

Assessment and Remediation of Chloride Impacted Groundwater: A Case Study

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Abstract

A groundwater remediation system has been constructed at the Gold Creek Gas Plant to intercept and recover chloride impacted groundwater from the shallow subsurface. The Gold Creek facility is a sour natural gas processing plant and is located approximately 50 km south of Grande Prairie, Alberta. The plant has been in operation since 1970 and historical operations at the site included the use of an evaporation pond, amine pond and burn pit to store processing byproducts including brine, amines and natural gas liquids. The evaporation pond, amine pond and burn pit were decommissioned in June 1993, and subsequently reclaimed in 1995. Elevated chloride concentrations in the shallow subsurface were first identified at the plant in 1986 with the installation of groundwater monitoring wells located downgradient of the ponds. In 1986, chloride concentrations as high as 60,000 mg/L were observed adjacent to the evaporation pond. Background chloride concentrations at the Gold Creek site are approximately 10 mg/L.

Site topography is slightly undulating and the site is underlain by clayey till with interbedded sand and silt lenses. The extent of chloride impact has been delineated by integrating the results of terrain conductivity surveys, vertical conductivity profiling, and semi-annual groundwater monitoring. Elevated chloride concentrations continue to be observed in the vicinity of the former ponds with maximum chloride concentrations occurring approximately 5 m below the water table at a depth of 7 m. The plume extends approximately 150 m north of the ponds and elevated chloride concentrations are observed adjacent to a wetland area at the north end of the lease. By comparing the results of historical terrain conductivity surveys and historical groundwater monitoring results, it is estimated that the chloride plume has migrated at a rate of approximately 5 m/year.

In November 2001, a groundwater remediation system was installed downgradient of the former ponds. The remediation objectives of the system are to remove chloride from the subsurface and prevent saline groundwater from discharging into the wetland area. The effectiveness of potential remediation system designs were evaluated using numerical simulations. The system is comprised of a shallow groundwater interception trench located adjacent to the wetland area and four large diameter recovery wells located near the former ponds. A produced water metering building contains an inlet manifold to facilitate discrete sampling and pumping rate control for each recovery well. The produced water is treated within the metering building to prevent corrosion and scaling during deep well disposal. It is anticipated that the remediation system will be in operation for approximately 10 years.

Introduction

Petroleum processing facilities often handle produced formation water with chloride concentrations greater than 50,000 mg/L. Shallow groundwater quality at these facilities may be impacted by the accidental release of formation water.

Elevated chloride concentrations can have negative effects on plants by moving upward through the plant and accumulating in the leaves. Accumulation of chloride in the leaves results in leaf burn, chlorosis, and twig die-back. Toxicity limits range from less than 178 mg/L to greater than 710 mg/L and vary with climatic conditions and the type of crop (CCRM, 1987).

The Canadian Drinking Water Quality Guidelines suggest chloride concentration greater than 250 mg/L is unsuitable for human consumption (Health Canada, 1996). Consumption of large quantities of saline water, with a total dissolved solids concentration greater than 10,000 mg/L, can cause physiological upset and ultimately death in the majority of terrestrial animals.

This case study summarizes the groundwater response plan at an upstream oil and gas processing facility for a shallow dissolved chloride plume with concentrations of up to 60,000 mg/L detected at an upstream gas processing facility.

Background

The Gold Creek Gas Plant was built in 1970 and is located approximately 50 km south of Grande Prairie, Alberta (Figure 1). Major onsite operations include inlet separation, gas dehydration, amine gas sweetening and regeneration. Historical operations at the site included the use of an evaporation pond, amine pond and burn pit to store processing byproducts including brine, amines and natural gas liquids. The evaporation pond, amine pond and burn pit were decommissioned in June 1993, and subsequently reclaimed in 1995.

A groundwater monitoring network was initially installed at the Gold Creek Gas Plant in 1986 and semi-annual groundwater monitoring has been conducted at the site each year from 1986 to present. Historical groundwater quality results indicate the background chloride concentration at the site is approximately 10 mg/L. Chloride concentrations as high as 60,000 mg/L were first noted downgradient of the ponds in 1986.

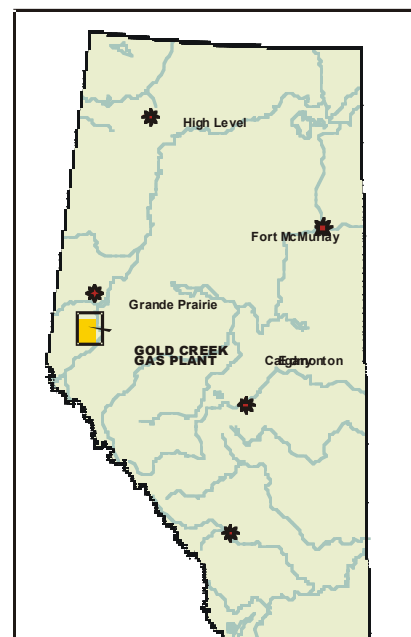


Figure 1. Site Location

In 1999, it was determined that subsurface chloride originating from the former pit/ponds was likely discharging to a wetland area at the north end of the lease. A detailed assessment of subsurface chloride, and the design and construction of a remediation system was subsequently initiated in 2000.

Site Hydrogeology

The plant is located on a gentle northwest slope at an elevation of 710 m above sea level (asl). The nearest watercourse in the vicinity of the plant is an ephemeral stream approximately 400 m northwest of the plant. This stream flows northeast and discharges to the Smoky River located approximately 4 km northeast of the Gas Plant.

The Gold Creek Gas Plant is underlain by firm, grey or brown, clayey till, with a trace of pebbles and coal fragments. The till contains interbedded lenses of sandy till, silt and sand which are more frequently observed at the north end of the site. The horizontal continuity of the sandy till, silt and sand units appears to be limited. The clay deposits overlay bedrock from the Upper Cretaceous period at a depth of approximately 50 m.

Topographic gradients in the plant vicinity and groundwater table elevations indicate that shallow groundwater flow north of the plant site is directed northward towards a wetland area (Figure 2). The horizontal hydraulic gradient appears to decrease to the north and is approximately 0.01 m/m in the vicinity of monitoring well 88-8. In general, the hydraulic conductivity of the surficial deposits north of the plant is slightly higher than deposits within and south of the plant. The increased frequency and continuity of sand and gravel lenses north of the plant are likely responsible for this trend. The geometric mean of hydraulic conductivity values from the 13 wells north of the former pit/ponds is 2×10^{-7} m/s.

Groundwater flow velocity through the higher permeability units, such as the sand lenses, is expected to be higher than in the lower permeability clay till. Groundwater flow within the sands and gravel units may be as high as 25 m/year. The results of EM surveys conducted in 1992 and 1998 (Komex, 1992; Komex 1998), however, indicate that the apparent chloride plume is migrating north of the former pit/ponds at approximately 5 m/year. This is a reasonable estimate of the horizontal groundwater flow velocity at the site.

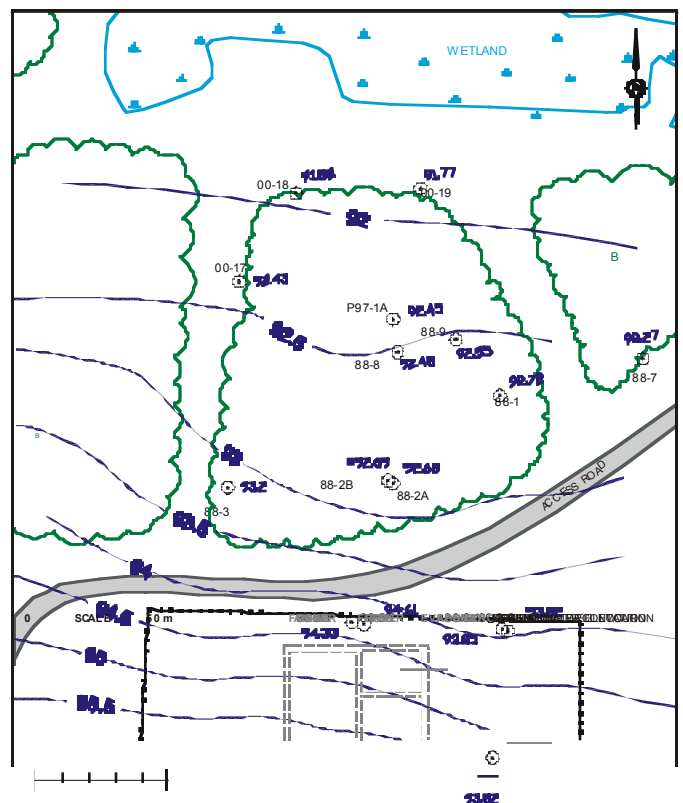


Figure 2. Groundwater Flow Map

Chloride Plume Assessment

In 2000, additional assessment work was completed north of the former pit/ponds to better delineate the chloride plume and design an effective remediation system. Assessment work included an EM 31 terrain conductivity survey, completing 26 vertical conductivity boreholes, and installing additional groundwater monitoring wells.

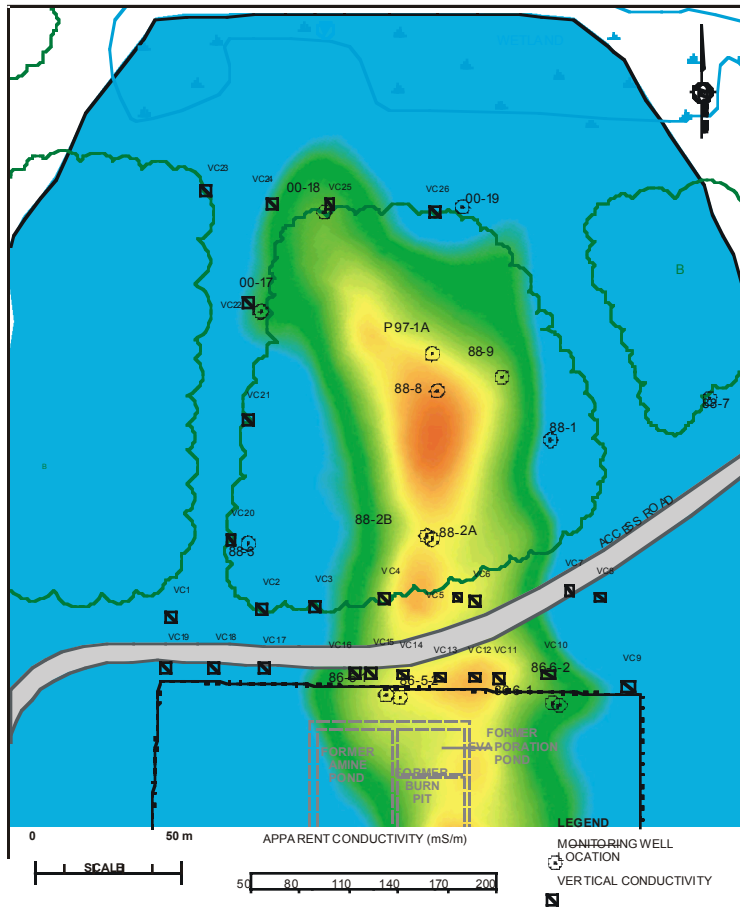


Figure 3. EM31 Apparent Conductivity Data Vertical Dipole

maximum apparent conductivity values recorded by the EM31 survey. Elevated soil conductivities were observed between 1m and 8m below ground surface (bgs) immediately north of the former pit/ponds and between 0 and 4 m bgs at the north end of the chloride plume.

Twenty-three groundwater monitoring wells have been installed north of the former pit/ponds. Groundwater samples are collected twice a year from these wells and are analyzed for various indicator parameters including chloride. Groundwater quality results from these three wells and 20 other wells located north of the former pit/ponds, suggest the 3,000 mg/L contour near the toe of the plume is less than 30 m wide. Slightly elevated chloride concentrations of approximately

An EM 31 survey was completed north of the former pit/ponds in November 2000. Apparent conductivity values ranged from less than 80 mS/m to approximately 150 mS/m and identified a 200 m long apparent conductivity anomaly initiating from the former pit/ponds. The width of the anomaly narrowed from approximately 100 m in the vicinity of former pit/ponds, to approximately 30 m wide adjacent to the wetland area (Figure 3).

Twenty-six vertical conductivity profiles were measured north of the former pit/ponds using a Geoprobe SC 400 instrument (Figure 3). The conductivity profiles collected from each borehole were used to delineate the vertical distribution of dissolved chlorides and to confirm the lateral extents of the plume identified by the EM survey. The maximum soil conductivity readings in the vertical conductivity profiles were found to be approximately coincident with the

300 mg/L were detected in the wetland in 2000. Groundwater quality data were used to calibrate the EM31 and vertical conductivity geophysical data.

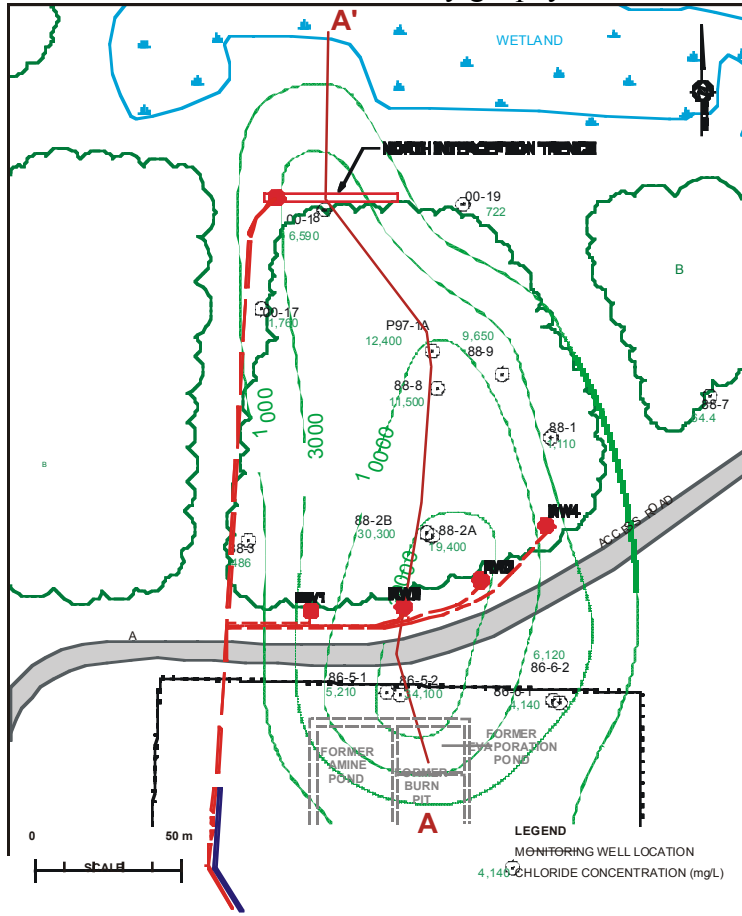


Figure 4. Areal Chloride Distribution Map

The integrated assessment results provide a good understanding of the areal (Figure 4) and vertical (Figure 5) distribution of the chloride plume. Based on the distribution of chlorides in the subsurface and an estimated porosity of 30%, it is estimated that approximately 240,000 kg of chloride is dissolved within the groundwater downgradient of the former ponds.

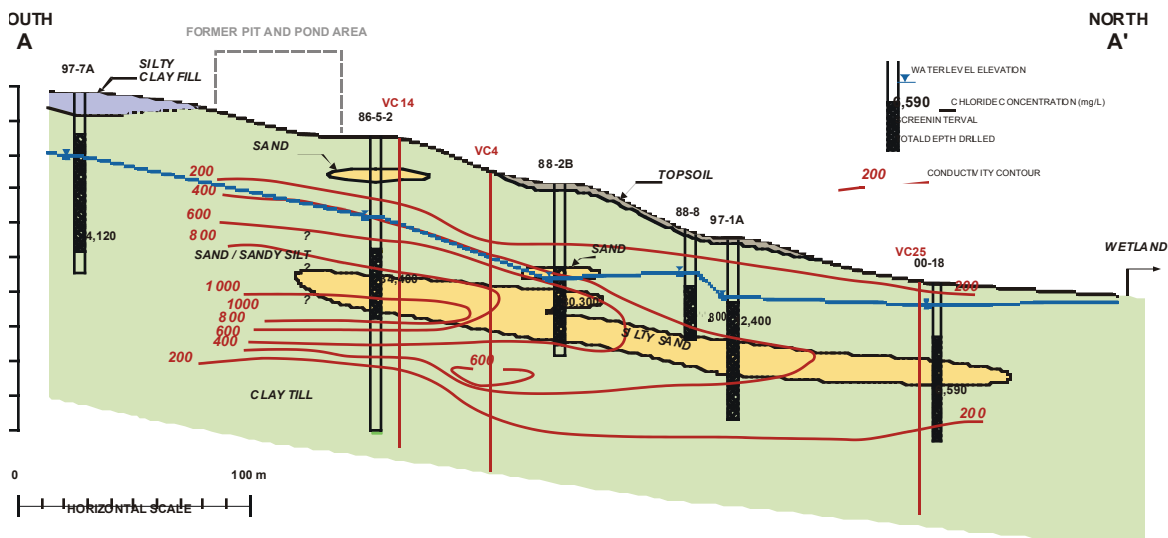


Figure 5. Vertical Chloride Distribution Map

Remediation System Design

The delineation results suggested that the chloride plume has migrated to the wetland area and has impacted surface water quality. The primary remediation objective was to protect the wetland from further impact by:

- 1) Capturing chloride impacted groundwater and prevent elevated chloride from discharging to the wetland.
- 2) Remove dissolved chloride from the subsurface.

In order to achieve the objectives, a groundwater interception system consisting of a 50 m long groundwater recovery trench and four groundwater recovery wells was installed (Figure 4).

The trench dimensions were designed to intersect the maximum observed chloride concentrations north of the aspens. By installing a 50 m long trench to a depth of 4.5 m bgs excellent capture of the chloride plume was ensured.

Four large diameter groundwater recovery wells were installed downgradient of the former pit/ponds to recover the highest chloride concentrations from the subsurface. Since elevated chloride concentrations at this location are observed between 1 and 8 m bgs, installation of a groundwater interception trench was considered unfeasible. Large diameter wells were installed to increase well productivity and wellbore storage.

Numerical Simulations

The number of required recovery wells and the spacing of the recovery wells was evaluated through the use of a simple numerical simulation. Simulations were completed using Groundwater Modelling System 3.1 (GMS 3.1) and Modflow 96 software.

The model domain was 680 m long (north-south), 1,100 m wide (east-west) and contained 6,724 cells. The clayey till was assigned a hydraulic conductivity of 2×10^{-7} m/s and a specific yield of 0.06. The east and west model boundaries were assigned a no flow condition and the north boundary was assigned a specified head condition equal to the approximate elevation of the northern wetland. The south boundary was also assigned a specified head corresponding to a north to south hydraulic gradient of 0.015 m/m. The steady state solution for the model is a uniform hydraulic gradient dipping to the north at a slope of 0.015 m/m. This steady state solution was used as the initial condition for each of the tested remediation system scenarios.

Simulation results indicate that a series of four recovery wells, located approximately 30 m north of the former pit/ponds area and spaced approximately 25 m apart, will be able to capture groundwater flowing northward from the former pit/ponds area. The recovery wells were simulated using a constant pumping rate of 0.4 m³/day. By pumping groundwater from the

recovery wells, a zone of hydraulic capture is predicted to develop around each well. A capture zone is defined as the aquifer volume within which all groundwater ‘particles’ flow into the well and are captured. The capture zones for the simulated wells are predicted to overlap and form a capture zone that envelops nearly the entire plume (Figure 6).

The model results also indicate that the recovery trench, located north of the aspen stand will be able to prevent chloride impacted groundwater from discharging in to the wetland area. Simulation results indicated that the trench productivity would decrease rapidly from approximately 10 m³/day during the initial dewatering to approximately 2 m³/day after one year of pumping (Figure 7).

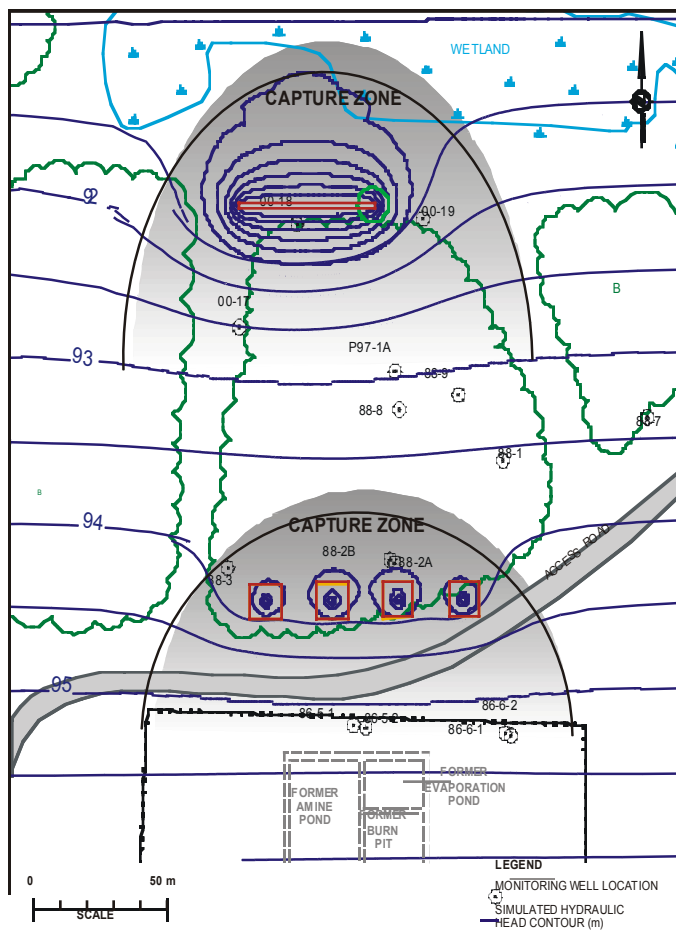


Figure 6. Predicted Hydraulic Head Distribution After Six Months

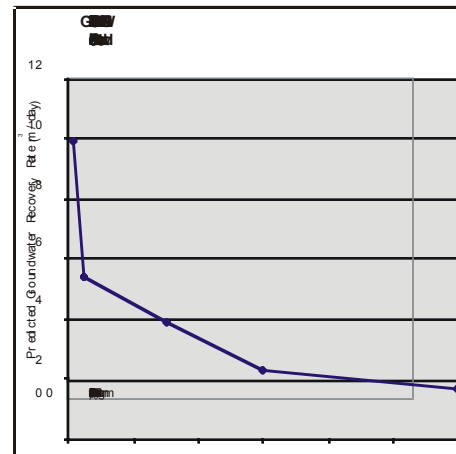


Figure 7. Predicted Groundwater Recovery Rate

Remediation System Construction

Installation of the trench, groundwater recovery wells, and buried water lines was completed in November 2001. The interception trench was excavated with a backhoe and backfilled with 1/2 inch washed gravel. Trench dimensions are 50 m long, 1.5 m wide, and 4.5 m deep. Groundwater intercepted by the trench is drained by a large diameter recovery well on the west end of the trench.

Four large diameter recovery wells (762 mm in diameter) were drilled north of the former pit/ponds with a caisson rig and completed to a depth of 8 m with a plastic culvert. Submersible pumps were suspended from a 4 inch PVC pipe attached to one side of the culvert. Recovered groundwater is pumped from each of the recovery wells to a metering building via buried 1 inch polyethylene water lines. The primary functions of the metering building are to:

- 1) Facilitate monitoring of the pumping rates and chloride production rates.
- 2) Control the pumping rate of each well.
- 3) To treat the recovered groundwater prior to being discharged to the existing produced water tanks.

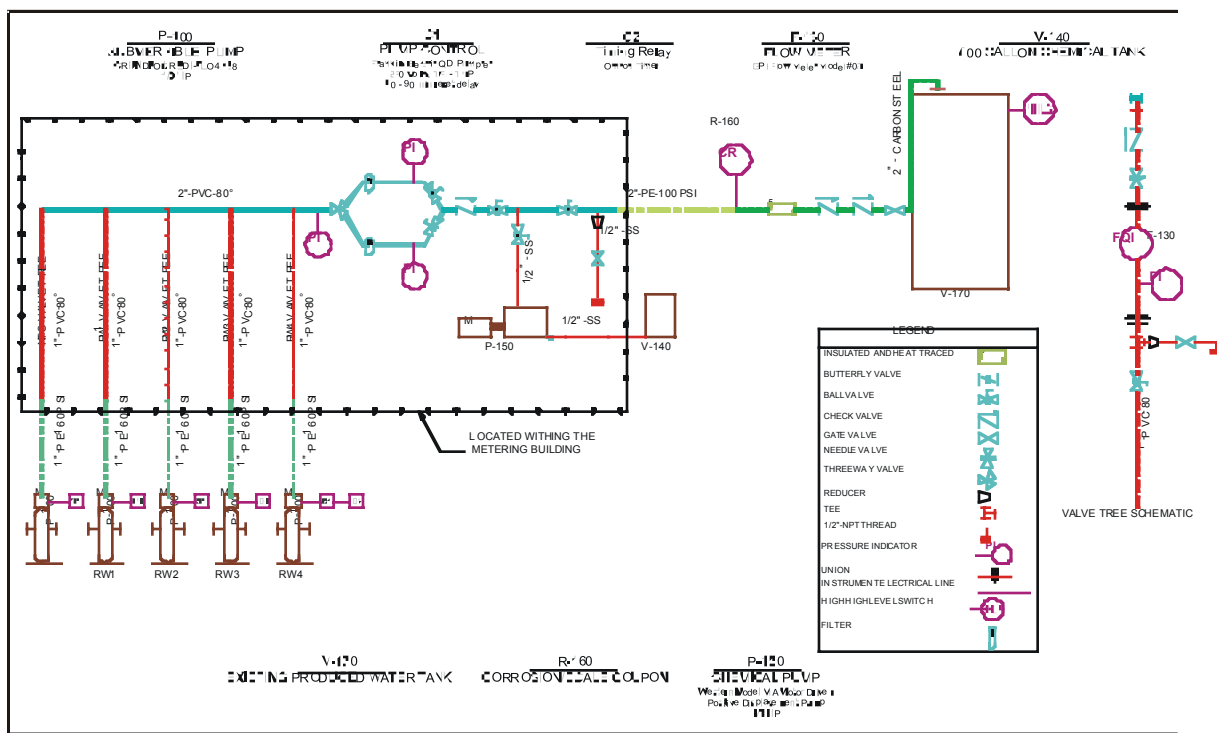


Figure 8. Groundwater Recovery System Process and Instrumentation Design

The recovered shallow groundwater will be mixed with sour produced water in the produced water tank prior to being disposed by deep well injection. Components of the metering building include a produced water manifold, a chemical pump, sampling ports, pressure gauges, water filters and flow meters (Figure 8).

The inlet manifold facilitates sampling and pumping rate control for each of the recovery well, prior to merging into a common 2 inch line. As precipitation of minerals or corrosion of the metal piping of the disposal system could impact gas plant operations recovered groundwater is treated by filtering and injecting 1,000 mg/L of Baker Petrolite CRW132 to prevent potential scaling, corrosion, oxidation and bacterial growth.

Remediation System Operations

The groundwater remediation system was commissioned on July 20, 2002. Initial production of the system is approximately 5 m³/day of recovered groundwater and approximately 50 kg/day of recovered chloride. For a three month period the recovered water will be discharged to a temporary 60 m³ above ground storage tank. Regular testing of the recovered water will be conducted throughout this period in order to test the effectiveness of water treatment. Provided the water treatment is successful the recovered groundwater will be diverted to the onsite produced water tank for deepwell injection in November, 2002.

Chloride removal from the subsurface will be quantified through monthly measurements of recovered water volumes and chloride concentrations at each recovery well. The hydraulic capture efficiency of the system will be evaluated through regular measurement of groundwater levels in surrounding monitoring wells.

Future work includes the development of a site specific remediation goal based on ecological risk to the aspen stand and the wetland. The recovery system is anticipated to be in operation for approximately 10 years.

References

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