Remedial Investigation Report
Burrton Oil Field Brine Plume

Kansas Department of Health and Environment

C2-040-73660
Project No. 118827

1/24/2020

Remedial Investigation Report
Burrton Oil Field Brine Plume

prepared for

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

Project No. 118827

1/24/2020

prepared by

Burns & McDonnell Engineering Company, Inc.
Wichita, Kansas

INDEX AND CERTIFICATION

Kansas Department of Health and Environment
Remedial Investigation Report
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Certification

I hereby certify, as a Professional Geologist in the state of Kansas, that the information in this document was assembled under my direct personal charge. This report is not intended or represented to be suitable for reuse by the Kansas Department of Health and Environment or others without specific verification or adaptation by the Geologist.

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Date: January 24, 2020

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LIST OF ABBREVIATIONS

Abbreviation	Term/Phrase/Name
AF	Acre Feet
BER	Bureau of Environmental Remediation
BOR	Bureau of Reclamation, U.S. Department of the Interior
Burns & McDonnell	Burns & McDonnell Engineering Company, Inc.
DWR	Division of Water Resources
EPA	Environmental Protection Agency
FS	Feasibility Study
GMD2	Groundwater Management District No. 2
GPM	Gallons per Minute
IGUCA	Intensive Groundwater Use Control Area
KCC	Kansas Corporation Commission
KDA	Kansas Department of Agriculture
KDHE	Kansas Department of Health and Environment
KGS	Kansas Geological Survey
KWO	Kansas Water Office
mg/L	Milligrams per Liter
MGD	Million Gallons per Day
NSDWR	National Secondary Drinking Water Regulations
ppm	Parts per Million
RI	Remedial Investigation
SMCL	Secondary Maximum Contaminant Levels

1.0 INTRODUCTION

The Burrton Oil Field is located west of the City of Burrton, Kansas, spanning portions of western Harvey and eastern Reno County. Development of the oil field began in the early 1930's, and during the early period of oil field development disposal of produced brine occurred through multiple methods. According to the State Board of Health in 1939, approximately 38% of brine disposal for the Burrton Oil Field was estimated to occur using evaporation pits (*Kansas Corporation Commission* (KCC)*, 2007*). The produced brine that was placed in evaporation pits 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 pits 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. The seepage of oil field brine into the aquifer has created a large area of intersecting plumes producing groundwater chloride concentrations in excess of useable standards for drinking water, agricultural irrigation, and most industrial applications.

The first groundwater monitoring data available for the area begins in the late 1930s by the City of Wichita followed by the installation of a monitoring well network by Groundwater Management District No. 2 (GMD2) in 1979. A significant increase in the number of water rights and pumping from the Equus Beds Aquifer began to develop in the area during the 1970s and early 1980s. In 1984, a 36-square mile area was designated as the Burrton Intensive Groundwater Use Control Area (IGUCA) as a result of concerns from both GMD2 and the Kansas Department of Agriculture (KDA), Division of Water Resources (DWR) that water rights development in the vicinity could impact brine plume movement (*Whittemore, 2012)*. The establishment of the Burrton IGUCA included findings which documented the geochemical determination that most of the chlorides above background concentrations in the Burrton Oil Field brine plume were from oil field brine rather than from natural saltwater occurring in the Arkansas River corridor *(Whittemore, 2012)*.

1.1 Scope of Work Description

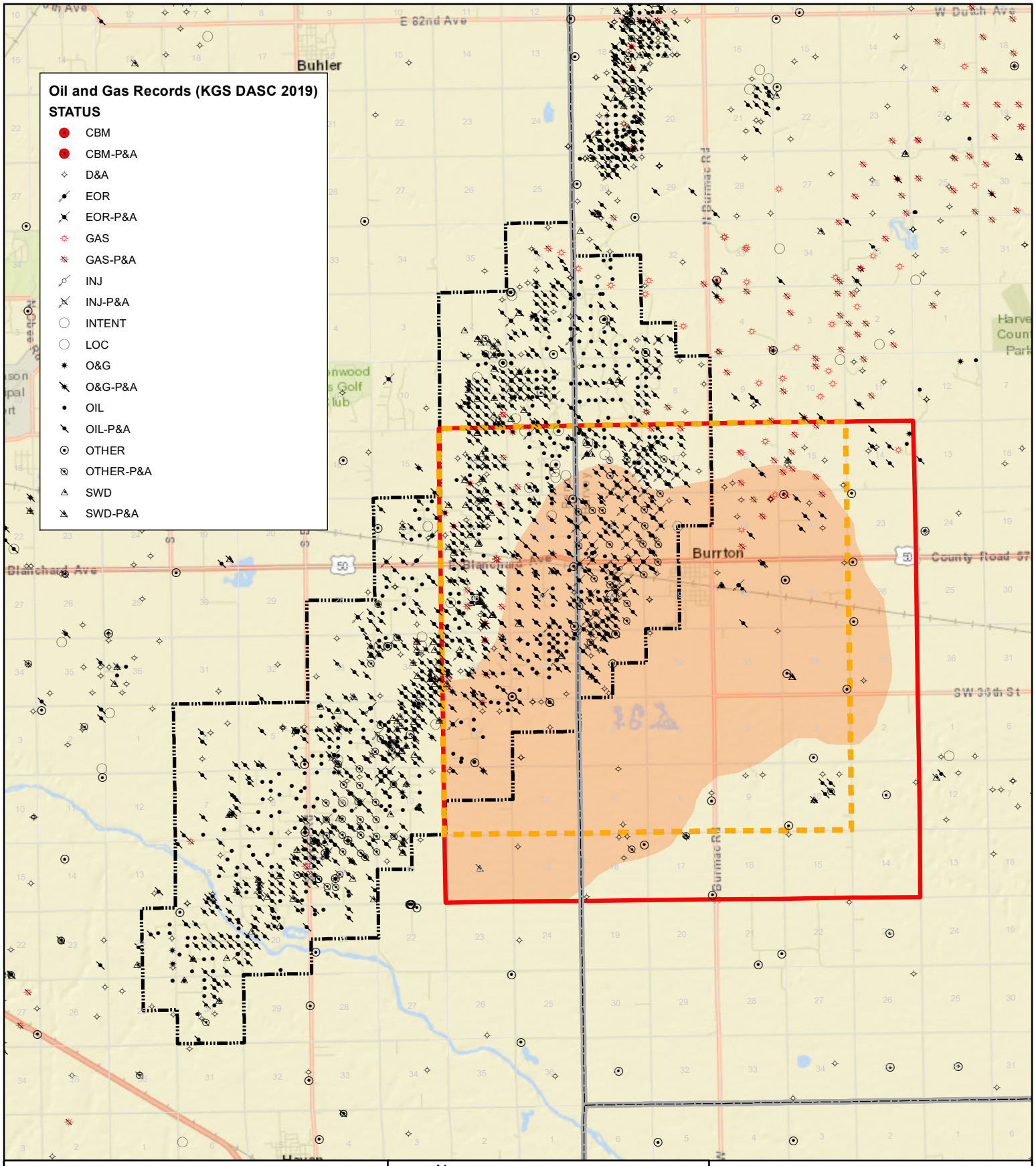
The Kansas Water Office (KWO) has provided funding through the State's Water Plan to complete a Remedial Investigation (RI) and Feasibility Study (FS) for the Burrton Oil Field Chloride Plume located in Harvey and Reno Counties, Kansas (Project Area). The Kansas Department of Health and Environment (KDHE), Bureau of Environmental Remediation (BER) is managing the project in coordination with the KWO under Work Order Number OS0407366001BMD. The primary objective of this RI Report will be to provide 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 remedial

alternatives which will be evaluated within a FS Report. As outlined in the *Remedial Investigation / Feasibility Study Work Plan, Burrton Oil Field Chloride Plume (Burns & McDonnell, 2019)*, components of this RI Report include:

- Characterization of the chloride plume using existing data
- Assessment of the contamination impacts to current and projected groundwater users
- Recommendation for preliminary high priority areas to consider for remediation wells

1.2 Project Site Location

The RI project area covers approximately 49 square miles, includes portions of Harvey and Reno counties, and extends roughly one mile east and one mile south of the current bounds of the Burrton IGUCA. The bounds of the project area are consistent with the anticipated extension of the Burrton IGUCA to the south and east based on the most recent review of the IGUCA (*KDA, DWR, 2016).* Based on 2018 water quality map data provided by the KWO and KCC, a significant portion of the project area exhibits groundwater chloride ion concentrations in excess of 250 milligrams per liter (mg/L) within one or more vertical zones of the aquifer (Figure 1-1).



Legend

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

N

1:120,000

0 1 2 4

Miles

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FIGURE 1-1
PROJECT AREA WITH CHLORIDE CONCENTRATIONS OVER 250 mg/L

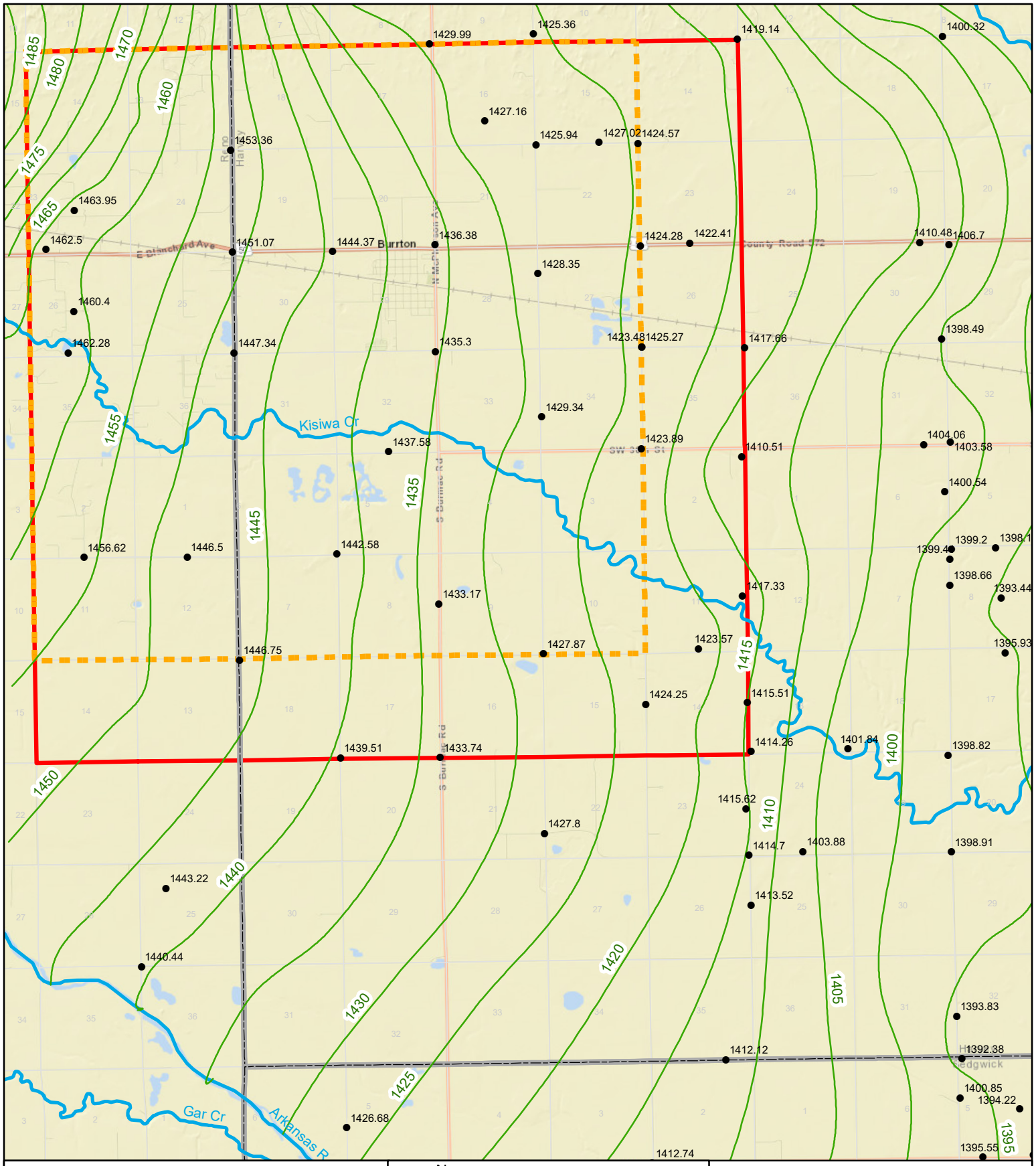
2.0 CHLORIDE PLUME CHARACTERIZATION

2.1 Hydrogeologic Setting

The Equus Beds Aquifer within the project area consists of unconsolidated deposits, generally Pleistocene in age, overlying Permian bedrock which consists of the Wellington Formation and Ninnescah Shale. Depth to bedrock from land surface varies in the area from approximately 100 to over 250 feet below land surface. Areas where depth to bedrock is deepest generally correlate to areas where combination of erosion and the dissolution and of a salt member of the Wellington formation occurred creating deeper bedrock valleys which were subsequently filled by unconsolidated sediments of the Equus Beds Aquifer. Aquifer materials include both fine-grained and coarse-grained materials consisting of sand, gravel, silt, and clay.

Throughout most of the project area three aquifer zones are generally recognized where semi-contiguous clay layers or lenses create vertical separation between aquifer zones. These zones are generally characterized by previous studies as the upper, middle, and lower aquifer. The shallow sand layers of the upper aquifer are generally recognized by previous studies as being less than 65 feet below ground surface. The upper aquifer zone exhibits unconfined conditions and reported hydraulic conductivities range from 1 (clayey zones) to 220 feet per day. The middle zone of the aquifer ranges in depth from approximately 65 to 175 feet below land surface. The middle aquifer zone generally exhibits unconfined conditions with reported hydraulic conductivities ranging from 5 to 300 feet per day. The lower zone of the aquifer where present ranges from approximately 175 to 285 feet below land surface. The lower aquifer zone generally exhibits unconfined to semi-confined conditions with reported hydraulic conductivities ranging from approximately 40 to 300 feet per day.

Regional groundwater flow in the area is generally to the east-southeast and locally may be influenced by seasonal groundwater pumping, recharge from precipitation, and groundwater surface water interactions from creeks and tributaries. Observed groundwater elevation data was obtained via the Kansas Geological Survey (KGS) WIZARD online database, and review of the information found that the greatest available data density in the project area was available for winter measurements of 2016-2017. The obtained groundwater elevation information was sorted, filtered, and plotted to provide an illustration of groundwater flow direction within the project area and surrounding areas (Figure 2-1).



Legend

- Dec 2016 - Jan 2017 Observed Groundwater Elevations (ft)
- Winter 2016-2017 Groundwater Elevation Contours (ft)
- Project Area Boundary
- Burrton IGUCA Boundary
- PLSS Sections
- County Boundaries

N

1:80,000

0 0.5 1 2

Miles

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FIGURE 2-1
2016 OBSERVED GROUNDWATER ELEVATIONS MIDDLE AND LOWER AQUIFER

2.2 Chloride Plume Source

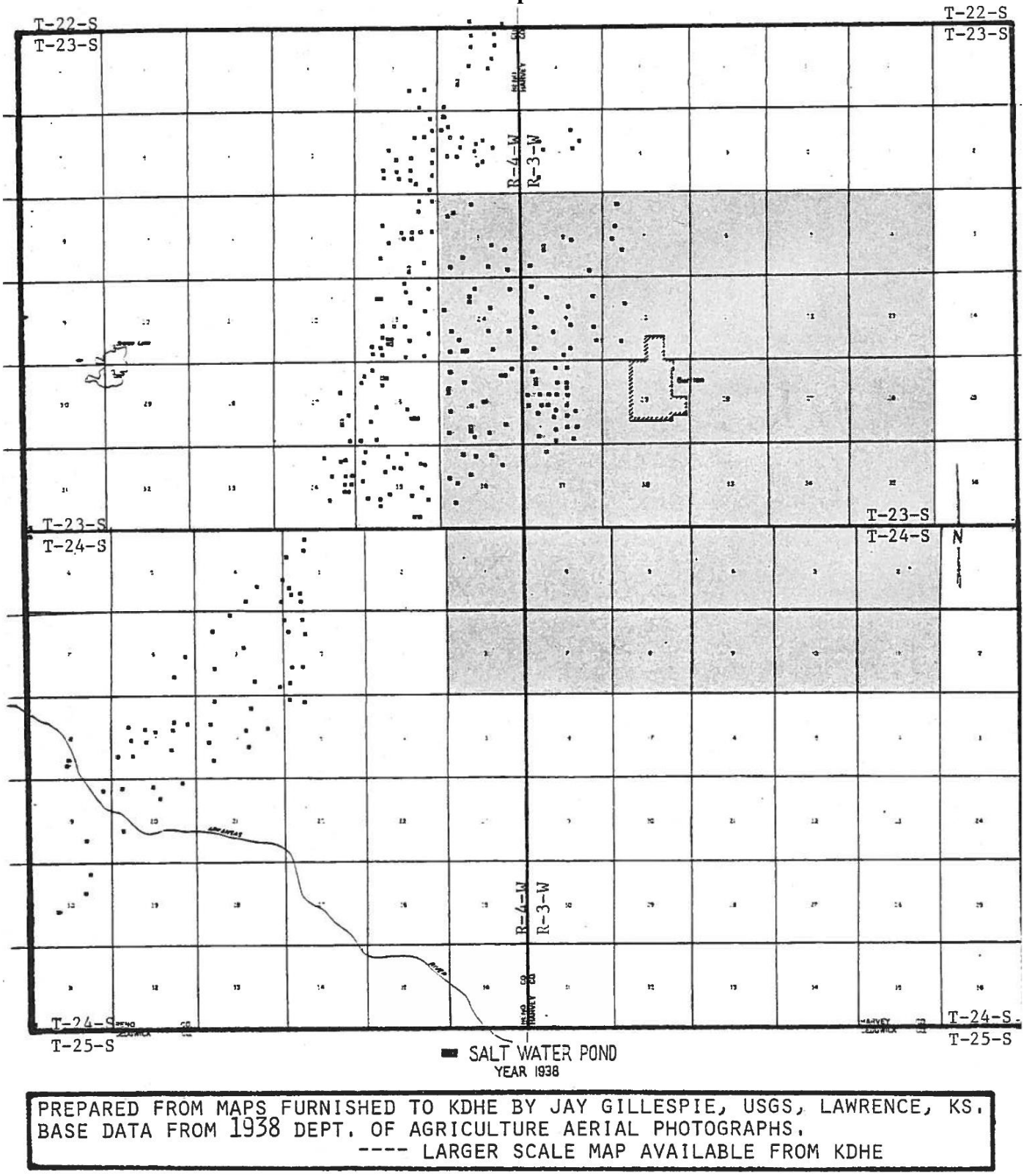
During early development of the Burrton Oil Field from 1931 through 1943, produced brine from oil field activities was placed in evaporation pits where the brine escaped containment via downward seepage into the shallow groundwater of the underlying Equus Beds Aquifer (*KCC, 2007*). Brine ponds were generally located near the producing well to minimize brine transmission infrastructure, therefore brine disposal activities generally overlap the extent of the Burrton Oil Field which is focused approximately one to two miles west of the City of Burrton (Figure 2-2). The average chloride concentration of disposed brine has been estimated at 96,000 mg/L. Shallow disposal wells were also used to dispose of oil field brine. These shallow brine disposal wells were completed into the Wellington formation and the injection pressures of the shallow brine disposal wells forced brine upward into the overlying Equus Beds Aquifer via artificial pathways such as unplugged or improperly abandoned test holes and wells (*Report of the Burrton Task Force, 1984*).

The seepage of oil field brine into the aquifer has created a large area of intersecting plumes resulting in groundwater chloride concentrations in excess of useable standards for drinking water, agricultural irrigation, and most industrial applications. Previous studies have estimated that during the period of 1931 through 1943 approximately 1.9 million tons of salt produced from oil field activities entered the aquifer via brine evaporation pits (*Report of the Burrton Task Force, 1984*). A survey in 1938 indicated groundwater chloride concentrations over 2,000 mg/L, and samples from Kisiwa Creek and related tributaries in the area reported concentrations ranging from 1,030 to over 83,000 mg/L. By the mid-1940s the practice of brine disposal into evaporation pits 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. After this shift to utilizing deep disposal wells for handling produced brine, previous studies indicate the aquifer may have also been contaminated by brine transmission pipeline leaks, releases from brine storage tanks, and or malfunctioning deep disposal wells.

2.3 Chloride Plume Extent and Migration

Previous studies have shown that most of the contamination of the aquifer originated at the surface where oil field brine evaporation pits leaked allowing downward percolation of brine into the upper zone of the aquifer. Previous studies have determined that the migration of the chloride plume laterally has generally been eastward following the natural groundwater gradient at a rate of approximately 0.8-1.0 feet/day (*Whittemore, 2012*). As the plume moves eastward, the higher density of the brine causes downward vertical migration within the aquifer. A combination of factors including the natural groundwater gradient, seasonal aquifer pumping influences, non-uniform clay zones, variable aquifer

Figure 2-2
Location of Brine Disposal Ponds in 1938

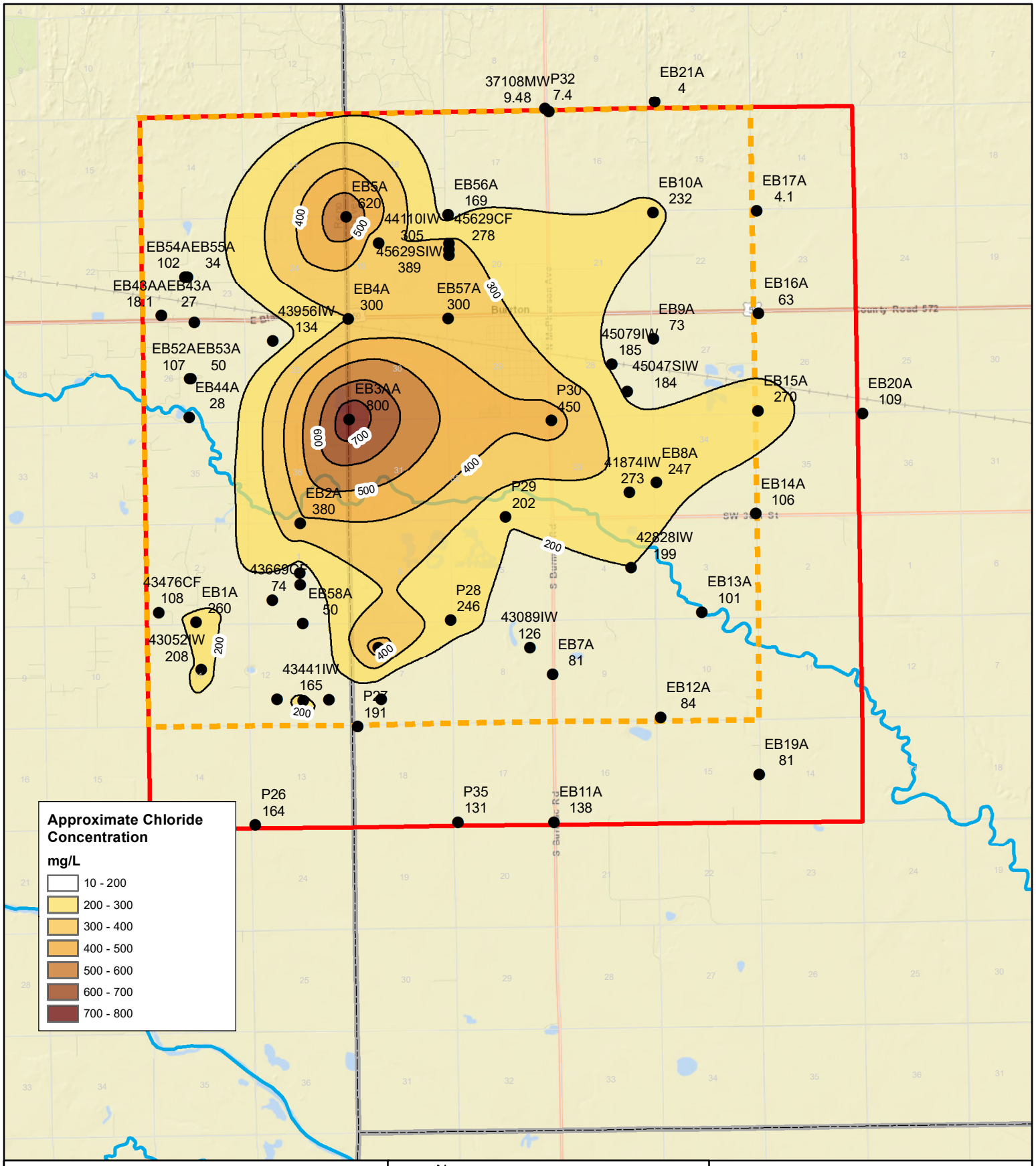


Source: Report of the Burrton Task Force to the Chief Engineer-Director of the Kansas State Board of Agriculture Division of Water Resources Concerning the Proposed Burrton IGUCA, February 21, 1984, page 44, Report Figure 15

permeability, and the bedrock surface underlying the aquifer create a complex system of pathways and drivers which define past plume migration and future migration potential.

The lateral and vertical extent of the Burrton Chloride plume has been monitored utilizing a network of monitoring wells and sampling of high capacity production wells. Previous studies have leveraged this observed data to illustrate both the eastward migration and downward vertical migration of the plume over time (*Whittemore, 2012*). Burns & McDonnell Engineering Company, Inc. (Burns & McDonnell) reviewed data provided by the KCC, GMD2, and the KWO to provide an updated estimate on the lateral and vertical extent of the plume based on observed chloride concentrations in groundwater samples taken in 2018 (Figures 2-3 through 2-5). The 2018 chloride concentration data indicates that the extent of the chloride plume is beyond the extent of the current bounds of the Burrton IGUCA consistent with the findings of the 2016 KDA DWR Burrton IGUCA Review (*KDA, DWR, 2016*). Based on the conclusions of previous studies and the natural gradient of the aquifer at the eastern extent of the project area, the brine plume is anticipated to continue migration to the east-southeast.

The modeling and simulation of future plume movement is beyond the scope of this RI Report, however the general direction and speed of anticipated brine plume movement has been characterized by previous studies. Within the project area, observed brine front migration rates have been observed at approximately 0.8-1.0 feet per day. The aquifer near the leading edge of the brine at the eastern edge of the project area exhibits a change in several natural hydrogeologic factors that are anticipated to accelerate movement of the plume. These factors include aquifer materials with a higher hydraulic conductivity, larger thicknesses of sand, and an increase in the hydraulic gradient. Assuming the higher end of the observed plume velocities (1 foot/day), indications are that chloride values in excess of 250 mg/L within the middle and lower zone of the aquifer could be observed outside the bounds of the eastern edge of the project area within approximately five years. Previous studies have indicated that once the plume reaches the lower portion of the aquifer and intersects the largely impermeable boundary of the underlying bedrock, plume migration direction and velocity can be complicated by the higher density brine following bedrock slope (Figure 2-6).



Legend

- Observed Chloride Concentrations 2018 (mg/L)
- Chloride Concentration Contours (mg/L)
- Burrton IGUCA Boundary
- Project Area Boundary
- PLSS Sections

N

1:80,000

0 0.5 1 2

Miles

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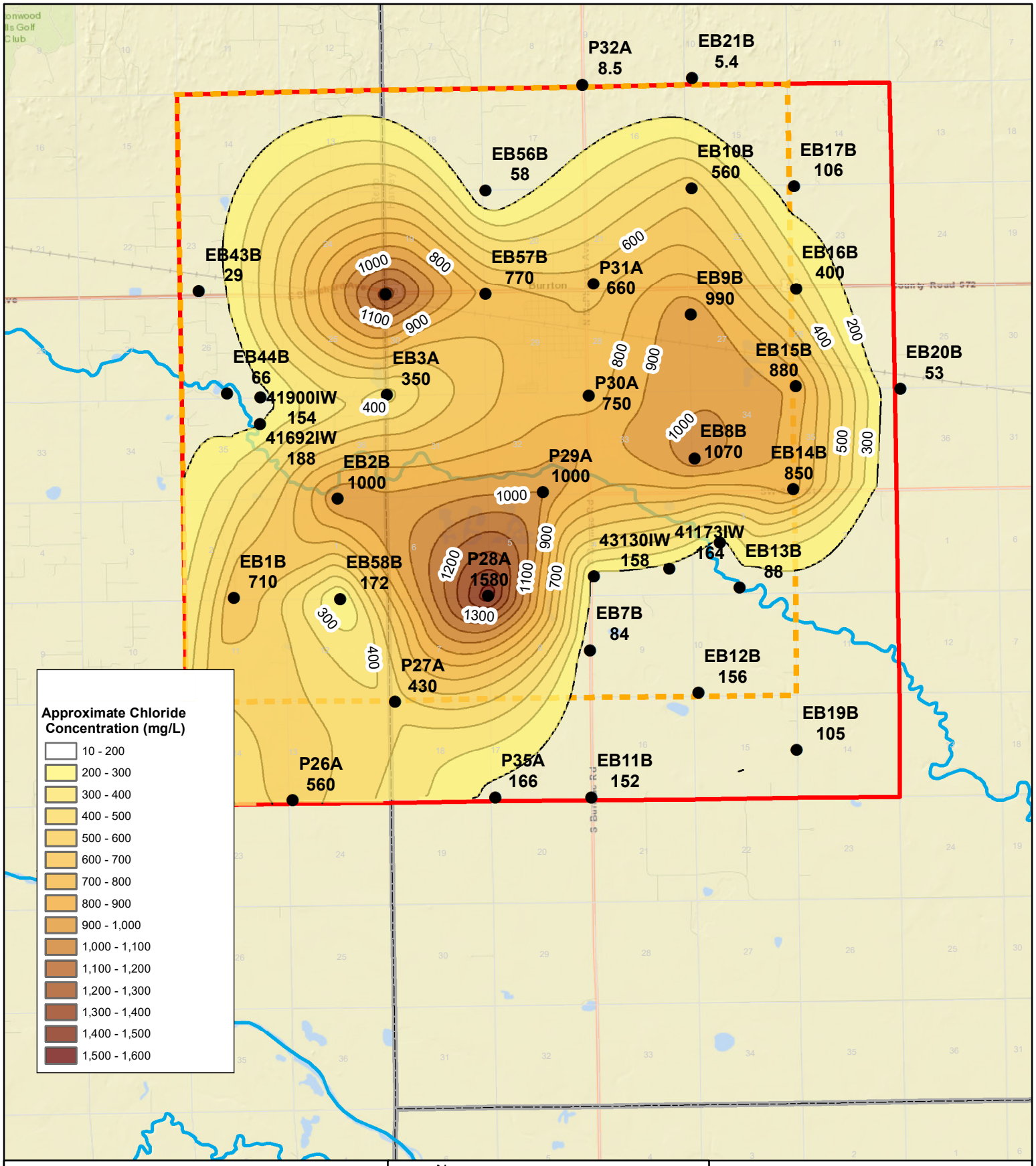
FIGURE 2-3
INTERPRETED 2018
GROUNDWATER CHLORIDE
CONCENTRATIONS
UPPER AQUIFER ZONE



Legend

- Observed Chloride Concentrations 2018 (mg/L)
- Chloride Concentration Contours (mg/L)
- Burrton IGUCA Boundary
- Project Area Boundary
- PLSS Sections

N

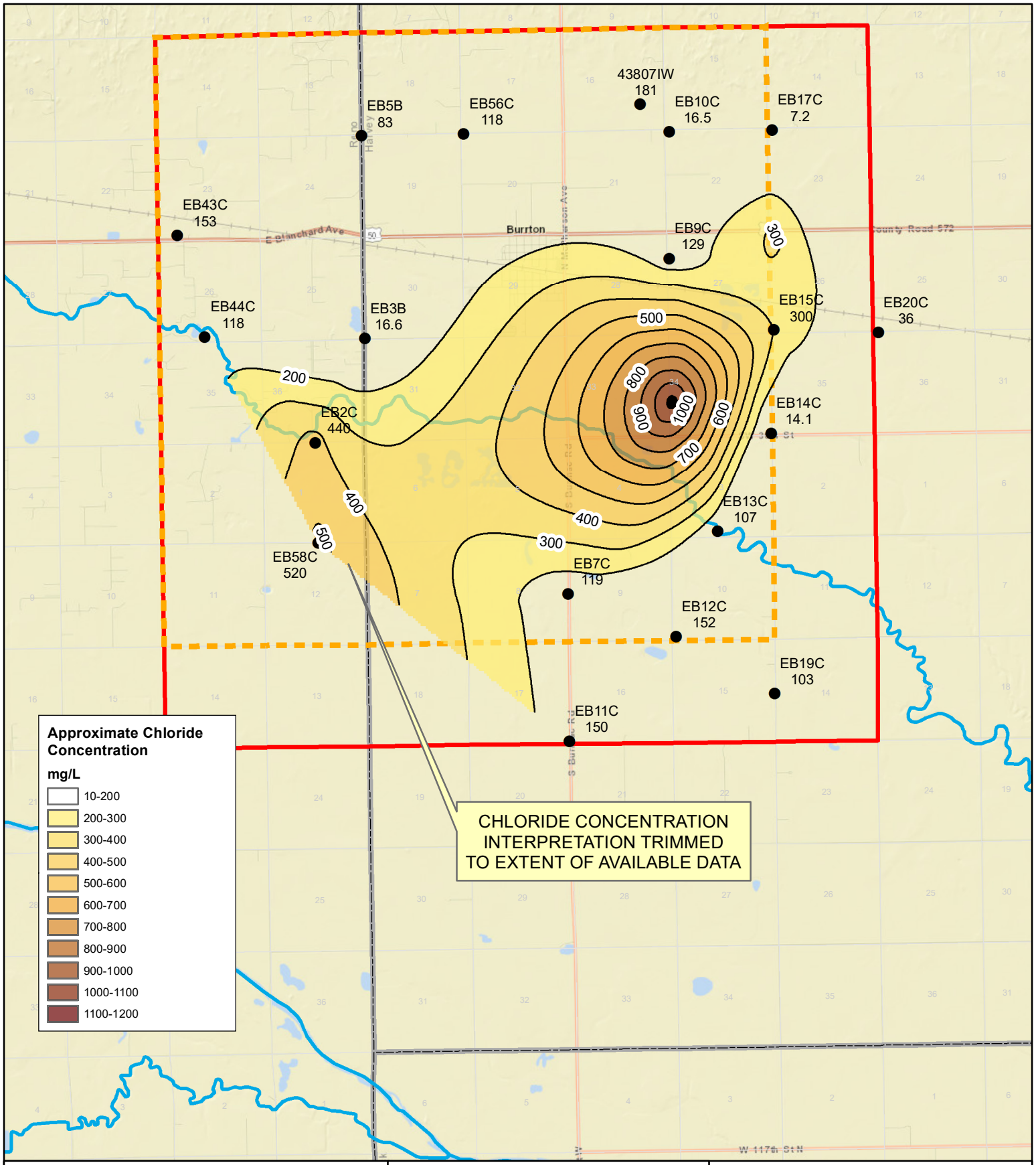
1:80,000

0 0.5 1 2

Miles

BURNS McDONNELL

FIGURE 2-4
INTERPRETED 2018
GROUNDWATER CHLORIDE
CONCENTRATIONS
MIDDLE AQUIFER ZONE



Legend

- Observed Chloride Concentrations (mg/L)
- Chloride Concentration Contours (mg/L)
- Burrton IGUCA Boundary
- Project Area Boundary
- PLSS Sections

N

1:80,000

0 0.5 1 2

Miles

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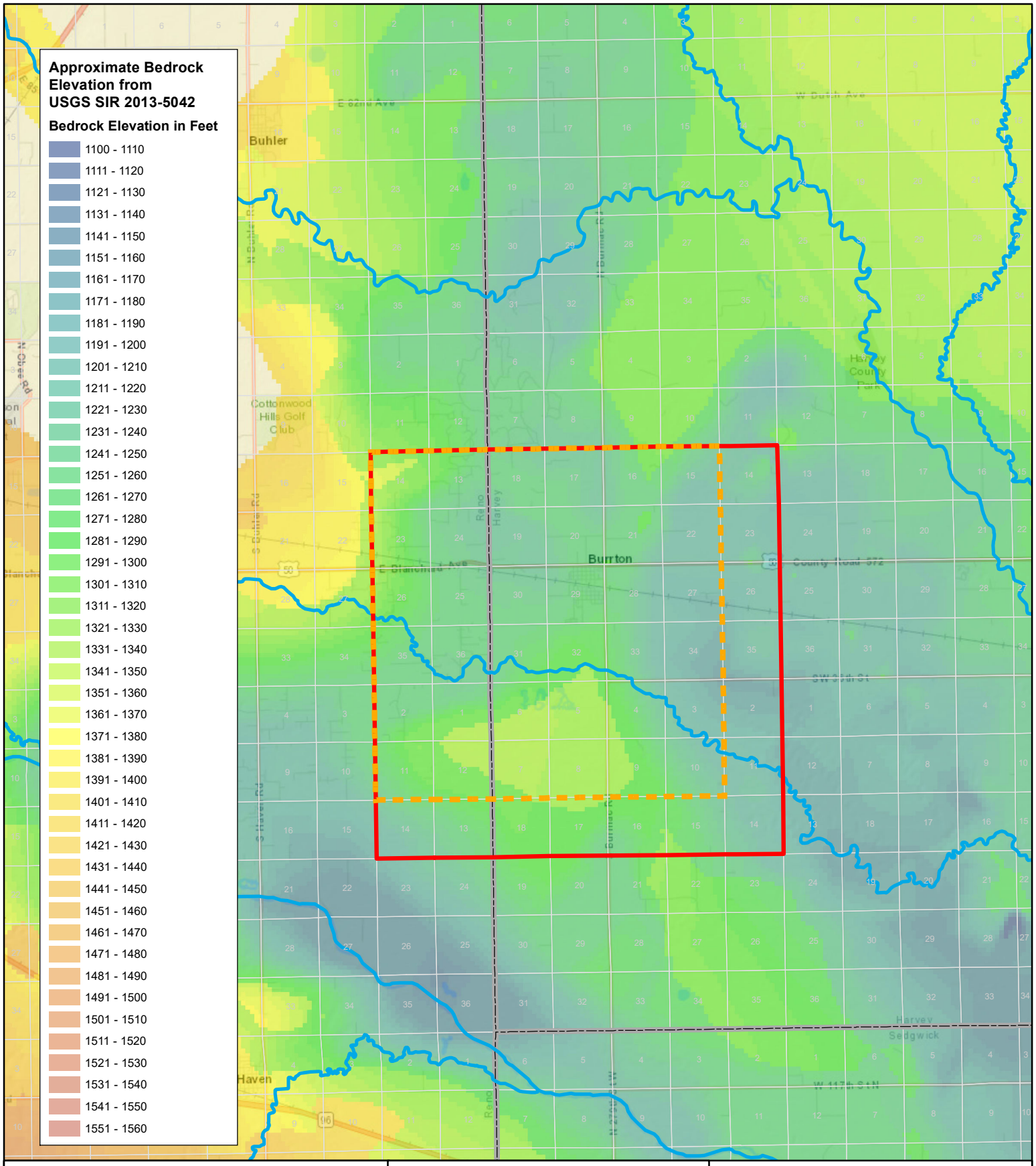
FIGURE 2-5
INTERPRETED 2018
GROUNDWATER CHLORIDE
CONCENTRATIONS
LOWER AQUIFER ZONE



Legend

- Burrton IGUCA Boundary
- Project Area Boundary
- County Boundaries
- PLSS Sections

N

1:140,000

0 1 2 4

Miles

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FIGURE 2-6

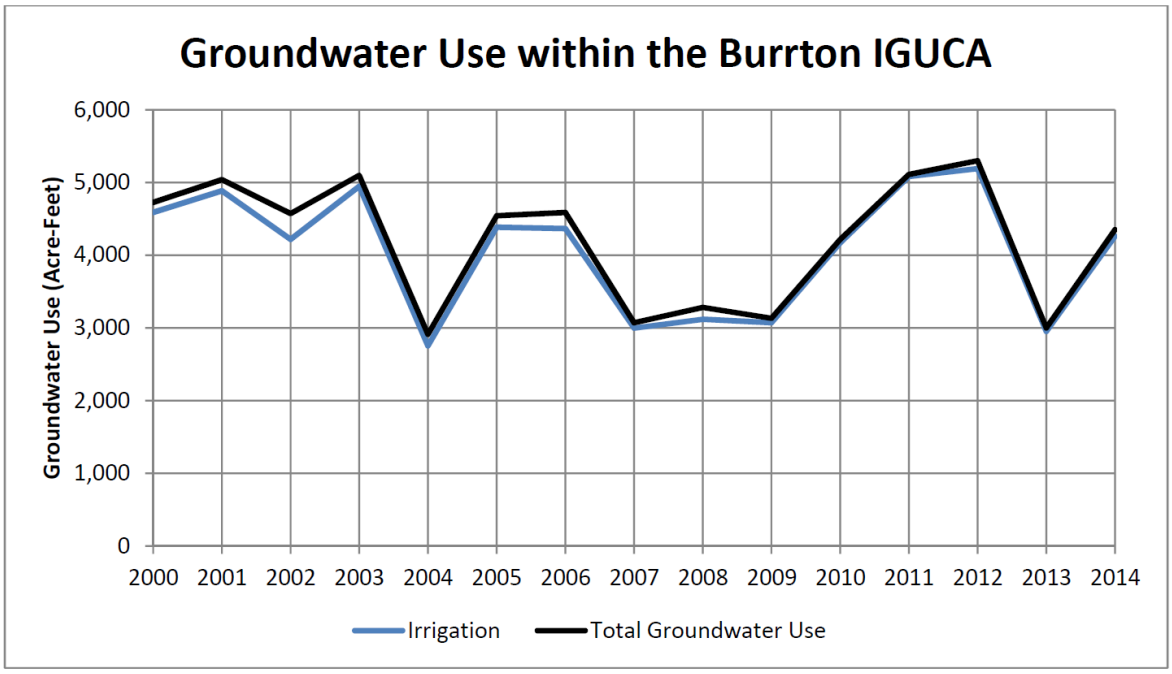
APPROXIMATE BEDROCK ELEVATION

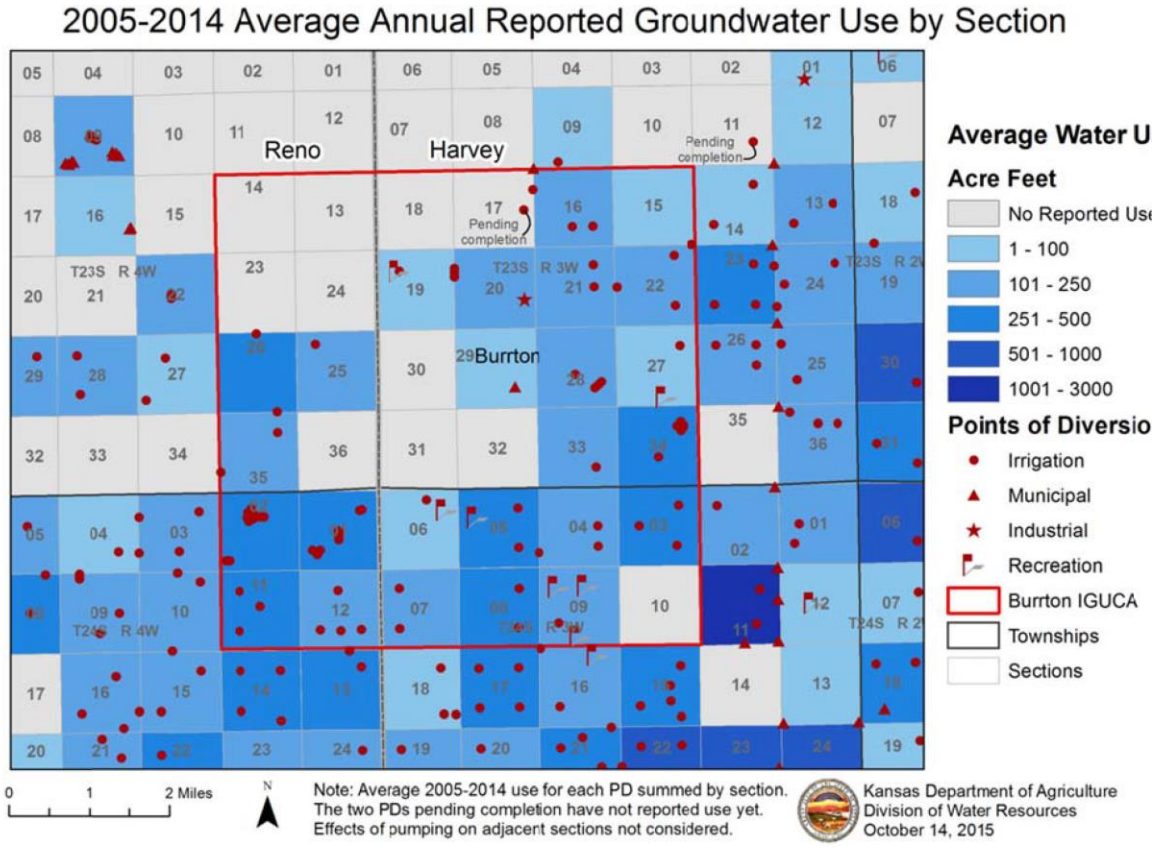
3.0 ASSESSMENT OF SITE CONTAMINATION IMPACTS

The primary contaminant of concern for this RI is the chloride ion . Sampling of groundwater within the area in 2018 reported chloride concentrations as high as 1,600 mg/L, and historic values approached 3,000 mg/L. Background groundwater concentrations for chloride in the project area (uncontaminated zones) have been reported below 30 mg/L. National Secondary Drinking Water Regulations (NSDWRs) established by the United States Environmental Protection Agency (EPA) set non-mandatory water quality standards, known as secondary maximum contaminant levels (SMCLs). They are established as guidelines to assist public water systems in managing their drinking water for aesthetic considerations, such as taste, color, and odor. These contaminants are generally not considered to present a risk to human health at or above the SMCL. Chloride is a regulated contaminant under existing NSDWRs, with an established SMCL of 250 mg/L. Chloride concentrations in drinking water above 250 mg/L result in a salty taste. Except for the City of Burrton, most of the project area is rural where drinking water is likely supplied by domestic wells. According to KGS online water well completion logs, there are approximately 200 domestic and livestock wells within the project area with approximately 150 wells located in an area where one or more zones of the aquifer are likely to exceed 250 mg/L for chloride.

The aquifer in the project area supports multiple beneficial uses with the main use of water reported as agricultural irrigation (*KDA, DWR, 2016)*. As of 2015, a total of approximately 7,400 Acre-Feet (AF) of groundwater appropriations have been allocated by the DWR. About 94% of the authorized quantity was allocated for irrigation and average reported total water use within the IGUCA for the period of 2000 to 2010 was approximately 3,100 AF per year (*KDA, DWR, 2016)*. Documentation indicates that there are portions of the aquifer within the project area where water rights development has been limited due to water rights safe-yield regulation, high chlorides, or limited aquifer yield (Figure 3-1). The anticipated acceptable level of chloride in irrigation water for primary crops in the area is likely near 350 mg/L but is also highly dependent on the crop, type of soils, and the irrigation method used (e.g., sprinkler, surface, subsurface drip) (*KDHE*, *BER Policy #BER-RS-13A, 2005)*. For example, a crop being irrigated by a spray irrigation method will result in direct contact of the water with plant leaves potentially resulting in more damage to the crop due to direct absorption of chloride and sodium ions through the plant leaves. The degree of damage to the crop is dependent on the concentration of the chloride and sodium ions, the duration of exposure, stage of plant growth when the exposure occurs, crop sensitivity, and the volume of water lost from the plant through transpiration (*KDHE, BER Policy #BER-RS-13A*, *2005*)(*BOR, 2001*).

Figure 3-1
Reported Groundwater Use within the Burrton IGUCA





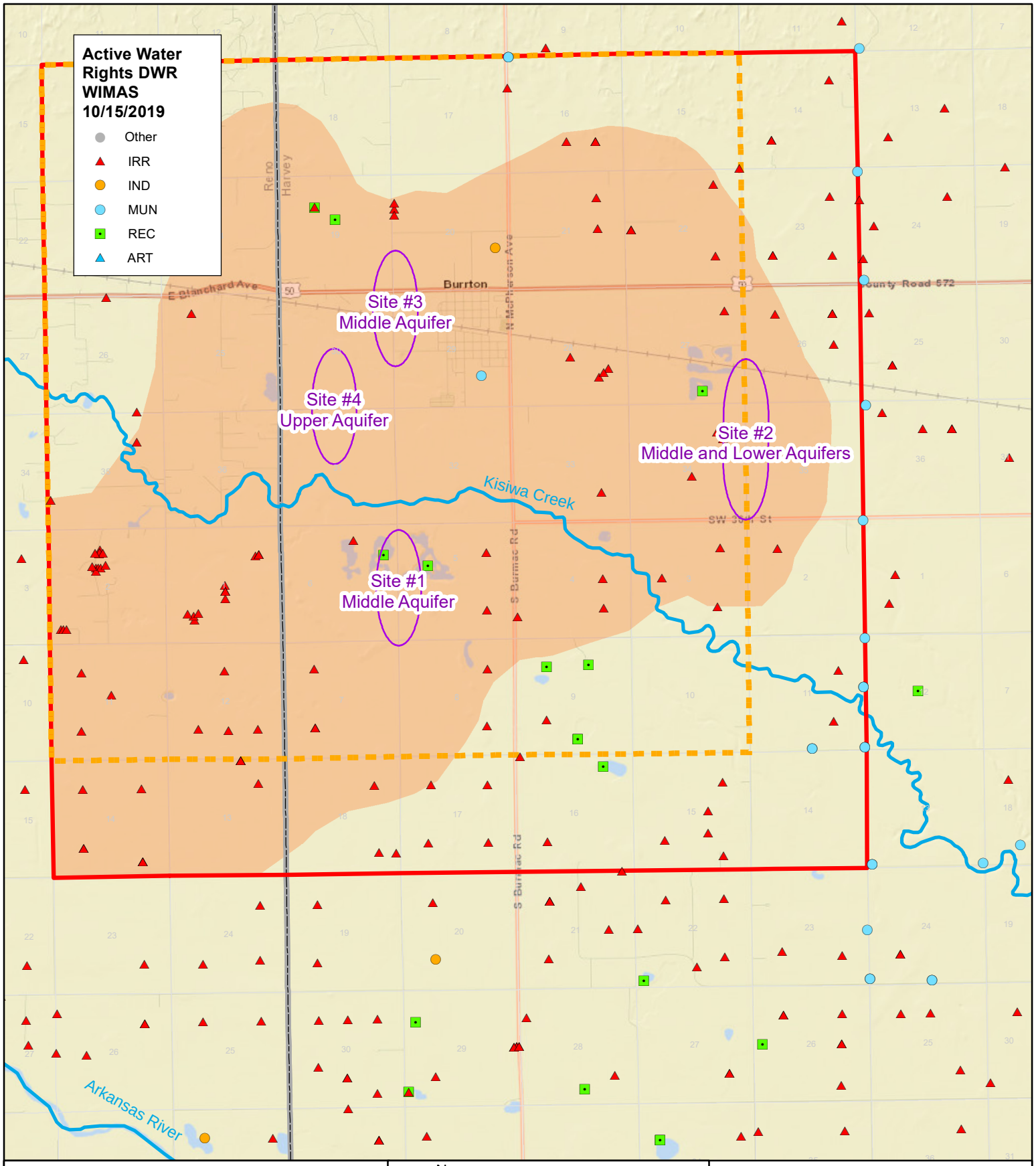
Source: Kansas Department of Agriculture, Division of Water Resources, Burrton IGUCA Review, Draft Final, March 2016, Figures 8 and 9, pages 21 and 22.

4.0 REMEDIATION STRATEGY

Previous studies have estimated that during the period of 1931 through 1943 approximately 1.9 million tons of salt produced from oil field activities entered the aquifer via brine evaporation pits. The average chloride concentration of brine disposed of into pits has been estimated at approximately 96,000 mg/L. The 1.9 million tons of salt mass is problematic given that over a period of roughly 80 years since contamination, the impacts of dilution, dispersion, and lateral migration have spread what was once site specific brine releases at the evaporation pits into a very large chloride contaminant plume affecting roughly 19,300 acres.

Restoration of the entire project area to pre-contamination conditions or the chloride SMCL of 250 mg/L is not feasible due to the amount of groundwater that would have to be removed and treated or pumped to disposal for removal of chlorides from the aquifer system. Furthermore, 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 would induce high chloride surface water infiltration into the aquifer from the Arkansas River, reducing the effectiveness of net chloride mass removal from the project area (*Burns & McDonnell, 2007*). Due to the extremely high total mass and extent of the chloride plume in the project area, remediation efforts will be most effective at strategic locations where remedial wells can be placed to mitigate further downgradient degradation or restore access to economically viable water quality.

Chloride concentrations and migration patterns of the oil field brine plume were reviewed for the project area to identify sites with the highest potential for encountering groundwater at concentrations at or over 1,000 mg/L. The general location for selected potential remediation sites is illustrated in Figure 4-1. The current spacing between monitoring wells within the project area is often in exceedance of one mile. The general location for potential remediation sites was developed based on best available nearby chloride concentration data, anticipated migration direction, and trends in the chloride concentrations at nearby monitoring wells. The primary contaminant of concern for this RI is the chloride ion, however oil field brine can contain other contaminants that could influence the viability of remedial alternatives. Additional site hydrogeologic and water quality characterization would is recommended and would be anticipated as part of the permitting and pre-design phase of a remediation project.



Legend

- Potential Remediation Sites
- Potential Groundwater >250ppm Chloride (Within Project Area)
- Burrton IGUCA Boundary
- Project Area Boundary
- PLSS Sections

N

1:70,000

0 0.5 1 2

Miles

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FIGURE 4-1
POTENTIAL REMEDIATION SITE LOCATIONS

Estimation of required remedial well pumping rates has been developed utilizing the USGS Equus Beds Groundwater Model (*Kelly, B.P., Pickett, L.L., Hansen, C.V., and Ziegler, A.C., 2013*) and estimated aquifer parameters within the project area. Based on these values and preliminary simulations using the model, Table 4-1 was developed to illustrate the approximate zone of capture based on 2-feet of drawdown at 30 days of constant pumping. The values provided for estimated remediation well flow rates in this RI are conceptual and were developed to provide estimated flow rates for support of remedial alternatives and water treatment feasibility analysis within a FS. The number, location, rate, and depths of remediation wells would be refined during the permitting and pre-design phase of a remediation project.

Table 4-1: Remediation Well Rates and Projected Radius of Influence

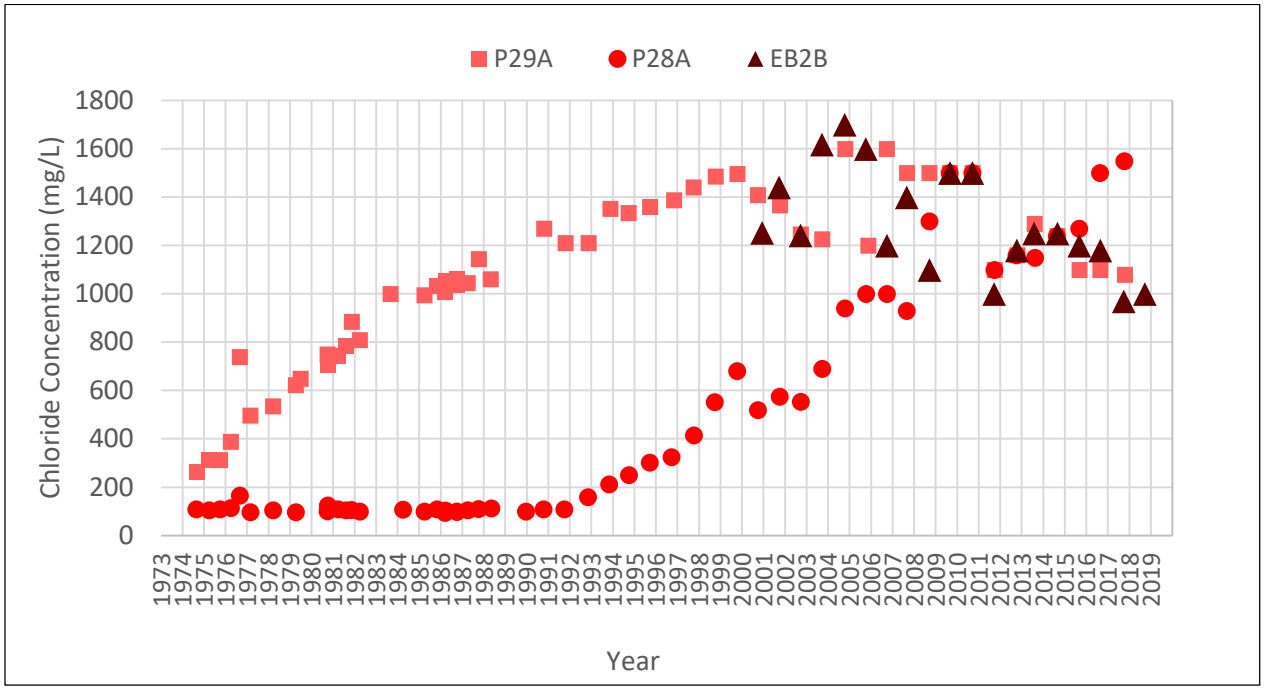
Well Pumping Rate (GPM)	Radius of Influence (feet)
100	150
200	400
300	900
400	1,400
500	1,800

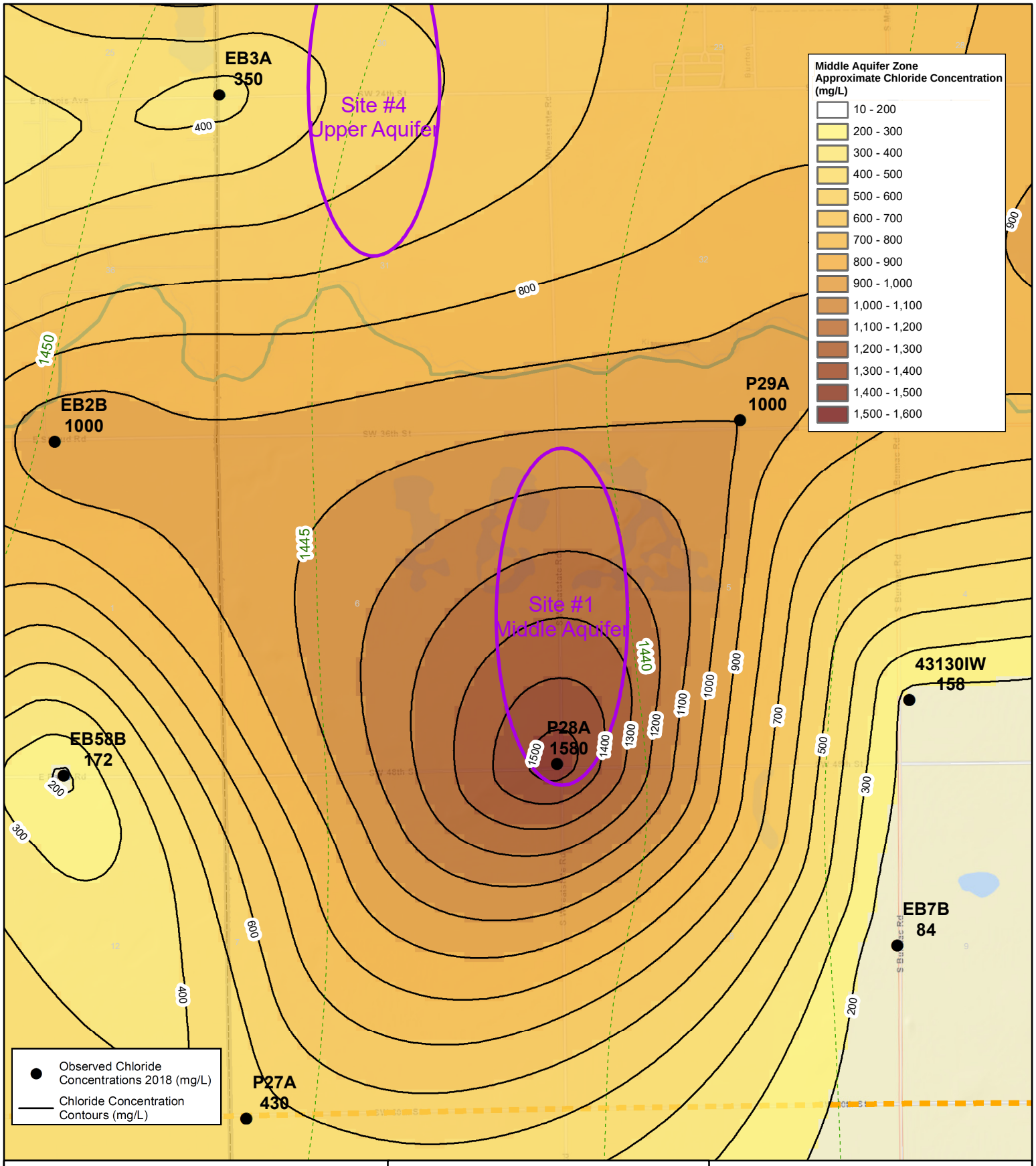
Calculated radius of influence based on 2 feet of drawdown at 30 days of constant pumping at indicated rate

4.1.1 Potential Remediation Site 1

Chloride values in the middle zone of the aquifer near this location are anticipated to continue to rise or remain high based on nearby observation data from groundwater monitoring sites (Figure 4-2). Potential remediation Site 1 is in the south-central portion of the project area to address an area of high chlorides located within the middle zone of the aquifer (Figure 4-3). Based on interpreted chloride concentrations and the anticipated eastward migration, an initial phase of two wells spaced approximately 1,800 feet apart completed in the middle zone of the aquifer operating at 300 gpm each is projected to provide a zone of capture with a width of approximately 3,600 feet. Wells are anticipated to require strategically placed screened intervals to maximize capture of high chloride groundwater from the middle zone of the aquifer.

Figure 4-2: Middle Aquifer Zone Chloride Concentrations Near Site 1 (mg/L)





Legend

- Potential Remediation Sites
- 2016 Groundwater Elevation Contours (ft)
- Burrton IGUCA Boundary
- Project Area Boundary
- PLSS Sections

N

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0 0.125 0.25 0.5 Miles

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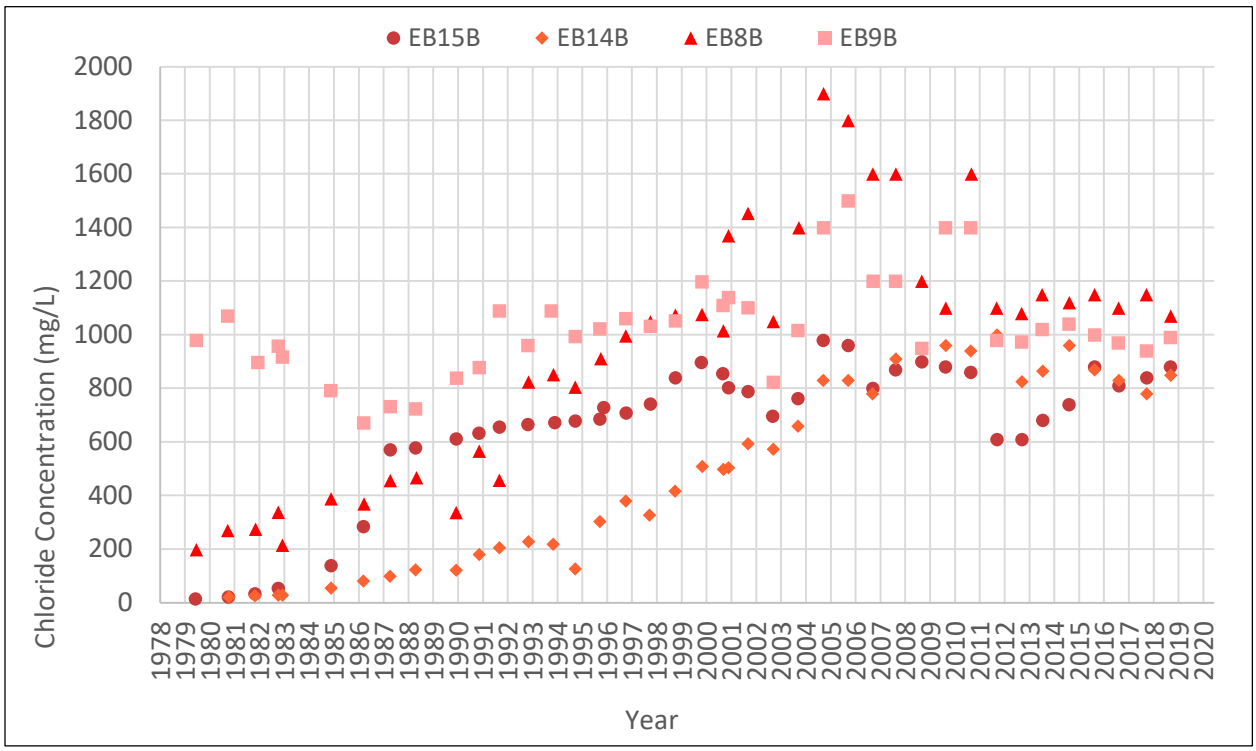
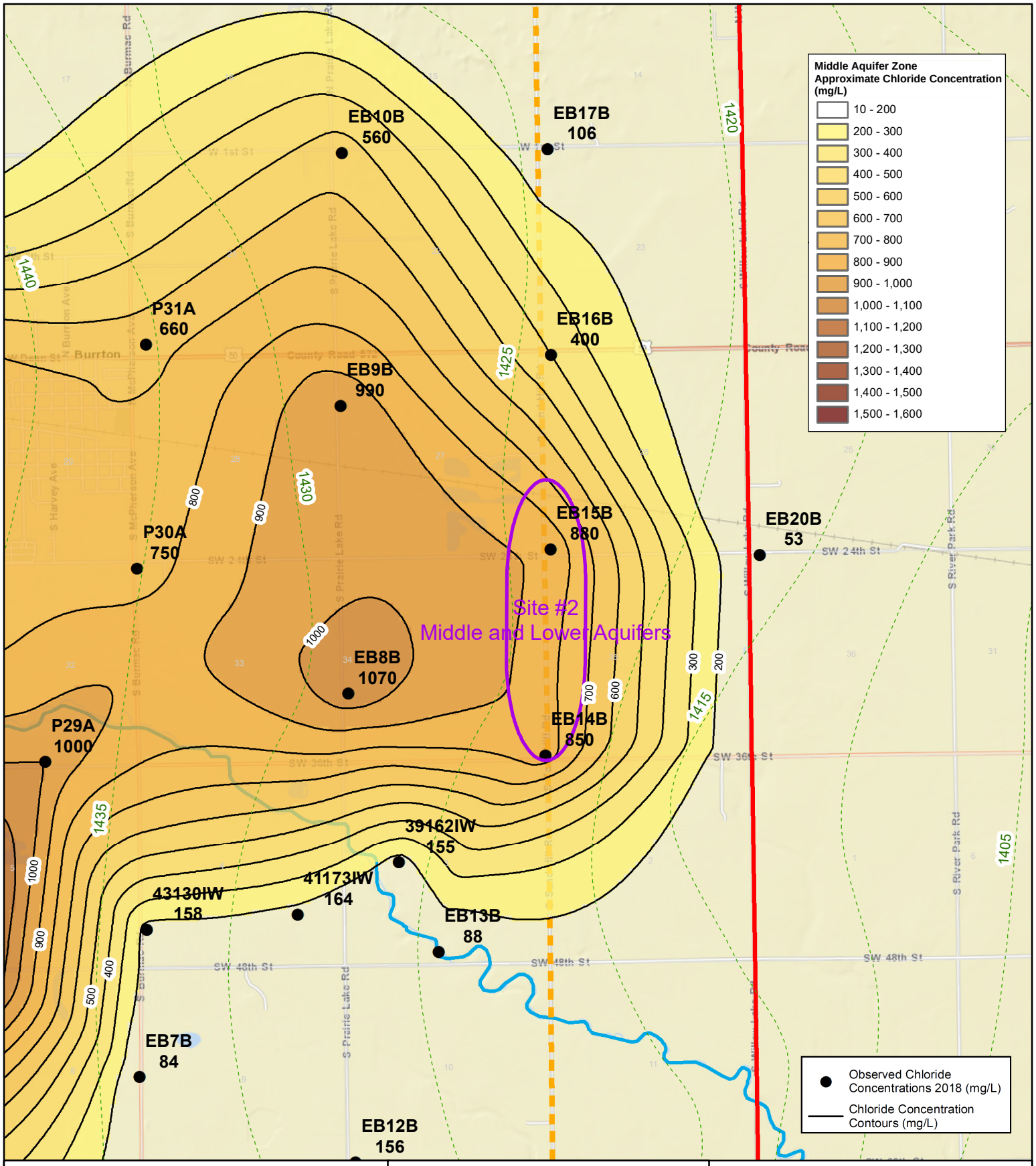
FIGURE 4-3
POTENTIAL REMEDIATION SITE 1 PROXIMITY TO MIDDLE AQUIFER ZONE BRINE PLUME

4.1.2 Potential Remediation Site 2

Chloride values in the middle zone of the aquifer are anticipated to continue to rise based on nearby observation data from groundwater monitoring sites EB15, EB14, and upgradient sites EB8, and EB9 (Figure 4-4). Potential remediation Site 2 is located on the eastern edge of the project area to address an area of high chlorides located within the middle zone of the aquifer (Figure 4-5). Chloride concentrations have also risen from background values in the upper and lower zones of the aquifer, with notable increases at groundwater monitoring site EB8 (Figures 4-6 and 4-7). Based on interpreted chloride concentrations and the anticipated eastward migration of the plume, capture of the high chloride groundwater indicated at monitoring sites EB8, 9, 14 and 15, could require total remediation well flow rates approaching 2,000 gpm. A phased project approach for this site is recommended that would allow for scaled increases in the number and total flow rate from remediation wells and phased increases in associated treatment infrastructure. An initial phase of two wells spaced approximately 1,800 feet apart completed in the middle zone of the aquifer operating at 300 gpm each is projected to provide a zone of capture with a width of approximately 3,600 feet. Wells are anticipated to require strategically placed screened intervals to maximize capture of high chloride groundwater from the middle zone of the aquifer. If long term trends continue to show trends and migration of upgradient chlorides into the lower zone of the aquifer, remediation wells could also be completed in the lower zone of the aquifer at this site.

Figure 4-4: Middle Aquifer Zone Chloride Concentrations (mg/L) Near Site 2





Legend

- Potential Remediation Sites
- 2016 Groundwater Elevation Contours (ft)
- Burrton IGUCA Boundary
- Project Area Boundary
- PLSS Sections

N

1:40,000

0 0.25 0.5 1 Miles

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FIGURE 4-5
POTENTIAL REMEDIATION SITE 2 PROXIMITY TO MIDDLE AQUIFER ZONE BRINE PLUME

Figure 4-6: Upper Aquifer Zone Chloride Concentrations (mg/L) Near Site 2

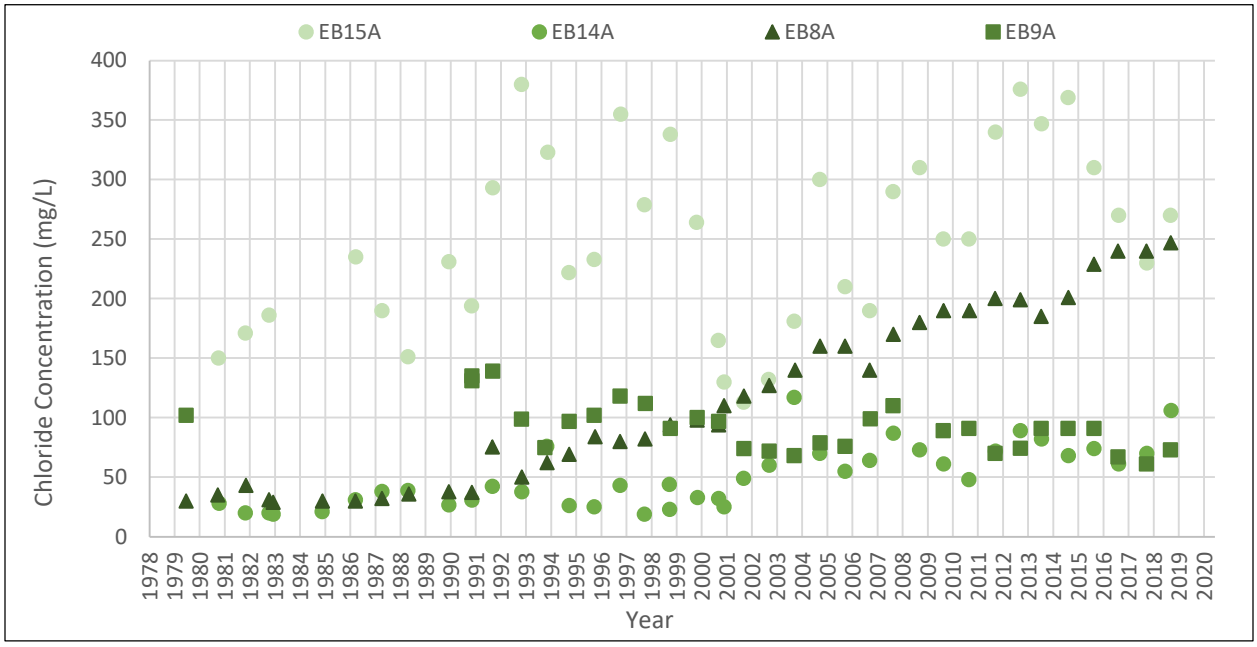
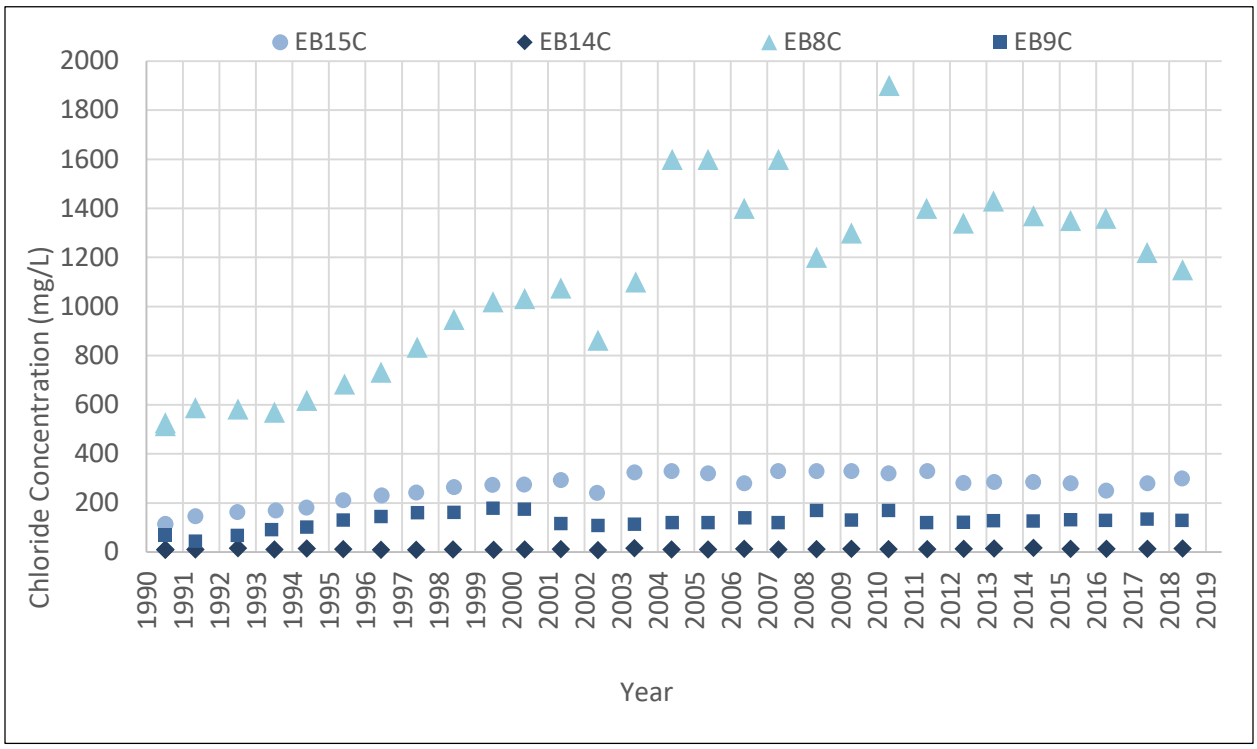


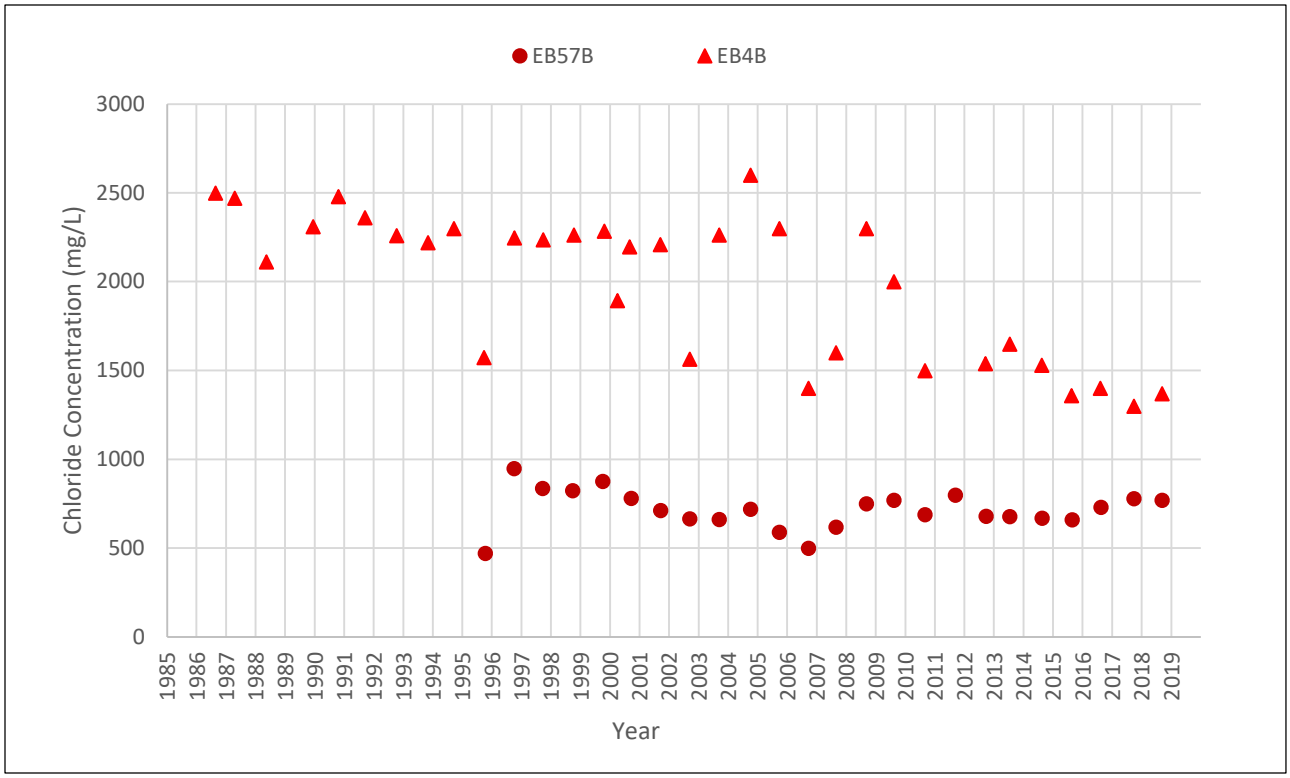
Figure 4-7: Lower Aquifer Zone Chloride Concentrations (mg/L) Near Site 2

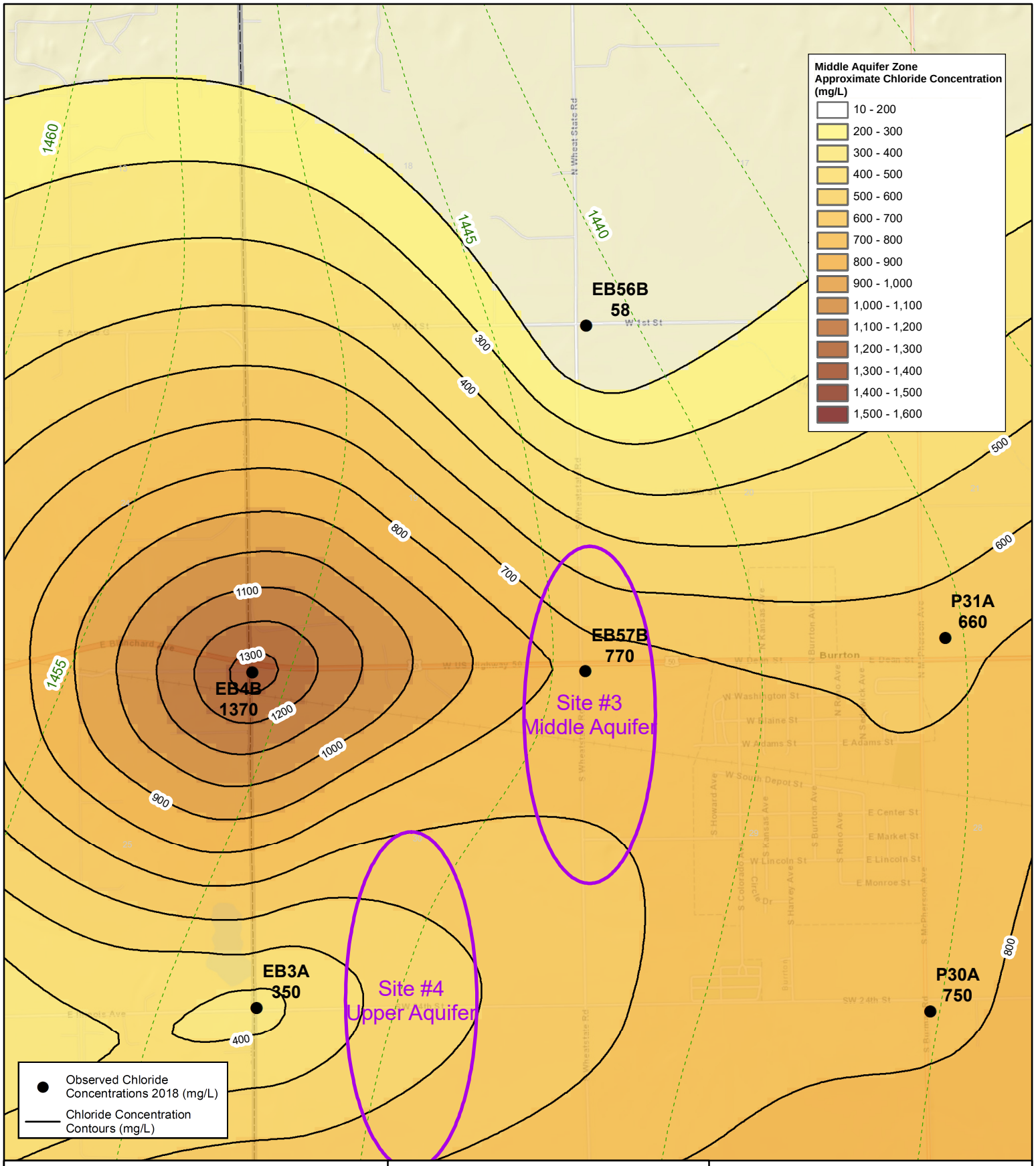


4.1.3 Potential Remediation Site 3

Chloride values in the middle zone of the aquifer near this location are anticipated to continue to remain high based on nearby observation data from groundwater monitoring sites EB57B and EB4B (Figure 4-8). Potential remediation Site 3 is in the north-central portion of the project area to address an area of high chlorides located within the middle zone of the aquifer (Figure 4-9). Based on interpreted chloride concentrations and the anticipated eastward migration, an initial phase of two wells spaced approximately 1,800 feet apart completed in the middle zone of the aquifer operating at 300 gpm each is projected to provide a zone of capture with a width of approximately 3,600 feet. Wells are anticipated to require strategically placed screened intervals to maximize capture of high chloride groundwater from the middle zone of the aquifer.

Figure 4-8: Middle Aquifer Zone Chloride Concentrations (mg/L) Near Site 3





Legend

- Potential Remediation Sites
- 2016 Groundwater Elevation Contours (ft)
- Burrton IGUCA Boundary
- Project Area Boundary
- PLSS Sections

N

1:24,000

0 0.125 0.25 0.5 Miles

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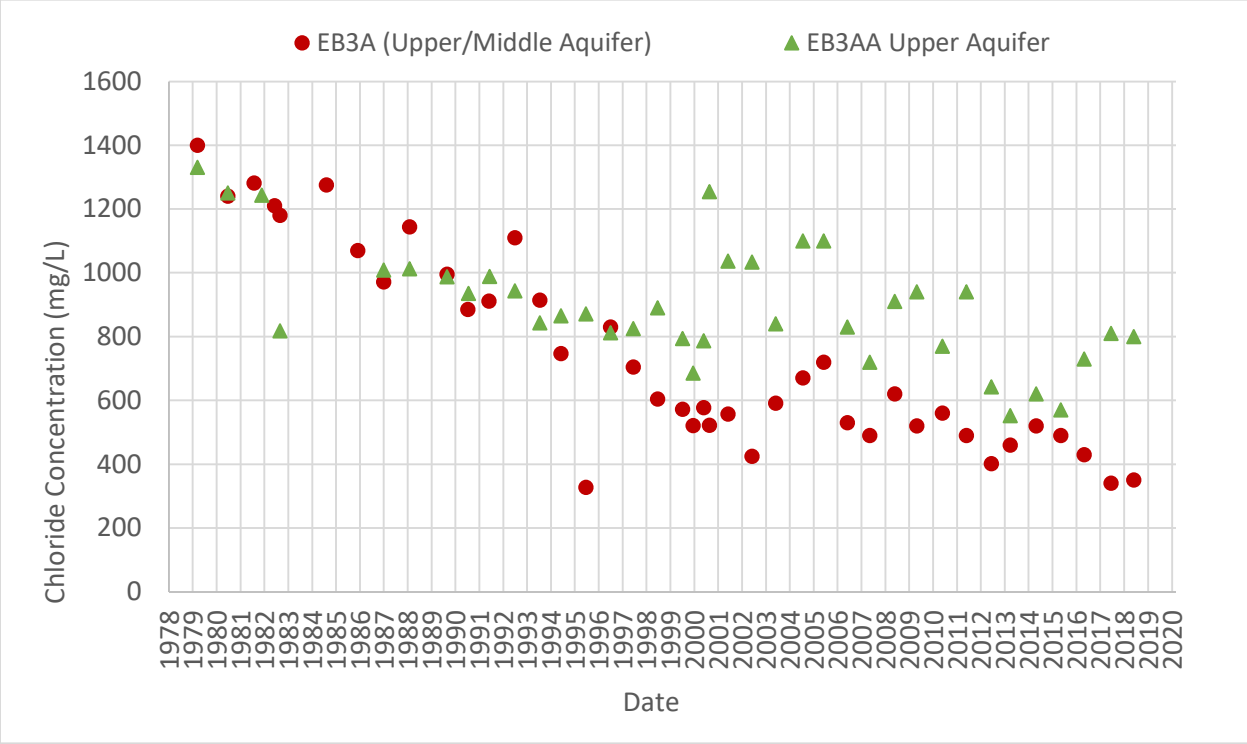
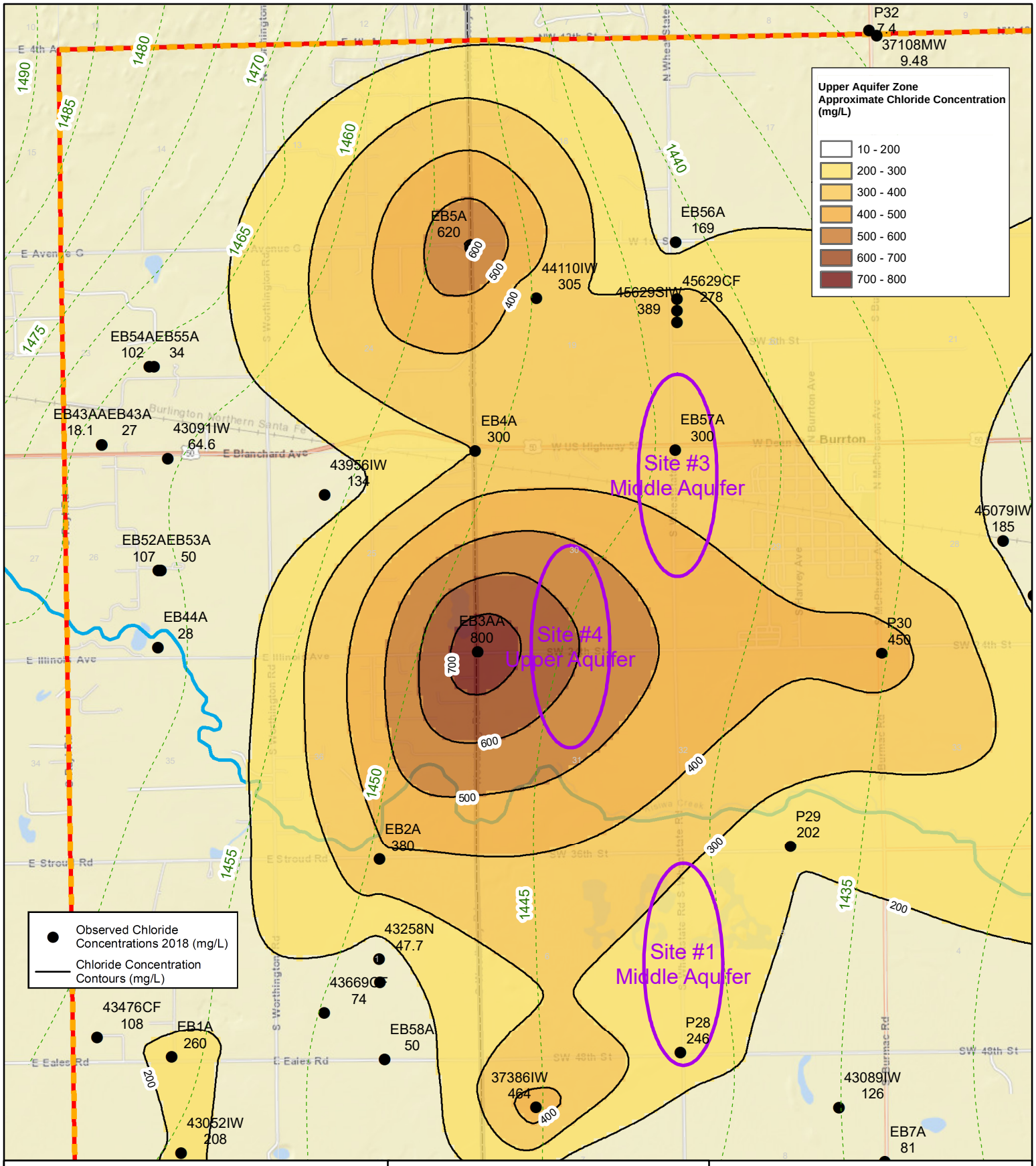
FIGURE 4-9
POTENTIAL REMEDIATION SITE 3 PROXIMITY TO MIDDLE AQUIFER ZONE BRINE PLUME

4.1.4 Potential Remediation Site 4

Chloride values in the upper aquifer zone at this site historically decreased from the 1980 to roughly the year 2000 (Figure 4-10). Chloride concentrations near the site within the upper zone the aquifer are higher than the middle and lower zones (Figure 4-11). Since the year 2000, observed values have ranged between 600 to 800 mg/L, with a much weaker decreasing trend. Due to the limited density of available monitoring wells in the area, an additional hydrogeologic investigation near this site would be valuable prior to any remedial action to identify potential upgradient sources and further delineate areas of high chloride concentrations. Based on interpreted chloride concentrations and the anticipated eastward migration of the plume, an initial phase of three wells spaced approximately 800 feet apart completed in the upper zone of the aquifer operating at 200 gpm each is projected to provide a zone of capture with a width of 2,400 feet. The limited available depth of completion may require more remediation wells at lower individual rates to achieve the net areal distribution and pumping rate desired to provide containment of upgradient contamination. Wells are anticipated to require strategically placed screened intervals to maximize capture of high chloride groundwater from the upper zone of the aquifer.

Figure 4-10: Upper Aquifer Zone Chloride Concentrations (mg/L) Near Site 4





Legend

- Potential Remediation Sites
- 2016 Groundwater Elevation Contours (ft)
- Burrton IGUCA Boundary
- Project Area Boundary
- PLSS Sections

N

1:40,000

0 0.25 0.5 1 Miles

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FIGURE 4-11
POTENTIAL REMEDIATION SITE 4 PROXIMITY TO UPPER AQUIFER ZONE BRINE PLUME

5.0 SUMMARY AND RECOMMENDATIONS

During early development of the Burrton Oil Field from 1931 through 1943, produced brine from oil field activities was placed in evaporation pits where the brine escaped containment via downward seepage into the shallow groundwater of the underlying Equus Beds Aquifer. 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. Previous studies have determined that the migration of the chloride plume laterally has generally been eastward following the natural groundwater gradient at a rate of approximately 0.8-1.0 foot/day (*Whittemore, 2012*). As the plume moves eastward, the higher density of the brine also causes downward vertical migration within the aquifer.

The primary contaminant of concern for this RI is the chloride ion. Ambient groundwater chloride concentrations prior to contamination were likely at or below 30 mg/L. Groundwater sampling in the area during 2018 reported chloride concentrations as high as 1,600 mg/L, and historic values approached 3,000 mg/L. Chloride is a regulated contaminant under existing NSDWRs, with an established SMCL of 250 mg/L. Chloride concentrations in drinking water above 250 mg/L result in a salty taste. Except for the City of Burrton, most of the project area is rural where drinking water is likely supplied by domestic wells. According to KGS online water well completion logs there are approximately 200 domestic and livestock wells within the project area with approximately 150 wells located in an area where one or more zones of the aquifer are likely to exceed 250 mg/L for chloride. The aquifer in the project area supports multiple beneficial uses, with agricultural irrigation being the primary use. The maximum anticipated acceptable level of chloride in irrigation water for primary crops in the area is likely near 350 mg/L but is also highly dependent on the crop, type of soils, and the irrigation method used. Past studies indicate that there are portions of the aquifer within the project area where water rights development has been directly impacted by the oil field brine contamination.

With no remedial action the high chloride groundwater will continue to migrate to the east/southeast in the direction of general groundwater flow. Previous studies have estimated that the plume will continue to move at the general rate of groundwater flow which is roughly 1-foot per day. As the plume moves eastward it will also likely move downward within the aquifer especially in areas with higher vertical permeability or lack of clays that would typically separate aquifer zones. As the plume reaches the eastern extent of the project area there is an increase in the observed groundwater gradient and an anticipated increase in aquifer hydraulic conductivity in both the middle and lower zones of the aquifer (*Kelly, B.P., Pickett, L.L., Hansen, C.V., and Ziegler, A.C., 2013*). These factors indicate that once the

plume extends outside of the bounds of the project area, groundwater plume velocity is likely to increase and will begin impacting additional downgradient aquifer users outside the project area.

Due to the extremely high total mass and extent of the chloride plume in the project area, remediation efforts will be most effective at strategic locations where remedial wells can be placed to mitigate further downgradient degradation or restore access to economically viable water quality. Recommended remediation sites have been developed based on sites with the highest potential for encountering groundwater at concentrations at or over 1,000 mg/L. The recommended general location for these potential remediation sites is illustrated on Figure 4-1. There are multiple alternatives for disposal, blending, or treatment of the extracted high chloride groundwater, and these are evaluated within a FS Report which accompanies this RI Report.

6.0 REFERENCES

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