Feasibility Study Report: Burrton Oil Field Brine Plume

Kansas Department of Health and Environment

C2-040-73660
Project No. 118827

Revision 0
1/24/2020

Feasibility Study Report: Burrton Oil Field Brine Plume

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Kansas Department of Health and Environment
C2-040-73660
Topeka, Kansas

Project No. 118827

Revision 0
1/24/2020

prepared by

Burns & McDonnell Engineering Company, Inc.
Kansas City, Missouri

INDEX AND CERTIFICATION

Kansas Department of Health and Environment
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Certification

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Jennifer A. Kessler, P.E., Kansas No. 26258

Date: 1-24-2020

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LIST OF ABBREVIATIONS

Abbreviation	**Term/Phrase/Name**
BER	Kansas Bureau of Environmental Remediation
BOR	Kansas Bureau of Reclamation
BMcD	Burns & McDonnell Engineering Company, Inc.
DWR	Kansas Division of Water Resources
ED	Electrodialysis
EDR	Electrodialysis Reversal
EPA	United States Environmental Protection Agency
FRP	Fiberglass Reinforced Plastic
FS	Feasibility Study
GC	General Contractor
GMD2	Groundwater Management District No. 2
gpm	Gallons per Minute
HDPE	High Density Polyethylene
IGUCA	Intensive Groundwater Use Control Area
I/O	Input/output
KCC	Kansas Corporation Commission
KDHE	Kansas Department of Health and Environment
KGS	Kansas Geological Survey
kWh	Kilowatt-Hour
KWO	Kansas Water Office
mg/L	Milligrams per liter
NPDES	National Pollutant Discharge Elimination System
O&M	Operations and Maintenance

Abbreviation	**Term/Phrase/Name**
OPC	Opinion of Probable Cost
RI	Remediation Investigation
RO	Reverse Osmosis
SCADA	Supervisory Control and Data Acquisition
SDI	Silt Density Index
SMCL	Secondary Maximum Contaminant Limit
TMDL	Total Maximum Daily Load
UIC	Underground Injection Control
VFD	Variable Frequency Drive
WIMAS	Water Information Management and Analysis System
WWC5	Water Well Completion Records Database
ZLD	Zero Liquid Discharge

1.0 EXECUTIVE SUMMARY

The Kansas Water Office (KWO) has funded this Feasibility Study (FS) Report through the Kansas Department of Health and Environment (KDHE) to examine possible remediation alternatives to address the oil field brine plume in the Equus Beds Aquifer near Burrton, Kansas. The plume was created by produced brine seepage into the aquifer from nearby oil field development primarily between 1931 and 1943. The groundwater plume has high chloride concentrations up to 1,600 milligrams per liter (mg/L), rendering it unusable for most purposes. This FS Report develops and evaluates alternatives for targeted remediation of the plume.

The Remediation Investigation (RI) Report that accompanies this FS Report identified four remediation site alternatives, which are illustrated in Figure 1-1. Restoration of the entire project area is not currently feasible due to the large mass of chloride present and the amount of water that would have to be extracted; however, targeted partial remediation can be implemented at strategic site(s), focusing on “hot spots” of particularly high chloride concentrations within the plume. It is anticipated that a single site would be selected for implementation initially with a flow of 600 gallons per minute (gpm) split among two or three remediation wells to withdraw high-chloride water. The wells would be situated in a line perpendicular to the flow of groundwater, with their overlapping cones of depression providing a zone of capture that mitigates further eastward advancement of the highest chloride concentrations in the local area. Remediation could be implemented later at additional sites and/or as an expansion of the initial site to increase its area of capture.

A variety of alternatives are available for targeted remediation of the chloride plume including disposal and/or treatment:

- **Deep well injection** involves pumping the high-chloride water to a deep disposal well where it is directed into deep, confined rock formations drilled thousands of feet below the lowermost underground source of drinking water. This results in the water being removed from the short-term hydrologic cycle. It is anticipated that a single deep disposal well would suffice for the initial remediation flow of 600 gpm from a single site. Permitting is a significant feasibility consideration for deep well disposal. Class I disposal well construction and permitting has been assumed for purposes of this evaluation.

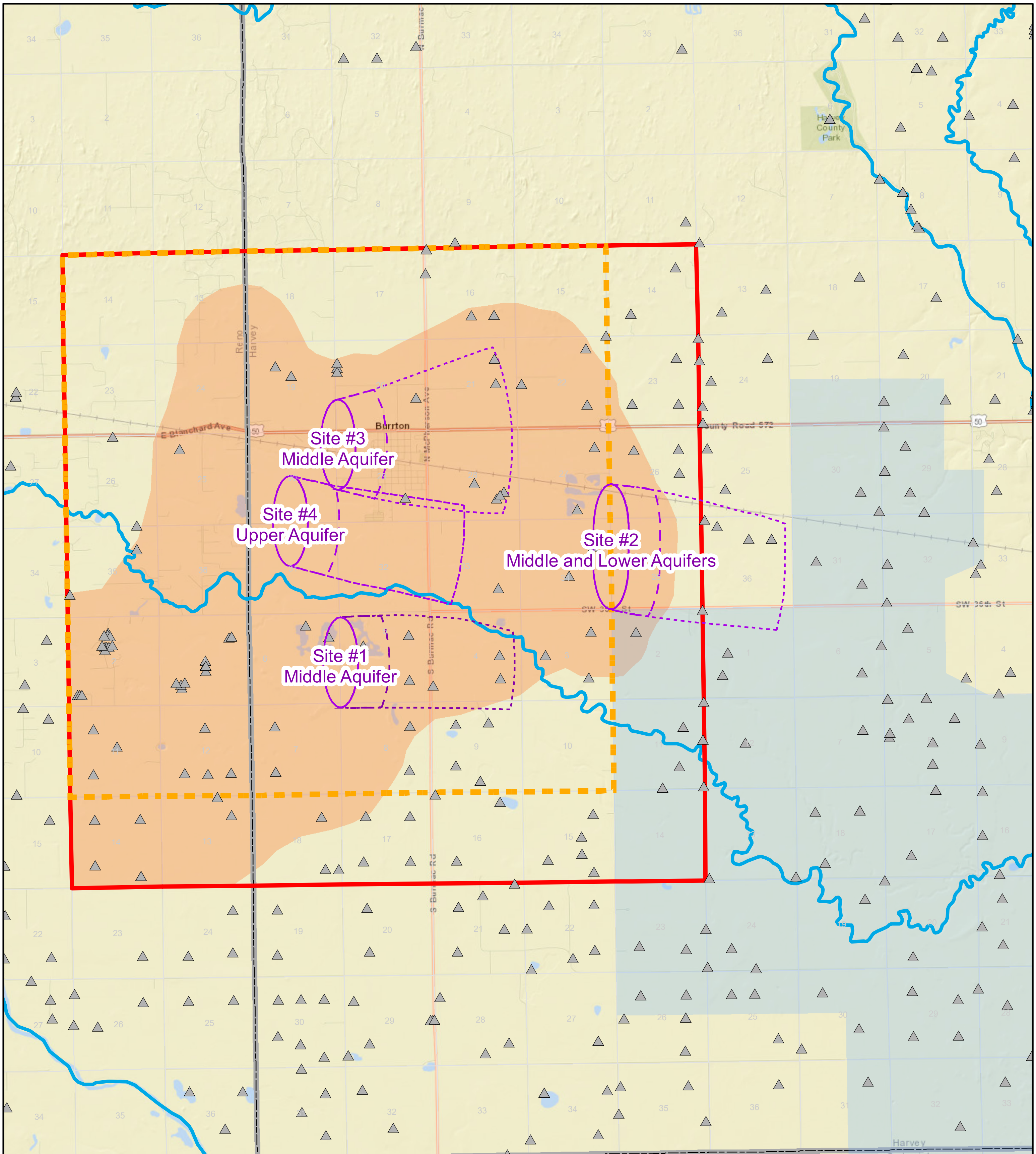
- **Evaporation ponds** are not a feasible option in this case due to the limited net evaporation rates in the area, resulting in a large land requirement and the risk of re-contamination of the underlying aquifer.

- **Blending** would entail diluting the high-chloride water with low-chloride groundwater and/or surface water to meet water quality standards applicable to a beneficial use and/or discharge to surface water. This allows the blended water to be utilized rather than simply disposed. In the absence of flow and water quality data for Kisiwa Creek, for purposes of this report it has been assumed that low-chloride wells would be installed to provide blending water. A large number of low-chloride wells would be required to provide the necessary degree of blending, starting at 15 wells (3,000 gpm) for Site 4, the lowest-chloride site. Consequently, blending does not appear to be a feasible option in this case, although it is recommended that water quality and flow data be collected for Kisiwa creek to check the viability of using primarily creek water for blending.

- **Treatment** to remove chloride from the groundwater is another option that would allow the water to be discharged and/or put to a beneficial use. Reverse osmosis (RO) treatment has been assumed for purposes of this report, although other technologies such as electrodialysis (ED) can be further evaluated during conceptual design once site-specific water quality is available. Any treatment technology will have a liquid or solid waste stream, but the volume of the waste is minimized compared to deep well disposal of the entire remediation water stream. For example, RO allows for recovery of approximately 80 percent of the remediation water for beneficial use or discharge, with only 20 percent comprising the concentrated waste brine that would need to be disposed of via deep well injection.

For each site, the feasible remediation alternatives of 1) deep well disposal and 2) treatment were developed at a conceptual level of detail covering their specific implementation at each of the four alternative sites. It is beyond the scope of this report to recommend a specific alternative; rather, information on the alternatives is presented for consideration and input by KDHE, KWO, and stakeholders. A summary comparison of the four site alternatives is presented in Table 1-1. A summary comparison of the remediation method alternatives is presented in Table 1-2.

It is recommended that KDHE and KWO seek input from stakeholders such as GMD2, landowners, well users, water right holders, and the public to guide the decision of whether to implement an initial remediation project, and if so, which site to develop initially and which remediation method to use. Should KDHE and KWO decide to move forward with a particular remediation site and method, the path forward would start with a hydrogeologic investigation to provide the design information for the final well locations, and determining how the project will be funded and who will be responsible for operations. Additional recommendations include collecting water quality and flow data for Kisiwa Creek to check the viability of using primarily creek water for blending.



Legend

- 5-Year Potential Impact Areas
- 25-Year Potential Impact Areas
- Remediation Sites
- Wichita Wellfield Area (USGS)
- Active Water Rights DWR WIMAS 10/15/2019
- Burrton IGUCA Boundary
- Project Area Boundary
- Potential Groundwater >250ppm Chloride (Within Project Area)
- PLSS Sections
- County Boundaries

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Figure 1-1

Potential Remediation Site Locations

Table 1-1: Site Alternatives Comparison

Parameter	Site 1	Site 2	Site 3	Site 4
Aquifer Zone Targeted for Remediation	Middle	Middle	Middle	Upper
Domestic Wells Downgradient from Capture Zone (25 Years)*	14	9	38	3
Water Rights Downgradient from Capture Zone (25 Years)	7	3	4	0
Aquifer zone for completion	Middle	Middle	Middle	Upper
Chloride concentration based on nearby monitoring wells	1,000 to 1,600 mg/L	800 to 1,000 mg/L	800 to 1,400 mg/L	600 to 800 mg/L
Anticipated chloride concentration in pumped remediation water**	1,000 to 1,300 mg/L	650 to 800 mg/L	650 to 1,100 mg/L	500 to 650 mg/L
Chloride removed (initial, assuming upper end of concentration range)	1,700 tons/year	1,100 tons/year	1,400 tons/year	900 tons/year
Number of remediation wells required	2	2	2	3
Distance between remediation wells	1,800 ft	1,800 ft	1,800 ft	800 ft
Width of zone of capture	3,600 ft	3,600 ft	3,600 ft	2,400 ft
Remediation flow for initial implementation	600 gpm total, 300 gpm per well	600 gpm total, 300 gpm per well	600 gpm total, 300 gpm per well	600 gpm total, 200 gpm per well
Nearby wells and water rights potentially subject to net pumping effect	Several	Several	Few	Few

* The KDHE Water Well Completion Records Database (WWC5) database does not include all domestic wells in Kansas, especially those drilled prior to 1974; additional domestic wells may be present.

** The anticipated chloride concentration in the pumped remediation water is less than that in the nearby monitoring wells because water from less contaminated zones of the aquifer is anticipated to cause some dilution during pumping.

Table 1-2: Remediation Alternatives Comparison

Parameter	No Action	Alternative 1: Deep Well Disposal	Alternative 2: Treatment
Downgradient Domestic Wells Affected by Plume (25 Years)	Up to 38 depending on site	Reduced number affected and/or reduced concentrations	Reduced number affected and/or reduced concentrations
Downgradient Water Rights Affected by Plume (25 Years)	Up to 7 depending on site	Reduced number affected and/or reduced concentrations	Reduced number affected and/or reduced concentrations
Regulatory and Permitting Requirements	• IGUCA remains in effect and is periodically updated	• IGUCA remains in effect and is periodically updated • GMD2 oversight • DWR water right application with GMD2 review • KDHE BER Coordination • 600 gpm disposal well permitted through KDHE UIC (Class I) or KCC (Class II) with monthly reporting	• IGUCA remains in effect and is periodically updated • GMD2 oversight • DWR water right application with GMD2 review • KDHE BER Coordination • 140± gpm disposal well permitted through KDHE UIC (Class I) or KCC (Class II) with monthly reporting • KDHE NPDES permit for Kisiwa Creek outfall with periodic reporting
Availability of Remediation Water for Use	No effect, water remains in aquifer	Unavailable, water is removed from hydrologic cycle	460± gpm available for use or discharge
Potential net pumping effect	None	Possible, especially with Sites 1 and 2	Possible, especially with Sites 1 and 2
Waste Stream Injected for Deep Well Disposal	None	600 gpm	140± gpm
Energy Consumption	None	170,000 kWh/year	1,030,000 kWh/year
Space required, property or easements	None	3.0 ac	Site 1: 9.5 ac Site 2: 17.0 ac Site 3: 16.5 ac Site 4: 9.5 ac
Visible Infrastructure	None	Disposal equalization tanks and an electrical panel with shade structure near each remediation well	Disposal equalization tanks, electrical building, three treatment system containers, electrical panel with shade structure near off-site remediation well, and outfall structure at Kisiwa Creek

Parameter	No Action	Alternative 1: Deep Well Disposal	Alternative 2: Treatment
Opinion of Probable Capital Cost	None	Each Site: $5,300,000	Site 1: $13,100,000 Site 2: $14,000,000 Site 3: $13,900,000 Site 4: $13,100,000
Opinion of Probable Annual O&M Cost	None	$103,000	$470,000
Opinion of Probable Lifecycle Cost (capital plus 20-year present value of O&M)	None	Each Site: $6,500,000	Site 1: $18,500,000 Site 2: $19,400,000 Site 3: $19,300,000 Site 4: $18,500,000

DWR = Kansas Division of Water Resources, IGUCA = Intensive Groundwater Use Control Area, NPDES = National Pollutant Discharge Elimination System, BER = Bureau of Environmental Remediation, KCC = Kansas Corporation Commission, kWh = kilowatt-hour, ac = acre, O&M = operation and maintenance

Note: For comparison, the probable cost to redrill a typical domestic well (replace with a deeper well completed in a different zone of the aquifer in order to access better quality water) would be approximately $5,000 to $10,000 per well for a 100 ft deep well including a pump, 30 percent contingency, and 15 percent engineering / project management.

2.0 INTRODUCTION

The KWO has funded this FS Report through KDHE to examine possible remediation alternatives to address the oil field brine plume in the Equus Beds Aquifer near Burrton, Kansas. The groundwater plume has high chloride concentrations up to 1,600 mg/L, rendering it unusable for most purposes. This FS Report develops and evaluates alternatives for targeted remediation of the plume.

2.1 Background

The RI Report that accompanies this FS Report described the history and characteristics of the Burrton chloride plume background in detail. In summary, the plume was created primarily between 1931 and 1943, when produced brine from nearby oil field development was disposed of in part via evaporation ponds. Brine in these surface ponds often escaped containment via downward seepage into the shallow groundwater of the underlying Equus Beds Aquifer (*KCC, 2007)*. By the mid-1940s the practice of brine disposal into evaporation ponds was largely eliminated and approximately 98% of all produced brine from the Burrton Oil Field was being routed to either deep or intermediate disposal wells to avoid further degradation of the Equus Beds Aquifer.

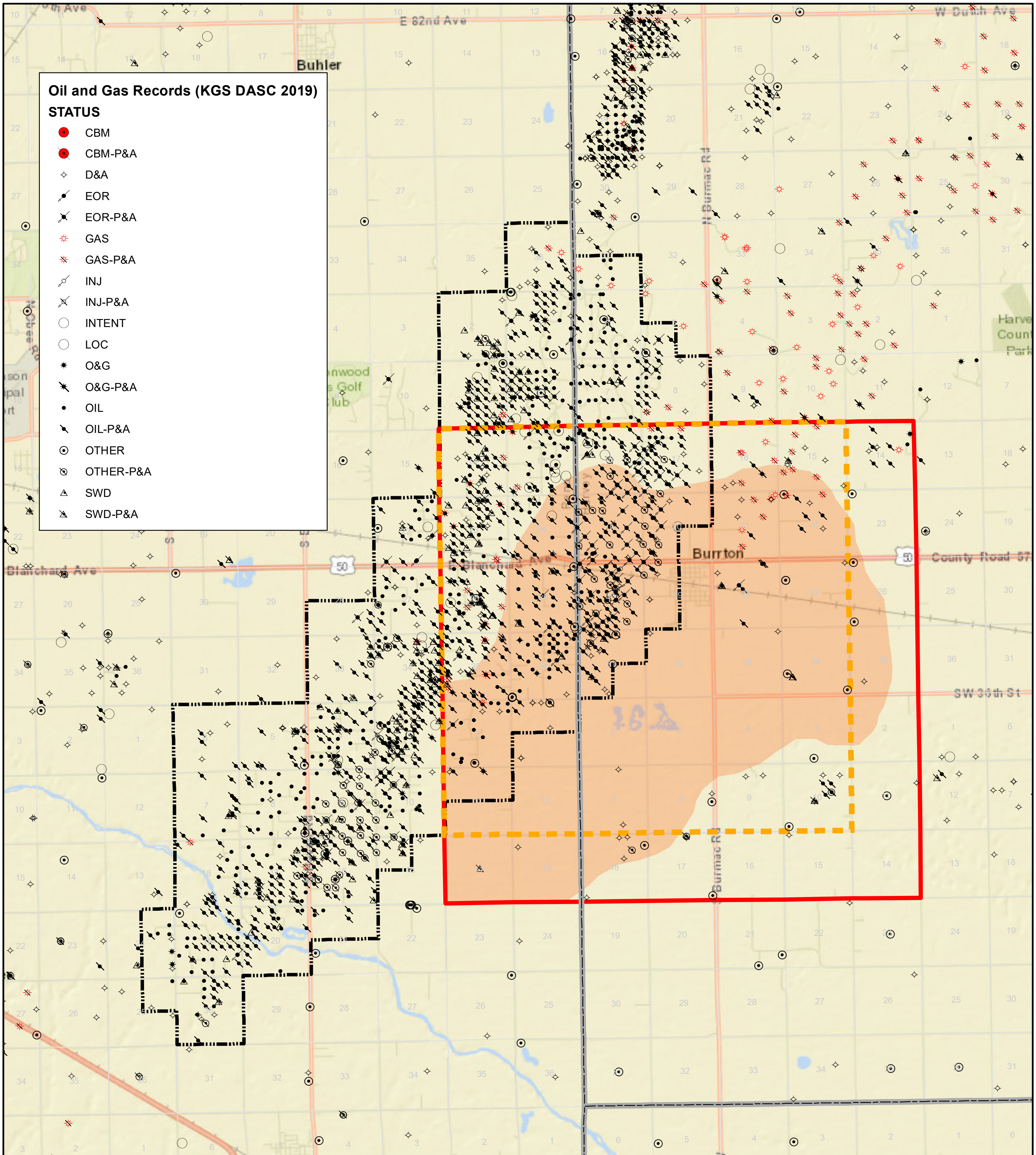
By the 1940s, seepage of oil field brine into the aquifer had created a large area of intersecting plumes with groundwater chloride concentrations in excess of useable standards for drinking water, agricultural irrigation, and most industrial applications. The average chloride concentration of disposed brine has been estimated at 96,000 mg/L, resulting in approximately 1.9 million tons of salt contaminating the aquifer (*Report of the Burrton Task Force, 1984*). Background groundwater concentrations for chloride in the project area (uncontaminated zones) have been reported below 30 mg/L. Measured chloride concentrations in the plume have approached 3,000 mg/L, significantly above the Environmental Protection Agency (EPA) secondary maximum contaminant limit (SMCL) for drinking water of 250 mg/L and the typical limit for agricultural irrigation use of approximately 350 mg/L *(KDHE Bureau of Environmental Remediation Guidance Policy #BER-RS-13A, 2005)*. Over time, the plume has undergone dispersion and eastward migration, generally following the natural groundwater gradient at a rate of approximately 0.8 to 1.0 feet/day *(Whittemore, 2012)*. The higher density of the brine also causes downward vertical migration within the aquifer.

The RI Report characterized the current state of the chloride plume. In 2018, chloride concentrations in the plume were measured as high as 1,600 mg/L. The area with chloride concentrations above 250 mg/L as of 2018 is illustrated in Figure 2-1. Movement of the leading edge of the brine at the eastern edge of the project area is anticipated to accelerate due to aquifer materials with a higher hydraulic conductivity, and a natural increase in the hydraulic gradient.

2.2 Remediation Site Alternatives

The RI Report identified four remediation site alternatives, which are illustrated in Figure 2-2. As explained in the report, restoration of the entire project area to pre-contamination conditions or the chloride SMCL of 250 mg/L is not currently feasible, given the large mass of the chloride distributed over 30 square miles of areal extent. This is primarily due to the amount of groundwater that would have to be removed and treated or pumped to disposal. The project area is located north of the Arkansas River which contains naturally occurring high concentrations of chloride. Pumping large quantities of groundwater from the project area (above approximately 8,000 gpm) would induce the infiltration of high-chloride surface water into the aquifer from the Arkansas River, reducing the effectiveness of net chloride mass removal from the project area (*Burns & McDonnell, 2007*).

Full remediation of the plume to ambient or background concentrations is not currently feasible; however, targeted partial remediation of the chloride plume can be implemented at strategic site(s), focusing on "hot spots" of particularly high chloride concentrations within the plume. This would involve installing remediation wells to withdraw high-chloride water, mitigating further downgradient degradation and potentially restoring access to water of usable quality. The four site alternatives identified in the RI Report were selected based on the available chloride concentration data, anticipated migration direction, and trends in the chloride concentrations at nearby monitoring wells. It is anticipated that a single site would be selected for implementation initially with a flow of 600 gpm split among two or three wells. The wells would be situated in a line perpendicular to the flow of groundwater, with their overlapping cones of depression providing a zone of capture that mitigates further eastward advancement of the highest chloride concentrations in the local area. The use of two or three wells is anticipated to provide a wider area of capture than a single well and allows for selective well screen depths to maximize capture of stratified chlorides within targeted zones of the aquifer. Remediation could be implemented later at additional sites and/or as an expansion of the initial site to increase its area of capture.



Legend

- Project Area Boundary
- Areas with Potential Groundwater >250ppm Chloride (Within Project Area)
- Burrton IGUCA Boundary
- Burrton Oil Field Field
- PLSS Sections
- County Boundaries

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Figure 2-1

Project Area with Chloride Concentrations over 250 mg/L

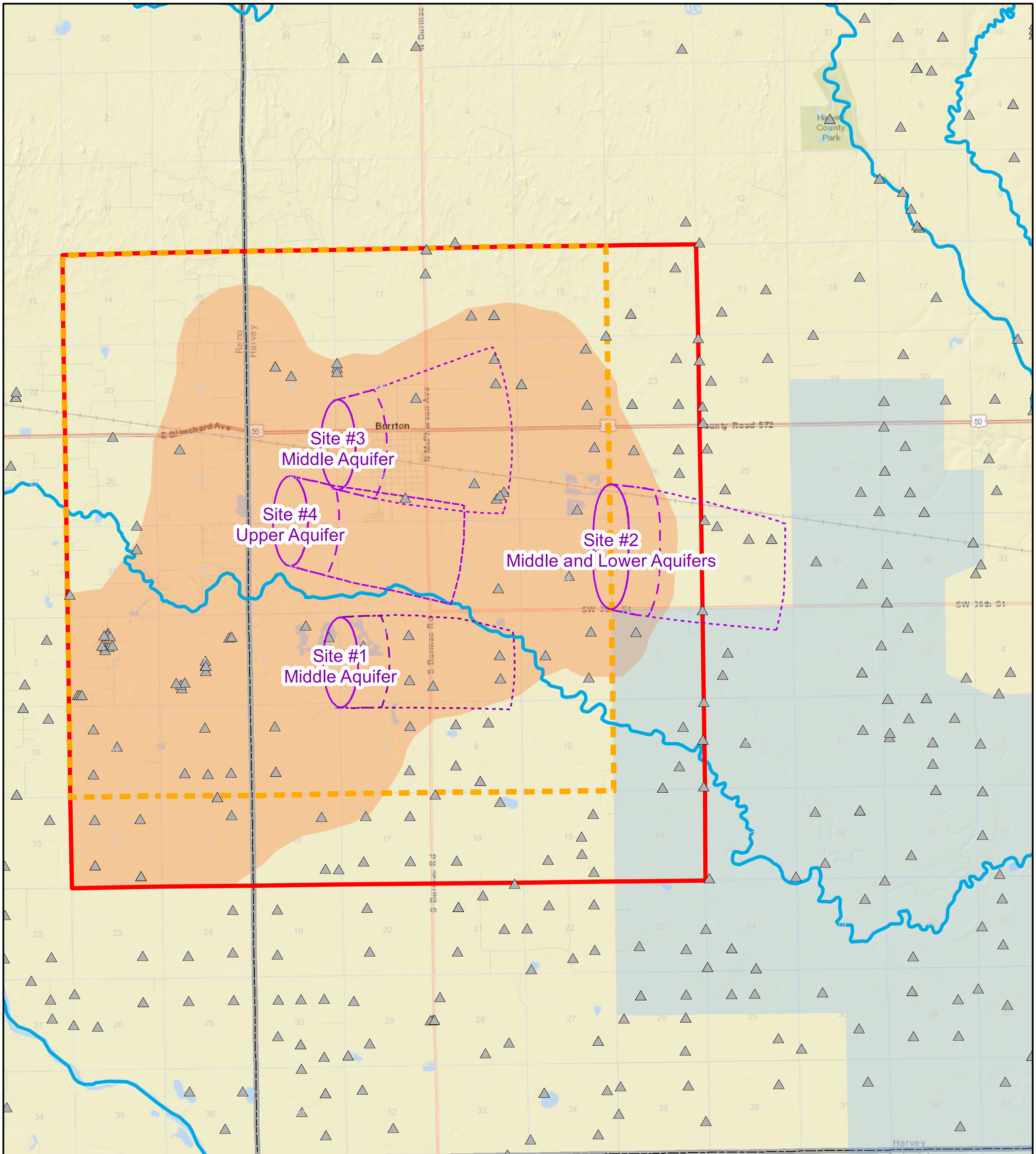

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Figure 2-2

Potential Remediation Site Locations

2.3 Scope of Work Description

The KWO has provided funding through the State's Water Plan to study the current state of the Burrton chloride plume and alternatives for remediation. The KDHE Bureau of Environmental Remediation (BER) is managing the project in coordination with the KWO under Work Order Number OS0407366001BMD. The RI Report provided a common set of updated maps of the extent of the chloride plume and recommended high priority locations for remediation wells and infrastructure common to viable remediation alternatives. As outlined in the *Remedial Investigation / Feasibility Study Work Plan, Burrton Oil Field Chloride Plume (Burns & McDonnell, 2019)*, components of this FS Report include:

- Identify and review water treatment technologies for the removal of chlorides
- Review anticipated waste stream management options from water produced by remediation wells and water treatment processes
- Identify the anticipated infrastructure to implement each selected alternative
- Determine health and environmental effects of the remedial action
- Develop opinions of probable cost for the remediation alternatives

3.0 GENERAL REMEDIATION TECHNOLOGIES

A variety of alternative technologies are available for targeted remediation of the Burrton chloride plume including disposal and/or treatment. Each technology is described in general terms in this section. The feasible remediation alternatives are further described in Section 4.0, covering their specific implementation at each of the four remediation sites.

3.1 No Action

The baseline alternative for the Burrton chloride plume would be no action which would result in continued plume migration to the east and southeast, as shown in Figure 2-2. Chlorides will continue to disperse with the natural groundwater gradient without intervention. The RI Report provides an assessment of the anticipated impacts to current and projected groundwater users and general chloride concentrations at which groundwater becomes unusable for domestic, municipal, and agricultural irrigation.

To illustrate areas of potential plume impact shown in Figure 2-2, approximate plume movement was evaluated based on continued migration in the direction of the observed groundwater gradient at a velocity matched to previous estimates of 1 foot per day. To evaluate the potential number of domestic wells and water rights (non-domestic) that could possibly be impacted, queries of the KDHE Water Well Completion Records Database (WWC5) and DWR/KGS Water Information Management and Analysis System (WIMAS) database were performed to retrieve a count of the number of domestic wells and water rights within each potential area of impact, which is shown in Table 3-1. Water rights are shown in Figure 2-2, and both water rights and domestic wells are shown in the larger-scale maps in Section 4.0. Note that the WWC5 database does not include all domestic wells in Kansas, especially those drilled prior to 1974; additional domestic wells may be present. Note also that the physical location of a well or use of a water right may vary from the approximate location contained in the databases and shown in the figure. Consequently, domestic wells with assigned geographic locations by quarter call may overlap and not be individually visible on the maps; however, the total count of domestic wells is based on the full query of domestic wells within the KDHE WWC5 database. Locations of water rights shown are based on the geographic location provided by the DWR WIMAS database, with a count provided by water right points of diversion.

Table 3-1: Site Alternatives Count of Downgradient Water Users (25 Years)

Parameter	Site 1	Site 2	Site 3	Site 4
Aquifer Zone Targeted for Remediation	Middle	Middle	Middle	Upper
Downgradient Wells from full width of "hot spot" that could ultimately be targeted for remediation:				
Downgradient Domestic Wells	27	16	47	11
Downgradient Water Rights	7	7	6	1
Downgradient Wells from initial 600 gpm remediation project capture zone*:				
Downgradient Domestic Wells	14	9	38	3
Downgradient Water Rights	7	3	4	0

* The exact number of downgradient wells could vary based on exact locations chosen for the remediation wells.

The illustrated potential impact areas are based on a conservative estimate assuming continued advective flow following the groundwater gradient (contaminant transport in the direction of the groundwater gradient only). The potential impact area of the remediation wells compared to a "no action" alternative is likely to be wider than the assumed capture zone due to other groundwater contaminant transport variables that carry contaminants cross-gradient such as seasonal groundwater pumping, areal changes in aquifer properties, plume density, dispersion, and diffusion. This is supported by previous reports which illustrate that while the plume is primarily migrating in the direction of the groundwater gradient, it is also increasing in total width and depth due to these other contaminant transport variables. Refinement of the anticipated areas of impact should be performed as part of the pre-design phase of a remediation project via a hydrogeologic investigation and groundwater model. The use of chloride transport groundwater modeling that includes the final conceptual location and yield of remedial wells would better illustrate the net impact of chloride transport with and without the conceptual remediation project

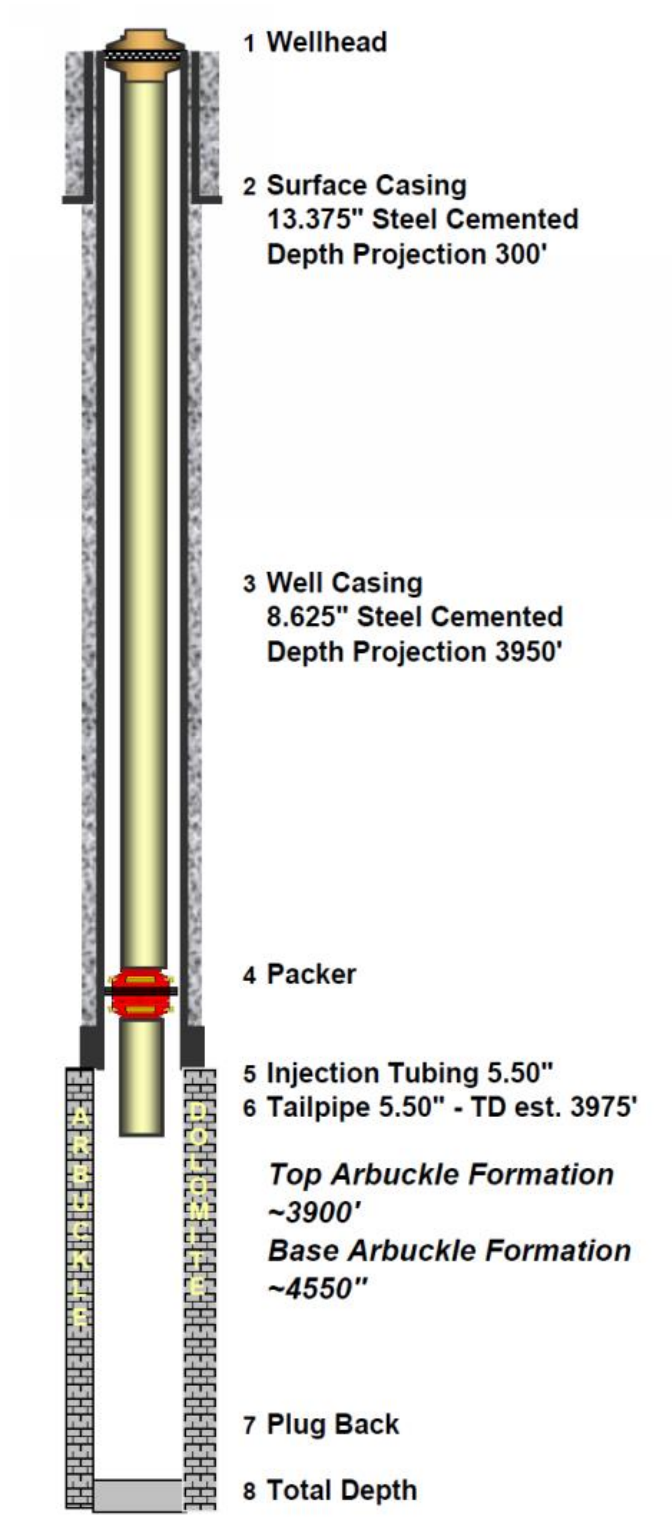
The users counted in Table 3-1 may or may not be impacted by the chloride plume or benefit from nearby remediation, depending on zone of completion and local hydrogeologic dynamics. Most domestic wells are already completed within the shallow upper zone of the aquifer (<50 ft) so they may or may not be impacted by the plume regardless of remediation of the middle zone of the aquifer at Sites 1, 2, and 3. Some of the water rights may utilize deeper wells located in the upper to lower zones of the aquifer. It is outside of the scope of this report to determine likelihood of impairment or predict future chloride concentrations. Levels of chloride impairment may vary and could potentially affect the upper zone, even where the upper zone does not typically experience high chloride levels; seasonal upconing of the underlying brine has been reported in the Burrton area from shallow high capacity wells where adequate clay separation between the upper and middle zones of the aquifer is not present.

3.2 Deep Well Disposal

Remediation via deep well injection is a method of disposal that is commonly used for highly concentrated waste streams that cannot be discharged to a nearby water body or put to beneficial use. Deep well injection involves pumping the high-chloride water to a deep disposal well where it is directed into deep, confined rock formations drilled thousands of feet below the lowermost underground source of drinking water. This results in the water being removed from the short-term hydrologic cycle.

It is anticipated that a single deep disposal well located near the proposed remediation wells will suffice for the initial remediation flow of 600 gpm from a single site. This would require 5 ½-inch injection casing or tubing. Flows above 600 gpm would likely require 7-inch casing/tubing or an additional disposal well. A conceptual deep disposal well design is shown in Figure 3-1. The projected total completed depth of the disposal well would be approximately 4,500 ft and would be completed in the Arbuckle formation with an injection interval of approximately 600 ft; the projected top of the Arbuckle is 3,900 ft.

Figure 3-1: Conceptual Deep Disposal Well



(From T&C Consulting)

3.2.1 Permitting for Deep Well Disposal

Permitting is a significant feasibility consideration for deep well disposal. The State of Kansas has been granted primacy by the EPA for regulation of the construction, operation, and closure of injection wells used to place fluids underground for storage or disposal. The State of Kansas regulates Underground Injection Control (UIC) via KDHE and the KCC. The EPA classification of injection wells includes the following types that may be considered for deep well disposal of the Burrton remediation water:

- Class I wells are used to inject hazardous or non-hazardous wastes into deep rock formations. In this case, injection is anticipated into the Arbuckle formation. Class I wells are not allowed to be injected under pressure; water enters the well by gravity flow. Class I wells have more stringent construction requirements than Class II wells for surface casing, cementing, and injection tubing. More intensive logging, well testing, and monitoring equipment are also required. KDHE currently regulates Class I injection wells.

- Class II wells are used exclusively to inject fluids associated with oil and natural gas production. In this case, injection is anticipated into the Arbuckle formation. Injection to Class II wells would be under atmospheric pressure similar to Class I wells. Class II wells are constructed similarly to Class I wells, but with less stringent requirements for construction and permitting. Class II wells are currently regulated by the KCC.

- Class V wells are used to inject non-hazardous fluids underground. Most Class V wells are used to dispose of wastes into or above underground sources of drinking water, although in this case injection would be to the deep Arbuckle formation. At other locations throughout the United States, waste streams from remediation and water treatment processes have been permitted under Class V regulations while requiring actual construction of the well under Class I or II construction standards. The permitting complexity and recurring monitoring and compliance testing in some cases has been less than that required by a Class I permit. KDHE currently regulates Class V wells.

For purposes of this report, it is assumed that new Class I disposal well(s) would be constructed for disposal of the remediation water. If possible from a regulatory perspective, it would be preferable to permit the well as Class II, which typically would be less cumbersome and less costly in terms of permitting and monitoring even if the well is constructed to the more stringent Class I standards. Use of a Class II well was previously authorized by KCC for a similar project in the Hollow-Nikkel Oil Field study in the early 1990s. This prior project was also a KDHE funded project for oil field brine remediation. It is also possible that existing Class II well(s) in the area could be utilized or repurposed for injection of the remediation water. Several such potential disposal wells have been identified in the western part of the IGUCA, as shown in Figure 2-1. However, the majority of these existing wells are at a distance from the potential remediation sites and may not provide the necessary disposal capacity.

It should be noted that in recent years a task force made up of representatives from Kansas Geological Survey (KGS), KDHE and the KCC has monitored and studied the effects of saltwater injection on seismic activity in Kansas. The results of this study led to KCC releasing several orders affecting Harper, Sumner, Kingman, Sedgwick and Barber Counties, where large volume deep well injection was present, and a majority of earthquakes were experienced. The orders required the following stipulations for injection wells in these counties:

1. Made operators verify the vertical depths of the wells located inside the Areas of Concern,
2. Instituted a daily injection report to be filed monthly for all large volume Arbuckle wells,
3. Defined large volume as more than 5,000 barrels of water per day (approximately 145 gpm), and
4. Set a daily maximum injection level of 16,000 barrels per day (approximately 467 gpm).

The Burrton chloride plume resides in both Harvey and Reno county. Neither Harvey nor Reno counties have been directly affected by the KCC order, however the regulating bodies participating in the task force have recommended that the stipulations of this order guide the design and permitting of all proposed injection wells within the State of Kansas.

3.3 Evaporation Ponds

Non-discharging evaporation is a method of disposal that would involve directing the high-chloride remediation water into shallow evaporation basins that occupy a large land surface area. A low permeability liner such as a clay or high-density polyethylene (HDPE) liner would prevent significant downward seepage of the lagoon contents. The method is appropriate for regions that have a relatively warm, dry climate with high net evaporation rates. Once the water has evaporated, the remaining dry chloride salts could be sold if a market is available or could be disposed of at another location. A potential disposal method could be to transport the chloride salts to the existing Underground Cavern Stabilization Facility near Hutchinson, Kansas.

The project area is located in a climate where humidity and levels of precipitation are not favorable to the evaporation method. The annual average potential net evaporation in the project area (gross evaporation less precipitation) is 23 inches per year *(DWR 1996)*. For the proposed remediation flow of 600 gpm (970 acre-feet per year), the average net evaporation rate would require a minimum evaporation pond area of over 500 acres, and additional area would be required to accommodate years that are wetter than average. Due to the land intensive nature of this disposal method and secondary risk of re-contamination of the aquifer, evaporation is not a feasible option for waste stream disposal for the Burrton remediation water.

3.4 Blending

Blending is a common remediation method for high-chloride groundwater that allows the water to be put to a beneficial use or discharged to surface water. This method involves diluting the high-chloride water with low-chloride groundwater and/or surface water to meet the water quality standards of the proposed beneficial use or receiving water body. Evaluating specific beneficial uses is outside the scope of this report, although a preliminary analysis of discharge to nearby surface water bodies has been completed. Surface water discharge would be a necessary component of any blending remediation alternative. To be effective at hydraulic containment of the plume and for maximum chloride mass removal, the ability to discharge should be provided so that the remediation wells can continue to operate during seasons or other periods when a beneficial use may not be able to receive blended water. For the purpose of feasibility analysis, the nearest available stream with potential capacity to receive discharge is Kisiwa Creek which runs from the west central to southeastern portion of the Project Area.

The design chloride concentration goal for blending would be 150 mg/L for consistent compliance with applicable water quality criteria. The EPA National Recommended Water Quality Criteria for Aquatic Life includes an acute limit for chloride of 860 mg/L and a chronic limit of 230 mg/L. KDHE's Kansas Surface Water Quality Standards list a numeric criterion of 860 mg/L for surface water. Kisiwa Creek may allow for recharge into the Equus Beds Aquifer via creek bed infiltration; therefore, at a minimum the EPA secondary drinking water standard of 250 mg/L may be applicable to avoid potential degradation of the surrounding shallow groundwater. The chloride concentration assumed for blending feasibility analysis is 150 mg/L to provide a margin for consistent regulatory compliance in light of variable produced concentrations; marketable water quality for multiple beneficial uses; and compatibility with surface water discharge. This assumes that background chloride levels in Kisiwa Creek are relatively low. Sampling of Kisiwa Creek is recommended before finalizing a remediation strategy as neither water quality data nor flow data are currently available for a detailed analysis of discharge impacts to Kisiwa Creek.

For surface water discharge of remediation water, it is typically recommended to blend remediation well water with effluent wastewater, diverted surface water, or groundwater to reduce the concentration of chlorides prior to the point of discharge. A reduced concentration at the point of discharge decreases negative impacts to the environment and wildlife at the point of discharge resulting from localized changes in water quality. The City of Burrton has an NPDES permit to discharge treated effluent from its wastewater lagoons into Kisiwa Creek; however, the lagoons rarely discharge effluent, so blending with wastewater is not viable.

It may be viable to discharge the remediation water to Kisiwa Creek after blending with diverted creek water and/or groundwater. The Kansas Surface Water Register, maintained and updated by the KDHE, shows that Kisiwa Creek is the nearest registered stream that could be a candidate for surface water discharge from the Burrton plume area. Kisiwa Creek is approximately 1.75 miles south of Burrton and drains into the Little Arkansas River. Kisiwa Creek does not appear to have current Total Maximum Daily Load (TMDL) constraints for chloride. Review of the TMDLs and the 2018 303(d) list determined that Kisiwa Creek has the following impairments:

1. Biology (High Priority)
2. Biology Sediment (High Priority)
3. Total Suspended Solids (High Priority)

Chloride was not identified as an impairment for Kisiwa Creek or the Little Arkansas River segment affected by the flow from Kisiwa Creek. However, the Arkansas River segment that accepts flows from the Little Arkansas River has a Medium Priority Impairment for chlorides with average chloride concentrations between 75 and 471 mg/L between 1990 and 2005. The KDHE monitoring site SC728, for the Little Arkansas River by Valley Center just before the confluence, shows an average concentration of 104 mg/L with a maximum of 200 mg/L for that time period.

In the absence of flow and water quality data for Kisiwa Creek, for purposes of this report it has been assumed that low-chloride wells would be installed to provide blending water for the remediation wells. The low-chloride wells would be installed in a relatively low-chloride zone of the aquifer within approximately 2 miles upgradient or cross-gradient from the remediation site to minimize impacts to the chloride plume migration rate. The final location of low chloride wells at a distance of 2 miles from the remediation site should limit the magnitude of influence on the plume’s direction. Additional groundwater modeling and chloride transport evaluation during pre-design of the project would provide a more detailed analysis. Based on this approach, a relatively large number of low-chloride wells would be required to provide the necessary degree of blending, as shown in Table 3-2. For that reason, blending is only considered further in this report as a viable remediation method for Site 4, where a smaller amount of low-chloride water would be required. It is recommended that water quality and flow data be collected for Kisiwa creek to check the viability of using primarily creek water for blending.

Table 3-2: Blending Parameters

	Site 1	Site 2	Site 3	Site 4
Chloride concentration in remediation water (mg/L)	1,300	800	1,100	650
Chloride concentration in nearby low-chloride zone (mg/L)	100	50	30	50
Remediation water flow (gpm)	600	600	600	600
Required low-chloride flow (gpm) to attain blended chloride concentration of 250 mg/L	4,200	1,650	2,318	1,200
Total blended flow (gpm)	4,800	2,250	2,918	1,800
Required number of low-chloride wells, assuming 200 gpm each	21	9	12	6
Required low-chloride flow (gpm) to attain blended chloride concentration of 150 mg/L	13,800	3,900	4,750	3,000
Total blended flow (gpm)	14,400*	4,500	5,350	3,600
Required number of low-chloride wells, assuming 200 gpm each	69	20	24	15
Approximate distance to low-chloride wells (miles)	1.5	2.0	2.5	2.0

* Exceeds the estimated 8,000 gpm limit for pumping out of the Equus Beds Aquifer for remediation purposes before pulling high-chloride water from the Arkansas River into the aquifer (*Burns & McDonnell 2007*).

3.5 Treatment

Treatment to remove chloride from the groundwater is another option that would allow the water to be discharged and/or put to a beneficial use. As mentioned previously, evaluation of specific beneficial uses is outside the scope of this report. As with the blending alternative, any proposed beneficial use of treated water would also need to include provisions for discharge to surface water so that the remediation wells could continue to operate if a beneficial use is not able to take the treated water. Specific treatment technologies are discussed in the following subsections including reverse osmosis (RO), electrodialysis (ED), and RO with zero liquid discharge (ZLD). Ion exchange is not applicable for chloride removal and was not evaluated in detail. Note that every water treatment technology described will result in a liquid or solid waste stream. RO treatment has been assumed for purposes of this report, although other technologies can be further evaluated during conceptual design once site-specific water quality is available. The target effluent chloride level after treatment would be 150 mg/L to accommodate a wide range of potential beneficial uses and for compliance with anticipated surface water discharge regulatory requirements.

Treatment of the remediation water is preferable to deep well disposal from an environmental and regulatory perspective. For example, with the use of RO, approximately 80 percent of the remediation water would be recovered for beneficial use or discharge, with only 20 percent comprising the concentrated waste brine that would need to be disposed of via deep well injection. This would be consistent with KDHE policies favoring waste volume minimization, as opposed to disposing of the entire remediation flow via deep well injection. KDHE Policy Memorandum #91-1, February 1991, Revised June 19, 2018, Determination of the Types of Wastes Eligible for Disposal into Class I UIC Wells states in part:

> *The use of Class I UIC wells will be considered only for those wastes that cannot be feasibly treated, stored or disposed by other methods. Therefore, each new application for the disposal of wastes shall be accompanied by a report detailing the results of studies of alternate methods of waste treatment, storage or disposal technologies including an economic analysis based on a 30 year time period, justifying why subsurface disposal is considered the most feasible method of disposal. In the event the applicant receives a Class I UIC Permit, the permittee will be expected to develop, periodically update and implement an ongoing waste minimization program which addresses the wastes being directed to the Class I UIC disposal well(s).*

Memorandum #91-1 provided the following long-term benefits of treating and reducing the volume of wastewaters into deep wells:

- Water resources stay in the short-term hydrologic cycle.
- Preserves pore space for those wastewaters and wastes that cannot be feasibly handled by other methods.
- Reduces the potential for induced seismicity as injection volumes have been found to be a factor for causing induced seismic events in areas where stressed faults exist.
- Reduces pressure buildup and static fluid level increases which can reduce the useful life of a disposal well.
- Assists with ensuring containment of injected wastewater.
- Minimization treatment may involve increased upfront costs but may also reduce costs of long-term operation.

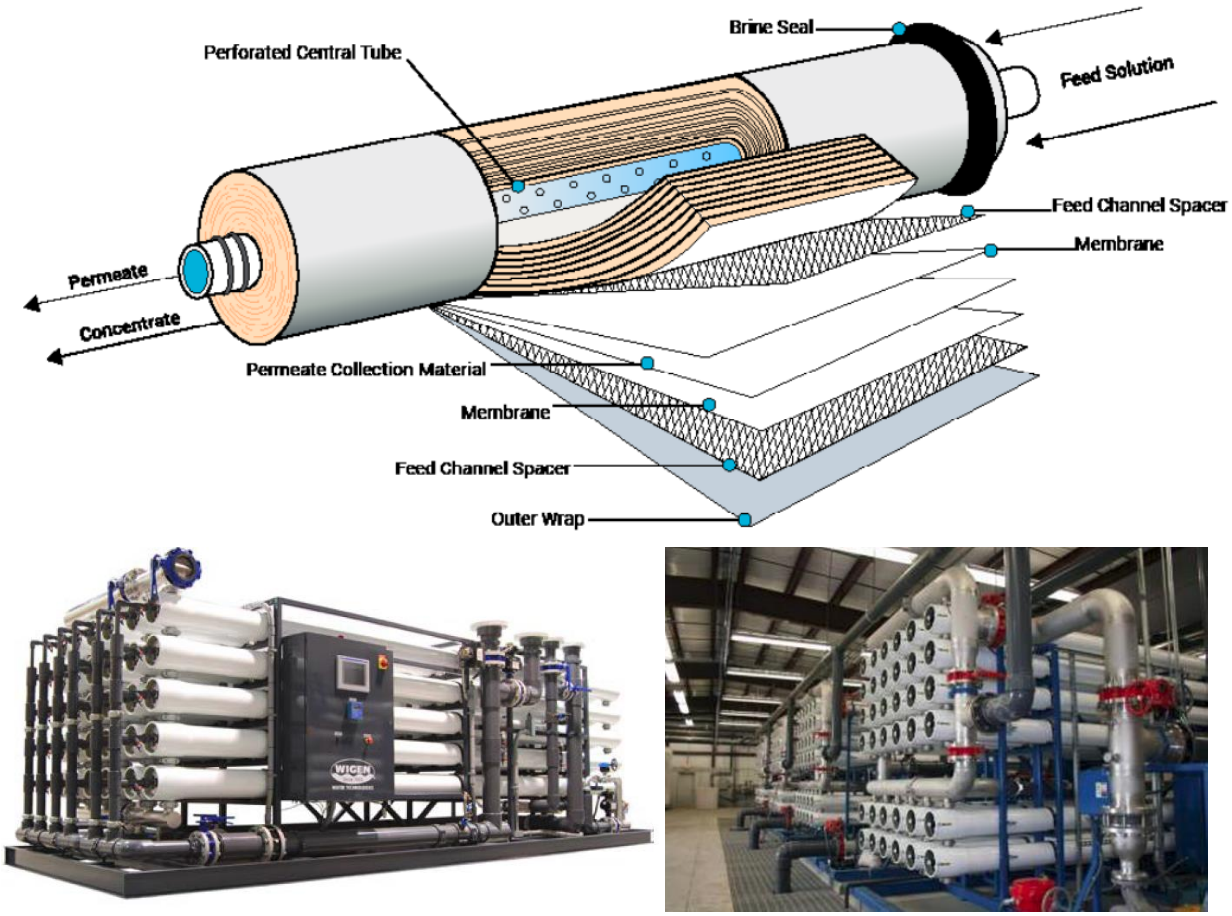
3.5.1 Reverse Osmosis Treatment

A likely option for groundwater remediation of chlorides is treatment via an RO membrane process. RO is the most common method of desalination at municipal and industrial scale. RO treatment uses pumps to pressurize contaminated water, overcoming the osmotic pressure difference between the feed and permeate sides of a semi-permeable membrane, allowing water to diffuse across the membrane as high quality permeate water while solutes are retained on the feed side. RO can remove up to 99% of all TDS from water, as well as many other contaminants, which cannot be filtered or treated by conventional treatment processes. The removed contaminants leave the system as a concentrate which must be disposed of appropriately. Since the concentrate is still a liquid, it can be disposed of via deep well injection, surface water discharge, or further treatment. For this project, RO would be used to minimize the volume of water disposed of via deep well injection, while conserving treated water.

Pretreatment is important to protect RO membranes. Common requirements are a silt density index (SDI) of less than 5 and a total iron and manganese concentration of 0.05 mg/L or less. RO membranes can reject dissolved iron and manganese as long as it remains in a reduced oxidation state, but the introduction of any air can allow enough iron precipitation to foul the membranes. Therefore, prior removal of iron and manganese is normally a good practice and is anticipated as part of any RO treatment implementation. Anti-scalant chemicals may also be required to limit scaling of the membranes and maximize recovery.

RO membranes are spiral wound into cylindrical elements that are loaded into a packaged skid. Figure 3-2 depicts a typical RO membrane element, skid, and system. In a typical configuration, low pressure pumps (anticipated to be the remediation well pumps) feed the water through cartridge filters with a pore size of approximately 5 microns to protect the membranes. High pressure pumps then pump the feed water through the elements to a finished water storage tank or discharge line. Some percentage of feed water is bypassed around the RO system and blended with the permeate to produce the desired blended effluent quality. The bypass blend allows the RO system to be smaller in capacity and more economical and helps stabilize the blended effluent by restoring a moderate amount of dissolved minerals. Sodium hydroxide (caustic) is also commonly fed for pH adjustment for further post-stabilization. For groundwater that is high in carbon dioxide or other dissolved gases, the permeate may also be routed through a decarbonation/degasification tower to strip these gases prior to blending with the bypass. Carbon dioxide data is not available for the Burrton groundwater. Ancillary equipment associated with RO systems includes clean-in-place equipment for periodic chemical cleaning of the membranes, chemical storage and feed facilities, and a control system provided by the manufacturer.

Figure 3-2: Typical Reverse Osmosis Element, Skid, and System



(From H2O Innovation and Wigen)

It is important to carefully match the number and capacity of RO trains to the required range of production. Unlike many other treatment processes, RO has a limited ability to turn down a single process train. An RO system is designed to operate at a specific flow rate for a given water quality. Feeding at a lower rate would increase the potential for scaling and fouling of the membranes. The RO system also must be flushed at every shutdown to avoid scaling, so it is preferable not to turn the system on and off frequently. The typical method of matching production with an RO system is to take entire skid(s) out of service or to curtail hours of operation of the plant each day. The conceptual Burrton remediation RO system at any of the proposed remediation sites would be designed to operate at a constant flow; any reductions in flow would need to correspond to a reduction in the blend flow, which would affect the blended effluent quality.

In 2000, the KCC and U.S. Bureau of Reclamation (BOR) signed a joint agreement to conduct an engineering study of desalting technologies to reduce chloride concentrations in the groundwater near Burrton, Kansas. The study evaluated the performance of RO and ED, (further described below) by conducting pilot-scale tests of each of the systems. The pilots were conducted from August to November, 2000. The objective of the pilot was to reduce chloride concentrations in groundwater from 1,500 mg/L to 130 mg/L.

The piloting results showed that both RO and ED were effective treatment processes for the chloride removal objectives, but each required pretreatment to reduce and control foulants. For the water quality encountered at the pilot site, the study determined that iron, manganese, barium sulfate, and colloidal particles were foulants of concern. To reduce iron and manganese, the pilot implemented pH adjustment, oxidation, detention, and media filtration through a conventional sand filter as pretreatment. Barium and sulfate ions were sequestered by keeping them dissolved using anti-scalant. Finally, remaining colloidal particles were removed through cartridge filters.

A similar pretreatment process is anticipated for an RO treatment system at any of the remediation sites to allow it to perform effectively and achieve the chloride removal objectives. Water quality data collected by Groundwater Management District No. 2 (GMD2) at monitoring wells near the proposed remediation sites shows similarities to the water quality reported in the BOR pilot study. Iron and manganese concentrations vary across wells and over time, frequently well above the EPA secondary drinking water standards of 0.30 mg/L and 0.05 mg/L respectively. Consequently, oxidation and filtration are recommended upstream of the RO system. Options would include conventional dual media filtration, greensand filtration, or microfiltration/ultrafiltration. A “full sweep” panel of water quality testing at the specific remediation site(s) would be required as part of a pre-design phase of any implementation of RO treatment as a remedial alternative.

Depending on manganese levels at the selected site, the use of anthracite and greensand media may be preferred over typical anthracite and sand media for iron and manganese pretreatment. Greensand is a manganese oxide coated media that oxidizes iron and manganese through ion exchange and/or catalytic oxidation and filters out the resulting particulates. Modern installations use the catalytic properties of the manganese oxide media coating to oxidize manganese, so that chlorine can be used as the oxidant instead of a stronger, more costly oxidant such as permanganate. Aeration may be an option for oxidation of iron upstream of the permanganate feed to reduce chemical usage and costs. The choice between conventional dual media filtration, greensand filtration, and microfiltration/ultrafiltration would be made during conceptual design following site-specific water quality testing.

The RO system and associated pretreatment would be provided as a packaged containerized system delivered to the treatment site. For the purpose of evaluating the feasibility and cost of alternatives within this report, RO manufacturers have provided projections of recovery and other parameters based on assumed water quality, which will need to be refined based on site-specific water quality testing. Greensand filtration is assumed. From the preliminary projections, the 600 gpm of flow from the remediation wells is anticipated to produce approximately 410 gpm of permeate and 140 gpm of concentrate with a 50 gpm bypass, for a total of 460 gpm of treated effluent. The treated effluent would be routed to Kisiwa Creek for discharge and could also be diverted for beneficial use. The concentrate would be routed to a deep disposal well co-located on the treatment site with one of the remediation wells. C900 PVC pipe is recommended for the piping to and from the RO system, including the remediation water feed, treated water effluent, and concentrate stream. Stainless steel piping is typical for the higher pressure piping internal to the packaged RO system. Pig launching and retrieval stations are assumed for the RO concentrate pipe to facilitate scale removal (cleaning) should it be needed.

3.5.2 Electrodialysis Treatment

Like RO, ED treatment is also a membrane treatment process. In contrast to RO, ED uses an electrical voltage rather than pressure to drive the separation process. The equipment consists of anionic and cationic selective membranes placed between an anode and cathode. An electric field is applied to force anions to move towards the anode and cations to move towards the cathode, passing through the selective membrane and collecting as concentrate. The vast majority of the feed water does not pass through the selective membranes and therefore is deionized. Some ED systems reverse the applied voltage, typically every 15 to 60 minutes, helping to reduce scaling (fouling) by removing accumulated charged particles from the membrane surfaces. This is known as electrodialysis reversal (EDR). ED tends to be more tolerant of iron, manganese, and particulates in the feedwater compared to RO, but in the absence of site-specific water quality data, filtration is assumed to be needed for ED pretreatment as with RO. ED may not require anti-scalant pretreatment, does not require high-pressure flow, results in longer membrane life, and has direct control of effluent water quality (by varying the applied voltage) in contrast to RO. However, ED does not remove microorganisms or organics. As with RO, ED produces a concentrate stream that would require disposal via deep disposal well. ED treatment can be further evaluated early in conceptual design of the remediation system once site-specific water quality data is available.

3.5.3 RO with Zero-Liquid Discharge (ZLD)

ZLD refers to processes that fully removes water from the concentrate stream resulting from an RO process. Removing water from the concentrate results in residual solid salts that can be disposed of via landfill. Toxicity tests and other applicable tests determine if the solid residual can be disposed of at a municipal solids waste landfill or a hazardous waste landfill. The ZLD process considered for this project is Mechanical Evaporation ZLD following RO treatment. Mechanical evaporation processes, or crystallization, uses heat to transform the concentrate from an RO process into a solid product using an evaporator. Evaporators are a common treatment process for the commercial production of salt but are also used for RO waste streams in industrial water treatment. However, crystallizers are not a typical process for municipal or remediation efforts as they are mechanically complex and have high capital and operation and maintenance (O&M) costs (energy costs). The advantage to using a ZLD technology for high-chloride groundwater remediation is eliminating the need to dispose of contaminated water through deep well disposal or surface water discharge by creating a solid product that can be disposed of via landfill and purified water that can be put to a beneficial use. If desired by KWO or KDHE, ZLD treatment could be further evaluated early in conceptual design of a remediation system once site-specific water quality data is available.

4.0 DETAILED REMEDIATION ALTERNATIVES

This section describes remediation alternatives at each of the four alternative remediation sites. The locations of the four sites are shown in Figure 2-2. For each site, the feasible alternatives are described below covering their specific conceptual implementation at the site. Opinions of probable cost for the alternatives are presented at the end of this section.

4.1 Site 1 Detailed Alternatives

Site 1 is located in the south-central portion of the project area to address an area of high chlorides within the middle zone of the aquifer as shown in Figure 4-1 to mitigate the effects of the plume on downstream agricultural users. Following the approach described above in Section 3.1, downgradient users for the Site 1 capture zone include 14 domestic wells registered with the KDHE water well database and 7 water rights listed with DWR. As previously mentioned, most domestic wells are already completed within the shallow upper zone of the aquifer (<50 ft) so they may or may not be impacted by the plume regardless of remediation of the middle zone of the aquifer at this site. Some of the water rights may utilize deeper wells located in the upper to lower zones of the aquifer. It is outside of the scope of this report to determine likelihood of impairment or predict future chloride concentrations.

Anticipated pumped chloride concentrations from remediation wells at Site 1 would be up to 1,300 mg/L, the highest of the four sites. Based on interpreted chloride concentrations and the anticipated eastward migration, the RI Report recommended an initial phase of two wells operating at 300 gpm each, which is projected to provide a preliminary zone of capture with a width of approximately 3,600 feet. Table 4-1 describes the Site 1 remediation wells. Wells are anticipated to require strategically placed screened intervals to maximize capture of high-chloride groundwater from the middle zone of the aquifer.

Table 4-1: Site 1 Remediation Well Summary

Parameter	Value
Aquifer zone for completion	Middle
Chloride concentration based on nearby monitoring wells	1,000 to 1,600 mg/L
Anticipated chloride concentration in pumped remediation water*	1,000 to 1,300 mg/L
Number of remediation wells required	2
Distance between remediation wells	1,800 ft
Width of zone of capture	3,600 ft
Remediation flow for initial implementation	600 gpm total, 300 gpm per well

* The anticipated chloride concentration in the pumped remediation water is less than that in the nearby monitoring wells because water from less contaminated zones of the aquifer is anticipated to cause some dilution during pumping.

The well siting and design would be similar across all the alternatives. It is assumed that the disposal well would be co-located with one of the remediation wells on a site with dimensions of approximately 100 ft by 200 to 300 ft. The off-site remediation well would be completed on a 100 ft by 100 ft site. An easement of this size would provide ample room for site access, tower rigging, and a re-drill of the remediation well within the lifecycle of the project if needed. To minimize potential net pumping effects, a distance of at least 960 ft would be maintained from existing domestic wells and at least 1,300 ft from existing water rights, although this may not be possible at Site 1 given the multiple nearby existing wells and water rights. The well contractor's scope would include the following for the remediation wells:

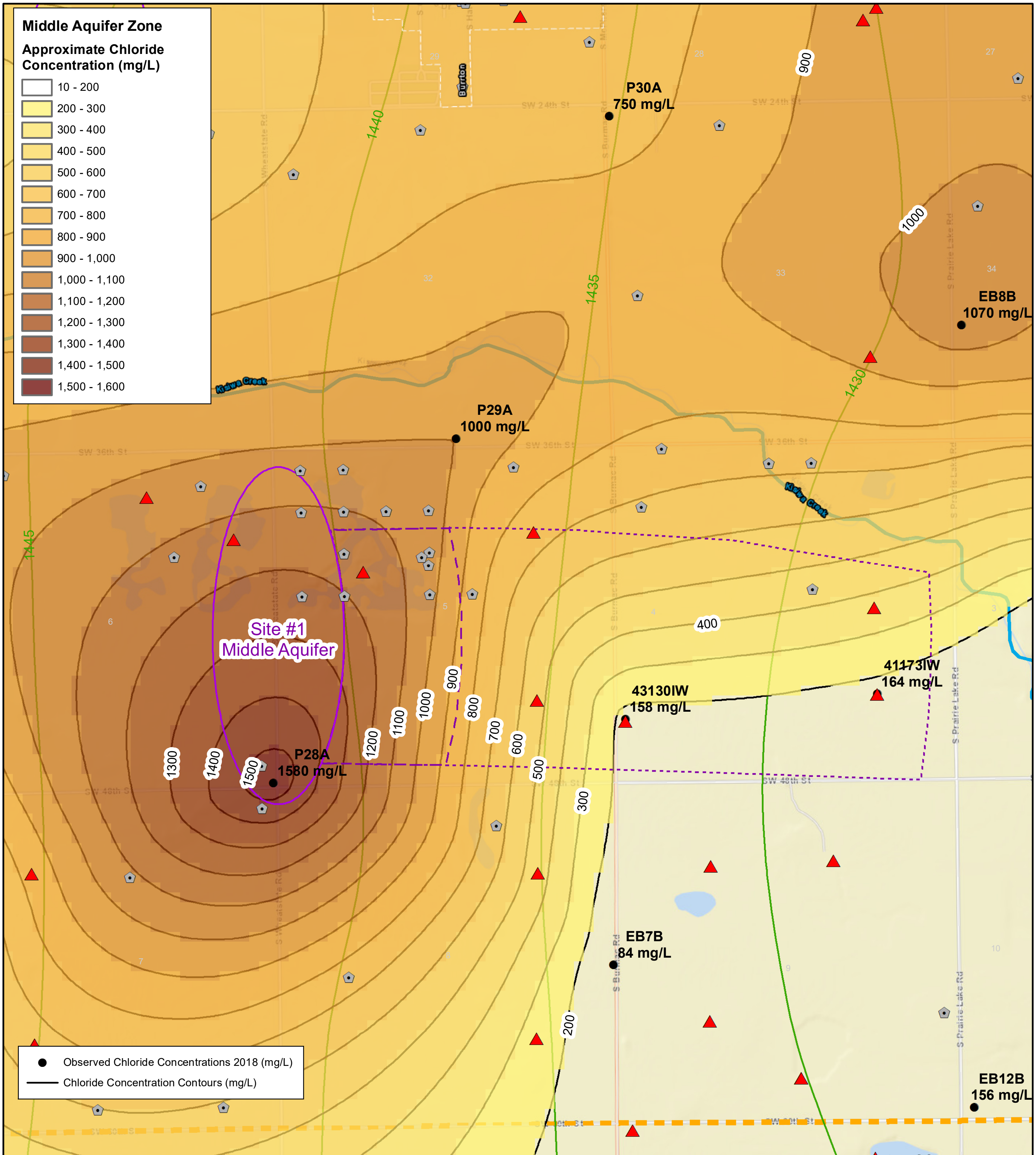
- Drill 5" shallow water supply well for drilling activities
- Drill remediation well using reverse circulation drilling method
    - PVC cased well construction (10-inch)
    - PVC high flow screen
    - Graded gravel pack and neat cement grout
    - Submersible pump and motor, variable frequency drive (VFD) rated, stainless steel
    - Surface pitless construction with approved well plates and seals
- All cuttings and drilling fluids would be containerized during drilling

- Haul off cuttings to appropriate regulatory disposal
- Haul off drilling fluids to appropriate regulated disposal

VFDs are assumed for the remediation well pump motors to reduce life cycle costs and allow the well to maintain the target flow despite fluctuations in water level due to nearby seasonal pumping. The VFDs, pump controller, input/output (I/O) hardware, and telemetry hardware would be mounted in a panel outdoors under a roof canopy. An electrical service would need to be installed for each remediation well site. Each remediation well's discharge piping would include a check valve and isolation gate valve in a vault as well as a flow meter in a separate vault. Likewise, the disposal well would be provided with a flow meter vault and a valve vault.

The remediation and disposal facilities would not require full time on-site personnel, so it is assumed that basic remote monitoring and control capability would be provided. A central Supervisory Control and Data Acquisition (SCADA) system with remote access capabilities would facilitate monitoring including system and pump status, water quality, flows, and pressures; and remote manipulation of control valves and VFDs. A small communication tower at the off-site remediation well would relay data to a small main tower receiver at the disposal well site where main SCADA equipment and controls would be housed. This tower would also communicate with remote controls and monitoring systems managed offsite by remediation site operations personnel. SCADA programming would allow for alarms, notifications, and additional automated controls based on conditions throughout the remediation system.

The northern half of Site 1 is in the Kisiwa Creek 100-year floodplain, so provisions would be required to elevate the wellhead and electrical components. The floodplain is approximately 1 to 2 ft above grade at the affected site.



Legend

- Domestic Wells KDHE WWC5 (11/11/2019)
- Active Water Rights DWR WIMAS 10/15/2019
- Remediation Sites
- Site 1 5-Year Potential Impact Area
- Site 1 25-Year Potential Impact Area
- Burrton IGUCA Boundary
- Project Area Boundary
- PLSS Sections
- 2016 Winter Groundwater Elevation Contours - 5ft Interval
- County Boundaries

N

1:24,000

0 1,000 2,000 4,000

Feet

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Figure 4-1

Remediation Site 1 Vicinity Map

4.1.1 Site 1, Alternative 1: Pump to Deep Well Disposal

Deep well disposal for Site 1 would involve constructing a deep disposal well to receive water from the two remediation wells at a combined flow of 600 gpm. For purposes of establishing an opinion of probable cost (OPC), it is assumed that the disposal well would be of Class I UIC construction. During conceptual design, consideration could be given to purchasing and repurposing an existing Class II disposal well rather than constructing a new disposal well. Assuming a new disposal well is constructed, it would be co-located with one of the remediation wells on a site with dimensions of approximately 100 ft by 200 ft. A 6-inch diameter pipeline would convey water from each remediation well to two equalization tanks (assumed to be insulated and heat traced HDPE, although other options would include welded or bolted steel or Fiberglass Reinforced Plastic (FRP) with a total volume of approximately 18,000 gallons. Water would travel from the tanks to the disposal well by gravity flow. Instrumentation and controls for the remediation and disposal wells would be as described above. A conceptual site plan for deep well disposal is shown in Figure 4-2.

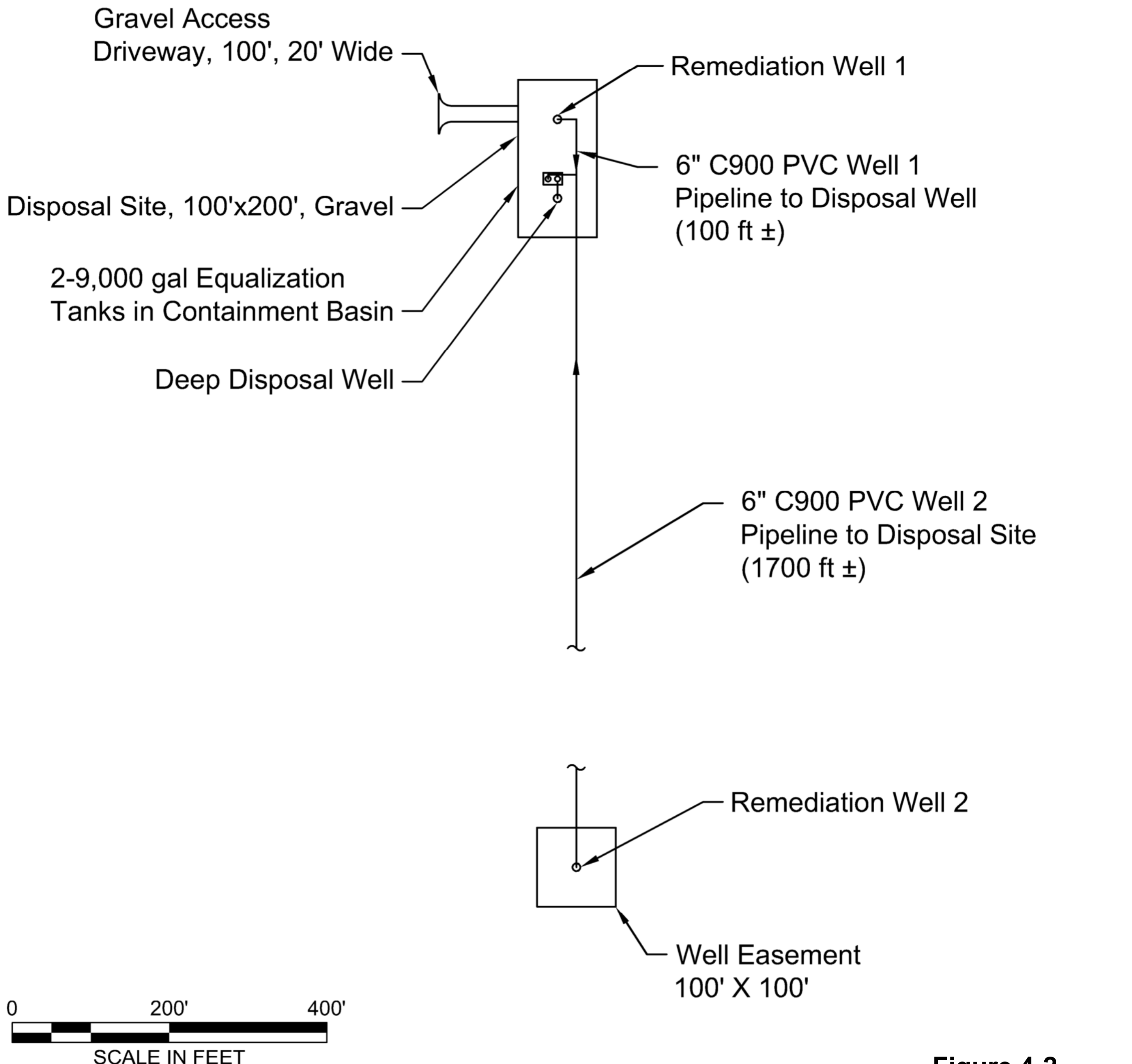

Figure 4-2

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SITE 1, ALTERNATIVE 1:
DEEP WELL DISPOSAL-
CONCEPTUAL SITE PLAN

BURRTON OIL FIELD BRINE PLUME
FEASIBILITY STUDY REPORT

date NOV. 13, 2019

designed

project 118827

contract

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4.1.2 Site 1, Alternative 2: Pump and Treat

Treatment of the Site 1 remediation water would involve establishing a treatment site for installation of a containerized RO system. It is assumed that the treatment unit and a Class I deep disposal well for concentrate would be co-located with one of the remediation wells on a 100 ft by 300 ft site. The disposal well would be construction as previously described in Section 4.1.1. Water from the two remediation wells (600 gpm) would enter the treatment unit, be oxidized with chlorine or permanganate, and undergo granular media filtration or greensand filtration for pretreatment. Most of the water would then pass through cartridge filters and undergo RO treatment, while the remainder (about 50 gpm) would be bypassed. The recovered blend of permeate and bypass would be about 460 gpm. The process would generate about 140 gpm of concentrated brine which would be directed to the disposal well. A conceptual site plan for treatment is shown in Figure 4-2. The following pipelines would be needed:

- 6-inch diameter pipeline to convey water from each remediation well to the treatment system, transitioning to 8-inch diameter at their confluence.
- 8-inch diameter treated effluent pipeline to convey water to Kisiwa Creek. The creek outfall is assumed to consist of a concrete headwall with a flap gate and riprap. A half mile branch of 8-inch pipe has been assumed for a connection to a beneficial use for purposes of the OPC. This would need to be updated once a specific beneficial use and location is identified.
- Short 4-inch diameter pipeline to convey concentrate to the on-site deep disposal well.

Instrumentation and controls for the remediation and disposal wells would be as described above. In addition, for this treatment option, the RO system manufacturer would supply a SCADA system for pretreatment and RO control system as an integral part of the equipment. I/O would be conveyed via the communication towers described above to facilitate remote SCADA operations managed offsite by operations personnel.

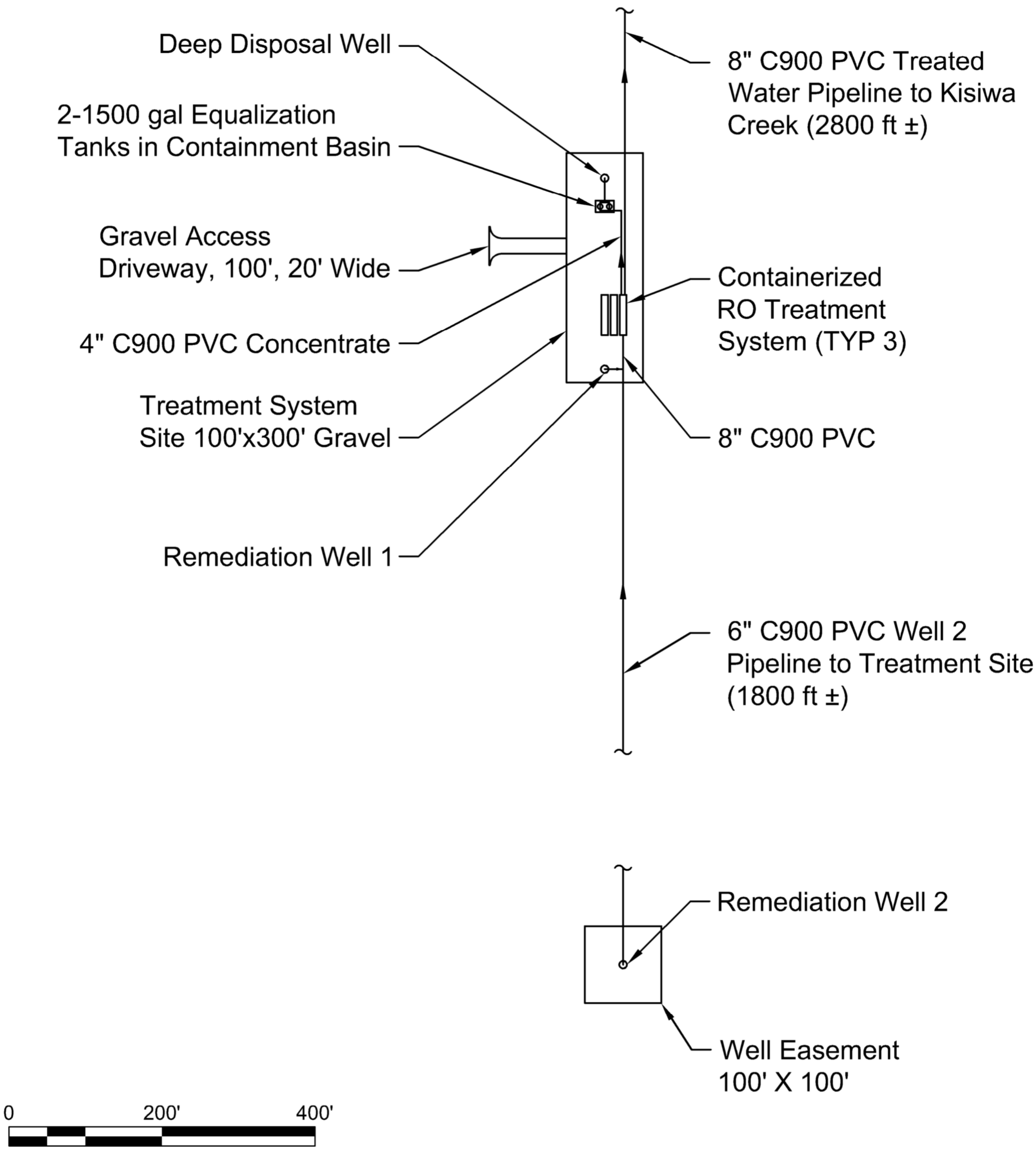

Figure 4-3

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SITE 1, ALTERNATIVE 2: PUMP AND TREAT- CONCEPTUAL SITE PLAN

BURRTON OIL FIELD BRINE PLUME FEASIBILITY STUDY REPORT

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4.2 Site 2 Detailed Alternatives

Site 2 is located on the eastern edge of the project area to address an area of high chlorides within the middle zone of the aquifer as shown in Figure 4-4. Following the approach described above in Section 3.1, downgradient users for the Site 2 capture zone include 9 domestic wells registered with the KDHE water well database and 3 water rights listed with DWR.

Anticipated pumped chloride concentrations from remediation wells at Site 2 would be up to 800 mg/L. Based on interpreted chloride concentrations and the anticipated eastward migration, the RI Report recommended an initial phase of two wells operating at 300 gpm each, which is projected to provide a preliminary zone of capture with a width of approximately 3,600 feet. Table 4-2 describes the Site 2 remediation wells. The well siting and design would be similar to that described above for Site 1. The southern half of Site 2 lies in the Kisiwa Creek 100-year floodplain, so provisions would be required to elevate the wellhead and electrical components. The floodplain is approximately 1 ft above grade at the affected site.

Table 4-2: Site 2 Remediation Well Summary

Parameter	Value
Aquifer zone for completion	Middle
Chloride concentration based on nearby monitoring wells	800 to 1,000 mg/L
Anticipated chloride concentration in pumped remediation water*	650 to 800 mg/L
Number of remediation wells required	2
Distance between remediation wells	1,800 ft
Width of zone of capture	3,600 ft
Remediation flow for initial implementation	600 gpm total, 300 gpm per well

* The anticipated chloride concentration in the pumped remediation water is less than that in the nearby monitoring wells because water from less contaminated zones of the aquifer is anticipated to cause some dilution during pumping.

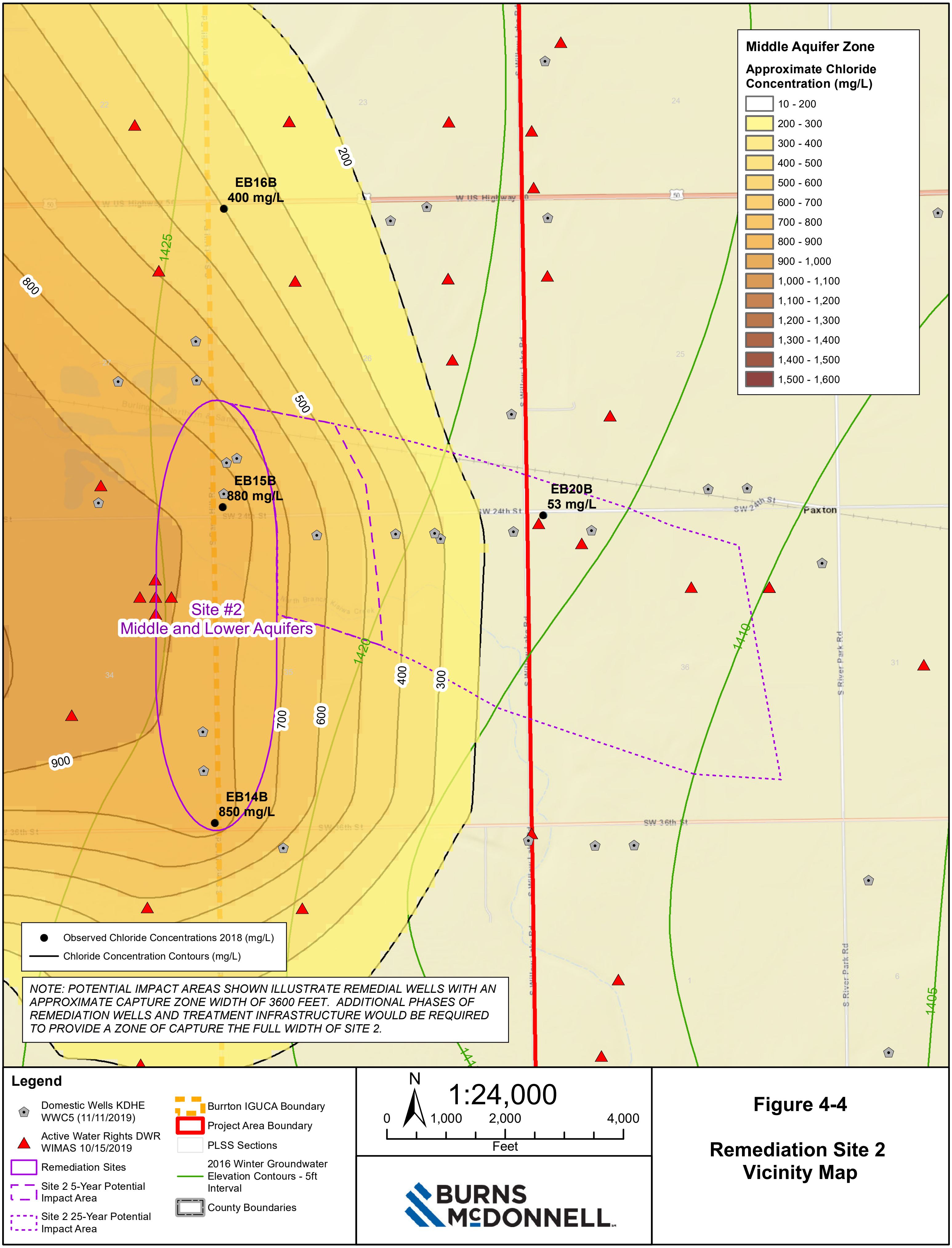


Figure 4-4

Remediation Site 2 Vicinity Map

4.2.1 Site 2, Alternative 1: Pump to Deep Well Disposal:

The deep well disposal implementation for Site 2 would be similar to that described above for Site 1, including the site plan.

4.2.2 Site 2, Alternative 2: Pump and Treat

The treatment implementation for Site 2 would be similar to that described above for Site 1, except that the treated water pipeline to Kisiwa Creek would be longer at approximately 9,300 ft, in addition to the assumed half mile branch to a beneficial use. Also, the site plan would be flipped north to south since Kisiwa Creek is to the south of Site 2.

4.3 Site 3 Detailed Alternatives

Site 3 is located in the north-central portion of the project area to address an area of high chlorides within the middle zone of the aquifer as shown in Figure 4-5. Following the approach described above in Section 3.1, downgradient users for the Site 3 capture zone include 38 domestic wells registered with the KDHE water well database and 4 water rights listed with DWR.

Anticipated pumped chloride concentrations from remediation wells at Site 3 would be up to 1,100 mg/L. Based on interpreted chloride concentrations and the anticipated eastward migration, the RI Report recommended an initial phase of two wells operating at 300 gpm each, which is projected to provide a preliminary zone of capture with a width of approximately 3,600 feet. Table 4-3 describes the Site 3 remediation wells. The well siting and design would be similar to that described above for Site 1. Neither of the Site 3 wells would be in a floodplain.

Table 4-3: Site 3 Remediation Well Summary

Parameter	Value
Aquifer zone for completion	Middle
Chloride concentration based on nearby monitoring wells	800 to 1,400 mg/L
Anticipated chloride concentration in pumped remediation water*	650 to 1,100 mg/L
Number of remediation wells required	2
Distance between remediation wells	1,800 ft
Width of zone of capture	3,600 ft
Remediation flow for initial implementation	600 gpm total, 300 gpm per well

* The anticipated chloride concentration in the pumped remediation water is less than that in the nearby monitoring wells because water from less contaminated zones of the aquifer is anticipated to cause some dilution during pumping.

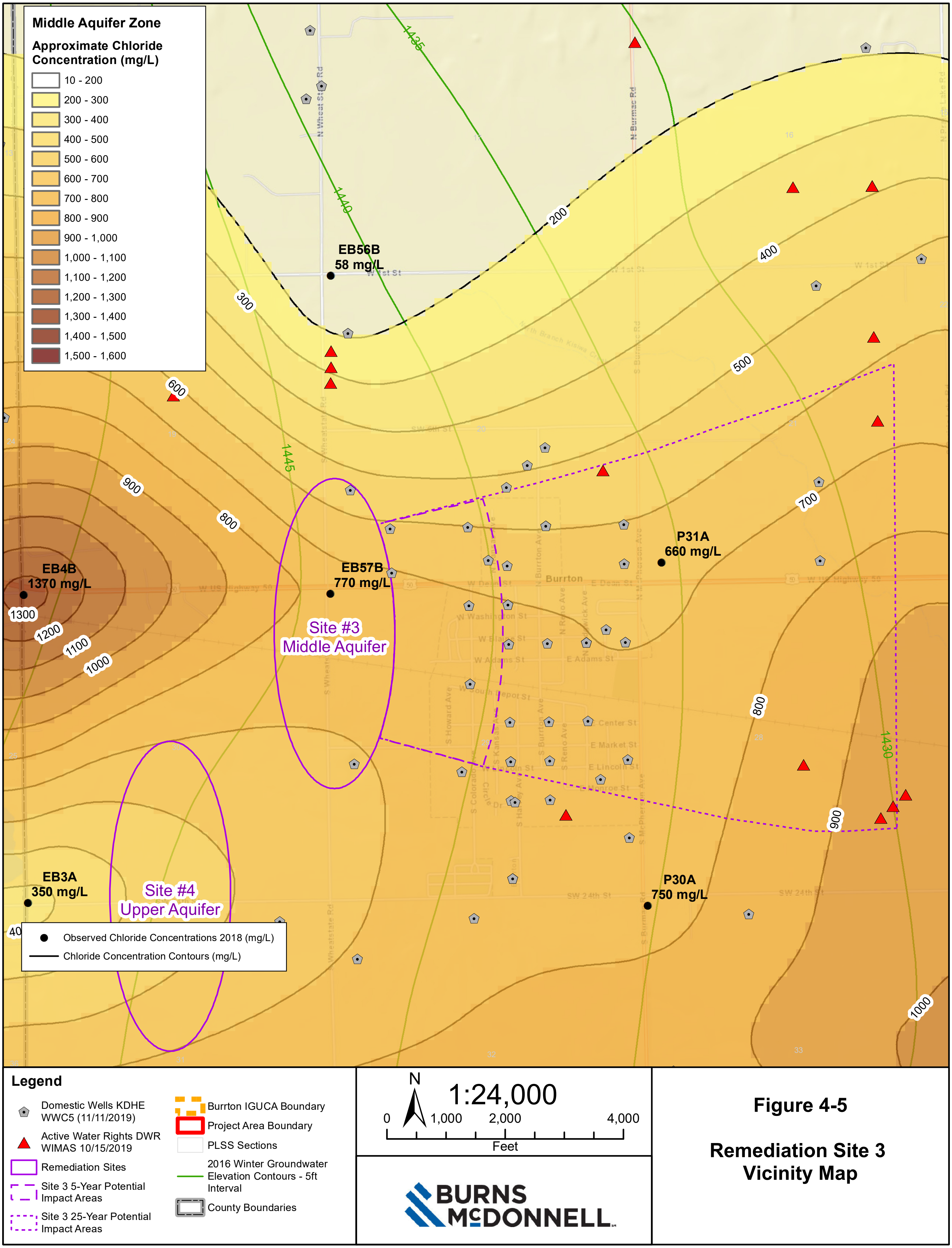


Figure 4-5

Remediation Site 3 Vicinity Map

4.3.1 Site 3, Alternative 1: Pump to Deep Well Disposal:

The deep well disposal implementation for Site 3 would be similar to that described above for Site 1, including the site plan.

4.3.2 Site 3, Alternative 2: Pump and Treat

The treatment implementation for Site 3 would be similar to that described above for Site 1, except that the treated water pipeline to Kisiwa Creek would be longer at approximately 8,750 ft, in addition to the assumed half mile branch to a beneficial use. Also, the site plan would be flipped north to south since Kisiwa Creek is to the south of Site 3.

4.4 Site 4 Detailed Alternatives

Site 4 is located in the north-central portion of the project area to address an area of high chlorides within the upper zone of the aquifer as shown in Figure 4-6. Following the approach described above in Section 3.1, downgradient users for the Site 4 capture zone include 3 domestic wells registered with the KDHE water well database and no water rights listed with DWR. Site 4 is the only site alternative targeting the upper zone of the aquifer, directly benefitting upper zone users including typical domestic users.

Anticipated pumped chloride concentrations from remediation wells at Site 3 would be up to 650 mg/L, the lowest out of the four sites. Based on interpreted chloride concentrations, the anticipated eastward migration, and the limited depth available for completion in the upper zone, the RI Report recommended an initial phase of three wells operating at 200 gpm each, which is projected to provide a preliminary zone of capture with a width of approximately 2,400 feet. Table 4-4 describes the Site 4 remediation wells. The well siting and design would be similar to that described above for Site 1. None of the Site 4 wells would be in a floodplain.

Table 4-4: Site 4 Remediation Well Summary

Parameter	Value
Aquifer zone for completion	Upper
Chloride concentration based on nearby monitoring wells	600 to 800 mg/L
Anticipated chloride concentration in pumped remediation water*	500 to 650 mg/L
Number of remediation wells required	3
Distance between remediation wells	800 ft
Width of zone of capture	2,400 ft
Remediation flow for initial implementation	600 gpm total, 200 gpm per well

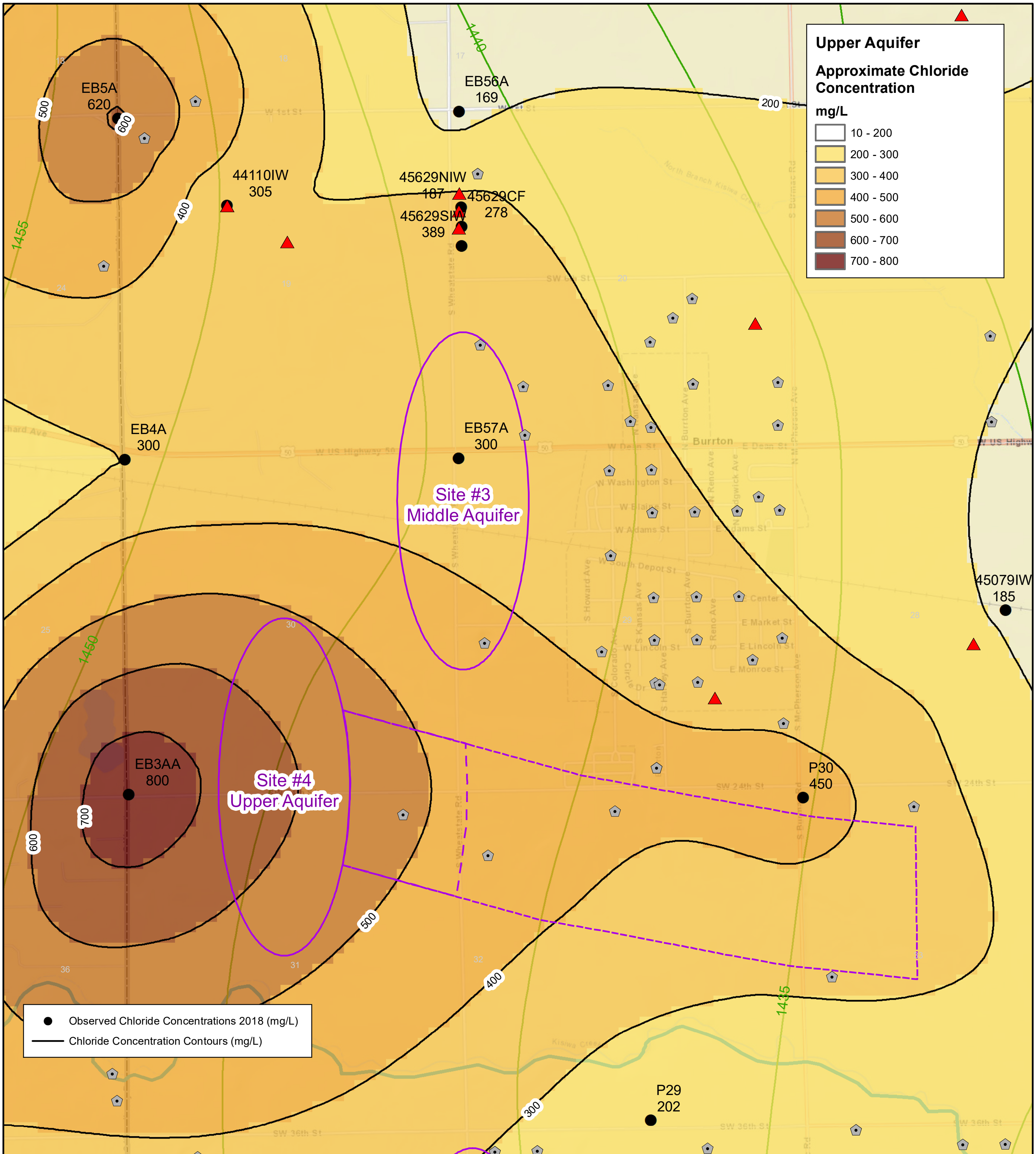
* The anticipated chloride concentration in the pumped remediation water is less than that in the nearby monitoring wells because water from less contaminated zones of the aquifer is anticipated to cause some dilution during pumping.

4.4.1 Site 4, Alternative 1: Pump to Deep Well Disposal:

The deep well disposal implementation for Site 4 would be similar to that described above for Site 1, including the site plan, except there would be three remediation well sites instead of two.

4.4.2 Site 4, Alternative 4: Pump and Treat

The treatment implementation for Site 4 would be similar to that described above for Site 1, except that there would be three remediation well sites instead of two. Also, the site plan would be flipped north to south since Kisiwa Creek is to the south of Site 4.



Legend

- Domestic Wells KDHE WWC5 (11/11/2019)
- Active Water Rights DWR WIMAS 10/15/2019
- Remediation Sites
- Site 4 - 5 Year Potential Impact Area
- Site 4 - 25 Year Potential Impact Area
- Burrton IGUCA Boundary
- Project Area Boundary
- PLSS Sections
- 2016 Winter Groundwater Elevation Contours - 5ft Interval
- County Boundaries

N

1:24,000

0 1,000 2,000 4,000

Feet

BURNS McDONNELL

Figure 4-6

Remediation Site 4 Vicinity Map

4.5 Opinions of Probable Cost

OPCs for each remediation alternative are summarized in Table 4-5 and Appendix A. An opinion of probable O&M costs is included in Table 4-6 and Appendix B. The OPCs are approximate and preliminary given the high-level nature of this FS Report. The OPCs are based on conceptual designs and include construction costs and other allowances including contingency, engineering, geotechnical, surveying, legal and other related costs. Construction cost estimates are based on current construction costs, with a current construction cost index of 11,489.75 for Kansas City, Missouri, for October 2019. Appropriate adjustments for escalation should be applied for budgeting purposes based on anticipated timeframes for implementation. The opinions of probable cost provided in this report are based on professional experience and judgment combined with information from similar past projects, vendors, contractors, and published sources. Burns & McDonnell has no control over weather, costs and availability of labor, material and equipment, labor productivity, construction contractors' procedures and methods, unavoidable delays, construction contractors' methods of determining prices, economic conditions, government regulations and laws (including the interpretation thereof), competitive bidding or market conditions and other factors affecting such opinions or projections. Consequently, Burns & McDonnell does not guarantee that actual costs will not vary from the opinions and projections developed herein.

Common markups include the following:

- Sales Tax: None, assumed exempt.
- General Contractor's (GC) General Conditions: 15 percent. Including mobilization and overhead.
- GC Insurance: 2 percent
- GC Bonds: 1 percent
- GC Margin: 15 percent
- Contingency: 30 percent. For accommodation of as-yet unknown conditions, requirements, changes, and similar factors
- Engineering: 15 percent. For design and construction phase engineering and typical incidental special services including environmental studies, geotechnical studies, legal services, land surveying, resident engineering, O&M manuals, and training of Owner's operations personnel

Additional provisions included in all the alternatives' OPC include the following:

- Hydrogeologic investigation to provide the design information for the final well locations including desktop and field investigations with test drilling, pump testing, groundwater modeling, and report for agency and stakeholder review

- Sixteen "full sweep" panels of water quality testing at the selected site to guide design of the disposal and/or treatment system
- Allowance for acquisition of property and easements
- Allowance for electrical service connection by power company
- 12 monitoring wells, 2 inches in diameter, up to 175 ft deep

Table 4-5: Alternatives Opinion of Probable Cost

Site Alternative	Alternative 1: Pump for Deep Well Disposal	Alternative 2: Pump and Treat
Site 1	$5,300,000	$13,100,000
Site 2	$5,300,000	$14,000,000
Site 3	$5,300,000	$13,900,000
Site 4	$5,300,000	$13,100,000

Table 4-6: Alternatives Opinion of Probable O&M Cost

Item	Alternative 1: Pump for Deep Well Disposal	Alternative 2: Pump and Treat
Annual O&M Cost	$103,000	$470,000
20-Year Present Value of O&M Costs*	$1,200,000	$5,400,000
Total Life Cycle Cost (Capital plus Present Value of O&M):		
Site 1	$6,500,000	$18,500,000
Site 2	$6,500,000	$19,400,000
Site 3	$6,500,000	$19,300,000
Site 4	$6,500,000	$18,500,000

* Assuming a discount rate of 6 percent.

5.0 ALTERNATIVES EVALUATION

It is beyond the scope of this report to recommend a specific alternative out of the feasible alternatives; rather, the information on the alternatives is presented for consideration and input by KDHE, KWO, and stakeholders. A summary comparison of the four site alternatives is presented in Table 5-1. A summary comparison of the remediation alternatives is presented in Table 5-2.

Table 5-1: Site Alternatives Comparison

Parameter	Site 1	Site 2	Site 3	Site 4
Aquifer Zone Targeted for Remediation	Middle	Middle	Middle	Upper
Domestic Wells Downgradient from Capture Zone (25 Years)*	14	9	38	3
Water Rights Downgradient from Capture Zone (25 Years)	7	3	4	0
Aquifer zone for completion	Middle	Middle	Middle	Upper
Chloride concentration based on nearby monitoring wells	1,000 to 1,600 mg/L	800 to 1,000 mg/L	800 to 1,400 mg/L	600 to 800 mg/L
Anticipated chloride concentration in pumped remediation water**	1,000 to 1,300 mg/L	650 to 800 mg/L	650 to 1,100 mg/L	500 to 650 mg/L
Chloride removed (initial, assuming upper end of concentration range)	1,700 tons/year	1,100 tons/year	1,400 tons/year	900 tons/year
Number of remediation wells required	2	2	2	3
Distance between remediation wells	1,800 ft	1,800 ft	1,800 ft	800 ft
Width of zone of capture	3,600 ft	3,600 ft	3,600 ft	2,400 ft
Remediation flow for initial implementation	600 gpm total, 300 gpm per well	600 gpm total, 300 gpm per well	600 gpm total, 300 gpm per well	600 gpm total, 200 gpm per well
Nearby wells and water rights potentially subject to net pumping effect	Several	Several	Few	Few

* The WWC5 database does not include all domestic wells in Kansas, especially those drilled prior to 1974; additional domestic wells may be present.

** The anticipated chloride concentration in the pumped remediation water is less than that in the nearby monitoring wells because water from less contaminated zones of the aquifer is anticipated to cause some dilution during pumping.

Table 5-2: Remediation Alternatives Comparison

Parameter	No Action	Alternative 1: Deep Well Disposal	Alternative 2: Treatment
Downgradient Domestic Wells Affected by Plume (25 Years)	Up to 38 depending on site	Reduced number affected and/or reduced concentrations	Reduced number affected and/or reduced concentrations
Downgradient Water Rights Affected by Plume (25 Years)	Up to 7 depending on site	Reduced number affected and/or reduced concentrations	Reduced number affected and/or reduced concentrations
Regulatory and Permitting Requirements	• IGUCA remains in effect and is periodically updated • GMD2 oversight	• IGUCA remains in effect and is periodically updated • GMD2 oversight • DWR water right application with GMD2 review • KDHE BER coordination • 600 gpm disposal well permitted through KDHE (Class I) or KCC (Class II) with monthly reporting	• IGUCA remains in effect and is periodically updated • GMD2 oversight • DWR water right application • with GMD2 review • KDHE BER coordination • 140± gpm disposal well permitted through KDHE (Class I) or KCC (Class II) with monthly reporting • KDHE NPDES permit for Kisiwa Creek outfall with periodic reporting
Availability of Remediation Water for Use	No effect, water remains in aquifer	Unavailable, water is removed from hydrologic cycle	460± gpm available for use or discharge
Potential net pumping effect	None	Possible, especially with Sites 1 and 2	Possible, especially with Sites 1 and 2
Waste Stream Injected for Deep Well Disposal	None	600 gpm	140± gpm
Energy Consumption	None	170,000 kWh/year	1,030,000 kWh/year
Space required, property or easements	None	3.0 ac	Site 1: 9.5 ac Site 2: 17.0 ac Site 3: 16.5 ac Site 4: 9.5 ac
Visible Infrastructure	None	Disposal equalization tanks and an electrical panel with shade structure near each remediation well	Disposal equalization tanks, electrical building, three treatment system containers, electrical panel with shade structure near off-site remediation well, and outfall structure at Kisiwa Creek

Parameter	No Action	Alternative 1: Deep Well Disposal	Alternative 2: Treatment
Opinion of Probable Capital Cost	None	Each Site: $5,300,000	Site 1: $13,100,000 Site 2: $14,000,000 Site 3: $13,900,000 Site 4: $13,100,000
Opinion of Probable Annual O&M Cost	None	$103,000	$470,000
Opinion of Probable Lifecycle Cost (capital plus 20-year present value of O&M)	None	Each Site: $6,500,000	Site 1: $18,500,000 Site 2: $19,400,000 Site 3: $19,300,000 Site 4: $18,500,000

Note: For comparison, the probable cost to redrill a typical domestic well (replace with a deeper well completed in a different zone of the aquifer in order to access better quality water) would be approximately $5,000 to $10,000 per well for a 100 ft deep well including a pump, 30 percent contingency, and 15 percent engineering / project management.

6.0 CONCLUSIONS

While full remediation of the Burrton chloride plume to ambient or background concentrations is not currently feasible, it is possible to implement targeted partial remediation at strategic site(s), focusing on "hot spots" of particularly high chloride concentrations within the plume to mitigate impacts to downgradient water users. Any of the four sites identified could be selected for implementation of an initial remediation project. Remediation could take the form of either deep well disposal or treatment with RO or a similar technology. Additional remediation could be implemented later at other sites and/or as an expansion of the initial site to increase its area of capture.

It is recommended that KDHE and KWO seek input from stakeholders such as GMD2, landowners, well users, water right holders, and the public to guide the decision of whether to implement an initial remediation project, and if so, which site to develop initially and which remediation method to use.

Additional recommendations include the following:

- Collect water quality and flow data for Kisiwa creek to check the viability of using primarily creek water for blending. These costs are not included in the OPCs presented herein; it is assumed that one or more state or federal agencies would collect the data.
- Initial path forward should KDHE and KWO decide to move forward with a particular remediation site and method would be as follows:
  - Hydrogeologic investigation to provide the design information for the final well locations
  - Determine how the project will be funded and who will be responsible for operations, such as an existing utility in the area or a third-party contract operations firm
  - Acquisition of property and easements
  - Installation of monitoring wells at selected site
  - "Full sweep" panels of water quality testing at the selected site to guide design of the disposal and/or treatment system
- Expand the GMD2 monitoring well network in the plume area, particularly at the leading edge of the plume, as recommended in the 2016 Burrton IGUCA Review report *(DWR 2016)* to better

guide possible future remediation efforts. Also, existing supply wells could be sampled with owners' permission to reduce the expense of drilling new monitoring wells.

7.0 REFERENCES

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Whittemore, Donald O., (KGS) Kansas Geological Survey Open-file Report 2012-1, *Distribution and Change in Salinity in the Equus Beds Aquifer in the Burrton Intensive Groundwater Use Control Area, A report for Kansas Department of Agriculture, Division of Water Resources*, April 2012

APPENDIX A - OPINIONS OF PROBABLE CONSTRUCTION COST

Burrton Chloride Plume Remediation Feasibility Study
Preliminary Opinion of Probable Cost Summaries

Site 1, Alternative 1: Pump for Deep Well Disposal

Item	Quantity	Unit	Unit Cost	OPC
Site Work	1	LS	$ 230,000	$ 230,000
10-inch Remediation Wells	2	EA	$ 54,000	$ 108,000
Class I Deep Disposal Well*	1	EA	$ 1,200,000	$ 1,200,000
2-inch Monitoring Wells	12	EA	$ 6,000	$ 72,000
Disposal Equalization Tanks (two) and Containment Basins	1	LS	$ 183,000	$ 183,000
6-inch C900 PVC Remediation Water Pipeline	1800	LF	$ 65	$ 117,000
Other Piping, Valves, Vaults, and Appurtenances	1	LS	$ 287,000	$ 287,000
Electrical, Instrumentation, and Controls	1	LS	$ 468,000	$ 468,000
Subtotal				**$ 2,665,000**
General Contractor (GC) General Conditions	15%			$ 400,000
GC Insurance	2%			$ 53,000
GC Bonds	1%			$ 27,000
GC Margin	15%			$ 400,000
Contingency	30%			$ 800,000
Subtotal - Construction OPC				**$ 4,345,000**
Engineering	15%			$ 652,000
Hydrogeologic Investigation	1	LS	$ 175,000	$ 175,000
Water Quality Testing Panels	16	EA	$ 1,600	$ 26,000
Property / Easement Acquisition Allowance**	1	LS	$ 30,000	$ 30,000
Power Company Service Allowance	1	LS	$ 75,000	$ 75,000
TOTAL OPC				**$ 5,300,000**

Notes applicable to all alternatives:

* Deep disposal well OPCs are as follows:
Class I Well construction with either Class I or Class V permitting
(4,500 ft total depth, 5 1/2-inch injection tubing): $ 1,200,000
Class II Well construction with Class II permitting (4,500 ft
total depth, 5 1/2-inch production casing): $ 270,000
Class I Wells have more construction requirements for surface casing, cementing, and injection tubing, and also require more intensive logging, well testing, and monitoring equipment.

** Property / Easement Acquisition Allowance does not include acquisition assistance services; assumes completed by Owner e.g KWO.

Site 1, Alternative 2: Pump and Treat

Item	Quantity	Unit	Unit Cost	OPC
Site Work	1	LS	$ 297,000	$ 297,000
10-inch Remediation Wells	2	EA	$ 54,000	$ 108,000
Class I Deep Disposal Well	1	EA	$ 1,200,000	$ 1,200,000
2-inch Monitoring Wells	12	EA	$ 6,000	$ 72,000
Disposal Equalization Tanks (two) and Containment Basins	1	LS	$ 77,000	$ 77,000
6-inch C900 PVC Remediation Water Pipeline	1800	LF	$ 65	$ 117,000
RO Treatment System with Pretreatment	1	LS	$ 2,598,000	$ 2,598,000
8-inch C900 PVC Treated Water Pipeline	5400	LF	$ 73	$ 394,000
Other Piping, Valves, Vaults, and Appurtenances	1	LS	$ 347,000	$ 347,000
Electrical Building, 20'x20' Metal Building	1	LS	$ 97,000	$ 97,000
Electrical, Instrumentation, and Controls	1	LS	$ 1,449,000	$ 1,449,000
Subtotal				**$ 6,756,000**
General Contractor (GC) General Conditions	15%			$ 1,013,000
GC Insurance	2%			$ 135,000
GC Bonds	1%			$ 68,000
GC Margin	15%			$ 1,013,000
Contingency	30%			$ 2,027,000
Subtotal - Construction OPC				**$ 11,012,000**
Engineering	15%			$ 1,652,000
Hydrogeologic Investigation	1	LS	$ 175,000	$ 175,000
Water Quality Testing Panels	16	EA	$ 1,600	$ 26,000
Property / Easement Acquisition Allowance	1	LS	$ 72,000	$ 72,000
Power Company Service Allowance	1	LS	$ 125,000	$ 125,000
TOTAL OPC				**$ 13,100,000**

Site 2, Alternative 1: Pump for Deep Well Disposal

Item	Quantity	Unit	Unit Cost	OPC
Site Work	1	LS	$ 230,000	$ 230,000
10-inch Remediation Wells	2	EA	$ 61,000	$ 122,000
Class I Deep Disposal Well	1	EA	$ 1,200,000	$ 1,200,000
2-inch Monitoring Wells	12	EA	$ 6,000	$ 72,000
Disposal Equalization Tanks (two) and Containment Basins	1	LS	$ 183,000	$ 183,000
6-inch C900 PVC Remediation Water Pipeline	1800	LF	$ 65	$ 117,000
Other Piping, Valves, Vaults, and Appurtenances	1	LS	$ 287,000	$ 287,000
Electrical, Instrumentation, and Controls	1	LS	$ 468,000	$ 468,000
Subtotal				**$ 2,679,000**
General Contractor (GC) General Conditions	15%			$ 402,000
GC Insurance	2%			$ 54,000
GC Bonds	1%			$ 27,000
GC Margin	15%			$ 402,000
Contingency	30%			$ 804,000
Subtotal - Construction OPC				**$ 4,368,000**
Engineering	15%			$ 655,000
Hydrogeologic Investigation	1	LS	$ 175,000	$ 175,000
Water Quality Testing Panels	16	EA	$ 1,600	$ 26,000
Property / Easement Acquisition Allowance	1	LS	$ 30,000	$ 30,000
Power Company Service Allowance	1	LS	$ 75,000	$ 75,000
TOTAL OPC				**$ 5,300,000**

Site 2, Alternative 2: Pump and Treat

Item	Quantity	Unit	Unit Cost	OPC
Site Work	1	LS	$ 297,000	$ 297,000
10-inch Remediation Wells	2	EA	$ 61,000	$ 122,000
Class I Deep Disposal Well	1	EA	$ 1,200,000	$ 1,200,000
2-inch Monitoring Wells	12	EA	$ 6,000	$ 72,000
Disposal Equalization Tanks (two) and Containment Basins	1	LS	$ 77,000	$ 77,000
6-inch C900 PVC Remediation Water Pipeline	1800	LF	$ 65	$ 117,000
RO Treatment System with Pretreatment	1	LS	$ 2,598,000	$ 2,598,000
8-inch C900 PVC Treated Water Pipeline	11900	LF	$ 73	$ 869,000
Other Piping, Valves, Vaults, and Appurtenances	1	LS	$ 347,000	$ 347,000
Electrical Building, 20'x20' Metal Building	1	LS	$ 97,000	$ 97,000
Electrical, Instrumentation, and Controls	1	LS	$ 1,449,000	$ 1,449,000
Subtotal				**$ 7,245,000**
General Contractor (GC) General Conditions	15%			$ 1,087,000
GC Insurance	2%			$ 145,000
GC Bonds	1%			$ 72,000
GC Margin	15%			$ 1,087,000
Contingency	30%			$ 2,174,000
Subtotal - Construction OPC				**$ 11,810,000**
Engineering	15%			$ 1,772,000
Hydrogeologic Investigation	1	LS	$ 175,000	$ 175,000
Water Quality Testing Panels	16	EA	$ 1,600	$ 26,000
Property / Easement Acquisition Allowance	1	LS	$ 114,000	$ 114,000
Power Company Service Allowance	1	LS	$ 125,000	$ 125,000
TOTAL OPC				**$ 14,000,000**

Site 3, Alternative 1: Pump for Deep Well Disposal

Item	Quantity	Unit	Unit Cost	OPC
Site Work	1	LS	$ 230,000	$ 230,000
10-inch Remediation Wells	2	EA	$ 60,000	$ 120,000
Class I Deep Disposal Well	1	EA	$ 1,200,000	$ 1,200,000
2-inch Monitoring Wells	12	EA	$ 6,000	$ 72,000
Disposal Equalization Tanks (two) and Containment Basins	1	LS	$ 183,000	$ 183,000
6-inch C900 PVC Remediation Water Pipeline	1800	LF	$ 65	$ 117,000
Other Piping, Valves, Vaults, and Appurtenances	1	LS	$ 287,000	$ 287,000
Electrical, Instrumentation, and Controls	1	LS	$ 468,000	$ 468,000
Subtotal				**$ 2,677,000**
General Contractor (GC) General Conditions	15%			$ 402,000
GC Insurance	2%			$ 54,000
GC Bonds	1%			$ 27,000
GC Margin	15%			$ 402,000
Contingency	30%			$ 803,000
Subtotal - Construction OPC				**$ 4,365,000**
Engineering	15%			$ 655,000
Hydrogeologic Investigation	1	LS	$ 175,000	$ 175,000
Water Quality Testing Panels	16	EA	$ 1,600	$ 26,000
Property / Easement Acquisition Allowance	1	LS	$ 30,000	$ 30,000
Power Company Service Allowance	1	LS	$ 75,000	$ 75,000
TOTAL OPC				**$ 5,300,000**

Site 3, Alternative 2: Pump and Treat

Item	Quantity	Unit	Unit Cost	OPC
Site Work	1	LS	$ 297,000	$ 297,000
10-inch Remediation Wells	2	EA	$ 60,000	$ 120,000
Class I Deep Disposal Well	1	EA	$ 1,200,000	$ 1,200,000
2-inch Monitoring Wells	12	EA	$ 6,000	$ 72,000
Disposal Equalization Tanks (two) and Containment Basins	1	LS	$ 77,000	$ 77,000
6-inch C900 PVC Remediation Water Pipeline	1800	LF	$ 65	$ 117,000
RO Treatment System with Pretreatment	1	LS	$ 2,598,000	$ 2,598,000
8-inch C900 PVC Treated Water Pipeline	11350	LF	$ 73	$ 829,000
Other Piping, Valves, Vaults, and Appurtenances	1	LS	$ 347,000	$ 347,000
Electrical Building, 20'x20' Metal Building	1	LS	$ 97,000	$ 97,000
Electrical, Instrumentation, and Controls	1	LS	$ 1,449,000	$ 1,449,000
Subtotal				**$ 7,203,000**
General Contractor (GC) General Conditions	15%			$ 1,080,000
GC Insurance	2%			$ 144,000
GC Bonds	1%			$ 72,000
GC Margin	15%			$ 1,080,000
Contingency	30%			$ 2,161,000
Subtotal - Construction OPC				**$ 11,740,000**
Engineering	15%			$ 1,761,000
Hydrogeologic Investigation	1	LS	$ 175,000	$ 175,000
Water Quality Testing Panels	16	EA	$ 1,600	$ 26,000
Property / Easement Acquisition Allowance	1	LS	$ 114,000	$ 114,000
Power Company Service Allowance	1	LS	$ 125,000	$ 125,000
TOTAL OPC				**$ 13,900,000**

Site 4, Alternative 1: Pump for Deep Well Disposal

Item	Quantity	Unit	Unit Cost	OPC
Site Work	1	LS	$ 230,000	$ 230,000
10-inch Remediation Wells	3	EA	$ 43,000	$ 129,000
Class I Deep Disposal Well	1	EA	$ 1,200,000	$ 1,200,000
2-inch Monitoring Wells	12	EA	$ 6,000	$ 72,000
Disposal Equalization Tanks (two) and Containment Basins	1	LS	$ 183,000	$ 183,000
6-inch C900 PVC Remediation Water Pipeline	1600	LF	$ 65	$ 104,000
Other Piping, Valves, Vaults, and Appurtenances	1	LS	$ 287,000	$ 287,000
Electrical, Instrumentation, and Controls	1	LS	$ 468,000	$ 468,000
Subtotal				**$ 2,673,000**
General Contractor (GC) General Conditions	15%			$ 401,000
GC Insurance	2%			$ 53,000
GC Bonds	1%			$ 27,000
GC Margin	15%			$ 401,000
Contingency	30%			$ 802,000
Subtotal - Construction OPC				**$ 4,357,000**
Engineering	15%			$ 654,000
Hydrogeologic Investigation	1	LS	$ 175,000	$ 175,000
Water Quality Testing Panels	16	EA	$ 1,600	$ 26,000
Property / Easement Acquisition Allowance	1	LS	$ 30,000	$ 30,000
Power Company Service Allowance	1	LS	$ 100,000	$ 100,000
TOTAL OPC				**$ 5,300,000**

Site 4, Alternative 2: Pump and Treat

Item	Quantity	Unit	Unit Cost	OPC
Site Work	1	LS	$ 297,000	$ 297,000
10-inch Remediation Wells	3	EA	$ 43,000	$ 129,000
Class I Deep Disposal Well	1	EA	$ 1,200,000	$ 1,200,000
2-inch Monitoring Wells	12	EA	$ 6,000	$ 72,000
Disposal Equalization Tanks (two) and Containment Basins	1	LS	$ 77,000	$ 77,000
6-inch C900 PVC Remediation Water Pipeline	1600	LF	$ 65	$ 104,000
RO Treatment System with Pretreatment	1	LS	$ 2,598,000	$ 2,598,000
8-inch C900 PVC Treated Water Pipeline	5400	LF	$ 73	$ 394,000
Other Piping, Valves, Vaults, and Appurtenances	1	LS	$ 347,000	$ 347,000
Electrical Building, 20'x20' Metal Building	1	LS	$ 97,000	$ 97,000
Electrical, Instrumentation, and Controls	1	LS	$ 1,449,000	$ 1,449,000
Subtotal				**$ 6,764,000**
General Contractor (GC) General Conditions	15%			$ 1,015,000
GC Insurance	2%			$ 135,000
GC Bonds	1%			$ 68,000
GC Margin	15%			$ 1,015,000
Contingency	30%			$ 2,029,000
Subtotal - Construction OPC				**$ 11,026,000**
Engineering	15%			$ 1,654,000
Hydrogeologic Investigation	1	LS	$ 175,000	$ 175,000
Water Quality Testing Panels	16	EA	$ 1,600	$ 26,000
Property / Easement Acquisition Allowance	1	LS	$ 72,000	$ 72,000
Power Company Service Allowance	1	LS	$ 150,000	$ 150,000
TOTAL OPC				**$ 13,100,000**

APPENDIX B - OPINIONS OF PROBABLE OPERATION AND MAINTENANCE COST

Burrton Chloride Plume Remediation Feasibility Study
Preliminary Opinion of Probable O&M Costs

Assumed production:	600	gpm
	0.86	mgd

Alternative 1: Pump for Deep Well Disposal

Item	Qty	Unit	Unit Cost	Cost	Note
Power*	170,000	kWh	$0.120	$20,000	
Filter cartridge replacement	1	LS	$2,000	$2,000	
Remediation Well Rehabilitation	0.67	LS	$10,000	$7,000	Rotation each well every 3 years
Miscellaneous supplies & equipment	1	LS	$15,000	$15,000	
Additional O&M Labor (salary & benefits)	0.5	person-yr	$50,000	$25,000	
HMI Software Licensing	1	LS	$2,000	$2,000	
KDHE Annual Pressure Fall Test	1	LS	$10,000	$10,000	For disposal well
KDHE Mechanical Integrity Test (MIT)	0.2	LS	$15,000	$3,000	For disposal well every 5 years
Sampling and analytical	1	LS	$2,000	$2,000	
Subtotal				$86,000	
Contingency	20%			$17,000	
TOTAL Annual				**$103,000**	

*** Power Calculations:**

Load	Qty	HP (each)	kW (each)	Runtime/yr (each, days)	% Power	kWh/year
Remediation Well Pumps	2	10	7	365	100%	131,000
9000 gal Disposal EQ Tank Heat Tracing	2		3.3	180	100%	29,000
Control Panel AC and other small loads						10,000
Total						170,000

Alternative 2: Pump and Treat

Chemicals to be used and anticipated dosages are yet to be finalized pending site-specific water quality sampling.

Item	Qty	Unit	Unit Cost	Cost	Note
Power*	1,033,000	kWh	$0.120	$124,000	
Chemicals: hypochlorite, bisulfite, antiscalant, caustic, membrane cleaning, etc.	1	LS	$100,000	$100,000	
Cartridge filter replacement	4	LS	$1,000	$4,000	Quarterly
RO element replacement	0.25	LS	$109,200	$27,000	Every 4 years
Pipeline Maintenance	0.33	LS	$10,000	$3,000	Line pigging every 3 years
Remediation Well Rehabilitation	0.67	LS	$10,000	$7,000	Rotation each well every 3 years
Miscellaneous supplies & equipment	1	LS	$30,000	$30,000	
Additional O&M Labor (salary & benefits)	1.5	person-yr	$50,000	$75,000	
HMI Software Licensing	1	LS	$2,000	$2,000	
KDHE Annual Pressure Fall Test	1	LS	$10,000	$10,000	For disposal well
KDHE Mechanical Integrity Test (MIT)	0.2	LS	$15,000	$3,000	For disposal well every 5 years
Sampling and analytical	1	LS	$2,000	$2,000	
Subtotal				$387,000	
Contingency	20%			$77,000	
TOTAL Annual				**$470,000**	

*** Power Calculations:**

Load	Qty	HP (each)	kW (each)	Runtime/yr (each, days)	% Power	kWh/year
Remediation Well Pumps	2	25	19	365	100%	327,000
High pressure pumps	2	50	37	365	100%	653,000
Greensand backwash pumps	1	40	30	2.6	100%	2,000
Greensand air scour blowers	1	15	11	2.2	100%	1,000
Treatment Container HVAC						15,000
Electrical Building HVAC						10,000
1500 gal Disposal EQ Tank Heat Tracing	2		1.1	180	100%	10,000
Control Panel AC and other small loads						15,000
Total						1,033,000

CREATE AMAZING.

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