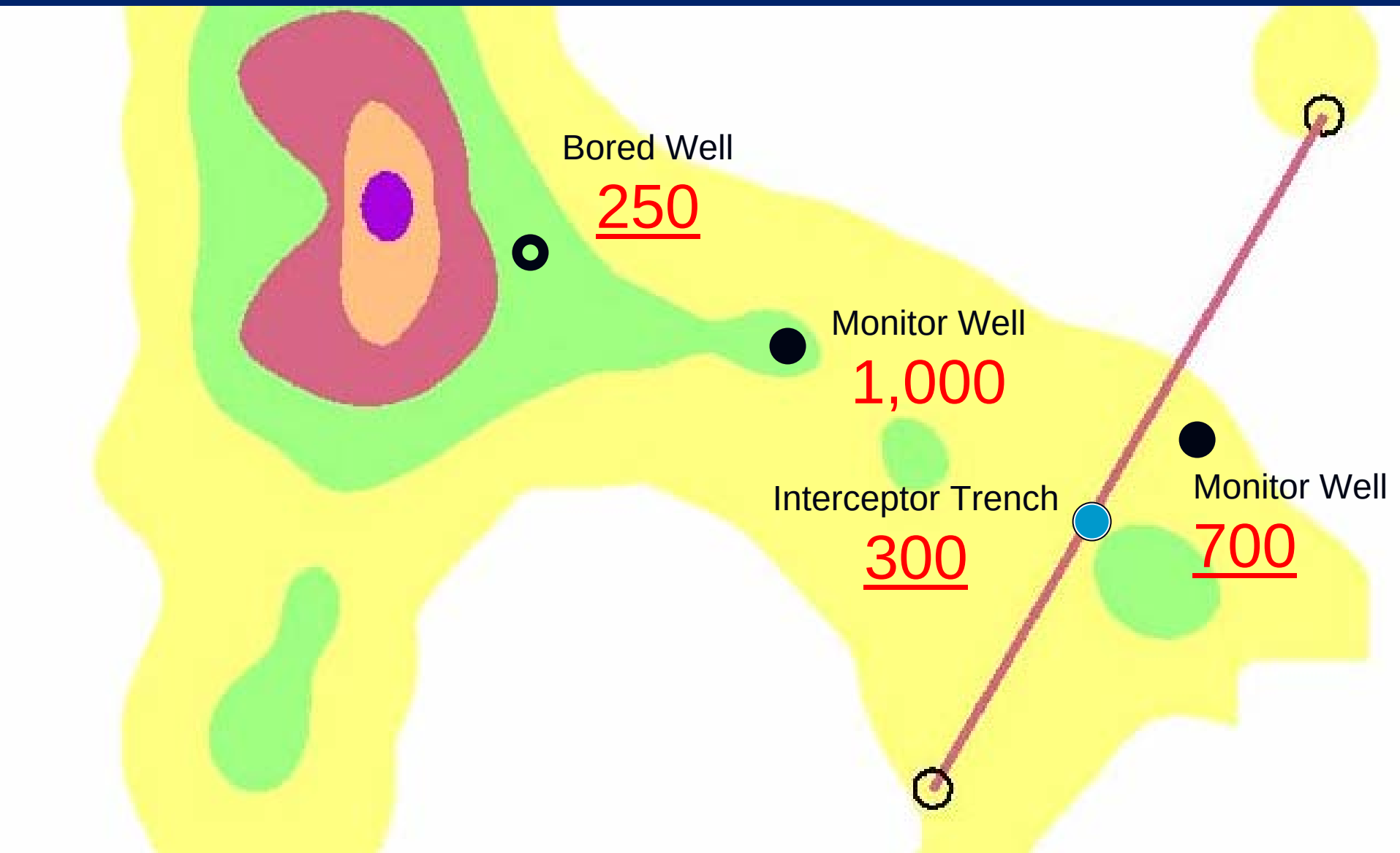
- Rapid response included:
  - installation of a groundwater recovery well near the source and a barrier recovery trench along the top of the bank
  - commissioning of a pumping and water management system tied to disposal well
  - monitoring of operating system and groundwater

Initial EM Survey and GW Chloride (mg/L)



EM Survey and Cl (mg/L) - 6 Years Later

(150 m3 pw equivalents)



Old Spill Sites

- Spills several decades old – with some history of periodic soil amendments and fresh water flushing
- No historical removal of salt mass through excavation or recovery
- Diffuse widespread plume often affecting a few hectares to tens of hectares

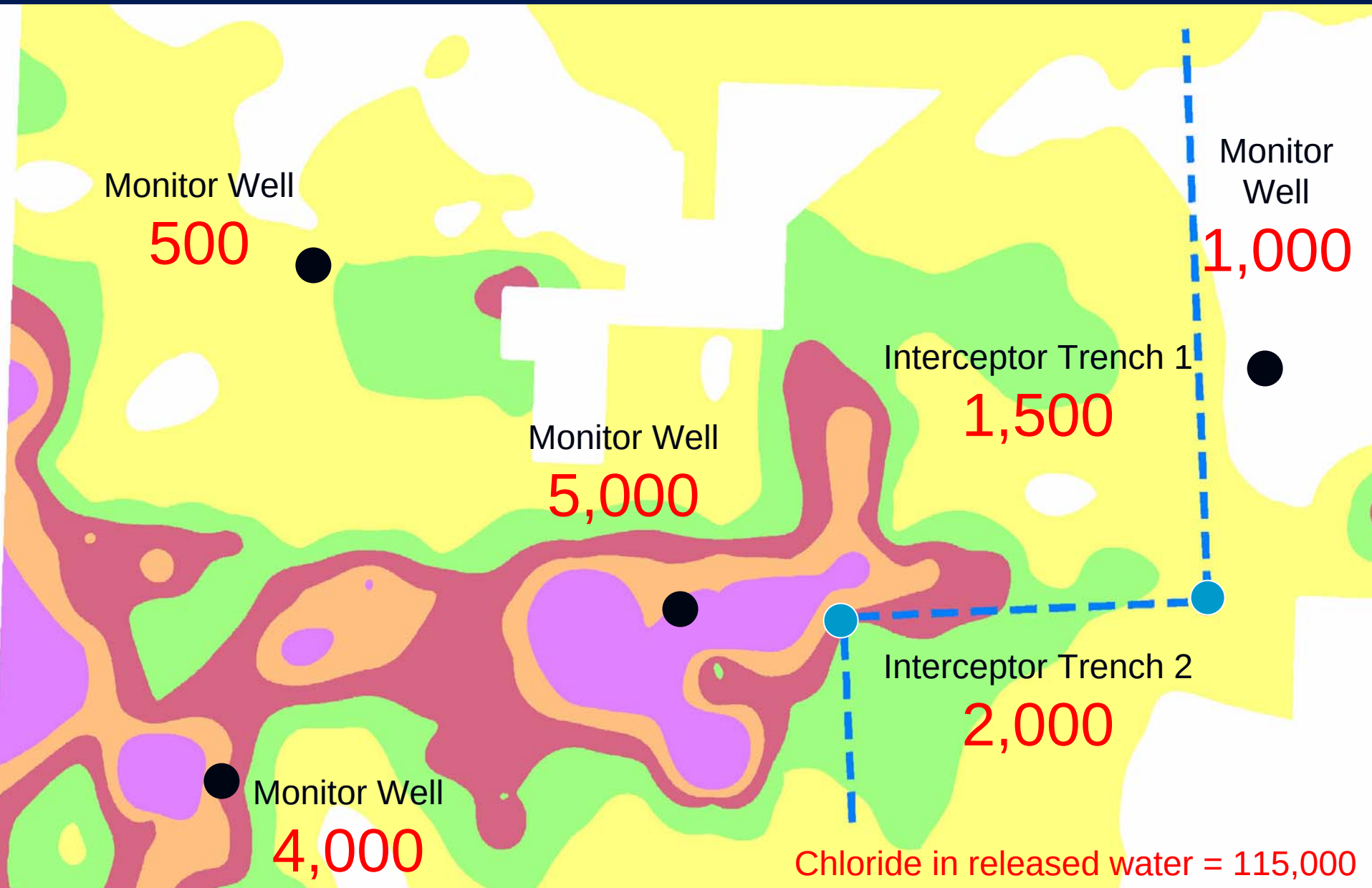
Site 4: 25 Year Old Spill Site on Agricultural and Residential Land

- Sudden failure of pipeline released a large volume of produced water on surface with substantive overland flow
- Approximately 5 hectares currently saline – both soil and groundwater (clay till underlain by bedrock at 3 to 4 m)
- Landowner well became saline, widespread tree death, affected fields planted to salt tolerant crops

Remediation Actions

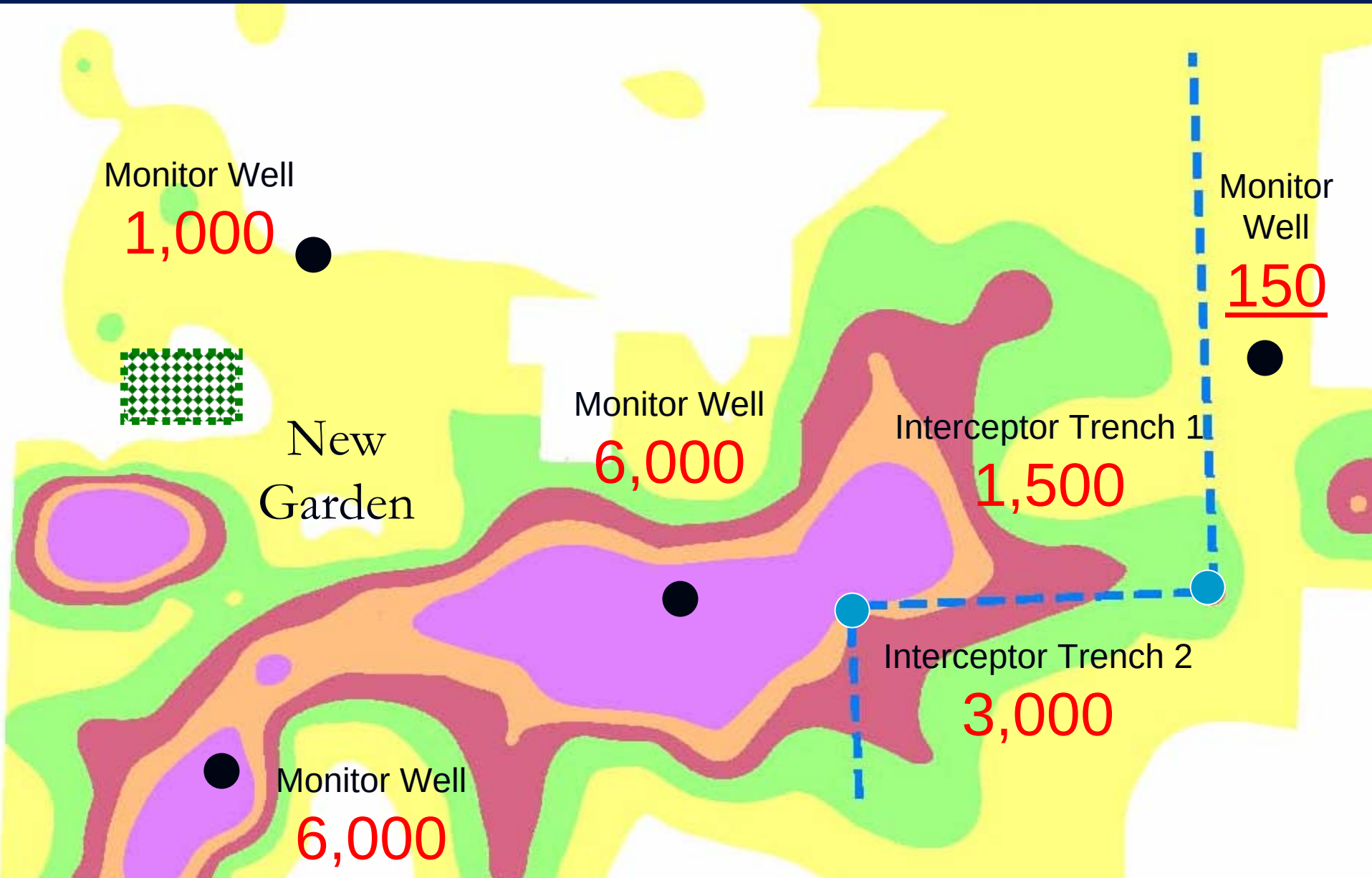
- Replaced landowner well with cistern and hauled water (10 years +), vegetable garden selected in low salinity area
- Trial groundwater recovery trench constructed on lease
- Barrier groundwater recovery trench constructed to protect downgradient forest
- Recovery systems tied in to nearby disposal well
- Site management plan developed to limit land use in the saline area – with compensation

Initial EM Survey and GW Chloride



EM Survey and Cl - 10 Years Later

(140 m3 pw equivalents)



Site 5: Flarepit and Spill Near Creek

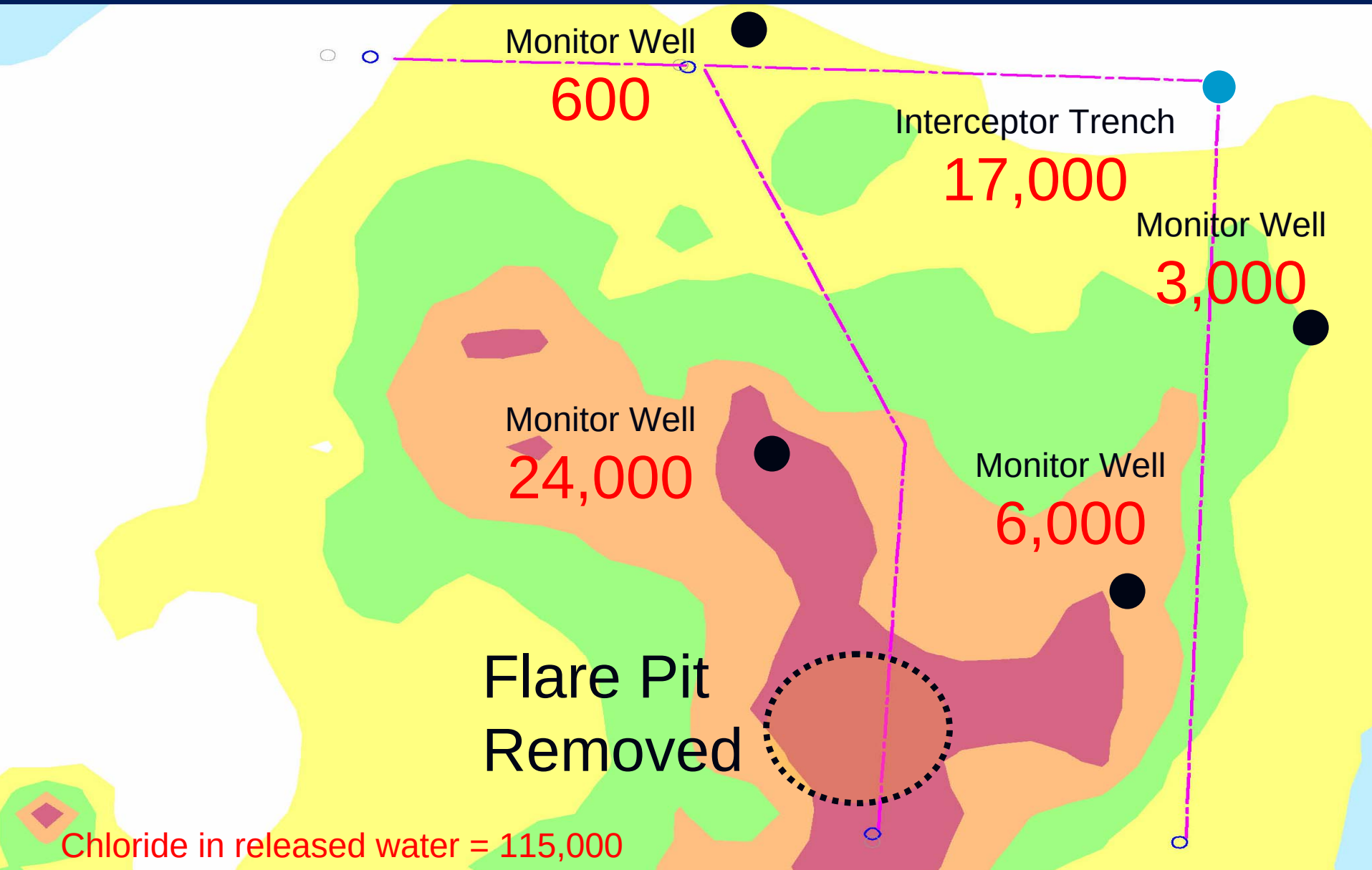
- Believed to be multiple produced water releases on lease and off lease prior to the 1980s
- Approximately 3 hectares salinized
- Adjacent to small creek with evidence of salinization at low flow
- Salts confined to a glacial till layer more than 10 m thick

Remediation Actions

- Removed flarepit and portion of saline source soils
- Installed barrier groundwater interception trench to protect creek and adjacent farmland
- Installed groundwater recovery trench through source area
- Installed pumping system tied to remote disposal well via new pipeline, maintain and monitor

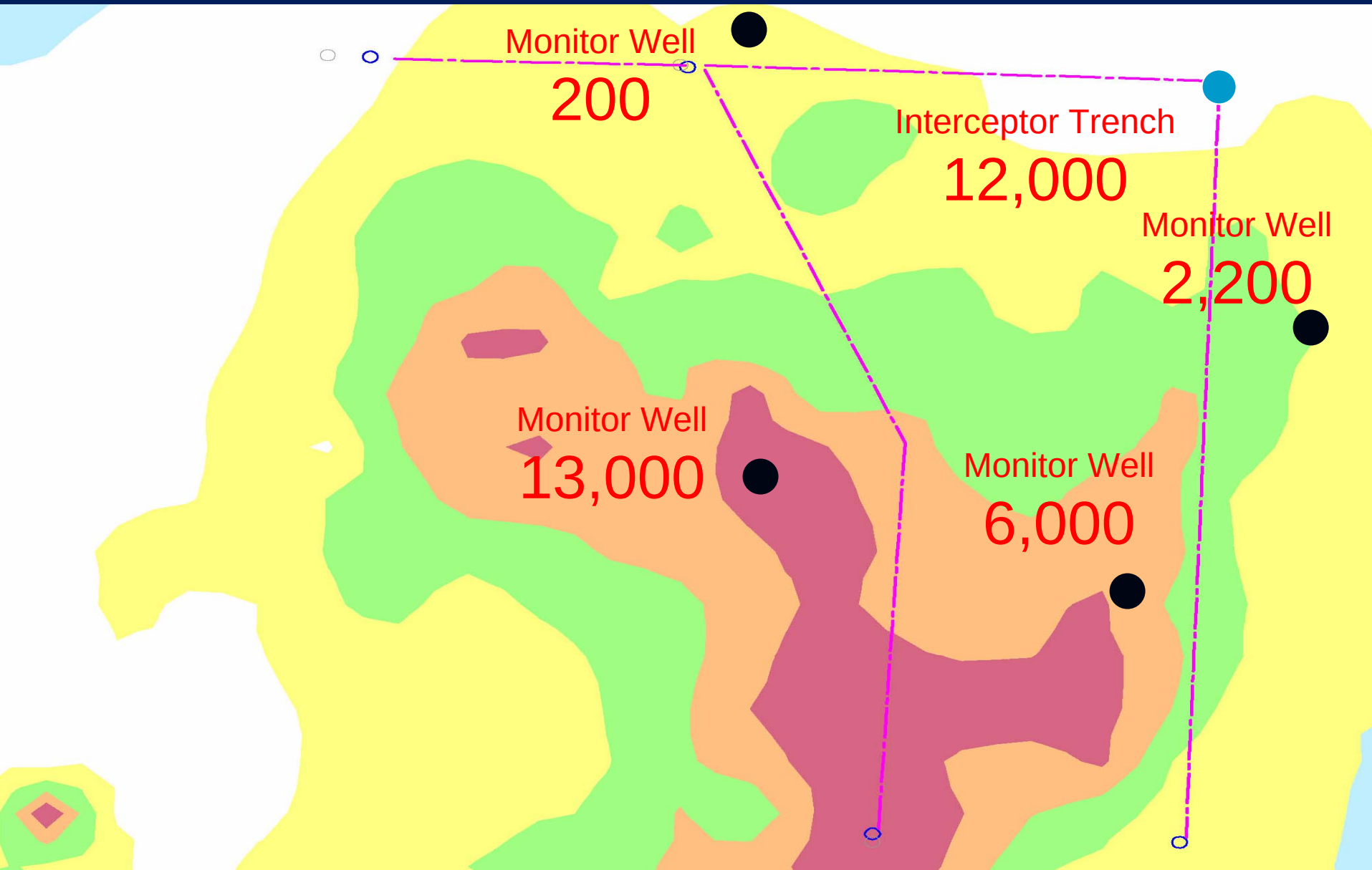
Linear Interceptor Trench

EM and Initial Chloride Conc.



Chloride (mg/L) 4 Years Later

(~750 m3 pw equivalents)



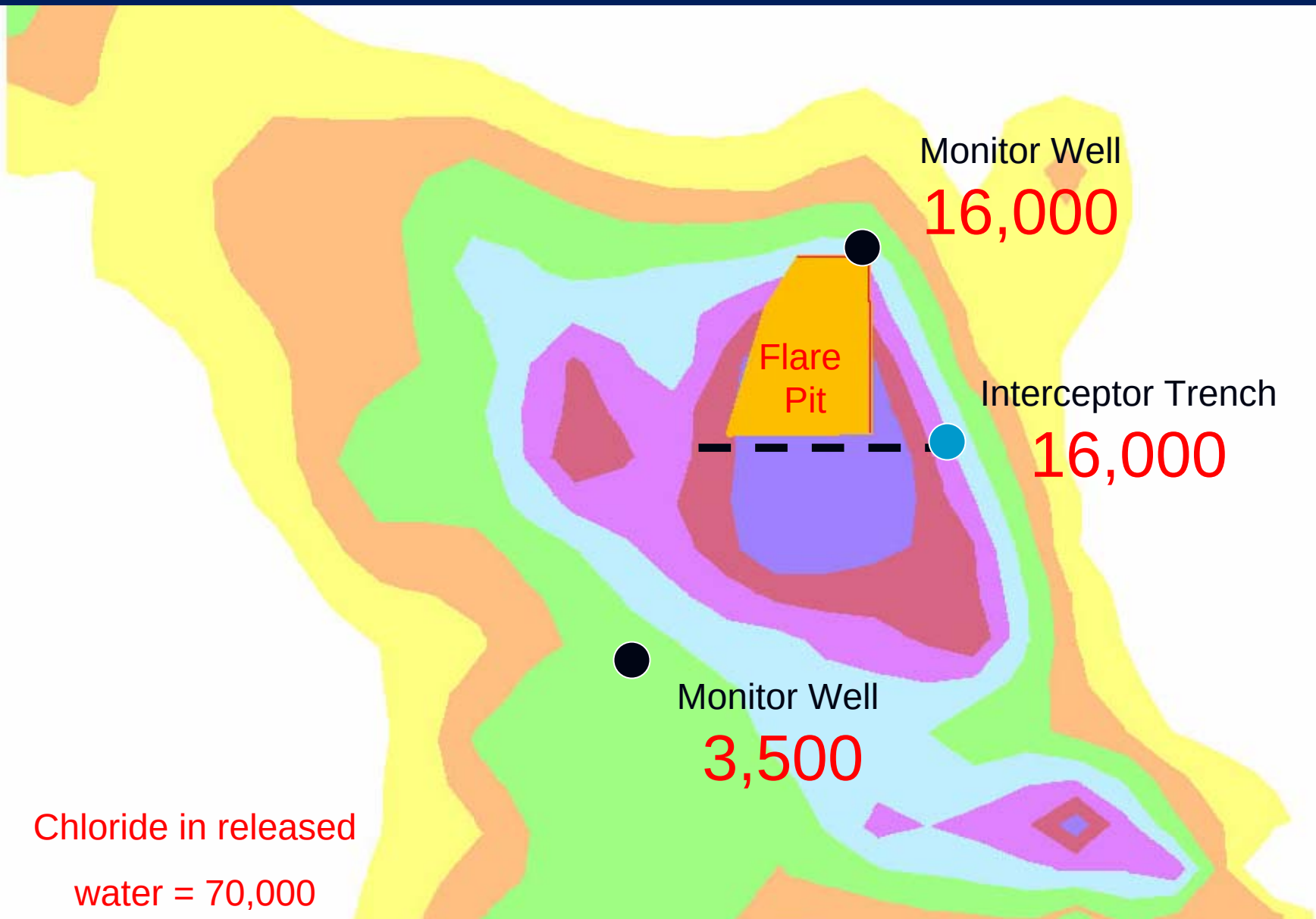
Site 6: Abandoned Battery Site

- Believed to be multiple produced water releases on lease prior to the 1980s
- Approximately 10 hectares salinized – both soil and groundwater
- Majority of salts lie within till layer but bedrock aquifer is shallow
- Surrounded by cropped agricultural land

Remediation Actions

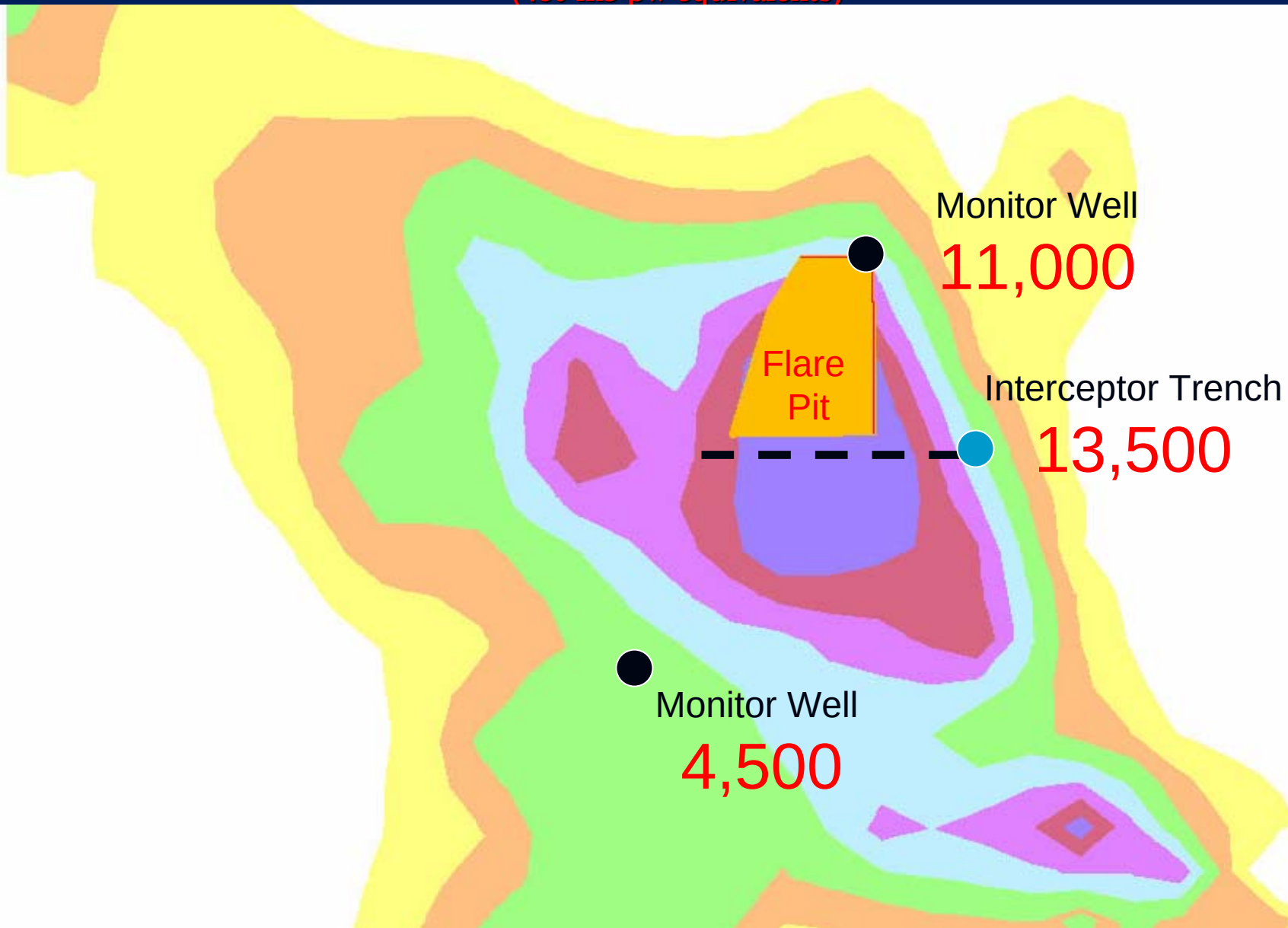
- Shallow tile field installed 25 years ago – majority of salts lie below tiles
- Flarepit and some source saline soils removed 10 years ago
- Trial groundwater interceptor installed on lease within flarepit excavation
- Installed pumping system tied to remote disposal well via liner in old pipeline, maintain and monitor

Initial Chloride Concentrations (mg/L)



Chloride 9 Years Later (mg/L)

(480 m3 pw equivalents)



Summary

- Groundwater recovery systems can effectively remove a significant portion of the source salt mass
- Combined recovery of 4,500 m3 of produced water equivalents from the six systems described
- Approximately equal to ~525 tonnes of NaCl or about 52 tandem dump truck loads

Summary (continued)

- In addition to mass removal, groundwater recovery systems are also effective for saline plume control that can protect drinking water supplies, plants and aquatic receptors
- For old spills in low to medium permeability settings, recovery of the primary salt mass may take more than 30 years

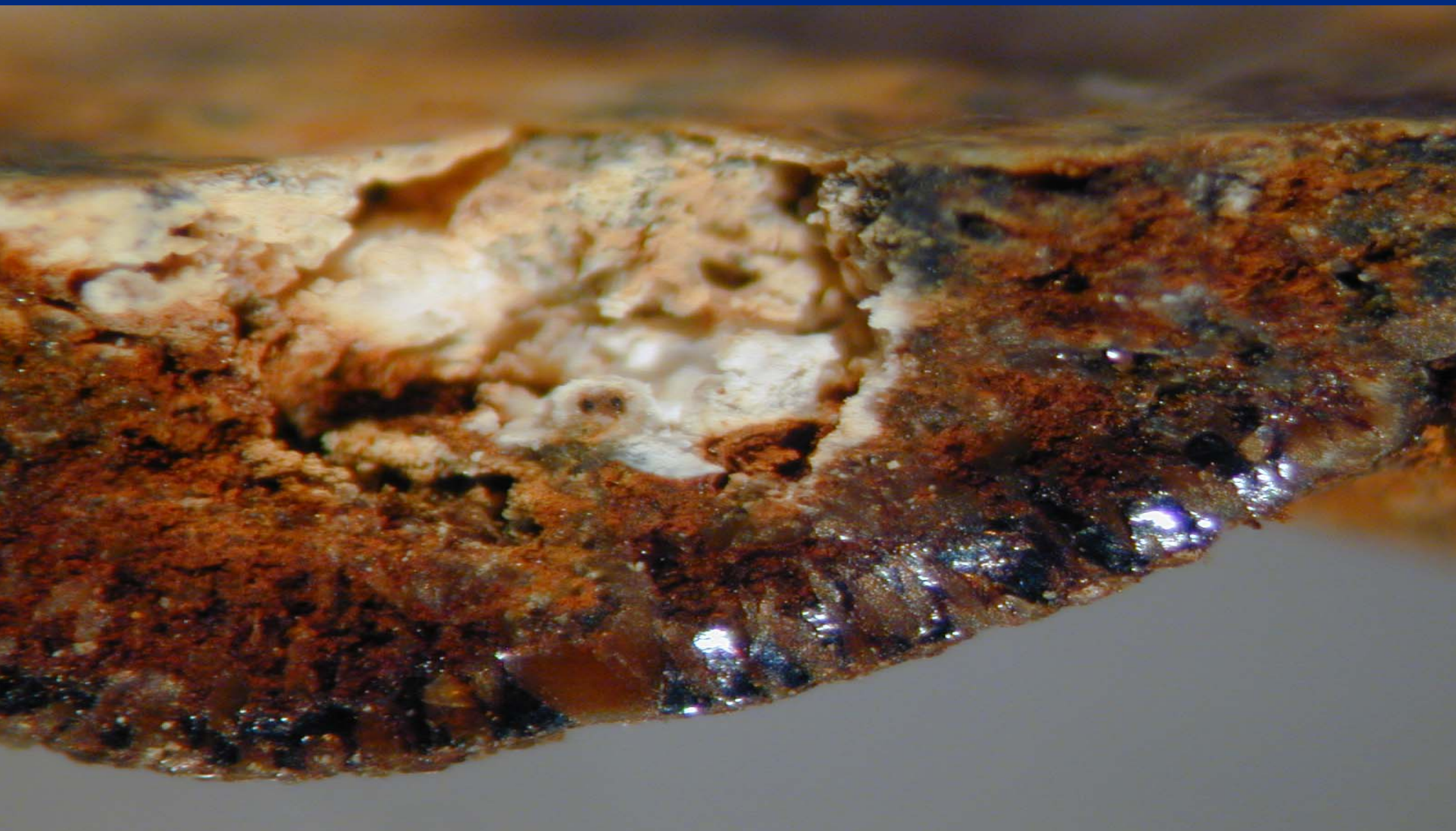
Long Term Issues

- Declining salt recovery rates as concentrations drop – therefore the cost / m3 of produced water equivalents goes up
- Salt reservoir remaining in the soil above the water table
- Maintenance, corrosion, scaling

Scale Problems

Scale Up Close

Calcium Carbonate, Iron Oxide and Magnetite



Other Considerations

- Enhance recovery using runoff capture, irrigation, water treatment and recycle, soil amendments, etc.
- Risk assessment, exposure control and land use management on privately owned sites
- Alternate ecosystem design on Crown sites with residual salts

NEVER GIVE UP!