Burrton IGUCA Remediation Study

Prepared for

Kansas Corporation Commission

1997

97-183-4

Burns & McDonnell

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Kansas Corporation Commission
130 S. Market Room 2078
Wichita, Kansas 67202-3802

KCCBURTN
Burrton IGUCA Remediation Study
Project 97-183-4

Ladies and Gentlemen:

Presented herewith is the report titled "*Burrton IGUCA Remediation Study*," in accordance with our contract for professional engineering services dated April 1, 1997. This engineering study evaluates potential high chloride remediation alternatives using groundwater and contaminant transport modeling and includes cost estimates for various alternatives.

Based on study results, large conventional remediation schemes have relatively small impacts on the mass of salt in the Burrton brine plume. Large volume pumping for plume remediation also has the negative impact of inducing flow of high chloride water from the Arkansas River into the area.

Study findings emphasize the long-term nature of remediation measures and the need for careful coordination of remediation, water supply, and management actions for the Equus Beds Aquifer. Recommendations are presented for immediate actions to enhance assessment of the suitability of the water for beneficial use and for a pilot plant remediation project which are needed prior to commitment to large-scale remediation efforts.

The assistance provided by the staff of the Kansas Corporation Commission during the course of this study is greatly appreciated. The project team remains ready to discuss the details of this report at your convenience.

Sincerely,

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Vice President

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KANSAS CORPORATION COMMISSION
BURRTON IGUCA REMEDIATION STUDY
PROJECT NO. 97-193-4

INDEX AND CERTIFICATION PAGE

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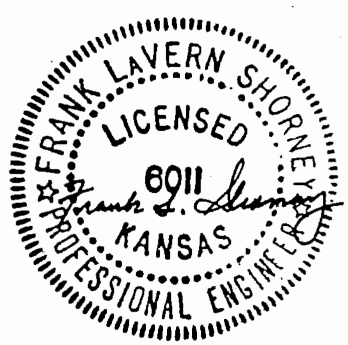
CERTIFICATION(S)



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Summary

SUMMARY

The Kansas Corporation Commission (KCC) is currently considering alternatives involving the control, treatment, beneficial use, and disposal of high chloride groundwater in the vicinity of the Burrton Intensive Groundwater Use Control Area (IGUCA). Past oil field operations near Burrton, Kansas have impacted the Equus Beds Aquifer in this region, resulting in a plume of elevated chloride concentration levels greater than 2,000 mg/L. This groundwater plume of high chlorides is slowly expanding and migrating southeast within the Equus Beds Aquifer, threatening downgradient irrigation and municipal supply wells. Current data indicates that chloride levels in several of the Wichita wells are increasing. Modeling indicates that portions of the plume are likely to reach the Wichita municipal well field in less than 50 years.

The primary objectives of this evaluation are to establish potential remediation alternatives using groundwater and contaminant transport modeling and develop cost estimates for the alternatives. Work includes refining the hydrogeology of the study area and reviewing historical chemical data to create a subregional model for predicting chloride concentrations and the effectiveness of the remediation scenarios.

SITE DESCRIPTION

The study area established for this evaluation is depicted by the subregional model boundary shown in Figure I-1 and is established to address the majority of chloride impacted groundwater originating from the former Burrton oil field. The model of the study area is derived from a larger regional groundwater model developed by the U.S. Geological Survey (USGS) and refined by the U.S. Bureau of Reclamation (USBR).

Both natural and man-made chloride sources have impacted the groundwater within the study area. Two natural sources include recharge from the Arkansas River and saltwater intrusion from the Wellington Formation. Three man-caused sources of chlorides occurring throughout the region include brine of evaporation pans from salt mining activities, brine from oil field

operations, and migration of saltwater from the Wellington Formation through faulty well casings. The primary source of the groundwater salinity in the project area originates from the Burrton and Hollow-Nikkel oil field activities.

MODELING

Several modeling studies have been conducted by the USGS, USBR, and others for the Equus Beds Aquifer due to its importance as a source of water for municipal, agricultural, and industrial use. The majority of modeling parameters used in this evaluation were derived from those utilized in the previous models. A regional model, shown in Figure S-1, was refined from a recent USBR model. The regional model was updated to include the 1990 to 1994 chloride concentrations, current river levels, well pumpage and recharge parameters, based on 1990 through 1994 data. The study area subregional model was developed with finer grid spacing than earlier models, to contribute to a more detailed evaluation of chloride movement. Three hydrostratigraphic units were delineated for the regional and subregional models as follows:

- Level A -- upper sand and gravel unit generally less than 50 feet below land surface (BLS)
- Level B -- middle fine grained sand, silt and clay unit generally greater than 50 feet and less than 170 feet BLS
- Level C -- lower coarse grained unit generally greater than 170 feet BLS and above bedrock.

Numerous modeling scenarios were established to determine the impact of control well pumpages and recharge on plume migration control and remediation. All scenarios were modeled for a 50 year time period beginning with the 1996 chloride distribution. A base, or no action, scenario assumes that no action was taken to remediate or control the chloride plume for the entire 50 year time period and current pumping stresses are constant. The result of a no action scenario was lateral spreading and migration of the chloride plume in the study area generally to the east, towards the Wichita well field. The plume tended to migrate to the lower levels of the aquifer, due to recharge of precipitation in the upper zone and pumping from the lower zones. The peak chloride concentrations decreased as the plume was diluted by precipitation and mixing with the surrounding groundwater. Results of other plume management scenarios were compared with the results of the base or no action case.

Several types of plume control wells or recharge features were included in the various modeled scenarios. These include:

- Interceptor and extraction wells - relatively low capacity wells installed at locations of high chloride concentrations. Pumping rates varied from about 100 to 400 gpm.
- Gradient control wells - located upgradient of the plume to reduce water levels, lowering the gradient and slowing plume migration. The gradient control wells were located in areas of medium to low chloride concentrations so the water could be beneficially reused with little treatment. These wells were simulated at up to a 400 gpm pumping rate.
- Recharge basins - recharge of pumpage from the gradient control wells into the formation to raise water levels downgradient of the plume to reduce the plume migration rate.

Initial modeling scenarios indicated that very high pumping and recharge rates would be required for complete plume management. Several scenarios were evaluated with plume control pumping rates of 4,000 gpm which resulted in the greatest impact on the plume. These scenarios can be summarized as follows:

- **Interceptor wells, 4,000 gpm:** 20 wells in the middle and lower layers of the aquifer pumping at a total rate of 4,000 gpm. The locations of these wells were similar to those located in the 1993 USBR model (Pruitt model, 1993). This was the highest pumping rate evaluated in the USBR study.

- **Plume control wells, 4,000 gpm:** 6 wells (gradient control wells) located upgradient of the plume and screened in Levels B and/or C and 17 wells (extraction wells) in the high concentration areas screened in Levels A and/or B pumping at a total rate of 4,000 gpm.

- **Plume control wells with recharge basins:** gradient control and extraction wells described above with the addition of four one-half acre recharge basins receiving 75% of the pumpage from the extraction well network assuming 25% is lost during water treatment. The recharge basins were located downgradient of the plume.

- **Base scenario with recharge effects from the Equus Beds Recharge Project with active recharge into Level C:** No action for 50 years with water levels 10 feet higher in the vicinity of the Wichita wells due to the recharge effects from the Equus Beds Recharge Project with active injection into level C at 388 gpm through 22 recharge wells.

- **Plume control wells, 4000 gpm, with recharge effects from the Equus Beds Recharge Project with active recharge into Level C:** 6 wells upgradient of the plume screened in levels B and/or C and 17 wells in the high concentration areas screened in levels A and/or B pumping at a total rate of 4000 gpm for 50 years with water levels 10 feet higher in the vicinity of the Wichita wells due to the recharge effects from the Equus Beds Recharge Project with active injection into Level C at 388 gpm through 22 recharge wells.

- **Plume control wells, 8000 gpm, with recharge effects from the Equus Beds Recharge Project with active recharge into Level C:** 6 wells upgradient of the plume screened in levels B and/or C and 17 wells in the high concentration areas screened in levels A and/or B pumping at a total rate of 8000 gpm for 50 years with water levels 10 feet higher in the vicinity of the Wichita wells due to the recharge effects from the Equus Beds Recharge Project with active injection into Level C at 388 gpm through 22 recharge wells.

The interceptor well scenarios were duplicated for the subregional model from previous modeling by the USBR which simulated the effects of placing withdrawal wells intercepting the highest concentrations areas of the plume, east of Burrton. These remediation scenarios removed a small portion of the plume and slows, but did not prevent, the impact of the chloride plume on the Wichita Well Field.

The layout of the plume control wells combined the use of extraction wells located in the high concentration zones of the chloride plume and higher capacity wells upgradient of the plume. The low-capacity extraction wells are designed to remove groundwater from areas of highest chloride concentration within Levels A and B. The gradient control wells are designed to control the local groundwater flow gradient restricting the migration of the high chloride plume. Plume migration control allows greater chloride removal efficiencies. Like the interceptor wells scenario, the modeled plume control layout slows the impact of the chloride plume, without significant chloride removal.

The modeling simulation of plume control wells with four recharge basins located along the 200 mg/L chloride isocontour shows some additional control over the plume, however, like the previous scenarios, the beneficial impacts are limited. In all of the above cases, the control measures resulted in recovery of 8 to 10 percent of the salt believed to have entered the aquifer from oil field activities.

Final modeling scenarios were conducted to reflect the effects of a recharge project being undertaken by the City of Wichita. The project involves recharge of the Equus Beds Aquifer with above-base flow from the Little Arkansas River. A modeling scenario was set up with the assumption that the water levels rose five or ten feet along the eastern portion of the study area.

Additional no action scenarios were modeled with the effects from the Equus Beds Recharge Project to assess the natural movement of the plume. The results of these modeling scenarios indicated that rising groundwater levels caused by the Equus Beds Recharge project significantly effect migration of the chloride plume. In Levels B and C, the leading edge of the plume was pushed more to the north toward Wichita City Wells Numbers 3 and 4. The addition of the plume control well network with a total pumping rate of 4,000 gpm counteracted the movement of the plume to the north. The reduced flow gradient in the aquifer allowed this remediation scenario to have the greatest, yet still minimal, impact on the control and removal of the plume.

REMEDIAL ALTERNATIVES

Several remedial options were considered for the use, treatment or disposal of the recovered water. These options included:

- Beneficial use of the gradient control pumpage by blending with a municipal water supply
- Treatment of extraction well pumpage by reverse osmosis (RO) and subsequent use or recharge
- Beneficial use of a blend of RO permeate and gradient control pumpage as a municipal water supply
- Disposal of extraction well pumpage to deep geologic formations
- Disposal of gradient control pumpage to the Arkansas River
- Disposal of blended extraction and gradient control pumpage to the Arkansas River

The RO process is the preferred technology for the treatment of groundwater in the vicinity of the study area. The beneficial reuse of RO permeate and/or pumpage from gradient control wells is through blending for use as a municipal water supply. The proximity of the potential recipient of the treated and/or blended water affects total pipeline costs. The preferred interconnect for the water is at the well field of the City of Wichita, due to proximity, water demand and the ability of the relative large system to provide greater dilution and thus, less stringent influent requirements.

The preferred disposal technique is through Class II disposal wells, primarily due to cost effectiveness compared to other options. This disposal option is suitable for relatively small pumpage volumes of particularly high chloride concentrations, including RO concentrate and pumpage from extraction wells. The Arkansas River is the nearest significant surface water body to the control well network, and is thus evaluated to receive pumpage from remediation of the chloride plume.

Several remediation alternatives were developed to provide control and removal of the groundwater plume, treatment of the pumpage, if applicable, and disposal. Capital and annual costs were subsequently estimated and compared among the alternatives. The combination of control techniques were similar for each alternative, involving a network of gradient control wells to control migration of the plume, and a network of extraction wells to remove groundwater exhibiting high chloride concentrations. Each alternative included a well and pipeline preliminary plan. The locations of these wells correspond to plume control well layout used in the subregional model. The sizing of alternative components is based on a 4,000 gpm flow rate from the entire control wells system. The alternatives are summarized as follows:

- **Alternative 1:** Discharge from the extraction well network is continuously directed to four Class II disposal wells. Effluent from the gradient control wells is pumped to a connection at the Wichita well field and blended with the Wichita water supply, as appropriate (Figure IV-1).

- **Alternative 2:** Discharge from the extraction well network is continuously directed to four Class II disposal wells. Gradient control well discharge is continuously directed to an outfall along the Arkansas River (Figure IV-2).

- **Alternative 3:** Discharge from the extraction and gradient control networks is discharged at an outfall along the Arkansas River (Figure IV-3).

- **Alternative 4:** Discharge from the extraction well network is piped to an RO treatment plant. RO concentrate is pumped to one Class II disposal well for disposal. RO permeate and gradient control pumpage is blended and discharged to a connection with the Wichita Well Field (Figure IV).

- **Alternative 5:** Discharge from the extraction well network is piped to an RO treatment plant. RO concentrate is pumped to one Class II disposal well. RO permeate and gradient control pumpage is blended and discharged to four one-half acre recharge basins (Figure IV -5).

- **Pilot Study:** This alternative is a pilot-scale installation of two 250 gpm extraction wells with disposal of pumpage to one Class II disposal well (Figure IV-6).

Estimates of capital costs, operation, maintenance, energy and equipment replacement costs are itemized for each of the remedial alternatives in Tables IV-6 through IV-11. Annual costs, involving energy and labor rates, were obtained from sources local to the study area. Operational costs were estimated to include one to four full-time employees, depending on the alternative, to monitor the well field, pipelines, collect samples, oversee maintenance, and monitor a Supervisory Control and Data Acquisition (SCADA) system. Operational and energy costs comprised the majority of annual expenditure for the alternatives. The capital and annual costs for the six alternatives are summarized below:

	Total Capital Costs	Total Annual Costs
Alternative 1	$7,470,000	$538,000
Alternative 2	$6,486,000	$453,000
Alternative 3	$6,803,000	$503,000
Alternative 4	$11,903,000	$1,643,000
Alternative 5	$10,275,000	$1,828,000
Pilot Study	$642,000	$123,000

Because of the high capital costs of Alternatives 1 through 5, no further cost analysis (i.e., present worth calculation) was performed. Groundwater modeling indicated that the pumpage rates for the evaluated alternatives were not adequate for control or remediation of the chloride plume. Therefore, complete plume remediation is likely to cost several times those given in above table. The pilot study was developed in response to the previous alternative costs estimates, as requested by KCC. This final alternative is intended as a initial step in addressing the need for action regarding the plume and to develop operating data to refine the assumptions used in this analysis. The pilot study operation will be the basis for further evaluation of remedial alternatives and possible design of larger systems.

STUDY FINDINGS

Previous studies by the Kansas Geological Survey (KGS) indicates that a withdrawal rate in access of 30,000 ac-ft/year (18,000 gpm) may be required to completely control the plume. In general, the Equus Beds Recharge Project reduces the flow gradients in the aquifer which aides the management of the plume. Use of the recovered water as a municipal supply is a positive beneficial use. Samples of groundwater from throughout the study area need to be obtained and tested for a complete EPA Safe Drinking Water Act set of parameters to evaluate the suitability of the water to be used as a municipal drinking water source. Part of the plume control strategy should include an evaluation of the high pumping rates down-gradient of the City of Wichita well field operation and analysis of methods to optimize pumping operations to mitigate the impacts of the salt plume.

The results of this study are important in showing that large scale pumping to control or remediate the Burrton brine plume would induce high chloride water into the study area from the Arkansas River and deep bedrock sources. This means that careful planning, siting of a remediation system, and coordination with other Equus Beds Aquifer Projects is critical on developing a good long term solution that does not cause negative impacts in other parts of the study area.

* * * * *

Introduction

INTRODUCTION

A. PURPOSE

Groundwater in the vicinity of Burrton, Kansas has been impacted by elevated chloride concentrations of greater than 2,000 mg/L, primarily caused by past oil field operations in the region. The plume of high chloride groundwater is expanding and migrating southeast in the Equus Beds Aquifer, threatening to contaminate a larger area of the aquifer which is used for municipal, industrial, and agricultural water supplies. The contaminated area around Burrton was designated as the Burrton Intensive Groundwater Use Control Area (IGUCA) by the state of Kansas in 1985. The IGUCA is within the boundaries of Equus Beds Groundwater Management District No. 2 (GMD2) which was formed in 1975 to manage the aquifer. To address the high chloride groundwater problem, the Kansas Corporation Commission (KCC) is seeking alternatives for the control, disposal, and/or beneficial use of high chloride water from the Burrton IGUCA.

The objectives of this evaluation are to define the hydrogeology of the groundwater in the study area, model the effects of various remedial alternatives on the chloride concentrations, and to outline potential alternatives for the control, disposal, and/or beneficial use of high-chloride groundwater from the Burrton IGUCA.

B. SCOPE

The major tasks performed in this study include the following:

- Prepare a subregional model including the Burrton IGUCA using a modified version of the USGS MODFLOW groundwater flow model to determine recovery well capacity, spacing and well/screen design criteria.

- Establish remediation scenarios for modeling, including no-action, pump-and-treat, deep well injection, and aquifer recharge components.

- Develop a contamination transport model, using the MT3D modeling program, to evaluate chloride migration in the Equus Beds Aquifer with no action and selected remediation scenarios.

- Use results of modeling scenarios to help determine potential alternatives to control, use and/or disposal of high-chloride groundwater.

- Coordinate up to two meetings with KCC, state regulatory agencies that have regulatory authority and local governments that may be impacted by the continued migration of the high chloride plume.

- Prepare estimates of capital, operation and maintenance costs for each feasible alternative developed in the engineering evaluation.

- Meet with KCC personnel to review alternatives and incorporate appropriate comments into the engineering evaluation.

- Prepare an engineering report summarizing the evaluations performed with exhibits, cost estimates, conclusions and recommendations.

* * * * *

Part I - Site Description

PART I
SITE DESCRIPTION

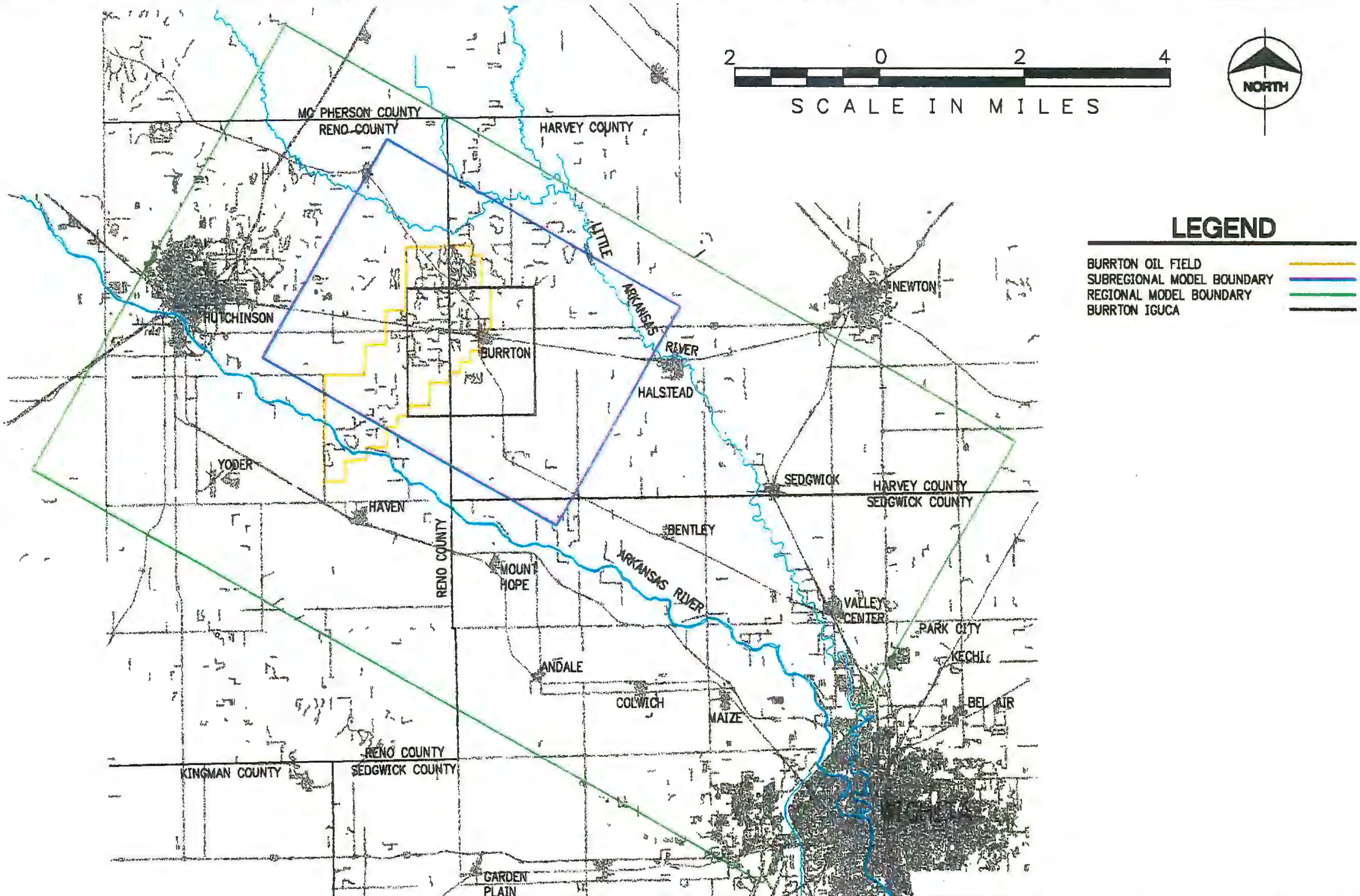
A. GENERAL

The Equus Beds Aquifer is the primary source of potable and irrigation water in south-central Kansas. The quality of the groundwater in the aquifer is generally very good, although salinity, indicated by the presence of chloride, has entered the aquifer from several sources. In the Burrton area, past oil field practices have resulted in a large area of high chloride groundwater. The hydrogeologic setting and large volume of groundwater pumpage within the study area have caused migration of the chloride plume, impacting agricultural and municipal wells.

B. STUDY AREA

The study area for this evaluation is shown in Figure I-1 as the subregional model boundary. This area occupies approximately 190 square miles and encompasses the majority of chloride impacted groundwater originating from the Burrton oil field. The subregional model is a portion of a larger regional groundwater model developed by the US Geological Survey (USGS) and refined by the US Bureau of Reclamation (USBR) to study the hydrogeology and salt migration in the area. The boundary of the regional model is located in south-central Kansas in parts of Reno, Harvey, and Sedgwick Counties.

The study area exhibits characteristics of a continental climate, with large variations in seasonal temperatures, moderate precipitation, and windy conditions. Temperatures range from daily averages of 2 °F in January to 81.4 °F in July. Temperatures reach a maximum of greater than 100 °F in the summer to less than -20 °F in winter. Average annual precipitation is about 30 inches per year, mostly in the form of rainfall. Approximately 15 inches of snow per year falls between December and March.



Burns & McDonnell

Figure I-1

STUDY AREA

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BURTON=burton.dwg

Topographic variation in the area is minimal, with land surfaces gently sloping toward major streams in the area.

C. SOURCES OF ELEVATED CHLORIDE CONCENTRATIONS

There are two natural sources of salinity entering the Equus Beds Aquifer, the infiltration of surface water from the Arkansas River and saltwater intrusion from the Wellington Formation. Three other sources of chlorides in the groundwater include brine from evaporation-pans of salt mining activities, brine from oil field operations, and migration of saltwater from the Wellington Formation through improperly constructed wells.

The Arkansas River receives saltwater discharge from Permian formations upstream of Hutchinson, Kansas. This is the source of high chloride concentrations in the river water which averages about 630 mg/L of chloride near the project area. Wells in the Equus Beds Aquifer located near the Arkansas River exhibit higher chloride concentrations than wells located further from the river (Spinazola, 1985). Infiltration of high chloride water from the river continues to impact the aquifer. Previous groundwater modeling studies (Myers, 1996, Pruitt, 1993, and Burns and McDonnell, 1994) demonstrate the interaction of the Arkansas River with the Equus Beds Aquifer and the impact of high chloride river water migrating into the aquifer.

High concentrations of chlorides are found in the deeper parts of the aquifer (a bedrock low) near the Arkansas River near the study area. These chlorides may have migrated from the Hutchinson Salt Member through fractures in the upper shale of the Wellington Formation. Chloride concentrations in this water have been detected as high as 4,000 mg/L (Whittemore, 1990).

During the late 1890's and early 1900's, salt companies in Hutchinson conducted salt-solution mining of the Hutchinson Salt Member of the Wellington Formation. Waste from evaporation-pans is reported to be a significant source of salinity in some parts of the Equus Beds Aquifer (Whittemore, 1990).

Permian saltwater and oil field brine migrating up around poorly cased disposal wells or poorly plugged boreholes are other possible sources of chlorides in the aquifer (Whittemore, 1990). Prior to the practice of injecting oil field brines into deep formations, the brines were commonly injected into the Permian Wellington Formation that underlies the Equus Beds Aquifer. In areas where the potentiometric surface in the Permian is greater than the water table elevations in the Equus Beds Aquifer, these wells and boreholes provide a potential conduit for the flow of brine from the Permian into the Equus Beds.

The primary source of groundwater salinity in the project area originates from the Burrton and Hollow-Nickel oil field activities. During the first half of the 20th century, numerous oil and gas wells were drilled in the vicinity of Burrton, Kansas. Saltwater brine, a by-product of oil and gas production, was pumped from the subsurface along with oil and gas. The brine was separated and discharged into nearby creeks and streams during original well discovery. In the 1930's and early 1940's, this practice was prohibited. The brine was then disposed of in evaporation pits or shallow injection wells until this practice was outlawed in the 1950's and the remaining pits were closed. Secondary sources are return flow from shallow disposal wells and the leaks in pipelines leading to these wells.

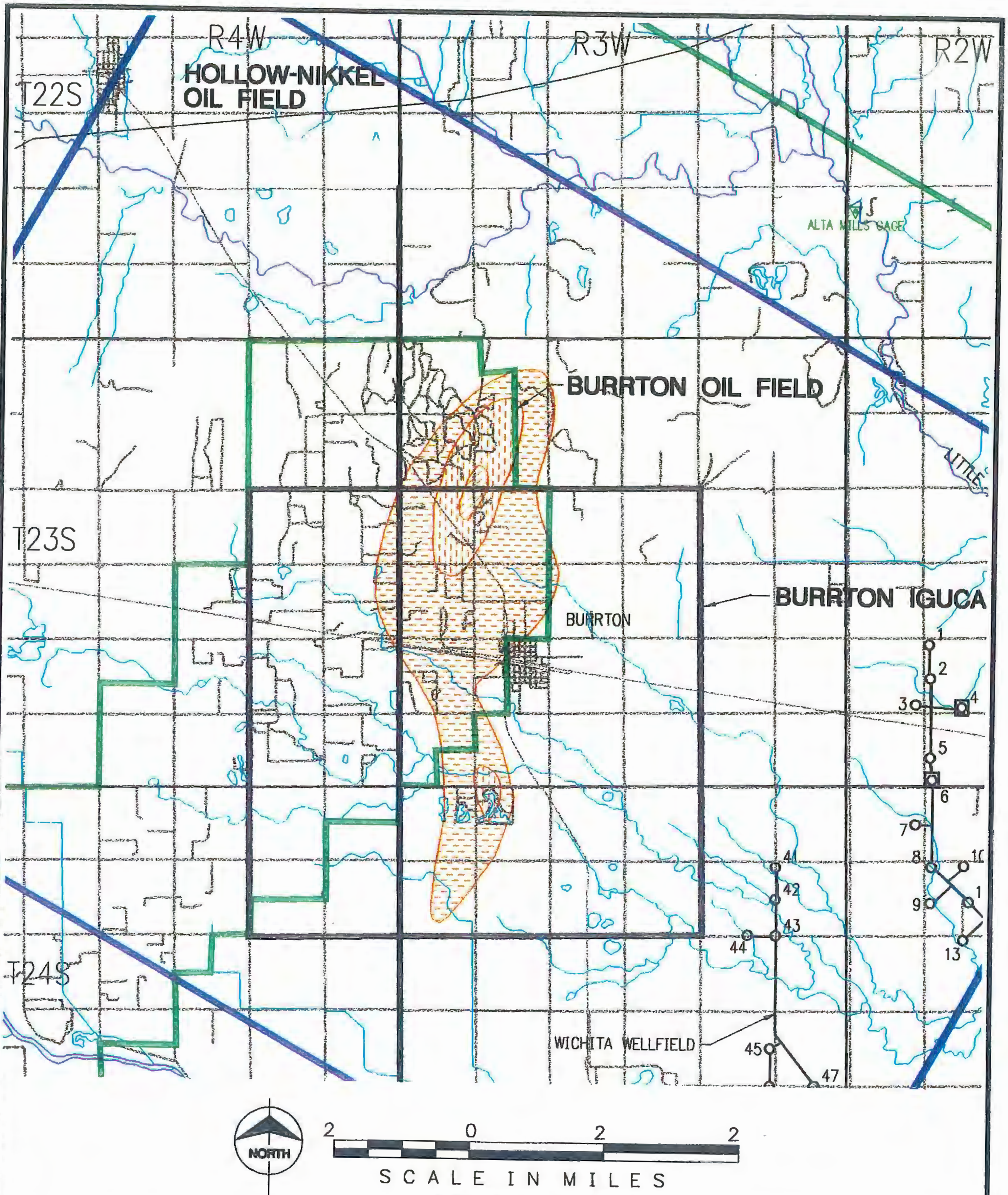
Several million barrels of brine were disposed of, much of which migrated into the shallow aquifer system. The resulting groundwater contamination plume is characterized by chloride concentrations currently exceeding 2,000 mg/L in some areas of the aquifer. Large areas of the aquifer have chloride concentrations exceeding the maximum contaminate level (MCL) of 250 mg/L. The Report of the Burrton Task Force (1984) concluded that about 1.9 million tons of salt was produced by oil field operations and that a large percentage of the salt has entered the aquifer. Additionally, some unknown amount is probably tied up in the soil due to closure of the brine ponds (Burrton Task Force, 1984).

D. EXTENT OF CONTAMINATION

A chloride plume in the Equus Beds Aquifer originating from the Burrton oil field area was recognized in the late 1940's. From 1948 until the use of shallow injection wells and evaporation pits ceased, the area of the plume expanded and concentrations levels increased. After the pits and shallow wells were closed, the plume continue to spread, migrating downgradient and moving to lower levels in the aquifer. The Kansas Corporation Commission (KCC) developed chloride concentration maps for the aquifer zones less than 50 feet and greater than 50 feet deep for 1948 and 1982 as reported in the Report of the Burrton Task Force (1984). These maps were reproduced and are shown in Figures I-2 through I-5.

Chloride concentration maps were developed for the study area based on data obtained during 1996 from Equus Beds Groundwater Management District No. 2 (GMD2) monitoring wells in the area. GMD2 monitoring wells have been constructed to track chloride values in three levels of the aquifer. A map was created for each of three hydrostratigraphic units described below:

- Level A, upper unit -- generally less than 50 feet below land surface (BLS) (Figure I-6)
- Level B, middle unit -- generally greater than 50 feet and less than 170 feet BLS (Figure I-7)
- Level C, lower unit -- generally greater than 170 feet BLS and above bedrock (Figure I-8)



CHLORIDE CONCENTRATION, mg/l

GREATER THAN 1,000 CL

GREATER THAN 500 CL

GREATER THAN 250 CL

SOURCE: BURRTON TASK FORCE REPORT (1984)

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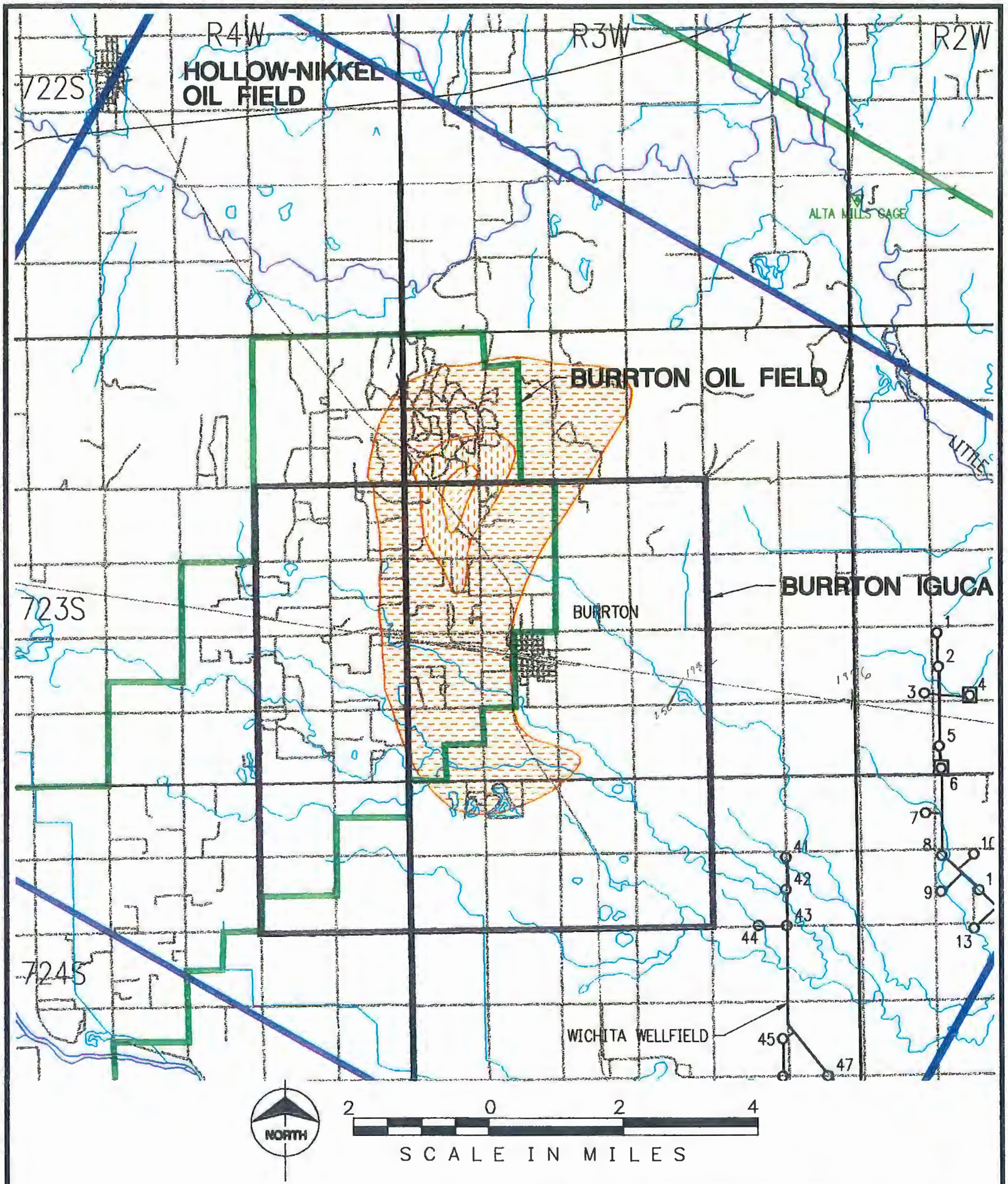
Figure I–2

CHLORIDE CONCENTRATION DATA 1948 LESS THAN 50 FT. DEEP



CHLORIDE CONCENTRATION, mg/l

GREATER THAN 1,000 CL

GREATER THAN 500 CL

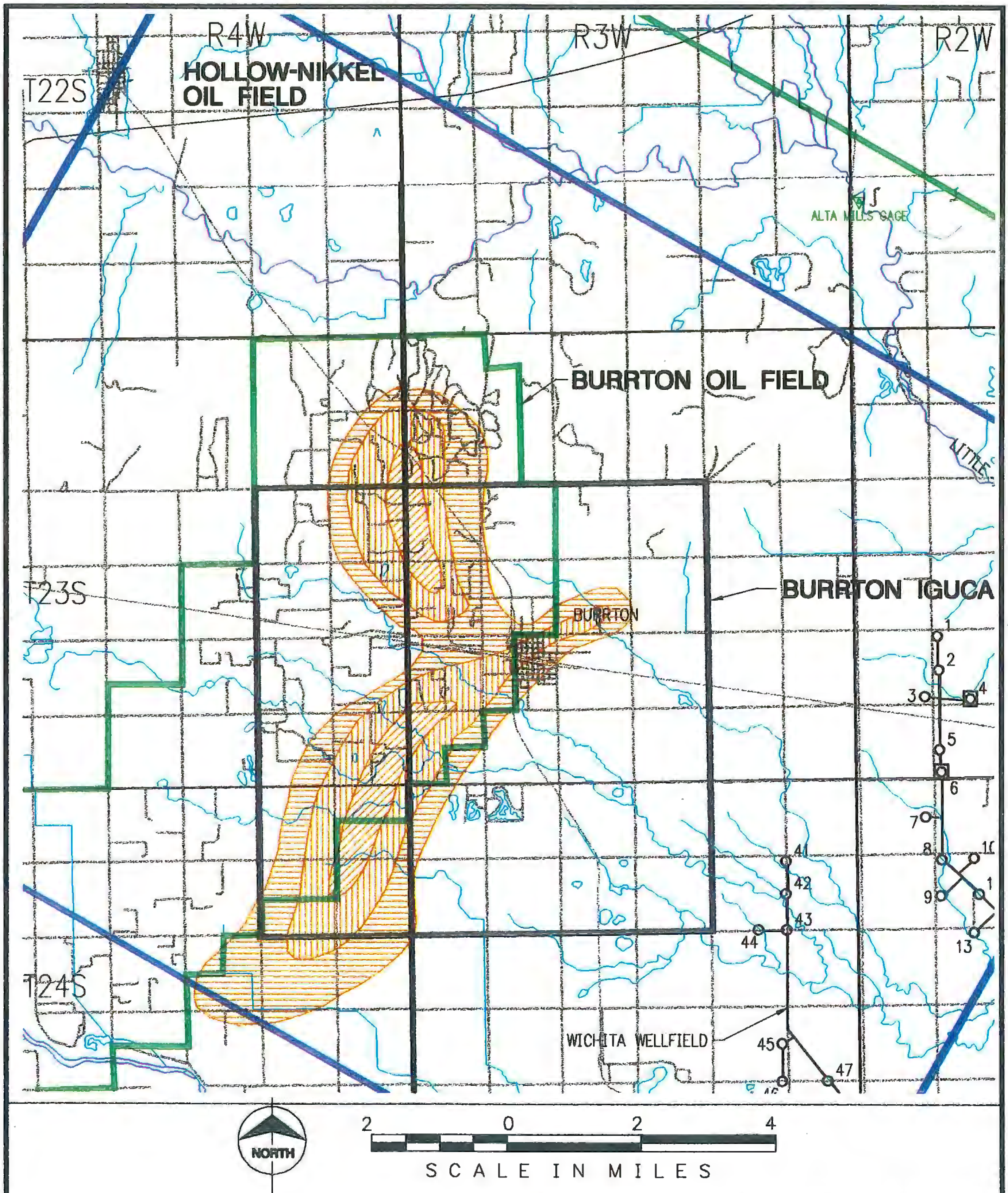
GREATER THAN 250 CL

SOURCE: BURRTON TASK FORCE REPORT (1984)

Burns & McDonnell

Figure I-3

CHLORIDE CONCENTRATION DATA 1948 DEEPER THAN 50 FT.



CHLORIDE CONCENTRATION, mg/l

GREATER THAN 1,000 CL

GREATER THAN 500 CL

GREATER THAN 250 CL

SOURCE: BURRTON TASK FORCE REPORT (1984)

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Figure I-4

CHLORIDE CONCENTRATION DATA 1982 LESS THAN 50 FT. DEEP

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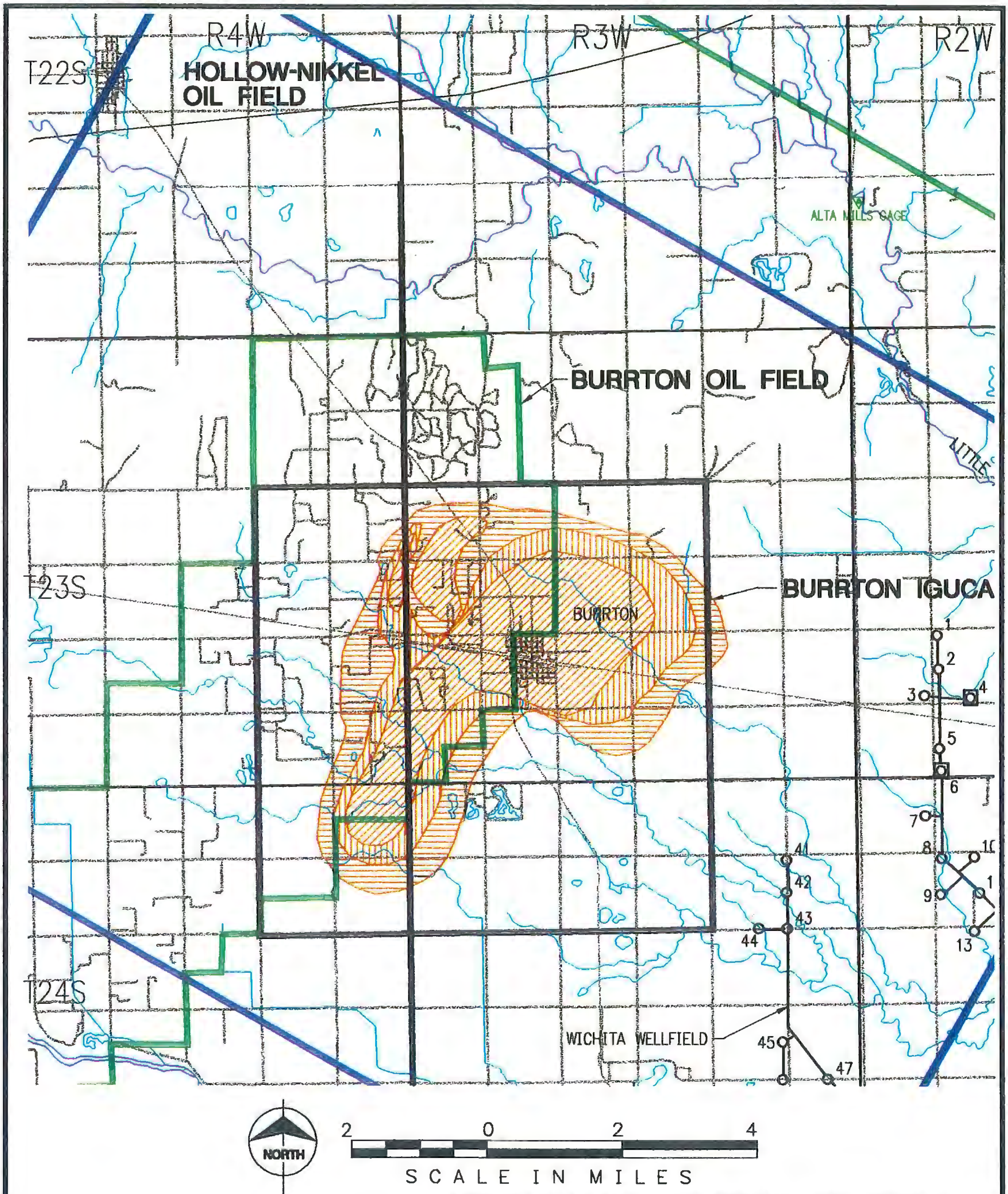

CHLORIDE CONCENTRATION, mg/l

GREATER THAN 1,000 CL
GREATER THAN 500 CL
GREATER THAN 250 CL

SOURCE: BURRTON TASK FORCE REPORT (1984)

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Figure I–5

CHLORIDE CONCENTRATION DATA 1982 DEEPER THAN 50 FT.

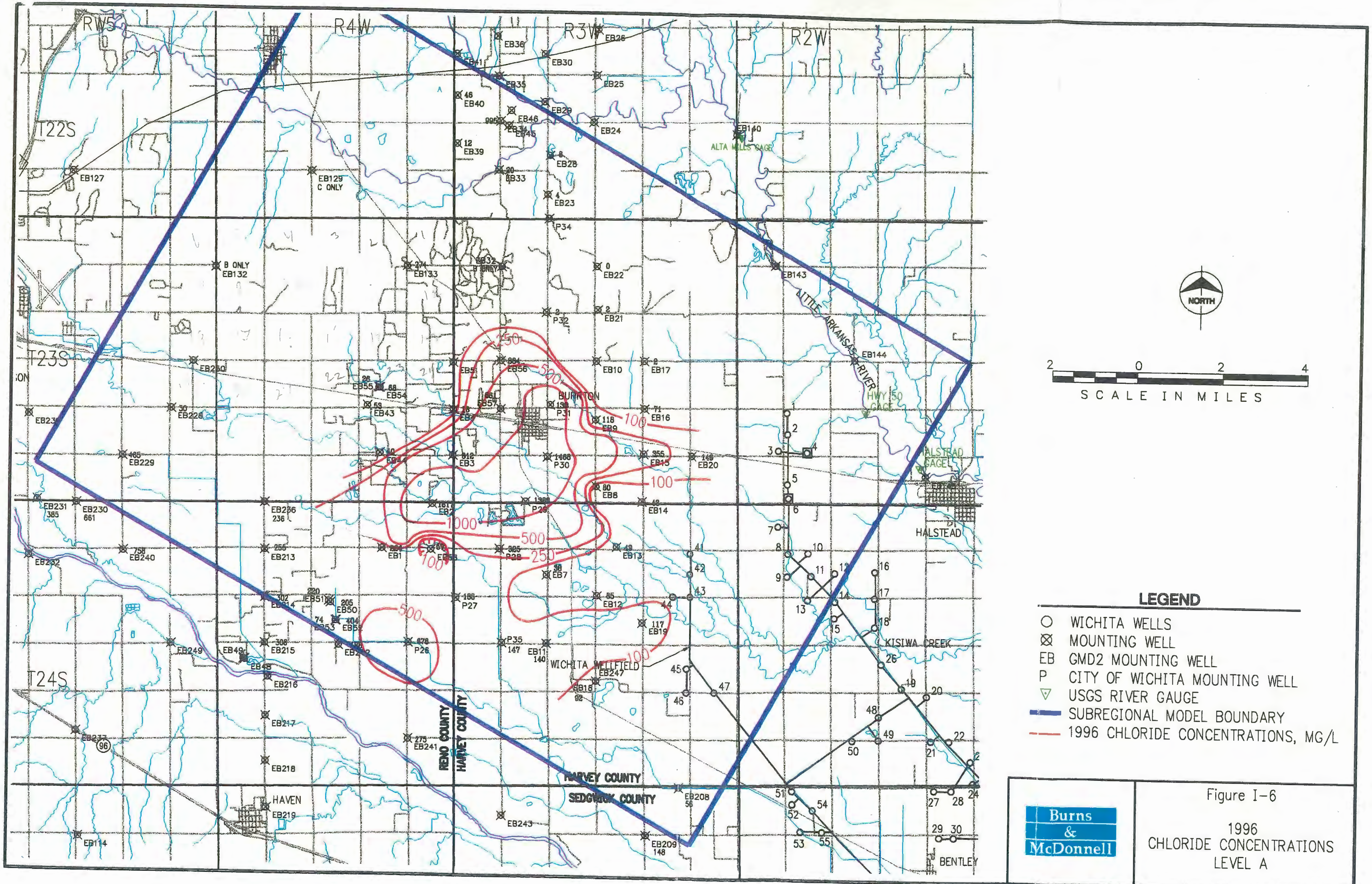


Figure I-6

1996
CHLORIDE CONCENTRATIONS
LEVEL A

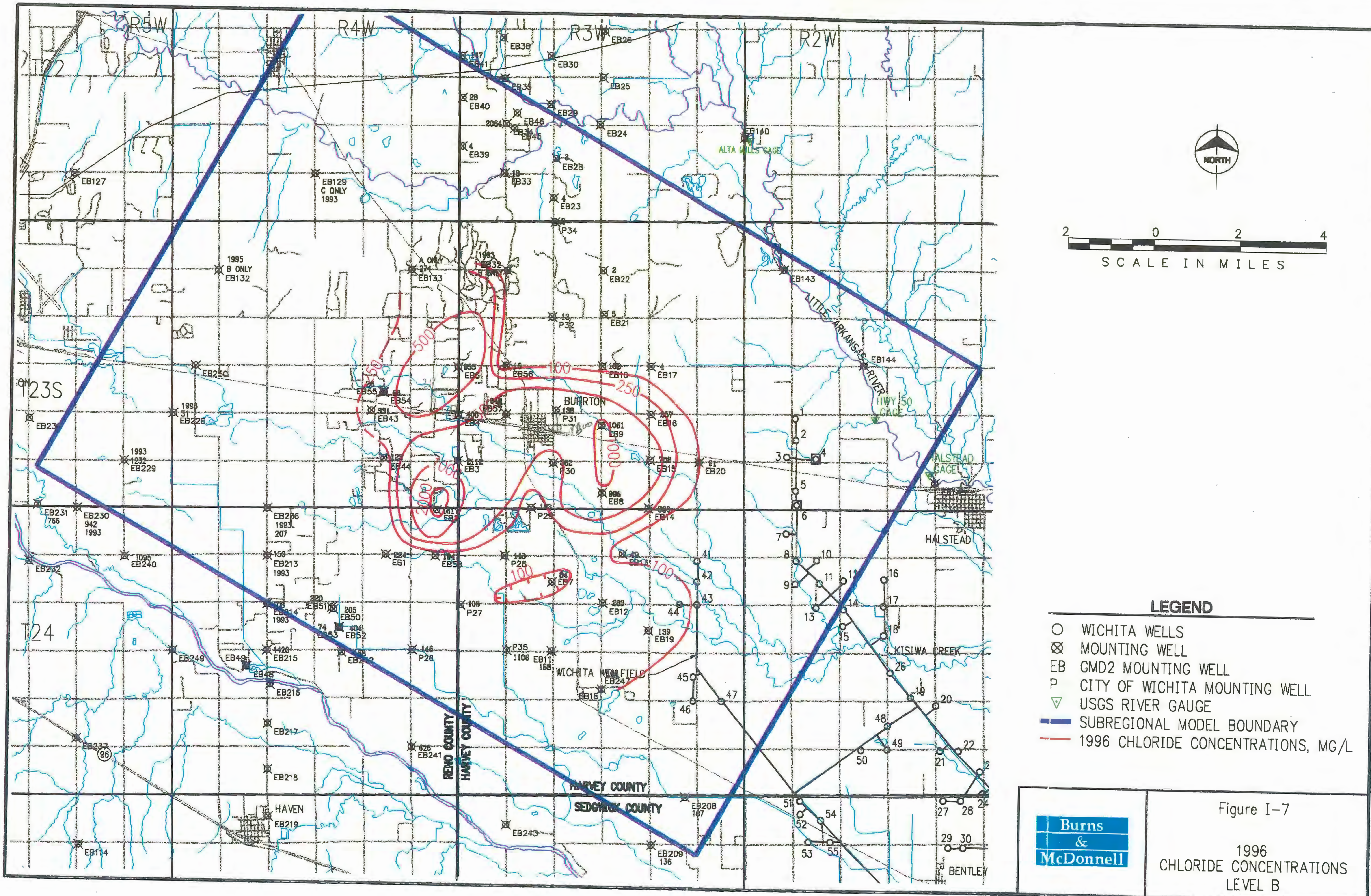
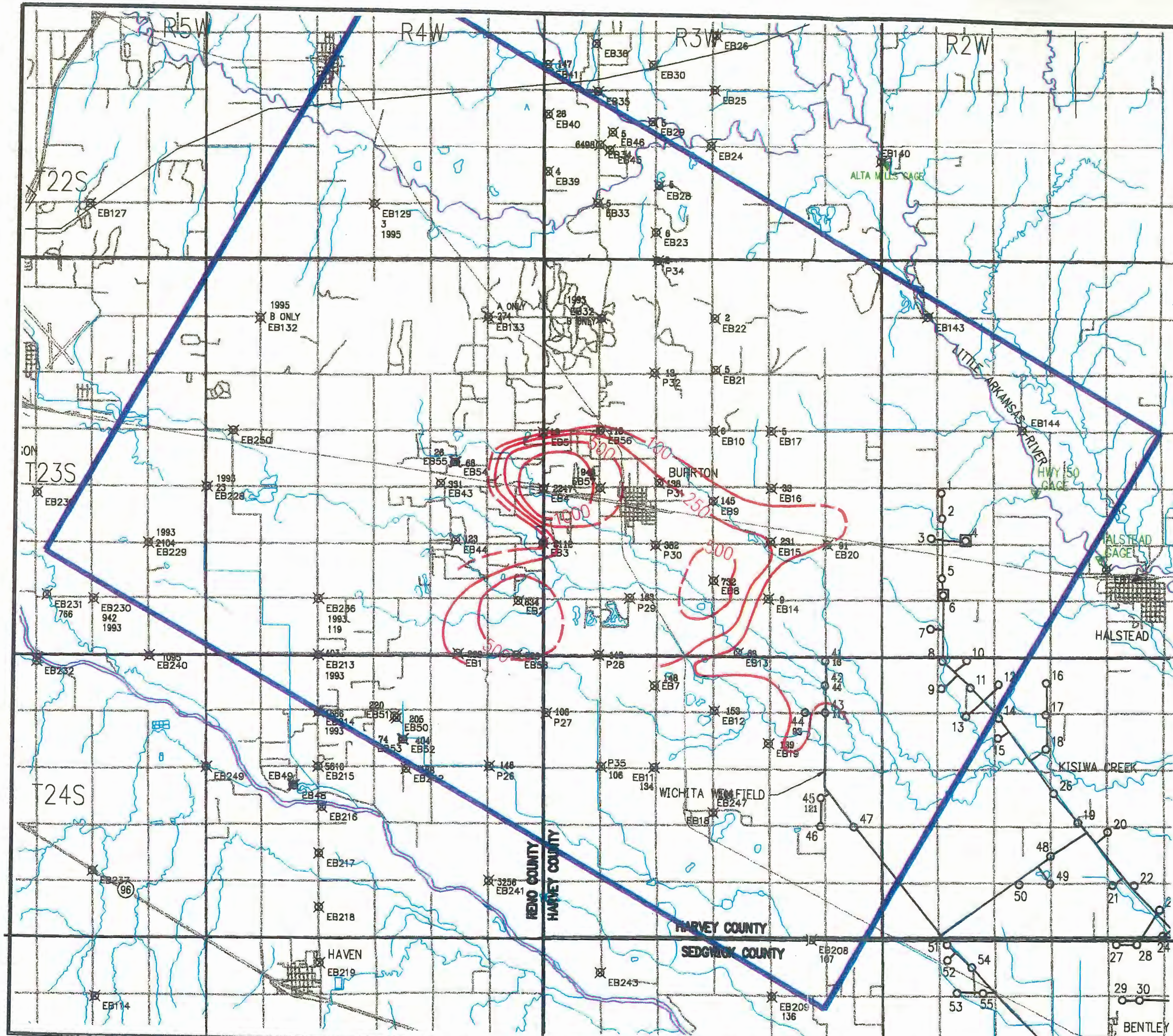


Figure I-7

1996
CHLORIDE CONCENTRATIONS
LEVEL B



NORTH

2 0 2 4

SCALE IN MILES

LEGEND

- ○ WICHITA WELLS
- ⊠ MOUNTING WELL
- EB GMD2 MOUNTING WELL
- P CITY OF WICHITA MOUNTING WELL
- ▽ USGS RIVER GAUGE
- SUBREGIONAL MODEL BOUNDARY
- 1996 CHLORIDE CONCENTRATIONS, MG/L

Burns & McDonnell

Figure I-8

1996
CHLORIDE CONCENTRATIONS
LEVEL C

From 1982 through 1996, the zone of contamination has expanded to the east particularly in Level A, the upper unit of the aquifer. Clay layers in the aquifer tend to perch the high chloride water, slowing its downward migration and causes the salt water to spread laterally in the shallower layers. As the salt water moves to the edges of the clay layers it can migrate downward to the next clay layer in a "stair-step" manner.

Work by the Kansas Geological Survey had shown that some salt remains in the unsaturated zone beneath the old pit areas. Little or no salt was found in control borings located outside the pit area. The salt in the unsaturated zone can provide a continuing source of chlorides to the aquifer due to leaching by recharge from precipitation, especially in areas with a high density of old brine evaporation pits. Although this source of salt is expected to slow natural attenuation of the plume, the impacts are expected to be relative minor compared to the magnitude of the salt plume (Don Whittemore, personal communication).

The Equus Beds Aquifer is the principal source of raw water for surrounding municipalities including Burrton, Halstead, and Wichita. The City of Wichita, Kansas has a large well field consisting of 55 wells. The City has typically used 60% groundwater from the Equus Beds Aquifer for municipal water supply. Groundwater withdrawal rates from the aquifer in the study area have steadily increased since the 1940's. At the present time, water rights and pumpage of all users exceed the natural recharge rate of the aquifer, estimated to be three to six inches per year. This overdevelopment of the aquifer has resulted in a reduction of static water levels. Originally, the depth to water in the Equus Beds Aquifer was relatively shallow, ranging from 10 to 20 feet below land surface. Currently depth to water ranges from 10 to 60 feet. In the area downgradient of the Burrton Intensive Groundwater Use Control Area (IGUCA), water rights have been filed to pump approximately 27.8 billion gallons per year by approximately 450 wells. Forty-eight percent of these water rights are for municipal use, and 51 percent are for irrigation use (Burns & McDonnell, 1994).

Water obtained from the Equus Beds Aquifer is generally of good quality. Changes in the groundwater flow gradients, caused by pumping, is expected to cause changes in groundwater quality by increasing infiltration from the Arkansas River and causing faster migration of the Burrton salt plume. Groundwater modeling performed by the Bureau of Reclamation (Pruitt, 1993) indicates that the average chloride concentration in the Wichita well field will increase from 55 mg/L at the present time to approximately 95 mg/L in year 2010 and 145 mg/L in year 2050. Maximum chloride levels could exceed 300 mg/L in some areas, well above the sensitivity level of 200 mg/L for agricultural uses and 250 mg/L, the Secondary Maximum Contaminant Level (SMCL) for municipal uses.

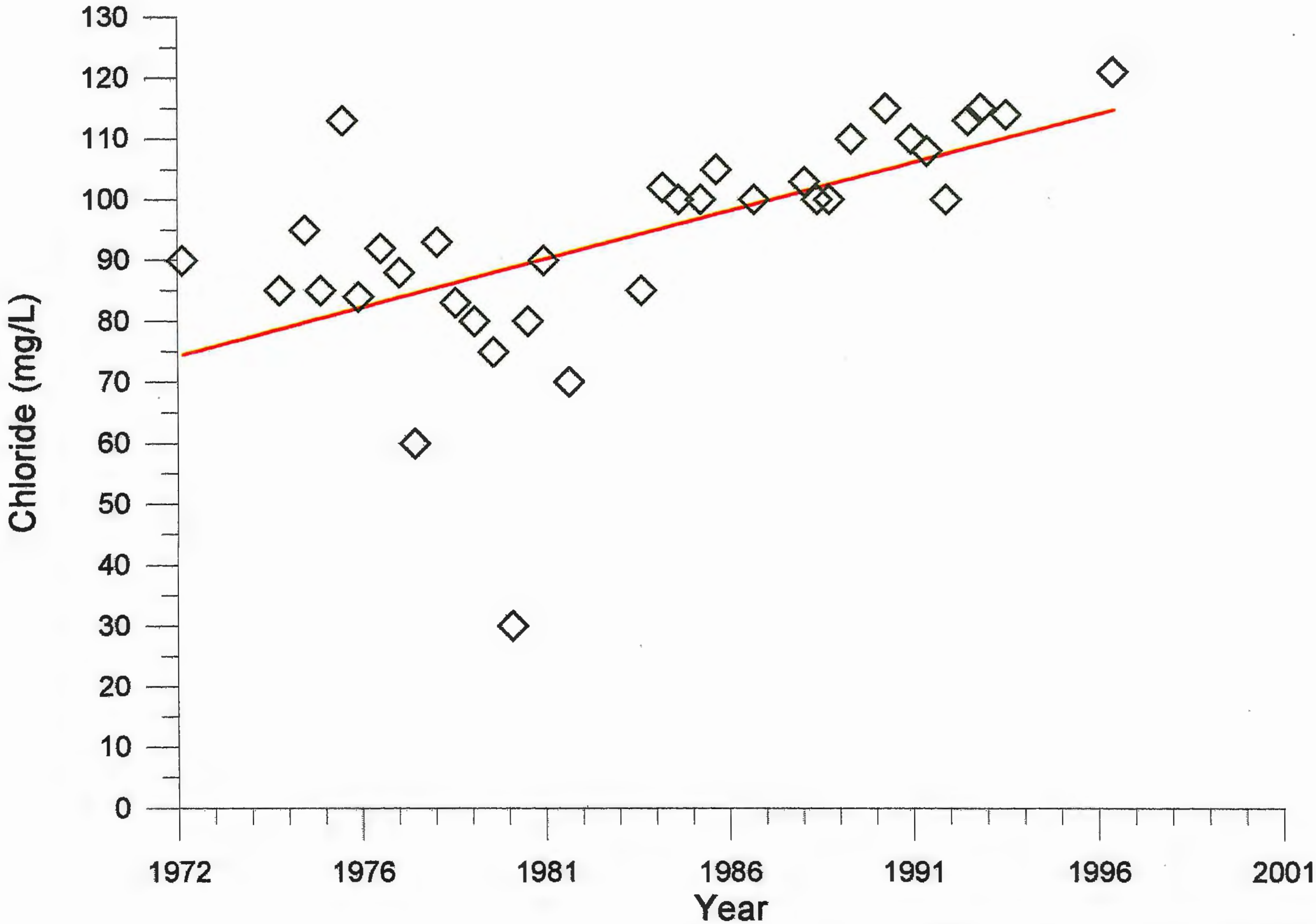
The Wichita City Wells Nos. 1 through 15 and 41 through 45 are downgradient of the Burrton chloride plume. They are also downgradient of the chlorides migrating from the Arkansas River and the deep saltwater originating from the Wellington Formation. Since 1972, the chloride levels in Wichita City Well No. 45 have risen from 75 mg/L to 113 mg/L (Figure I-9).

E. GEOLOGY

1. Physiography

The study area is located near the boundary of the Great Bend Prairie physiographic region and the High Plains region of the Central Lowlands physiographic province. Based on aquifer characteristics, the Great Bend Prairie and western areas of Kansas underlain by the Ogallala Formation have been grouped into one groundwater region and is considered to be part of the Great Bend region. The Great Bend Prairie physiographic province (also known as the Wellington and McPherson Lowlands) is characterized by large areas of low topographic relief.

This area of low relief is disrupted by a belt of sand dunes trending northwest-southeast along the northeast side of the Arkansas River Valley (Williams and



Burns & McDonnell

Figure I-9

CHLORIDE CONCENTRATIONS
WICHITA CITY WELL NO. 45

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Lohman, 1949 and Hathaway et al, 1981). Wind-blown sand and silt form another major belt of sand dunes extending southwestward from Rice County across Reno County, between the northern edge of the Arkansas River Valley and the Little Arkansas River to an eastern terminus northeast of Burrton in Harvey County, Kansas. In addition, small isolated sand dunes occur locally in the area. Soils in the area include excessively drained soils with loamy or silty subsoil on the uplands, well-drained soils with clayey subsoil on ridges and side slopes, imperfectly drained and loamy soils with clayey subsoils in well-drained sandy soils on level plains, and deep loamy soil over sandy or gravelly material in the breaks and along alluvial lands.

2. Topography and Drainage

Land surface elevation in the study area range from a low of about 1380 feet above mean sea level (MSL) where the Little Arkansas River leaves the study area, to a high of about 1500 feet MSL near the northwest corner of the study area. Therefore, topography generally slopes downward to the southeast.

The major streams in the vicinity of the study area are the Arkansas River and the Little Arkansas River. The Arkansas River flows to the southeast in a relatively straight, slightly braided channel and is typically entrenched 5 to 10 feet below the adjacent land surface. The Little Arkansas River meanders, flowing east and southeast, with its channel entrenched 15 to 20 feet below the adjacent land surface. The confluence of the Little Arkansas River with the Arkansas River is in Wichita.

3. Bedrock

The bedrock underlying the unconsolidated deposits in the study area consists primarily of early Permian age (approximately 240 million years old) shales of the

Wellington Formation and Ninnescah Shale (Burns & McDonnell, 1994). The configurations of the bedrock surface in the study area is shown in Figure I-10.

The Wellington Formation, a member of the Sumner Group, is predominantly shale with minor amounts of limestone, dolomite, siltstone, gypsum and anhydrite. The shales are chiefly gray and greenish-grey, with some red, maroon, and purple shale. The limestones and dolomites are generally light colored and argillaceous. Thick beds of salt are present in the subsurface. The Wellington Formation includes the Hollenberg Limestone Member, an argillaceous, dolomitic limestone of limited extent and a thickness of 1 to 5 feet; the Carlton limestone Member, a lenticular limestone beneath the Hutchinson Salt Member; the Hutchinson Salt Member, with a thickness greater than 700 feet, but typically 300 feet; and the Milan Limestone Member, a thin bedded greenish-gray shaley limestone or dolomitic limestone typically underlain by a thin bed of maroon and gray shale, possibly as thick as 8 feet. The thickness of the Wellington Formation is approximately 700 feet (Zeller, 1968).

The Ninnescah is a predominantly silty shale, mostly red, but contains some gray shale, argillaceous limestone and dolomite, and calcareous siltstone. This formation also contains salt in areas southwest of the Equus Beds. The Runnymede Sandstone Member marks the top of the Ninnescah Shale. This fine-grained, gray to grayish-green siltstone and sandstone has an average thickness of 7 to 8 feet. The thickness of the Ninnescah averages approximately 300 feet, and may reach a maximum of 450 feet (Zeller, 1968).

4. Unconsolidated Deposits

According to Williams and Lohman (1949), the McPherson Formation is the formation name applied to the earth materials which fill the McPherson channel, and to older and younger Pleistocene stream and slope deposits which extend

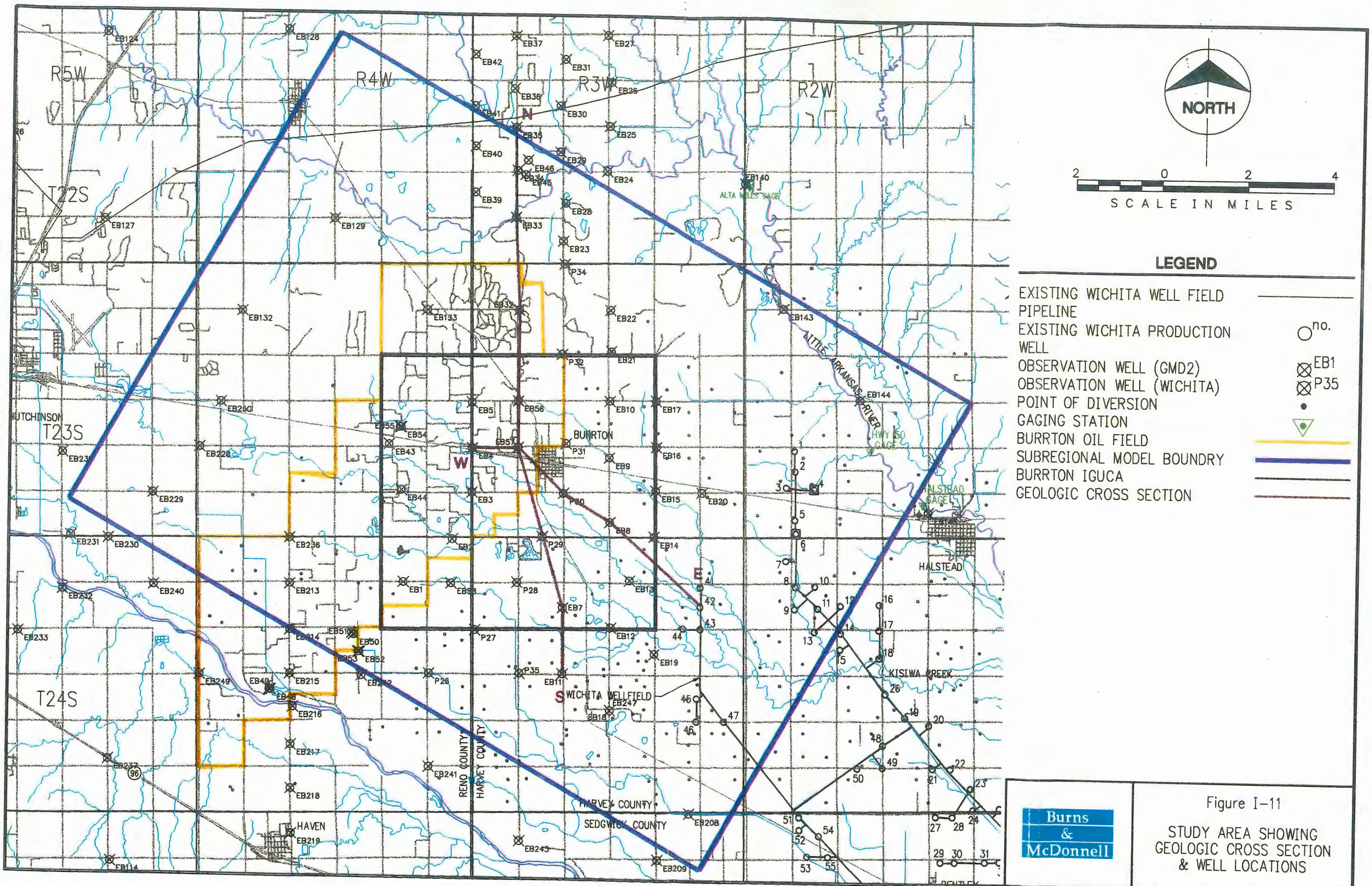

Figure I-11

STUDY AREA SHOWING GEOLOGIC CROSS SECTION & WELL LOCATIONS

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eastward from the McPherson Valley. Zeller (1968) classified the Pleistocene age sediments and indicates the McPherson Formation is comparable to the Grand Island Formation. A complete description of the unconsolidated materials have been provided by Zeller.

The sand dunes that occupy part of the area between the Little Arkansas River and the Arkansas River have been in the process of formation since early Pleistocene time. The older dunes probably were beginning to form while the streams depositing the McPherson formation were flowing southward through the area. The dunes consist mainly of fine- to medium-grained, well rounded quartz sand. Silt, clay, and organic material are locally mixed forming zones which may represent the formation of soils in quiescent periods and interdune pond areas. The higher sand dunes have been developed by prevailing southerly and southwesterly winds (Williams and Lohman, 1949).

5. Soils

Soils in the area tend to be sandy and loamy with poorly defined surface drainage features. Soil associations were mapped by Hoffman, Dowd, and others by combining data for individual counties, grouping various soil associations presented on county soil maps, and some regrouping of mapping units to better reflect the proportional pattern of soils in natural landscapes for a multi-county area. Hathaway et al (1981) provides an extensive description of the soils in this area.

6. Structure

The strata were effected by the building of the Rocky Mountains during which the rocks were uplifted and tilted. Erosion following uplift (approximately 63 million years ago) removed overlying rocks and exposed the salt-bearing part of the Wellington Formation to solution by ground and surface waters. A depressional area resulted in the eastern part of the region and became progressively deeper as solution and erosion proceeded westward down the dip of the Wellington. Early in the Pleistocene Epoch (2 million years ago) a stream flowing southwestward entered this area near Lindsborg and continued past McPherson and Mound Ridge southward, west of Wichita forming a channel. The channel extends southward where it converges with another channel. Toward the end of the first stage of the Pleistocene Epoch, the streams which had been active in eroding the McPherson Valley apparently became overloaded and deposited their suspended load and bed load over much of the valley. A large unconformity occurs between the older deposits of the McPherson Formation and the channel deposits (Williams and Lohman, 1949).

Because of either a smaller supply of water, an abundance of available detritus, or subsidence of the bedrock surface due to dissolution, the valleys formed by stream erosion began to be filled. After this valley filling had been in progress, it is believed that the stream flowing southward into the area was captured by headward erosion of an eastward-flowing stream in the vicinity of Salina, and the direction of flow was reversed.

The study area is located at the conjunction of the Salina and Sedgwick Basins. The Salina Basin, or Central Nebraska Basin, is limited on the east by the Nemaha Anticline, on the west by the Cambridge Arch and Central Kansas Uplift, and on the south by an indistinct, unnamed saddle. The axis of this post-Mississippian syncline trends northwest and plunges northward into the deeper part of the basin in north-central Kansas. The basin extends over an area of about 12,700 square miles and is the second largest basin in Kansas. Minor structures in the basin include the Abilene Anticline, the northern part of the Voshell Anticline, and the Wilson-Burns Element (Merriam, 1963).

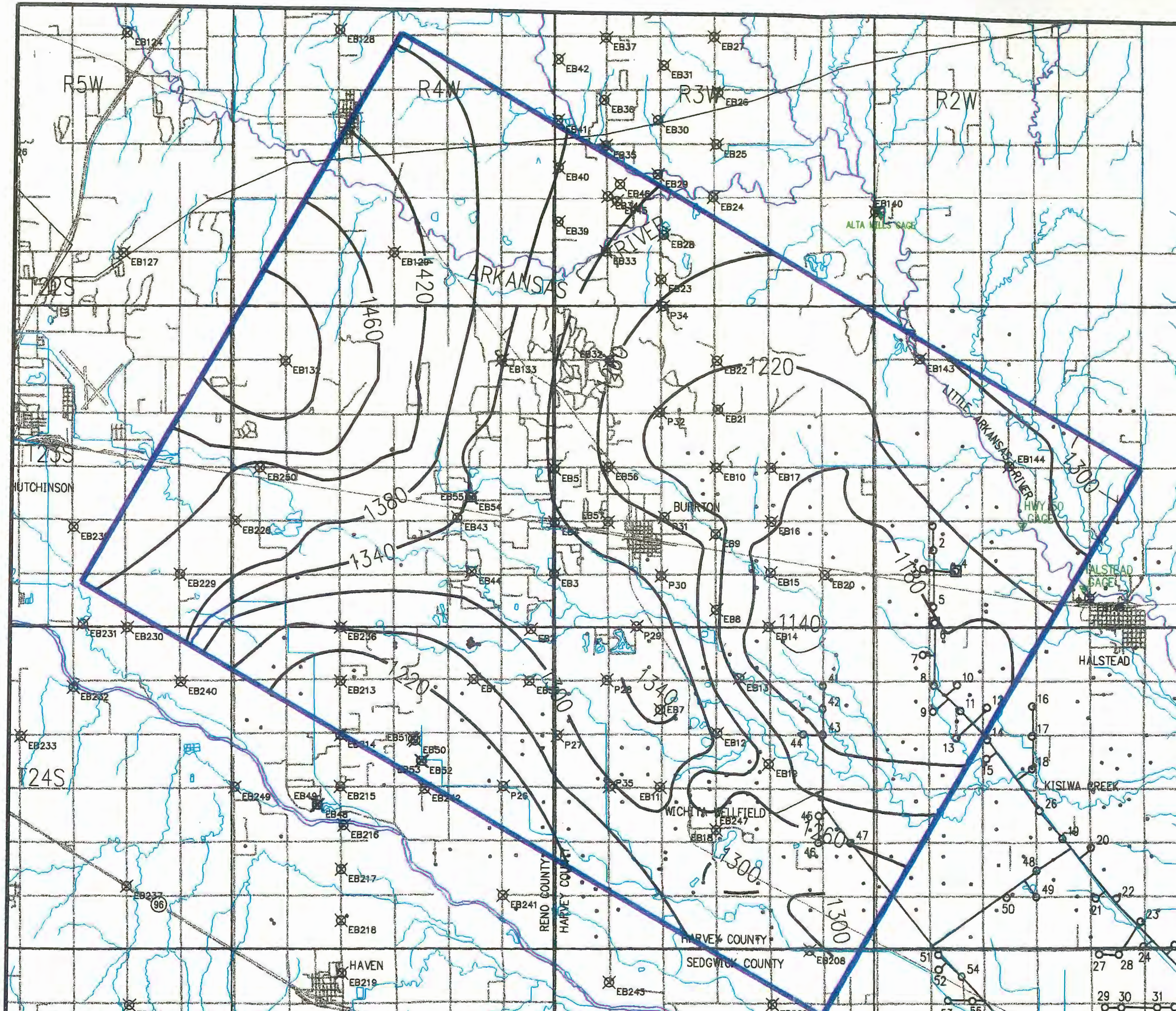
The Sedgwick Basin is a shelf-like, southerly plunging area in south-central Kansas, with an area of about 8,000 square miles. It is a major pre-Desmoinesian, post-Mississippian feature bounded on the east by the Nemaha Anticline, and the Pratt Anticline to the west. An indistinct saddle separates it from the Salina Basin on the north. Minor structures, approximately parallel with the Nemaha Anticline, have been recognized in the basin. These include the Bluff City Anticline, Conway Syncline, Elbing Anticline, Halstead-Graber Anticline, and the southern end of the Voshell Anticline (Merriam, 1963).

Faults are located along the eastern and western boundaries of the basins associated with the Nemaha Anticline to the northeast and the Central Kansas Uplift to the west. A normal fault, approximately 35 miles in length, trends in a northwest corner of Harvey County, and into central McPherson County (Merriam, 1963). One small earthquake occurred in the Salina Basin, as well as a moderate one in the area between the Sedgwick and Salina Basins.

F. HYDROGEOLOGY

The Equus Beds Aquifer is the eastern-most portion of the High Plains Aquifer system in Kansas. The Equus Beds are named for the equine fossils found in the unconsolidated sediments in this area. Three hydrogeologic units are generally recognized in the area; an upper sand and gravel unit; a middle fine grained (fine sand, silt, and clay) unit; and a lower coarse grained unit. These units are not consistent and vary greatly throughout the area. Typical cross-sections were developed. Their locations are shown in Figure I-11. The cross-sections are presented in Figure I-12.

Variations in bedrock elevations cause large variations in the saturated thickness of the Equus Beds Aquifer in the Wichita well field area. Saturated thickness within the study area ranges from less than 100 feet to over 200 feet.



NORTH

2 0 2 4

SCALE IN MILES

LEGEND

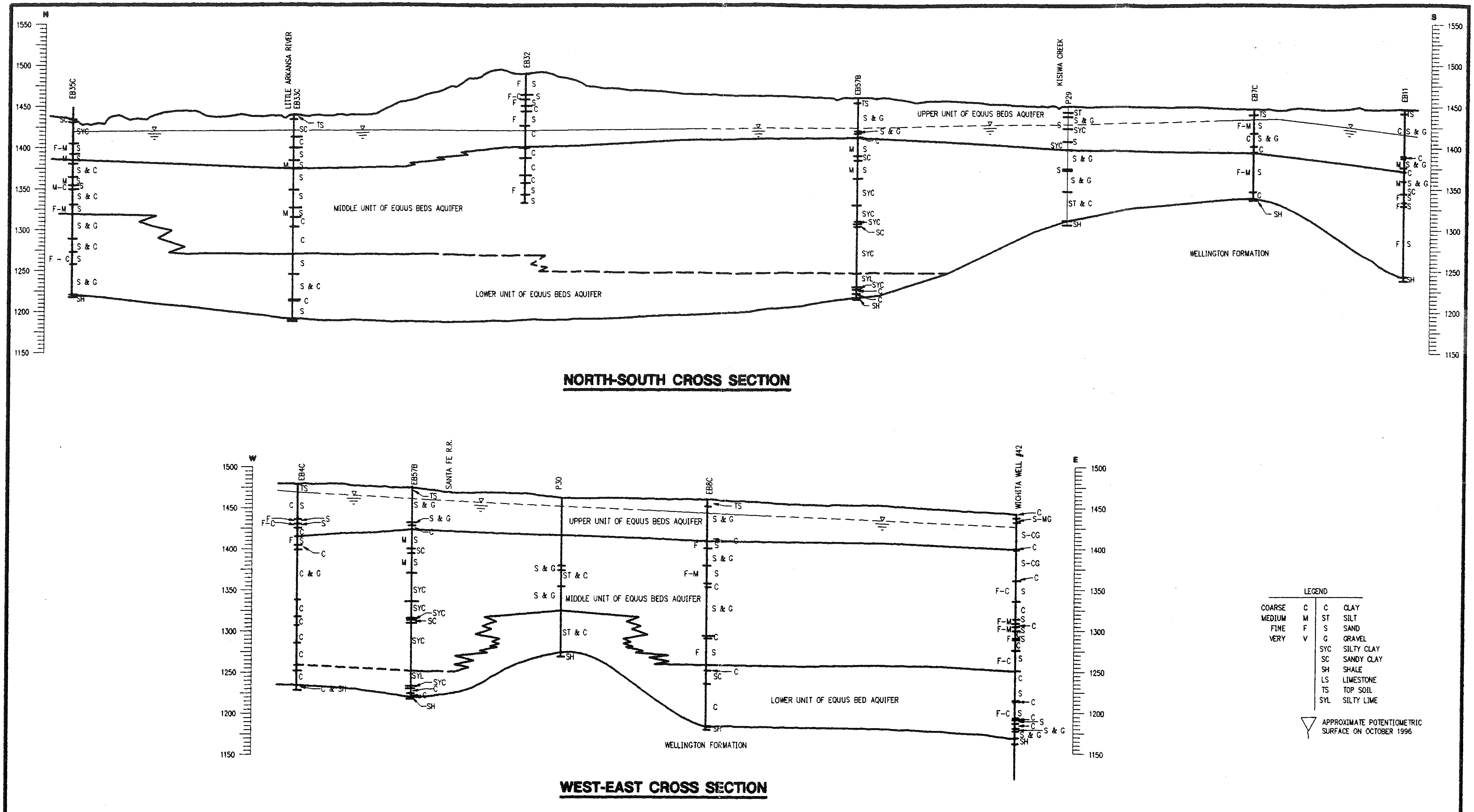
EXISTING WICHITA WELL FIELD PIPELINE	
EXISTING WICHITA PRODUCTION WELL	○no.
OBSERVATION WELL (GMD2)	⊗EB1
OBSERVATION WELL (WICHITA)	⊗P35
POINT OF DIVERSION	•
GAGING STATION	
BEDROCK CONTOURS	
SUBREGIONAL MODEL BOUNDARY	

SOURCE: WILLIAMS AND LOHMAN, 1949 AND OTHERS

Burns & McDonnell

Figure I-10

BURTON IGUCA REMEDIATION STUDY BEDROCK SURFACE



HORIZ. 4000 0 4000 8000

SCALE IN FEET

VERTICAL EXAGGERATION = 40

Burns & McDonnell

Figure I-12

GEOLOGIC CROSS-SECTIONS

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Originally, the depth to water in the Equus Beds Aquifer was relatively shallow, ranging from 10 to 20 feet below land surface. After decades of municipal and irrigation pumping, current depth to water ranges from 10 to 50 feet. The original water table had a southeast gradient of approximately 6 feet per mile. Today, the groundwater gradient is modified by pumping; however, there is still an eastward gradient allowing flow toward the Little Arkansas River. Figure I-13 shows the surface of the water table in 1996.

1. <u>Recharge</u>

The primary sources of recharge to the Equus Beds Aquifer are precipitation and inflow from the Arkansas River. Recharge from precipitation is estimated to range from three to six inches per year which is approximately 10 to 29 percent of the annual precipitation of 30 inches. The flat topography and generally sandy nature of the surface soils southwest of the Little Arkansas River allows rapid infiltration of precipitation in the region.

The Equus Beds Aquifer is also recharged by underflow from aquifer materials from the west and stream losses in areas where the groundwater is lower than the surface water levels. The Arkansas River is currently believed to be a losing stream in the reach between Hutchinson and Wichita. Recent groundwater modeling estimates an average of 50 cubic feet per second (cfs) is entering the aquifer from the Arkansas River through this reach (Burns & McDonnell, 1994).

2. <u>Discharge</u>

Water is lost from the Equus Beds Aquifer from evapotranspiration, pumping, underflow out of the aquifer, and discharge to streams as baseflow. In areas that the water table is near land surface, groundwater can be lost directly from evaporation. Groundwater is also taken up by vegetation with deep root systems that intercept the water table, allowing absorbed water to be lost through transpiration to the atmosphere.

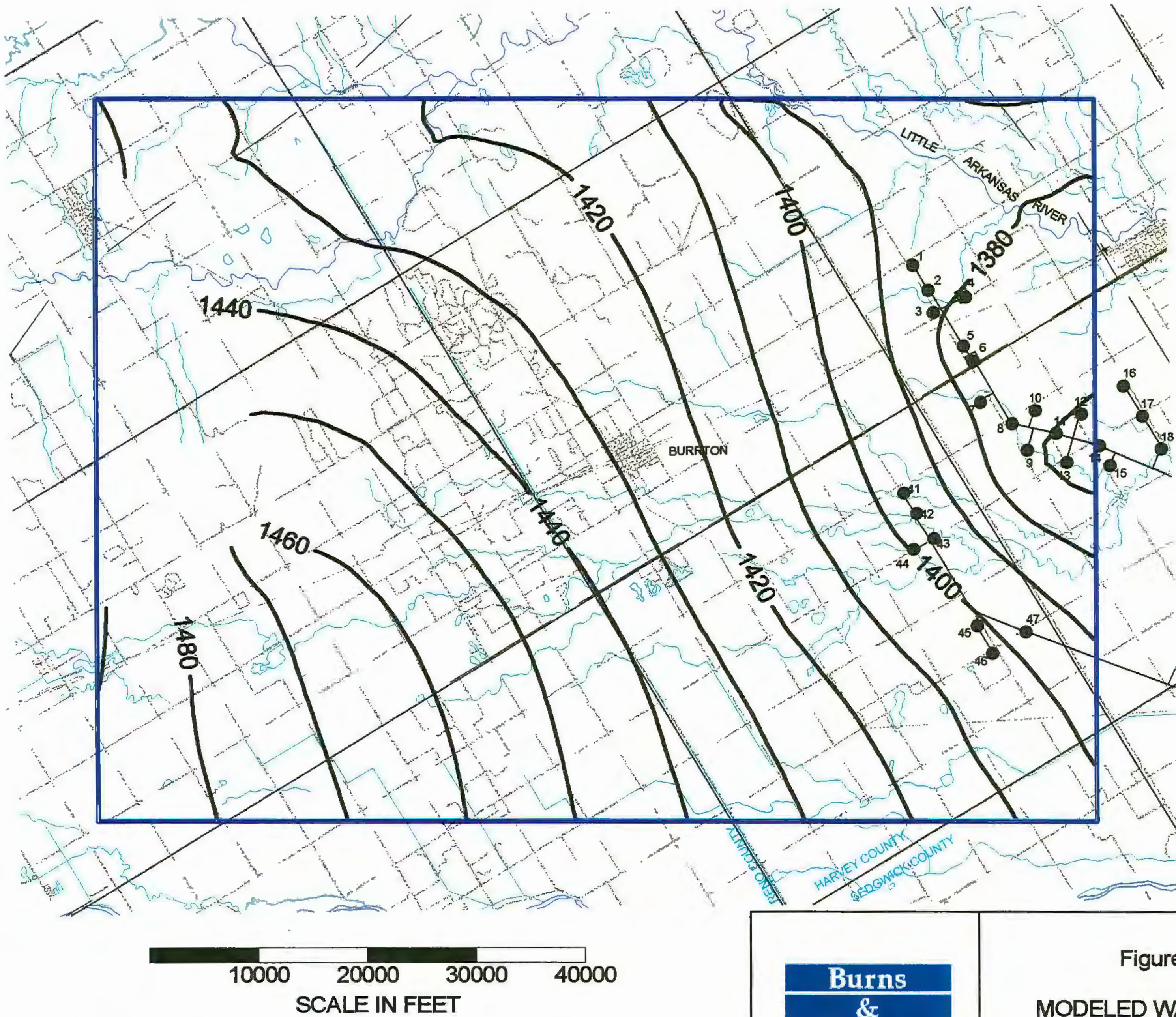

Figure I-13

MODELED WATER TABLE
1996

Note: Based on Pruitt Model (1996)

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The Equus Beds Aquifer within the study area was developed with wells beginning in the late 1930's and early 1940's. The initial water rights were established for municipal use. Later in the late 1960's and 1970's, a large volume of water rights were filed for irrigation. Within the Wichita well field area, water rights have been filed to pump approximately 27.8 billion gallons per year by approximately 450 wells. Forty-eight percent of these water rights are for municipal use and 51 percent are for irrigation use (Burns & McDonnell, 1994).

The bedrock high occurring north and east of the Little Arkansas River generally prevents underflow out of the Equus Beds in that direction. A small amount of underflow loss occurs to the southeast into alluvium of the Arkansas and Little Arkansas Rivers near the confluence of the two rivers (Burns & McDonnell, 1994).

Where the groundwater levels are higher than stream levels, water is lost from the aquifer to the stream as baseflow. Baseflow in the Little Arkansas River is provided by discharge from the Equus Beds Aquifer. As more water is removed by pumping, less water is available for seepage into the river as baseflow. Alternately, during times of higher groundwater levels due to lower pumping and recharge, baseflow is increased. Previous computer modeling suggests that pre-development baseflow to the Little Arkansas River was about 60.5 cfs and the recent baseflow to be about 27.4 cfs, a 33.1 cfs reduction over 50 years (Burns & McDonnell, 1994).

3. <u>Aquifer Parameters</u>

A number of aquifer pumping tests have been collected by the USGS from wells constructed in the Equus Beds Aquifer and evaluated to determine hydrogeological parameters throughout the aquifer. Aquifer parameters summarized from the USGS Open-File Report 85-200 are as follows:

	Average	Range
Transmissivity (feet^2/day)	13,100	34,000-7,300
Storage Coefficient (dimensionless)	0.03	0.16-0.0008

The upper materials generally act as an unconfined aquifer and materials below the intermediate fine grained materials (where present) act in a confined or semi-confined manner. In areas where fine-grained materials cause the aquifer to react as a confined system, such as the northern end of the Wichita well field area, large changes in water levels are noted with during pumping or from recharge.

4. Surface Hydrology

The study area is located several miles north of the Arkansas River and encompasses a portion of the Little Arkansas River Basin. The Little Arkansas River has a mean annual flow of 284 cubic feet per second (cfs) (205,600 acre-feet per year) at Valley Center, Kansas, based on 69 years of historical records. The Arkansas River has a mean annual flow of 1,014 cfs at the Wichita gage, based on 56 years of records. The gage at Wichita is below the confluence of the two rivers and therefore includes the flows from the Little Arkansas River (Burns & McDonnell, 1994).

Groundwater and river flow interact and move depending on water levels of the groundwater and river. The interaction is influenced to some extent by the conductivity of the river bed materials. Sediments in the Arkansas and Little Arkansas Rivers are relatively coarse, allowing rapid infiltration of water into the riverbank or rapid exfiltration of water to the stream.

* * * * *

Part II - Modeling

PART II

MODELING

A. GENERAL

Many studies have been conducted on the Equus Beds Aquifer because of its importance as a source of water for municipal, agricultural, and industrial use. The occurrence of chloride in parts of the aquifer, in streams, and bedrock has been a major concern and has resulted in several groundwater flow and transport modeling studies. The early models simulated the Equus Beds Aquifer as a single layer and focused on specific aspects of the groundwater flow system and the transport of chloride from specific concentrated sources (Myers et al, 1996). Groundwater flow models have been used to determine the long-term safe yield of the aquifer (Green and Pogge, 1977) and to describe the groundwater flow (Spinazola et al, 1985). The migration of chlorides in the Equus Beds aquifer has been studied using solute transport models, also (Sophocleous, 1983, Spinazola, 1985).

The US Geological Survey (USGS) was the first organization to develop a groundwater model of the Equus Beds Aquifer using MODFLOW, a USGS three-dimensional, finite-difference, groundwater flow model written by McDonald and Harbaugh (McDonald and Harbaugh, 1988). MODFLOW is a well documented model that is widely used and accepted by many regulatory agencies. This model uses a modular method of data entry to simulate specific aspects of the aquifer system such as wells, rivers, recharge, and evapotranspiration, along with aquifer properties.

The USGS office in Lawrence, Kansas developed a groundwater flow model to study the stream-aquifer system of the Arkansas River and the Equus Beds Aquifer (Myers, 1996). The USGS model area includes the current study area for the Burrton Intensive Groundwater Use Control Area (IGUCA) Remediation Study. In the study conducted by the USGS, the hydrologic and chemical interaction of the Arkansas River with the Equus Beds Aquifer was modeled. Steady state and transient simulations were conducted. A steady state model was developed to represent aquifer and stream conditions during the late 1930's. Transient modeling was used to simulate the conditions from 1940 through 1989. Transient modeling was also used for projections beyond 1989.

The U. S. Bureau of Reclamation (USBR), under contract with Equus Beds Groundwater Management District No. 2 (GMD2), modified the USGS model in order to conduct a contaminant transport study (Pruitt, 1993). The purpose of the study was to evaluate the potential for the migration of saline water from the Arkansas River, deep natural saltwater, and brine from the Burrton oil field operations into the Equus Beds Aquifer. To improve the accuracy of the transport modeling, the Bureau of Reclamation refined the model grid spacing and made the grid cells more square-shaped.

In an additional study conducted by the USBR, under contract with the City of Hutchinson, the USGS MODFLOW model was expanded to the west and south and grid spacing was refined. The purpose of this study was to determine the potential impacts of increased pumpage in the Hutchinson area on water quality and supply (Pruitt, 1996). An additional stress period was added to the model to represent the time period from 1990 to 1994.

For the current study, the first USBR transient MODFLOW and contaminant transport models were utilized (Pruitt, 1993). These models were updated to include an additional stress period to represent 1990 to 1994 time period. From this regional model, a subregional model was created for the Burrton IGUCA.

B. GROUNDWATER MODEL

1. <u>Conceptual Model</u>

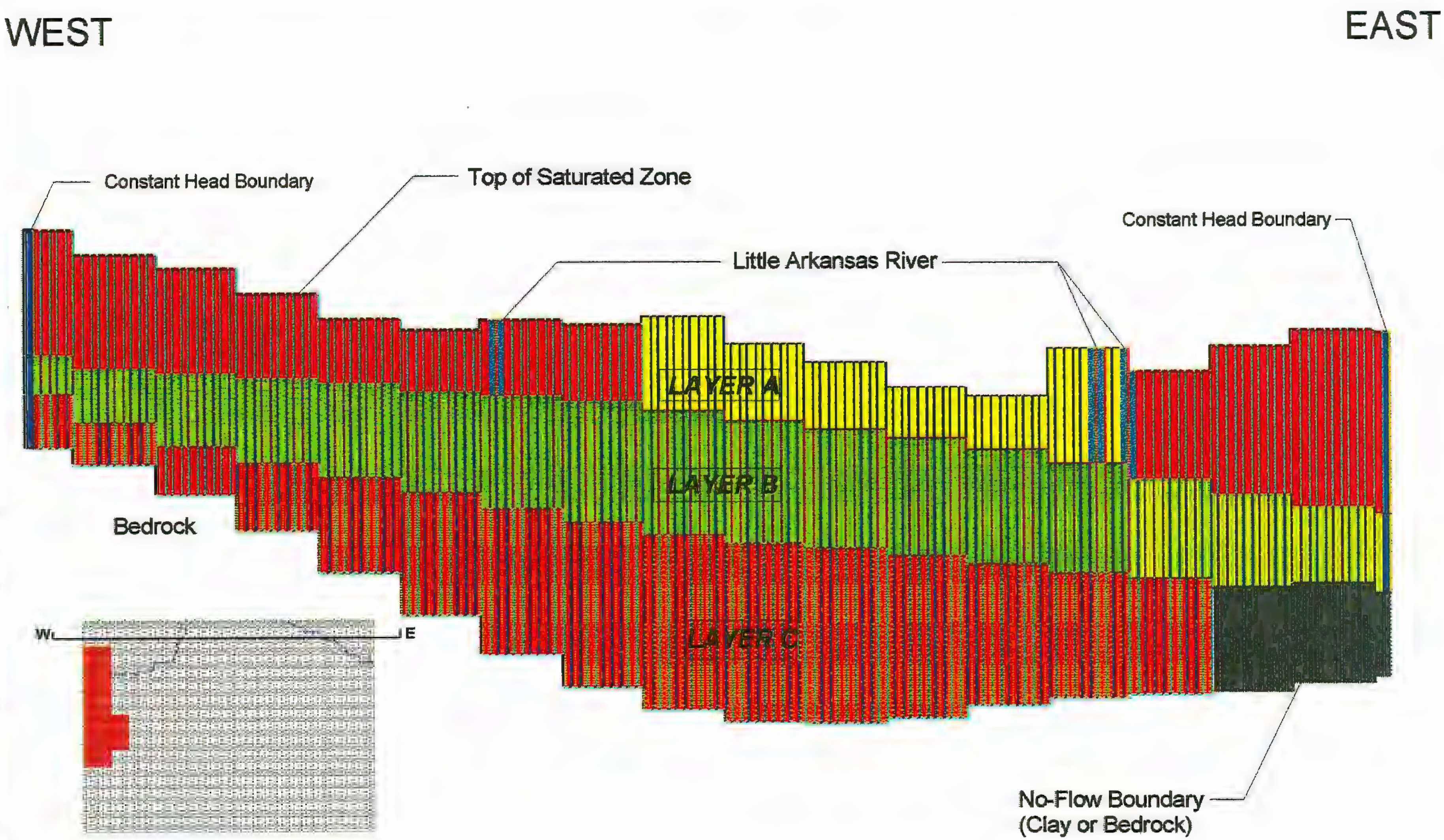
A conceptual model is a block diagram showing how geological conditions are simplified for computer modeling simulations. The Equus Beds Aquifer has three recognized hydrogeologic units. It receives recharge from precipitation, through overlying rivers, and as underflow from surrounding formations. The block diagram in Figure II-1 shows a simplified cross-section of the general aquifer configuration and is the basis for the MODFLOW model construction.

Typically, models are constructed using natural flow boundaries as the boundaries for the model. However, due to the detailed information required for this study, the entire aquifer could not be included. The subregional model utilizes natural boundaries where possible. The Equus Beds Aquifer overlies the Wellington Formation and Ninnescah Shale which have low permeabilities that limit groundwater flow. These natural boundaries are used in the model as a lower boundary and portions of the lateral boundaries. In the areas where the natural aquifer extends beyond the model boundaries, constant head cells were used to simulate the effects of distant parts of the aquifer.

River cells in the top layer of the models were used to simulate the interaction of the groundwater and surface water bodies in the model area. The Arkansas River and the Little Arkansas River and their tributaries are the major water bodies in this area. In the subregional model, only the Little Arkansas River is present.

The aquifer properties used in this model were collected and evaluated for the previous groundwater models. These properties were not modified for this model. Aquifer properties for the models include horizontal and vertical hydraulic conductivity, storage coefficient, and specific yield. Horizontal hydraulic conductivity ranges from 55 to 1,000 feet/day, and vertical conductivities range from 50 to 1,200 feet/day. (Myers, 1996). Storage coefficients range between 0.0004 and 0.16 with specific yields of 0.0006 to 0.22 (Myers, 1996).

Recharge to the Equus Beds Aquifer from precipitation occurs across the study area except where shale outcrops. The amount of recharge from precipitation is



Legend

- Hydraulic Conductivity Range K= 25 ft/day to 75 ft/day
- Hydraulic Conductivity Range K= 75 ft/day to 150 ft/day
- Hydraulic Conductivity Range K= 150 ft/day to 1200 ft/day
- Layer C not present

Not to Scale

Burns & McDonnell

Figure II-1

SUBREGIONAL CONCEPTUAL MODEL

J:\kccburtn\971834\engineer\models\gwvsub\john\xsec.grf the total precipitation minus surface runoff and evapotranspiration. Mean annual recharge values for the area range from 0.44 to 6.02 inches (Myers, 1996).

Like recharge, discharge through evapotranspiration occurs across the study area. The two components of evapotranspiration are discharge from the unsaturated zone and phreatophytic consumption of the saturated zone. The recharge values set for the regional model allow for evapotranspiration from the unsaturated zone. Phreatophytic consumption of the saturated zone is simulated separately (Myers, 1996).

Pumpage is a major source of discharge from the Equus Beds Aquifer. Groundwater is pumped from the aquifer for irrigation, municipal, and industrial use. The average groundwater withdrawal from the study area through wells during 1990 to 1994 was approximately 31,920 acre-feet/year.

2. Regional Model

For this study, the primary area of interest is the Burrton IGUCA. This area is included in the USBR model, however the grid spacing in this area is too large to provide a detailed evaluation of the migration of chlorides in the Burrton area. In addition, the model is only current through 1989. In order to operate with current conditions, Burns & McDonnell updated the USBR model to include the 1990 to 1994 time period. An additional stress period was created to represent this time period. In the MODFLOW model, the stream, recharge, and well packages were updated with information for this time period. In addition, current chloride concentrations in the Arkansas River were included in the transport model.

In the USGS model, recharge was a function of 1940 precipitation, soil type, and thickness of clay in the unsaturated zone. The same recharge distribution was maintained for the new 1990 to 1994 stress period of the regional model. The precipitation data for 1990 through 1994 was obtained from the Hutchinson, McPherson, Newton, and Wichita climatic stations and from the Reno, McPherson, Harvey, and Sedgwick GMD2 climatic stations. The recharge rates were determined from this data by following the method used to determine the rates for the original USGS model (Myer, 1996). First, the recharge for each steady state cell was divided by the mean annual precipitation for the steady state time period (1995 to 1939). The resulting values were multiplied by the mean annual precipitation for the 1990 to 1994 time period for the model area. The mean annual precipitation for this period for the regional model area was 28.1 inches per year.

Discharge from the aquifer through wells for the regional model area was adjusted from the 1990 to 1994 pumpage data used for the second USBR model (Pruitt, 1996). The data set was modified to include only the wells in this study area and redistributed for the grid geometry of the original USBR model.

The base flow was updated for the starting reach of the Arkansas River and Little Arkansas River. The stream routing module (Prudic, 1988) calculated the stream flows for the downstream cells. The stream flow for the Arkansas River was determined from data collected at the gaging station on the Arkansas River near Hutchinson for the 1990 to 1994 period. Data for the Little Arkansas River was obtained from the Little Arkansas River at Valley Center for the same time period. The original USGS model assumed base flow to be the stream flow that was exceeded 70 percent of the time. This assumption was applied to the stream flow data for the 1990 to 1994 period. Stream flows for the starting reaches of the Arkansas and Little Arkansas Rivers were determined by trial and error until the stream flows simulated by the stream routing model approximated the base flow at the gages at Hutchinson and Valley Center.

A comparison between water budgets and predicted heads from the updated USBR model was used to evaluate the modifications and updates of the regional model used for this study. The predicted heads for both models are similar and the water budget for the study's regional model has volumetric water budget discrepancy of 0.01 percent. Volumetric water budget discrepancy less than 1 percent is generally adequate for modeling studies.

3. Subregional Model

In order to provide the necessary detail with current conditions, Telescopic Mesh Refinement (TMR), a modeling technique, was used to create a subregional model with finer grid spacing for the Burrton IGUCA study area. Figure I-1 shows the location of the boundary for the subregional model along with the boundary for the regional model.

A uniform grid spacing was used across the model to give good resolution of all parts of the study area. Row spacing was set at 508 feet and column spacing at 500 feet to provide adequate resolution for the study. The boundary conditions for the subregional model represent zones of no flow and the regional groundwater and surface water flow conditions for 1994. Starting groundwater and surface water flow conditions for the subregional model were determined by the regional model. Figure II-2 shows the boundary conditions for the subregional model.

During the development of the subregional model, the stream cells of the regional model were converted to river cells and restricted to cells that overlie the Little Arkansas River. The values for river stage were determined from the regional model.

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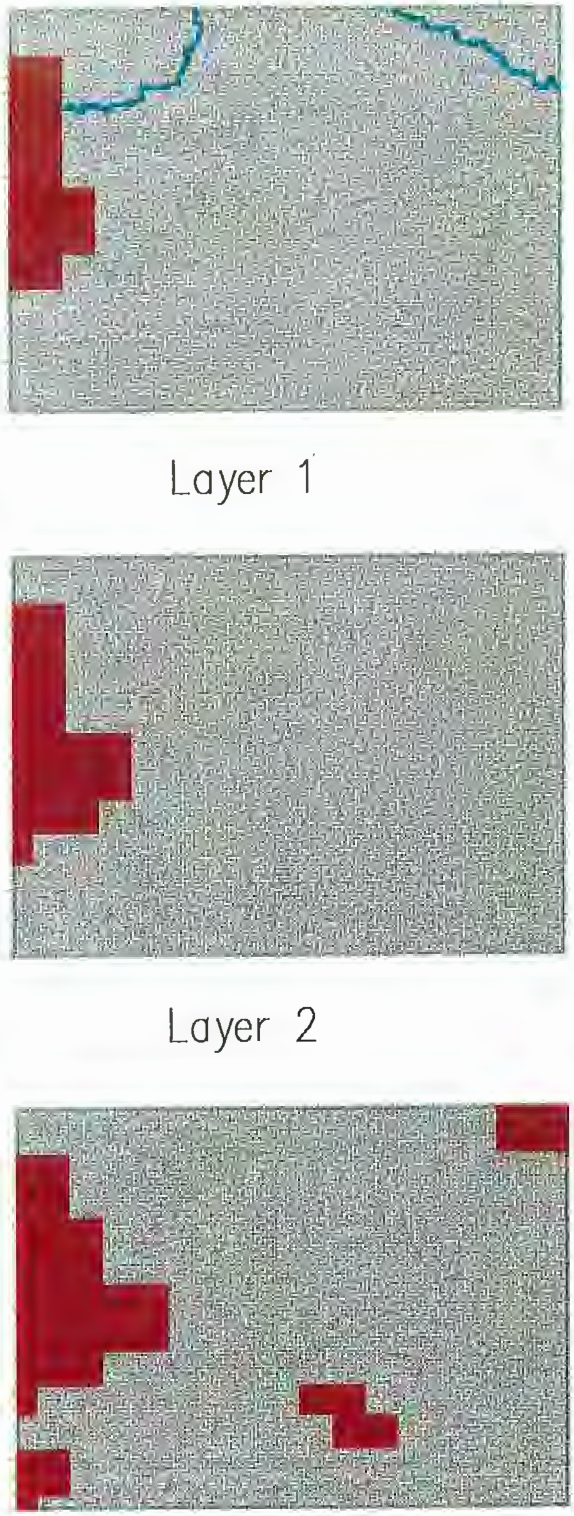

Layer 1

Layer 2

Layer 3

NOTE
NO FLOW CELLS DUE TO CLAY ON HIGH BEDROCK

LEGEND

CONSTANT HEAD
NO FLOW
RIVER

Burns & McDonnell

Figure II-2

SUBREGIONAL MODEL BOUNDARY CONDITIONS

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Recharge, evapotranspiration, and the aquifer properties were not modified from the regional model for the development of the subregional model.

C. CONTAMINANT TRANSPORT MODEL

1. Subregional Model

MT3D (Papadopulos and Associates, Inc., 1992), a modular three-dimensional transport model, was used to predict the migration of chlorides in the Equus Beds Aquifer. The regional contaminant transport model developed by the Bureau of Reclamation (Pruitt, 1993) was used to develop the subregional model used for this study. The subregional contaminant transport model focuses on the chloride plume in the Burrton oil field area. The migration of chlorides was evaluated under conditions of no action and with several alternatives to control and remediate the plume.

The MT3D program is used to model advection, dispersion, and chemical reactions of contaminants in groundwater, and is a companion program to MODFLOW. Output from the groundwater flow simulations is used in the contaminant transport modeling.

A detailed description of the MT3D program and the assumptions for applying the model to the migration of chlorides in the Equus Beds Aquifer is contained in the USBR Technical Report on modeling chlorides in the Equus Beds Aquifer (Pruitt, 1993).

2. Boundary Conditions and Initial Concentrations

The boundary conditions established in the groundwater flow model were maintained for the contaminant transport model. Data obtained from GMD2 and from previous modeling (Pruitt, 1996) was used to establish the initial concentration of chloride for the study area. Chloride associated with the Burrton

IGUCA was the main focus of the model. Figures I-2, I-3, and I-4 show the concentration of chloride present in the aquifer in 1996. This chloride distribution was used as the initial concentration condition for all model simulations.

The impacts of chlorides migrating from the Arkansas River and the deep natural saltwater were also considered. The Arkansas River provides a continuous source of chloride into the aquifer. Constant concentration cells located along the southern boundary of the top layer of the model represent the influx of chlorides from the Arkansas River into the model area.

Like the Arkansas River, the deep natural saltwater migrating from the Wellington Formation is a continuous source of chloride. Constant concentration cells at the southern boundary of the deepest layer simulate the intrusion of deep saltwater from the bedrock into the study area.

D. MODELING SCENARIOS

The modeling runs for the management simulations were established for a 50 year time period beginning with the 1996 conditions. The stresses and chloride concentrations from the Arkansas River and deep aquifer were assumed to remain constant during the projected time period. The changes in water level demonstrates the impact that pumpage and recharge has on the aquifer. The base scenario assumes that no action is taken to remediate or control the chloride plume for the 50 year time period. The results from the plume management simulations were compared with the results from base (no action) scenario.

Management simulations conducted for this study are described in the following Table II-1.

Table II-1
MANAGEMENT SIMULATIONS

Run	Management Action
1a	**No Action.** 1996 stresses and conditions held constant for 50 years.
Plume Interception	
2a	Reproduced from the USBR study (Pruitt, 1993). Ten wells screened in levels B and C with a total pumping rate of 1000 gallons per minute (gpm).
2b	Reproduced from the USBR study (Pruitt, 1993). Ten wells screened in levels B and C with a total pumping rate of 2000 gpm.
2c	Reproduced from the USBR study (Pruitt, 1993). Ten wells screened in levels B and C with a total pumping rate of 4000 gpm.
Plume Control	
3a	Six gradient control wells and 17 extraction wells with a total pumping rate of 1000 gpm.
3b	Six gradient control wells and 17 extraction wells with a total pumping rate of 2000 gpm.
3c	Six gradient control wells and 17 extraction wells with a total pumping rate of 4000 gpm.
Plume Control with Recharge Basins	
4a	Six gradient control wells and 17 extraction wells with a total pumping rate of 4000 gpm. 75% of pumpage from the extraction wells (1500 gpm) recharged downgradient of the plume.
Equus Beds Recharge Project	
5a	Water levels five feet higher in the vicinity of the Wichita Well System due to recharge effects from the Equus Beds Recharge Project.
5b	Water levels ten feet higher in the vicinity of the Wichita Well System due to recharge effects from the Equus Beds Recharge Project.
5c	Water levels ten feet higher in the vicinity of the Wichita Well System due to recharge effects from the Equus Beds Recharge Project with active injection into level C through 22 wells at a total rate of 8,530 gpm.

Table II-_ (continued)
MANAGEMENT SIMULATIONS

Run	Management Action
Equus Beds Recharge Project with Plume Control	
6a	Water levels five feet higher in the vicinity of the Wichita Well System due to recharge effects from the Equus Beds Recharge Project, and Six gradient control wells and 17 extraction wells with a total pumping rate of 4000 gpm.
6b	Water levels ten feet higher in the vicinity of the Wichita Well System due to recharge effects from the Equus Beds Recharge Project, and Six gradient control wells and 17 extraction wells with a total pumping rate of 4000 gpm.
6c	Water levels ten feet higher in the vicinity of the Wichita Well System due to recharge effects from the Equus Beds Recharge Project with active injection into level C through 22 wells at a total rate of 8,530 gpm, and Six gradient control wells and 17 extraction wells with a total pumping rate of 4000 gpm.
6d	Water levels ten feet higher in the vicinity of the Wichita Well System due to recharge effects from the Equus Beds Recharge Project with active injection into level C through 22 wells at a total rate of 8,530 gpm, and Six gradient control wells and 17 extraction wells with a total pumping rate of 8000 gpm.
Pilot Installation	
7a	Two wells screened in levels A and B pumping at a total rate of 500 gpm.

E. MANAGEMENT SIMULATION RESULTS

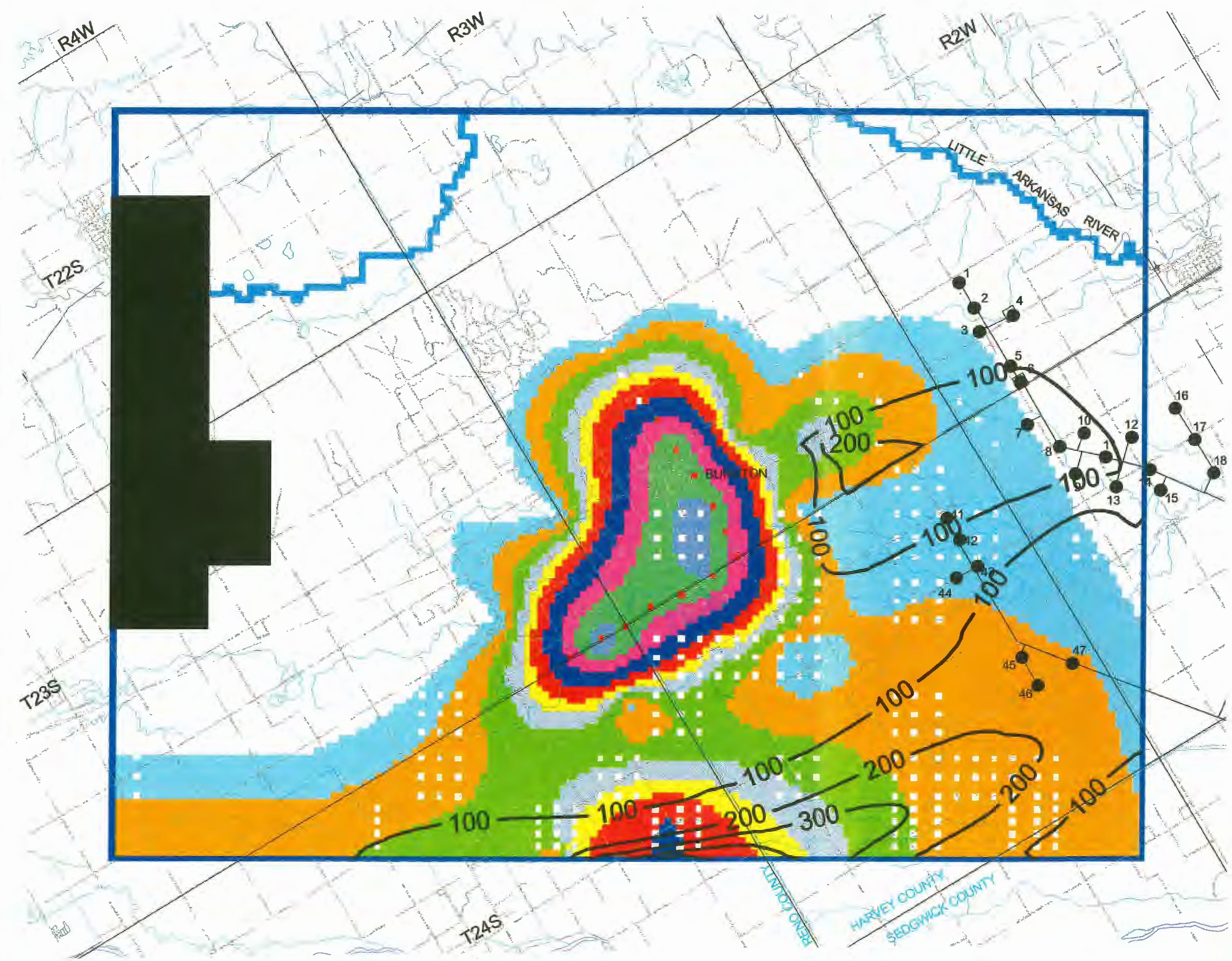
1. No Action (1a)

The result of modeling a no action scenario (1a) is lateral spreading and migration of the chloride plume generally to the east, towards the Wichita well field. The plume also moves deeper into the aquifer. The peak chloride concentrations decrease as the plume is diluted by precipitation and mixing with the surrounding groundwater. Figures II-3 through II-5 show the predicted extent of the plume in all three hydrostratigraphic layers after 50 years if no action is taken to control migration. As shown in Table II-2, if no action is taken to control or remediate the plume, the total area affected by chloride concentrations of 500 mg/L or greater is 2.9 and 11.8 square miles in level B and level C, respectively.

2. Plume Interceptor Wells (2a, 2b, and 2c)

Previous modeling by the USBR (Pruitt, 1993) simulated the effects of placing withdrawal wells in the eastern portion of the plume to inhibit migration of the plume toward the Wichita Municipal Well Field. A total of 20 interceptor wells were located east of Burrton (Figure II-6) to withdraw groundwater from the middle and lower layers of the aquifer. Pumping rates for each well of 50, 100, and 200 gallons per minute (gpm) were simulated. The total pumpage for these management simulations were 1000, 2000, and 4000 gpm, respectively.

The USBR interception scenarios were duplicated with the subregional model developed for this study using 1996 aquifer conditions and chloride concentrations. Figures II-7, II-8, and II-9 show the extent of the chloride plume after 50 years for the 4000 gpm management simulation (2c). These wells do not prevent the plume from affecting the well field, however, they do lower the chloride concentrations significantly.



10000 20000 30000 40000
SCALE IN FEET

CONTOUR INTERVAL = 100 mg/l

LEGEND

Chloride Isoconcentration Line (Modeled for 50 Years)

Wichita Municipal Well

1996 Chlorides Concentrations

50 mg/l	500 mg/l	1750 mg/l
100 mg/l	750 mg/l	2000 mg/l
200 mg/l	1000 mg/l	
300 mg/l	1250 mg/l	
400 mg/l	1500 mg/l	

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Figure II-3

LEVEL A
CHLORIDE CONCENTRATIONS
1 NO ACTION
FOR 50 YEARS

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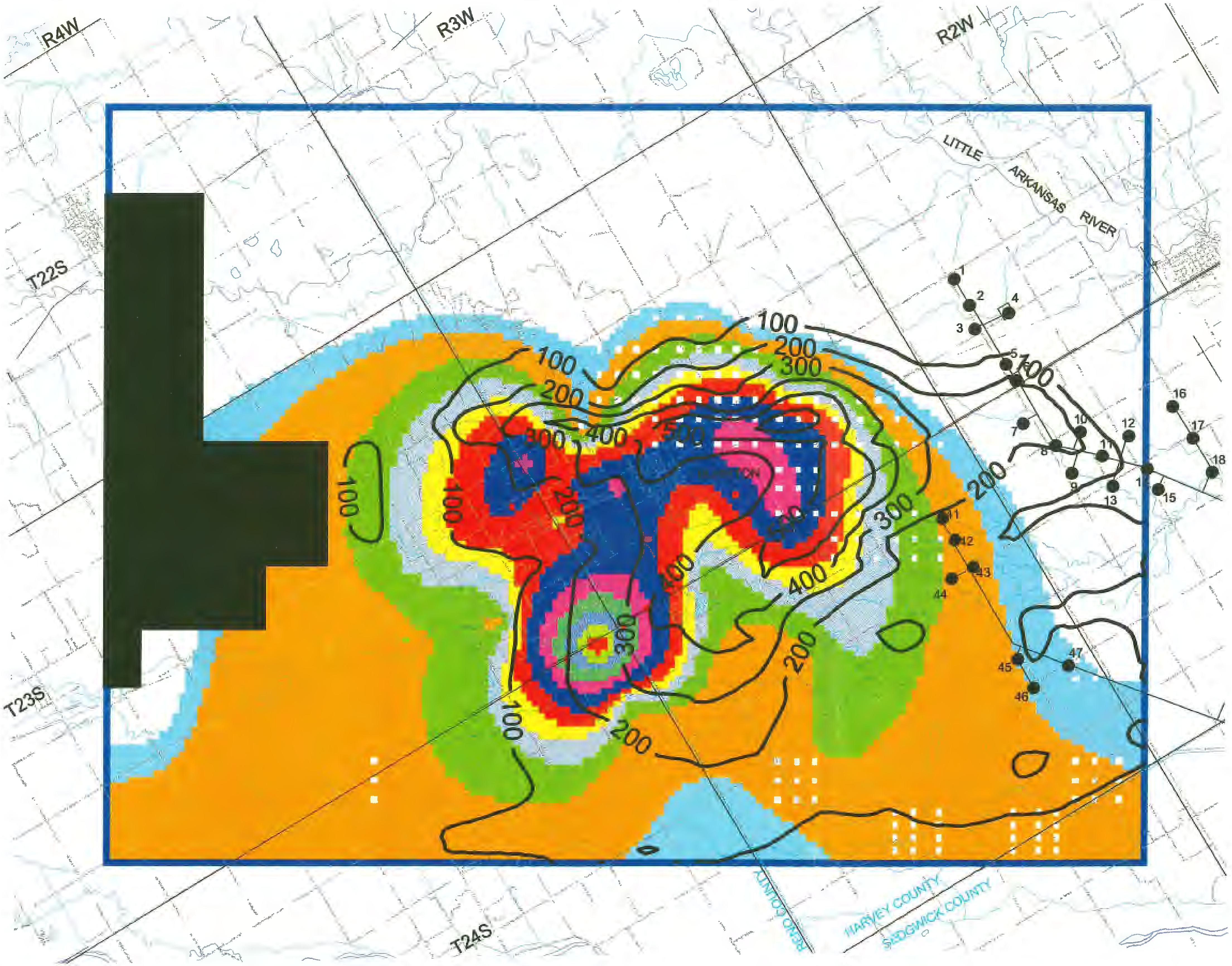

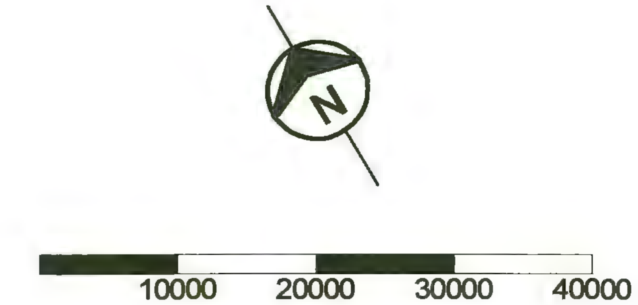

SCALE IN FEET

CONTOUR INTERVAL = 100 mg/l

LEGEND

Chloride Isoconcentration Line (Modeled for 50 Years)

Wichita Municipal Well

1996 Chloride Concentrations

50 mg/l	500 mg/l	1750 mg/l
100 mg/l	750 mg/l	2000 mg/l
200 mg/l	1000 mg/l	
300 mg/l	1250 mg/l	
400 mg/l	1500 mg/l	

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Figure II-4

LEVEL B
CHLORIDE CONCENTRATIONS
1 NO ACTION
FOR 50 YEARS

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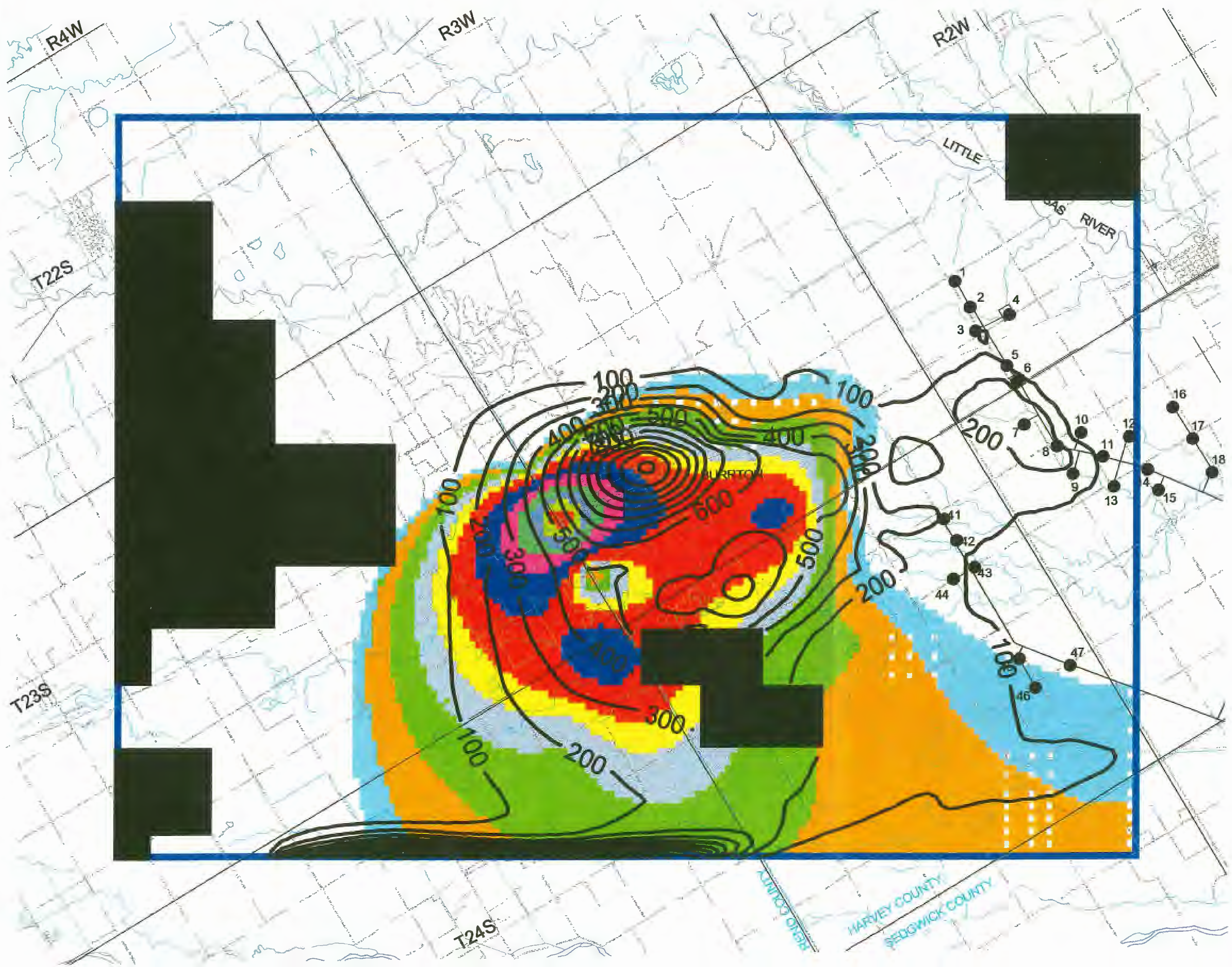

N

10000 20000 30000 40000
SCALE IN FEET

CONTOUR INTERVAL = 100 mg/l

LEGEND

Chloride Isoconcentration Line (Modeled for 50 Years)

Wichita Municipal Well

1996 Chloride Concentrations

50 mg/l	500 mg/l	1750 mg/l
100 mg/l	750 mg/l	2000 mg/l
200 mg/l	1000 mg/l	
300 mg/l	1250 mg/l	
400 mg/l	1500 mg/l	

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Figure II-5

LEVEL C
CHLORIDE CONCENTRATIONS
1 NO ACTION
FOR 50 YEARS

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Table II-2

Total Land Area
above
High Chloride Levels in Groundwater
(square miles)

Scenario	Level A	Level B	Level C
Current (measured 1996 concentrations)			
250 mg/L	18.8	20.8	16.7
500 mg/L	9.8	13.5	3.9
Modeled Simulations After 50 years (500 mg/L)			
1 - no action	-	2.9	11.8
2c - USBR interceptor wells at 4,000 gpm	-	0.5	8.1
3c - Plume Control (extraction and gradient control wells)	-	1.7	7.7
4a - Plume Control with recharge basins	-	1.6	8.6
5c - Equus Bed Recharge Project with no plume control	-	3.8	11.7
6c - Equus Beds Recharge Project with 4,000 gpm plume control	-	2.0	8.5
6d - Equus Beds Recharge Project with 8,000 gpm plume control	-	1.3	6.3

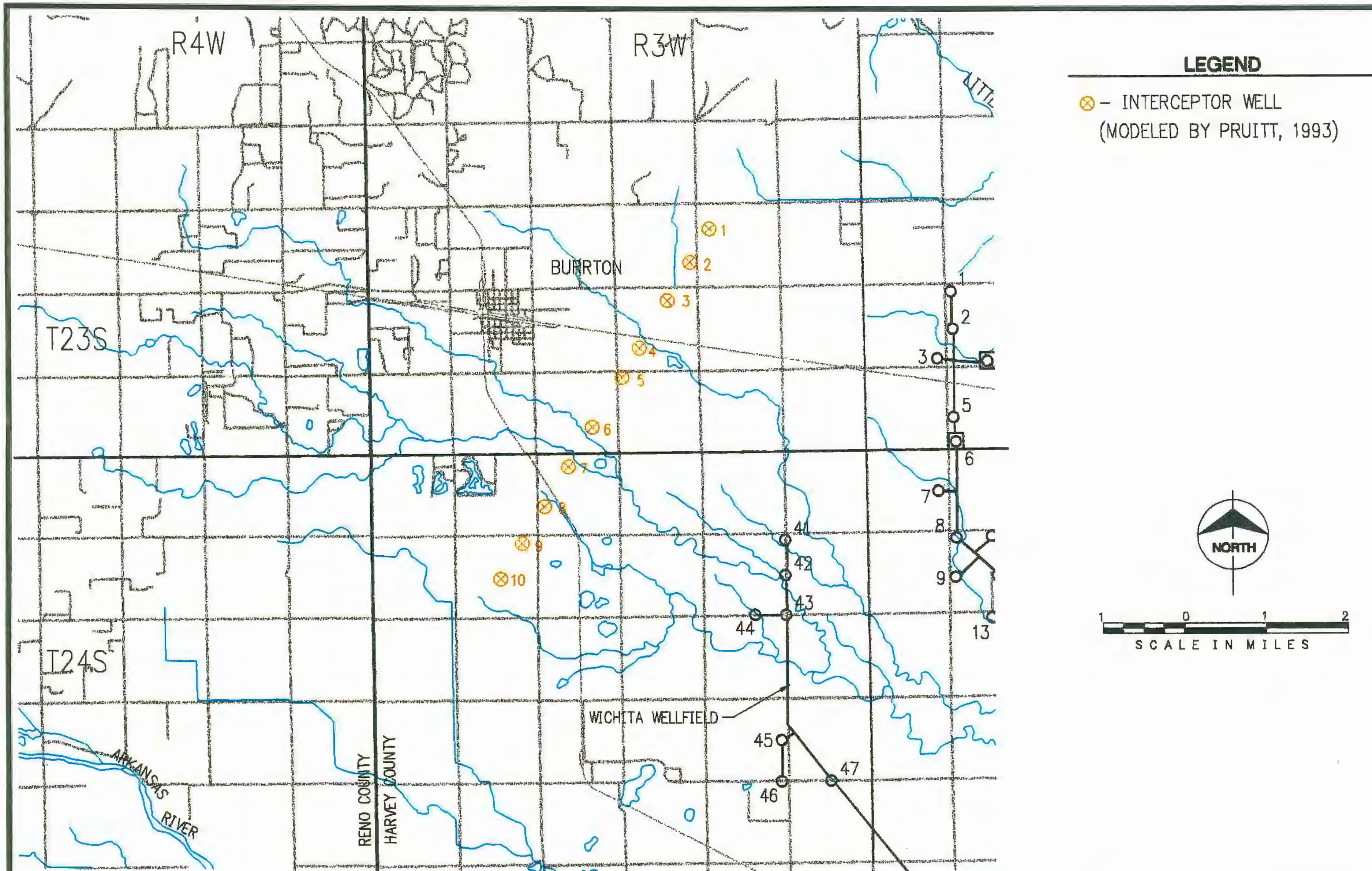

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Figure II – 6

2 PLUME INTERCEPTION
WELL LOCATIONS

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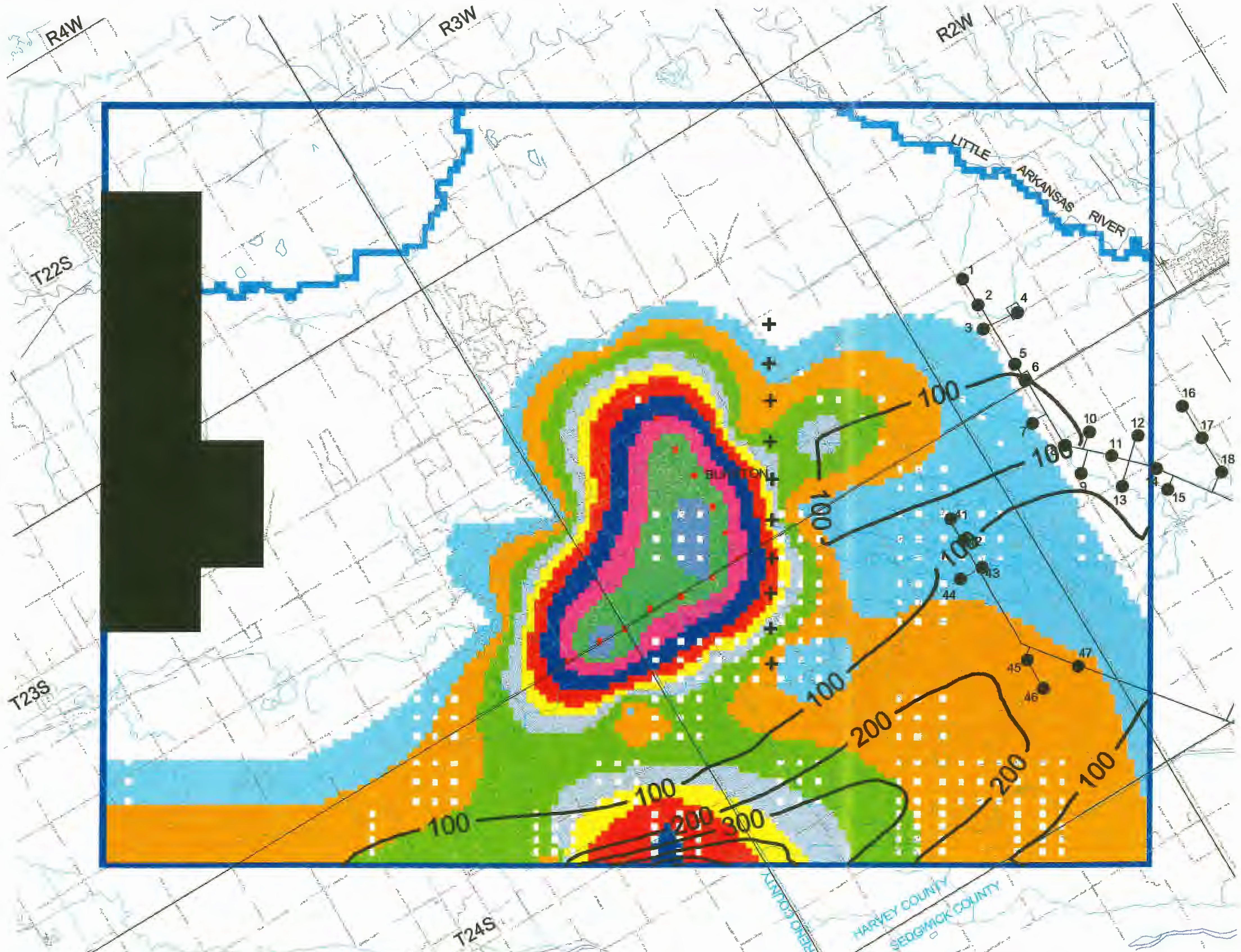

N

10000 20000 30000 40000

SCALE IN FEET

CONTOUR INTERVAL = 100 mg/l

LEGEND

- Chloride Isoconcentration Line (Modeled for 50 Years)
- ● Wichita Municipal Well
- + Interceptor Well (Modeled by Pruitt, 1993)

1996 Chloride Concentrations

50 mg/l	500 mg/l	1750 mg/l
100 mg/l	750 mg/l	2000 mg/l
200 mg/l	1000 mg/l	
300 mg/l	1250 mg/l	
400 mg/l	1500 mg/l	

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Figure II-7

LEVEL A
CHLORIDE CONCENTRATIONS
2C PLUME INTERCEPTION
4,000 GPM FOR 50 YEARS

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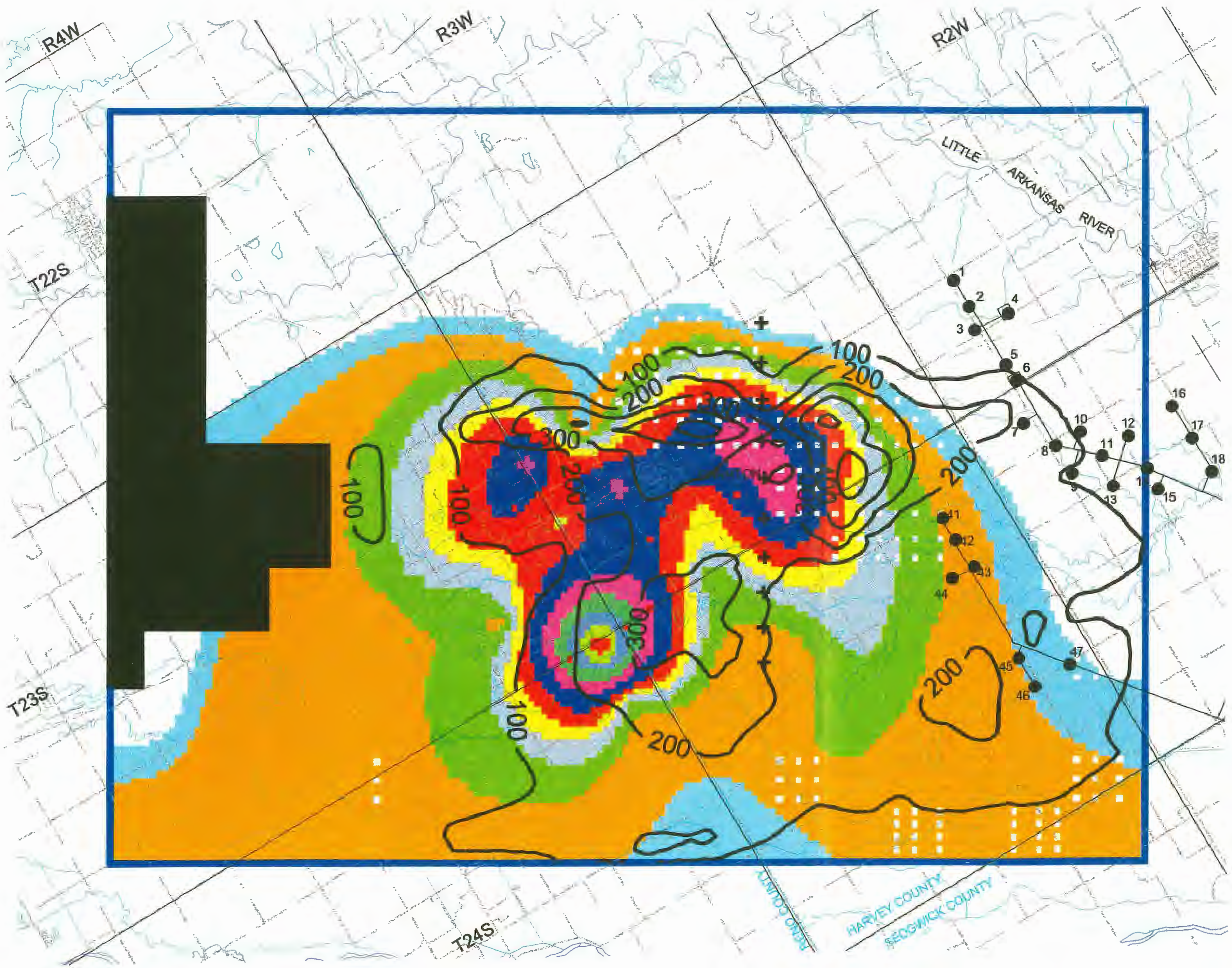

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Figure II-8

LEVEL B
CHLORIDE CONCENTRATIONS
2C PLUME INTERCEPTION
4000 GPM FOR 50 YEARS

J:\KCCBURTN\971834\ENGINEER\MODELS\GWVSUB\CONC\96C4_2L.SRF

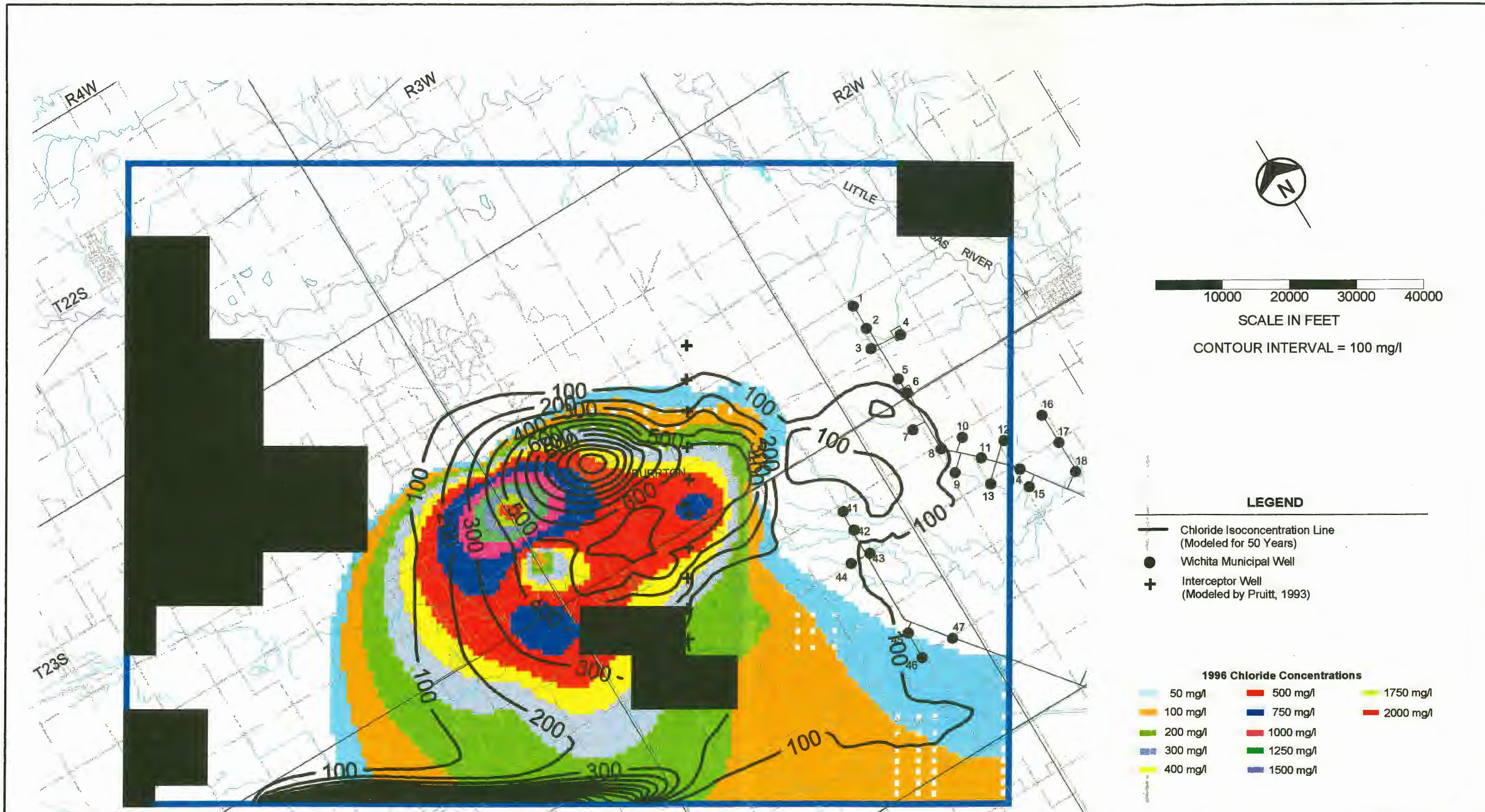

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Figure II-9

LEVEL C
CHLORIDE CONCENTRATIONS
2C PLUME INTERCEPTION
4000 GPM FOR 50 YEARS

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With the USBR simulation well layout, the area impacted by chloride concentrations exceeding 500 mg/L is reduced to 0.5 and 8.1 square miles in levels B and C, respectively. The use of the intercepter wells also reduces the impact of the chloride plume on the Wichita Well Field.

Over the 50 year time period, the MT3D modeling predicts that approximately 175,000 tons of chlorides as salt (NaCl) will be removed by the interceptor wells pumping at a total rate of 4,000 gpm for the management simulation 2c.

Table II-3 lists selected management simulations and shows the effects each scenario on the predicted chloride balance within the model area. The second column of the table shows the mass of brine removed from the aquifer by the remediation wells (interceptor wells, extraction wells, and/or gradient control wells) in terms of salt (NaCl). The table also lists the amount of salt induced into the model area in response to the remediation pumping. The source of the salt (chlorides) in-flow to the model area is either the Arkansas River and/or the deep Permian saltwater located in the bedrock channel under the Arkansas River.

Graphs of the chloride concentrations over the 50 year model period were created for simulated well No. 5 which is centrally located in the line of interceptor wells. The simulated well withdraws water from the middle and lower layers of the aquifer (Figures II-10 and II-11). In layer B, the high concentration zones of the plume migrate past the well, and in layer C, the lowest layer, the high concentration zones remain in the vicinity of the well. In comparison with the no action scenario, the layer B chloride concentrations are reduced by approximately 200 mg/L. However, in layer C, these wells have very little impact on the chloride concentrations.

Table II-3

SUMMARY OF MODEL SALT BUDGET[1]
(Tons of salt)

Management Simulation	Salt Removed by Extraction and Gradient Control Wells	Salt Entering Study Area		Net Salt Removed from Study Area		Salt Prevented from Entering Little Ark. River
		Induced from River and Bedrock	Recharge[3] Wells	Tons	Percent[2]	
2c Plume Interception 4,000 gpm	174,400	57,500		116,900	33	1,900
3c Plume Control 4,000 gpm	131,600	132,100		(500)	100	1,500
5a Equus Beds Recharge Project	-	(70,700)	4,200	66,500		(1,400)
6c Equus Beds Recharge Project with Plume Control, 4,000 gpm	133,900	9,000	4,200	120,700	7	1,500
6d Equus Beds Recharge Project with Plume Control, 8,000 gpm	257,000	107,100	4,200	145,700	42	3,200
7a Pilot 500 gpm	31,100	10,300	-	20,800	33	400

Notes:
1. Comparison of no action and management simulations for 50 years of operation.
2. Comparison of salt entering the study area with salt removed by the management simulation.
3. Assumes 60 mg/l chloride in recharge water.

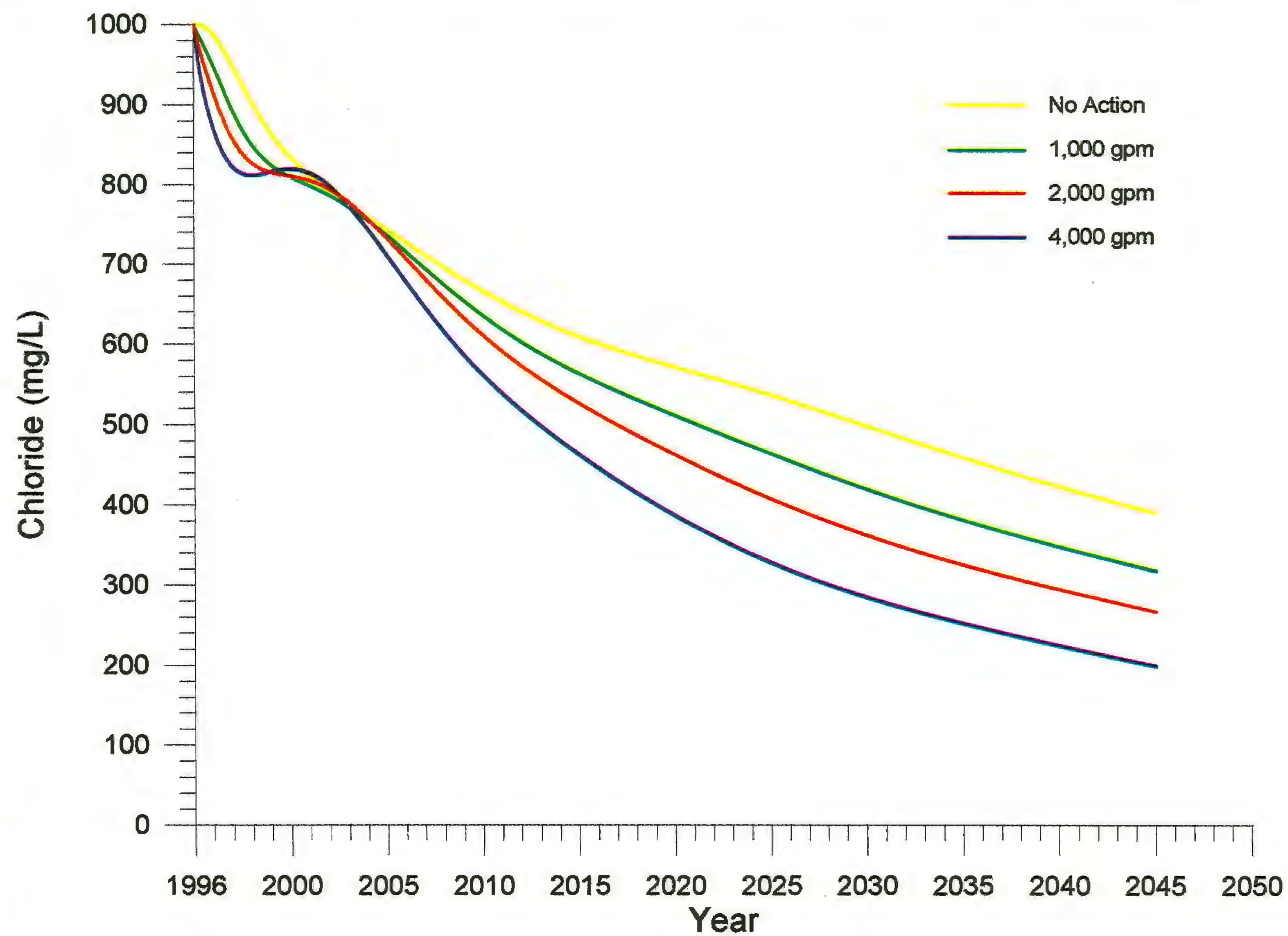

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Figure II-10

USBR INTERCEPTOR WELLS
CHLORIDE CONCENTRATIONS
WELL 5 - LEVEL B

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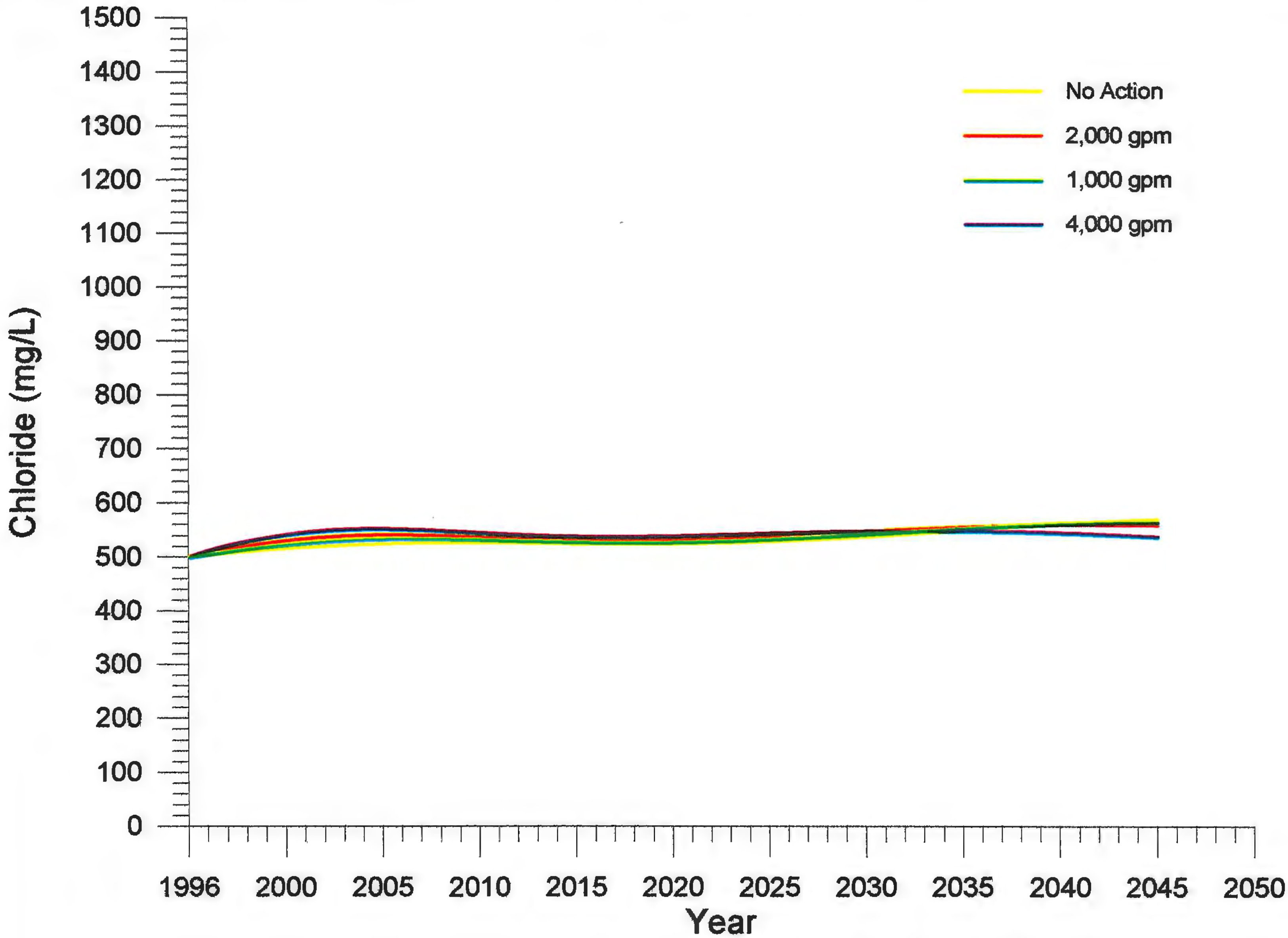

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Figure II-11

USBR INTERCEPTOR WELLS
CHLORIDE CONCENTRATIONS
WELL 5 - LEVEL C

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3. Plume Control (3a, 3b and 3c)

Based on the results of the no action and interceptor well scenarios, an initial withdrawal well layout was established. This layout combined the use of extraction wells located in the high concentration zones of the chloride plume and higher capacity wells upgradient of the plume. The low-capacity extraction wells are designed to remove groundwater from areas of highest chloride concentrations within hydrostratigraphic levels A and B. The gradient control wells are designed to control the local groundwater flow gradient restricting the migration of the high chloride plume within hydrostratigraphic Levels A, B and C. Plume migration control allows greater removal efficiency of high chloride concentrations by the extraction wells. The well layout is shown in Figure II-12.

Seventeen extraction wells were located in the high concentration zones of the plume with four wells screened into Level A, two wells screened into Level B, and 11 wells screened into both hydrostratigraphic units. Where feasible, wells were screened into both units to control costs by minimizing the number of wells constructed. The capacity of these wells are selected at a maximum of 87 gallons per minute (gpm) or 174 gpm, for wells screened into one or two units, respectively. The relatively low capacity of these wells was selected to prevent pulling clean water from outside of the contaminated area, thus requiring greater treatment and disposal volumes.

Six gradient control wells were placed upgradient of the main part of the plume in an area of moderate levels of chloride concentration. These wells are about two miles upgradient of the series of extraction wells to limit movement of the chloride plume. Four wells were screened in Levels B and C with two wells screened in Level B only. The maximum pumping rates for these wells were selected as 400 gpm for wells screened in two layers and 200 gpm for wells screened in a single layer.

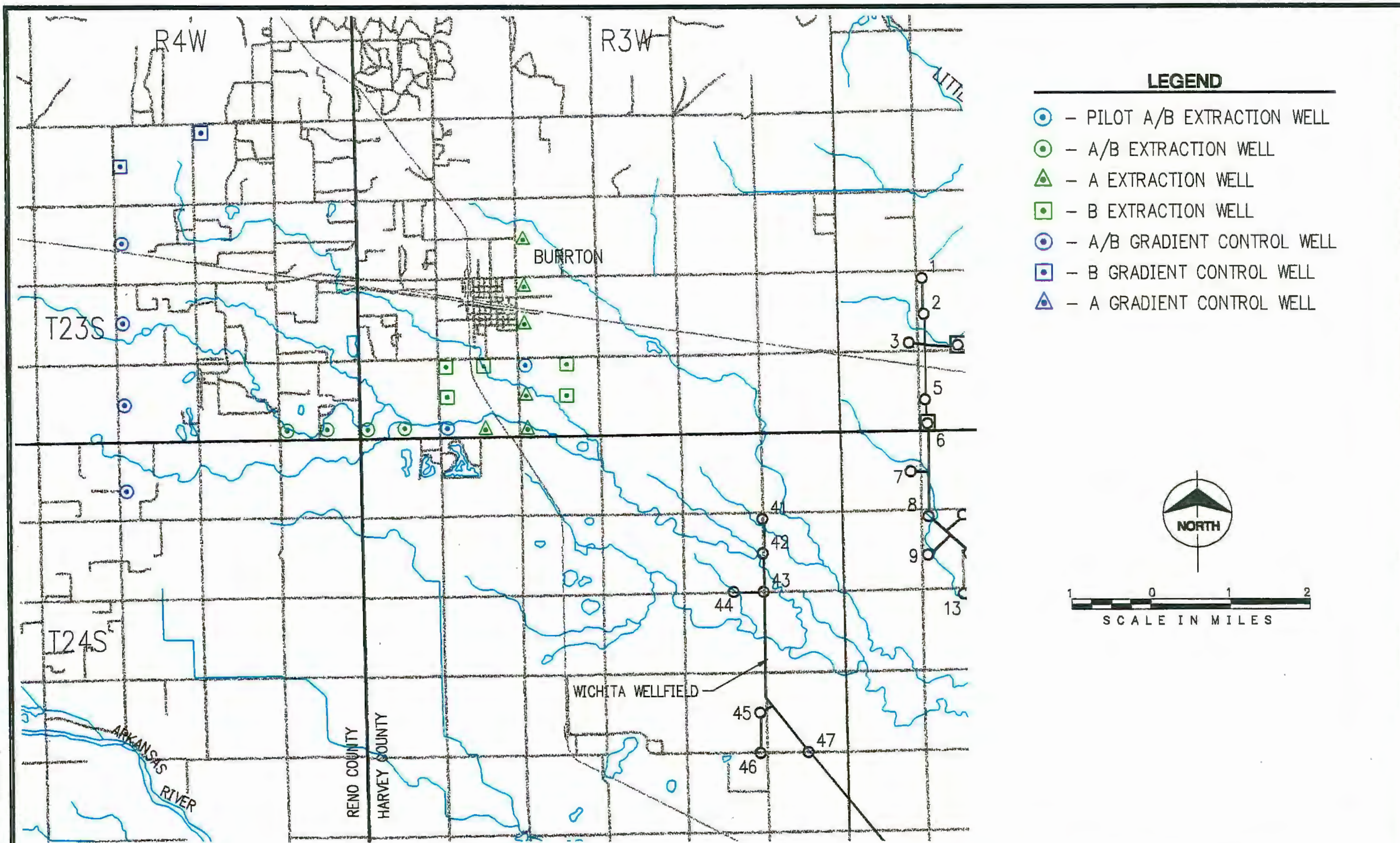

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Figure II – 12

3 PLUME CONTROL WELL LOCATIONS

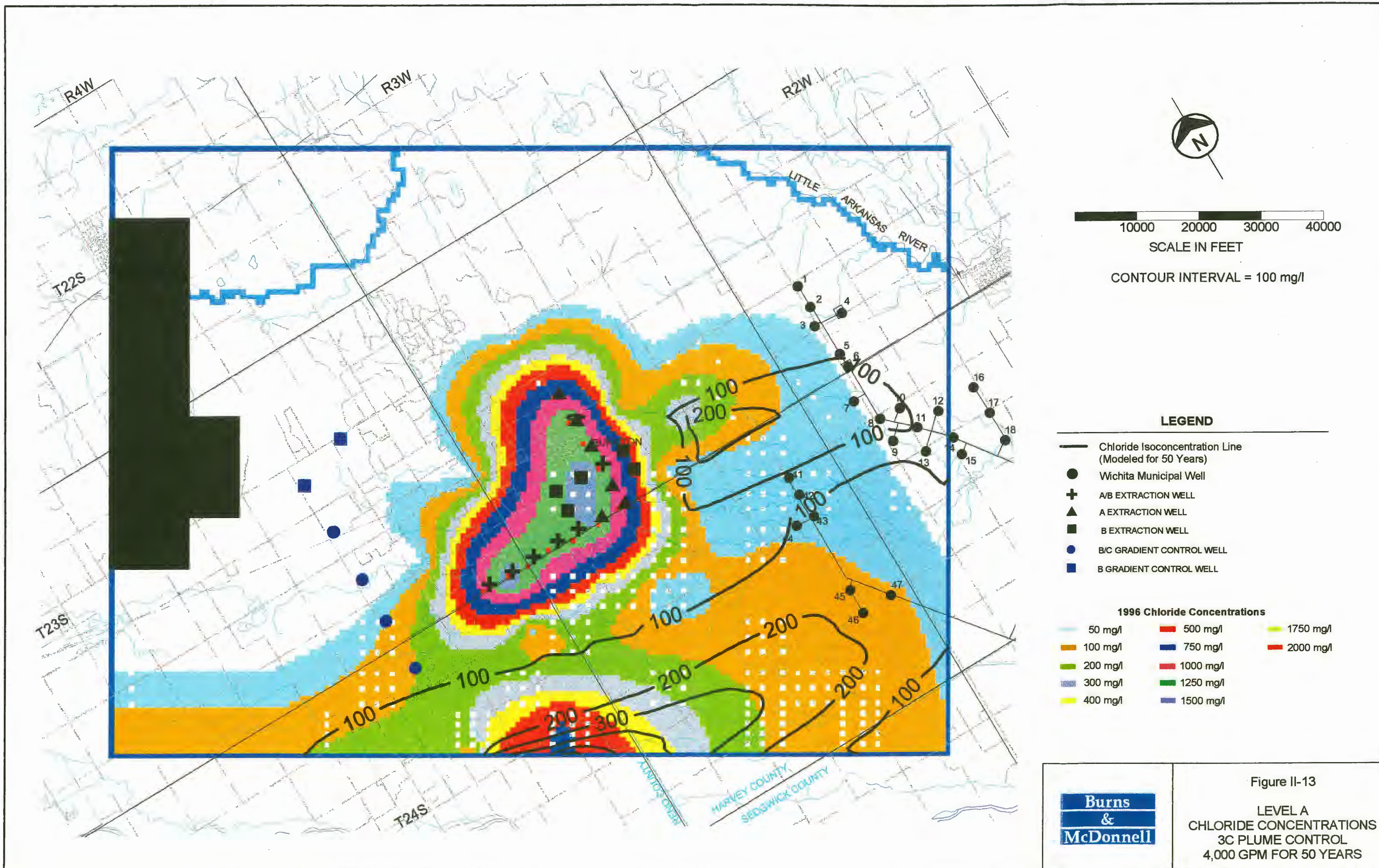

Figure II-13

LEVEL A
CHLORIDE CONCENTRATIONS
3C PLUME CONTROL
4,000 GPM FOR 50 YEARS

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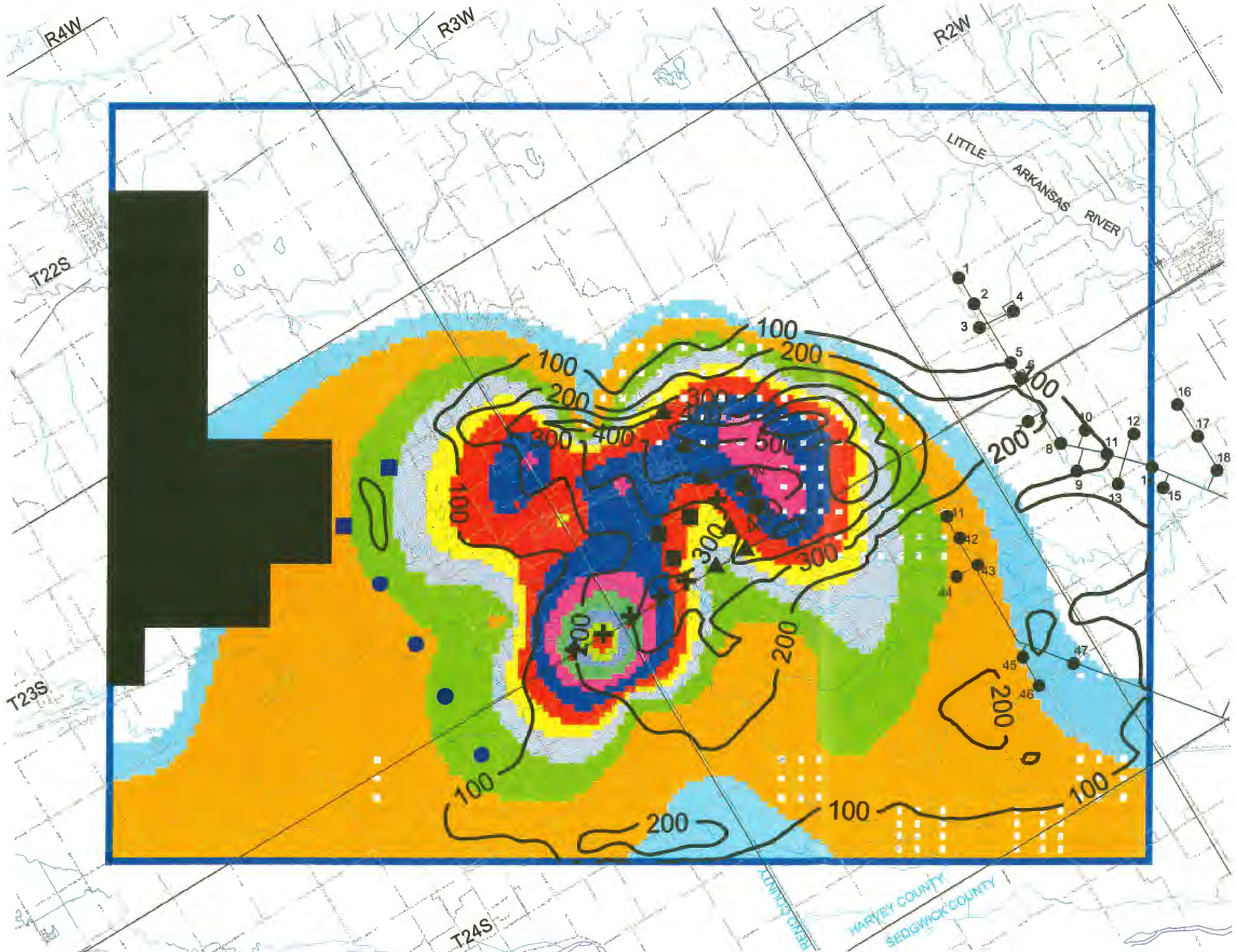

10000 20000 30000 40000

SCALE IN FEET

CONTOUR INTERVAL = 100 mg/l

LEGEND

- Chloride Isoconcentration Line (Modeled for 50 Years)
- Wichita Municipal Well
- A/B EXTRACTION WELL
- A EXTRACTION WELL
- B EXTRACTION WELL
- B/C GRADIENT CONTROL WELL
- B GRADIENT CONTROL WELL

1996 Chloride Concentrations

50 mg/l	500 mg/l	1750 mg/l
100 mg/l	750 mg/l	2000 mg/l
200 mg/l	1000 mg/l	
300 mg/l	1250 mg/l	
400 mg/l	1500 mg/l	

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Figure II-14

LEVEL B
CHLORIDE CONCENTRATIONS
3C PLUME CONTROL
4000 GPM FOR 50 YEARS

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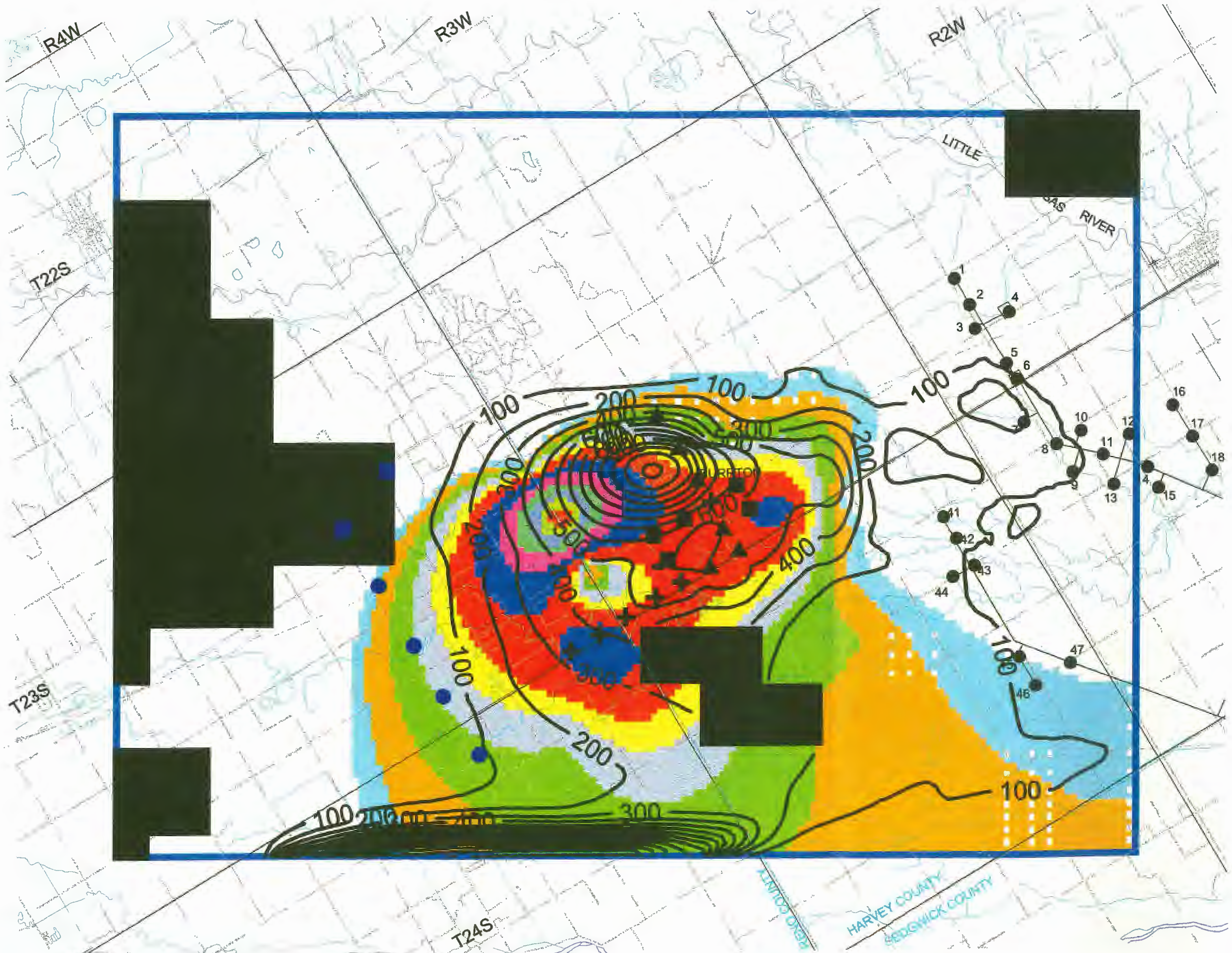

10000 20000 30000 40000
SCALE IN FEET

CONTOUR INTERVAL = 100 mg/l

LEGEND

- Chloride Isoconcentration Line (Modeled for 50 Years)
- Wichita Municipal Well
- A/B EXTRACTION WELL
- A EXTRACTION WELL
- B EXTRACTION WELL
- B/C GRADIENT CONTROL WELL
- B GRADIENT CONTROL WELL

1996 Chloride Concentrations

50 mg/l	500 mg/l	1750 mg/l
100 mg/l	750 mg/l	2000 mg/l
200 mg/l	1000 mg/l	
300 mg/l	1250 mg/l	
400 mg/l	1500 mg/l	

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Figure II-15

LEVEL C
CHLORIDE CONCENTRATIONS
3C PLUME CONTROL
4000 GPM FOR 50 YEARS

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The total pumpage for the extraction wells and gradient control wells is 4000 gpm selected to reflect the pumpage modeled by the USBR (simulation 3c). Additional scenarios used total pumping rates of 2000 gpm and 1000 gpm (simulations 3c and 3b). Pumping rates for individual wells were reduced by 50% and 75% for these simulations. Figures II-13 through II-15 show the predicted chloride concentrations for management simulation 3c (4000 gpm for 50 years). Like the interceptor wells modeled by the USBR, these wells do not prevent the plume from affecting the Wichita Well Field, however, the use of this layout of wells lessens the impact of the chloride plume on the well field. As shown in Table II-2, the surface area impacted by chloride concentrations exceeding 500 mg/L is reduced to 1.7 and 7.7 square miles in levels B and C, respectively. These modeling results indicate that this scenario is less effective in level B and more effective in level C when compared to the USBR interceptor well layout pumping at equivalent rates.

Figures II-16 and II-17 shows the chloride concentrations over time for gradient simulated control well no. 3, located in the heart of the plume, as predicted by the contaminant transport model. The initial chloride concentrations range from about 100 mg/L for groundwater from Layer B to 200 mg/L for Layer C. After 50 years, the concentrations drop to about 20 mg/L and 30 mg/L, respectively. Initially, these concentrations are greater than the ambient chloride levels ranging up to 75 mg/L for the Equus Beds Aquifer. However, they are much less than the concentrations of the discharge water from the USBR interceptor wells.

The MT3D modeling estimated that approximately 132,000 tons of chlorides (as salt) are extracted over the 50 year period with management simulation 3c (4,000 gpm). However, because of the response of the hydrogeologic system, additional chloride is introduced into the model area because of the changing groundwater gradient. With this management simulation, there is an equivalent amount of

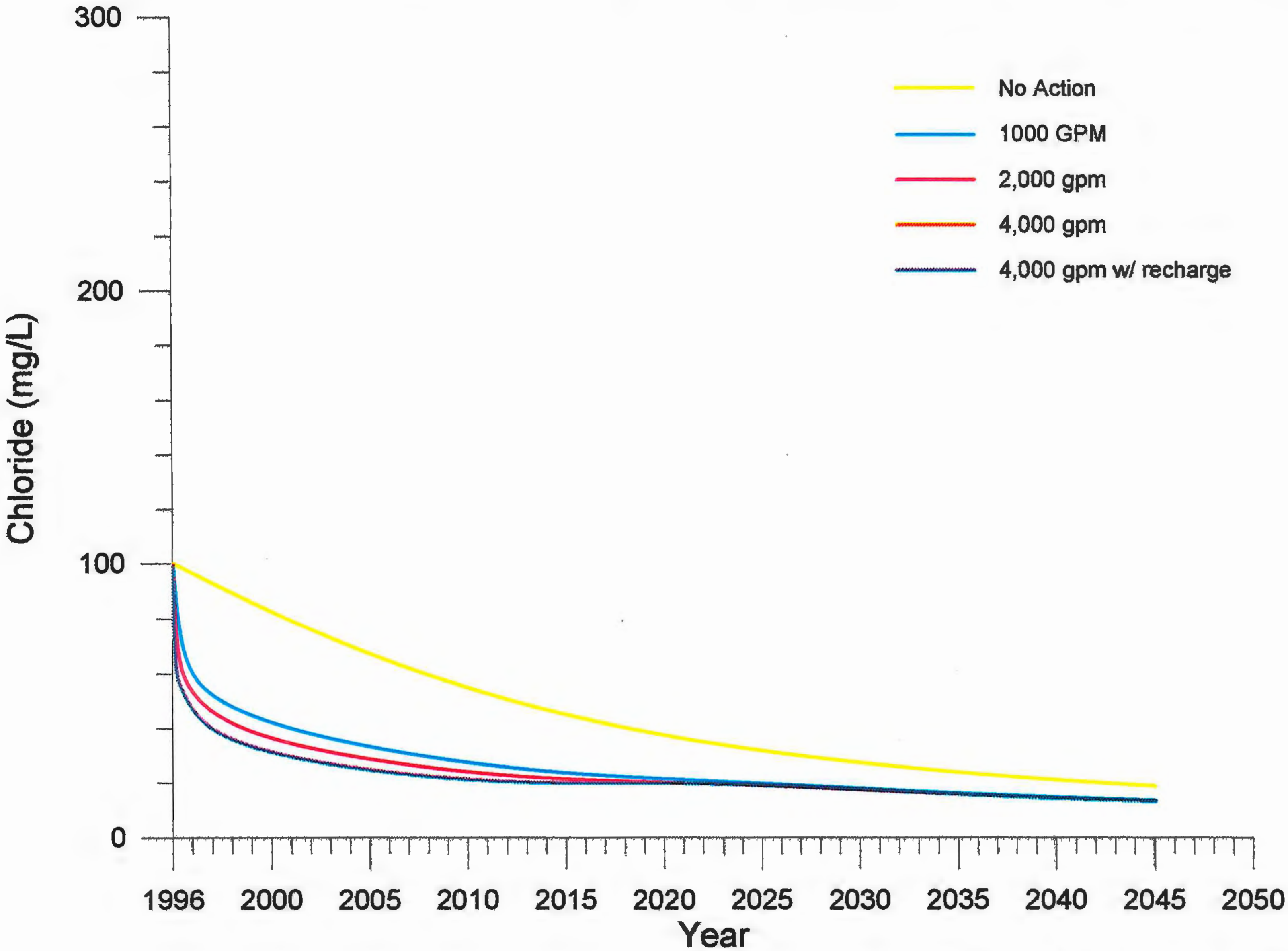

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Figure II-16

CHLORIDE CONCENTRATIONS
GRADIENT CONTROL WELL 3
LEVEL B

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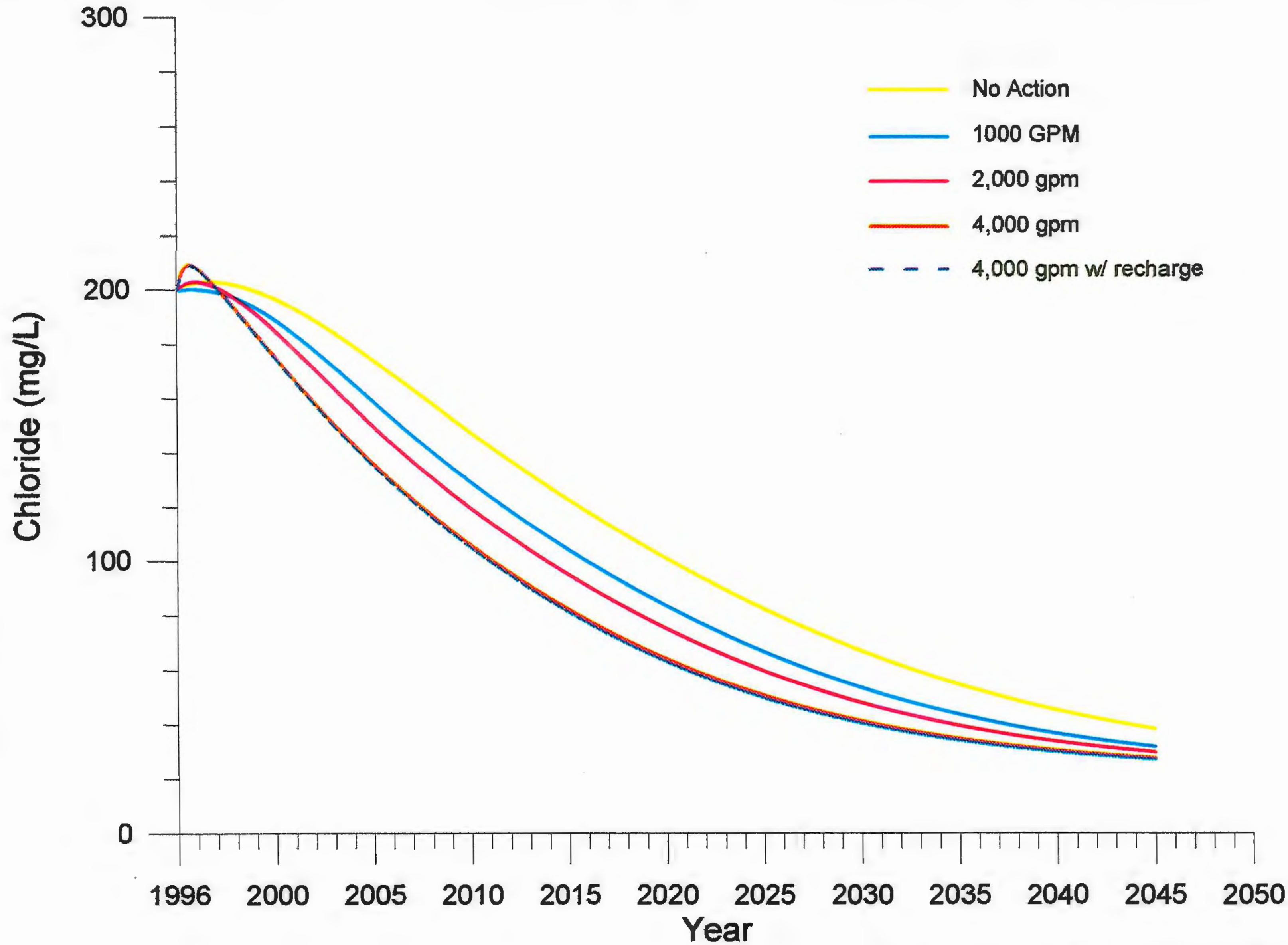

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Figure II-17

CHLORIDE CONCENTRATIONS
GRADIENT CONTROL WELL 3
LEVEL C

J:\KCCBURTN\971834\ENGINEER\MODELS\GWVSUB\CONC\GC3GC.GRF chlorides pulled into the model area from the south as was extracted with the remediation wells resulting in very little net improvement in the study area.

4. Plume Control with Recharge Basins (4a)

Both treated water and pumpage from the gradient control wells can potentially be recharged into the Equus Beds Aquifer downgradient of the extraction well system. A simulation was conducted using management simulation 3c (4000 gpm) combined with four recharge basins (Figure II-18). The total recharge rate was selected to be 75 percent of the water pumped with the extraction wells, assuming that 25 percent is lost with reverse osmosis water treatment. The recharge water was assumed to possess a maximum chloride level of 150 mg/L and be recharged at a rate of 375 gpm in each of four basins. The recharge basins were located along the downgradient 200 mg/L chloride concentration contour. Figures II-19 through II-21 show the chloride concentrations after 50 years for this simulation. The addition of the recharge basins provides some additional control over the plume, however, like the previous scenarios, the impacts at this pumping rate are limited.

5. Plume Control Impacts of the Equus Beds Groundwater Recharge Project (5a, 5b and 5c)

The City of Wichita has undertaken a project to recharge the city's Equus Beds Well Field with above-base flow water from the Little Arkansas River. Management simulations were conducted to allow for the effects from the Equus Beds Recharge Project. Modeling scenarios were set up with the assumptions of the water levels rising five (5a) and ten feet (5b) along the eastern portion of the study area. Scenarios assuming that no action was taken to control or remediate the plume were conducted to assess the natural movement of the plume under large scale recharge conditions.

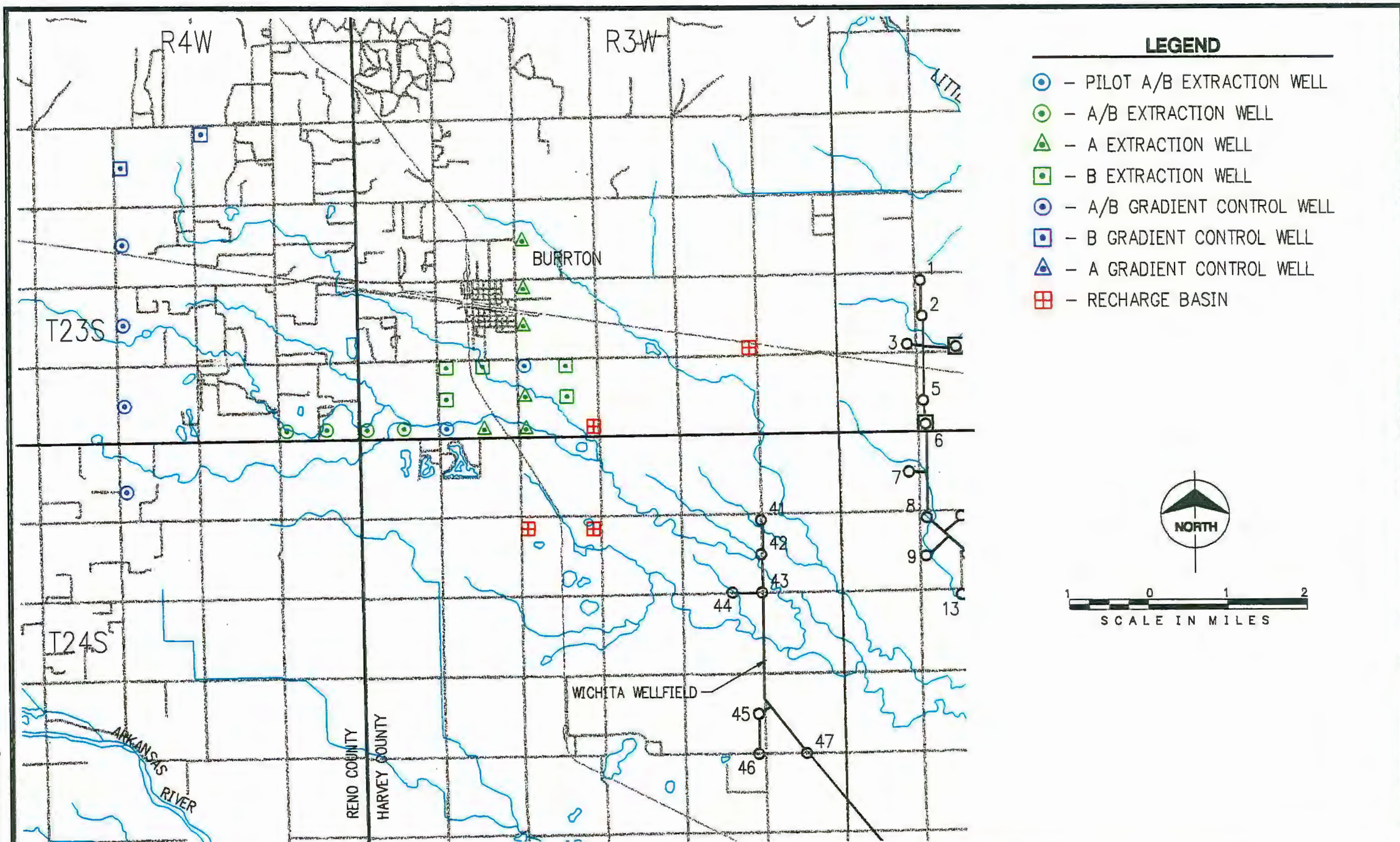

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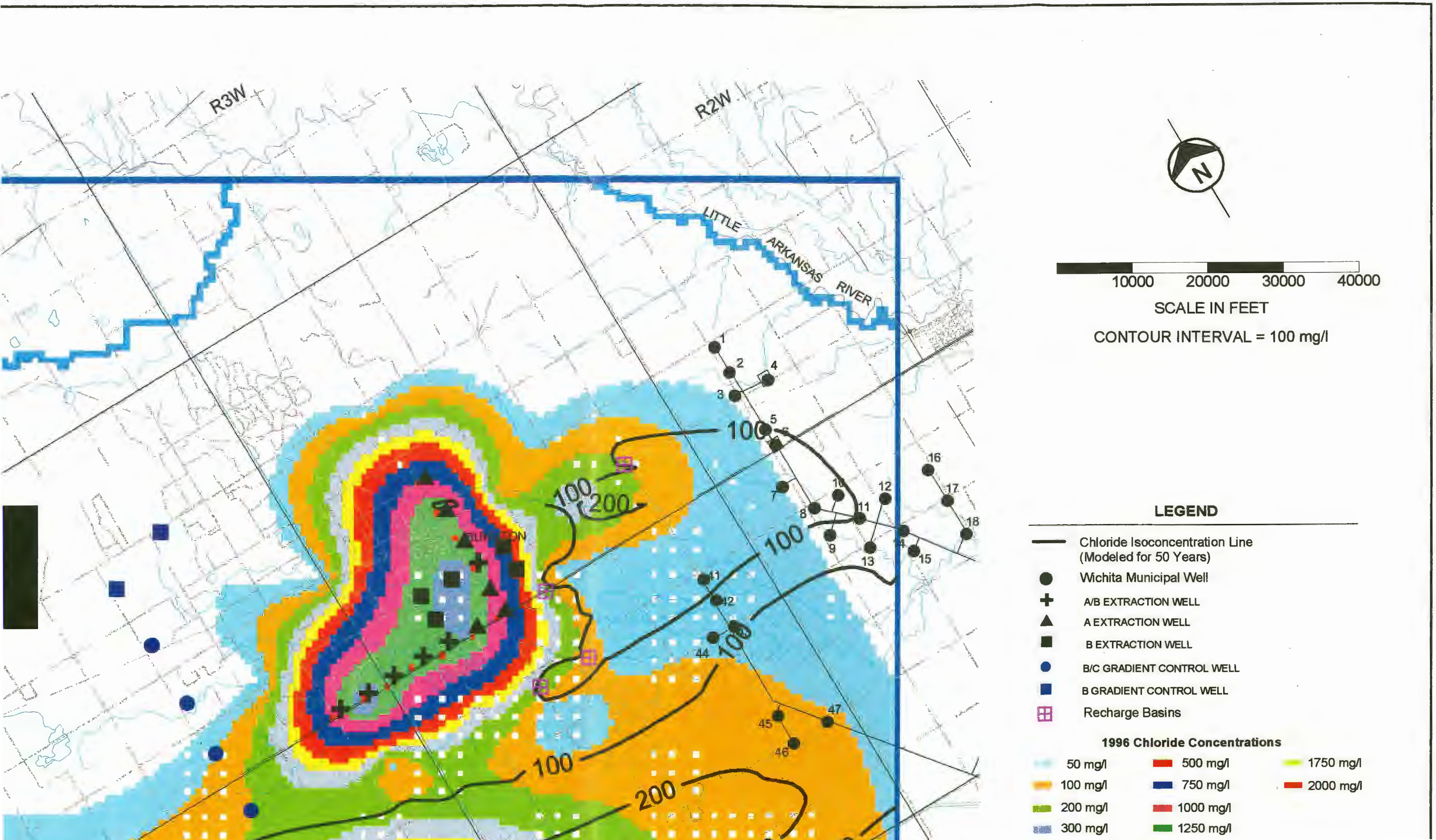
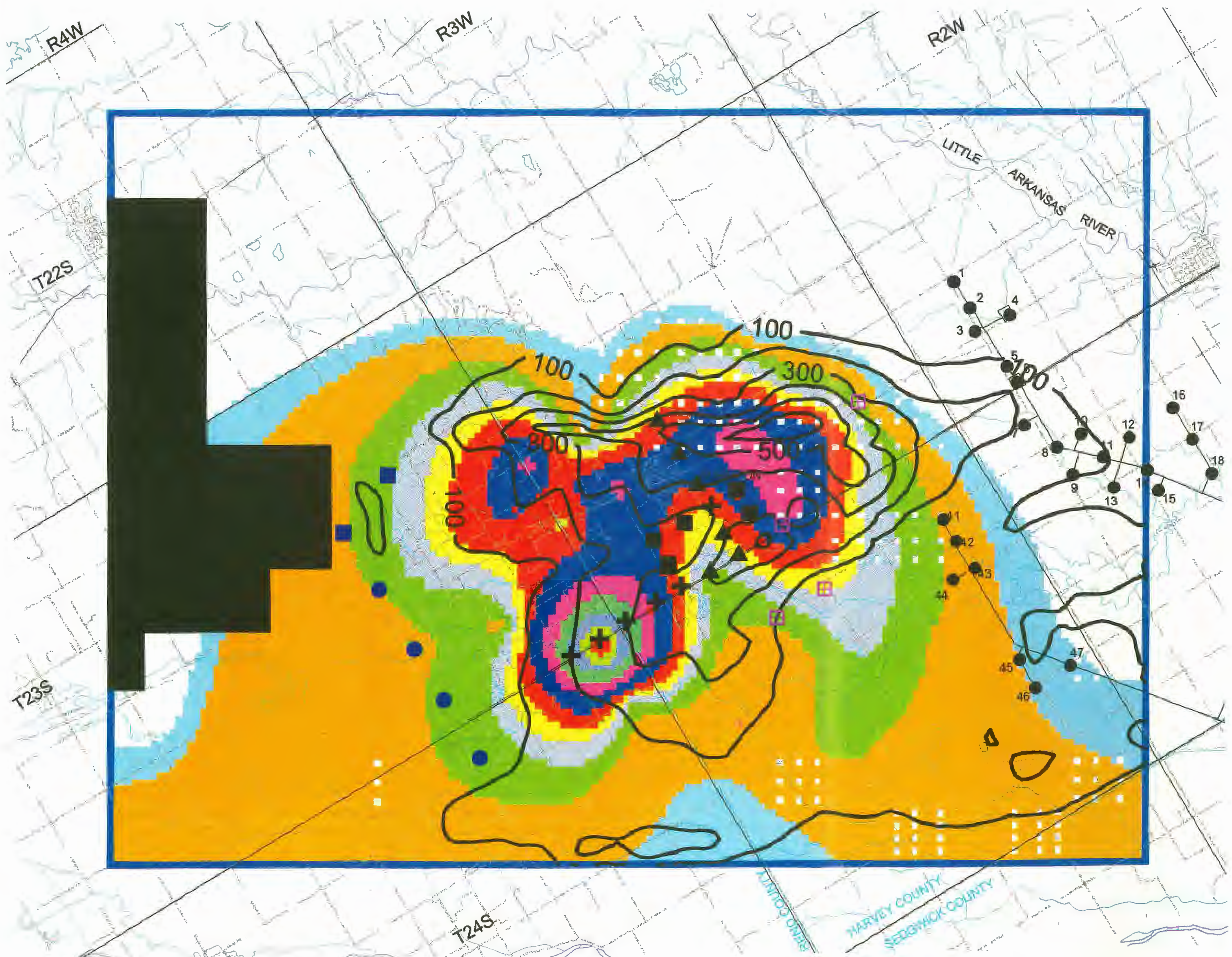
Figure II – 18

3 PLUME CONTROL
WITH RECHARGE BASINS
WELL AND BASIN LOCATIONS



R3W
R2W
LITTLE ARKANSAS RIVER
N
10000
20000
30000
40000
SCALE IN FEET
CONTOUR INTERVAL = 100 mg/l
100
200
LEGEND
Chloride Isoconcentration Line (Modeled for 50 Years)
Wichita Municipal Well
A/B EXTRACTION WELL
A EXTRACTION WELL
B EXTRACTION WELL
B/C GRADIENT CONTROL WELL
B GRADIENT CONTROL WELL
Recharge Basins
1996 Chloride Concentrations
50 mg/l
100 mg/l
200 mg/l
300 mg/l
500 mg/l
750 mg/l
1000 mg/l
1250 mg/l
1750 mg/l
2000 mg/l



10000 20000 30000 40000
SCALE IN FEET

CONTOUR INTERVAL = 100 mg/l

LEGEND

- Chloride Isoconcentration Line (Modeled for 50 Years)
- Wichita Municipal Well
- A/B EXTRACTION WELL
- A EXTRACTION WELL
- B EXTRACTION WELL
- B/C GRADIENT CONTROL WELL
- B GRADIENT CONTROL WELL
- Recharge Basins

1996 Chloride Concentrations

50 mg/l	500 mg/l	1750 mg/l
100 mg/l	750 mg/l	2000 mg/l
200 mg/l	1000 mg/l	
300 mg/l	1250 mg/l	
400 mg/l	1500 mg/l	

Burns & McDonnell

Figure II-20

LEVEL B
CHLORIDE CONCENTRATIONS
4A PLUME CONTROL
WITH RECHARGE BASINS
4000 GPM FOR 50 YEARS

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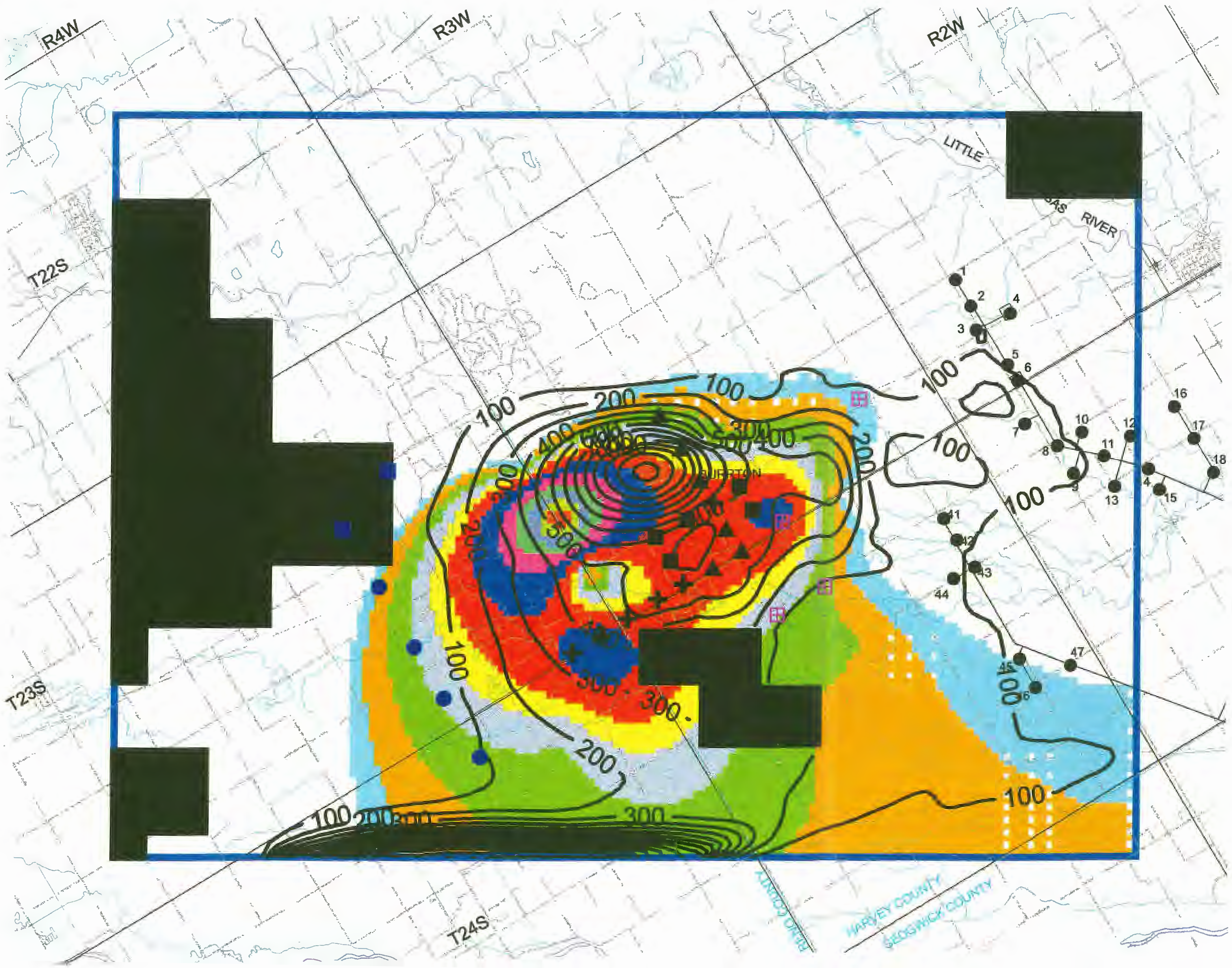

SCALE IN FEET: 10000 20000 30000 40000

CONTOUR INTERVAL = 100 mg/l

LEGEND

- Chloride Isoconcentration Line (Modeled for 50 Years)
- Wichita Municipal Well
- A/B EXTRACTION WELL
- A EXTRACTION WELL
- B EXTRACTION WELL
- B/C GRADIENT CONTROL WELL
- B GRADIENT CONTROL WELL
- Recharge Basins

1996 Chloride Concentrations

50 mg/l	500 mg/l	1750 mg/l
100 mg/l	750 mg/l	2000 mg/l
200 mg/l	1000 mg/l	
300 mg/l	1250 mg/l	
400 mg/l	1500 mg/l	

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Figure II-21

LEVEL C
CHLORIDE CONCENTRATIONS
4A PLUME CONTROL
WITH RECHARGE BASINS
4000 GPM FOR 50 YEARS

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After reviewing the results from these scenarios, an additional scenario (5c) was performed using recharge wells as conceptually proposed for the Equus Beds Aquifer recharge operation. Simulation 5c assumes 22 wells, representing Equus Beds recharge wells, were operating at an average rate of 8,530 gpm. This rate is based on the anticipated average annual volume of water that is expected to be recharged during full scale operations. This rate is estimated to be approximately 627 acre-feet/year in the model area. The recharge wells were assumed to be screened and injecting water in level C.

This scenario was modeled for 50 years assuming no action was taken to control or remediate the Burrton chloride plume. Figures II-22 through II-24 show the chloride concentrations for this simulation. The results of modeling the full scale Equus Beds Recharge Project show a significant effect on the migration of the chloride plume. The surface area affected by chloride concentrations exceeding 500 mg/L is 3.8 and 11.7 square miles in levels B and C, respectively (Table II-2). The modeling demonstrates that the injection of fresh water into level C causes the plume to widen to the north and south as the downgradient migration is slowed.

6. <u>Equus Beds Recharge with Plume Control (6a, 6b, 6c and 6d)</u>

The above Equus Beds recharge simulations were combined with plume control pumping (3c with rates of 4,000 gpm) to analyze the combined impacts of the two operations. A fourth management simulation (6d) was performed to analyze the impacts of plume control pumping at rates of 8,000 gpm.

The effects of the plume control wells at a pumping rate of 4000 gpm (simulation 3c) to this scenario is shown in Figures II-25 through II-27. The reduced flow gradients in the aquifer allows the remediation scenario to have a greater impact on the control and removal of the plume. The surface area impacted by chloride

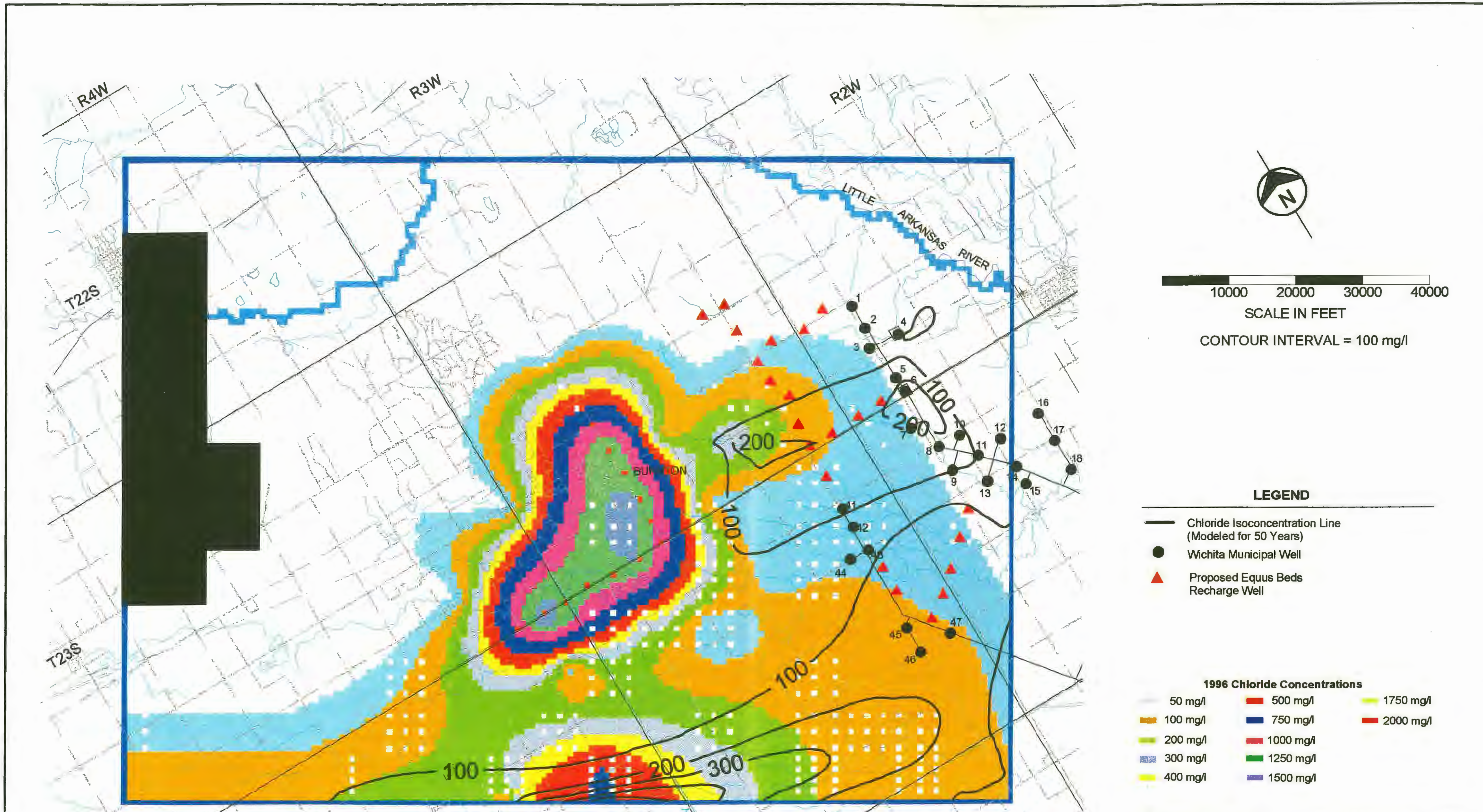

Figure II-22

LEVEL A
CHLORIDE CONCENTRATIONS
5C EQUUS BEDS
RECHARGE PROJECT
8530 GPM FOR 50 YEARS

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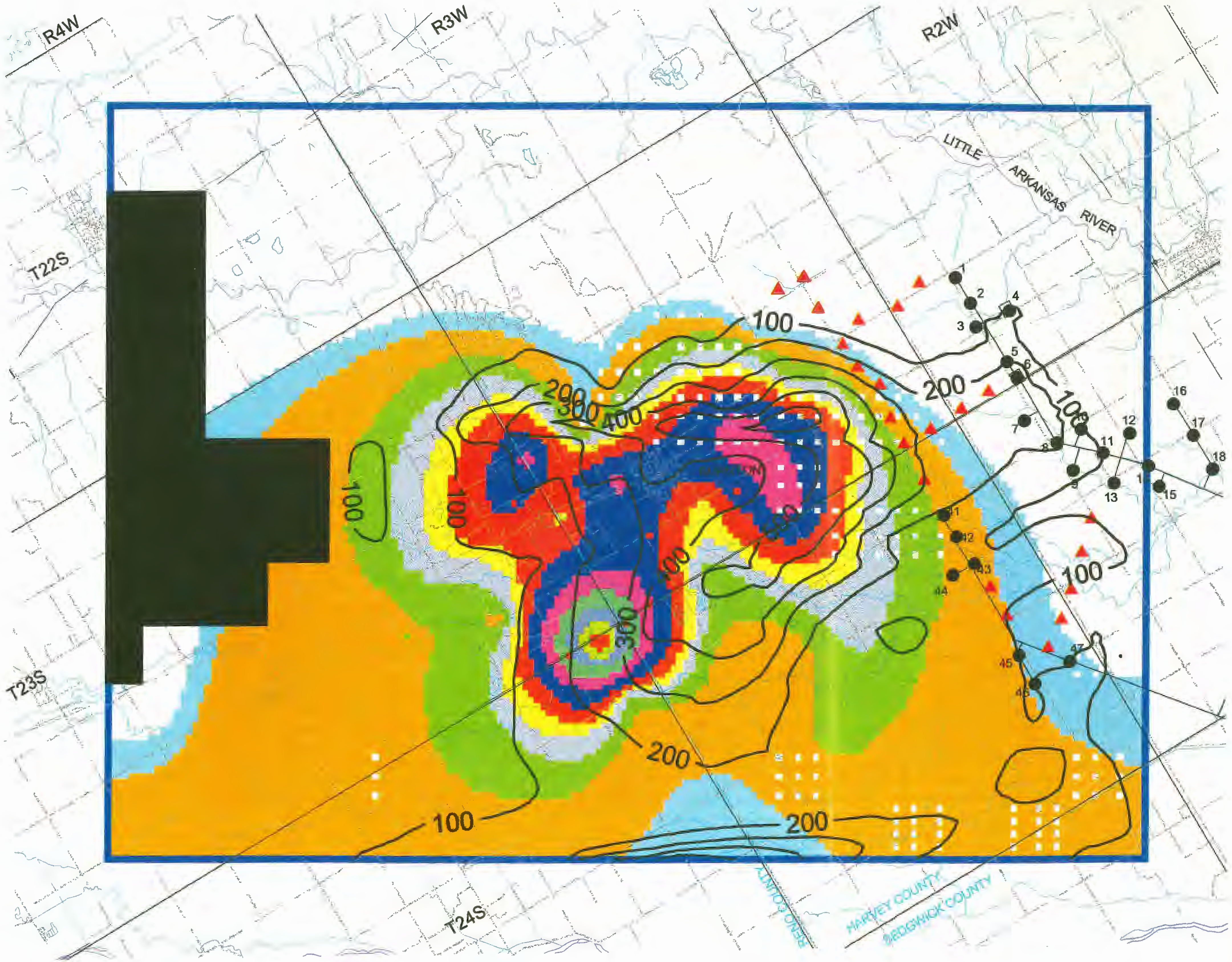

N

SCALE IN FEET: 10000 20000 30000 40000

CONTOUR INTERVAL = 100 mg/l

LEGEND

- Chloride Isoconcentration Line (Modeled for 50 Years)
- Wichita Municipal Well
- Proposed Equus Beds Recharge Well

1996 Chloride Concentrations

50 mg/l	500 mg/l	1750 mg/l
100 mg/l	750 mg/l	2000 mg/l
200 mg/l	1000 mg/l	
300 mg/l	1250 mg/l	
400 mg/l	1500 mg/l	

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Figure II-23

LEVEL B
CHLORIDE CONCENTRATIONS
5C EQUUS BEDS
RECHARGE PROJECT
8530 GPM FOR 50 YEARS

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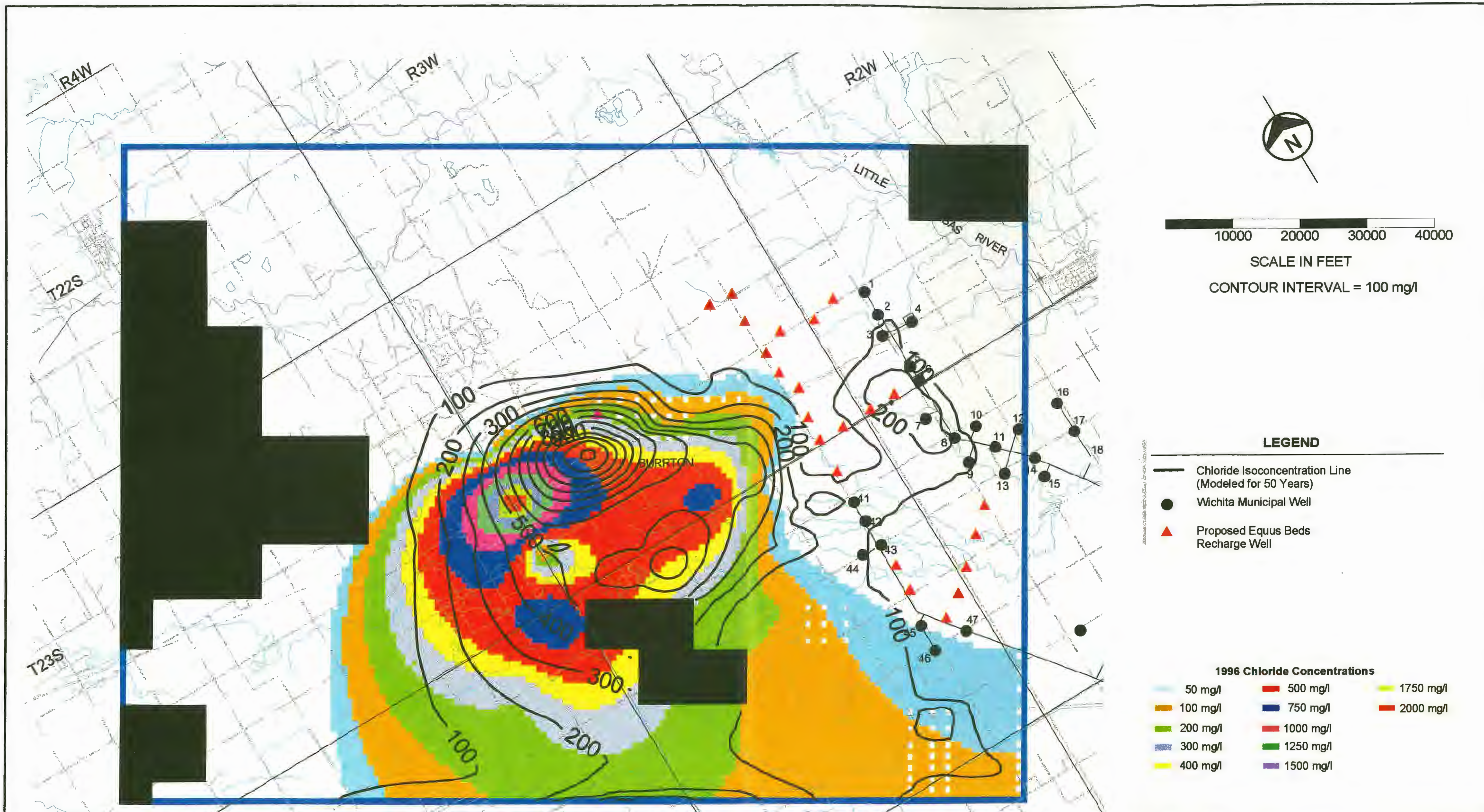

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Figure II-24

LEVEL C
CHLORIDE CONCENTRATIONS
5C EQUUS BEDS
RECHARGE PROJECT
8530 GPM FOR 50 YEARS

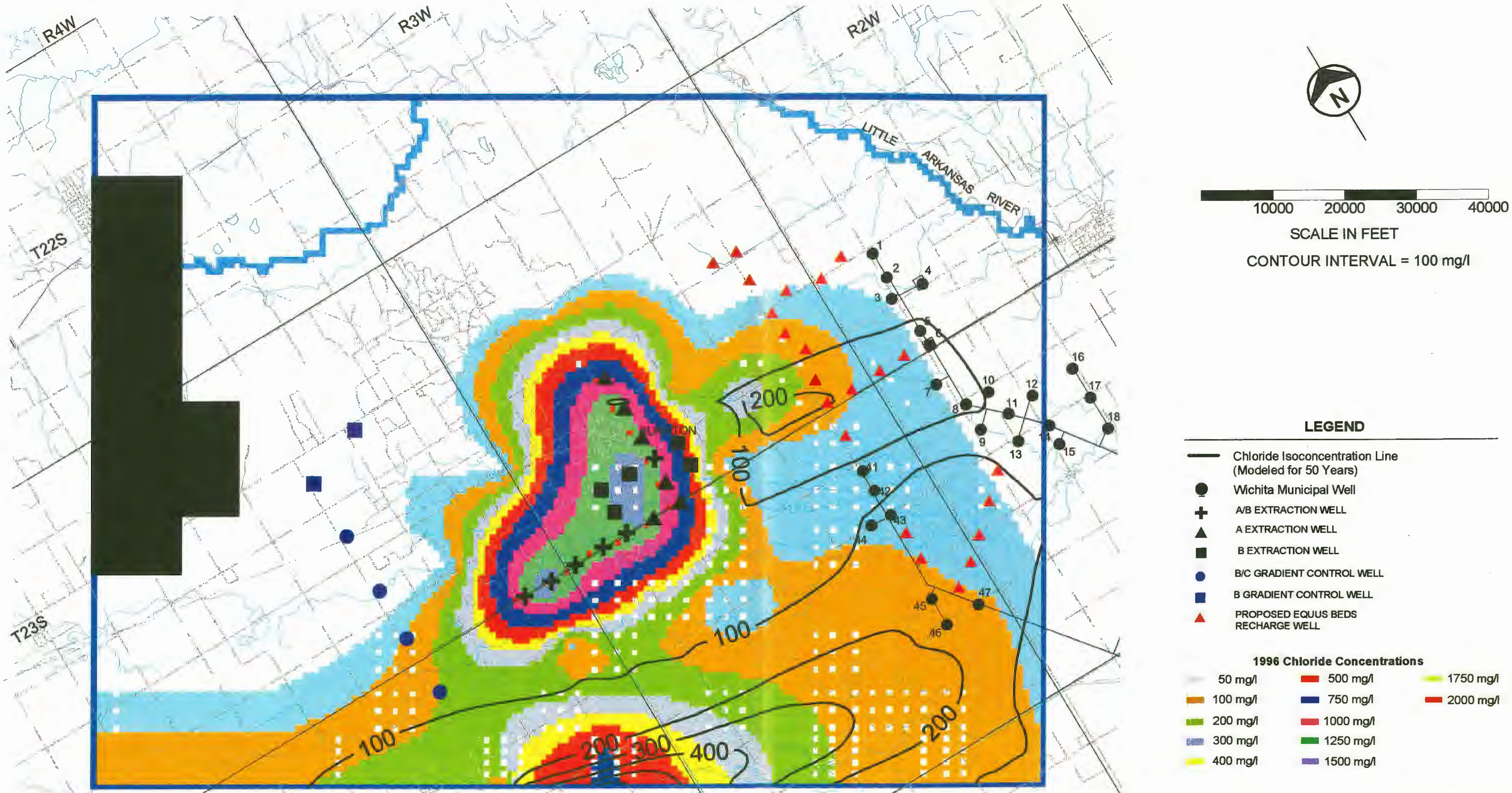

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Figure II-25

LEVEL A
CHLORIDE CONCENTRATIONS
6C EQUUS BEDS RECHARGE
PROJECT WITH PLUME CONTROL
4000 GPM FOR 50 YEARS

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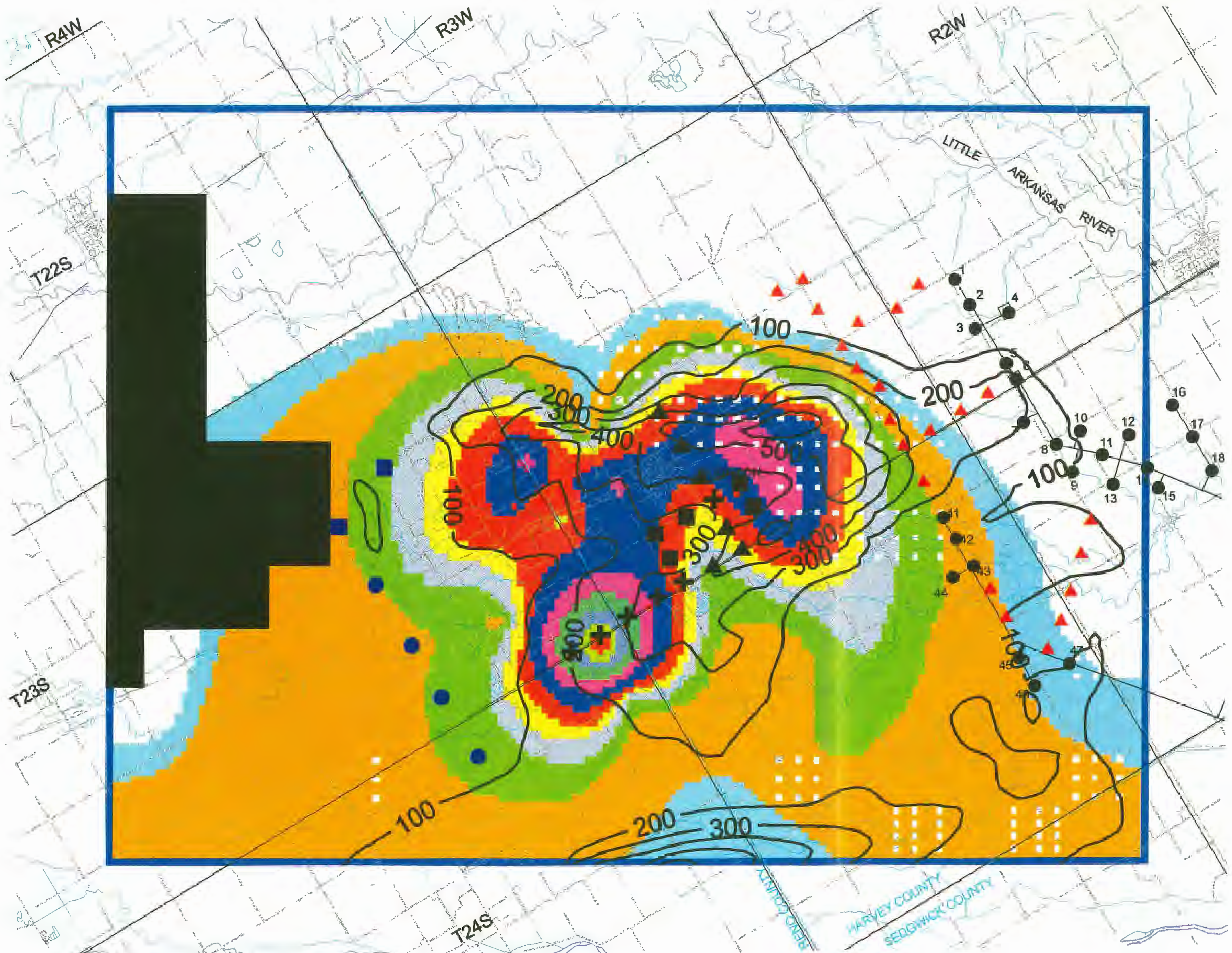

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Figure II-26

LEVEL B
CHLORIDE CONCENTRATIONS
6C EQUUS BEDS RECHARGE
PROJECT WITH PLUME CONTROL
4000 GPM FOR 50 YEARS

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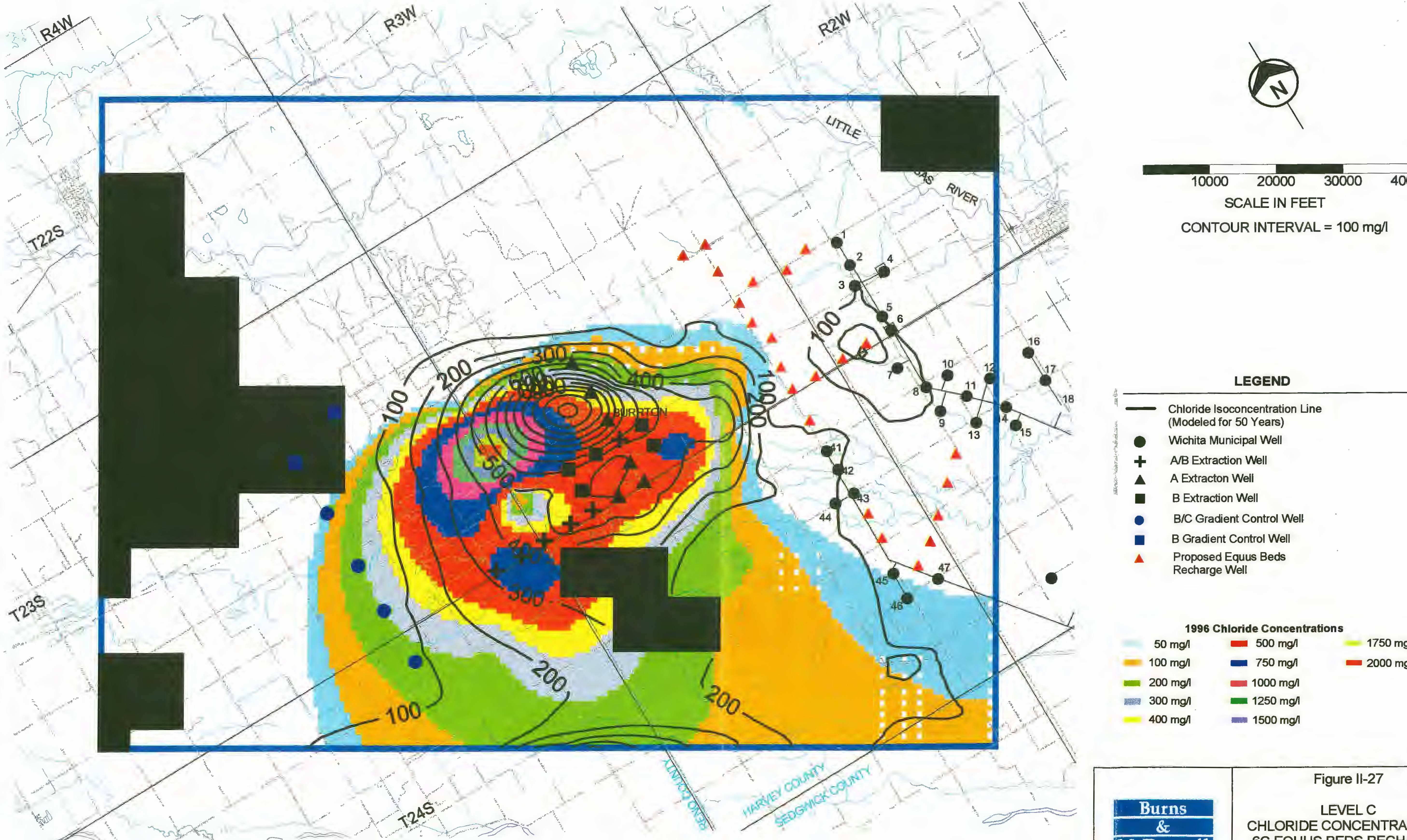

Burns & McDonnell

Figure II-27

LEVEL C
CHLORIDE CONCENTRATIONS
6C EQUUS BEDS RECHARGE
PROJECT WTH PLUME CONTROL
4000 GPM FOR 50 YEARS

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concentrations in the plume exceeding 500 mg/L is reduced to 2.0 and 8.5 square miles in levels B and C, respectively (Table II-2). Over the 50 year period, approximately 121,000 tons of salt are removed from the Equus Beds Aquifer with this management simulation. Additionally, with this scenario only 9,000 tons are pulled into the model area in response to the remediation pumping which is a significant improvement over the other management simulations. Only 7% of the salt removed from the plume is replaced with salt from outside of the model area (Table II-3).

When the plume control pumping rate was raised to 8,000 gpm (simulation 6d), the plume reduction was even more significant as shown in Figures II-28 through II-30. The impacted surface area for chloride concentrations exceeding 500 mg/L is reduced to 1.3 and 6.3 square miles for levels B and C, respectively (Table II-2). The modeling shows that approximately 257,000 tons of salt are removed. However, over 100,000 tons of salt is induced from the south. The net reduction of salt in the study area is 146,000 tons. The percentage of the salt pulled into the model area is 42 percent of the salt removed from the plume area (Table II-3).

These results shows that discharge pumping rate will have to be carefully established in order to obtain opium salt removal efficiency for the entire study area. Also, timing with other pumping stresses or recharge activities will have significant impacts or benefits to the remediation plan.

7. Pilot Study (7a)

A pilot scenario with a total pumping rate of 500 gpm was modeled using the 1996 conditions of the aquifer. Two wells were selected from plume control pumping simulation and pumped at 250 gpm each (Figure II-12). Simulation of the pilot study shows the approximately 21,000 tons of salt would be removed from the system over a 50 year time period.

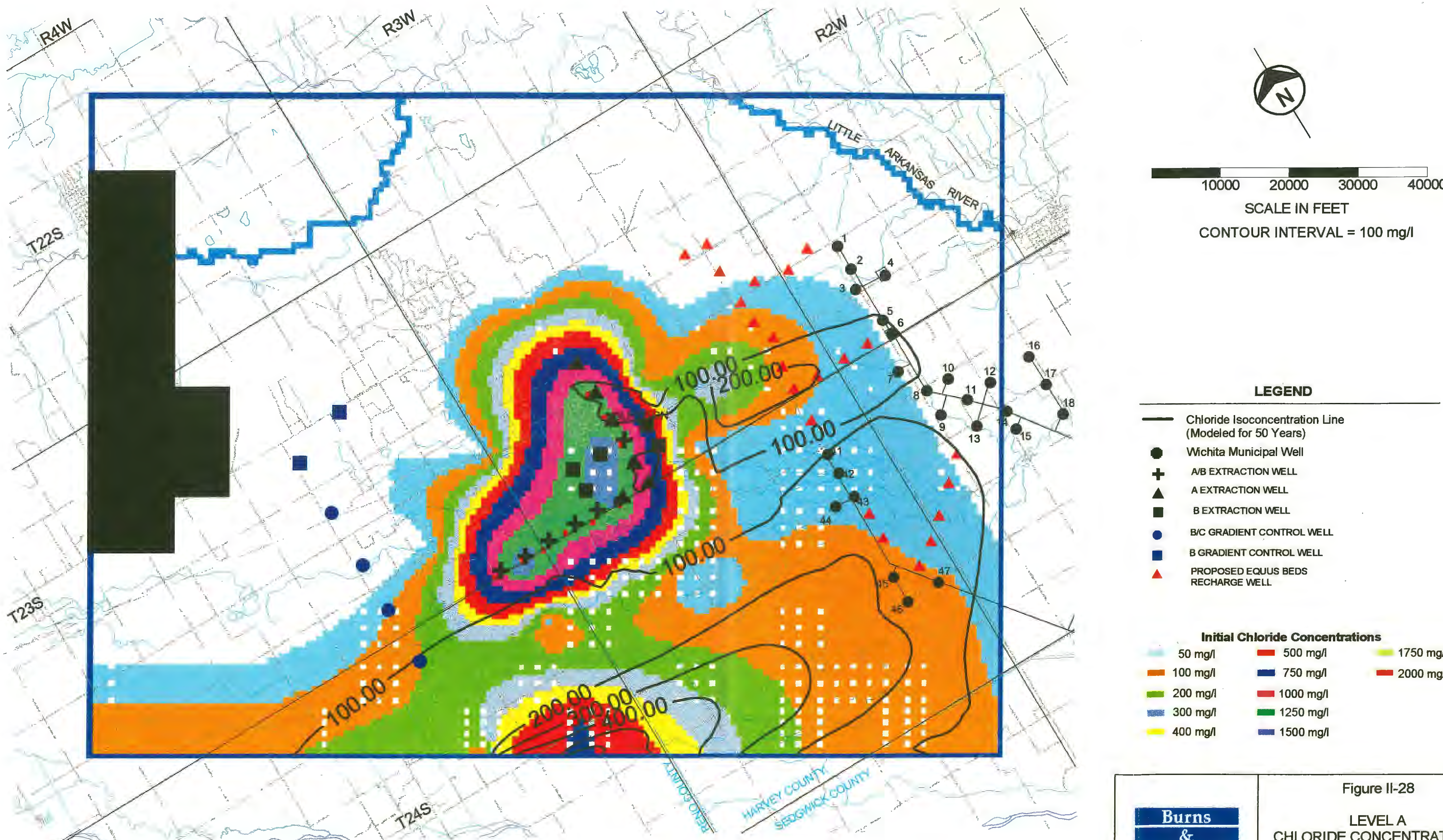

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Figure II-28

LEVEL A
CHLORIDE CONCENTRATIONS
6D EQUUS BEDS RECHARGE
PROJECT WITH PLUME CONTROL
8000 GPM FOR 50 YEARS

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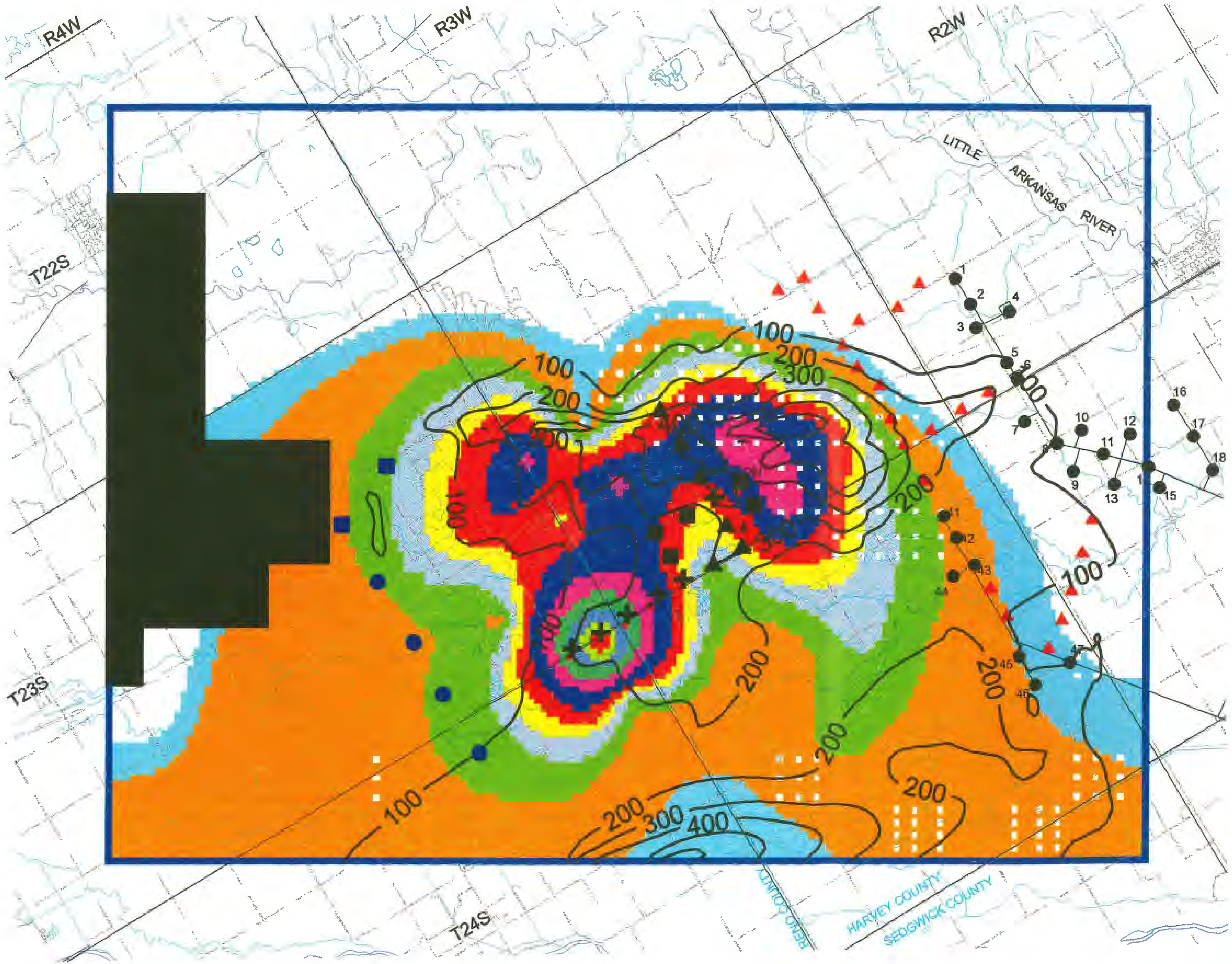

10000 20000 30000 40000

SCALE IN FEET

CONTOUR INTERVAL = 100 mg/l

LEGEND

- Chloride Isoconcentration Line (Modeled for 50 Years)
- Wichita Municipal Well
- A/B EXTRACTION WELL
- A EXTRACTION WELL
- B EXTRACTION WELL
- B/C GRADIENT CONTROL WELL
- B GRADIENT CONTROL WELL
- PROPOSED EQUUS BEDS RECHARGE WELL

1996 Chloride Concentrations

50 mg/l	500 mg/l	1750 mg/l
100 mg/l	750 mg/l	2000 mg/l
200 mg/l	1000 mg/l	
300 mg/l	1250 mg/l	
400 mg/l	1500 mg/l	

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Figure II-29

LEVEL B
CHLORIDE CONCENTRATIONS
6D EQUUS BEDS RECHARGE
PROJECT WITH PLUME CONTROL
8000 GPM FOR 50 YEARS

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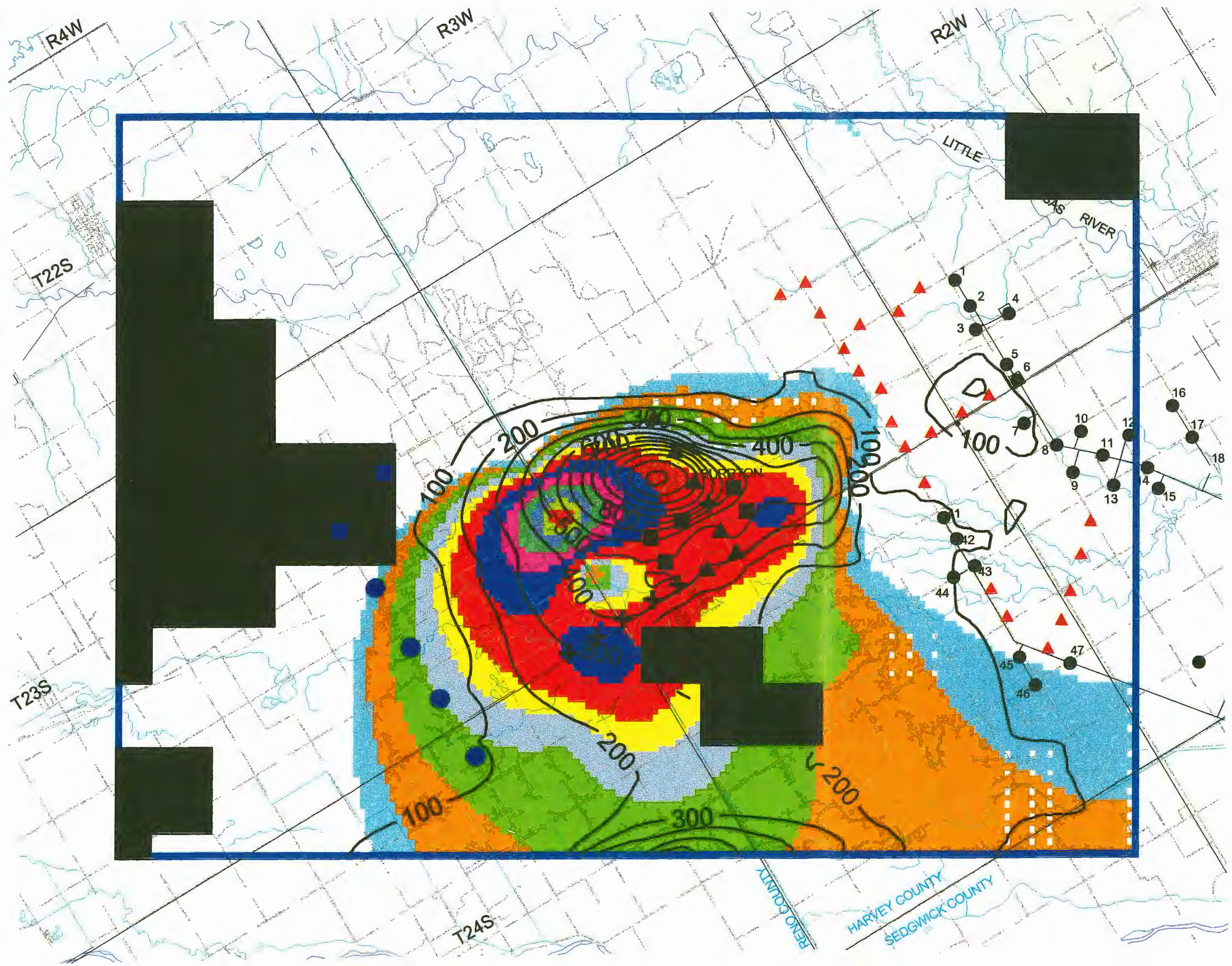

LEGEND

- Chloride Isoconcentration Line (Modeled for 50 Years)
- Wichita Municipal Well
- A/B EXTRACTION WELL
- A EXTRACTION WELL
- B EXTRACTION WELL
- B/C GRADIENT CONTROL WELL
- B GRADIENT CONTROL WELL
- PROPOSED EQUUS BEDS RECHARGE WELL

1996 Chloride Concentrations

50 mg/l	500 mg/l	1750 mg/l
100 mg/l	750 mg/l	2000 mg/l
200 mg/l	1000 mg/l	
300 mg/l	1250 mg/l	
400 mg/l	1500 mg/l	

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Figure II-30

LEVEL C
CHLORIDE CONCENTRATIONS
6D EQUUS BEDS RECHARGE
PROJECT WITH PLLUME CONTROL
8000 GPM FOR 50 YEARS

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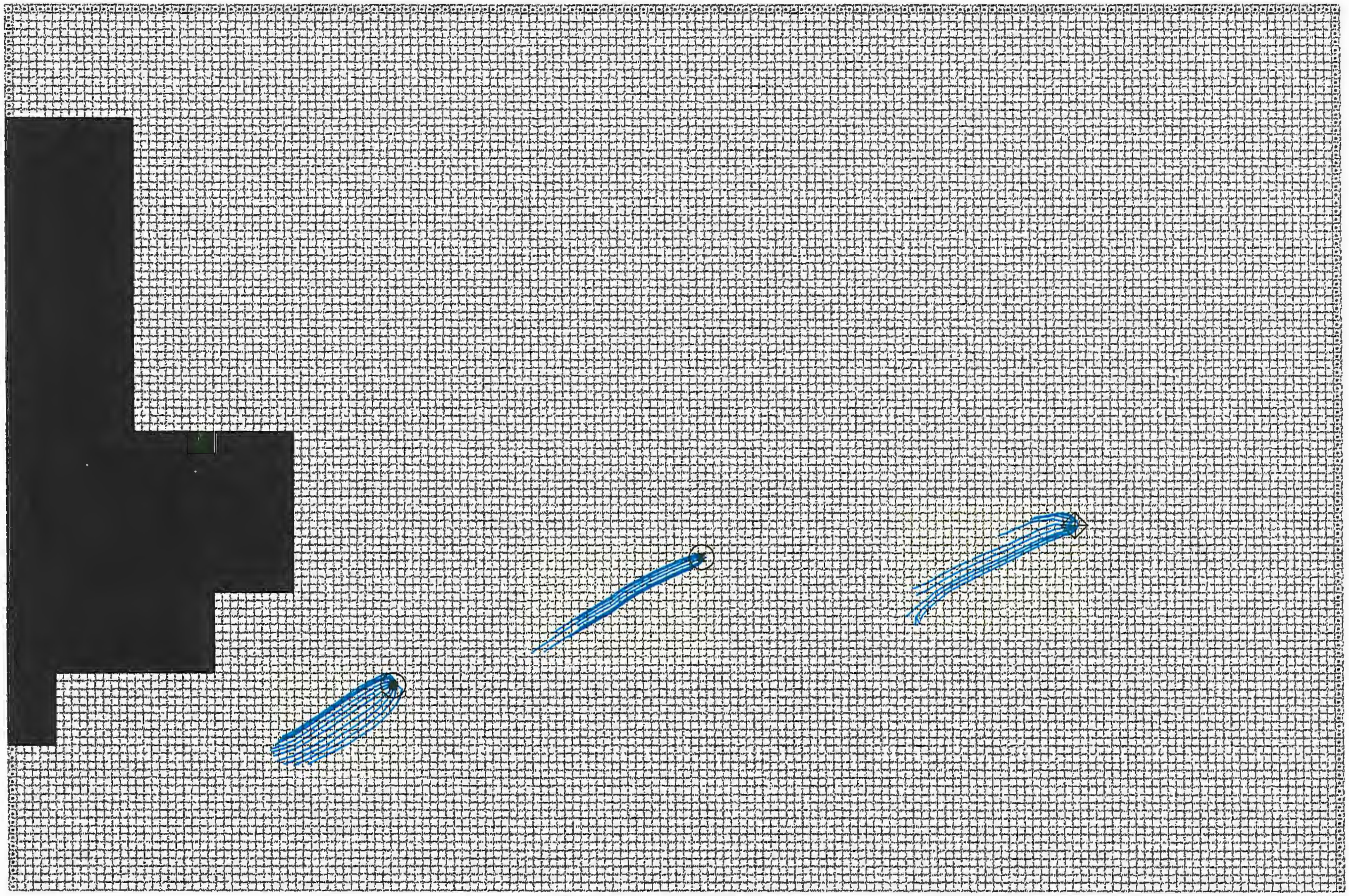
F. PARTICLE TRACKING ANALYSIS

Another USGS computer program was used to evaluate the capture area of plume control wells and the movement of chloride in the vicinity of plume control and municipal wells. The USGS program MODPATH uses the results of the MODFLOW simulations to track the path and time of travel of particles in the groundwater system. Backward tracking of several particles will show the capture area of a well pumping for a specified time period. Because chloride is a "conservative" constituent, a constituent that is not adsorbed or modified by aquifer materials, movement of chlorides will match that of water particles as modeled by the MODPATH program.

Figure II-31 shows the 50-year capture area for typical gradient control wells, "hot spot" extraction wells, and municipal water supply wells. Additionally, a cross-section of the particle tracking from a high capacity municipal supply well, shown in Figure II-32, show water particles migrating to lower layers due to the pumping stress.

* * * * *



LEGEND

- · CONTSANT HEAD BOUNDARY
- ■ NO FLOW CELL
- — PARTICLE TRACE
- ⊙ MUNICIPAL WELL
- ⊗ EXTRACTION WELL
- ⊕ GRADIENT CONTROL WELL

10000 0 10000 20000

S C A L E I N F E E T

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Figure II-31

50 YEAR CAPTURE AREA FOR TYPICAL GRADIENT CONTROL WELL, EXTRACTION WELL, AND MUNICIPAL WELL

CROSS-SECTION ALONG ROW 77

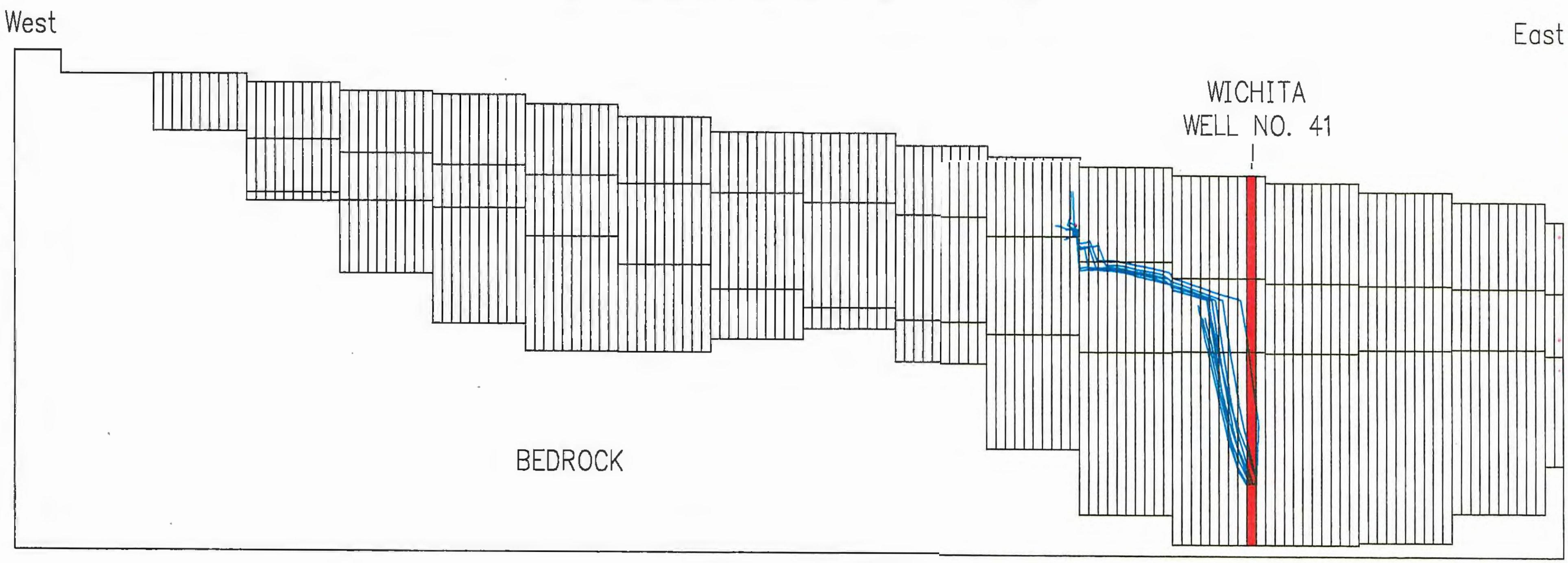

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Figure II-32

MIGRATION OF WATER PARTICLES FROM LEVEL A TO LEVEL C WICHITA WELL NO. 41

Part III - Remediation Technologies

PART III

REMEDIATION TECHNOLOGIES

A. GENERAL

Remediation techniques for the beneficial reuse or disposal of water pumped from plume control wells are evaluated herein. The development of these remedial technologies involve a comprehensive review of existing water quality, establishment of water quality goals for each reuse or disposal technique, and analyses of modeling results to balance water volume and chloride concentration. These reuse or disposal technologies are based on pumping strategies similar to those modeled in the management simulations described in Part II.

B. MEMBRANE TREATMENT PROCESSES

A primary purpose behind the development and continued research of membrane technologies has been desalination of municipal drinking water supplies. Electrodialysis (ED) and reverse osmosis (RO) have been used since the early 1960's in competition with distillation processes. Distillation processes include multistage-flash evaporation, multiple-effect evaporation, and vapor compression. Distillation technologies currently account for approximately 60 percent of the world's desalting capacity, whereas RO and ED respectively account for about 35 and 6 percent.

Over the last 10 years RO treatment capacity worldwide has increased by about 20 to 30 percent, while distillation capacity has decreased about 10 percent. Although there is greater total worldwide desalting capacity by distillation, there is a greater number of treatment plants employing membrane processes. This is due to increased interest in microbial removal, technological improvements and reductions in RO costs relative to distillation. Therefore, only membrane processes are considered further for this evaluation to control costs and maximize water quality and potential beneficial uses.

Several pressure driven membrane processes are applicable for current water treatment standards. These processes include RO, nanofiltration (NF), ultrafiltration (UF) and microfiltration (MF) and are distinguished by varying operating pressures and membrane pore size. Larger pore size results in lower operating pressures. The processes can be ranked by decreasing operating pressures and increasing pore sizes as follows: RO, NF, UF and MF. Only the dense RO membranes are specifically tailored to retain salts and low-molecular-weight solutes as found in groundwater in the Burrton area.

Another membrane technology, electrodialysis (ED), is technically applicable to this project. Electrodialysis is an operation by which ions are driven through ion-selective membranes under the influence of an electrical potential. By alternating cation- and anion-selective membranes in a stacked arrangement with thin channels between them, it is possible to produce alternating channels of fluid that are respectively enriched and depleted in ions. A typical ED application is large-scale production of potable water from brackish water fails to remove significant levels of organics.

The RO process is the preferred over ED for the remediation of chlorides from the groundwater in the study area for the following reasons:

- RO process has superior treatment effectiveness for saline feed water relative to other pressure-driven membrane processes.
- RO has greater organic removal efficiencies compared to ED.
- RO requires less land area and less capital expenditure than ED, for water quality and capacities considered in this report.

1. <u>Reverse Osmosis</u>

The size and cost of a RO system designed to treat water from the extraction wells to meet current drinking water standards depends on the quality and quantity of water to be treated. The assumed water input rate (feed rate) is based on the total pumpage from the extraction well network. Feed water quality is assumed to be the average of available analytical data from 1990 to 1996 from a selected monitoring wells in the immediate vicinity of the extraction well network. The water quality data used for the cost estimates is summarized in Table III-1.

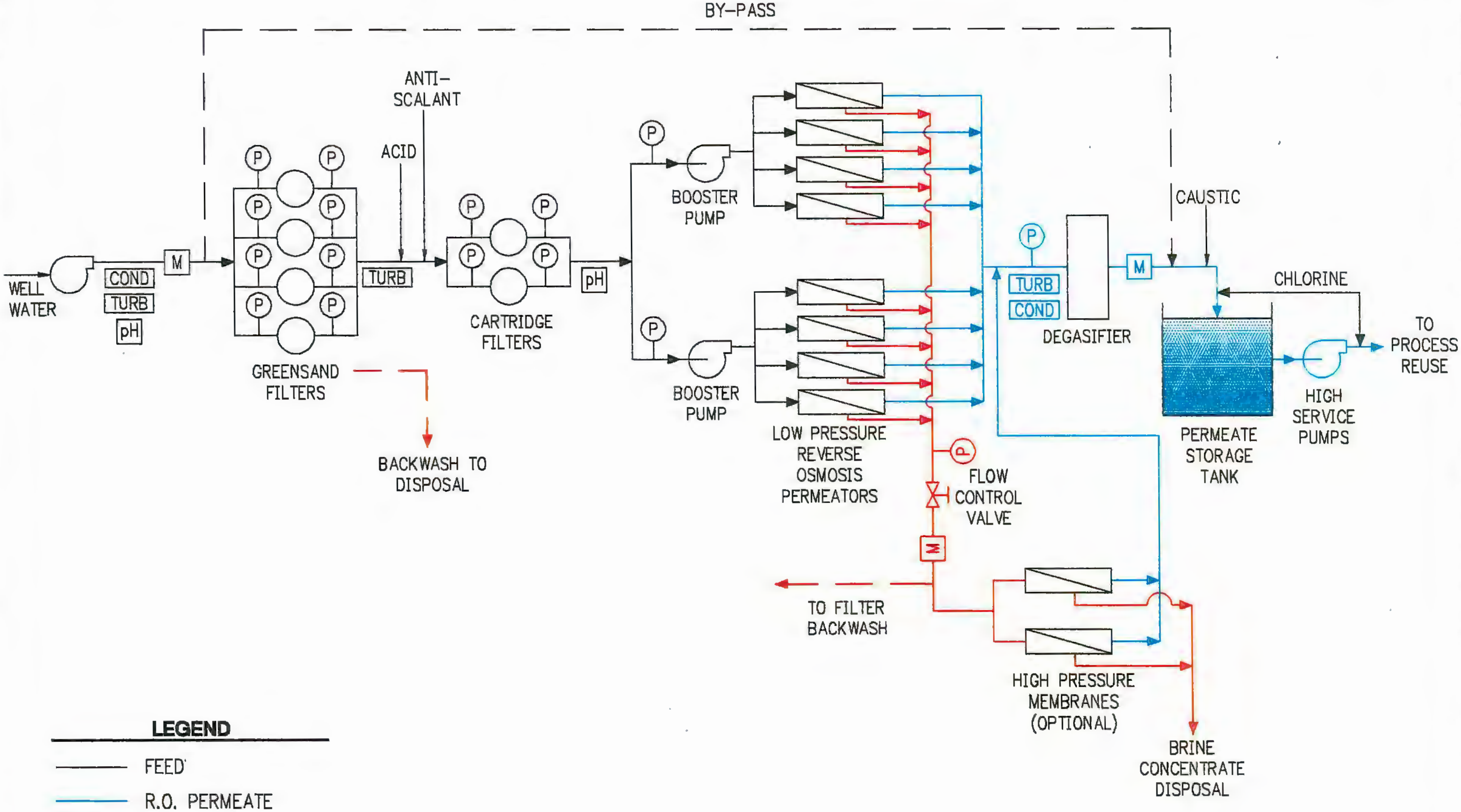
A schematic for an RO treatment system applicable to this project is shown in Figure III-1. Each treatment train of the RO facility would consist of a chemical pre-treatment system, including greensand filters and cartridge filters to remove iron, manganese, and solids, booster pumps to pressurize the feed water, RO permeators, a degasifier, chemical post-treatment units, and various appurtenances. The RO membranes permit only water (permeate), and not dissolved ions, to pass through its pores. Contaminants are left behind in a brine solution or concentrate. The concentrate contains a significantly higher level of dissolved solids than the feed solution, thus requiring additional treatment or disposal.

The water to be treated contains significant levels of iron and manganese and will require pretreatment to prevent rapid RO membrane fouling. Pretreatment will also extend the life of the membranes and reduce maintenance costs. A typical pretreatment process to remove iron, manganese and solids, consists of aeration with greensand filters and 5 to 10 micron cartridge filters followed by acidification.

Table III - 1

RO FEED WATER QUALITY CHARACTERISTICS

Temperature	50 deg. F
Calcium	240 mg/L
Magnesium	105 mg/L
Sodium	500 mg/L
Potassium	7 mg/L
Barium	0.05 mg/L
Iron	30 mg/L
Sulfate	32 mg/L
Chloride	1280 mg/L
Nitrate	0.05 mg/L
Fluoride	0.28 mg/L
TDS	3020 mg/L
pH	7.45
Total Hardness	820 mg/L as $CaCO_3$
Total Alkalinity	150 mg/L as $CaCO_3$
Turbidity (NTU)	42
Specific Conductance	4380



LEGEND

- FEED
- R.O. PERMEATE
- R.O. REJECTS
- (P) PRESSURE GAUGE
- [M] FLOW METER
- [TURB] TURBIDIMETER
- [COND] CONDUCTIVITY METER
- [pH] pH METER

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Figure III–1

REVERSE OSMOSIS SCHEMATIC

a. Waste Minimization (High Pressure Membranes)

The RO concentrate flow rate from the low-pressure membranes is estimated to be 15 to 25 percent of the extraction wells pumping rate or about 75 to 300 gpm. One deep disposal well, discussed below, could potentially accommodate this flow. To further reduce the volume of waste, the RO concentrate could be further treated with use of high pressure RO membranes or by using wastewater evaporators.

The treatment system would still require one deep disposal well. The capital and operating costs for the addition of a high pressure membrane system or evaporator is not justified for this project at the flow rates reflected by the modeling scenarios. The use of these systems may be re-evaluated in the event higher volumes of concentrate are produced that would require an additional deep disposal well or if disposal well flow rates are less than expected.

b. Reverse Osmosis Plant Pilot Study

The Kansas Department of Health and Environment (KDHE) typically require a pilot plant study to verify the performance of an RO installation used for the treatment of a potable water supply. These studies serve to determine actual membrane performance, required chemical feed rates, optimal flux, ion rejection and recovery. Treatment of chloride-impacted groundwater to drinking water standards is considered a tested and proven technology. Recent discussions with KDHE indicated a willingness of the agency to accept a 1-year performance bond from the RO vendor as a substitute for a pilot study. KDHE would establish parameters indicative of success, in agreement with the recipient of the RO-treated water.

C. BENEFICIAL REUSE

The greatest potential for reuse of all or part of the water from the extraction or gradient control wells is for municipal use. Presently, there is little potential in the study area for industrial reuse of the recovered high chloride water. Additionally, potential use of the water for oil field flooding operations is limited. Therefore, blending of permeate from the RO process or pumpage from the gradient control wells with an existing municipal water supply was evaluated for beneficial reuse. The use of this flow by the City of Wichita and smaller nearby communities may be considered, depending on future water needs and requirements.

1. Public Water District

Several communities within the vicinity of the study area, including Sedgwick, Halstead and Newton, are currently considering a consolidation of water rights into a public water district. This consolidation would be centered at the Mission treatment facility, located about eight miles southwest of Newton. Transmission mains would interconnect the facility to nearby communities and the north Newton well field. The total average day water demand for Sedgwick, Halstead and Newton is currently estimated to be less than 5 million gallons per day (MGD) and is not expected to grow significantly during the next decade.

2. City of Wichita

The City of Wichita is performing studies to implement their Integrated Local Water Supply Plan (Plan). The Plan was adopted by Wichita in 1993 and has been slightly modified based on ongoing studies. Current studies indicate that the City will need additional water sources to meet a projected demand of 98.5 MGD in Year 2010. The Plan uses raw water from the following local sources. Associated chloride concentrations are also listed:

Water Source	Chloride Level (mg/L)
Cheney Reservoir	160 to 190
Equus Beds Aquifer	50 to 75
Local Well Field Expansion	Being studied
Local (E&S) Well Field	200
Bentley Reserve Well Field	350 to 800
Little Arkansas River	5 to 350

Under the City's Plan pumpage from the Equus Beds and Bentley Reserve Well Fields would be blended at a 3 to 1 ratio to maintain a chloride concentration of less than 200 mg/L in the finished water. The City's maximum desired finished water chloride concentration is 200 mg/L and their goal is 125 to 150 mg/L.

Recharge of the Equus Beds Aquifer in the City's well field area is a key component of the Plan. Above-base flow from the Little Arkansas River will be recharged and stored in the aquifer for recovery during dry periods. It is recognized by the City that the recharge project will also help reduce the migration of salt water from the Arkansas River and the Burrton area. Recharge activities, as currently planned, include recharge of treated above-base flow surface water through recharge basins and recharge of induced river infiltration through recharge basins and recharge wells. It is anticipated that the transmission and distribution of the recharge water will be through the existing well field pipeline system.

Potential addition of high chloride water from the Burrton plume management pumping to the Wichita aqueduct for City use will have to be carefully evaluated for the final design. The Equus Beds Well Field must continue to operate as a water supply source during recharge activities and water used for recharge must maintain a relatively low chloride content. The addition of high chloride water into the well field piping near the northwest section of the system could create control problems during recharge activities. To minimize impact to the Equus

Beds Aquifer, the high chloride water would require treatment to reduce chlorides to about 50 mg/L while recharge operations are in progress.

Chloride levels of pumpage from the extraction and/or gradient control well system could be allowed to exceed 50 mg/L if the flow could be directed to Wichita without being recharged into the aquifer or interfering with well field operation. The impacts of using water with chlorides of 125 to 1,500 mg/L are listed in Table III-2 and are based on the City's desired chloride concentration limit of 150 and the maximum limit of 200 mg/L for the blended finished water. Assumptions of the analysis are as follows:

- Wichita service area average day demand in Year 2010 is 98.5 MGD.
- Cheney Reservoir provides about 60 percent of demand at a chloride concentration of 175 mg/L .
- Equus Beds provides about 30 percent of demand at a chloride concentration of 60 mg/L.
- Local Well Field provides about 10 percent of demand at a chloride concentration of 200 mg/L.

Review of this data shows that if the City maintains a finished water chloride target of 150 mg/L the maximum flow rate that could be accepted at an influent concentration of 500 mg/L would be about 1.4 MGD (about 970 gpm). If the City would accept a higher finished water chloride target, larger volumes of Burrton plume control water could be used.

Table III-2
Potential Usable Flow (MGD)
from
Burrton Plume Control Wells

Control Well Influent	Wichita Finished Water Chloride Target	
Chloride Conc. (mg/L)	150 mg/L	200 mg/L
125	-*	-*
250	2.8	22.4
500	1.4	11.2
1,000	0.7	5.6
1,500	0.5	3.7

* If chloride concentration is less than the City's finished water target the potential usable flow is limited to control well system capacity.

Additionally, water providers experience seasonal variations in water demand which will influence the amount of remediation water that can be used. During the winter, with lower system demands, the amount or chloride concentration of the remediation water may have to be lowered to not exceed finished water target limit. In the summer, with higher demands, larger volumes of water or higher concentration may be feasible without exceeding the desired water quality limits.

Management simulation 3c assumes a total discharge rate 4,000 gpm (5.8 MGD) with the flow evenly divided between gradient control wells and extraction wells. The contaminant transport model indicated that the initial average concentration for the entire flow would be about 620 mg/L. After approximately three years, the concentration would fall below 500 mg/L. The modeled chloride concentrations (mg/L) of discharges from the gradient control and extraction wells are as follows:

	Gradient Control	Extraction	Blended
Initial	175	1,100	620
1 Year	135	1,000	570
5 Year	105	790	450

D. DISPOSAL TECHNIQUES

Disposal options for extraction well pumpage include deep well injection and discharge to surface water. Only deep well injection of brine concentrate from the RO process is considered. Other disposal options for RO concentrate, including mechanical evaporators, crystallizers and spray dryers are precluded from in-depth evaluation due to high capital costs associated with systems in this capacity range. Discharge of extraction well pumpage and/or RO concentrate into a local public owned treatment works (POTW) is not a feasible disposal option because of discharge water quantity and quality.

1. Deep Well Injection

Deep well injection is suitable for relatively small volumes of particularly high chloride concentrations, including RO concentrate and pumpage from extraction wells. The chloride levels from the extraction wells or RO concentrate may be to high for blending with an existing municipal water supply or discharge to a stream using a National Pollutant Discharge Elimination System (NPDES) permit.

Injection wells are a disposal option in which liquid wastes are injected into deep porous subsurface rock formations. Careful design and operation of injection wells is important to prevent movement of wastes into or between underground sources of drinking water.

Brine wastes related to oil field operations can be disposed of in Class II wells. These wells are regulated by Kansas Corporation Commission (KCC). A schematic of a typical Class II disposal well is shown in Figure III-2. Class II includes wells that inject fluids:

- that are brought to the surface in connection with conventional natural gas storage operations or conventional oil or natural gas production and may be commingled with wastewater from gas plants that are an integral part of production operations, unless those waters are classified as a hazardous waste at the time of injection.

- for enhanced recovery of oil or natural gas.

- for storage of hydrocarbons that are liquid at standard temperature and pressure.

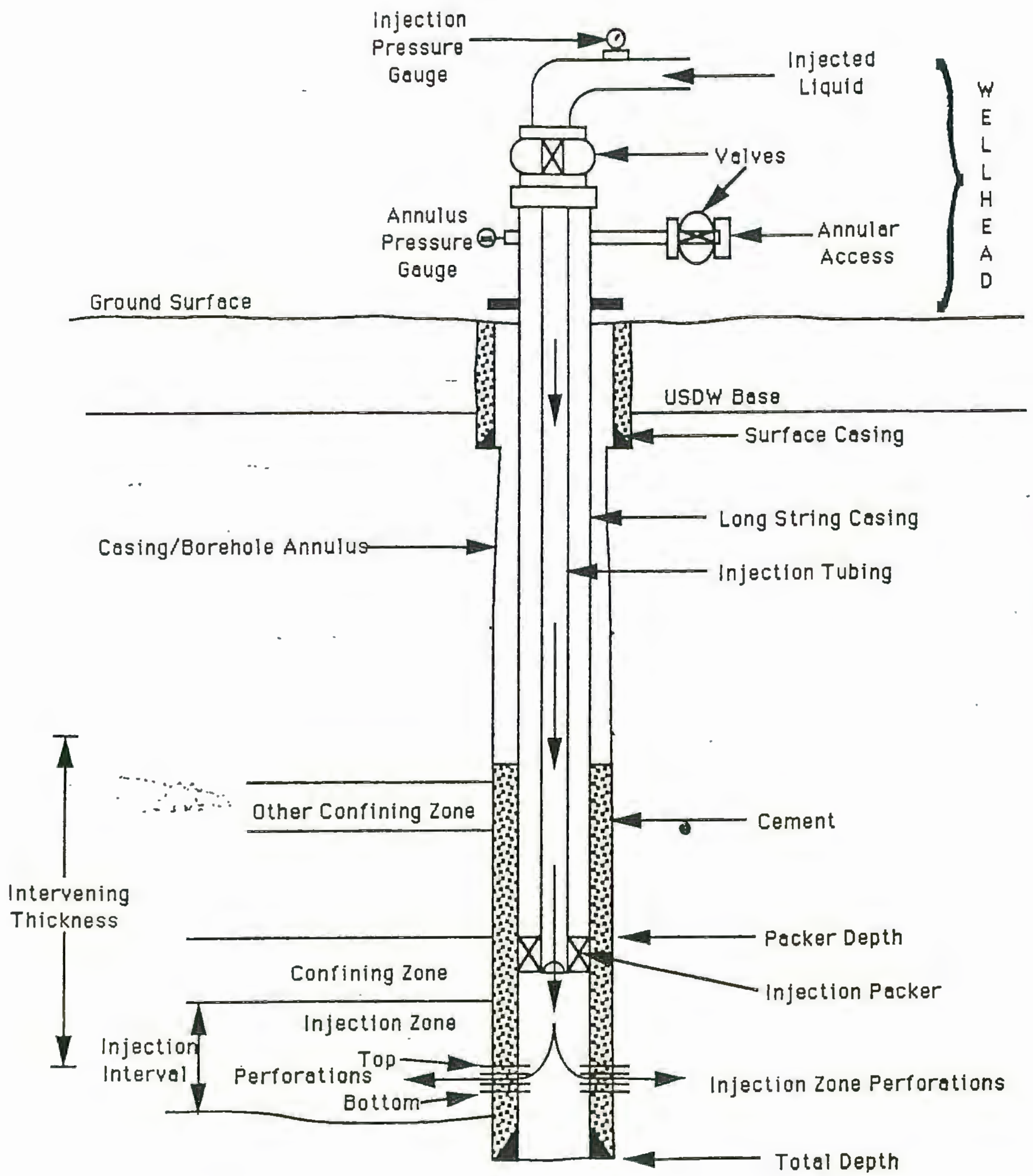

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FIGURE III-2

SCHEMATIC OF CLASS II INJECTION WELL

SOURCE: KCC, 1997

In discussions concerning this project, EPA has confirmed that the RO concentrate resulting from treating groundwater containing oil field brine, in addition to high chloride water from the extraction wells, can be disposed in Class II wells regulated by KCC.

These wells would be constructed to depth of about 4,500 feet deep into the Arbuckle Formation. Typical capacity of a Class II well ranges from about 15,000 - 20,000 barrels per day (440 - 580 gpm). No spacing limitations are known. Additional pump head is not required because adequate head is provided by the water column within the well. Surge tanks are required to provide a manageable, continuous flow rate into a disposal well.

Due to the significant capital costs of this option, the minimization of disposal volume is prudent. This minimization can be achieved by placing extraction wells only were necessary within the zones of highest chloride concentrations in the plume.

2. Discharge to Surface Water

The Arkansas River is the nearest significant surface water body to the extraction/gradient control well system. The median chloride concentration of the water in the river near this project area is about 630 mg/L. Because of the river's high flow volume and high chloride concentration, the river was evaluated to receive discharge from Burrton plume control and extraction wells.

A NPDES permit will be required by KDHE to discharge all or a portion of the pumpage, provided that the discharge meets all applicable requirements of the Clean Water Act (CWA) relating to effluent limitations, water quality standards and implementation plans, new source performance standards, toxic and pretreatment effluent standards, inspections, monitoring and entry provisions.

Treatment may be deemed necessary to stabilize the concentrate or to remove constituents harmful to the receiving water flora and fauna or both. The most common treatment requirement is aeration to increase the DO concentration. The chloride concentrations of the discharged water allowable under an NPDES permit are anticipated to be less than concentrations within the Arkansas River.

Pending regulatory reviews, chloride levels allowable through future NPDES permit renewals are likely to become more stringent. Discharge to the Arkansas River may currently be allowed considering the quality of the receiving water. Allowable chloride discharge standards are currently under review and are to be finalized by Year 2001. Permits issued under current standards would then be required to meet those new standards.

Chloride concentrations in the Arkansas River generally increase downstream of Great Bend Kansas, located approximately 60 miles upstream of Hutchinson. The source of elevated chloride concentrations is thought to be salt marshes on tributaries to the Arkansas River upstream of Hutchinson. Within the study area, water from the Arkansas River is classified as brackish or salty.

Chloride concentrations from samples of Arkansas River water collected near Hutchinson, Haven, Mount Hope, Bentley, and Maize the median generally ranges from 620 to 640 mg/L (Myers, 1996).

Blending of pumpages from extraction and gradient control wells can be considered to lower chloride concentrations and provide a more continuous discharge rate to surface water.

3. Evaporation Ponds

Solar evaporation is a well-established method for removing water from concentrated brines. Solar evaporation ponds have been used for centuries to recover salt (sodium chloride) from seawater. Evaporation ponds for concentrated brine disposal are appropriate primarily for regions of the United States having a relatively warm, dry climate with high evaporation rates, level terrain, and low land costs. There are several advantages associated with evaporation ponds which include simple construction, low maintenance, low energy requirements and little operator attention.

Despite the advantages of evaporation ponds, state permitting and other problems can limit their application. Evaporation ponds were not included as a remedial alternative for several reasons: (1) the study area is not characterized by particularly high year-round evaporation rates and the pumping is relatively high throughout the year, (2) KDHE is more reluctant to permit these structures because they generally fail and leak, contaminating the underlying groundwater.

* * * * *

Part IV - Remediation Alternatives

PART IV

REMEDIATION ALTERNATIVES

A. GENERAL

Five remediaton alternatives, based on the modeled management simulations, were developed to provide control and removal of the chloride plume, treatment of the pumpage (if applicable) and disposal and/or transmission for beneficial use of the water. Capital and annual costs are estimated and used to compare the alternatives. The layout of the gradient control and extraction wells are similar for each alternative. Each alternative includes a preliminary well and pipeline plan. These plans were developed using well locations correspond to management simulations with interceptor and gradient control wells used in the subregional model. The sizing of alternative components is based on a 4,000 gallons per minute (gpm) flow rate from the entire control well system. Additionally, individual component costs can be used to modify the evaluated alternatives. The alternatives are summarized as follows:

- **Alternative 1:** Pumpage from the extraction well network, 2,000 gpm, is continuously directed to four Class II disposal wells. Effluent from the gradient control wells, 2,000 gpm, are pumped to a connection at the Wichita Well Field and blended with the Wichita water supply and is shown in Figure IV-1.

- **Alternative 2:** Pumpage from the extraction well network, 2,000 gpm, is continuously directed to four Class II disposal wells. Gradient control well discharge is continuously directed to an outfall along the Arkansas River and is shown in Figure IV-2.

- **Alternative 3:** Pumpage from the extraction and gradient control networks are blended and discharged at an outfall along the Arkansas River and are shown in Figure IV-3.

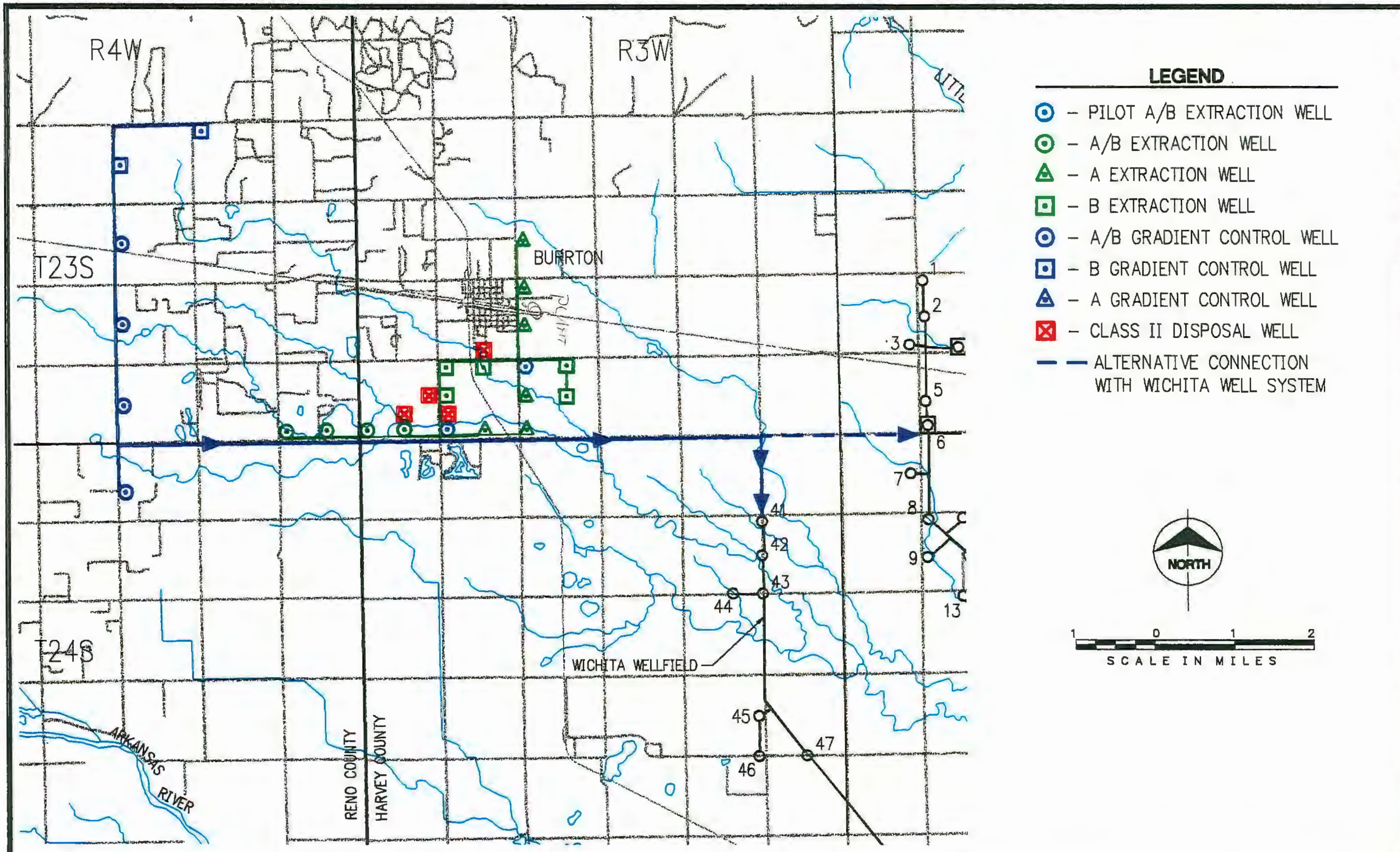

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Figure IV – 1

ALTERNATIVE 1

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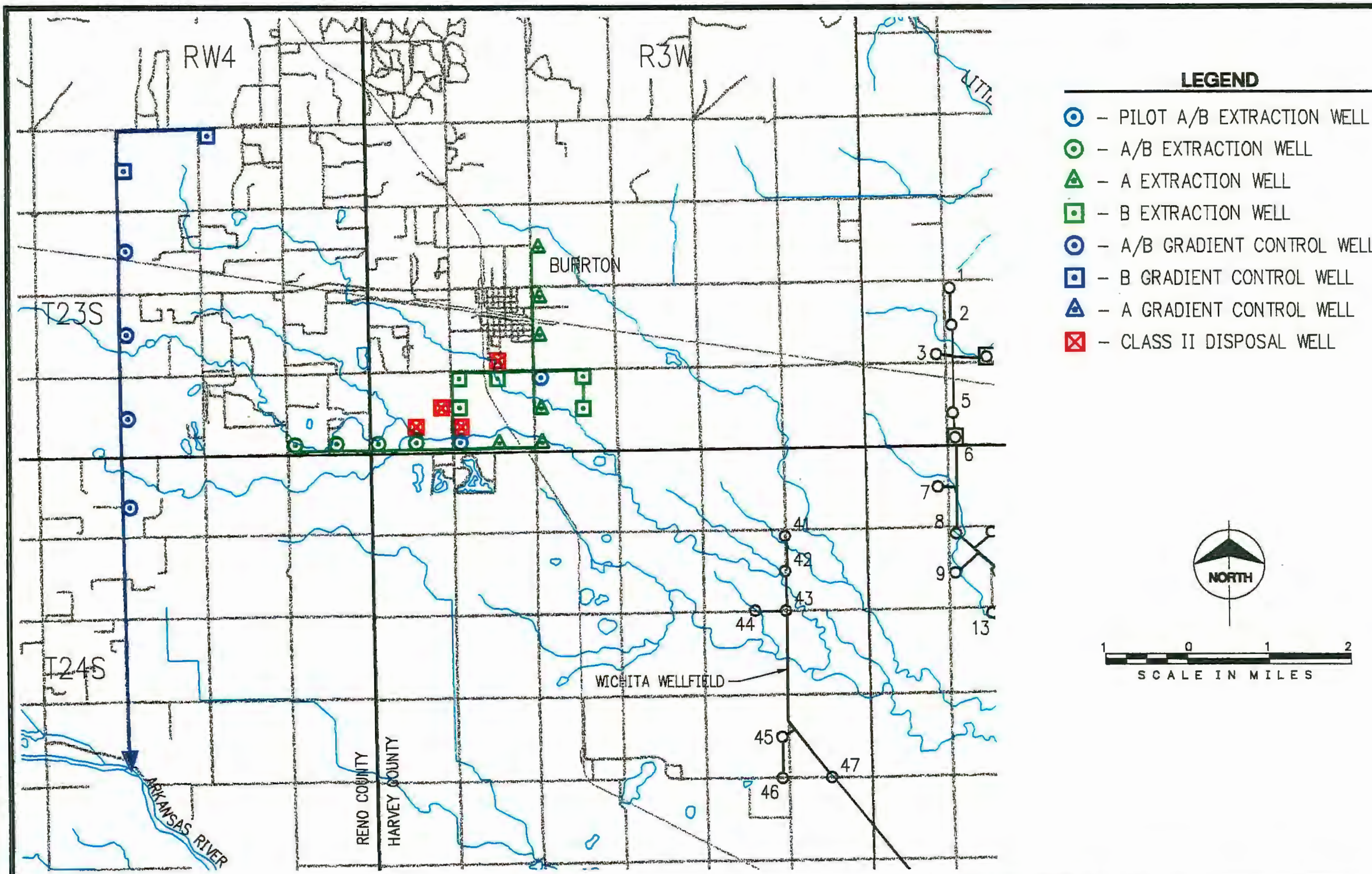

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Figure IV – 2

ALTERNATIVE 2

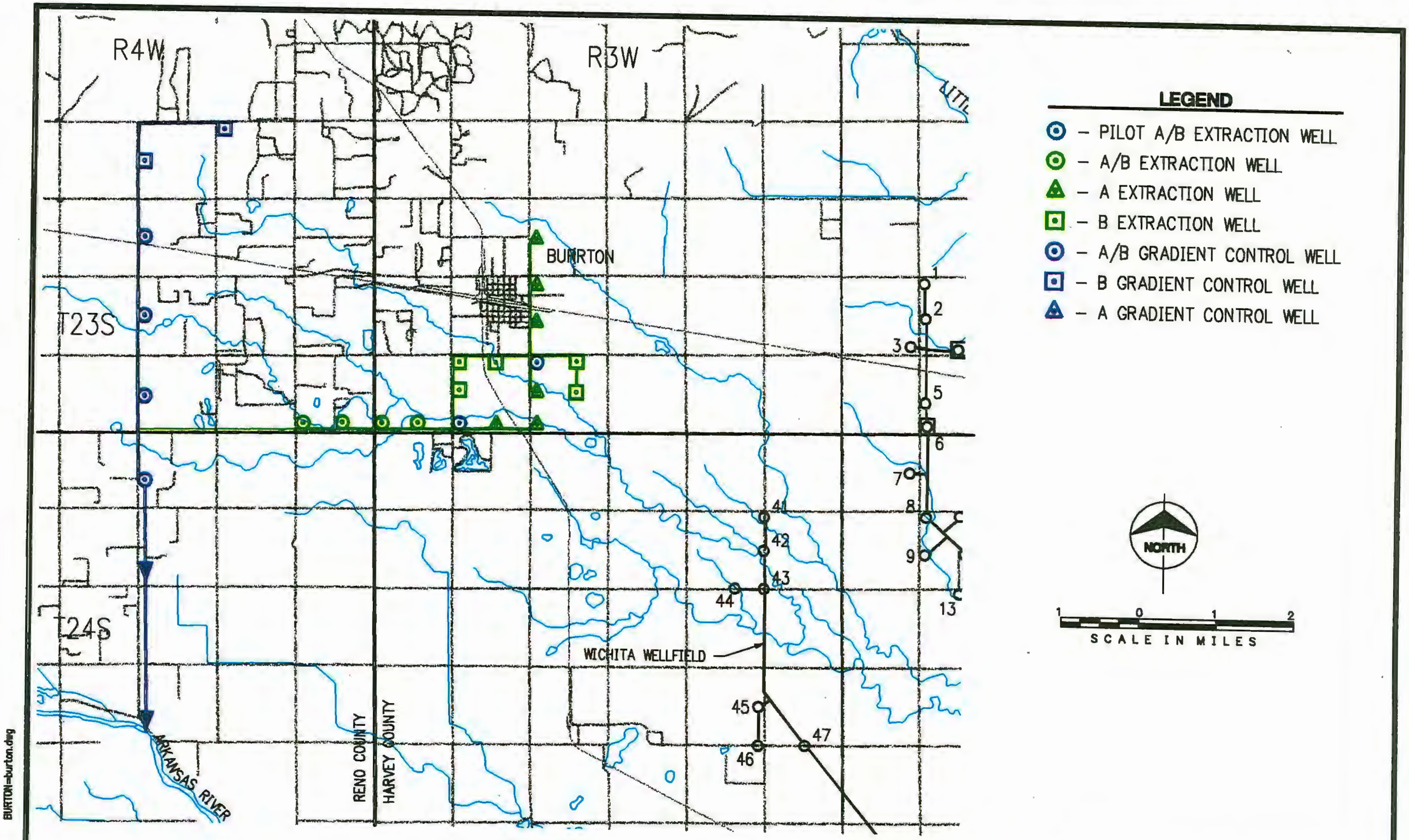

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Figure IV – 3

ALTERNATIVE 3

- **Alternative 4:** Pumpage from the extraction well network, 2,000 gpm, is routed to a reverse osmosis (RO) treatment plant. RO concentrate is disposed via one Class II disposal well. RO permeate and gradient control pumpage is blended and discharged at a connection with the Wichita Well Field and is shown in Figure IV-4.

- **Alternative 5:** Pumpage from the extraction well network, 2,000 gpm, is routed to an RO treatment plant. RO concentrate is disposed via one Class II disposal well. RO permeate and gradient control pumpage is blended and discharged to four one-half acre recharge basins and is shown in Figure IV -5.

After initial evaluation of the alternatives, costs were developed a pilot-scale installation of two 250 gpm extraction wells with disposal of pumpage to one Class II disposal well and is shown in Figure IV-6.

Alternatives 1, 4 and 5 require a recipient for blended or RO treated water. The proximity of the potential recipient affects total pipeline costs. Two water suppliers have been identified as potential recipient of the reclaimed water. These are the proposed public water supply district and the City of Wichita. The public water district interconnect is assumed to be at Halstead which is several mile further east that a connection with the existing Wichita well field pipeline. Additionally, the demands of the public water district may not be large enough to utilize the entire volume of water reclaimed from the Burrton brine plume. The City of Wichita has the capacity and potential demand to utilize all of the projects flows on a continuous basis provided the water quality does not interfere with recharge or normal water supply operations. Therefore, the City of Wichita is considered to be the recipient of water from the gradient or extraction well networks of each applicable remedial alternative for costing purposes.

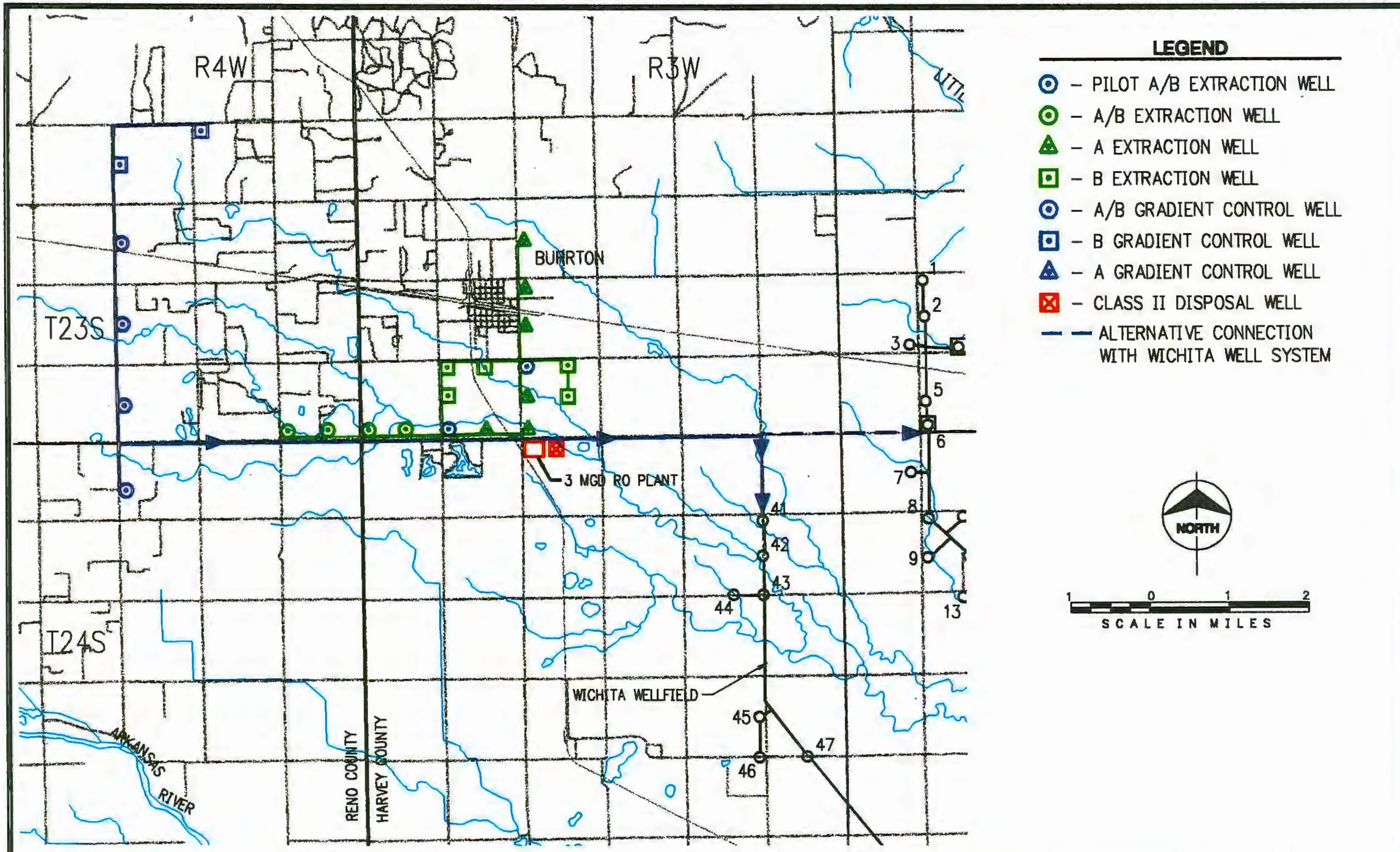

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Figure IV – 4

ALTERNATIVE 4

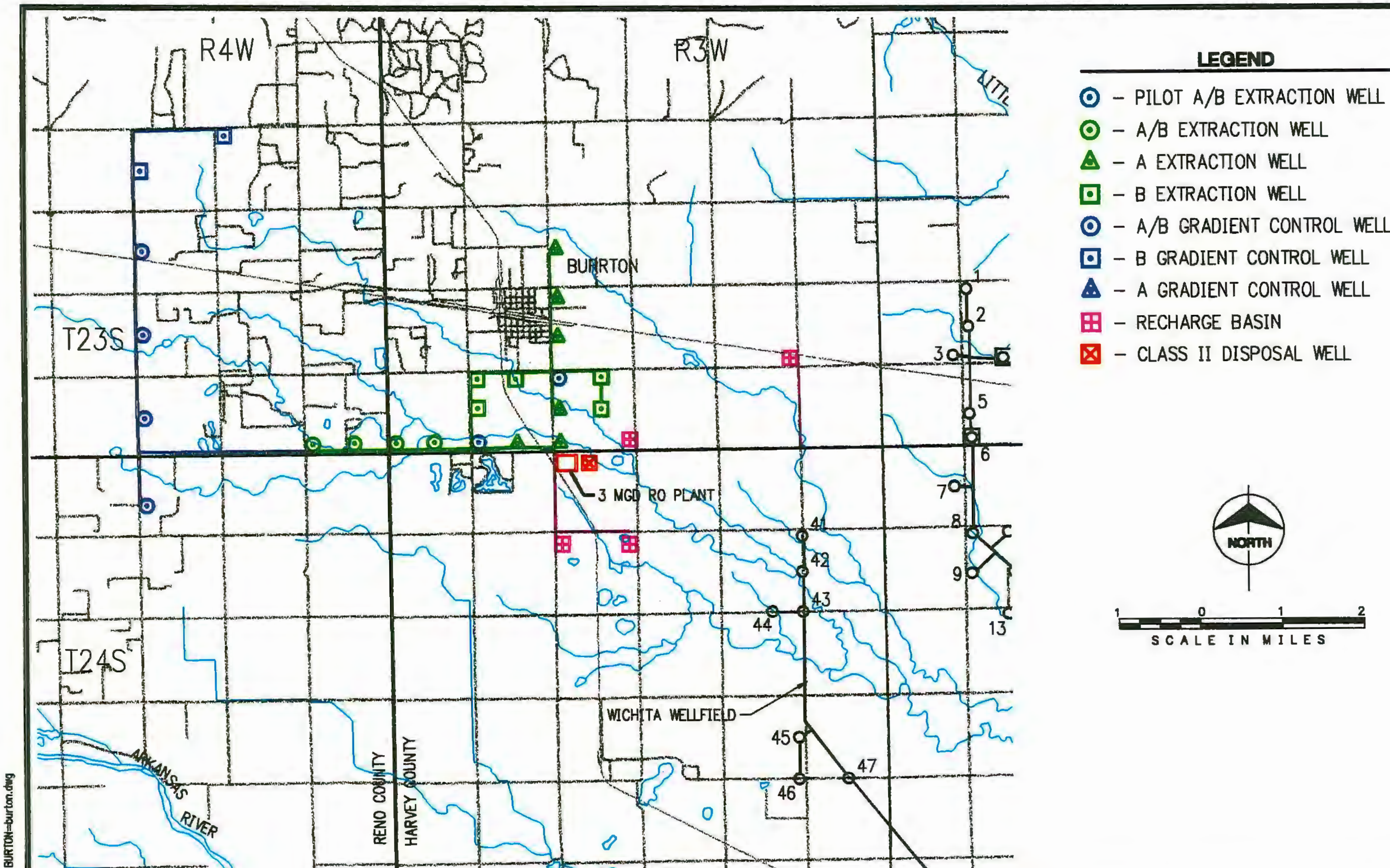

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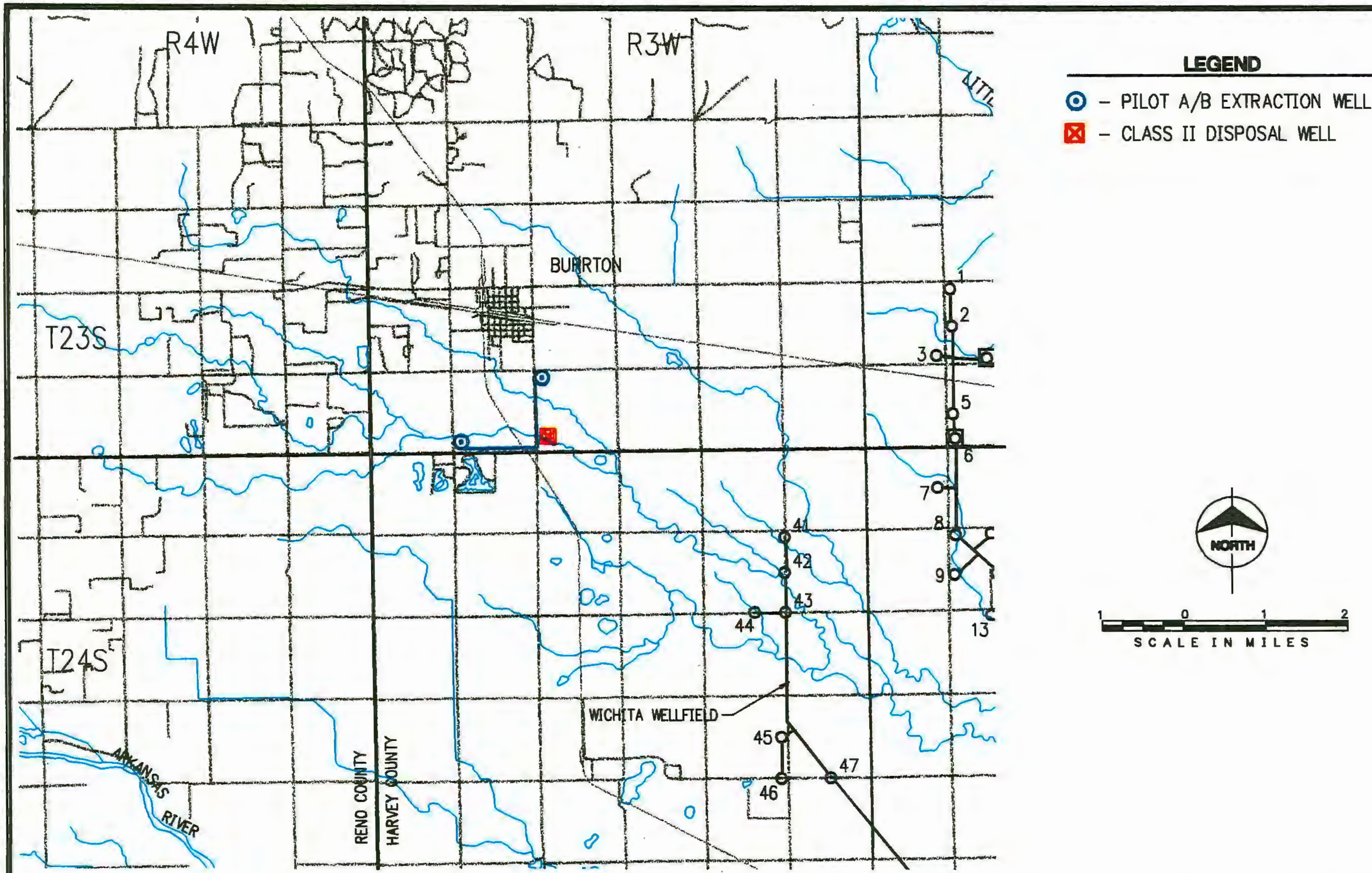
Figure IV – 5

ALTERNATIVE 5



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Burns & McDonnell

Figure IV – 6

ALTERNATIVE 6
PILOT PROJECT

B. CAPITAL COSTS FOR ALTERNATIVE COMPONENTS

The alternatives listed above have many similar components including extraction wells, gradient control wells, Class II disposal wells and an RO treatment plant. Costs for these components are used to develop capital and present worth costs for each alternative. The individual components are discussed below.

1. Extraction Wells

Capital costs for the extraction wells corresponding to the management simulations using plume interceptor wells (2a, 2b and 2c) are summarized in Table IV-1. Based on the modeling simulations, six wells are screened into Level A, five wells are screened into Level B, and six wells are screened into both levels. The approximate pumping rate for wells screened in one level is 90 gpm and wells screened in both levels are estimated to pump 180 gpm from the groundwater plume. Pump motor sizing vary among the remedial alternatives because of different pumping head requirements; therefore additional motor costs to achieve required pumping heads at the wells was priced separately for each alternative.

The capital costs for the plume control interceptor wells are the same for all remedial alternatives.

2. Gradient Control Wells

Capital cost estimates for gradient control wells, screened into Level B and/or C are given in Table IV-2. The maximum pumping rate modeled in the management simulations using gradient control wells include two wells at 200 gpm screened in Level B and four wells pumping 400 gpm screened in both Levels B and C. Motor costs were adjusted for each alternative because of different pumping head requirements.

Table IV -1

CAPITAL COSTS FOR EXTRACTION WELLS:

	Quantity	Unit Cost	Total cost
90 and 180 gpm wells, 50' and 200' TD			
Construction, development and testing of 10" x 24" x 50' well,* (screened into Level A)	6	22,000	132,000
Construction, development and testing of 10" x 24" x 200' well* (screened into Level B)	5	49,000	245,000
Construction, development and testing of 12" x 30" x 200' well* (screened into Level A and B)	6	54,000	324,000
Provision and installation of 10" pitless unit, pad and piping to valve vault	17	5,500	94,000
Provision and installation of 12" pitless unit, pad and piping to valve vault	17	7,000	119,000
Provision and installation of valve vault with 4" piping including a flow meter, check valve and gate valve.	17	7,000	119,000
Provision and installation of 90 gpm at 50' TDH submersible pump, discharge column, cable, check valve, airline and control panel, motor, (50 TD).	6	5,600	34,000
Provision and installation of 90 gpm at 50' TDH submersible pump, discharge column, cable, check valve, airline and control panel, motor (200' TD).	5	6,200	31,000
Provision and installation of 180 gpm at 50' TDH submersible pump, discharge column, cable, check valve, airline and control panel, motor (200' TD).	6	7,500	45,000
SUBTOTAL:			**1,143,000**
Contingency (20%)			229,000
SUBTOTAL:			**1,372,000**
Engineering, Legal, Surveying, etc.			206,000
TOTAL CAPITAL COSTS:			**1,578,000**

Note: * wells designated by (casing diameter) x (bore diameter) x (total well depth)

COSTS.WK4

Table IV -2

CAPITAL COSTS FOR GRADIENT CONTROL WELLS:

	Quantity	Unit Cost	Total cost
200 and 400 gpm wells, 200' average TD			
Construction, development and testing of 12" x 30" x 200' well,* 200 gpm, (screened into Level B)	2	53,000	106,000
Construction, development and testing of 18" x 36" x 200' well,* 400 gpm, (screened into Level B and C)	4	70,000	280,000
Provision and installation of 12" pitless unit, pad and piping to valve vault	2	7,000	14,000
Provision and installation of 18" pitless unit, pad and piping to valve vault	4	15,750	63,000
Provision and installation of valve vault with 4" piping including flow meter, check valve and gate valve	2	7,000	14,000
Provision and installation of valve vault with 6" piping including flow meter, check valve and gate valve	4	7,500	30,000
Provision and installation of 200 gpm at 200' TDH submersible pump, discharge column, cable, check valve, airline and control panel, motor, (200 TD).	2	11,500	23,000
Provision and installation of 400 gpm at 200' TDH submersible pump, discharge column, cable, check valve, airline and control panel, motor, (200 TD).	4	16,500	66,000
SUBTOTAL:			**596,000**
Contingency (20%)			119,000
SUBTOTAL:			**715,000**
Engineering, Legal, Surveying, etc.			107,000
TOTAL CAPITAL COSTS:			**822,000**

Note: * wells designated by (casing diameter) x (bore diameter) x (total well depth)

Capital costs for the gradient control pipeline network are also included in Alternatives 1 through 5.

3. Class II Disposal Wells

Capital costs for a Class II disposal wells are summarized in Table IV-3. These costs, provided by KCC, are actual costs incurred for the recent construction of a Class II well in Kansas. Operation and maintenance (O & M) costs for a disposal well are minimal. Annual maintenance is estimated at about $200 for periodic leak testing and minor repairs. Operational costs are included within overall well field and pipeline operations for each alternative that uses this disposal option (Alternatives 1, 2, 4 and 5).

The costs developed in Table IV-3 are for deep well disposal of extraction well discharge water in Alternatives 1, 2 and 6 and for RO concentrate in Alternatives 4 and 5.

4. Reverse Osmosis Plant

Estimated capital costs for an RO plant to treat extraction well discharge water is listed in Table IV-4. The feed water flow rate is assumed to reflect the total pumpage of 2,000 gpm from the extraction well network of modeled in the management simulations. The RO plant is sized at a nominal 3 MGD. Assumptions regarding the costs are as follows:

- RO feed water characteristics are indicated in Table III-1 and conservatively assumed to remain constant throughout the life of the remediation.

- high pressure membranes to treat RO concentrate are not cost effective at a 3 MGD plant influent feed rate.

Table IV -3

CAPITAL COSTS FOR CLASS II DISPOSAL WELLS:

	Quantity	Unit Cost	Total cost
Class II disposal wells (4)			
Drilling costs:			
Contractor supervision	40	300	12,000
Footage (7" diameter)	15,800	6	99,000
Labor	480	185	89,000
Drill bits, etc.			20,000
Rental--slimhole drill string			42,000
Water hauling services			10,000
Excavation/earthwork			4,000
Drilling fluid disposal/waste management			
Closed mud system			20,000
Drilling fluids/technical services			19,000
Trucking			6,000
Wireline services			10,000
Cement materials and services			
Conductor string			4,000
Surface pipe string			10,000
Casing			
20" conductor string			6,000
13 3/8" surface pipe			46,000
Trucking			8,000
Completion Costs:			
Casing			
7" disposal string			134,000
4 1/2" plastic lined tubing			76,000
Misc. connections and heads			6,000
Misc. Services			8,000
Trucking			8,000
Labor for casing crew			10,000
Cement materials and services (7" disposal string)			10,000
Wireline services (cased hole)			12,000
Acid treatment			8,000
Oil field rental--misc. equipment			6,000
Supervision	20	350	7,000
Site restoration			2,000
Surge tank/misc. equipment:			
250-barrel closed top fiberglass tank (12' x 12')	12	3,350	40,000
Concrete pad/misc. plumbing fittings			6,000
SUBTOTAL:			**738,000**
Contingency (5%)			37,000
SUBTOTAL:			**775,000**
Engineering, Legal, Surveying, etc.			116,000
TOTAL CAPITAL COSTS:			**891,000**

COSTS.WK4

Table IV -4

CAPITAL COSTS FOR 3-MGD REVERSE OSMOSIS PLANT:

	Quantity	Unit Cost	Total cost
Greensand filters			270,000
R.O. membrane,cartridge filters, pressure units and booster pumps			1,400,000
RO startup and warranty			45,000
Degasifier			400,000
Cleaning system for R.O. membranes			65,000
Chlorine contact chamber/clearwell			100,000
Chemical storage/feed system			150,000
Process piping			200,000
SCADA, instrumentation and controls (RO plant only)			100,000
Building and sitework (incl. HVAC, plumbing and electrical)			200,000
Yard piping and raw water piping and connections			300,000
High service pumps with motors to municipal water supply system			50,000
SUBTOTAL:			**3,280,000**
Contingency (20%)			656,000
SUBTOTAL:			**3,936,000**
Engineering, Legal, Surveying, etc.			590,000
TOTAL CAPITAL COSTS:			**4,526,000**

COSTS.WK4

- principle components of the system are as itemized in Table IV-4.

- the permeate will meet all applicable federal and state drinking water standards and will have a maximum chloride effluent concentration of 125 mg/L.

- a pilot study will not be necessary, due to the tested and proven status of the RO process for the treatment of chloride impacted feed water.

The assumed water treatment goal of 125 mg/L was chosen so that the total pumpage from the extraction well could be accommodated by potential water suppliers in the area as a public water supply. A lower treatment goal will be required if the blended water is used for recharge or if a higher permeate flow rate is deemed necessary.

An RO plant is a component of both Alternatives 4 and 5.

5. <u>Recharge Basins</u>

Only Alternative 5 includes recharge basins to replenish the Equus Beds Aquifer with water derived from this plume control project. The effects of recharge basins on plume migration control were modeled, assuming 75 % of the 2,000 gpm of pumpage from the gradient control well system was recharged downgradient of the plume. Four recharge basins, each occupying one-half acre of area and receiving 375 gpm of flow were located where groundwater currently has chloride concentrations of 100 to 200 mg/L. Recharge into the proposed areas may require less stringent treatment goals, due to the higher ambient chloride concentrations in the aquifer at this location, in comparison to ambient chloride levels closer to the Wichita Well Field.

Capital costs for the four recharge basins are itemized in Table IV-5. These costs are based on information from the Equus Beds Groundwater Recharge Demonstration Project.

6. Pipelines

Each of the remedial alternatives includes a unique network of transmission and header pipelines, depicted in Figures IV-1 through IV-6. The primary criterion of limiting flow velocities to 5 ft/sec or less was utilized for the selection or pipeline diameters for the preliminary plans of each alternative. The preferred pipeline material for header pipes and transmission mains is PVC, for standard diameters up to 16 inches, due to superior corrosion resistance and cost effectiveness. Unit costs for common pipe sizes were determined from rates currently applicable to the study area. These unit costs are summarized below:

- 6" PVC: $8/LF
- 8" PVC: $10/LF
- 12" PVC: $15/LF
- 16" PVC: $20/LF
- 24" ductile iron pipe (DIP): $50/LF

The easement unit cost was estimated at $1/ft. Costs for air release valves were estimated under the assumption that one valve would be placed per quarter mile of pipeline.

C. REMEDIAL ALTERNATIVES COST ESTIMATES

Estimates of capital costs, operation, maintenance, energy and equipment replacement costs are itemized for each of the remedial alternatives 1 through 5 in Tables IV-6 through IV-10. These costs for the pilot system are shown in Table IV-11. Annual costs, involving energy and labor rates, were obtained from sources local to the study area.

Table IV -5

CAPITAL COSTS FOR RECHARGE BASINS:

	Quantity	Unit Cost	Total cost
Earthwork and materials for recharge basins (4 @ 1/2 acre/basin)	4	70,000	280,000
Slope protection	4	50,000	200,000
Control building (at each basin)	4	20,000	80,000
Control building piping and valves	4	15,000	60,000
Yard piping	4	10,000	40,000
Misc. site work	4	10,000	40,000
Monitoring well (6 wells, 70' deep)	6	2,500	15,000
Piezometers (15 piezometers, 70' deep)	15	700	11,000
Fencing	4	1,800	7,000
SCADA	4	25,000	100,000
SUBTOTAL:			**833,000**
Contingency (20%)			167,000
SUBTOTAL:			**1,000,000**
Engineering, Legal, Surveying, etc.			150,000
TOTAL CAPITAL COSTS:			**1,150,000**

COSTS.WK4

Table I V -6

ALTERNATIVE COST SUMMARY

ALTERNATIVE 1:

Extraction wells to Class II disposal wells
Gradient control wells to Wichita well field

Capital costs:	**Quantity**	**Unit Cost**	**Total cost**
Extraction wells (17)			1,143,000
Class II disposal wells (4)			738,000
Gradient control wells (6)			596,000 ←
Add for required total dynamic pump head (TDH)			59,000
Transmission and header pipelines:			
4" diameter pipe and fittings	10,600	7	74,000
6" diameter pipe and fittings	21,200	8	170,000
8" diameter pipe and fittings	21,200	10	212,000
12" diameter pipe and fittings	18,600	15	279,000
16" diameter pipe and fittings	48,000	6 ~~20~~	960,000
4" connections from wells to header (50' per well)	550	7	4,000
6" connections from wells to header (50' per well)	1,150	8	9,000
Easement	121,300	1	121,000
Air/Vacuum valves	92	2,000	184,000
Interconnect/meter vault			35,000
Operations building (incl. HVAC, electrical, plumbing, site work)			100,000
SCADA, instrumentation and controls			730,000
SUBTOTAL:			**5,414,000**
Contingency (20%)			1,083,000
SUBTOTAL:			**6,497,000**
Engineering, Legal, Surveying, etc.			975,000
TOTAL CAPITAL COSTS:			**7,472,000**
Annual O & M Costs:			
Well field and pipeline operations (1 FT supervisor, 2 FT assistants)			225,000
Well field and pipeline maintenance (by contractors)			30,000
Energy costs ($0.10/kwh)			275,000
Lab fees			8,000
TOTAL O & M COST ($/yr.)			**538,000**

Table IV - 7

ALTERNATIVE 2:

Extraction wells to Class II disposal wells
Gradient control wells to Arkansas River

Capital costs:	Quantity	Unit Cost	Total cost
Extraction wells (17)			1,143,000
Class II disposal wells (4)			738,000
Gradient control wells (6)			596,000
Add for required total dynamic pump head (TDH)			30,000
Transmission and header pipelines:			
4" diameter pipe and fittings	10,600	7	74,000
6" diameter pipe and fittings	21,200	8	170,000
8" diameter pipe and fittings	18,600	10	186,000
12" diameter pipe and fittings	21,200	15	318,000
16" diameter pipe and fittings	17,500	20	350,000
4" connections from wells to header (50' per well)	550	7	4,000
6" connections from wells to header (50' per well)	1,150	8	9,000
Easement	90,800	1	91,000
Air/Vacuum valves	69	2,000	138,000
Outfall			25,000
Operations building (incl. HVAC, electrical, plumbing, site work)			100,000
SCADA, instrumentation and controls			730,000
SUBTOTAL:			**4,702,000**
Contingency (20%)			940,000
SUBTOTAL:			**5,642,000**
Engineering, Legal, Surveying, etc.			846,000
TOTAL CAPITAL COSTS:			**6,488,000**
Annual O & M Costs:			
Well field and pipeline operations (1 FT supervisor, 2 FT assistants)			225,000
Well field and pipeline maintenance (by contractors)			30,000
Energy costs ($0.10/kwh)			190,000
Lab fees			8,000
TOTAL O & M COST ($/yr.)			**453,000**

Table IV - 8

ALTERNATIVE 3:

Extraction and gradient control wells to Arkansas River

Capital costs:	Quantity	Unit Cost	Total cost
Extraction wells (17)			1,143,000
Gradient control wells (6)			596,000
Add for required total dynamic pump head (TDH)			37,000
Transmission and header pipelines:			
4" diameter pipe and fittings	10,600	7	74,000
6" diameter pipe and fittings	18,600	8	149,000
8" diameter pipe and fittings	10,600	10	106,000
12" diameter pipe and fittings	18,600	15	279,000
16" diameter pipe and fittings	21,200	20	424,000
24" diameter pipe and fittings	20,000	50	1,000,000
4" connections from wells to header (50' per well)	550	7	4,000
6" connections from wells to header (50' per well)	1,150	8	9,000
Easement	101,300	1	101,000
Air/Vacuum valves	77	2,000	154,000
Outfall			25,000
Operations building (incl. HVAC, electrical, plumbing, site work)			100,000
SCADA, instrumentation and controls			730,000
SUBTOTAL:			**4,931,000**
Contingency (20%)			986,000
SUBTOTAL:			**5,917,000**
Engineering, Legal, Surveying, etc.			888,000
TOTAL CAPITAL COSTS:			**6,805,000**
Annual O & M Costs:			
Well field and pipeline operations (1 FT supervisor, 2 FT assistants)			225,000
Well field and pipeline maintenance (by contractors)			30,000
Energy costs ($0.10/kwh)			240,000
Lab fees			8,000
TOTAL O & M COST ($/yr.)			**503,000**

Table IV - 9

ALTERNATIVE 4:

Extraction and gradient control wells to RO (with bypass) to Wichita
RO concentrate to disposal well

Capital costs:	**Quantity**	**Unit Cost**	**Total cost**
Extraction wells (17)			1,143,000
Class II disposal well (1)			185,000
Gradient control wells (6)			596,000
Add for required total dynamic pump head (TDH)			35,000
3-MGD R.O. plant with bypass			3,280,000
Transmission and header pipelines:			
4" diameter pipe and fittings	8,000	7	56,000
6" diameter pipe and fittings	16,000	8	128,000
8" diameter pipe and fittings	13,300	10	133,000
12" diameter pipe and fittings	18,600	15	279,000
16" diameter pipe and fittings	21,200	20	424,000
24" diameter pipe and fittings	26,500	50	1,325,000
4" connections from wells to header (50' per well)	550	7	4,000
6" connections from wells to header (50' per well)	1,150	8	9,000
Easement	105,300	1	105,000
Air/Vacuum valves	80	2,000	160,000
Interconnect/meter vault			35,000
SCADA, instrumentation and controls			730,000
SUBTOTAL:			**8,627,000**
Contingency (20%)			1,725,000
SUBTOTAL:			**10,352,000**
Engineering, Legal, Surveying, etc.			1,553,000
TOTAL CAPITAL COSTS:			**11,905,000**
Annual O & M Costs:			
Well field and pipeline O & M			705,000
Well field and pipeline maintenance (by contractors)			30,000
Energy costs ($0.10/kwh)			240,000
Lab fees			8,000
R.O. plant O & M			660,000
TOTAL O & M COST ($/yr.)			**1,643,000**

Table IV - 10

ALTERNATIVE 5:

Extraction and gradient control wells to RO (with bypass) to recharge
RO concentrate to disposal well

Capital costs:	**Quantity**	**Unit Cost**	**Total cost**
Extraction wells (17)	17		1,143,000
Class II disposal well (1)	1		185,000
Gradient control wells (6)	6		596,000
Add for required total dynamic pump head (TDH)			35,000
3-MGD R.O. plant with bypass			3,280,000
Recharge basins (4)	4		280,000
Transmission and header pipelines:			
4" diameter pipe and fittings	8,000	7	56,000
6" diameter pipe and fittings	16,000	8	128,000
8" diameter pipe and fittings	29,200	10	292,000
12" diameter pipe and fittings	29,200	15	438,000
16" diameter pipe and fittings	21,200	20	424,000
24" diameter pipe and fittings	5,300	50	265,000
4" connections from wells to header (50' per well)	550	7	4,000
6" connections from wells to header (50' per well)	1,150	8	9,000
Easement	110,600	1	111,000
Air/Vacuum valves	84	2,000	168,000
Interconnect/meter vault			35,000
SCADA, instrumentation and controls			855,000
SUBTOTAL:			**8,304,000**
Contingency (20%)			1,661,000
SUBTOTAL:			**9,965,000**
Engineering, Legal, Surveying, etc.			1,495,000
TOTAL CAPITAL COSTS:			**11,460,000**
Annual O & M Costs:			
Well field, pipeline, and recharge basin O & M			870,000
Well field and pipeline maintenance (by contractors)			30,000
Energy costs ($0.10/kwh)			260,000
Lab fees			8,000
R.O. plant O & M			660,000
TOTAL O & M COST ($/yr.)			**1,828,000**

Table IV - 11

PILOT-SCALE EXTRACTION WELL SYSTEM

Capital costs:	**Quantity**	**Unit Cost**	**Total cost**
Extraction wells (2); 250 gpm each	2	84,000	168,000
Class II disposal well (1)	1		185,000
Transmission and header pipelines:			
6" diameter pipe and fittings	10,600	8	85,000
4" connections from wells to header (50' per well)	100	7	700
Easement	10,700	1	11,000
Air/Vacuum valves	8	2,000	16,000
Operations building (incl. HVAC, electrical, plumbing, site work)			100,000
SCADA, instrumentation and controls			81,000
Monitoring wells	6	2,500	15,000
SUBTOTAL:			**662,000**
Contingency (20%)			132,000
SUBTOTAL:			**794,000**
Engineering, Legal, Surveying, etc.			119,000
TOTAL CAPITAL COSTS:			**913,000**
Annual O & M Costs:			
Well operations (1 FT supervisory)			65,000
Well field and pipeline maintenance (by contractors)			35,000
Energy costs ($0.10/kwh)			15,000
Lab fees			8,000
TOTAL O & M COST ($/yr.)			**123,000**

COSTS.WK4

Operational costs are estimated to employ one to four full-time employees, depending on the alternative, to monitor the well field, pipelines, collect samples, oversee maintenance, and monitor a Supervisory Control and Data Acquisition (SCADA) system. Operational and energy costs comprise the majority of annual expenditure for the alternatives. The capital and annual costs for the five alternative and the pilot installation are summarized below:

	Total Capital Costs	Total Annual Costs
Alternative 1	$7,470,000	$538,000
Alternative 2	$6,486,000	$453,000
Alternative 3	$6,803,000	$503,000
Alternative 4	$11,903,000	$1,643,000
Alternative 5	$10,275,000	$1,828,000
Pilot Installation	$642,000	$123,000

The high costs estimated for Alternatives 1 through 5 indicate that these options may be cost prohibitive. Therefore, no further cost analysis (i.e., present worth calculations) was performed. Groundwater modeling demonstrates that the pumpage rates used in these alternatives is not adequate to completely remediate the Burrton brine plume; therefore, complete plume remediation is likely to cost several times those given in the above table.

Because of the high preliminary costs estimates for the evaluated alternatives, KCC requested that a cost estimate be developed for a pilot installation. The pilot installation is intended as a initial step to begin remediation and develop additional information, including better definition of aquifer parameters and chemical composition of the groundwater, needed for a more precise design of a larger remediation system.

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Part V - Conclusions and Recommendations

PART V

CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

Brine contamination of the Equus Beds Aquifer in the Burrton Intensive Groundwater Use Control Area (IGUCA) covers a very large area. Approximately 22 square miles in the vicinity of Burrton is underlain by water with chloride levels greater than the MCL of 250 mg/L. Review of previous investigations, analysis of computer modeling for this study, discussions from the first project meeting with the local water authorities provide the basis for the following conclusions.

1. The water quality of the Equus Beds Aquifer is generally very good with chloride levels ranging from 10 to 55 mg/L.

2. Several natural and man-caused sources of salt threaten the water quality of the Equus Beds Aquifer. Overdevelopment and pumping in excess of the aquifer's safe yield has increased migration of existing high chloride water and has induced movement of outside sources of chlorides into the aquifer.

3. The leading edge of the Burrton chloride plume has reached several of the municipal wells operated by the City of Wichita. Wichita Well Nos. 43 and 44 have chloride levels above 100 mg/L.

4. If no action is taken, the plume will continue to migrate to the east and deeper into the aquifer in response to the groundwater flow and aquifer pumping stresses from irrigation and municipal demands. The peak chloride concentrations will decrease as the plume is diluted. However, modeling shows that large areas, in excess of 11 square miles, will continue to have groundwater with chloride levels in excess of 500 mg/L.

5. Even with the evaluated plume management scenarios, a large chloride plume with concentrations of 100 to 1000 mg/L will reach downgradient irrigation wells and more of the City of Wichita's wells in the next 50 years; however, the size of the impacted area will be reduced and the peak concentration will be reduced. The use of interceptor wells as determined by the US Bureau of Reclamation (USBR) only slows the impact of the plume on the City of Wichita Well Field. This is also the case with many of the management simulations modeled for this study which combines the use of gradient control wells and extraction wells.

   The management simulations using recharge basins downgradient of the present location of the plume provide little additional control over the chloride plume at the pumping rates evaluated because of large downgradient pumping stresses.

6. The maximum salt removal rate modeled by the USBR interceptor well layout (simulation 2c) and the management simulation 4c from this study (a combination of gradient control wells and extraction wells) is about 130,000 to 170,00 tons of salt over the 50 year simulation period. This represents approximately 7 to 9 percent of the salt that is estimated to have entered the aquifer from past oil field operations. Even with these simulations, significant migration of the plume toward the Wichita Well Field will continue to occur.

7. Higher pumping rates will remove greater amounts of salt; however, increased groundwater gradients will induce high chloride water flow from the Arkansas River or additional subsurface brine from the deeper bedrock valley. In some modeling scenarios, the amount of salt removed was completely replaced by salt entering the model area from the Arkansas River or subsurface sources with no net chloride improvement in the study area.

8. Previous modeling studies by the Kansas Geological Survey (KGS) concluded that pumping rates of 90 cubic feet per second (cfs) for three years followed by pumping rates of 55 cfs thereafter was required to completely control the Burrton oil field brine (Heidari, 1987). Pumping and disposing of this volume of contaminated groundwater was considered in the KGS report as not practical and would induce substantial flow of high chloride water from the Arkansas River and bedrock valleys.

9. The aquifer recharge program being investigated by the City of Wichita with state and federal agencies is found to be a significant factor in the management of the Burrton salt plume. Higher water levels provided through such a recharge project reduces the groundwater gradient which will slow the migration of the salt plume. Slower migration of the plume allows extraction wells to be more efficient. The higher water levels will also reduce the amount of salt entering the system from the Arkansas River during remediation pumping.

10. Downgradient pumping stresses appears to have significant impacts on the migration of the Burrton salt plume. Management or reduction of downgradient pumping may be a second significant factor in the management of the Burrton chloride plume, although specific scenarios were not evaluated as part of this investigation. Replacement of some downgradient municipal with upgradient diversion from the gradient control well is expected to have additional significant impacts in slowing the plume.

11. The gradient control wells used in modeled management simulations withdraw groundwater with relatively low chloride concentrations. Initially, the chlorides are approximately 300 to 500 mg/L and decline to ambient levels. This water requires little, if any treatment prior to beneficial use. Extraction wells may have

initial concentrations of near 1,500 mg/L. Use of this water would require treatment or dilution with larger amounts of potable water prior to use.

12. The conclusions from the groundwater modeling for this study are based on the model flow assumptions which use relatively wide-spread data and are based the updated USBR model. Additional geologic data, aquifer information, and chloride concentration information would allow the model to be modified to more accurately represent the study area for detailed design of remediation systems.

13. Reverse osmosis (RO) is the preferred treatment technology for removing chlorides from the groundwater in the study area. The low concentration permeate from the RO process could be used beneficially by blending with a municipal water supply or as recharge into the aquifer to act as a barrier to the migration of the plume. The RO concentrate could be disposed of through deep well injection.

14. The treated water from the RO process and/or dilute brine from gradient control or extractions wells could be blended into a municipal water system for beneficial use. The City of Wichita is a near by municipal water supply system with flows large enough to dilute moderate amounts of high chloride water for potable use. The City of Wichita has a desired finished-water chloride limit of 150 mg/L. Up to 1.4 MGD of plume control water at a chloride concentration of 500 mg/L could be used and not exceed the desired maximum finished water chloride limit. Larger amounts of plume control water could be used if the average chloride content is reduced by blending or treatment.

15. Recharge of the RO permeate into the aquifer would act to raise water levels in the aquifer and act as a barrier to slow migration of the plume. Water recharged into areas along the edge of the plume may require less treatment due to the

higher ambient chloride concentrations in these areas resulting in lower treatment costs than if the water were used for a public water supply. Recharge at locations close to the plume would have a greater effect on local groundwater; however, only recharging treated high-chloride water or gradient control water will not have a significant impact in controlling the plume.

16. Five remediation alternatives were considered to develop comparative cost estimates. The capital costs for the five evaluated alternatives ranged from $6,486,000 to $11,903,000. The costs for these alternatives were based on the 4,000 gpm total pumping rate for the management of the plume.

17. A pilot study would provide additional information about the aquifer and the chloride concentrations both in the plume and in the extracted groundwater. In addition, the pilot study would provide information to develop a larger scale RO treatment system, including membrane performance, chemical feed rates, optimal flux, and ion rejection and recovery rates. Siting of the pilot study facilities will require test hole drilling to determine final well location and design.

B. RECOMMENDATIONS

The following recommendations are based on the results of the modeling analysis of the Burrton oil brine area that was derived form the USBR's initial contaminant transport model of the region and updated to currently available information (1996); information provided in other reports concerning the proposed Equus Beds Groundwater Recharge Demonstration Project; and cost estimates developed for selected management simulations.

1. Because of the magnitude of the Burrton salt plume and the delicate balance of pumping with the inflow of salt from outside sources, phased implementation of

remedial measures is recommended so that hydrogeologic system response can be evaluated before larger and more expensive systems are installed.

2. Initial analysis indicates that relatively costly remediation measures would remove 8 to 10 percent of the salt contamination. This evaluation is based on modeling assumptions and data that widely space across the study area. In order to develop additional data and operation experience to determine more precisely how the aquifer will react to clean up measures, a pilot remediation program is recommended.

   A pilot study with two recovery wells, one injection well, and six to eight additional monitoring wells is highly recommended. The additional monitoring wells are to evaluate aquifer response to the cleanup efforts and determine the suitability of using the recovered water in a public water supply system. The new monitoring wells should be constructed to standards that allow for organic water quality analyses. Additionally, detailed water quality analysis of the recovered water from the pilot operation will allow a more detailed evaluation of treatment required and costs for expanded remediation systems.

2. After a period of operation and data collection, the model should be refined for a more detailed evaluation, siting, and design of expanded remediation systems.

3. Additional modeling studies should be conducted to evaluate supplemental plume management strategies involving alternate operation of the City of Wichita Well Field and surrounding irrigators to reduce the impacts of the salt plume. Options include, but are not limited to the following:
   - reduced Wichita Well Field pumping near the plume and obtaining greater amounts of water for their demands at more distant well field locations.

- replacing larger volumes of Wichita Well Field water with plume management water (and reduced well field pumping).
- Seasonal (or long time period cyclic) pumping of the Wichita wells near the plume to allow long periods of water level recovery.

- Reduced pumping for all irrigators and municipal supplies to the aquifers "safe yield" capacity as defined by the GMD2.

4. Additional water quality analysis is recommended. Complete safe drinking water analyses are needed to confirm the water will meet EPA drinking water standards and could be used in municipal systems. It is recommended that six to ten "environmental quality" monitoring wells be constructed throughout the Burrton salt plume and water quality samples collected for the complete EPA drinking water quality analysis.

5. Begin discussions with the federal, state and local agencies to explore the regulatory constraints of using the plume control water for municipal use. Specific issues include:
   - water rights for the plume control wells and impacts to the existing municipal water rights.
   - funding of the facilities.
   - water quality monitoring requirements.

* * * * *

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