# EXHIBIT J

# Arkansas River Water Management Improvement Study

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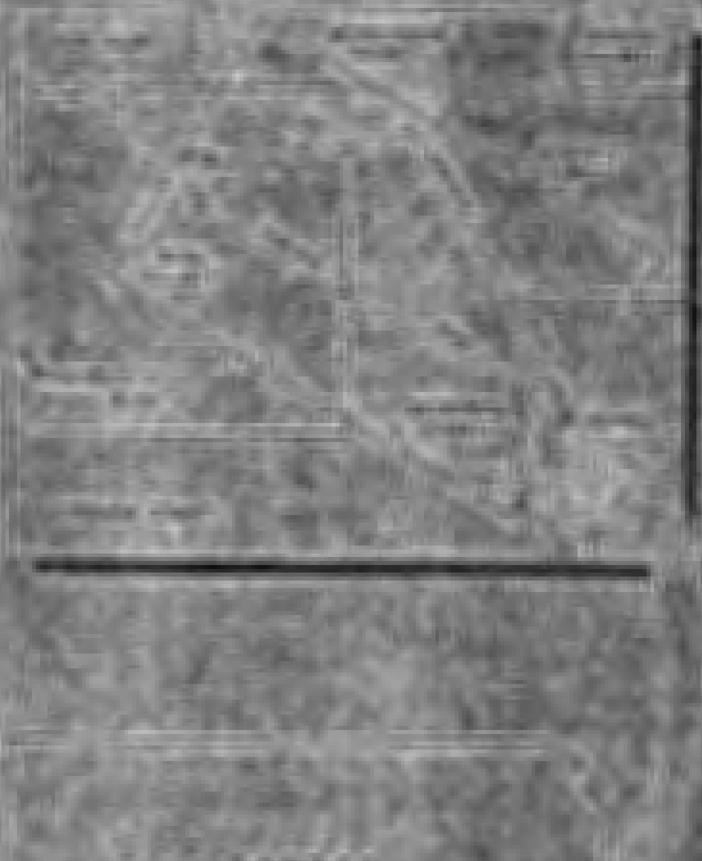
## Technical Report



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# ABSTRACT

The Arkansas River Water Management Improvement Study is a joint effort by the Kansas Water Office, Equus Beds Groundwater Management District No. 2, the U.S. Geological Survey, and the Bureau of Reclamation (Reclamation). Reclamation's portion of the study used ground-water flow and chloride transport models of the Equus Beds aquifer system to investigate management strategies and issues about water-quality degradation of the aquifer.

Models used were a flow model of the Equus Beds system which uses the three-dimensional, finite-difference, flow model program (MODFLOW) and a transport model, developed and calibrated to simulate 1940-1989 chloride conditions in the Equus Beds aquifer.

The study considered three sources of salinity present in the aquifer: chloride from Arkansas River water entering the aquifer, deep natural saltwater, and brine from oil field operations.

# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| ARWMIS | Arkansas River Water Management Improvement Study |
| gpm | gallons per minute |
| GMD2 | Equus Beds Groundwater Management District No. 2 |
| KWO | Kansas Water Office |
| mg/L | milligrams/liter |
| m.s.l. | mean sea level |
| MT3D | A modular three-dimensional transport model program |
| MODFLOW | Three dimensional, finite difference flow model program |
| Reclamation | Bureau of Reclamation |
| USGS | U.S. Geological Survey |
| WATSTORE | A USGS data base |

## CONTENTS

## Contents



## APPENDIXES

## Contents

## TABLES



## FIGURES

Contents

## FIGURES

## Contents

## FIGURES

## Summary

In 1988, the Arkansas River Water Management Improvement Study (ARWMIS) was formed to examine the hydrogeology and water quality of the Arkansas River-Equus Beds aquifer system. As a part of this study, Bureau of Reclamation (Reclamation) modeled the Equus Beds aquifer to investigate management issues regarding water quality degradation of the Equus Beds aquifer. The modeling examined ground-water flow and the transport of chloride[1] in the aquifer.

The Equus Beds aquifer provides most of the fresh and usable water in south-central Kansas. Ground-water withdrawals from the Equus Beds aquifer between Hutchinson and Wichita in Kansas have been increasing since the 1940's. The city of Wichita's principal water supply, Wichita well field, is located in the Equus Beds aquifer east of Burrton.

**Salinity Sources**

The quality of the ground water in the area is generally good, although salinity from natural and manmade sources has entered the ground water. Naturally occurring sources include Arkansas River water and natural saltwater located in the deepest part of the aquifer around a bedrock low, or trough, near the course of the Arkansas River. Brine from oil field operations, evaporation-pan brine from salt-refining activities, and the possible migration of saltwater around disposal wells or poorly cased boreholes completed in or below the Wellington Formation are sources of salinity from human activities.

**Models**

The study used two numerical models:

- A flow model of the Equus Beds system using a three-dimensional, finite-difference, flow model program (MODFLOW) that was developed by the U.S. Geological Survey (USGS) (Myers et al., in review). This model was used as the basis for the investigation of chloride transport in the aquifer. The flow model was modified by increasing the resolution of the

[1] In this report, chloride serves as an indicator of the salinity in the ground water.

finite-difference grid and was used in conjunction with a transport model (Papadopulos and Associates, Inc., 1992).

- A transport model developed and calibrated to simulate 1940-1989 chloride conditions in the Equus Beds aquifer. The transport model was used to characterize the movement of chloride from specific sources[2] during the calibration period (1940-1989) and the projection period (1990-2049). Additional simulations were made to investigate potential management strategies.

**Results**

Field data and results from these simulations indicate that chloride plumes are migrating from the Arkansas River and Burrton Oil Field area toward the Wichita well field area. The transport model predicts that chloride concentrations would be as high as 400 milligrams per liter (mg/L) in the south part and 300 mg/L in the extreme northwest part of the well field by 2049.[3] The saltwater plume originating in the Burrton Oil Field area would contribute the largest amount of chloride to the Wichita well field area until about 2010, when the Arkansas River would become the largest contributor.

The increasing pumpage from the aquifer is primarily responsible for the contribution of chloride from the Arkansas River as well as the oil field saltwater plume's movement toward the well field. Withdrawals from the aquifer have also induced significant vertical movement of chloride from the upper and middle layers into the lower part of the Equus Beds aquifer.

Maintaining present withdrawals or further developing the aquifer could accelerate chloride migration from these salinity sources to areas of development.

**Management Strategies**

The study investigated potential management strategies and concerns regarding chloride degradation of the Equus Beds aquifer.

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[2] The Arkansas River, natural saltwater located deep in the aquifer, and brine from the Burrton Oil Field.

[3] The secondary drinking water standard for chloride is 250 mg/L.

- Applying recharge water between the Arkansas River and the Wichita well field area appears to inhibit the movement of chloride from the river to the aquifer.
- Installing withdrawal wells in areas of high chloride concentration appears to minimize the impact of the Burrton Oil Field saltwater on the Wichita well field area.
- Reducing pumping within the Wichita well field area decreases the impacts from each of the salinity sources considered, the Arkansas River, deep natural saltwater, and the Burrton Oil Field brine.
- Eliminating flow in the Arkansas River significantly decreases heads and demonstrates the importance of the river serving as a water supply to recharge the aquifer.
- Eliminating agricultural pumping near the Arkansas River because of poor quality water would have minimal impacts on ground-water flow and quality in the aquifer.

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## Introduction

In 1988, the Arkansas River Water Management Improvement Study (ARWMIS) began as a joint effort of the Kansas Water Office (KWO), the Equus Beds Groundwater Management District No. 2 (GMD2), the U.S. Geological Survey (USGS), and the U.S. Bureau of Reclamation (Reclamation). One of Reclamation's principal tasks was to investigate strategies to effectively manage the Equus Beds aquifer.

This report presents the results of transport model simulations of chloride in the stream-aquifer system and the Equus Beds. This work is largely based on the flow model developed by USGS as a portion of the ARWMIS study. Calibration simulations have been performed for chloride transport for the period 1940-1989. In addition, model simulations are used to predict the movement of chloride in the Equus Beds aquifer.

This report also discusses the modeling results of simulations investigating management concerns regarding water quality degradation of the Equus Beds aquifer.

### *Background*

The Equus Beds aquifer provides most of the fresh and usable water in south-central Kansas. Ground-water withdrawals from the Equus Beds aquifer between Hutchinson and Wichita in Kansas have been increasing since the 1940's. The city of Wichita's principal water supply, Wichita well field, is located in the Equus Beds aquifer east of Burrton.

The quality of the ground water in the area is generally good, although salinity, indicated by the presence of chloride, has entered the aquifer from several sources. This portion of the ARWMIS study examined the following sources.

- **Arkansas River water**—generally saline through the project area from salinity sources upstream from Hutchinson, Kansas.
- **Natural saltwater located in the deepest part of the aquifer** around a bedrock low, or trough, near the course of the Arkansas River. High concentrations of

natural chloride have probably intruded from the underlying Wellington Formation into the deepest portions of the Equus Beds.

- **Brine from Burrton Oil Field activities**—oil field brine contamination from the Burrton Oil Field area has rendered water unsuitable for most uses in portions of the Equus Beds aquifer near Burrton.

Other sources that were not examined include:

- **Brine from Hollow-Nikkel Oil Field activities**.
- **Evaporation-pan brine** from salt-refining activities.
- **Possible migration of chloride** via poorly cased boreholes or disposal wells completed in or below the Wellington Formation.

Maintaining present withdrawals or further developing the aquifer could accelerate migration of saltwater from these salinity sources to areas of development.

Understanding the hydrologic and hydrochemical aspects of the stream-aquifer system could lead to improved management of the available water resources in the study area.

### *Purpose*

The purpose of Reclamation's Modeling Management Strategies portion of the ARWMIS is to examine water management strategies and issues regarding water quality degradation of the Equus Beds aquifer. The primary objective is to determine how aquifer use affects the distribution of chloride from the main sources of chloride within the aqnifer.

### *Description of Study Area*[4]

The study area is located in south-central Kansas in parts of Reno, Harvey, McPherson, and Sedgwick Counties (figure 1). Principal cities in the area are Hutchinson, Newton, and Wichita. Towns and water features in the area are shown in figure 2.

[4] This section was extracted and modified from Myers et al., in review.

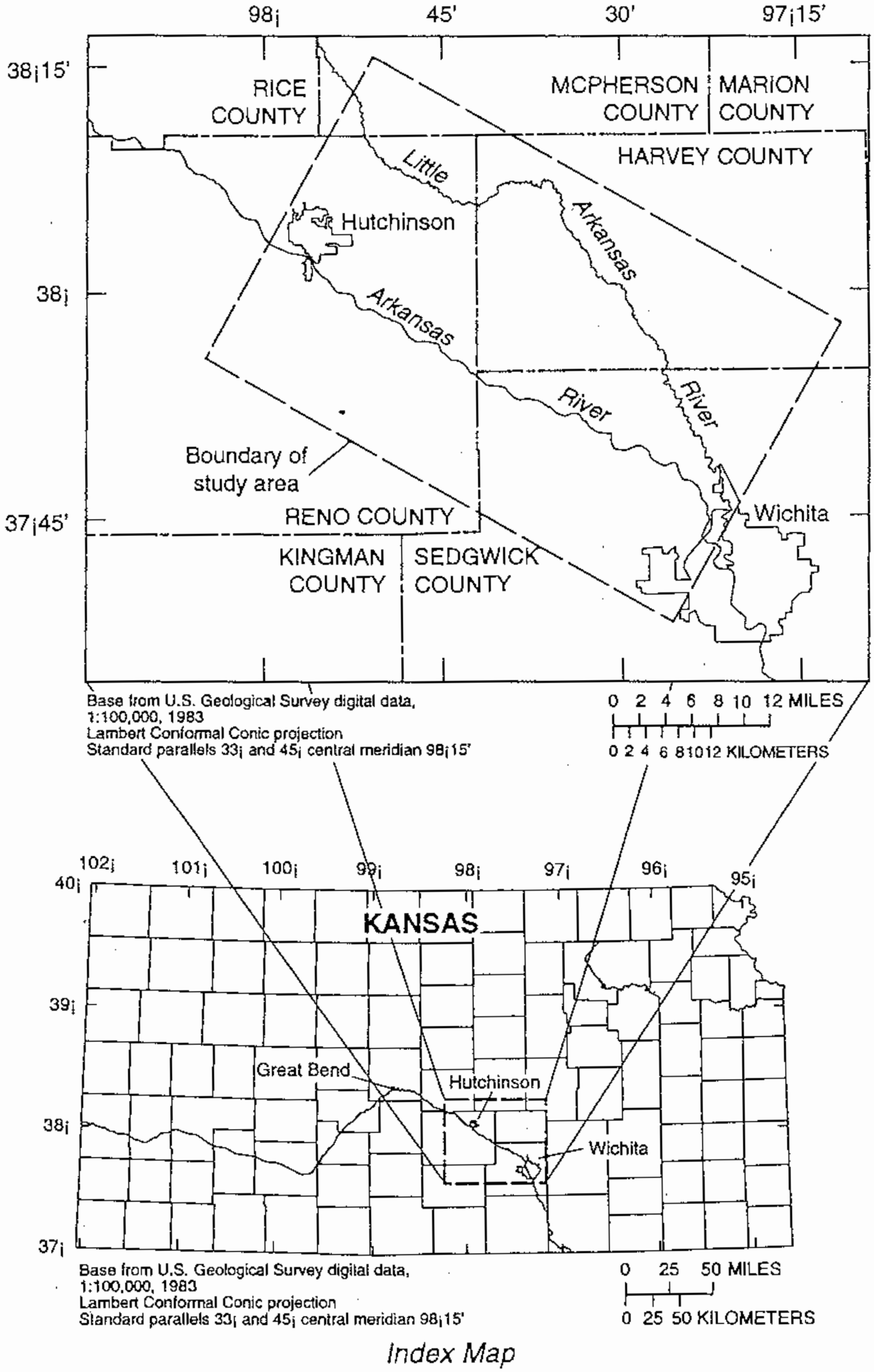


Figure 1.—Location of study area.

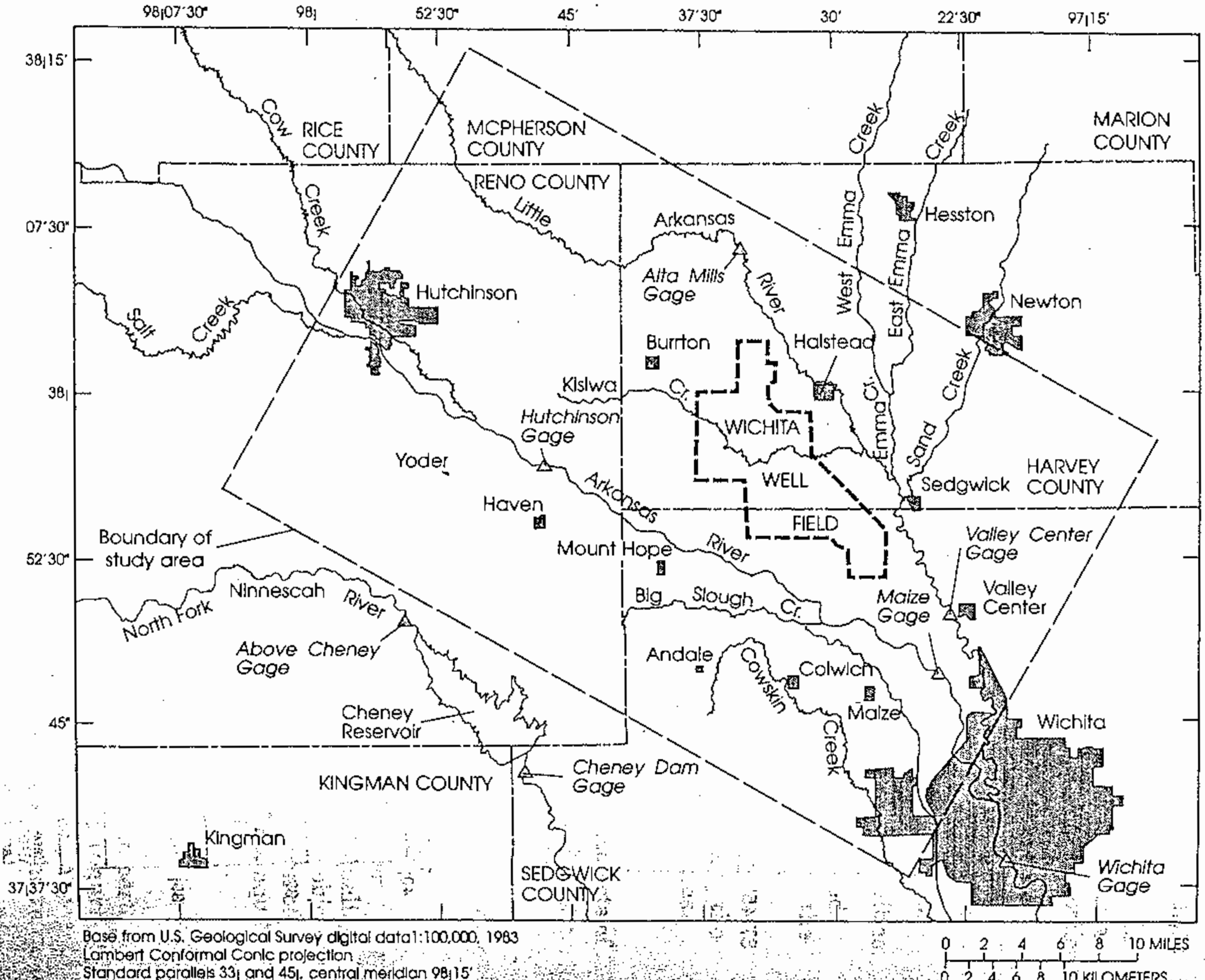


Figure 2.—Principal features in and around the study area.

The Equus Beds study area is in a subhumid portion of south-central Kansas. Annual precipitation averages about 30 inches per year from rainfall in spring and summer and snowfall typically from December through March. Temperatures vary widely throughout the year with average July highs in the mid-90's degrees Fahrenheit and lows in the upper 60's. Average January temperatures range from the mid-40's to the low 20's.

There is very little topographic relief over the study area except for an area of sand dunes near Hutchinson. Mostly, the land surface slopes gently toward the major streams in the area.

The Arkansas River and the Little Arkansas River are the major streams in the study area (figure 1). The Arkansas River flows southeast in a fairly straight, slightly braided channel. The Arkansas River channel is entrenched 5 to 10 feet below the adjacent land surface. In contrast, the Little Arkansas River meanders as it flows east and southeast to its confluence with the Arkansas River in Wichita. The channel of the Little Arkansas River is entrenched 15 to 20 feet below the adjacent land surface. Several small creeks flow into the Arkansas and Little Arkansas Rivers in the study area (figure 2).

#### *USGS Contributions to the Study*

USGS prepared the *Hydrologic and Chemical Interaction of the Arkansas River and the Equus Beds Aquifer between Hutchinson and Wichita, South-Central Kansas* (Myers et al., in review) as part of the ARWMIS. This report presents the results of a hydrogeologic and water quality study of the Arkansas River-Equus Beds aquifer system using flow modeling and particle tracking simulations of the river-aquifer system between Hutchinson and Wichita. Simulations of ground-water flow for calibration purposes cover the period 1940-1989. Model simulations are used to project the effects of natural and human-induced stresses on the river-aquifer system. The report also discusses sources and movement of chloride in the Equus Beds aquifer.

### *Methods of Study*

For this portion of the ARWMIS study, Reclamation investigated management concerns by modeling flow and chloride transport.

Reclamation used the USGS flow model as a starting point and foundation for investigating the impacts of management concerns in the stream-aquifer system and the Equus Beds. The USGS flow model was accepted as a reasonable representation of the aquifer system within the study area. Any significant changes in the flow model would demand considerable time and effort in recalibration. However, a finer spaced finite-difference grid was necessary to adequately define the velocity flow field for the transport model, which required regridding. Reviewing these results indicated that the regridded flow model was an acceptable representation of the original flow model and required no further calibration.

Previous transport modeling studies were used to establish transport parameters and initial concentrations of chloride in the aquifer. Historical chloride data obtained from USGS and the GMD2 were used for transient calibration of the transport model. Transport model data were refined during calibration of the transient model to approximate graphs of chloride concentration versus time at sites within the study area.

Simulations were made to characterize the transport of chloride from specific sources during the calibration period (1940-1989) and the projection period (1990-2049). These chloride sources are: the Arkansas River, deep natural saltwater, and saltwater from the Burrton Oil Field. Simulations were also performed to investigate potential management strategies and issues.

### *Previous Studies*[5]

The Equus Beds aquifer is an important source of water for cities, industries, and farms. The importance of this water source and high chloride concentrations in parts of the aquifer, streams, and adjacent rocks have made the Equus Beds aquifer a center of academic attention. Many

[5] This section was extracted and modified from Myers et al., in review.

hydrogeologic, water quality, ground-water flow model, and solute-transport studies concerning this aquifer have been completed.

- Williams and Lohman (1949) wrote an extensive work on the geology and ground-water resources of the Equus Beds.
- Williams (1946) studied ground-water conditions near Hutchinson.
- Williams and Lohman (1947), Stramel (1956, 1962a, 1962b, and 1967), and Petri et al. (1964) studied the aquifer in the Wichita well field area.
- Bayne (1956), Lane and Miller (1965), and Bevans (1988) described the geology and hydrology of Reno and Sedgwick Counties.
- Green and Pogge (1977), McElwee et al. (1979), and Spinazola et al. (1985) developed ground-water flow models of all or part of the Equus Beds.
- Gogel (1981) and Spinazola et al. (1985) modeled the underlying Wellington aquifer.
- Sophocleous (1983), Spinazola et al. (1985), and Heidari et al. (1986) developed solute-transport models to predict the movement of chloride in the Equus Beds, particularly in relation to the Wichita well field.

Many investigations have focused on water quality, salinity in particular:

- Leonard and Kleinschmidt (1976) studied the occurrence of saline water in the Little Arkansas River basin.
- Hathaway et al. (1981) studied the chemical quality of irrigation water in the Equus Beds area.
- Williams (1946) discussed the origin of large concentrations of chloride in the aquifer near Hutchinson.
- Gogel (1981) discussed the potential for discharge of saltwater from Permian rocks to the Equus Beds.
- Whittemore (1982-1990) and Whittemore and Basel (1982) identified sources of saltwater brines in the Equus Beds using chloride-iodide and chloride-bromide ratios.

## Physiography

The major part of the study area is located in the Osage Plains section of the Central Lowland Province in the Physical Divisions of the United States as determined by Fenneman (1931). The Arkansas River section described by Schoewe (1949) is equivalent to the Osage Plains section. These areas are composed of sands, silts, and clays over bedrock.

This area is composed of old scarped plains with entrenched streams. Part of the area is located in the Great Plains Province which is described as a submaturely to maturely dissected plateau and is characterized by flat to gently rolling terrain. Surface elevations range from about 1200 feet mean sea level (m.s.l.) in the southeast near Wichita to about 1650 feet m.s.l. near Hutchinson to the north.

Wind-blown sand and silt form a major belt of sand dunes between the northern edge of the Arkansas River Valley and the Little Arkansas River. These sand belts extend southeastward from Rice County across Reno County. The eastern end is northeast of Burrton in Harvey County, Kansas. Small, isolated sand dune areas also 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 subsoil and well-drained sandy soils on level plains.
- Deep loamy soil over sandy or gravelly material in the breaks and along alluvial lands.

Some of the uplands and breaks are used for rangeland, but cultivated crops (mainly wheat, alfalfa, and grain sorghum) are grown on the majority of the lands.

## Geology

Bedrock in the study area consists mainly of limestones and shales of the Chase Group as well as shales, thin sandstones and siltstones, and evaporites of the overlying Sumner Group. Both the Chase and Sumner Groups are Permian, and the Chase Group is thicker than the Sumner in the study area. Included in the Sumner Group is the Wellington Formation, which has lower, middle, and upper members. The lower member (Lower Anhydrite) consists of gray shale with some dolomite and many thin gypsum and anhydrite beds. The middle member (Hutchinson Salt) consists of salt, interbedded with minor shale, gypsum, and anhydrite. The Hutchinson Salt Member occurs about 650 feet below ground level in the Hutchinson, Kansas, area and is mined at that location. The upper member (Upper Shale) consists of mainly gray shale with minor amounts of gypsum, anhydrite, dolomite, and siltstone (figure 1 in appendix A).

The Wellington Formation is up to 750 feet thick, but the thickness is an average of 250 feet. Natural dissolution of the Hutchinson Salt Member and subsequent subsidence and collapse of overlying rock has resulted in as much as 350 feet of Tertiary and Quaternary sediment accumulation. This accumulation is known as the Equus Beds Formation (figure 2 in appendix A). Because the Equus Beds Formation is permeable, most of this formation acts as an aquifer.

Tertiary and Quaternary age alluvium, known as the Equus Beds Formation, consists of sand and gravel, interfingered with lenses of silt and clay. The Equus Beds Formation overlies most of the bedrock in the study area. Maximum thickness of these sediments occurs in a north-south-trending buried valley known as the McPherson Channel in McPherson, Harvey, and northern Sedgwick Counties and in the southeasterly trending Arkansas River bedrock valley in Reno and Sedgwick Counties. The bedrock surface is low near the course of the Arkansas River (figure 3 in appendix A). Saltwater from the Hutchinson Salt Member of the Wellington Formation may be entering the Equus Beds aquifer around this bedrock low, or trough.

The study divided the Equus Beds Formation into layers: lower, middle, and upper on the basis of the characteristics of the sediment accumulation that makes up the Equus Beds Formation. The lower and upper layers contain mostly sand and gravel with interbedded clay or silty clay. The middle layer contains more fine-grained material. The model of the aquifer contained three layers to reflect the relative permeability and other properties of the three layers of the Equus Beds Formation.

Areas of continued subsidence are indicated by a linear trend of water-filled depressions and sinkholes. Subsidence and collapse, together with pre-Quaternary subaerial erosion, has resulted in a very irregular bedrock surface (figure 3 in appendix A).

Also included in the Sumner Group and conformably overlying the Wellington Formation is the Ninnescah Shale, which consists of alternating beds of brownish-red silty shale and siltstone interbedded with thin beds of gray-green shale and siltstone and very thin layers of satinspar gypsum. The Wellington Formation crops out in the east part of the study area while the Ninnescah Shale crops out in the western part of the study area. Figure 3 shows the contact of the aquifer with Permian bedrock.

Dune sands overlie formation rock near Hutchinson and overlie the Equus Beds east of Hutchinson. The dunes consist of fine-grained, tan sand with interbedded buried soil zones. Maximum thickness of the dune sand is about 150 feet. Wind-blown silt deposits (loess) about 30 feet thick occur on uplands southwest of the Arkansas River, but they thin rapidly toward the river (figure 1 in appendix A).

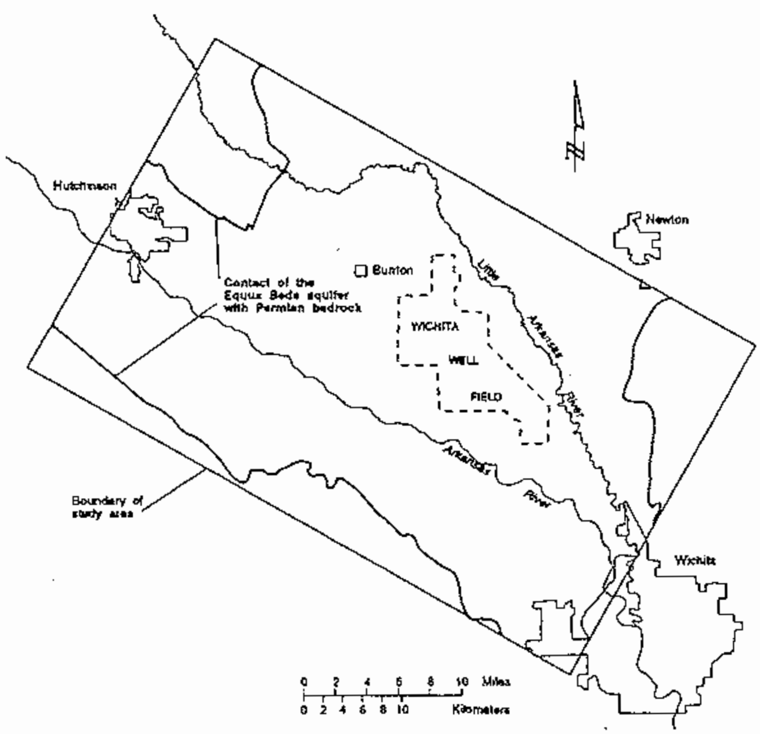


Figure 3.—Contact of Equus Beds aquifer with Permian bedrock within the study area.

### *Hydrology*

About 11 percent of the 1.2 million acres of agricultural land in Harvey, McPherson, Reno, and Sedgwick Counties use supplemental irrigation, primarily from the ground-water supply (Equus Beds Groundwater Management District No. 2, 1990). Various investigators estimate that recharge to the ground-water supply is in the range of 4 to 6 inches per year, or about 20 percent of the 30 inches of annual precipitation in the Equus Beds area (Spinazola et al., 1985).

Rainfall runoff and irrigation return flows feed the Arkansas River in the Equus Beds area. Snowmelt from the Rocky Mountains is a relatively minor factor in the seasonal runoff patterns observed. Snowmelt greatly influences regulated releases from reservoirs far upstream, but very few substantial releases from snowmelt reach the study area. The Arkansas River generally loses water to the ground-water system during extended periods of flow. However, at times, gains in the river from the ground-water supply in this reach can also be substantial, but this is not a consistent pattern.

#### *Surface Water*

Principal surface water features are shown in figure 2. The most important tributary to the Arkansas River in this area is the Little Arkansas River, fed primarily by irrigation return flow and, at times, by rainfall runoff. The Little Arkansas River joins the Arkansas River just downstream of the study area and consistently gains water from the aquifer.

Peak flows in terms of both instantaneous rates and monthly runoff volumes can occur at various times of the year. However, these most commonly occur in the rainy months of spring and early summer. Minimum flows are usually reached in the late summer, fall, and early winter after the seasonal irrigation withdrawals.

The Water Resources Data publications of USGS provide complete annual summaries of the measured data. Several stations in these publications are useful to verify model results.

The primary gauging stations on the main stem are:

> *Location:* The Arkansas River near Hutchinson.
> *Drainage area:* 38,910 square miles—7,186 square miles probably noncontributing.
> *Record:* From October 1959 to the present.
> *Average annual discharge:* 386,900 acre-feet.

> *Location:* The Arkansas River near Maize.
> *Drainage area:* 39,110 square miles—7,186 square miles probably noncontributing.
> *Record:* From March 1987 to the present.

The period of record for the Maize station is so short that an average annual discharge cannot be compared reliably to other stations on the river.

Other stations near the study area on the Arkansas River are:

> *Location:* The Arkansas River at Wichita.
> *Drainage area:* 40,490 square miles—7,263 square miles probably noncontributing.
> *Record:* From July 1934 to the present.
> *Average annual discharge:* 745,500 acre-feet.

> *Location:* The Arkansas River at Derby.
> *Drainage area:* 40,830 square miles—7,263 square miles probably noncontributing.
> *Record:* From October 1968 to the present.
> *Average annual discharge:* 802,700 acre-feet.

The two stream gauges on the Little Arkansas River are:

> *Location:* The Little Arkansas River at Alta Mills.
> *Drainage area:* 736 square miles—55 square miles probably noncontributing.
> *Record:* From June 1973 to the present.
> *Average annual discharge:* 147,100 acre-feet.

> *Location:* The Little Arkansas River at Valley Center.
*Drainage area:* 1,327 square miles—77 square miles probably noncontributing.
*Record:* From June 1922 to the present.
*Average annual discharge:* 208,700 acre-feet.

Detailed information about the extremes at all stations is available in Equus Beds (Groundwater Management District No. 2, 1990) and also in the Water Resources Data publications.

While outside of the study area, two gauges on the North Fork of the Ninnescah River also provide further insights into the hydrology of the general region:

> *Location:* North Fork Ninnescah River above Cheney Reservoir.
*Drainage area:* 787 square miles—237 square miles probably noncontributing.
*Record:* From July 1965 to the present.
*Average annual discharge:* 107,200 acre-feet.

> *Location:* North Fork Ninnescah River at Cheney Dam.
*Drainage area:* 901 square miles—237 square miles probably noncontributing.
*Record:* From October 1964 to the present.
*Average annual discharge:* 85,490 acre-feet. (Evaporation losses and diversions for water supply from Cheney Reservoir may account for, at least in part, the reduced flow at this station.)

Additional tributaries and their locations within the study area are given in Equus Beds (Groundwater Management District No. 2, 1990).

The only major reservoir in the study area is Reclamation's Cheney Reservoir. However, the reservoir is outside the study area at the extreme south end of the Equus Beds District and minimally affects the surface water situation in the study area. Its total storage capacity is 566,300 acre-feet. The reservoir is a multiple purpose facility which provides water supplies for municipal, industrial, fish and wildlife, and recreational purposes. A substantial portion of the storage is reserved for flood control.

### *Ground water*[6]

The generally shallow depth to the water table and the large saturated thickness make Equus Beds sediment an important source of ground water. Near the Arkansas River, the water table may be as little as 10 feet below the surface, depending on the altitude of the land and the amount of drawdown induced by pumping wells. Data collected indicate that the maximum saturated thickness within the study area, about 300 feet, occurs near the course of the Arkansas River where the bedrock surface is low (figure 3 in appendix A).

The Arkansas and Little Arkansas Rivers, to a large extent, control the direction of ground-water flow in the study area, as indicated by potentiometric-surface maps based on water-level data collected during 1940 and 1989 (figures 4 and 5 in appendix A). Near the Arkansas River, ground water flows southeast and generally parallels the direction of riverflow with very little vertical flow. Near the Little Arkansas River, ground water flows toward the river. Southwest of the Arkansas River near Hutchinson, ground water flows to the northeast. Except for the Wichita well field area, the direction of ground-water flow in the 1980's is generally unchanged from that in the 1940's. Water-level data from nested observation wells along the Arkansas River show that the overall direction of ground-water flow is similar in the upper, middle, and lower layers.

The sand dune area near Hutchinson contains zones of perched water as indicated by water levels in nearby wells that differ by as much as 27 feet (Williams and Lohman, 1949, table 37, wells 375 and 376). The sand dunes also contain interdune ponds (Williams, 1946) and springs (Williams and Lohman, 1949). Nevertheless, the sand dunes are an effective precipitation-capture area and probably recharge a larger percentage of precipitation than other areas in the study area (Williams, 1946). A mound of ground water in Equus Beds sediment under and near the southern edge of the sand dunes attests to the recharge capacity of the dunes.

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[6] This section was extracted and modified from Myers et al., in review.

## ..ater Use[7]

Well water withdrawals are a significant source of discharge from the Equus Beds aquifer. Prior to 1940, water was withdrawn from the Equus Beds near the cities of Hutchinson and Wichita and used mainly for municipal and industrial purposes (Spinazola et al., 1985). The Wichita well field (initially holding 25 wells in 1940 and increasing to 55 wells in 1992) helped develop water withdrawals. Municipal water use increased rapidly from 1940 to about 1952 (figure 4). Water withdrawals from the aquifer were fairly constant throughout the 1950's. However, in the late 1950's and early 1960's, agricultural and industrial water uses began increasing. Agricultural water use was fairly uniform in distribution over the study area, including the Wichita well field. Industrial water use was limited to local areas. In the mid-1970's, agricultural water use increased substantially and has been the single largest use of water since the early 1980's (figure 4).

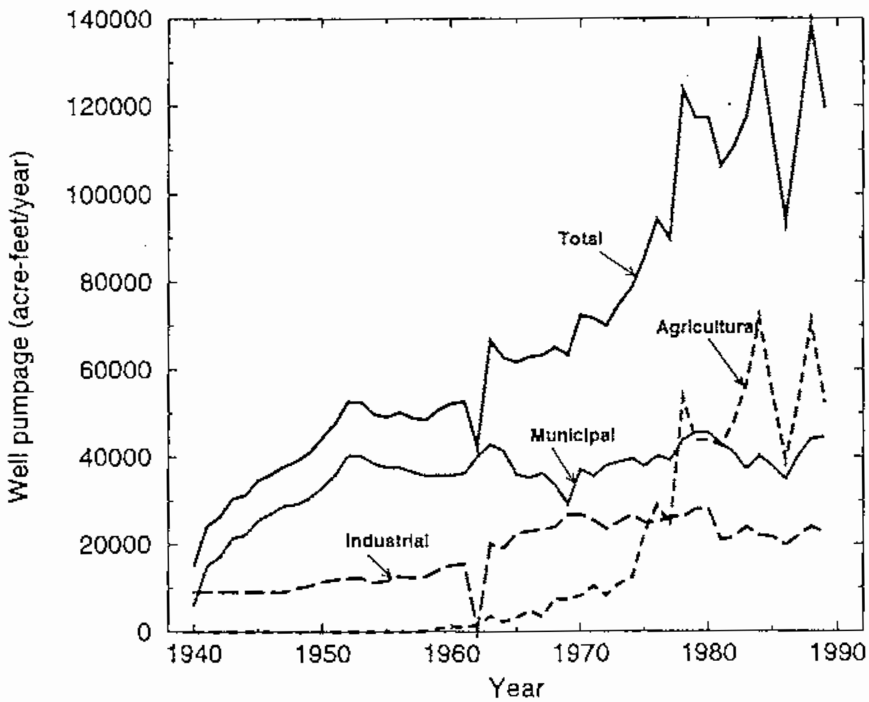


Figure 4.—Industrial, municipal, agricultural, and total pumpage from the Equus Beds aquifer in study area for 1940-1989 (Myers et al., in review).

[7] This section was extracted and modified from Myers et al., in review.

Most of the municipal wells in the Wichita well field produce water from the middle and lower layers of the Equus Beds aquifer. Irrigation wells near the Arkansas River usually produce water from the upper and middle layers because of the large chloride concentrations found in the bedrock lower layer that parallels the river. Irrigation wells farther from the river may produce water from all three layers. Industrial wells may also produce water from all three layers.

## Water Quality

This portion of the ARWMIS study focused on salinity in the Equus Beds aquifer as indicated by the presence of chloride. To provide a reference comparison, the secondary drinking water standard for chloride is 250 milligrams per liter (mg/L). This standard reflects the acceptability of the water to the public and is primarily based on taste or undesirable effects on various domestic uses.

### *Salinity Sources*

Geochemical characterization of ground waters in the alluvial aquifer of the Arkansas River valley from Hutchinson to Wichita suggests there may be five different sources of salinity (Whittemore, 1990). Naturally occurring sources include Arkansas River water and natural saltwater located in the deepest part of the aquifer around a bedrock low, or trough, near the course of the Arkansas River. Salinity sources introduced by human activities include brine from oil field operations, evaporation-pan brine from salt-refining activities, and migration of saltwater through disposal wells or poorly cased boreholes from the Wellington Formation.

***Chloride originating from the Arkansas River.***—The salinity in the Arkansas River is primarily attributed to Permian saltwater entering the river upstream of the study area (Whittemore, 1990). Measured chloride concentrations ranged between 363 and 907 mg/L at the Hutchinson station between 1961 and 1978 (Spinazola et al., 1985). A median chloride concentration of 630 mg/L was found in samples collected near the towns of Hutchinson, Haven, Mt. Hope, Bentley, and Maize (Myers et al., in review). In general, as flows in the river increase, the chloride concentration decreases (Myers et al., in review).

*Deep Natural Saltwater.*—Natural saltwater is located in the deepest part of the aquifer around a bedrock low, or trough, near the course of the Arkansas River (figure 5). The origin of this saltwater is not definitely known. Whittemore (1990) reports "the predominant source of salinity [is] the natural intrusion of saltwaters from Permian strata underlying the aquifer, both within and upstream of the study area." This sources includes the probable intrusion of high concentrations of chloride from the Wellington Formation in the deepest portions of the Equus Beds within the study area. Most notably, this chloride is thought to be intruding into the bedrock low, or trough, that parallels the Arkansas River. Figure 6 shows how saltwater from the Wellington Formation possibly intrudes from the collapsed Hutchinson Salt Member through fractures in the upper shale member of the Wellington Formation into the Equus Beds aquifer.

The chloride concentration from wells in the Wellington Formation averaged about 150,000 mg/L in 15 water samples from the Wellington Formation (Gogel, 1981). This chloride is attributed to the natural dissolution of evaporite deposits in Lower Permian rocks and the injection of oil field brine (Spinazola et al., 1985). Chloride in the Equus Beds alluvial

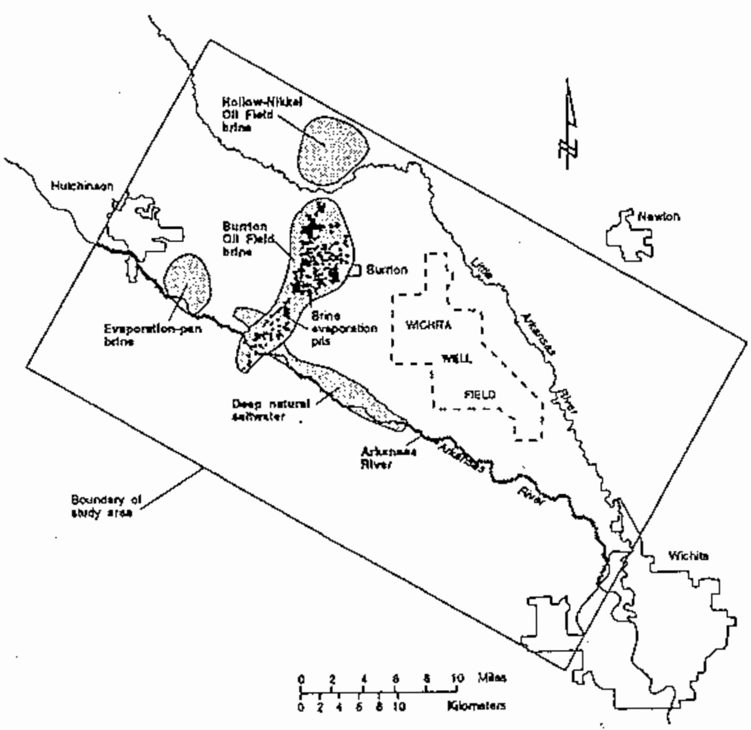


Figure 5.—Salinity sources.

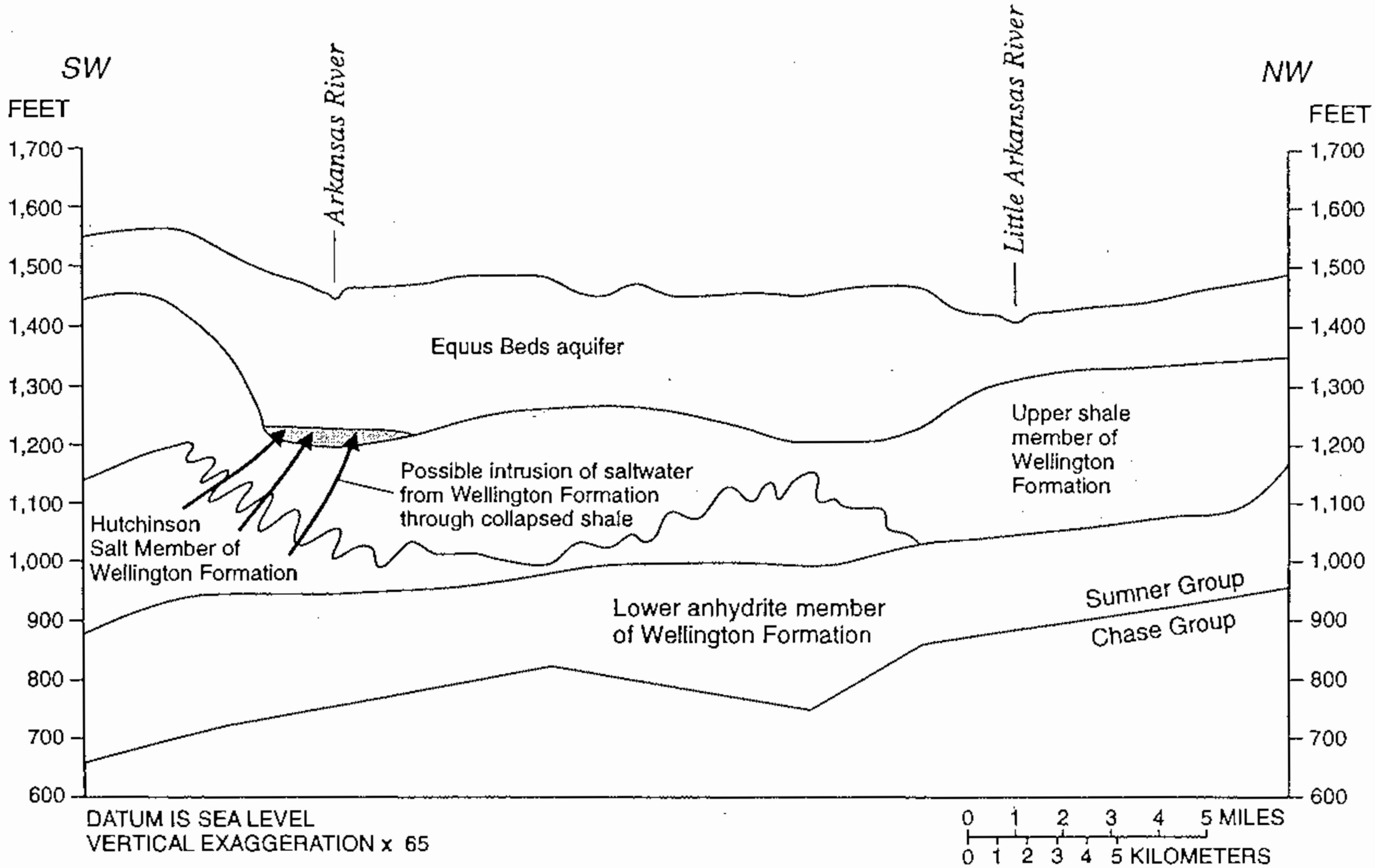


Figure 6.—Possible intrusion of saltwater from the Wellington Formation into the Equus Beds aquifer.

aquifer thought to have intruded from the Wellington Formation has been measured at concentrations as high as 4,000 mg/L in deep wells installed along the Arkansas River (Whittemore, 1990).

*Oil Field Brine from Oil Field Activities.*—Another primary salinity source comes from pollution from oil field brines (Burrton and Hollow-Nikkel Oil Fields). Brine was disposed of in surface pits in the Burrton Oil Field area mainly during the 1930's to 1940's (Whittemore, 1990) (figure 5). Five brine analyses from the oil field in 1943 indicated an average chloride concentration of around 120,000 mg/L (Schoewe, 1943). In the early 1950's, ground-water chloride concentrations over 7,000 mg/L were measured in the area of the surface pits. More recently, measured concentrations in the same areas are generally less than 2,000 mg/L. The concentrations decrease as the initial mass of chloride is mixed with larger volumes of water and diluted by recharge from precipitation.

*Waste Brine from Evaporation Pans.*—Waste brine from evaporation pans used in the late 1890's and early 1900's by salt companies in Hutchinson have been identified as a significant salinity source (Whittemore, 1990). The evaporation pans contained brine from salt-solution mining of the Hutchinson Salt Member of the Wellington Formation (figure 5). The contamination is most concentrated in the intermediate and deep portions of the Equus Beds with concentration contributions of 200 to almost 1,900 mg/L chloride at 13 out of the 16 wells at 5 sites (Whittemore, 1990).

*Human-Caused Sources from the Wellington Formation.*—Permian saltwater together with oil field brine that flowed up around disposal wells or poorly cased boreholes from the Wellington Formation may be another source of salinity (Whittemore, 1990). Oil brines were disposed of in the Wellington Formation prior to the accepted practice of deep well injection (Whittemore, 1990). In some areas in the Wellington Formation, the potentiometric surface has a higher altitude than the water table of the overlying Equus Beds aquifer (Gogel, 1981). Boreholes may allow a small flow from the Wellington Formation to the Equus Beds aquifer.

This study considers three of these sources:

- Saltwater originating in the Arkansas River.
- Deep natural saltwater.
- Oil field brine from the Burrton Oil Field activities.

*Surface Water*[7]

Arkansas River water becomes increasingly salty downstream of Great Bend, Kansas. Most of this salt probably comes from salt marshes upstream of Hutchinson (Williams, 1946). Within the study area, Arkansas River water contains enough chloride to be classified as brackish or salty (Williams, 1946). Williams and Lohman (1949) reported that concentrations of chloride in Arkansas River water samples collected during the winter of 1934-1935 ranged from 392 to 460 and 750 to 1,895 mg/L at two sampling sites near Hutchinson. The chloride concentrations from 750 to 1,895 mg/L were downstream from a sewage outlet (Williams and Lohman, 1949). Chloride concentrations taken at the same location were generally over 1,000 mg/L and reached as high as 1,400 mg/L during low riverflows in the fall of 1937 (Williams and Lohman, 1949).

From August 1988 to July 1991, samples of Arkansas River water were collected at sites along the river near the towns of Hutchinson, Haven, Mt. Hope, Bentley, and Maize. Median chloride concentrations for these five sites ranged from 620 to 640 mg/L. The median chloride concentration for all of these samples is 630 mg/L. Generally, flow in the river and chloride concentration are inversely related (figures 6a-b in appendix A). The chloride load in the river (figure 6c in appendix A), a function of flow and concentration, fluctuates. The chloride load depends on the chloride concentration in water sources that supply flow to the river.

The Little Arkansas River also is known to have carried salty water, although generally not in as large concentrations as in the Arkansas River. Leonard and Kleinschmidt (1976) reported that chloride concentrations at Valley Center ranged from 56 to 220 mg/L in water samples collected during

[7] This section was extracted and modified from Myers et al., in review.

1960-1972. The maximum chloride concentrations in the Little Arkansas River occurred near the mouths of tributaries that drain oil fields (Leonard and Kleinschmidt, 1976).

#### *Ground Water*

Ground-water quality in the study area is generally good, although chloride contamination has occurred from the sources previously described (figure 5). Chloride concentration data[8] at various well locations show areas of the aquifer that have been contaminated by these sources (figure 7). Because the model predicted values for 1989 while the measured data for 1989 might be lacking, the concentrations displayed in figure 7 were obtained by averaging measured data collected between 1986 and 1992. Also, wells had to be assigned a layer number that the measured data could represent. Many wells lacked complete information, making the assignment of a layer number impossible. Therefore, the data presented is processed and has a moderate degree of uncertainty associated with it.

Arkansas River water and the deep natural saltwater are naturally occurring sources of chloride. Measured chloride concentrations are generally higher along the Arkansas River. Concentrations are very high in the deepest portion of the aquifer below the Arkansas River where the deep natural saltwater resides.

Brine from oil field operations and evaporation-pan brine from salt-refining activities are among human-caused sources of chloride. High chloride concentrations are found in the Burrton Oil Field, Hollow-Nikkel Oil Field, and evaporation-pan brine areas in all three layers (figures 5 and 7).

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[8] Data collected by the USGS during this study and data from the GMD2 and USGS WATSTORE databases.

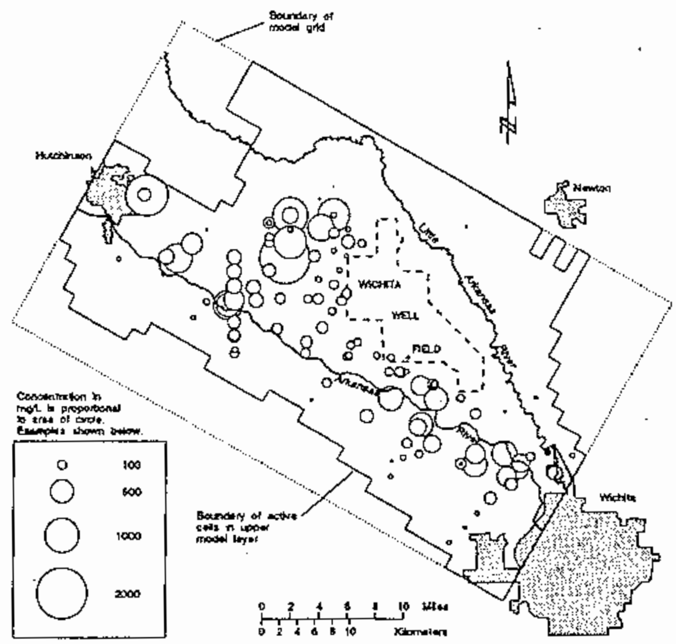


Figure 7a.—Average chloride concentrations of measured data (1986-1992) in the Equus Beds aquifer, upper layer. Chloride concentration in mg/L is proportional to the areas of the circles. The center of the circle indicates where the measurement was taken.

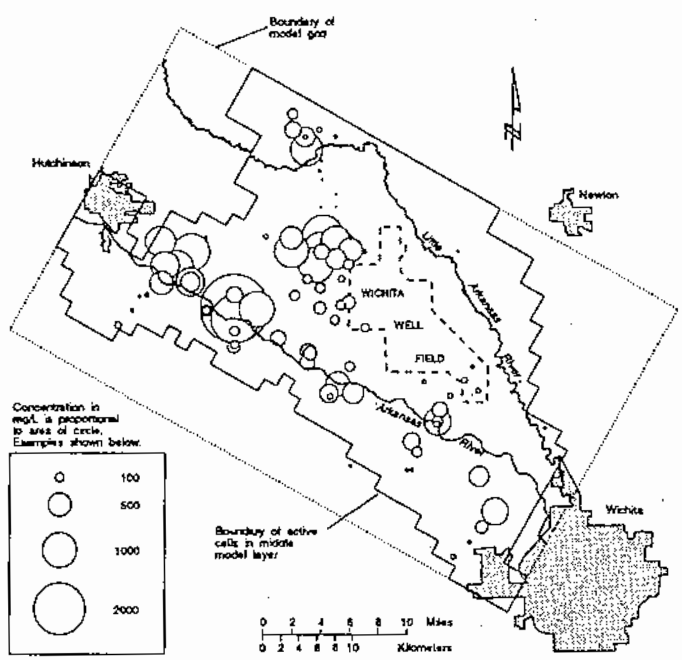


Figure 7b.—Average chloride concentrations of measured data (1986-1992) in the Equus Beds aquifer, middle layer. Chloride concentration in mg/L is proportional to the areas of the circles. The center of the circle indicates where the measurement was taken.

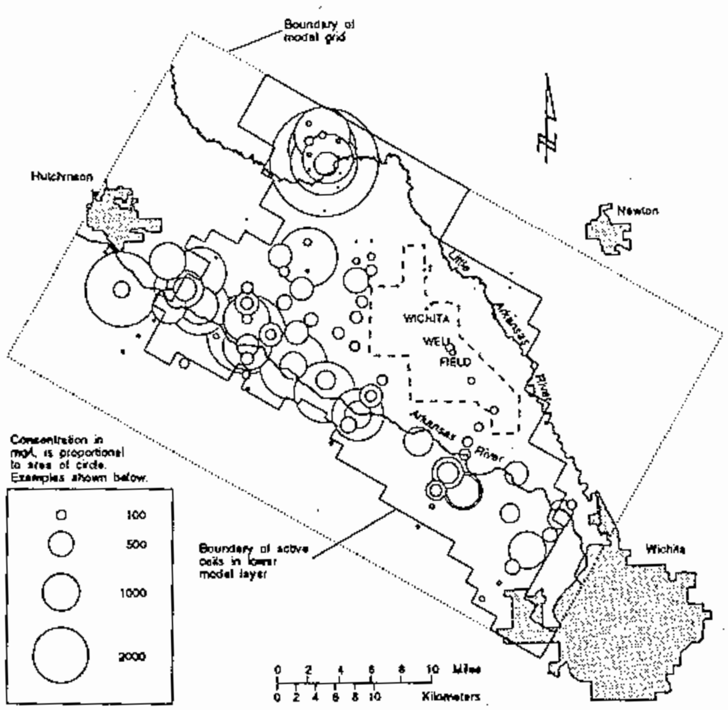


Figure 7c.—Average chloride concentrations of measured data (1986-1992) in the Equus Beds aquifer, lower layer. Chloride concentration in mg/L is proportional to the areas of the circles. The center of the circle indicates where the measurement was taken.

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### Ground-Water Flow Model

The USGS developed a ground-water flow model using MODFLOW—a three-dimensional, finite-difference, flow model program (McDonald and Harbaugh, 1988). This program was used to simulate the stream-aquifer system and the Equus Beds aquifer. Both steady-state and transient simulations were performed. A detailed discussion of the model geometry, aquifer properties, stresses, calibration, and sensitivity analysis is given in the USGS report (Myers et al., in review).

The transport model program used in this study uses MODFLOW to solve the flow equation. The USGS flow model was modified by reducing the spacing of the finite-difference grid. This was necessary to adequately define the flow field for transport modeling in areas of interest. The resulting flow model was determined to be an acceptable representation of the original USGS flow model.

#### *USGS Flow Model*

The USGS data sets that comprise the steady-state and transient models are based on a model geometry of 34 rows, 42 columns, and 3 layers (figure 8). The grid was oriented with variably spaced rows parallel to the Arkansas River. The grid spacing was smaller near the river. No-flow boundaries were simulated where Permian bedrock provides a natural barrier to ground-water flow. Clay layers within the Equus Beds aquifer are accounted for by varying vertical and horizontal hydraulic conductivity in the model layers. Constant-head boundaries were used to represent areas where the Equus Beds aquifer extends beyond the model boundaries. Layer thicknesses near the Arkansas River were determined from lithologic and gamma logs of drill holes. Away-from-the-river thicknesses were determined from lithologic descriptions only (Myers et al., in review). The primary source of aquifer-property data was a previous study by Spinazola et al. (1985). Myers et al. (in review) contains a detailed discussion of model geometry, boundary conditions, properties, stresses, and results. Maps from this USGS report that display much of this information are in appendix B.

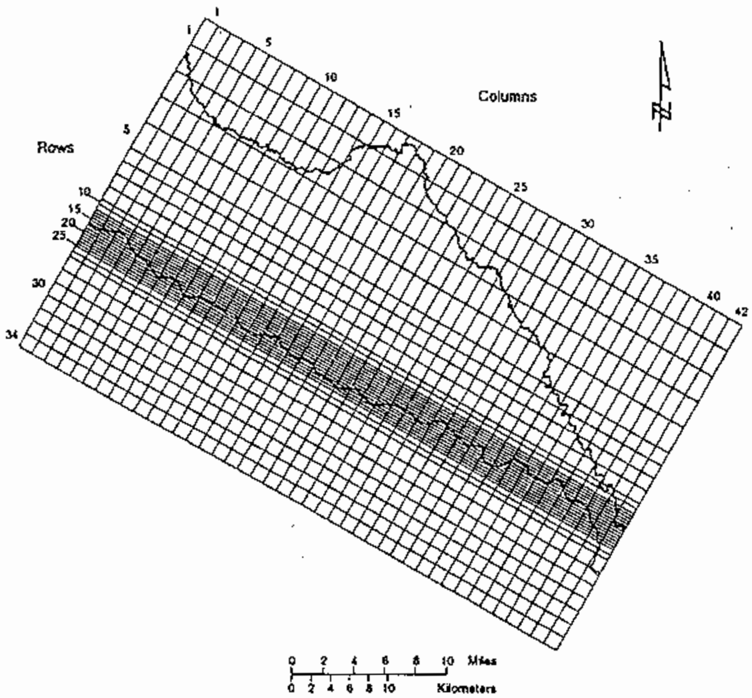


Figure 8.—Model grid (34 rows X 42 columns) from USGS flow model.

*Calibration.*—The steady-state and transient models were calibrated by comparing simulated head distributions to measured head distributions for the years 1940 (steady-state), 1971, 1980, and 1989 (Myers et al., in review). Also, simulated streamflow was compared to measured streamflow and simulated heads were compared to well hydrographs for the transient calibration.

*Sensitivity Analyses.*—Myers et al. (in review) performed sensitivity analyses that indicated the models are most sensitive to hydraulic conductivity and recharge.

*Stresses.*—Stresses simulated in the steady-state and transient flow models include recharge, evapotranspiration, streamflow, stream leakage, and pumpage by wells (Myers et al., in review).

Recharge Values.—Recharge values reported by Spinazola et al. (1985) were adjusted through calibration resulting in values ranging from 0.1 to 5.5 inches per year for the steady-state model. Recharge values for the transient model were adjusted based on average precipitation for each stress period.

Evapotranspiration Rate.—Evapotranspiration rate was determined through calibration with a maximum rate of 3.5 inches per year with the water table at land surface and a linear decrease to 0 where the water table is 10 feet or more below the land surface for both the steady-state and transient models (Myers et al., in review).

Streamflow and Leakage.—Streamflow and stream leakage were simulated using a stream-routing module (Prudic, 1988) in the MODFLOW program.

Pumpage.—Well pumpage developed by Spinazola et al. (1985) was used for the first five stress periods. Myers et al. (in review) developed pumpage data for the sixth stress period and prorated pumpage among the model layers.

***Reclamation's Adaptation of the USGS Flow Model***

The finite-difference grid was modified by reducing the grid spacing and making grid cells more square shaped in the areas where transport is important. The original grid had a geometry of 34 rows and 42 columns (figure 8). This grid was subdivided (figure 9) so that the resulting grid has a geometry of 54 rows and 84 columns. The new grid is simply a subdivision of the USGS grid and includes the original grid lines.

A reduced grid spacing better defines the flow field, thus improving the accuracy of transport modeling. Square-shaped grid cells minimize numerical errors in particle tracking procedures used in transport modeling.

The steps taken in regridding the flow model were intended to preserve the USGS flow model to avoid recalibrating a new flow model.

***Method of Regridding.***—The USGS flow model data sets were converted to data sets that represented an equivalent flow model based on a grid geometry of 54 rows and 84 columns.

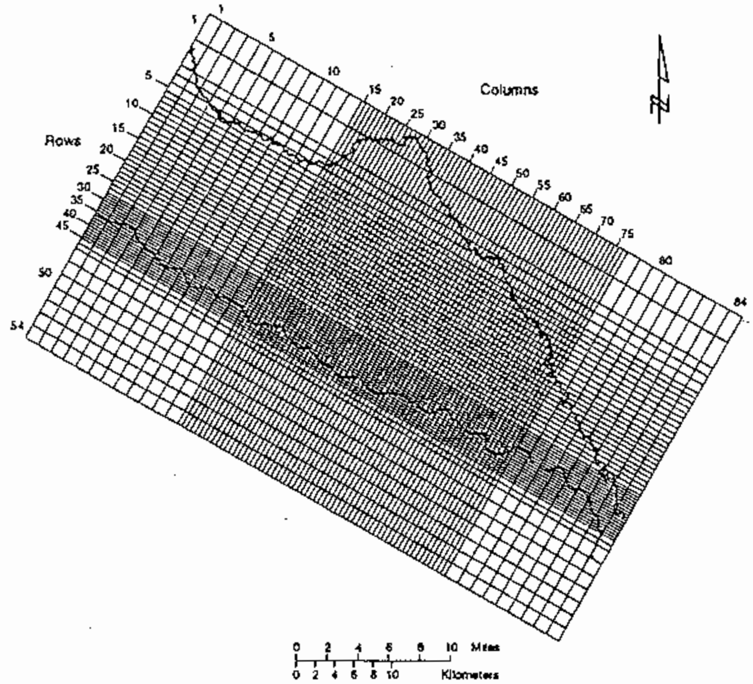


Figure 9.—Model grid (54 rows X 84 columns).

All spatial data (i.e., model input that varies with geographic position) had to be reprocessed. The two types of spatial data input to the flow model are:

1. A value for every grid cell, or a matrix of values (e.g., aquifer porous media properties, elevations, recharge, and boundaries).

2. A value for a single grid cell (e.g., pumping rate or streambed conductance).

In the regrid procedure, each cell in the USGS grid (supercell) was subdivided into a number of smaller cells (subcells). Spatial data of type 1 were processed by simply assigning the supercell value to the corresponding subcells. For type 2 data, the value of the supercell was prorated to the corresponding subcells by the fraction of the area that the subcell is relative to the original supercell area.

***Results of Grid Modification.***—Predicted heads and the overall water budget were used to evaluate the validity of the regridded flow model.

Predicted Heads.—The predicted heads for each of the model layers were compared with results from the USGS model for both the steady-state and transient simulations (figures 7 and 8 in appendix A show comparisons of these predicted heads). In each comparison, the predicted heads are almost identical.

Water Budget.—The water budget at the end of the steady-state and transient simulations was compared for both models. The overall budget comparison was reasonable, but some significant differences were found in the stream leakage term. The regridded model shows a net increase in leakage from streams to the aquifer of 2 percent for the steady-state case and 7 percent for the transient case.

Stream Leakage.—The leakage for each stream supercell in the USGS model (34 X 42) was compared to the net leakage for the corresponding subcells in the regridded model. At this detailed level, the leakage may vary significantly between the two models. But as more supercells are considered, the difference in cumulative leakage between the two models decreases.

The differences in the stream leakage can be attributed to the method used to convert data in the stream package resulted in roughly three times the number of grid cells representing streams in the regridded model as compared to the USGS model. Relatively large grid cells (supercells) are used to represent the Arkansas and Little Arkansas Rivers in the USGS model. Thus, regridding allows each original stream supercell to be represented by numerous subcells. This approach was taken to produce an equivalent model rather than to improve on resolution of stresses and boundaries. An equivalent model does not have to be recalibrated. An improved model would represent the streams with only the grid cells necessary but would require further calibration.

## Solute-Transport Model

To simulate the movement of chloride in solution from 1940 to 2049 and to predict the effects of management alternatives on chloride movement in part of the Equus Beds aquifer, the study used a modular three-dimensional transport model program, MT3D (Papadopulos and Associates, Inc., 1992).

The MT3D transport model is a computer program used to simulate advection, dispersion, and chemical reactions of contaminants in ground-water flow system (Papadopulos and Associates, Inc., 1992). It was developed for use with any block-centered finite-difference flow model, such as MODFLOW.

### *Governing Equation*

The governing partial differential equation describing three-dimensional transport of contaminants in ground water can be written as follows (Papadopulos and Associates, Inc., 1992):

$$\frac{\partial C}{\partial t}=\frac{\partial}{\partial \chi_i}\left(D_{ij}\frac{\partial C}{\partial \chi_j}\right)-\frac{\partial}{\partial \chi_i}(v_i C)+\frac{q_s}{\theta}C_s+\sum_{k=1}^{N}R_k$$

where

| | |
|---|---|
| $C$ | is the concentration of contaminants dissolved in ground water, $ML^{-3}$ |
| $t$ | is time, $T$ |
| $x_i$ | is the distance along the respective Cartesian coordinate axis, $L$ |
| $D_{ij}$ | is the hydrodynamic dispersion coefficient, $L^2T^{-1}$ |
| $v_i$ | is the seepage or linear pore water velocity, LT-1 |
| $q_s$ | is the volumetric flux of water per unit volume of aquifer representing sources (positive) and sinks (negative), $T^{-1}$ |
| $C_s$ | is the concentration of the sources or sinks, $ML^{-3}$ |
| $\theta$ | is the porosity of the porous medium, dimensionless |
| $\sum_{k=1}^{N} R_k$ | is a chemical reaction term, $ML^{-3}T^{-1}$ |
| M | is the fundamental unit of mass |
| L | is the fundamental unit of length |
| T | is the fundamental unit of time |

The four terms on the right-hand side of the equation are, from left to right: the dispersion term, the advection term, the sink/source term, and the chemical reaction term.

Dispersion.—Hydrodynamic dispersion, represented by the first term in the governing equation, is the process of solution mixing due to the variation of ground-water velocity around the mean advective velocity. It reflects the heterogeneity of the aquifer on a smaller scale than the scale associated with the measurement of analysis of advection (McWhorter, 1992). Parameters representing hydrodynamic dispersion can be considered ignorance factors which depend on the scale of heterogeneity. The transport model uses the following parameters to account for this process:

- Longitudinal dispersivity.
- The ratio of transverse to longitudinal dispersivity.
- The ratio of vertical to longitudinal dispersivity.

***Advection.***—Advection, represented by the second term in the governing equation, is the tendency for the chemical to be carried along by the water in which it is dissolved. Advection is characterized by the magnitude and direction of ground-water flow, which depends on the hydraulic gradient, the hydraulic conductivity, and the effective porosity in the aquifer (McWhorter, 1992). The hydraulic conductivity distribution is input, and the hydraulic gradient is represented in the output of the USGS flow model. The transport model uses the output of the flow model together with the aquifer's effective porosity in solving the advective part of the transport equation.

***Sink/Source.***—The third term in the governing equation is referred to as the sink/source term. It represents chemicals dissolved in water entering the simulated domain or system through sources, or chemicals dissolved in water leaving the simulated domain through sinks (Papadopulos and Associates, Inc., 1992). The sinks and sources considered in this study include wells, rivers, and recharge.

***Chemical Reaction.***—The fourth term in the governing equation is referred to as the chemical reaction term. In this study, chloride is the contaminant being considered. Chloride is a conservative ion and does not readily participate in chemical reactions. Hem states:

> *"Chloride ions do not significantly enter into oxidation or reduction reactions, form no important solute complexes with other ions, do not form salts of low solubility, are not significantly adsorbed on mineral surfaces and play few vital biochemical roles."* (Hem, 1970, p. 172)

Therefore, chemical reactions need not be considered for this study.

*Solution Techniques*

The MT3D transport model provides four options in solving the three-dimensional governing equation:

- The method of characteristics.
- The modified method of characteristics.
- A hybrid of these two methods.
- The pure finite-difference method.

Papadopulos and Associates (1992) provides a detailed discussion of these solution techniques. This portion of the ARWMIS study explored these options and decided to use the pure finite-difference method.

The method of characteristics technique was implemented in the USGS two-dimensional solute transport model (Konikow and Bredehoeft, 1978). That model has been used extensively in field studies. The method of characteristics technique solves the advection term of the governing equation with a set of moving particles. Also, it solves the dispersion term with an explicit version of the block-centered finite-difference method.

The pure finite-difference method solves all terms in the transport equation using the finite-difference scheme, solving the unexpanded advection term and the sink/source directly based on an upstream weighing scheme (Papadopulos and Associates, Inc., 1992).

*Assumptions for Applying the Transport Model*

The transport model requires the following assumptions about the Equus Beds aquifer:

- Darcy's law is valid, and hydraulic-head gradients are the only significant driving mechanism for fluid flow.
- The porosity and hydraulic conductivity of the aquifer are constant with time.

- Gradients of fluid density, viscosity, and temperature do not affect the velocity distribution.
- No chemical reactions occur that affect the concentration of the solute, the fluid properties, or the aquifer properties.
- Ionic and molecular diffusion are negligible contributors to the total dispersive flux.

#### *Boundary Conditions*

Boundary conditions regarding transport include active concentration cells and constant concentration cells. All cells which were active cells in the regridded flow model were considered to be active concentration cells. Constant concentration cells were located in the lower layer below the Arkansas River (figure 10) to represent deep natural saltwater, indicated by chloride, that resides in the area of a bedrock low, or trough (Whittemore, 1990).

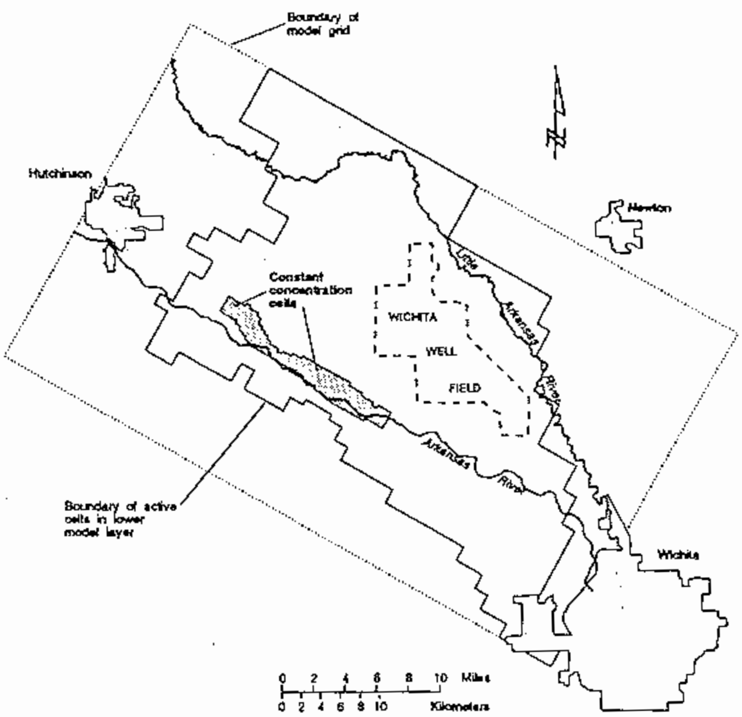


Figure 10.—Constant concentration boundaries for lower model layer.

### *Initial Conditions*

*Initial Concentration.*—The initial concentration of chloride in the study area for 1940 was determined by combining data from work by Spinazola et al. (1985) and data obtained by the USGS during this portion of the ARWMIS study. Reclamation considered several sources of chloride: oil field brine from the Burrton Oil Field, saltwater from the Arkansas River, and deep natural saltwater.

*Oil Field Brine.*—A mass-balance approach was used to estimate the initial concentration of chloride from oil field brine (Spinazola et al., 1985). This involved estimating the mass of chloride produced from oil production operations during 1932-1943 and distributing this chloride in areas where the brine surface pits were located. These pits functioned as recharge pits as the brine was recharged to the shallow ground water. By 1944, 95 percent of the brine was disposed of through injection wells into deep zones below the Equus Beds (Williams and Lohman, 1949).

Reclamation estimated the mass of chloride by using the following procedure (Spinazola et al., 1985). Oil production from 1932-1943 was compiled for the Burrton Oil Field from records at the Kansas Geological Survey. The volume of brine produced was determined by multiplying the total oil volume by a brine-to-oil ratio (table 1). Based on the average of five chloride analyses by Schoewe (1943), the total volume of brine disposed into the surface pits was assumed to have a chloride concentration of 120,000 mg/L, resulting in a total mass of approximately 1.3 million tons of chloride introduced into the Equus Beds aquifer.

This mass of chloride was distributed to the aquifer in areas where the brine evaporation pits were located. Figure 5 shows the pit locations within the Burrton Oil Field produced from aerial photography taken when the pits were active (Burrton Task Force, 1984). The total mass of chloride was equally divided and distributed to the pits identified on this map. The concentration of chloride for cells containing pits was determined by mixing the mass of chloride for that cell with the volume of water in storage beneath the cell in the upper and middle model layers, since most of the chloride originating from the evaporation pits is in the shallow and intermediate depths of the aquifer (Whittemore, 1990). The

Table 1.—Calculated brine production from the Burrton Petroleum Field, 1932-1943[1]

| Year(s) | Oil production (millions of barrels) | Brine-to-oil ratio | Brine production (millions of barrels) | Percentage of brine production disposed into evaporation pits | Brine disposed into evaporation pits (millions of barrels) |
|---|---|---|---|---|---|
| 1932-37 | 21.4 | 2 | 42.8 | 90 | 38.52 |
| 1938 | 3.5 | 3 | 10.5 | 60 | 6.3 |
| 1939 | 3.1 | 5 | 15.5 | 40 | 6.2 |
| 1940 | 2.6 | 6 | 15.6 | 30 | 4.68 |
| 1941 | 2.5 | 6 | 15 | 20 | 3 |
| 1942 | 2 | 6 | 12 | 10 | 1.2 |
| 1943 | 3.3 | 6 | 19.8 | 5 | .99 |
| Total | | | | | 60.89 |

[1] Table 1 is taken from Spinazola et al., 1985, p. 56.

amount of chloride applied to each layer was adjusted during calibration with 20 percent of the chloride applied to the upper layer and 80 percent applied to the middle layer.

Although the surface pits were completed in the upper layer of the aquifer, the higher density of the brine appears to result in a high percentage of chloride sinking to the lower permeability layers of the middle layer. The model code does not account for density. Valid model results can be expected only after the concentrations drop to levels where density has minimal effects. Mixing the mass of chloride with the volume of water in storage yields maximum concentrations of around 18,000 mg/L—well below the level where density is a significant factor in transport.

***Other Chloride Distribution.***—The chloride distribution in areas of the model not affected by oil field brine was determined from historical water quality data provided by the USGS (WATSTORE data base) and from a 1940 chloride-distribution map of the Equus Beds aquifer by Williams and Lohman (1949). Figure 11 displays the contour maps of the resulting initial chloride concentrations used in the modeling.

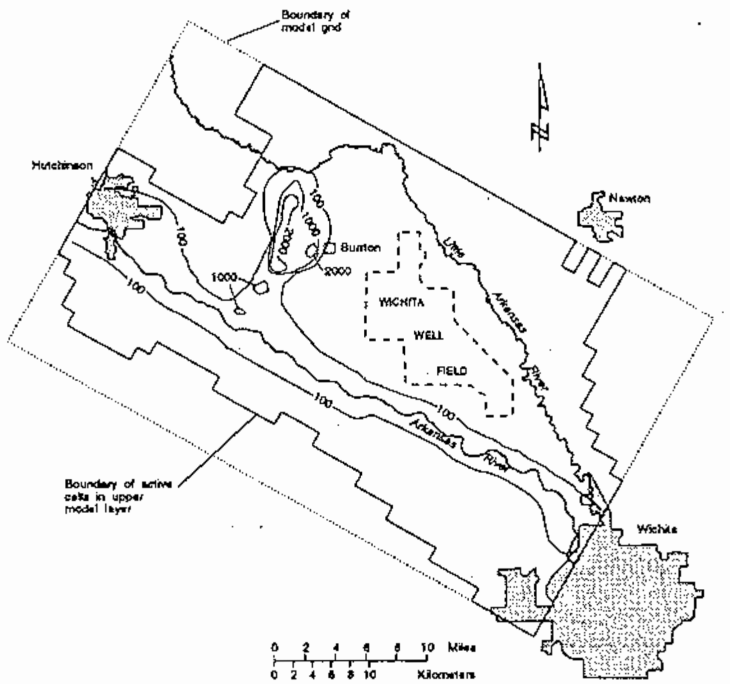


Figure 11a.—Distribution of chloride representing initial conditions for upper model layer, 1940.

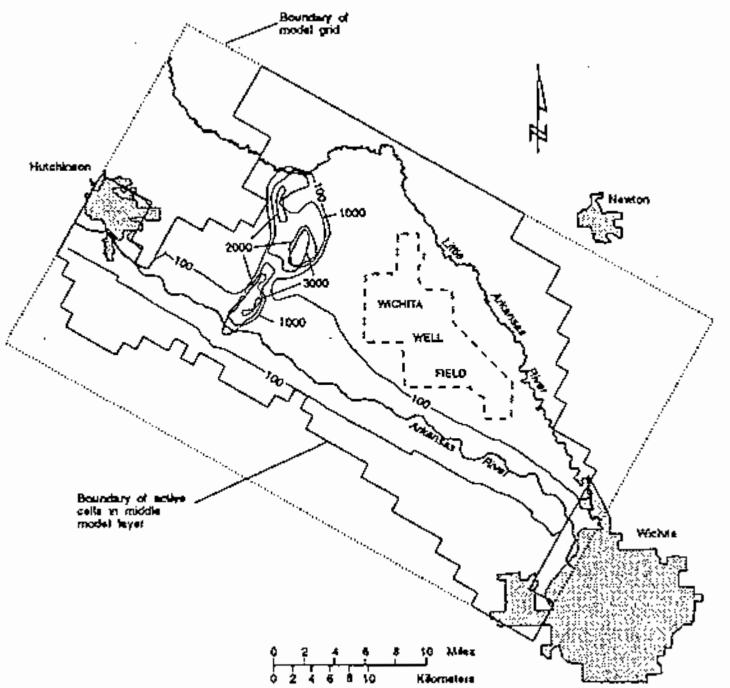


Figure 11b.—Distribution of chloride representing initial conditions for middle model layer, 1940.

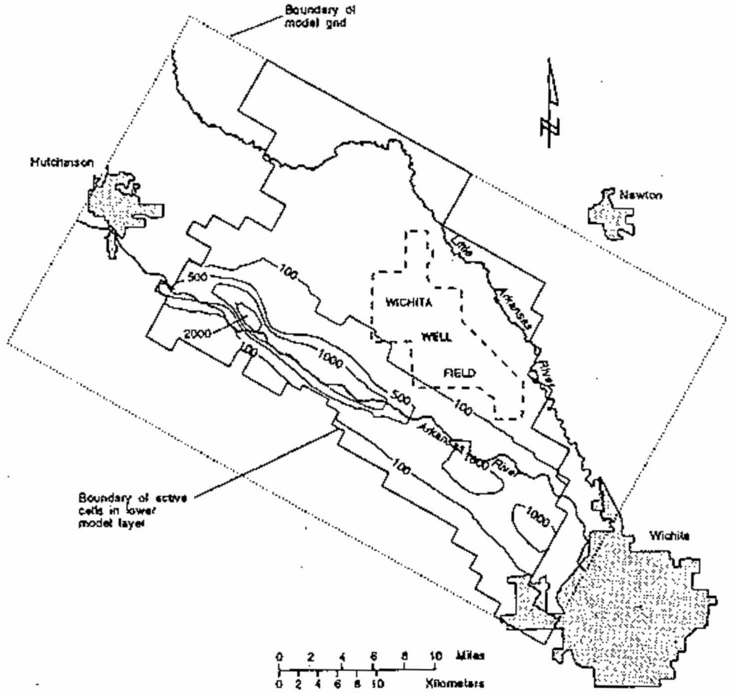


Figure 11c.—Distribution of chloride representing initial conditions for lower model layer, 1940.

***Evaporation-Pan and Hollow-Nikkel Oil Field Brine.***—These sources were not considered in calibration because of the location of the contamination and lack of data. Waste brine from evaporation pans used in the late 1890's and early 1900's by salt companies in Hutchinson is another significant salinity source (Whittemore, 1990). These pans contained brine from salt-solution mining of the Hutchinson Salt Member of the Wellington Formation and were located southeast of Hutchinson and just north of the Arkansas River (figure 5).

The Hollow-Nikkel Oil Field is located near the edge of the model grid where accurate modeling could not be expected. The location and estimated extent of salinity from these sources make these sources much less of a threat than salinity from the Arkansas River or Burrton Oil Field. In addition, little information is available concerning the volumes and concentrations of brines that were introduced into the aquifer. This makes determining initial conditions difficult.

### *Arkansas River as a Chloride Source*

The Arkansas River was modeled as a continuous source of chloride. During a simulation, reaches of the river that lose water would contribute chloride to the aquifer at a given concentration. Reclamation determined this concentration, which varied from 480 mg/L to 630 mg/L from historical data (table 2). Historical data (USGS WATSTORE database) was available from 1961 to the present. The concentration for the first two stress periods was assigned the same value as the third stress period.

Table 2.—Average chloride concentrations from 1940 to 1989

| Stress period | Chloride concentration (mg/L) |
|---|---|
| 1940-1952 | 480 |
| 1953-1958 | 480 |
| 1959-1963 | 480 |
| 1964-1970 | 520 |
| 1971-1979 | 600 |
| 1980-1989 | 630 |

### *Transport Parameters*

The necessary transport parameters describe the advection and dispersion processes. The model inputs required are:

- Effective porosity.
- Longitudinal dispersivity.
- The ratio of transverse to longitudinal dispersivity.
- The ratio of vertical to longitudinal dispersivity.

Laboratory analysis of porosity from samples of the aquifer materials ranged from 24.1 to 60.2 percent (Williams and Lohman, 1949). The higher porosity values are typically associated with clays that have high porosities but low effective porosities. The **effective porosity** is the pore space which water is able to flow through, whereas the porosity is a measure of the total pore space. A previous study representing the aquifer as a single layer used a value of 25 percent for effective porosity determined through calibration (Spinazola et al., 1985).

Values of **effective porosity** for the three-layer model used in this study were determined through the calibration process. The resulting effective porosity values used in the transport model are 30 percent for the upper and lower layers and 20 percent for the middle layer. A smaller value for effective porosity results in faster movement of the water and, thus, the contaminant in the aquifer. These values were determined by comparing predicted chloride breakthrough curves with measured values at various locations in the study area. A smaller effective porosity value for the middle layer may be attributed to more poorly sorted materials. Myers et al. (in review) reports the middle layer consists of clay or silty clay interbedded with sand and gravel and has generally more fine-grain material than the lower and upper layers.

Spinazola et al. (1985) determined that values of 100 feet for **longitudinal dispersion** and 0.3 for the **ratio of transverse to longitudinal dispersion** resulted in a best-fit between model results and measured data. These values were adopted for the transport model. The **ratio of vertical to longitudinal dispersion** was assumed to be negligible, based on sensitivity runs.

#### *Transient Calibration*

***Method of Characteristics.***—The transport method originally used was the method of characteristics. The method exhibited numerical problems during projection (1990-2049) simulations. These problems were manifested in large mass balance errors and unreasonable predicted chloride concentrations. A possible source of these problems is that the flow model was vertically discretized using a deformed mesh. The deformed vertical discretization can introduce numerical discretization errors (Papadopulos and Associates, Inc., 1992). Because of the numerical problems experienced with the method of characteristics during predictive runs, the pure finite-difference method was used.

However, the method of characteristics was reasonably stable during the transient calibration period (1940-1989). During this period, the pure finite-difference method compared reasonably with the method of characteristics. Figure 12 shows the predicted chloride distribution using the pure finite-difference method.

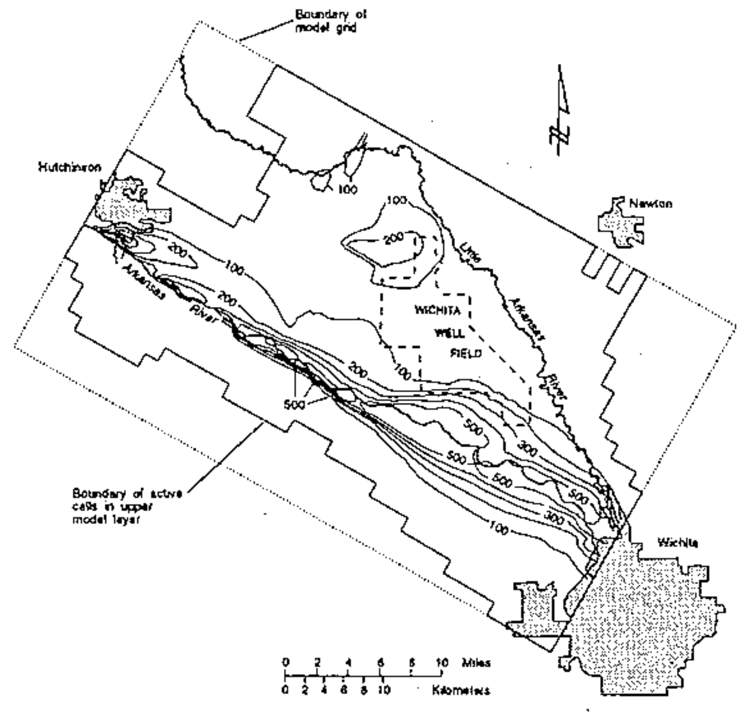


Figure 12a.—Predicted chloride distribution in 1989 for upper model layer.

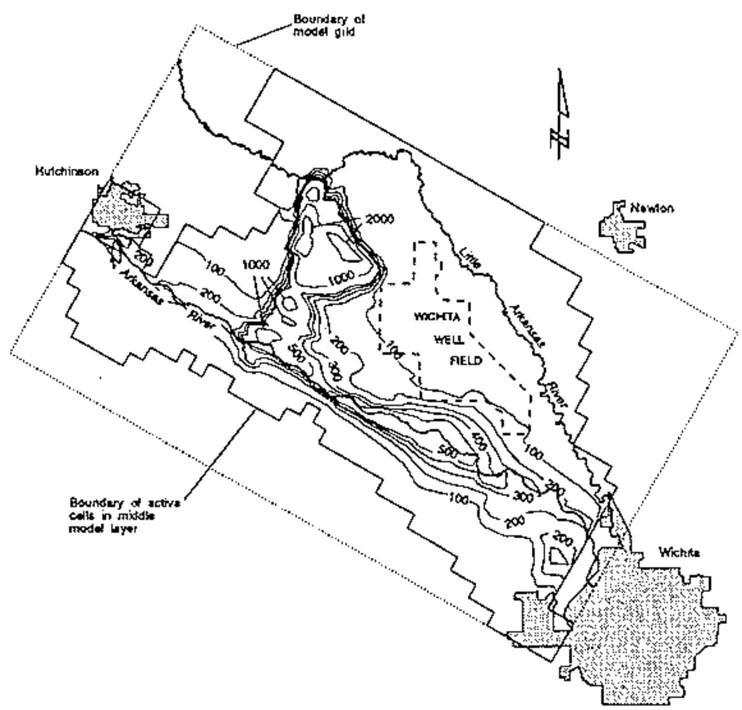


Figure 12b.—Predicted chloride distribution in 1989 for middle model layer.

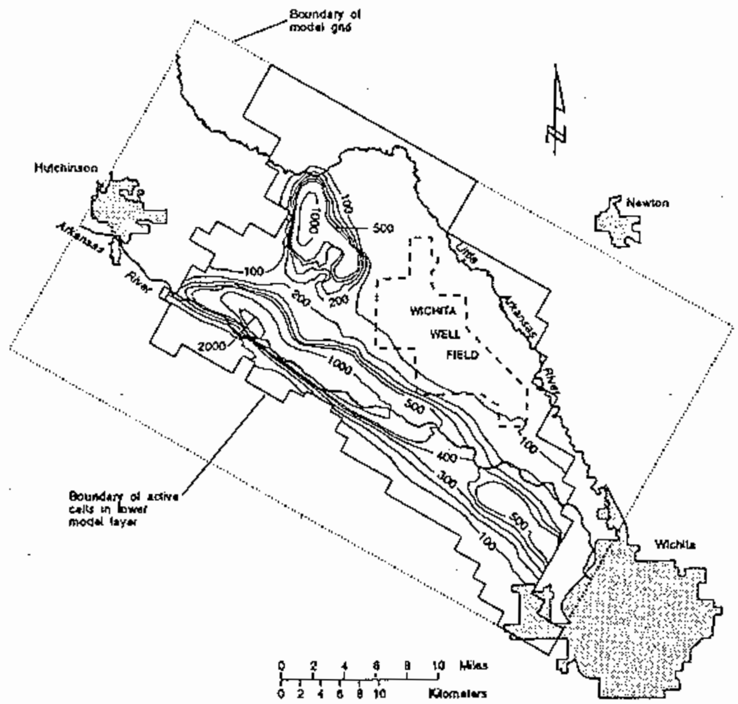


Figure 12c.—Predicted chloride distribution in 1989 for lower model layer.

***Pure Finite-Difference Method.***—The pure finite-difference method can lead to significant numerical dispersion for some problems. Numerical dispersion is caused by the finite-difference approximation of the first-order derivatives (advection term), which involves errors of the order of magnitude of the second-order derivative (dispersion term) (Bear and Verruijt, 1987). Predicted results at the completion of the transient calibration using the pure finite-difference method were compared with those predicted by the method of characteristics. The predicted chloride distributions in 1989 for the two methods compare reasonably. This was assumed to indicate that numerical dispersion was not a prohibitive factor for the problem being studied.

***Calibration.***—For this portion of the study, Reclamation calibrated the transient transport model by attempting to match graphs of measured chloride concentrations versus time with predicted chloride concentrations versus time at various well locations within the study area. These wells were assigned layer numbers corresponding to layers in the model by comparing completion information with layer elevations. Most of the wells used for calibration are located between the chloride sources (Arkansas River and brine evaporation pits) and the Wichita well field area (figure 9 in appendix A). Special attention was given to matching measured well data that exhibited a trend of increasing chloride concentration (breakthrough of chloride). Calibrating to measured chloride concentrations over time permits trends rather than just magnitudes of chloride concentration at a given time to be considered.

Comparing graphs of measured and predicted chloride concentration versus time (appendix C) provide a measure of how well the flow and transport models are calibrated. The best data for calibration is located between the Burrton Oil Field and the Wichita well field where breakthrough curves could be seen in the measured data from numerous wells.

***Calibration Results.***—The transport model predicts concentration curves that are relatively smooth and gradually changing, while the measured data may be more erratic (see the data for well 212 in appendix C as an example). The transport model is based on averaged conditions and is unable to account for local variability around a given well site. Predicted values are also output at regular intervals. The measured data is often not sampled at regular intervals and may contain bad readings resulting from sampling technique, laboratory procedures, or other problems. These potential errors may account for many of points that appear to be outlier values (such as well 312 around 1985).

The bulk of the brine from oil field operations was placed in the middle layer of the model when establishing initial conditions. The graphs of predicted chloride concentration which show breakthrough of this chloride toward the Wichita well field display a good approximation of actual conditions (see appendix C, wells 392, 412, 441, 672, 675, and 798).

The model appears to somewhat overpredict the rate of chloride movement in the upper layer. This is especially evident between the Arkansas River and the Wichita well field (well numbers 121, 122, 150, 152, and 626). Detailed adjustment of effective porosity values within reasonable ranges did not improve the calibration, indicating that additional work on the flow model may be necessary to make further improvements. For this reason, it was decided that assigning uniform values for each layer was a more realistic approach than trying to tweak the model to make detailed improvements.

*1989 Chloride Distribution.*—The 1989 predicted distribution of chloride compared to actual measurements provides useful insights into the strengths and weaknesses of the model (figure 10 in appendix A), although this comparison may not be as indicative of the validity of the model as the comparison of predicted and measured concentrations values over time.

Some areas of high measured chloride concentrations were not considered in the model (figure 7). These areas include the evaporation-pan area and the Hollow-Nikkel Oil Field area. (See the "Salinity Sources" discussion in the "Water Quality" section.)

### *Definition of Zones for Interpreting Model Results*

Model results were processed to produce graphs of average chloride concentration, mass of chloride, and average water level versus time for specific areas within the model grid. Specific areas were defined where chloride transport was considered to be important. This process was intended to simplify the interpretation of model results and to allow easy comparison of different simulations. For example, the average chloride concentration within a given area can be plotted versus time.

This type of plot allows trends to be easily identified and the results of different simulations, such as management alternatives, to be easily compared for that area. These tasks can often be difficult when using contour maps to display results. Typically, contour maps of chloride distribution would be used to evaluate model results. In identifying trends or variations in predicted concentrations over time for a given simulation, numerous chloride distribution maps would have to be produced, including a map for each model layer at different times. To interpret these results, the investigator would need to compare these maps. In addition, comparing multiple simulations would require repeating this process for each simulation, rapidly increasing the number of maps that need to be considered and the complexity of interpreting the results. By producing graphs of average concentration for particular areas, this process can be greatly simplified.

Three areas to evaluate the model results over time were designated to reflect the major areas of concern: transport of chloride toward the Wichita well field from the Burrton Oil Field area, the Arkansas River, and the deep natural saltwater (figure 13). These are:

- **River zone**—defined to evaluate the transport for chloride primarily originating in the Arkansas River and from the deep natural saltwater.
- **Brine zone**—defined to evaluate results for chloride which originated as oil field brine from the Burrton area.
- **Well field zone**—defined to evaluate the impacts of all chloride sources on the area where the Wichita well field is located.

The results of calibration, projection, and management simulations were processed and presented as graphs of average chloride concentration, mass of chloride, and average water level versus time within the defined areas. The average concentration for each layer in an area was computed as the mass of chloride divided by the volume of water in storage for

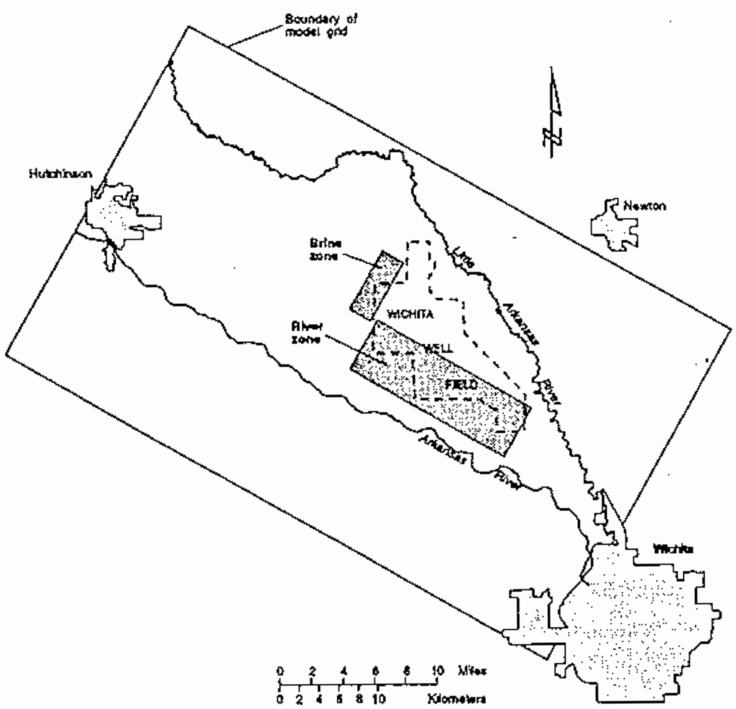


Figure 13a.—Areas used in evaluating model results, brine and river zones.

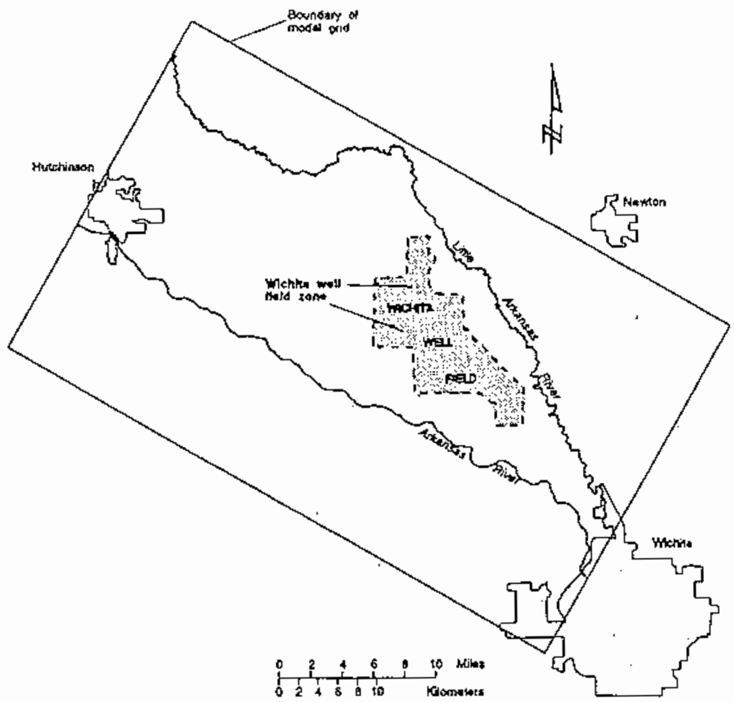


Figure 13b.—Areas used in evaluating model results, Wichita well field zone.

that layer and area. Viewing these graphs permits results to be evaluated in a transient sense and to look at specific concerns, such as transport of saltwater to the Wichita well field from the Arkansas River.

## Transport Model Projection

Projections of chloride transport were made for the period 1990 through 2049. The projections were made assuming stresses and chloride concentration in the Arkansas River for the final stress period of the calibrated model would remain constant throughout the projection simulation. The predicted change in water level in 1989 and 2049 from 1940 conditions shows the impact of withdrawals from the aquifer. A cone of depression would be centered over the Wichita well field (figure 14). The predicted distribution of chloride in 1989 and 2049 when compared with the initial conditions reflects how the chloride distribution has changed and is estimated to change over time (figures 11, 12, and 15).

Predicted distributions of chloride concentration indicate the movement of a chloride plume from the Arkansas River toward the Wichita well field. Graphs of chloride mass and

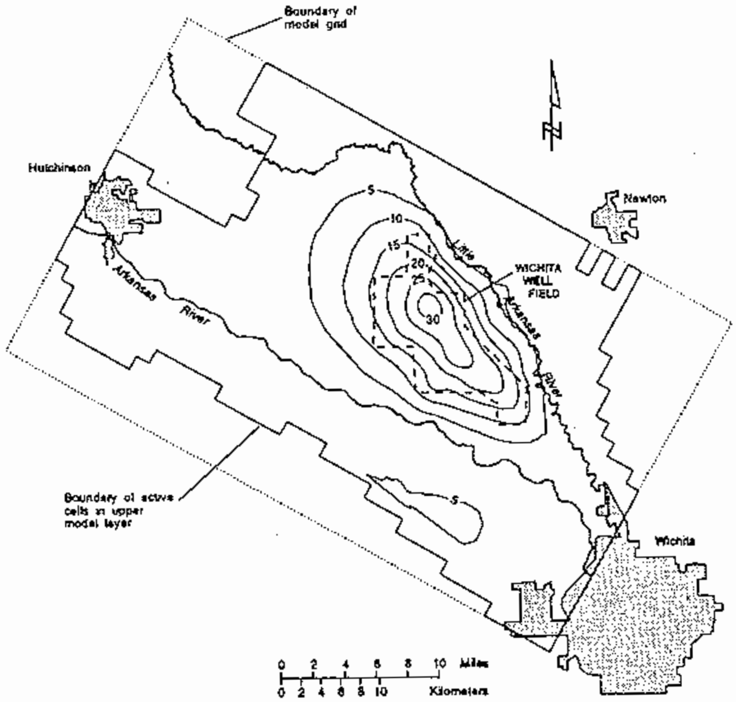


Figure 14a.—Predicted drawdown since 1940 in 1989.

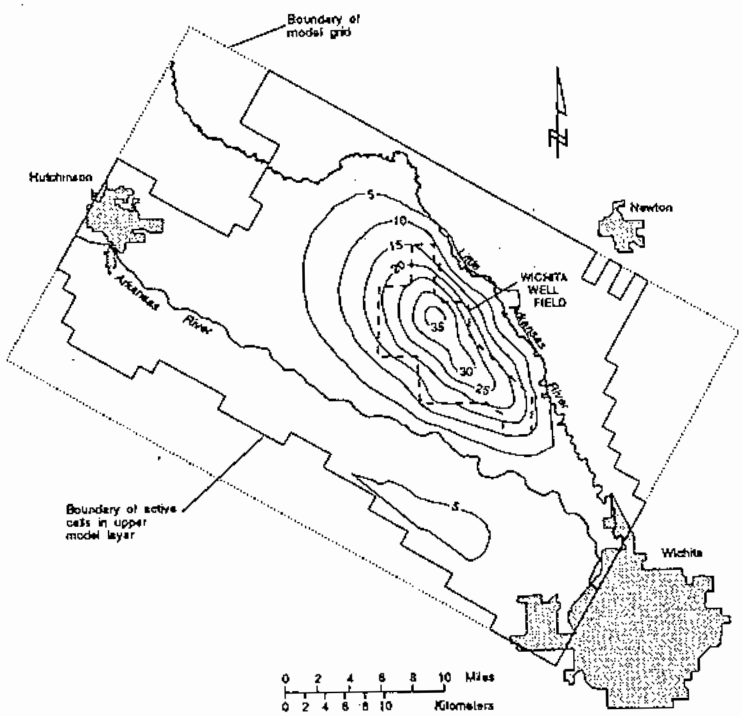


Figure 14b.—Predicted drawdown since 1940 in 2049.

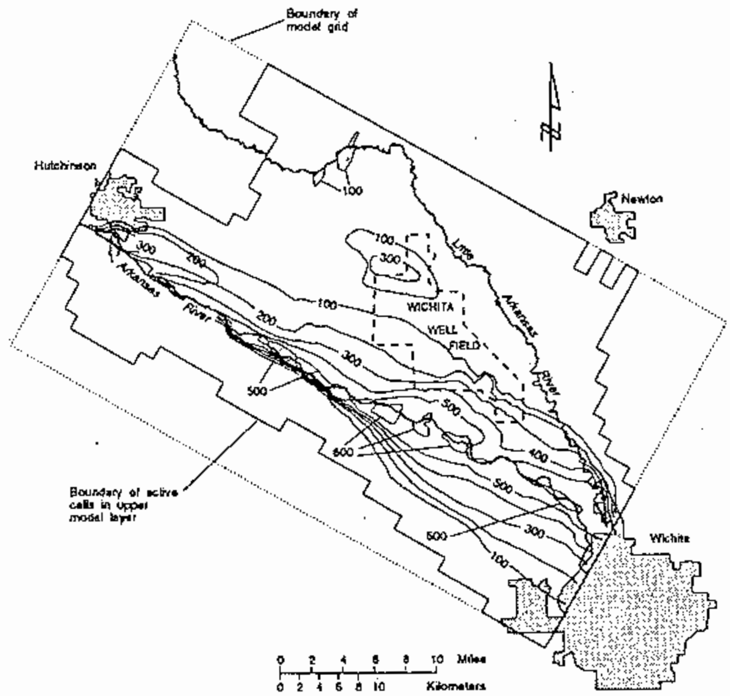

Figure 15a.—Predicted chloride distribution in 2049 for upper model layer.

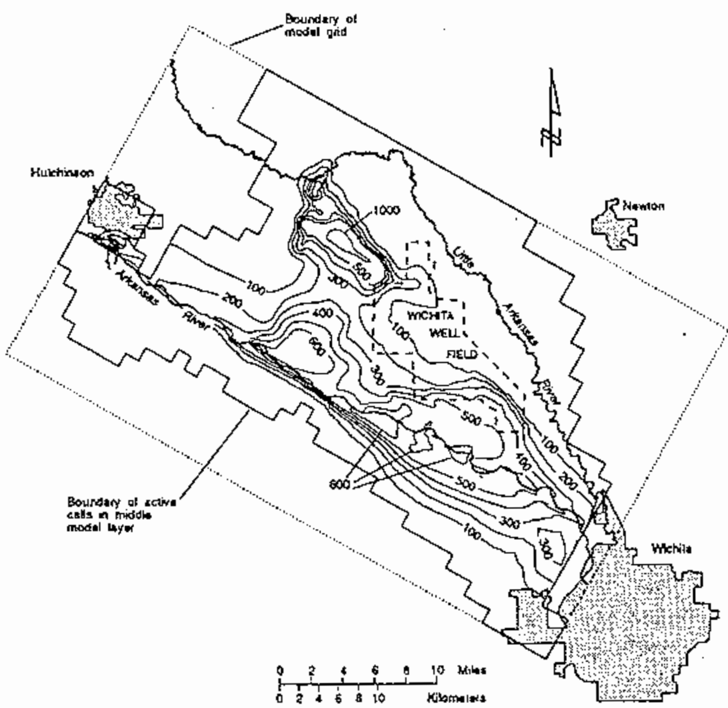

Figure 15b.—Predicted chloride distribution in 2049 for middle model layer.

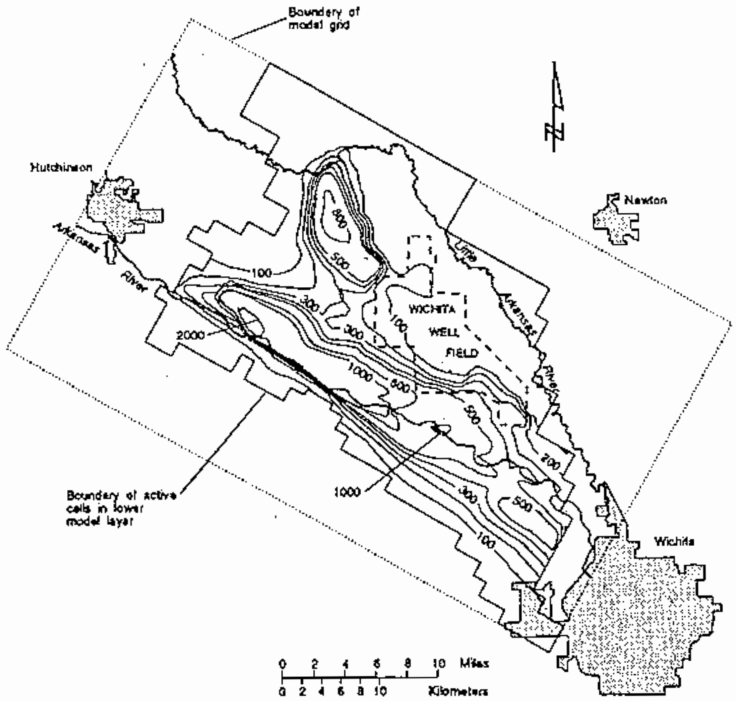


Figure 15c.—Predicted chloride distribution in 2049 for lower model layer.

average concentration versus time represent the movement of this plume in each layer through the river zone (figure 16). In general, the oil field saltwater plume originating in the Burrton area would disperse and move to the east, toward the Little Arkansas River and the Wichita well field. The oil field saltwater would also move vertically to the lower layer from above. Graphs for the brine zone illustrate changes for this plume in mass and concentration from 1940 through 2049 (figure 17). A more detailed discussion of these results is presented in a later section.

### *Reference Simulation*

The reference simulation is a combination of the calibration simulation (1940-1989) and the base projection simulation (1989-2049) to provide a continual model period from 1940-2049.

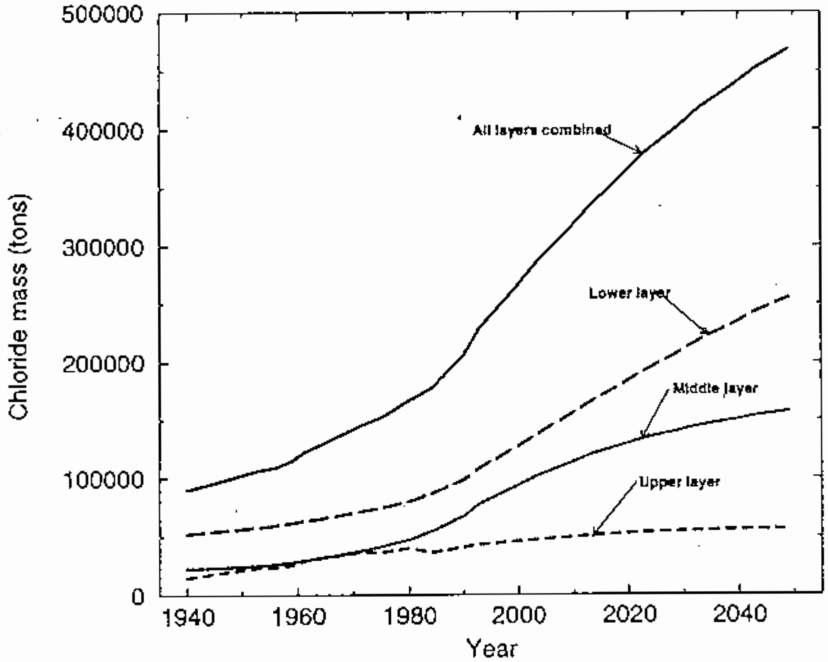


Figure 16a.—Predicted chloride mass for the river zone, 1940-2049.

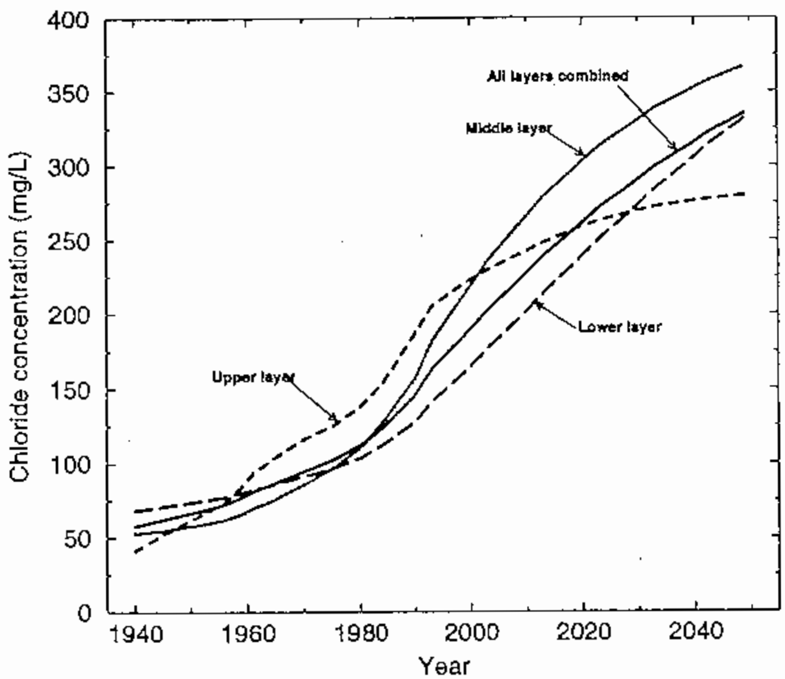


Figure 16b.—Predicted chloride average concentration for the river zone, 1940-2049.

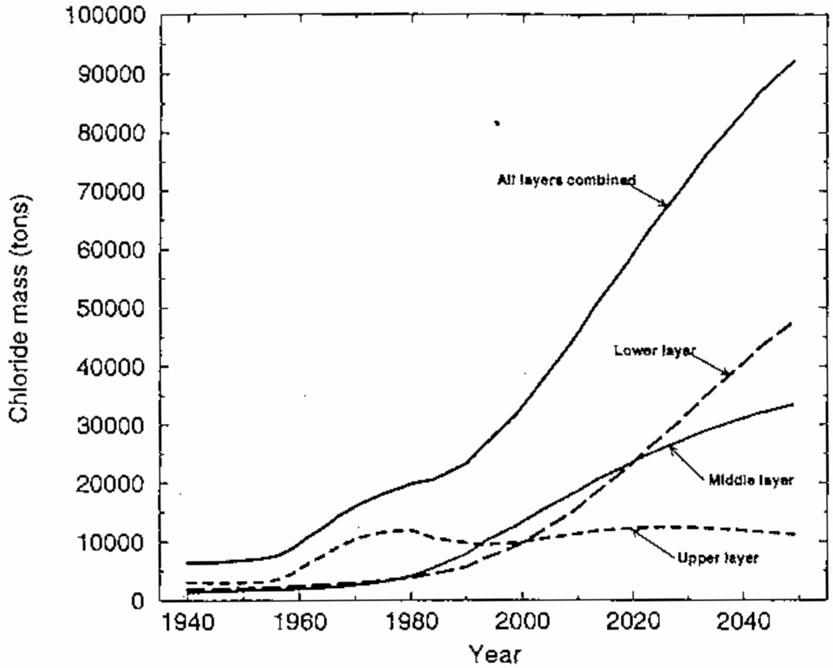


Figure 17a.—Predicted chloride mass for the brine zone, 1940-2049.

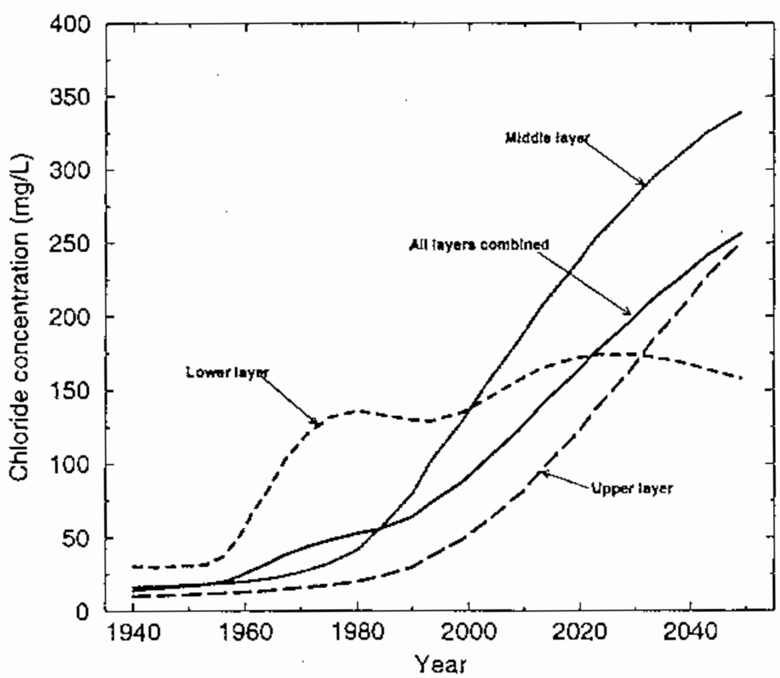


Figure 17b.—Predicted chloride average concentration for the brine zone, 1940-2049.

The base projection was made assuming that stresses and the chloride concentration in the Arkansas River for the final stress period of the calibrated model (1980-1989) would remain constant throughout the projection simulation period.

The results from the following simulations were evaluated by comparing them with the results from the reference simulation:

- Sensitivity.
- Simulations of individual sources.

Results from management simulations were compared with results from the base projection simulation to cover the same time period (1990-2049).

Results from the reference simulation indicate that chloride plumes are migrating from the Arkansas River and Burrton Oil Field area toward the Wichita well field area. The transport model predicts that chloride concentrations would be as high as 400 mg/L in the south part and 300 mg/L in the extreme northwest part of the well field by 2049. The predicted movement of these plumes is considered to be reasonable, while more uncertainty exists concerning the predicted arrival times.

## Sensitivity Analysis

Sensitivity analyses were performed by varying effective porosity and hydrodynamic dispersion coefficients. For each sensitivity simulation, one of the parameters was increased or decreased a proportionate amount from the accepted or calibrated value. This increase or decrease was then applied uniformly over the entire model grid. The impact on predicted chloride concentration was evaluated by comparing the predicted average concentrations from the sensitivity simulations with that of the reference simulation in areas of interest.

The transport model is most sensitive to effective porosity and relatively insensitive to values representing hydrodynamic dispersion for the three areas defined.

### *Sensitivity to Effective Porosity*

*River Zone.*—For the river zone, the concentration graphs deviate steadily from those for the reference simulation (1940-2049) (figure 11a in appendix A). The Arkansas River provided a continuous source of chloride, the primary source that impacts the river zone. Varying effective porosity values impacts the travel time of chloride from the river into the river zone and affects the appearance of the breakthrough curve.

*Brine Zone.*—The source of chloride impacting the brine zone is primarily oil field brine from the Burrton Oil Field. Movement of oil field saltwater into this zone is sensitive to effective porosity throughout the reference simulation (figure 11b in appendix A). This source is noncontinuous and has initial conditions that are not uniformly distributed. Consequently, slugs or pockets of higher chloride concentrations break through at different times. The result is a more variable concentration graph that is more pronounced for smaller effective porosity values (figure 11b in appendix A).

*Well Field Zone.*—The chloride concentration graphs for the well field zone indicate influence from both chloride sources, the Arkansas River and oil field brine, based on similarities with both the graph for the river zone and the graph for the brine zone (figure 11c in appendix A).

### *Sensitivity to Dispersion Parameters*

Values representing hydrodynamic dispersion include longitudinal dispersivity and lateral dispersivity. The predicted average chloride concentrations are relatively insensitive to these parameters for the defined areas (figures 12 and 13 in appendix A).

### *Comparison of Zones and Parameters*

The relative sensitivity of predicted chloride concentrations to a parameter can also be evaluated by observing the percent change in concentration as a function of the percent change in the parameter. The absolute percent change in average predicted chloride concentration for all layers combined in an area can be plotted against the percent change in the parameter.

Sensitivity to porosity evaluated at the end of the calibration period is very similar for the different areas. The brine zone displays the greatest sensitivity for a negative percent change in porosity (figure 14a in appendix A). A similar analysis for longitudinal dispersivity indicates that the brine zone is significantly more sensitive to longitudinal dispersivity than the river zone or the well field zone (figure 14b in appendix A).

The sensitivity to porosity is relatively much higher than the sensitivity to longitudinal dispersivity for the three defined areas (figure 14c in appendix A).

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## Summary of Simulations

Table 3 describes some of the simulations run under this study, with a brief discussion of the general results from each simulation. When not stated otherwise, the management simulation used the same boundary conditions, initial conditions, and stresses as the base projection. The data for these boundary conditions, initial conditions, and stresses are taken from data used in the last stress period in the calibration simulation (1980-1989). Section "Solute-Transport Model" provides more information on how these data were obtained and used. Initial conditions are those predicted by the calibrated model in 1989 as reflected in figure 12. The sections following this table—"Basic Simulations," "Simulations of Individual Sources," and "Management Simulations"—provide an overview of the simulations and results.

The reference simulations are further described in "Transport Model Projection."

Table 3 is also reproduced in appendix A for readers who wish to consult the table while reading about the further details of these simulations discussed in the following sections.

Table 3.—Summary of simulations

| Reference simulations | Results |
|---|---|
| **Calibration** (1940-1989): Considered transport of chloride in the Equus Beds aquifer. Sources considered are: the Arkansas River, deep natural saltwater, and oil field brine. Calibration performed by attempting to match chloride breakthrough curves of measured data at various locations. | Reasonable representation of actual conditions in the primary areas of interest from the Arkansas River and the Burrton Oil Field area to the Wichita well field area. The model appears to over-predict the rate of chloride movement in the upper layer. |
| **Base projection** (1990-2049): Projection of conditions existing at the end of the calibration simulation to the year 2049.<br><br>*Boundary conditions, initial conditions, and stresses*: Same as those existing at the end of the calibration simulation in 1989. | *Water elevations*: Cone of depression centered over the Wichita well field area.<br><br>*Chloride movement*: Plumes migrating from the Arkansas River and Burrton Oil Field area toward the Wichita well field area. Predicted chloride concentrations are as high as 400 mg/L in the southern part and 300 mg/L extreme northwest part of the well field by 2049. |
| **Simulations of individual sources** | **Results** |
| **Arkansas River** (1940-2049): Saltwater flowing from the river to the aquifer was considered as the only source of chloride. Chloride concentrations in the river varied from 480 mg/L to 630 mg/L from 1940 to 1989 and were constant at 630 mg/L from 1990 to 2049.<br><br>*Initial conditions*: No chloride present in aquifer in 1940. | Water from the river accounts for the majority of chloride in the upper layer. Significant vertical movement of chloride from the river to the middle and lower model layers. Chloride plume in all layers expanding toward the Wichita well field area. |
| **Deep natural saltwater** (1940-2049). Natural chloride located around a low or trough in the bedrock surface near the course of the Arkansas River was considered as the only source of chloride.<br><br>*Boundary conditions*: Constant concentration cells in the lower layer represent chloride in the trough below the river.<br><br>*Initial conditions*: The concentration of chloride ranges from 900 to 4,000 mg/L in the constant concentration cells. | Chloride is moving from the trough to the east toward the Wichita well field primarily in the lower layer, with some movement upward into the middle layer. |

Table 3.—Summary of simulations (continued)

| Simulations of individual sources (continued) | Results (continued) |
| --- | --- |
| **Burrton Oil Field brine** (1940-2049). Brine from oil field operations that was disposed into surface pits from the 1930's to 1940's considered as the only source of chloride.<br><br>*Initial conditions*: Chloride placed in upper and middle model layers. | Movement of the brine is primarily to the east toward the Wichita well field and Little Arkansas River. Significant vertical movement of chloride into the lower layer from the middle layer. |
| **Management simulations (1990-2049)** | **Results** |
| **Investigate the impacts of Arkansas River flow on the aquifer.**<br><br>(2a) Divert Arkansas River upstream of study area.<br><br>*Stresses*: No flow in Arkansas River during simulation.<br><br>(2b) Divert Arkansas River upstream of study area and eliminate underflow entering study area below Arkansas River.<br><br>*Stresses*: No flow in Arkansas River during simulation.<br><br>*Boundary conditions*: Constant head cells eliminated in upper and middle model layers below Arkansas River at the northwest boundary of the model. | These simulations demonstrate the importance of the Arkansas River acting as a water supply for the aquifer.<br><br>*Water elevations*:<br><br>(2a) Predicted to fall as much as 25 feet near the river with an average drop of about 13 feet within the Wichita well field zone.<br><br>(2b) Greater impacts than simulation 2a.<br><br>*Chloride movement*:<br><br>(2a) Little movement of the chloride plume that originated from the river toward the Wichita well field, because the river has been removed as a water and chloride source.<br><br>(2b) Results similar to simulation 2a. |
| **Install pumping wells to intercept oil field saltwater.** Install pumping wells strategically located to remove chloride from the aquifer.<br><br>*Stresses*: Twenty wells located in the middle and lower model layers (10 each layer) pumping a total of:<br><br>(4a2) 3,200 acre-feet per year (100/gallons per minute/well)<br>(4b2) 1,600 acre-feet per year (50/gallons per minute/well)<br>(4c2) 6,400 acre-feet per year (200/gallons per minute/well) | *Water elevations*: All simulations resulted in a cone of depression centered at the pumping wells. Maximum water elevation drops of around 3, 7, and 15 feet as withdrawal rates increase.<br><br>*Chloride movement*: Effective in minimizing the impact of the Burrton oil field saltwater on the Wichita well field area.<br><br>*Brine zone*: Average chloride concentrations decrease as withdrawal rates increase by as much as 30 percent from that predicted by the base projection. |

Table 3.—Summary of simulations (continued)

| Management simulations (1990-2049) (continued) | Results (continued) |
|---|---|
| **Eliminate pumping near Arkansas River** in an area from the Little Arkansas River to approximately 33 miles north. Pumping in this area may become undesirable as chloride concentrations increase in the aquifer.<br><br>*Stresses*: Eliminated pumping within this area in the:<br>(3a) upper model layer (15,300 acre-feet per year) and<br>(3b) upper and middle model layers (18,500 acre-feet per year) | *Water elevations*. Minimal impacts.<br><br>*Chloride movement*. Minimal impacts.<br><br>*River zone*. Rate of chloride concentration increase is only slightly less than that of the base projection. |
| **Place hydraulic barrier along Arkansas River** by recharging better quality water between the Arkansas River and the Wichita well field to inhibit the movement of poor quality water from the river to the aquifer.<br><br>*Stresses*: The water was recharged to the upper layer at the following rate, concentration, and location:<br><br>(5a) 5,600 acre-feet per year, 150 mg/L, 1 mile north of Arkansas River.<br>(5b) 2,800 acre-feet per year, 150 mg/L, 1 mile north of Arkansas River.<br>(5c) 11,200 acre-feet per year, 150 mg/L, 1 mile north of Arkansas River.<br>(5d) 5,600 acre-feet per year, 150 mg/L, 2 miles north of Arkansas River.<br>(7a) 5,600 acre-feet per year, 50 mg/L, 1 mile north of Arkansas River.<br>(7b) 5,600 acre-feet per year, 250 mg/L, 1 mile north of Arkansas River.<br>(5e) Alternatively, withdrawals were reduced in the lower model layer by 5,600 acre-feet per year in the southern portion of the Wichita well field. | *Water elevations*: Minimal impact with a maximum rise of 3 feet at the recharge location.<br><br>*Chloride movement*: In general, effective in inhibiting the movement of chloride from the river.<br><br>*River zone*: Average chloride concentrations are decreased from the base projection by as much as 23 percent at the highest recharge rate. The decreases in average concentration are less for lower recharge rates. The predicted concentrations are relatively insensitive to the concentrations of recharge water and the areas of recharge considered. Reducing withdrawals within the Wichita well field was less effective in reducing chloride concentration from that predicted in the base projection. |

Table 3.—Summary of simulations (continued)

| Management simulations (1990-2049) (continued) | Results (continued) |
|---|---|
| **Reduce pumping within the Wichita well field** to lessen the water quality impact from chloride sources.<br><br>*Stresses*: Pumping was reduced within the well field area by the following total amount:<br><br>(8a1) 5,600 acre-feet per year, lower layer<br>(8a2) 11,200 acre-feet per year, lower layer<br>(8a3) 16,800 acre-feet per year, lower layer<br>(8a4) 22,400 acre-feet per year, lower layer<br>(8b1) 5,600 acre-feet per year, all layers<br>(8b2) 11,200 acre-feet per year, all layers<br>(8b3) 16,800 acre-feet per year, all layers<br>(8b4) 22,400 acre-feet per year, all layers<br>(8c1) 5,600 acre-feet per year, upper layer<br>(8d1) 5,600 acre-feet per year, middle layer | *Water elevations*: Increased for all simulations with the largest increases centered in the Wichita well field area.<br><br>*Chloride movement*: In general, decreases the impacts from chloride sources. Larger reductions in withdrawals have a greater impact in reducing average chloride concentrations. Average concentrations are relatively insensitive to the model layer in which withdrawals are reduced. |

## Simulations of Individual Sources

### *General Methodology*

The transport of chloride observed in the calibration and projection simulations (1940-2049) can be further characterized by considering each source individually. This allows the relative movement and distribution of chloride in the aquifer source to be evaluated for each source:

- The Arkansas River.
- Deep natural saltwater.
- Brine from the Burrton Oil Field.

Characterizing transport from each of these sources helps to better understand how the aquifer is being contaminated and provides insights into the effective management of the aquifer.

These simulations involved changing the initial and boundary conditions to reflect only the source being considered. They cover the calibration and projection periods from 1940 through 2049. Because the relative contribution from each source to this distribution cannot be determined, these simulations only consider the chloride contributed to the aquifer since 1940 from the source being considered. They do not consider the initial distribution of chloride in the aquifer in 1940. Therefore, the results are used to compare the relative predicted movement and distributions of chloride from these sources.

Chloride distribution maps for each layer were produced for 1989 and 2049, as well as graphs of chloride concentration, chloride mass, and water level versus time for the three zones previously defined.

### *General Conclusion*

The increasing pumpage from the aquifer is primarily responsible for the Arkansas River's contribution of chloride and the oil field saltwater plume's movement toward the well-field. Withdrawals from the aquifer have also induced significant vertical movement of chloride into the lower part of the Equus Beds aquifer. Chloride from the Arkansas River appears to pose the greatest long-term threat to the quality of water in the well field zone.

*Arkansas River*

Chloride originating in the Arkansas River was simulated by assigning a chloride concentration to water that flows from the Arkansas River to the aquifer. Chloride concentrations in the river varied from 480 mg/L to 630 mg/L from 1940 to 1989 (table 2) and were constant at 630 mg/L from 1990 through 2049. The aquifer was assumed not to have any chloride present at the start of the simulation in 1940 because only the chloride contributed to the aquifer since 1940 was considered.

The Arkansas River accounts for the majority of chloride in the upper layer (figures 15-20 in appendix A). There would be significant vertical movement of chloride originating in the river to the middle and lower model layers, with a plume of chloride in all layers that expanded toward the well field zone (figures 15 and 16 in appendix A). The plume in the lower layer is predicted to reach the southern boundary of the well field by 2049, though calibration results suggest that the rate of chloride movement in this area may be overpredicted.

The influence of withdrawals from the aquifer during 1940 to 1989 (figure 4), especially by the Wichita well field, would be primarily responsible for the movement of chloride from the Arkansas River into the aquifer. Losses from the Arkansas River increase when gradients inducing flow between the river and aquifer increase. The gradients are increased by withdrawals from the aquifer (figure 18). In 1940, the Arkansas River had a simulated net gain of about 15,000 acre-feet per year within the study area. By 1989, there would be a net loss of about 38,000 acre-feet per year.

The water elevation would fall as much as 30 feet, with an average drop within the well field zone of about 20 feet (figures 14a and 19). The large drawdowns in this zone have induced vertical movement of chloride into the middle and lower layers, since roughly 74 percent of the pumpage in this zone is from the middle and lower layers (from data provided by Myers et al., in review). Water levels are predicted to reach steady-state conditions around 2010 with an average water level drop of about 24 feet in the well field zone.

Chloride mass and concentration graphs for the river zone for each layer characterize chloride transport over time from the Arkansas River toward the well field. The mass of chloride would increase steadily from about 1990 with the bulk

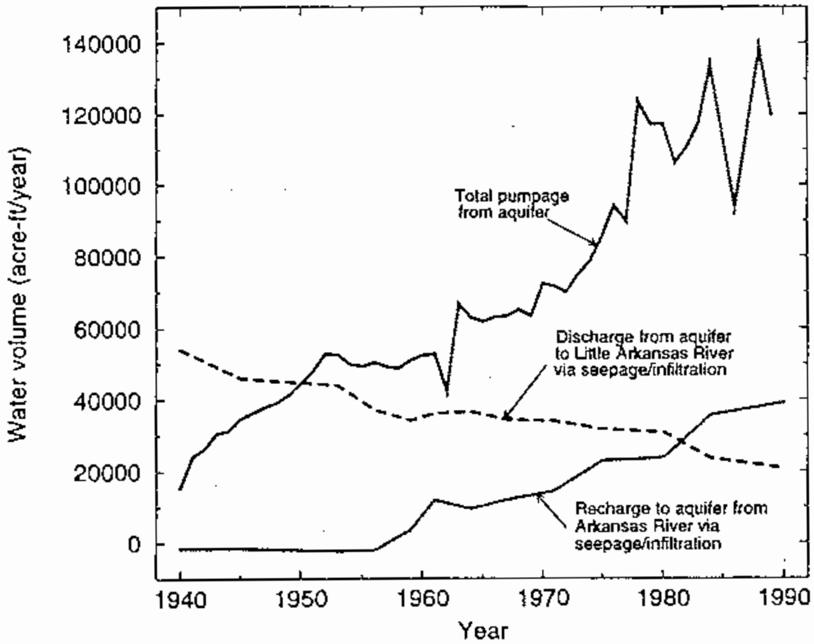


Figure 18.—Total pumpage from aquifer and simulated net stream losses/gains in the Arkansas and Little Arkansas Rivers, 1940-1989.

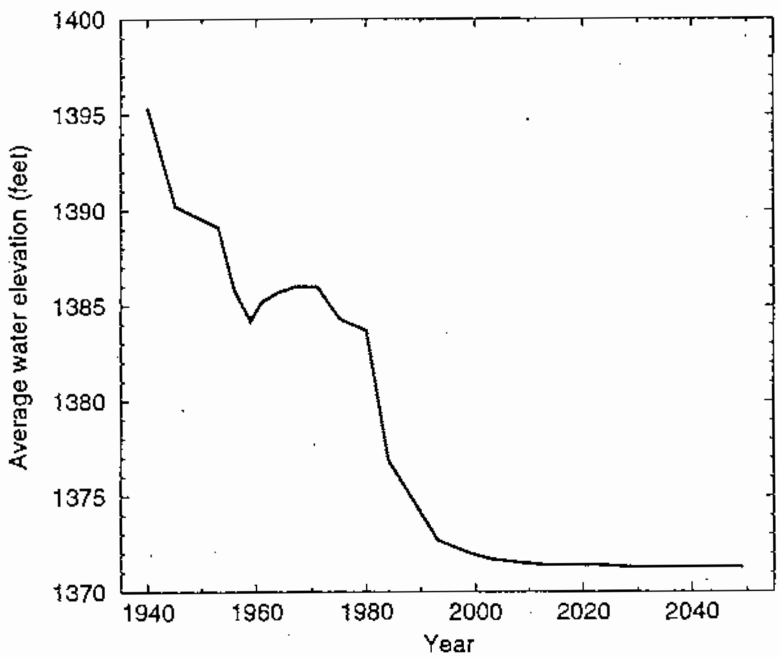


Figure 19.—Predicted average water table elevation in the Wichita well field zone, 1940-1989.

entering the middle and lower model layers (figure 21a in appendix A). After 1990, the mass of chloride in the upper layer would change only slightly when compared to the middle and lower layers because almost as much chloride would leave the zone as enters it. As the chloride plume moves downgradient in the upper layer, it would be displaced downward and diluted by recharge from precipitation. The average chloride concentration in 2049 would be much less in the lower layer than the upper layer (figure 21b in appendix A), although the lower layer would contain more than twice the mass of chloride because the lower layer has much more water in storage than the upper layer.

#### *Deep Natural Saltwater*

Natural saltwater located in the deepest part of the aquifer around a bedrock low, or trough, near the course of the Arkansas River is simulated by using constant concentration cells in the lower model layer (figures 10 and 20). The concentration of these cells ranges from 900 mg/L to 4,000 mg/L. This is the only chloride shown as present in the aquifer in 1940 for this simulation.

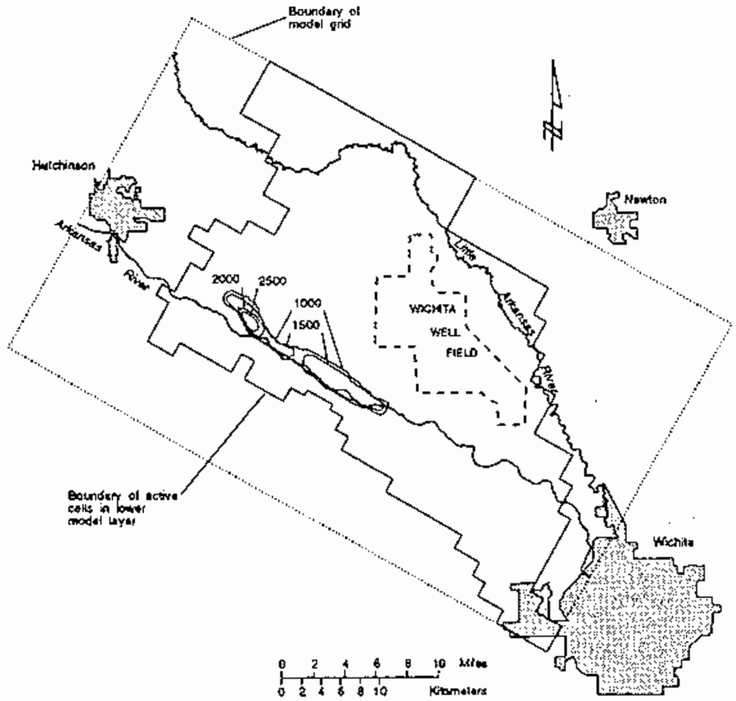


Figure 20.—Distribution of chloride in the lower model layer, representing initial conditions with deep natural saltwater as the only chloride source, 1940.

Chloride would move from the constant concentration cells to the east toward the well field primarily in the lower layer with some movement upward into the middle layer (figures 17 and 18 in appendix A). Movement of chloride into the river zone would be predominantly in the lower layer and would increase steadily from about 1990 on (figure 22 in appendix A).

#### *Burrton Oil Field Brine*

Chloride from the Burrton Oil Field operations is simulated with the initial conditions for oil field brine in the upper and middle model layers, as discussed previously (figure 21). All other chloride sources are excluded from the simulation with no chloride initially present in the lower layer.

Movement of chloride would be primarily to the east toward the Wichita well field and Little Arkansas River (figures 15 and 16 in appendix A). The majority of the chloride initially placed in the upper layer would have moved into the middle layer by 1989. Movement of chloride into the lower layer from

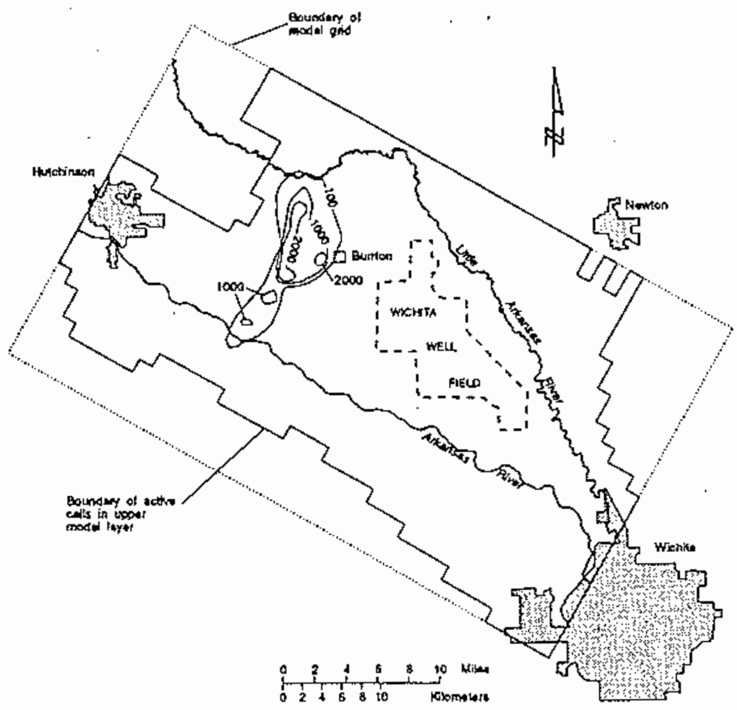


Figure 21a.—Distribution of chloride in the upper model layer, representing initial conditions with oil field brine as the only chloride source, 1940.

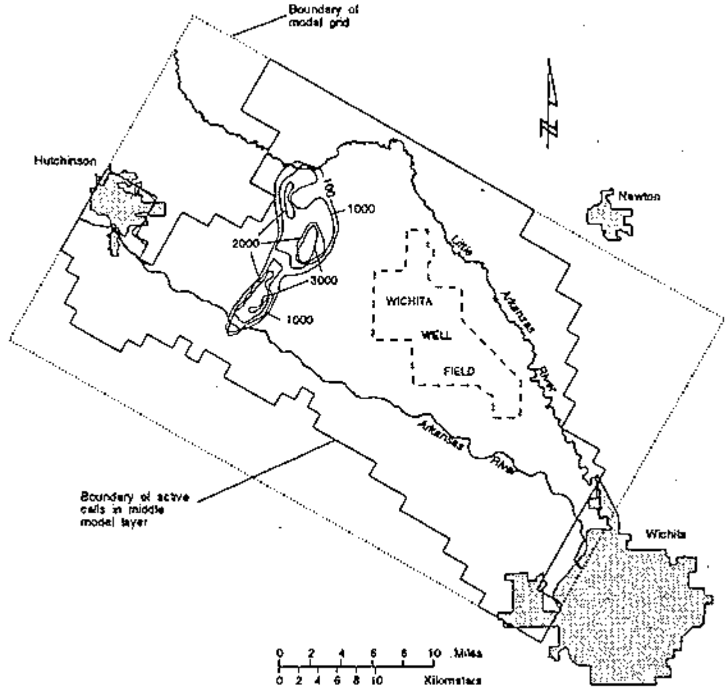


Figure 21b.—Distribution of chloride in the middle model layer, representing initial conditions with oil field brine as the only chloride source, 1940.

above would be significant. This vertical movement is attributed to pumping from the middle and lower layers, primarily within the well field zone.

The withdrawals of water in the well field zone significantly influence the movement of the oil field saltwater. Water levels prior to well development indicate that flow in the northern half of the saltwater plume would be to the northeast toward the Little Arkansas River (figure 4 in appendix A). Movement would be almost due east toward the well field at the present. Thus, eventually much of the Burrton Oil Field saltwater would be collected by the Wichita well field.

The predicted plume in the middle and lower layers would reach beyond the northwest border of the well field zone by 2049. By this time, the plume would have dispersed with peak chloride concentrations decreasing as the initial mass of chloride is mixed with larger volumes of water and is diluted by recharge from precipitation. In addition, chloride would be removed from the aquifer by wells and flow into the Little Arkansas River.

Graphs of the chloride mass and average concentration versus time within the brine zone for each layer characterize transport of the oil field saltwater plume toward the well field (figure 23 in appendix A). The plume would arrive in this zone around 1952 in the upper layer with a peak in mass around 1980. Later arrivals in the middle and lower layers would be followed by steady increases in mass and concentration.

#### *Impacts of Individual Sources on the Wichita Well Field*

The relative impacts of specific sources on a defined area, such as the Wichita well field area, can be observed by comparing graphs for each source. Each figure presents a graph for the reference simulation (1940-2049) as well as graphs for each source: the Arkansas River, deep natural saltwater, and oil field brine. The chloride mass graphs do not balance because the simulations of individual sources do not consider the chloride that was in the aquifer in 1940. The difference between the sum of the chloride mass of the three sources and the 1940-2049 reference simulation varies through time. Thus, the sum will be less because of the chloride actually present in the aquifer in 1940 and the redistribution of that chloride with time.

Examination of graphs for the well field zone indicates that the Arkansas River poses the greatest threat through 2049, although the oil field saltwater plume contributes a significant amount of chloride (figure 24 in appendix A). Chloride mass and concentration from the river would steadily increase from about 1990 to 2049, while curves for the oil field saltwater would flatten out somewhat. The oil field saltwater would contribute the largest mass of chloride until about 2010 when the Arkansas River would become the largest contributor.

Inspection of graphs for the reference simulation reveal that by 2049 over half of the chloride would be located in the lower layer, although the average concentration would be at least as low as that in the other layers (figure 25 in appendix A). The lower layer has more water in storage than the other layers and even at a lower concentration can contain more mass.

Graphs for the lower layer for different sources indicate that the Arkansas River and oil field brine would have contributed similar amounts of chloride, while the deep natural saltwater would account for a smaller but increasing amount (figure 26 in appendix A).

## Management Simulations

### *General Methodology*

Potential management issues and strategies were investigated, and the results from these simulations were predicted through 2049. These simulations primarily involved modifying the stresses on the aquifer in the flow model to represent new conditions. All changes in stresses were assumed to begin in 2000.

Results were evaluated by using:

- Water level difference maps.
- Chloride concentration maps.
- Water level graphs.
- Chloride mass and concentration graphs.

The water level difference maps depict the difference between water levels predicted by the simulation being investigated and the base projection.

### *Investigate Impacts of Arkansas River Flow*

The Arkansas River loses water during extended periods of baseflow in much of the model area and provides a significant amount of water to the aquifer. Two simulations were run to investigate the impacts of flow in the Arkansas River:

1. **Arkansas River streamflow set to zero.** As water demands upstream increase in the future, flows in the river may decrease. The entire flow of the Arkansas River was assumed to be diverted upstream of the model area and was simulated by reducing riverflow to zero where the river enters the model area.

2. **No-flow boundary and zero streamflow.** For a more extreme scenario, the constant head boundary located where the Arkansas River enters the

model area (northwestern edge) was changed to a no-flow boundary in addition to a streamflow of zero in the Arkansas River. Although this scenario is unrealistic, simulation results demonstrate the importance of Arkansas River and subsurface flows as water sources to the aquifer.

The impacts of eliminating Arkansas River flow into the area demonstrate the importance of the river acting as a water supply for the aquifer. The projected water levels in 2049 would drop as much as 25 feet near the river, with average drops of about 13 and 9 feet within the river zone and well field zone (figures 27a and 28 in appendix A). The predicted water level differences reveal where water is currently being supplied to the aquifer from the river. The greatest amount of water (and thus chloride) currently being contributed to the aquifer is around the maximum predicted water level differences along the river (figure 27a in appendix A). The primary impacts of removing Arkansas River flow stem from the removal of the water and chloride source. Consequently, the chloride plume that originated from the river would move only slightly toward the Wichita well field (figure 29 in appendix A).

In addition to removing riverflow, the second simulation involving the no-flow boundary would have a greater impact in the well field zone and a much greater impact on water levels in the Hutchinson area (figure 27b in appendix A). Water quality impacts are similar to the first simulation (figure 29 in appendix A).

The scenarios necessary to produce these conditions may be unrealistic, and the simulations do not account for the change in boundary conditions that would actually occur. For example, a lack of flow in the Arkansas River because of conditions upstream would likely change the boundary conditions along the northwestern edge of the model because water levels upstream of the model also depend on flow in the river.

#### *Eliminate Pumping Near Arkansas River*

Pumping ground water for agricultural use near the Arkansas River may become undesirable in the future as chloride concentrations increase in the aquifer. Most pumping near the river is from the upper two layers of the model. Pumping was eliminated from these layers within an area extending north of the river for about 3 miles (figure 22). Simulations were made to represent scenarios with no pumping from the upper layer and with no pumping from the upper and middle layers within this area.

The impacts of eliminating this pumping would be minimal with a water level rise of as much as 7 feet and average water level rises of 3 and 4 feet within the river zone predicted by 2049 for the two simulations (figures 30 and 31a in appendix A). The rate of chloride concentration increase in the river zone would be only slightly less than that of the base projection with a predicted decrease in average concentration of about 20 mg/L by 2049 (figure 31b in appendix A).

#### *Install Pumping Wells to Intercept Oil Field Saltwater*

Installing pumping wells in strategic locations to remove chloride from the aquifer may effectively minimize the impact of Burrton Oil Field saltwater on the Wichita well field. A relatively large mass of chloride may be removed from the

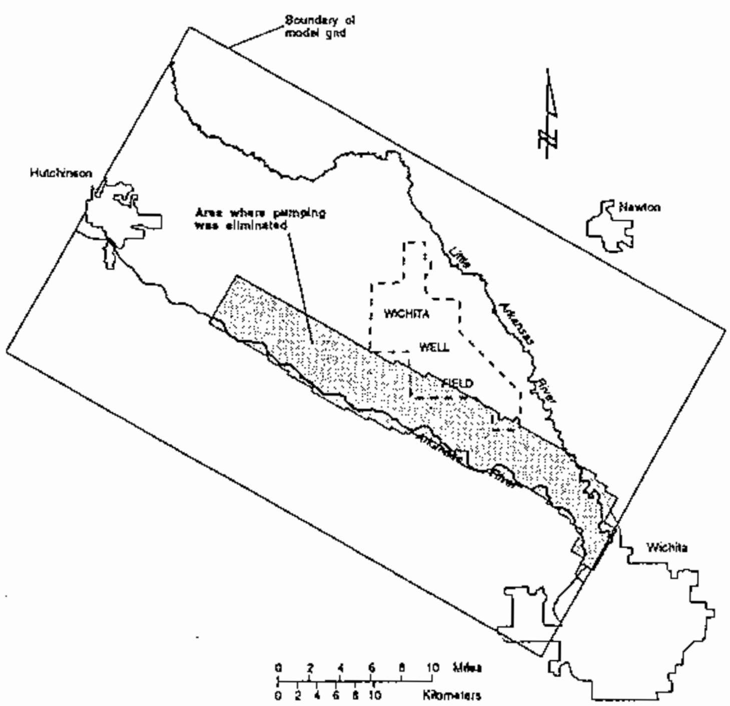


Figure 22.—Area where pumping was eliminated near the Arkansas River.

aquifer by locating withdrawal wells in the highest concentration area of the plume. A total of 20 wells located just east of Burrton were assumed to be divided between the middle and lower model layers (figure 23). Pumping rates for each well of 50, 100, and 200 gallons per minute (gpm) were considered. The water produced might be blended with the Wichita well field supply water.

All three simulations with varying withdrawal rates result in a cone of depression centered at the pumping wells and have an extent which increases as withdrawals are increased. Maximum water level drops of around 3, 7, and 15 feet are predicted in 2049 for the three withdrawal rates relative to the base projection. Drawdown impacts would reach the well field zone (figure 32 in appendix A).

The results of these simulations for water quality were evaluated using graphs of average chloride concentration. The average chloride concentrations within the brine zone decrease in the middle and lower layers as withdrawal rates would increase (figure 33 in appendix A). At the highest withdrawal rate of 200 gpm per well (a total of 6,450 acre-feet

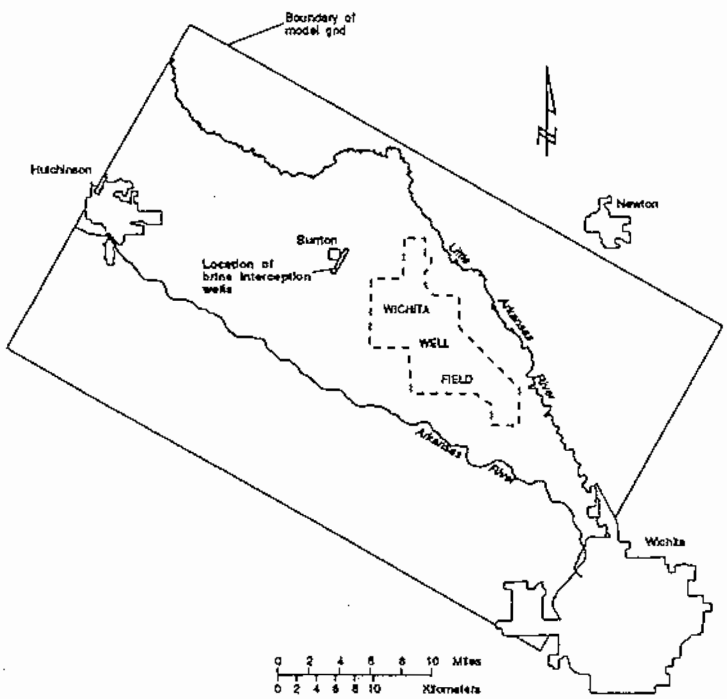


Figure 23.—Location of oil field brine interception wells.

per year for all wells), average chloride concentrations are predicted to fall approximately 30 percent from the base projection in 2049.

The predicted average concentration of the produced water from the interception wells would decrease over time for the middle and lower layers (figures 34a-b in appendix A) with a maximum concentration for the two layers averaged of about 1,150 mg/L when pumping starts in 2000. This water could be blended with and supplement Wichita well field water, which would result in initial chloride concentrations of around 170, 120, and 90 mg/L for the three withdrawal rates considered and around 30 mg/L without blending (figure 34c in appendix A). The calculated concentrations converge to similar values over time. This assumes that the total water provided (from the well field and interception wells) would equal the current production from the well field of approximately 35,000 acre-feet per year.

#### *Place Hydraulic Barrier Along Arkansas River*

The recharge of better quality water to the aquifer between the Arkansas River and the Wichita well field might mitigate the movement of chloride to the aquifer from the river, though the source of this recharge water has not been identified. This water was assumed to be recharged evenly to the upper layer along a narrow band approximately 1 mile north of the Arkansas River (figure 24). Total recharge rates of 2,528; 5,650; and 11,300 acre-feet per year as well as chloride concentrations of 50, 150, and 250 mg/L, were applied along this band. The location of a similar recharge band 2 miles north of the river was also considered (figure 24). In addition, a simulation showed the effects of reducing pumpage from the lower model layer within the southern part of the Wichita well field area.

For all simulations with varying recharge rates, there would be a minimal impact on water levels with a maximum rise of 3 feet and an average rise within the river zone of about 2 feet at a recharge rate of 11,300 acre-feet per year (figures 35 and 36 in appendix A). The simulations with varying recharge rates assume a recharge water concentration of 150 mg/L chloride. At a recharge rate of 11,300 acre-feet per year, the average concentration would decrease from the base projection of about 23 and 13 percent within the river zone

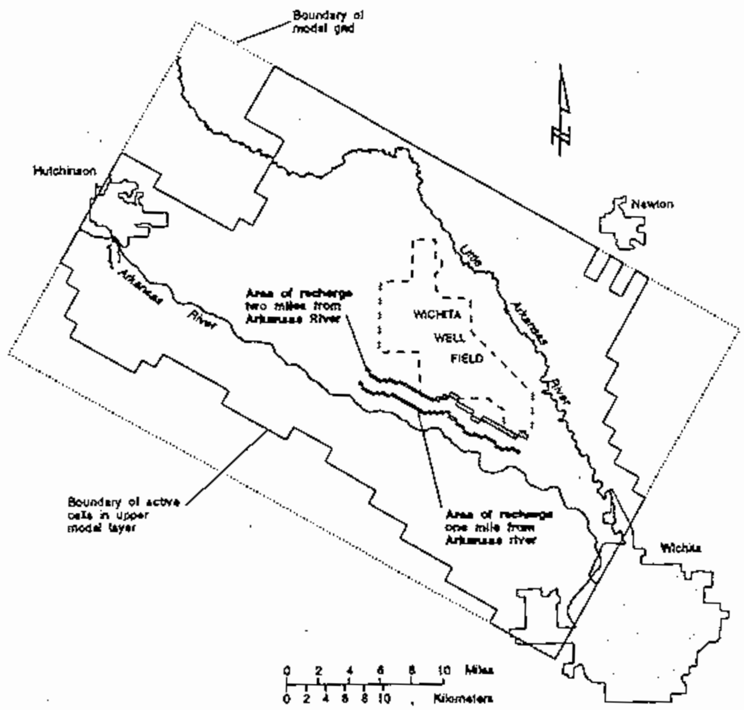


Figure 24.—Hydraulic barrier recharge locations.

and well field zone. The decreases in average concentration would be less for lower recharge rates (figure 37 in appendix A). The largest impact is on the upper layer with decreases in average concentration from the base projection within the river zone of 41, 33, and 15 percent for the three respective layers at a recharge rate of 11,300 acre-feet per year (figure 38 in appendix A). The impacts are similar in the well field zone.

The predicted concentrations are relatively insensitive to the concentrations of recharge water and the areas of the recharge considered in these simulations (figure 39 in appendix A).

An alternative to the hydraulic barrier approach would be to supplement water produced from the well field with recharge water directly, thereby allowing well field production to be decreased. Blending a higher chloride recharge water with a much larger volume of produced water would minimize water quality impacts on the water supply. In this simulation, pumpage equivalent to 5,650 acre-feet per year was removed from the lower layer in the southern part of the well field (figure 25).

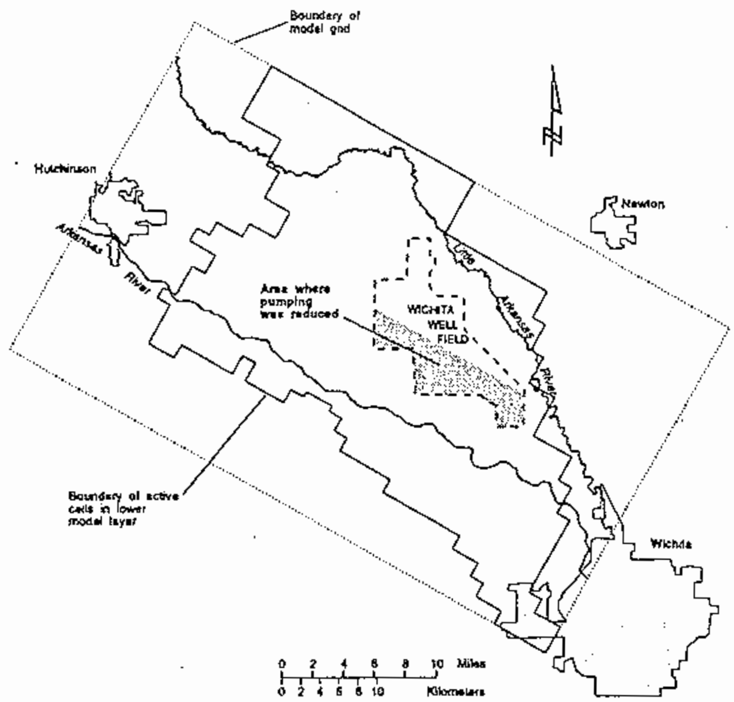


Figure 25.—Area of reduced pumping within Wichita well field zone.

This alternative is slightly less effective than the hydraulic barrier approach in reducing chloride concentrations from that predicted in the base projection (figure 40 in appendix A). Resulting average chloride concentrations were smaller only in the lower layer of the river zone and well field zone when compared with the hydraulic barrier scenario (figure 41 in appendix A).

#### *Reduce Pumping Within the Wichita Well Field*

Decreased withdrawals from within the Wichita well field area may lessen the water quality impact from chloride sources. Reduced production from the well field area might be possible if an alternative source of water could supplement the water produced from the aquifer. Withdrawals were reduced by 5,600; 11,200; 16,800; and 22,400 acre-feet per year in the lower model layer. These same reductions were also applied evenly to all three layers. In addition, a comparison between layers was made for a reduction in withdrawals of 5,600 acre-feet per year.

All simulations of reduced withdrawals result in increased water levels; the largest increases center in the Wichita well field area (figure 42 in appendix A). A maximum water level rise of approximately 19 feet and an average rise of around 12 feet is predicted within the Wichita well field area for a reduction in pumpage of 22,400 acre-feet per year (figure 43 in appendix A).

The predicted average concentrations in the brine and river zones appear to be relatively insensitive to the layer in which withdrawals are reduced, though reductions in the deeper layers seem to have slightly more impact on concentration (figure 44 in appendix A). As expected, larger reductions in withdrawals would have a greater impact in reducing average concentrations.

## Comparison of Management Simulations

The management simulations affect the Equus Beds aquifer and rivers to different degrees. These impacts are compared for stream losses and gains, water levels, and the distribution of salinity in the aquifer.

### *Impacts on Arkansas River*

The Arkansas River generally loses water throughout the study area during extended periods of baseflow. This water loss from the river to the Equus Beds aquifer is directly related to the stresses in the aquifer. Losses from the river have increased as pumpage from this aquifer has increased (figure 18). The contribution of salinity from the river is, therefore, a function of river losses resulting from aquifer withdrawals. The predicted net loss of water from the Arkansas River in the study area was compared for each of the predictive simulations (figure 26).

Most simulations performed involve decreasing the net withdrawal of water from the aquifer. This decrease creates a corresponding decrease in river losses (figure 26). The simulations of interception wells (simulations 4a2, 4b2, and 4c2) involve increased withdrawals from the aquifer and result in increased losses from the Arkansas River. In general, as the net stress (pumpage less recharge) on the aquifer is decreased, the net loss from the river also decreases. Also, as the simulated stress (artificial recharge or decreased withdrawals) is located nearer to the Arkansas River, the impact on river losses increases. For example, the recharge of

11,200 acre-feet per year to the upper layer at two different locations (simulations 5a and 5d) indicates a greater impact on river losses for the location nearest the river (simulation 5a). The simulations that eliminate pumping near the river (simulations 3a and 3b) show a much greater effect on river losses than simulations that decrease the net withdrawals from the aquifer by similar amounts (simulations 8a3 and 8b3).

#### *Impacts on Little Arkansas River*

The Little Arkansas River generally gains throughout the study area. This gain of water from the aquifer is directly related to the stresses in the aquifer. As withdrawals from the Equus Beds have increased over time, gains from the aquifer have decreased (figure 18). The predicted net gain of water to the river from the aquifer in the study area was compared for each of the predictive simulations (figure 27).

In general, as the net stress (pumpage less recharge) on the aquifer is decreased, the net gain in the Little Arkansas River increases. In addition, as the location of the simulated stress (artificial recharge or decreased withdrawals) nears the Little Arkansas River, the impact on river gains grows. For example, decreasing withdrawals by 11,200 acre-feet per year in the lower layer within the Wichita well field area (simulation 8a2) would result in roughly twice the gains in the Little Arkansas River when compared to the simulation of recharge of 11,300 acre-feet per year to the upper layer much farther from the Little Arkansas River and near the Arkansas River (simulation 5c).

#### *Movement of Natural Salinity*

The sources of natural salinity include the Arkansas River and the deep natural saltwater. The impacts of management simulations on water quality for these sources can be evaluated using average chloride concentrations within the river zone (figure 28).

The importance of the Arkansas River as a salinity source was demonstrated by simulating the diversion of the river upstream of the study area (figure 28; simulation 2a). Predicted average chloride concentrations within the river zone would not increase significantly, confirming that river

## LEGEND OF SIMULATIONS

(1) **Base Projection.** Projection of the conditions existing at the end of the calibration simulation to the year 2049.

**Impacts of Arkansas River flow:**

(2a) Diversion of Arkansas River upstream of study area.
(2b) Simulation 2a and elimination of underflow entering study area below the Arkansas River.

**Eliminate pumping near Arkansas River by:**

(3a) 15,300 acre-feet per year in upper model layer.
(3b) 18,500 acre-feet per year in upper and middle model layers.

**Install interception wells** with total withdrawal rate of:

(4a2) 3,200 acre-feet per year.
(4b2) 1,600 acre-feet per year.
(4c2) 6,400 acre-feet per year.

**Place hydraulic barrier along Arkansas River:** water recharged to the upper model layer at the following rate, concentration, and location north of Arkansas River:

(5a) 5,600 acre-feet per year, 150 mg/L, 1 mile.
(5b) 2,800 acre-feet per year, 150 mg/L, 1 mile.
(5c) 11,200 acre-feet per year, 150 mg/L, 1 mile.
(5d) 5,600 acre-feet per year, 150 mg/L, 2 miles.
(7a) 5,600 acre-feet per year, 50 mg/L, 1 mile.
(7b) 5,600 acre-feet per year, 250 mg/L, 1 mile.
(5e) Alternatively, withdrawals were reduced in the lower model layer by 5,600 acre-feet per year in the southern portion of the Wichita well field.

**Reduce pumping within the Wichita well field by:**

(8a1) 5,600 acre-feet per year in lower layer.
(8a2) 11,200 acre-feet per year in lower layer.
(8a3) 16,800 acre-feet per year in lower layer.
(8a4) 22,400 acre-feet per year in lower layer.
(8b1) 5,600 acre-feet per year in all layers.
(8b2) 11,200 acre-feet per year in all layers.
(8b3) 16,800 acre-feet per year in all layers
(8b4) 22,400 acre-feet per year in all layers.
(8c1) 5,600 acre-feet per year in upper layer.
(8d1) 5,600 acre-feet per year in middle layer.

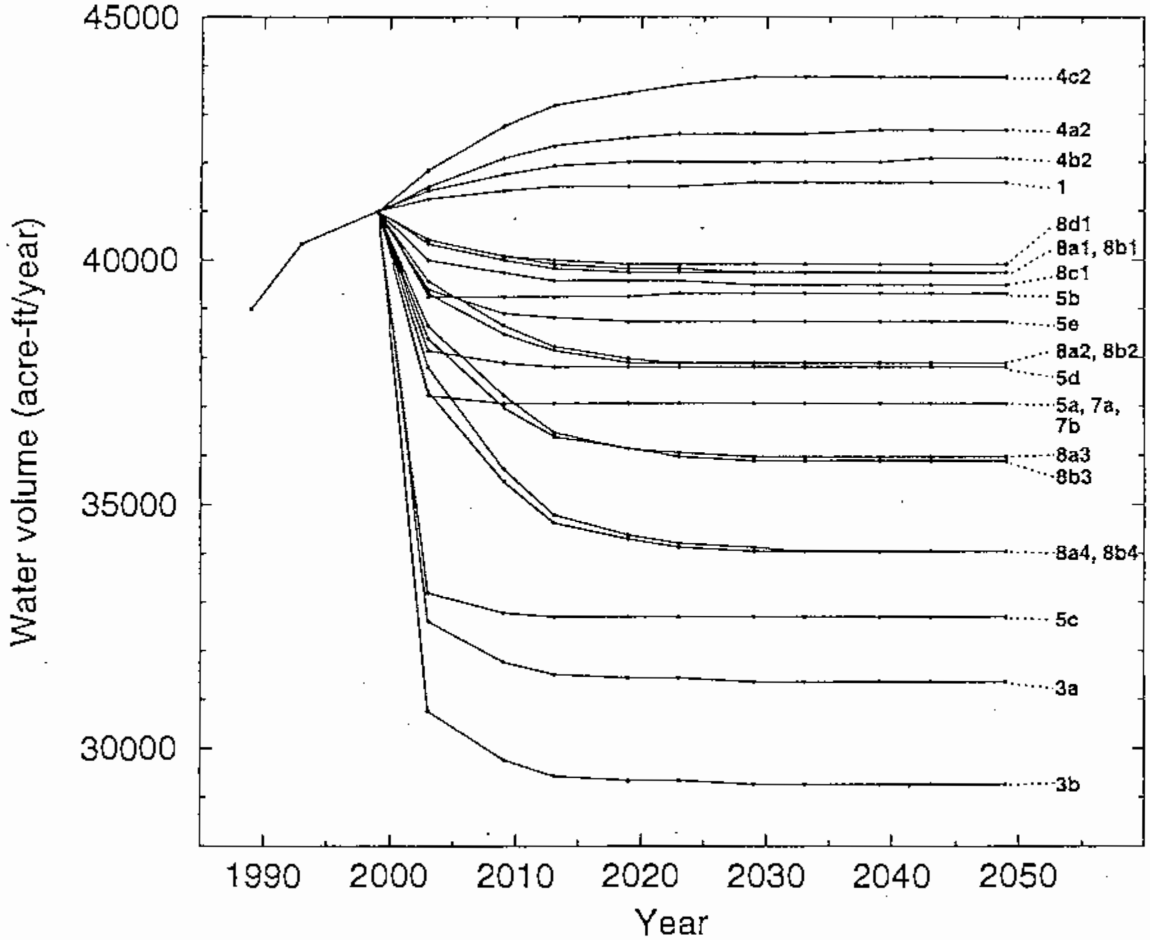


Figure 26.—Predicted net loss of water from the Arkansas River to the aquifer for predictive simulations, 1989-2049.

## LEGEND OF SIMULATIONS

(1) **Base Projection.** Projection of the conditions existing at the end of the calibration simulation to the year 2049.

**Impacts of Arkansas River flow:**

(2a) Diversion of Arkansas River upstream of study area.
(2b) Simulation 2a and elimination of underflow entering study area below the Arkansas River.

**Eliminate pumping near Arkansas River by:**

(3a) 15,300 acre-feet per year in upper model layer.
(3b) 18,500 acre-feet per year in upper and middle model layers.

**Install interception wells** with total withdrawal rate of:

(4a2) 3,200 acre-feet per year.
(4b2) 1,600 acre-feet per year.
(4c2) 6,400 acre-feet per year.

**Place hydraulic barrier along Arkansas River:** water recharged to the upper model layer at the following rate, concentration, and location north of Arkansas River:

(5a) 5,600 acre-feet per year, 150 mg/L, 1 mile.
(5b) 2,800 acre-feet per year, 150 mg/L, 1 mile.
(5c) 11,200 acre-feet per year, 150 mg/L, 1 mile.
(5d) 5,600 acre-feet per year, 150 mg/L, 2 miles.
(7a) 5,600 acre-feet per year, 50 mg/L, 1 mile.
(7b) 5,600 acre-feet per year, 250 mg/L, 1 mile.
(5e) Alternatively, withdrawals were reduced in the lower model layer by 5,600 acre-feet per year in the southern portion of the Wichita well field.

**Reduce pumping within the Wichita well field** by:

(8a1) 5,600 acre-feet per year in lower layer.
(8a2) 11,200 acre-feet per year in lower layer.
(8a3) 16,800 acre-feet per year in lower layer.
(8a4) 22,400 acre-feet per year in lower layer.
(8b1) 5,600 acre-feet per year in all layers.
(8b2) 11,200 acre-feet per year in all layers.
(8b3) 16,800 acre-feet per year in all layers
(8b4) 22,400 acre-feet per year in all layers.
(8c1) 5,600 acre-feet per year in upper layer.
(8d1) 5,600 acre-feet per year in middle layer.

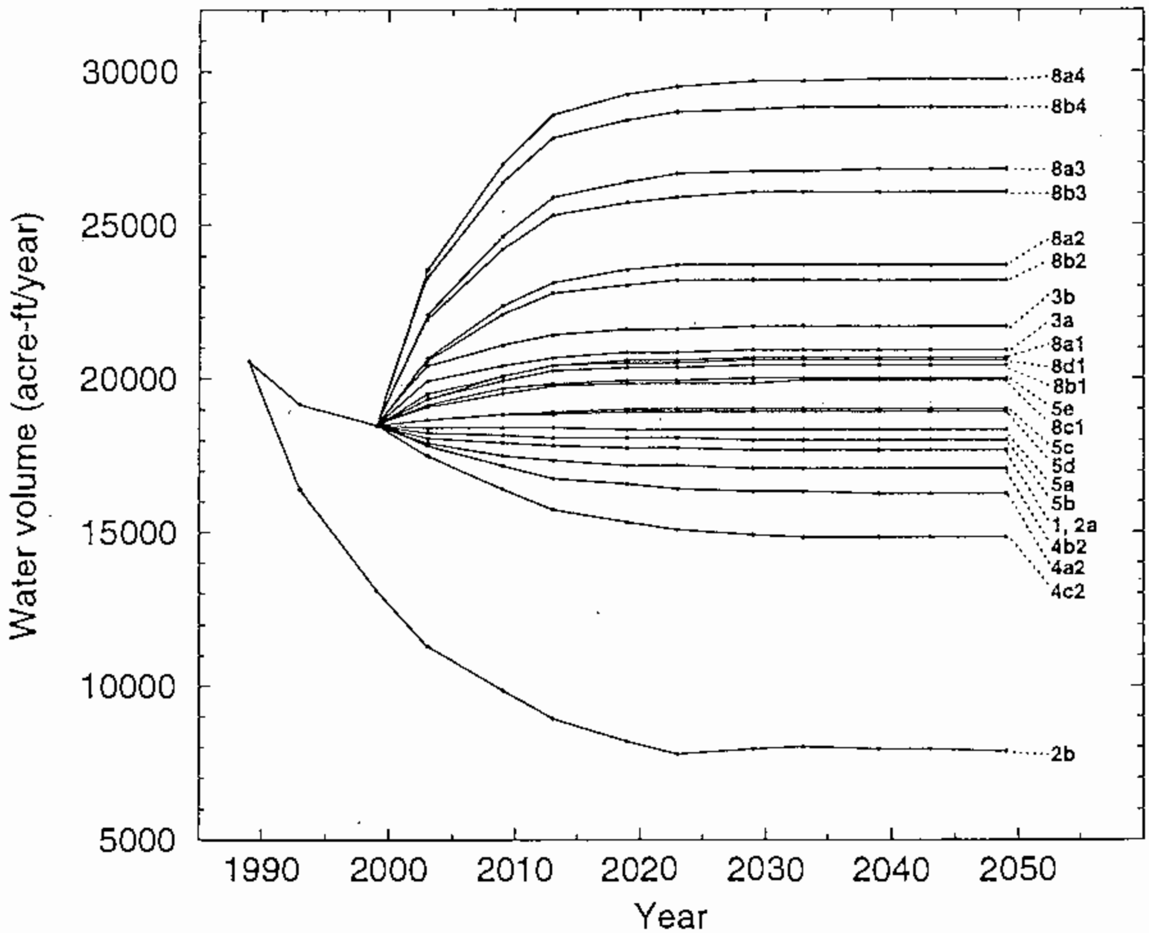


Figure 27.—Predicted net gain of water to the Little Arkansas River from the aquifer for predictive simulations, 1989-2049.

contributions to the aquifer are primarily responsible for the chloride plume migrating through the river zone toward the Wichita well field. Chloride from the deep natural saltwater appears to be less of an immediate threat to the Wichita well field.

Using a hydraulic barrier between the Arkansas River and the Wichita well field area appears to be an effective approach to minimize the impact of chloride from natural sources (figure 28; simulations 5a, 5b, 5c, 5d, 7a, and 7b). This water barrier is more effective as recharge rates are increased. Application of the recharge water reduces losses from the Arkansas River (figure 26) and dilutes the resulting chloride plume.

Reductions in pumpage within the Wichita well field area (all of simulation 8) favorably inhibit the migration of chloride from the Arkansas River but are less effective than the hydraulic barrier approach in terms of the amount of water required. For example, recharging 11,200 acre-feet per year as a hydraulic barrier (simulation 5c) would be much more effective in reducing chloride concentrations than reducing pumpage by 11,200 acre-feet per year (simulation 8a2) within the river zone (figure 28).

#### *Movement of Oil Field Saltwater Plume*

The saltwater plume from the Burrton Oil Field operations is moving primarily to the east toward the Wichita well field and the Little Arkansas River. Impacts of management simulations on water quality for this source can be evaluated using average chloride concentrations within the brine zone (figure 29).

An effective approach in minimizing the impact of the oil field saltwater plume on the well field zone appears to be the use of interception wells. These wells would be located to withdraw water from the highest concentration areas of the saltwater plume. The reduction of average concentrations in the brine zone increases as withdrawal rates increase (figure 29; simulations 4a2, 4b2, and 4c2).

Reducing pumping in the well field zone (all of simulation 8) would deter the migration of the saltwater plume, but this approach would be less effective than the interception well approach. For example, withdrawing 1,600 acre-feet per year (simulation 4b2) through strategically located interception wells may be almost as effective in reducing chloride concentrations as reducing pumpage by 16,800 acre-feet per year (simulation 8b3) within the brine zone (figure 29).

#### *Impacts on Wichita Well Field Water Quality*

Natural chloride sources and the saltwater from Burrton Oil Field operations affect the water quality in the Wichita well field area. The impacts of management simulations on water quality in the Wichita well field can be evaluated using average chloride concentrations within the Wichita well field area (figure 30).

Both the hydraulic barrier (all of simulations 5 and 7) and pumping reduction (all of simulation 8) scenarios show similar impacts (figure 30). The hydraulic barrier scenarios restrict chloride movement from the Arkansas River, while reductions in pumpage would reduce chloride migration from both the Arkansas River and the Burrton Oil Field saltwater.

# LEGEND OF SIMULATIONS

(1) **Base Projection.** Projection of the conditions existing at the end of the calibration simulation to the year 2049.

**Impacts of Arkansas River flow:**

(2a) Diversion of Arkansas River upstream of study area.
(2b) Simulation 2a and elimination of underflow entering study area below the Arkansas River.

**Eliminate pumping near Arkansas River by:**

(3a) 15,300 acre-feet per year in upper model layer.
(3b) 18,500 acre-feet per year in upper and middle model layers.

**Install interception wells** with total withdrawal rate of:

(4a2) 3,200 acre-feet per year.
(4b2) 1,600 acre-feet per year.
(4c2) 6,400 acre-feet per year.

**Place hydraulic barrier along Arkansas River:** water recharged to the upper model layer at the following rate, concentration, and location north of Arkansas River:

(5a) 5,600 acre-feet per year, 150 mg/L, 1 mile.
(5b) 2,800 acre-feet per year, 150 mg/L, 1 mile.
(5c) 11,200 acre-feet per year, 150 mg/L, 1 mile.
(5d) 5,600 acre-feet per year, 150 mg/L, 2 miles.
(7a) 5,600 acre-feet per year, 50 mg/L, 1 mile.
(7b) 5,600 acre-feet per year, 250 mg/L, 1 mile.
(5e) Alternatively, withdrawals were reduced in the lower model layer by 5,600 acre-feet per year in the southern portion of the Wichita well field.

**Reduce pumping within the Wichita well field by:**

(8a1) 5,600 acre-feet per year in lower layer.
(8a2) 11,200 acre-feet per year in lower layer.
(8a3) 16,800 acre-feet per year in lower layer.
(8a4) 22,400 acre-feet per year in lower layer.
(8b1) 5,600 acre-feet per year in all layers.
(8b2) 11,200 acre-feet per year in all layers.
(8b3) 16,800 acre-feet per year in all layers
(8b4) 22,400 acre-feet per year in all layers.
(8c1) 5,600 acre-feet per year in upper layer.
(8d1) 5,600 acre-feet per year in middle layer.

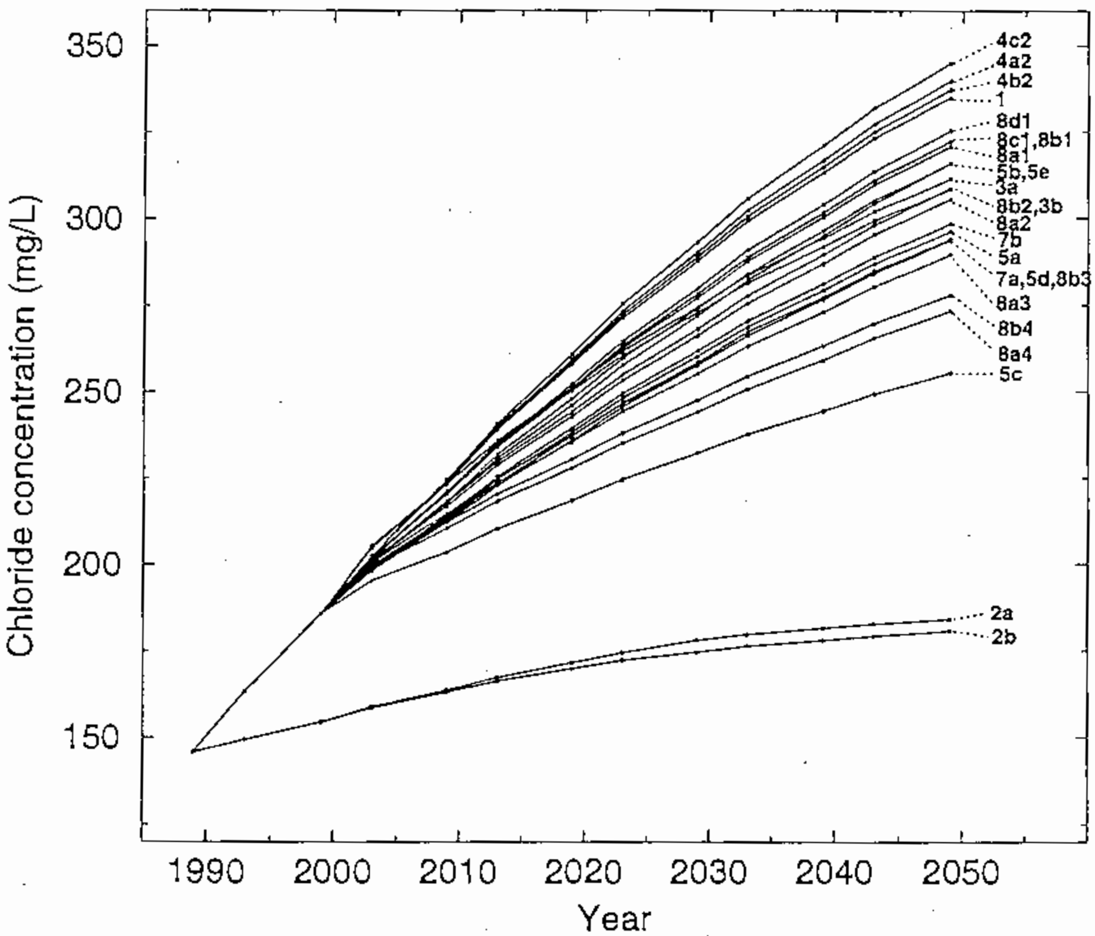


Figure 28.—Predicted average chloride concentration in the river zone for predictive simulations, 1989-2049.

## LEGEND OF SIMULATIONS

(1) **Base Projection.** Projection of the conditions existing at the end of the calibration simulation to the year 2049.

**Impacts of Arkansas River flow:**

(2a) Diversion of Arkansas River upstream of study area.
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(5e) Alternatively, withdrawals were reduced in the lower model layer by 5,600 acre-feet per year in the southern portion of the Wichita well field.

**Reduce pumping within the Wichita well field by:**

(8a1) 5,600 acre-feet per year in lower layer.
(8a2) 11,200 acre-feet per year in lower layer.
(8a3) 16,800 acre-feet per year in lower layer.
(8a4) 22,400 acre-feet per year in lower layer.
(8b1) 5,600 acre-feet per year in all layers.
(8b2) 11,200 acre-feet per year in all layers.
(8b3) 16,800 acre-feet per year in all layers
(8b4) 22,400 acre-feet per year in all layers.
(8c1) 5,600 acre-feet per year in upper layer.
(8d1) 5,600 acre-feet per year in middle layer.

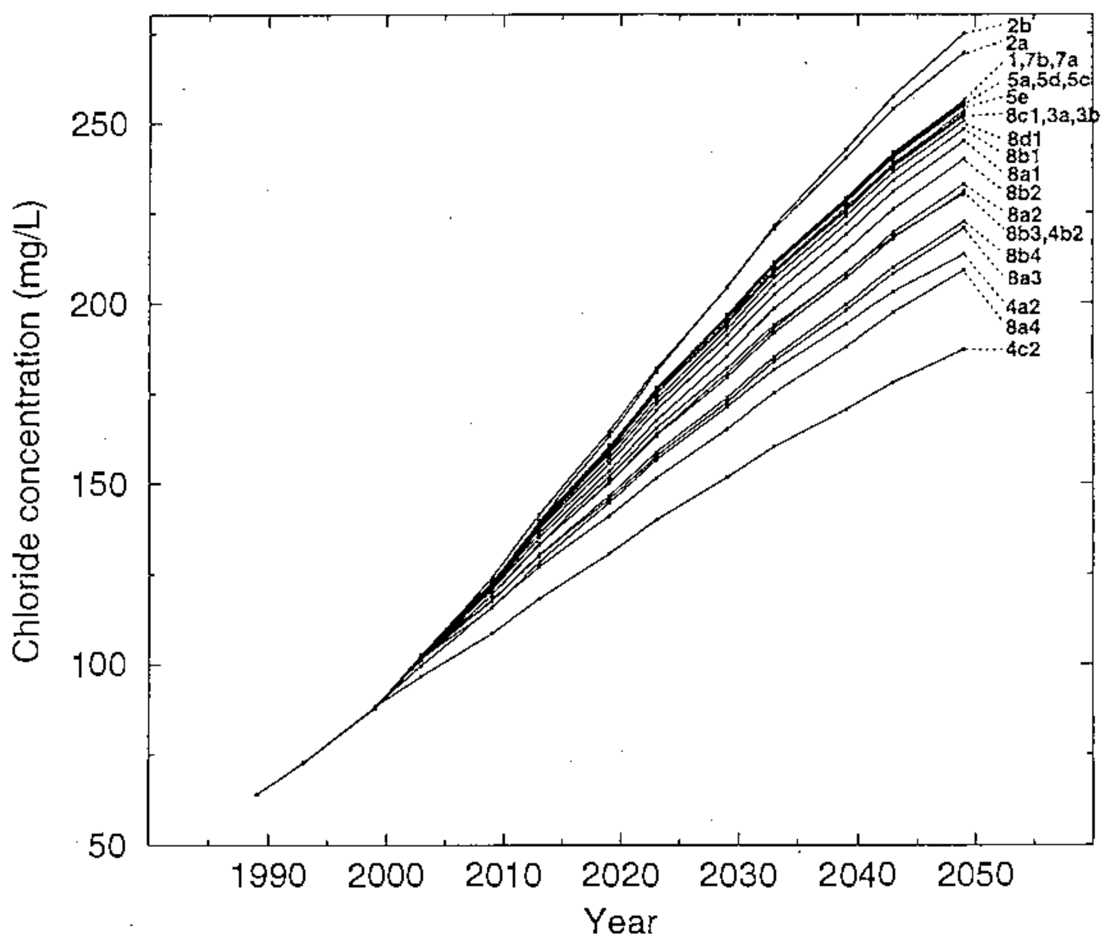


Figure 29.—Predicted average chloride concentration in the brine zone for predictive simulations, 1989-2049.

## LEGEND OF SIMULATIONS

(1) **Base Projection.** Projection of the conditions existing at the end of the calibration simulation to the year 2049.

**Impacts of Arkansas River flow:**

(2a) Diversion of Arkansas River upstream of study area.
(2b) Simulation 2a and elimination of underflow entering study area below the Arkansas River.

**Eliminate pumping near Arkansas River by:**

(3a) 15,300 acre-feet per year in upper model layer.
(3b) 18,500 acre-feet per year in upper and middle model layers.

**Install interception wells** with total withdrawal rate of:

(4a2) 3,200 acre-feet per year.
(4b2) 1,600 acre-feet per year.
(4c2) 6,400 acre-feet per year.

**Place hydraulic barrier along Arkansas River:** water recharged to the upper model layer at the following rate, concentration, and location north of Arkansas River:

(5a) 5,600 acre-feet per year, 150 mg/L, 1 mile.
(5b) 2,800 acre-feet per year, 150 mg/L, 1 mile.
(5c) 11,200 acre-feet per year, 150 mg/L, 1 mile.
(5d) 5,600 acre-feet per year, 150 mg/L, 2 miles.
(7a) 5,600 acre-feet per year, 50 mg/L, 1 mile.
(7b) 5,600 acre-feet per year, 250 mg/L, 1 mile.
(5e) Alternatively, withdrawals were reduced in the lower model layer by 5,600 acre-feet per year in the southern portion of the Wichita well field.

**Reduce pumping within the Wichita well field by:**

(8a1) 5,600 acre-feet per year in lower layer.
(8a2) 11,200 acre-feet per year in lower layer.
(8a3) 16,800 acre-feet per year in lower layer.
(8a4) 22,400 acre-feet per year in lower layer.
(8b1) 5,600 acre-feet per year in all layers.
(8b2) 11,200 acre-feet per year in all layers.
(8b3) 16,800 acre-feet per year in all layers
(8b4) 22,400 acre-feet per year in all layers.
(8c1) 5,600 acre-feet per year in upper layer.
(8d1) 5,600 acre-feet per year in middle layer.

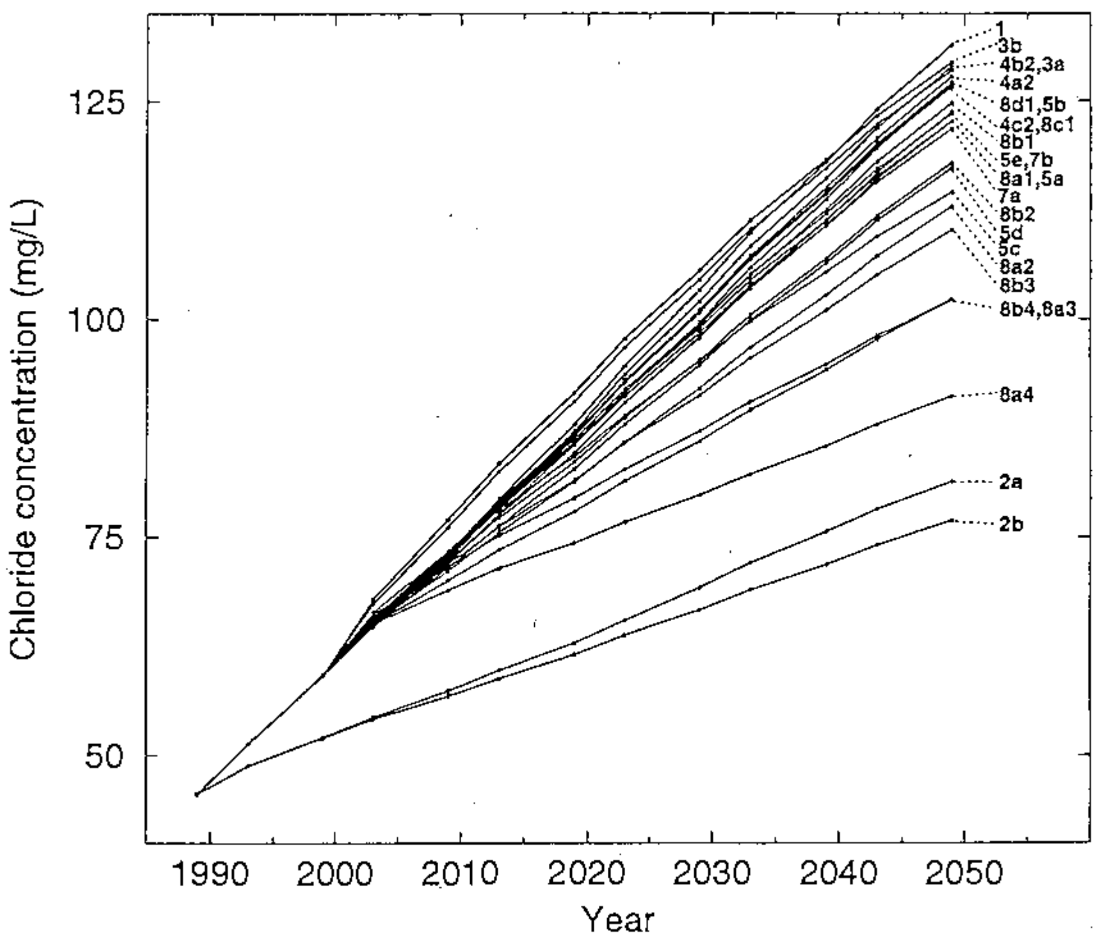


Figure 30.—Predicted average chloride concentration in the Wichita well field area for predictive simulations, 1989-2049.

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# APPENDIX A

Corroborative Figures Mentioned in this Report

Table A-1.—Summary of simulations

| Reference simulations | Results |
|---|---|
| **Calibration** (1940-1989): Considered transport of chloride in the Equus Beds aquifer. Sources considered are: the Arkansas River, deep natural saltwater, and oil field brine. Calibration performed by attempting to match chloride breakthrough curves of measured data at various locations. | Reasonable representation of actual conditions in the primary areas of interest from the Arkansas River and the Burrton Oil Field area to the Wichita well field area. The model appears to over-predict the rate of chloride movement in the upper layer. |
| **Base projection** (1990-2049): Projection of conditions existing at the end of the calibration simulation to the year 2049.<br><br>*Boundary conditions, initial conditions, and stresses*: Same as those existing at the end of the calibration simulation in 1989. | *Water elevations*: Cone of depression centered over the Wichita well field area.<br><br>*Chloride movement*: Plumes migrating from the Arkansas River and Burrton Oil Field area toward the Wichita well field area. Predicted chloride concentrations are as high as 400 mg/L in the southern part and 300 mg/L extreme northwest part of the well field by 2049. |
| **Simulations of individual sources** | **Results** |
| **Arkansas River** (1940-2049): Saltwater flowing from the river to the aquifer was considered as the only source of chloride. Chloride concentrations in the river varied from 480 mg/L to 630 mg/L from 1940 to 1989 and were constant at 630 mg/L from 1990 to 2049.<br><br>*Initial conditions*: No chloride present in aquifer in 1940. | Water from the river accounts for the majority of chloride in the upper layer. Significant vertical movement of chloride from the river to the middle and lower model layers. Chloride plume in all layers expanding toward the Wichita well field area. |
| **Deep natural saltwater** (1940-2049). Natural chloride located around a low or trough in the bedrock surface near the course of the Arkansas River was considered as the only source of chloride.<br><br>*Boundary conditions*: Constant concentration cells in the lower layer represent chloride in the trough below the river.<br><br>*Initial conditions*: The concentration of chloride ranges from 900 to 4,000 mg/L in the constant concentration cells. | Chloride is moving from the trough to the east toward the Wichita well field primarily in the lower layer, with some movement upward into the middle layer. |

Table A-1.—Summary of simulations (continued)

| Simulations of individual sources (continued) | Results (continued) |
| --- | --- |
| **Burrton Oil Field brine** (1940-2049). Brine from oil field operations that was disposed into surface pits from the 1930's to 1940's considered as the only source of chloride.<br><br>*Initial conditions*: Chloride placed in upper and middle model layers. | Movement of the brine is primarily to the east toward the Wichita well field and Little Arkansas River. Significant vertical movement of chloride into the lower layer from the middle layer. |
| **Management simulations (1990-2049)** | **Results** |
| **Investigate the impacts of Arkansas River flow on the aquifer.**<br><br>(2a) Divert Arkansas River upstream of study area.<br><br>*Stresses*: No flow in Arkansas River during simulation.<br><br>(2b) Divert Arkansas River upstream of study area and eliminate underflow entering study area below Arkansas River.<br><br>*Stresses*: No flow in Arkansas River during simulation.<br><br>*Boundary conditions*: Constant head cells eliminated in upper and middle model layers below Arkansas River at the northwest boundary of the model. | These simulations demonstrate the importance of the Arkansas River acting as a water supply for the aquifer.<br><br>*Water elevations*:<br><br>(2a) Predicted to fall as much as 25 feet near the river with an average drop of about 13 feet within the Wichita well field zone.<br><br>(2b) Greater impacts than simulation 2a.<br><br>*Chloride movement*:<br><br>(2a) Little movement of the chloride plume that originated from the river toward the Wichita well field, because the river has been removed as a water and chloride source.<br><br>(2b) Results similar to simulation 2a. |
| **Install pumping wells to intercept oil field saltwater.** Install pumping wells strategically located to remove chloride from the aquifer.<br><br>*Stresses*: Twenty wells located in the middle and lower model layers (10 each layer) pumping a total of:<br><br>(4a2) 3,200 acre-feet per year (100/gallons per minute/well)<br>(4b2) 1,600 acre-feet per year (50/gallons per minute/well)<br>(4c2) 6,400 acre-feet per year (200/gallons per minute/well) | *Water elevations*: All simulations resulted in a cone of depression centered at the pumping wells. Maximum water elevation drops of around 3, 7, and 15 feet as withdrawal rates increase.<br><br>*Chloride movement*: Effective in minimizing the impact of the Burrton oil field saltwater on the Wichita well field area.<br><br>*Brine zone*: Average chloride concentrations decrease as withdrawal rates increase by as much as 30 percent from that predicted by the base projection. |

Table A-1.—Summary of simulations (continued)

| Management simulations (1990-2049) (continued) | Results (continued) |
|---|---|
| **Eliminate pumping near Arkansas River** in an area from the Little Arkansas River to approximately 33 miles north. Pumping in this area may become undesirable as chloride concentrations increase in the aquifer.<br><br>*Stresses*: Eliminated pumping within this area in the:<br>(3a) upper model layer (15,300 acre-feet per year) and<br>(3b) upper and middle model layers (18,500 acre-feet per year) | *Water elevations*. Minimal impacts.<br><br>*Chloride movement*. Minimal impacts.<br><br>*River zone*. Rate of chloride concentration increase is only slightly less than that of the base projection. |
| **Place hydraulic barrier along Arkansas River** by recharging better quality water between the Arkansas River and the Wichita well field to inhibit the movement of poor quality water from the river to the aquifer.<br><br>*Stresses*: The water was recharged to the upper layer at the following rate, concentration, and location:<br><br>(5a) 5,600 acre-feet per year, 150 mg/L, 1 mile north of Arkansas River.<br>(5b) 2,800 acre-feet per year, 150 mg/L, 1 mile north of Arkansas River.<br>(5c) 11,200 acre-feet per year, 150 mg/L, 1 mile north of Arkansas River.<br>(5d) 5,600 acre-feet per year, 150 mg/L, 2 miles north of Arkansas River.<br>(7a) 5,600 acre-feet per year, 50 mg/L, 1 mile north of Arkansas River.<br>(7b) 5,600 acre-feet per year, 250 mg/L, 1 mile north of Arkansas River.<br>(5e) Alternatively, withdrawals were reduced in the lower model layer by 5,600 acre-feet per year in the southern portion of the Wichita well field. | *Water elevations*: Minimal impact with a maximum rise of 3 feet at the recharge location.<br><br>*Chloride movement*: In general, effective in inhibiting the movement of chloride from the river.<br><br>*River zone*: Average chloride concentrations are decreased from the base projection by as much as 23 percent at the highest recharge rate. The decreases in average concentration are less for lower recharge rates. The predicted concentrations are relatively insensitive to the concentrations of recharge water and the areas of recharge considered. Reducing withdrawals within the Wichita well field was less effective in reducing chloride concentration from that predicted in the base projection. |

Table A-1.—Summary of simulations (continued)

| Management simulations (1990-2049) (continued) | Results (continued) |
|---|---|
| **Reduce pumping within the Wichita well field** to lessen the water quality impact from chloride sources.<br><br>*Stresses*: Pumping was reduced within the well field area by the following total amount:<br><br>(8a1) 5,600 acre-feet per year, lower layer<br>(8a2) 11,200 acre-feet per year, lower layer<br>(8a3) 16,800 acre-feet per year, lower layer<br>(8a4) 22,400 acre-feet per year, lower layer<br>(8b1) 5,600 acre-feet per year, all layers<br>(8b2) 11,200 acre-feet per year, all layers<br>(8b3) 16,800 acre-feet per year, all layers<br>(8b4) 22,400 acre-feet per year, all layers<br>(8c1) 5,600 acre-feet per year, upper layer<br>(8d1) 5,600 acre-feet per year, middle layer | *Water elevations*: Increased for all simulations with the largest increases centered in the Wichita well field area.<br><br>*Chloride movement*: In general, decreases the impacts from chloride sources. Larger reductions in withdrawals have a greater impact in reducing average chloride concentrations. Average concentrations are relatively insensitive to the model layer in which withdrawals are reduced. |

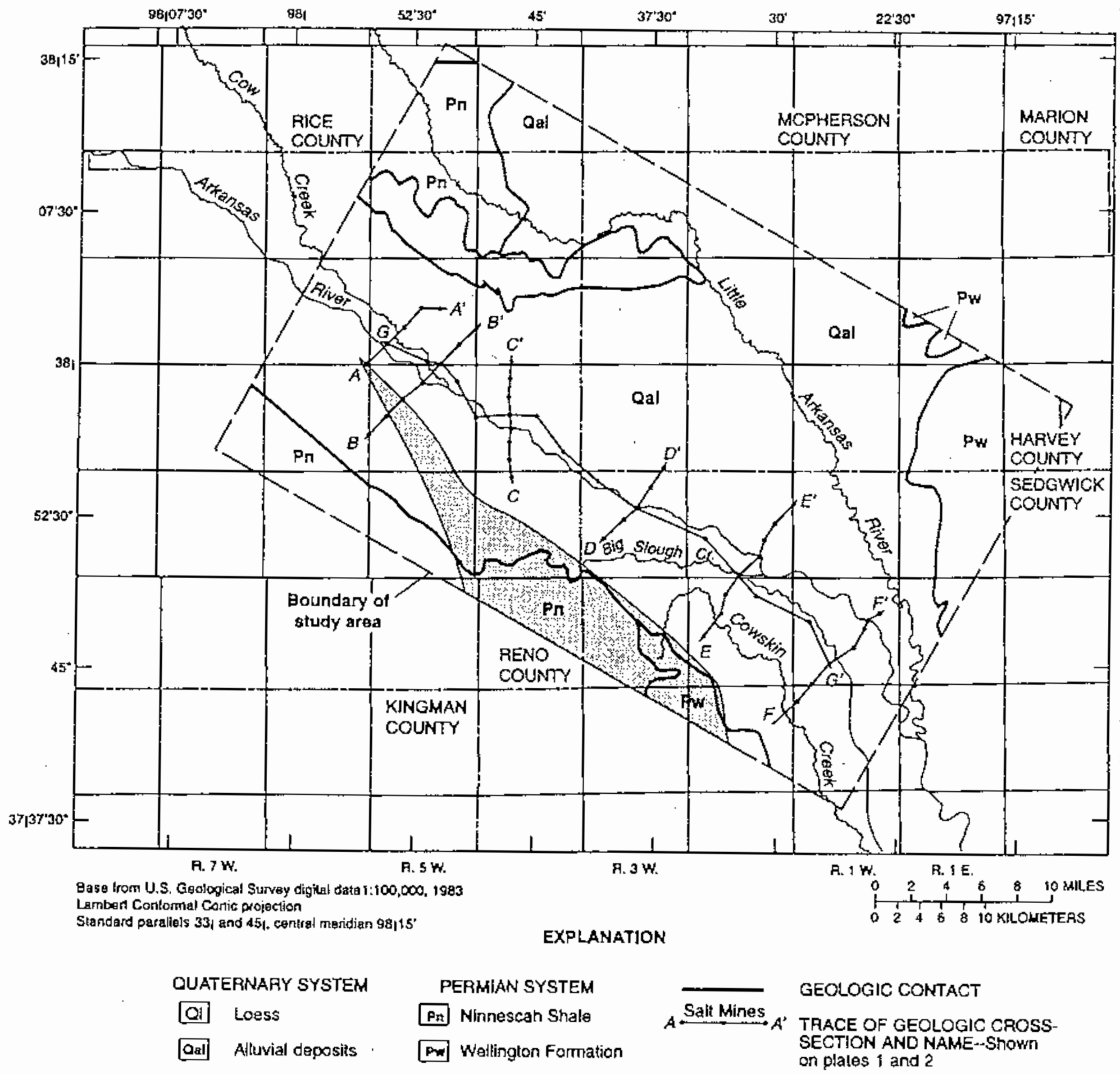
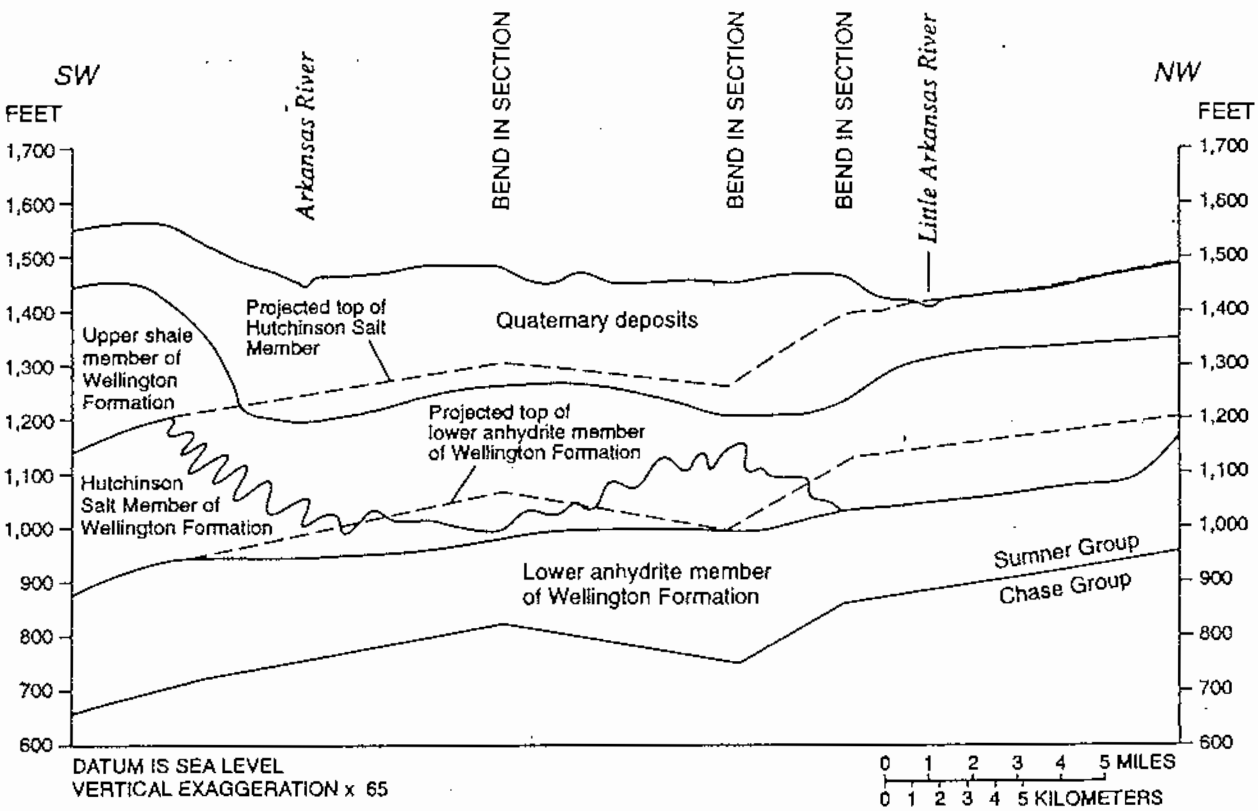
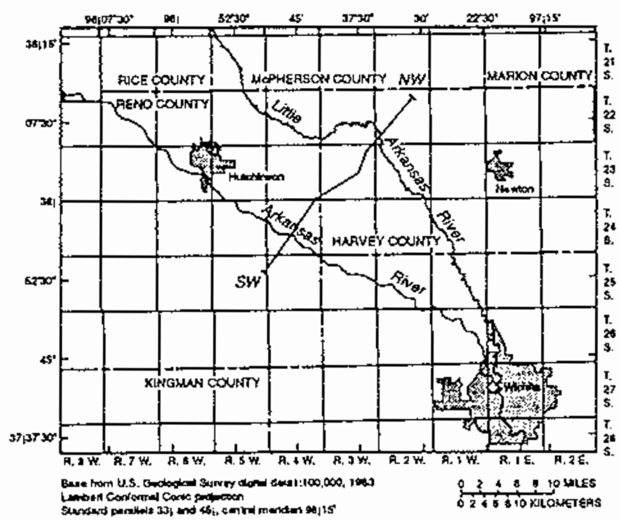



Figure A-1.—Areal geology, traces of geologic cross sections, and cross-section names.




*Index map*

Figure A-2.—Geologic section showing present and projected past extent of the Hutchinson Salt Member (Myers et al., in review).

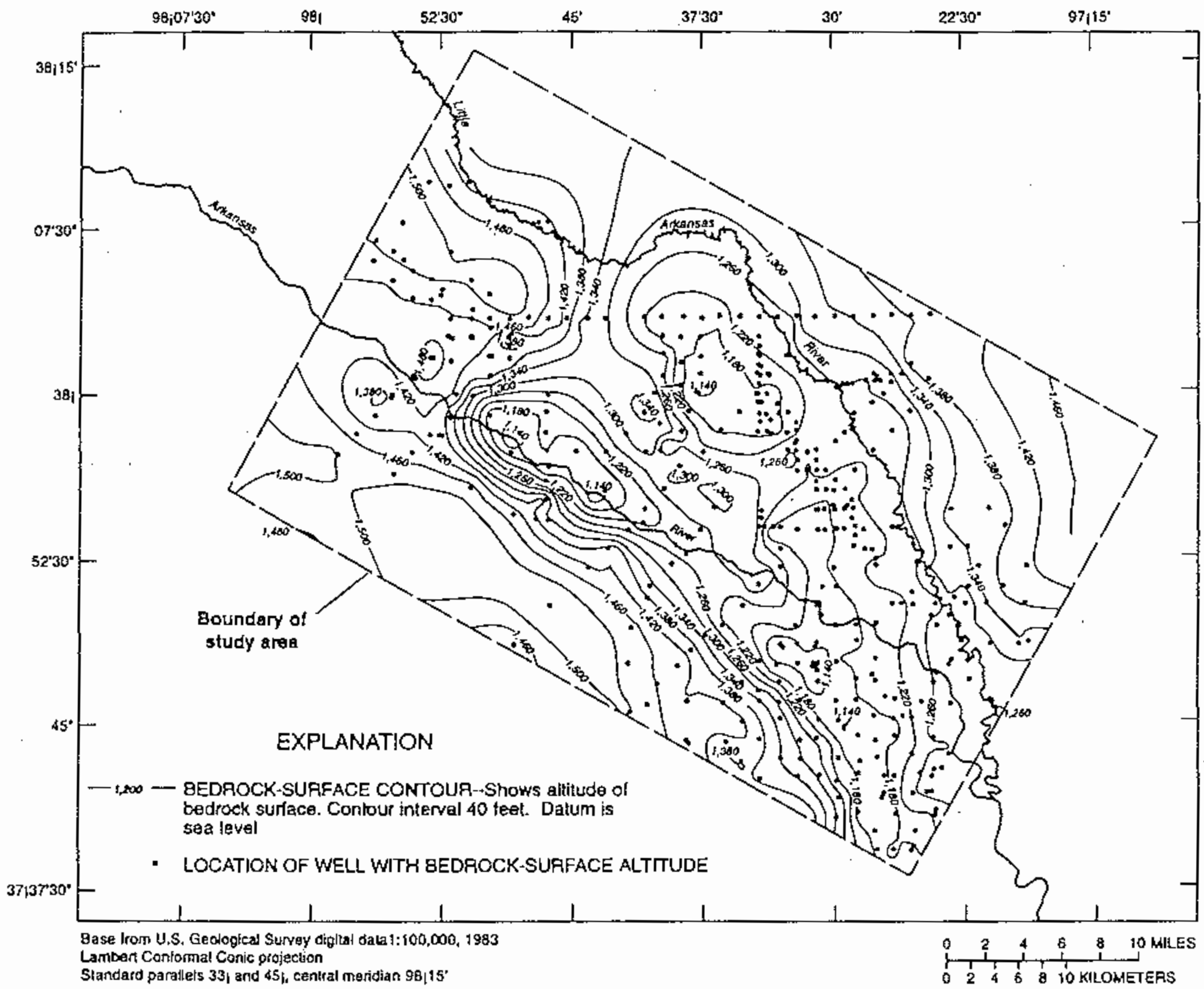



Figure A-3.—Altitude of bedrock surface (from Myers et al., in review).

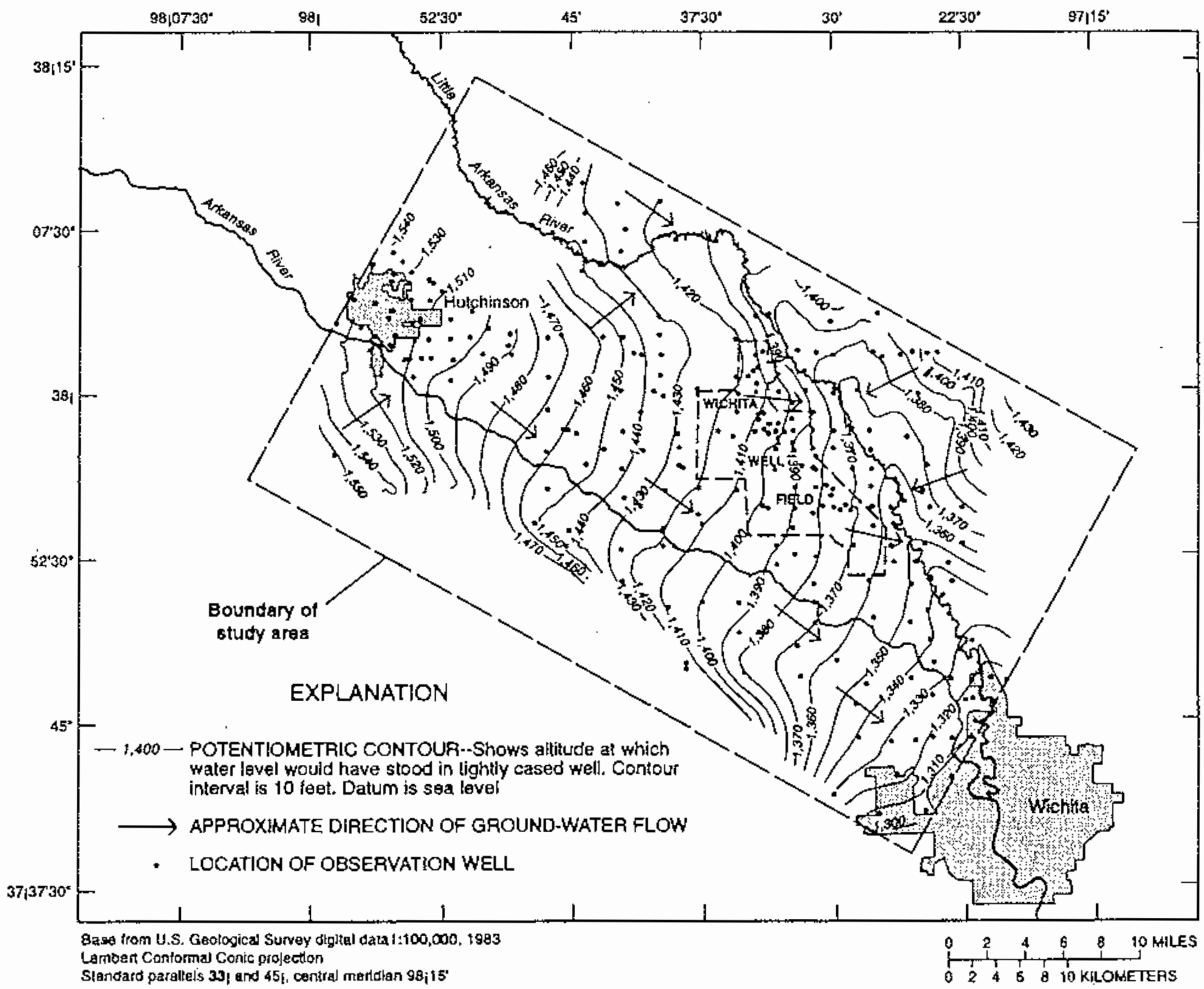



Figure A-4.—Potentiometric surface in the Equus Beds aquifer, 1940 (Myers et al., in review).

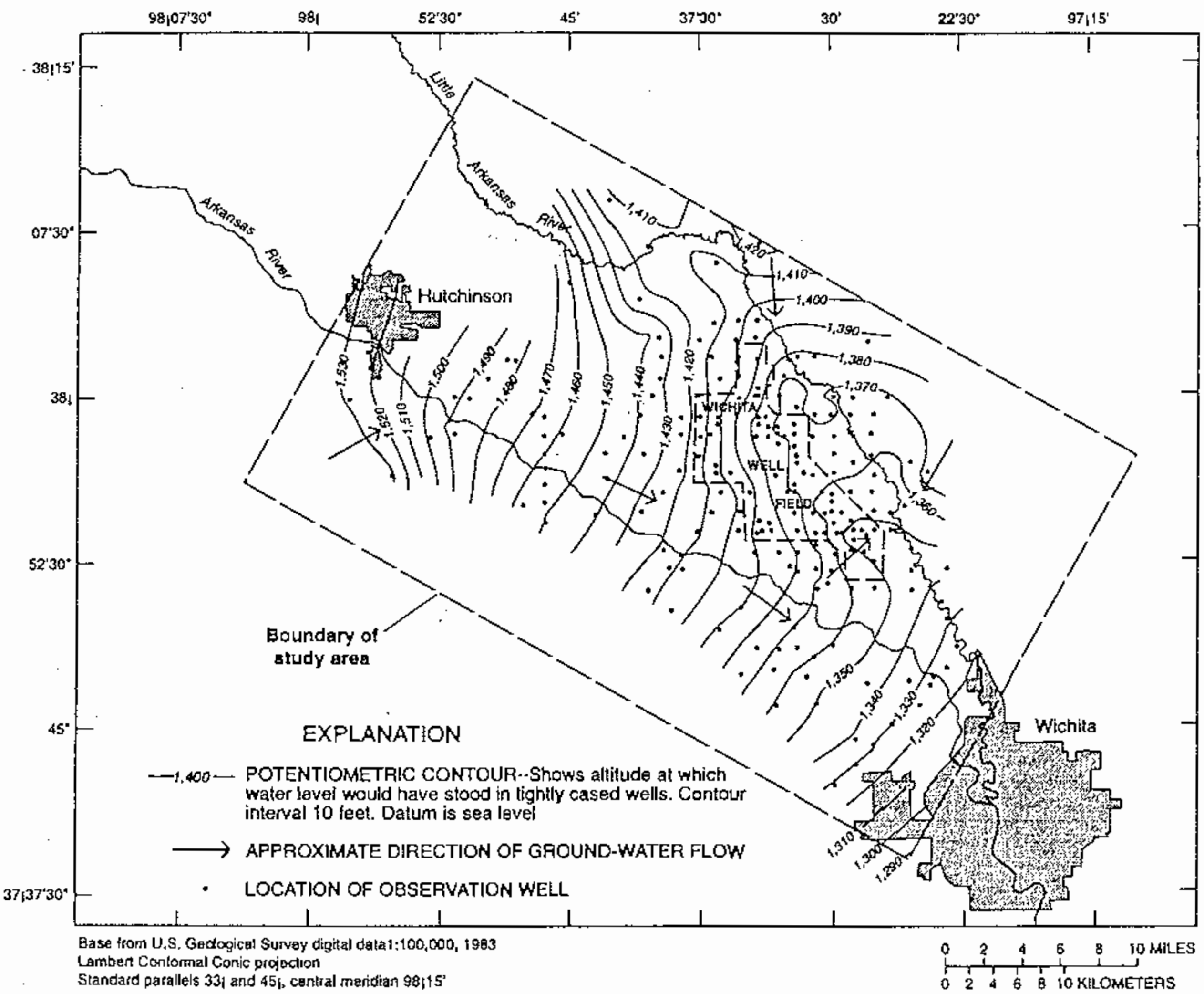



Figure A-5.—Potentiometric surface in the Equus Beds aquifer, 1989 (Myers et al., in review).

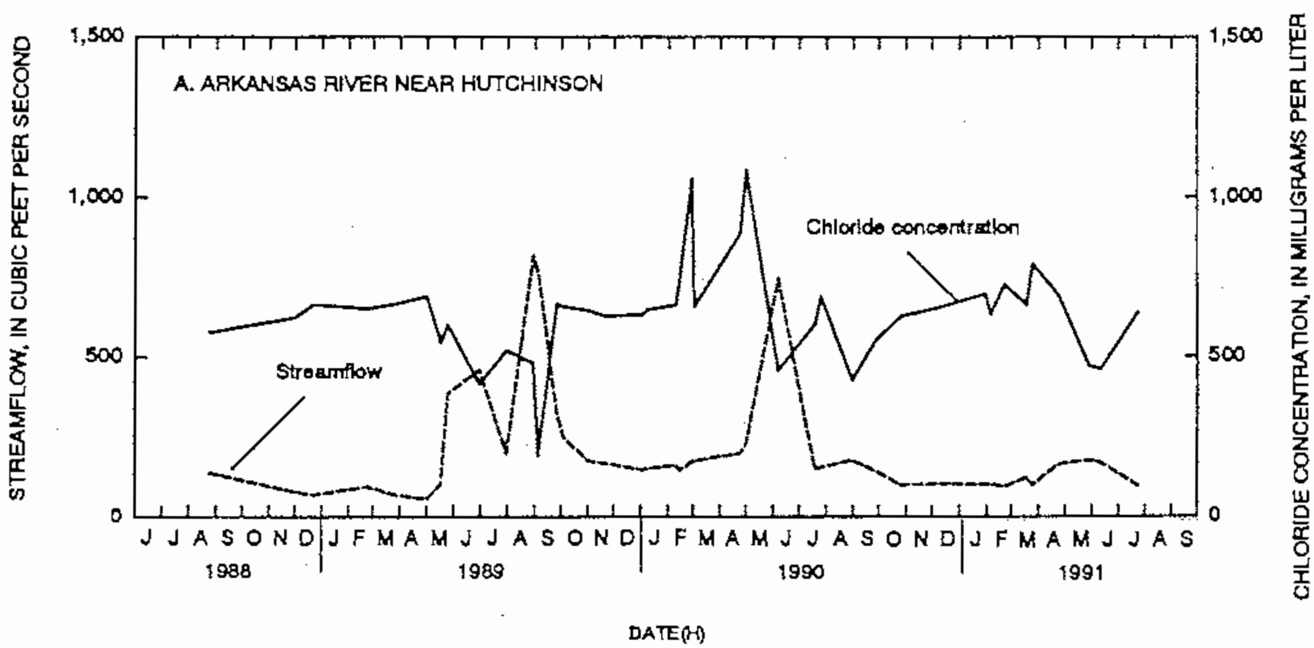



Figure A-6a.—Streamflow and chloride concentration at the Arkansas River near Hutchinson gauging station, August 1988-July 1991 (Myers et al., in review).

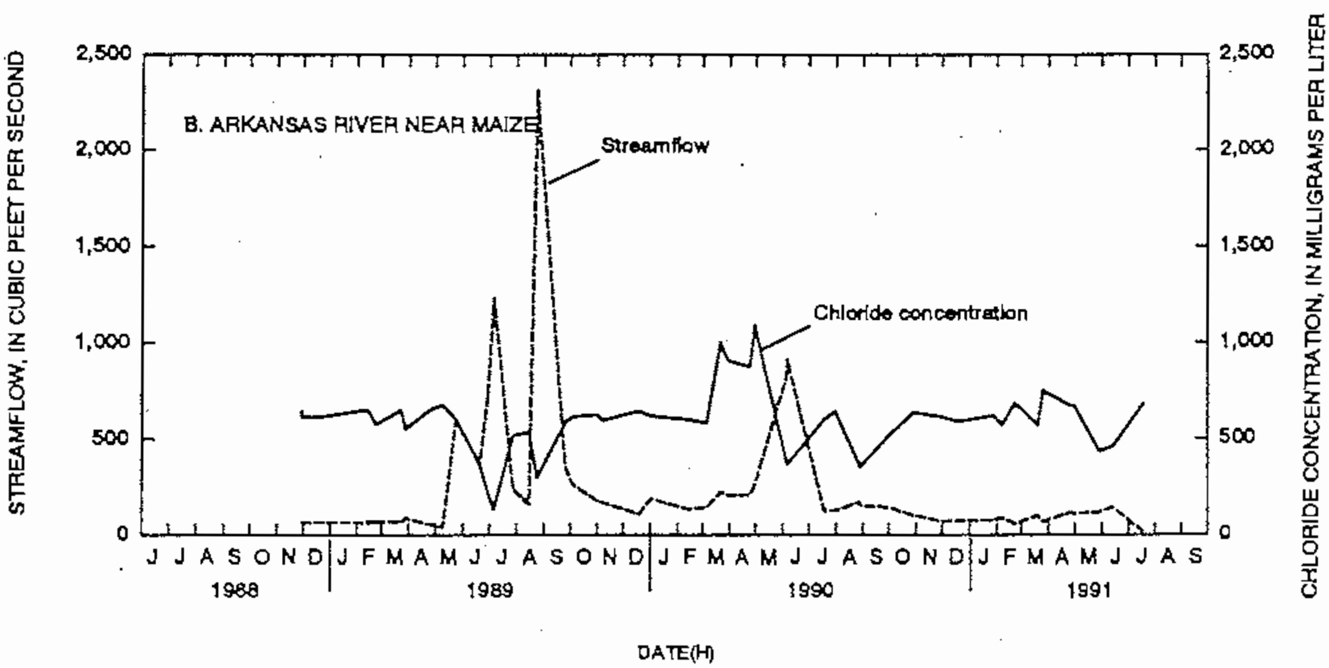



Figure A-6b.—Streamflow and chloride concentration at the Arkansas River near Maize gauging station, November 1988-July 1991 (Myers et al., in review).

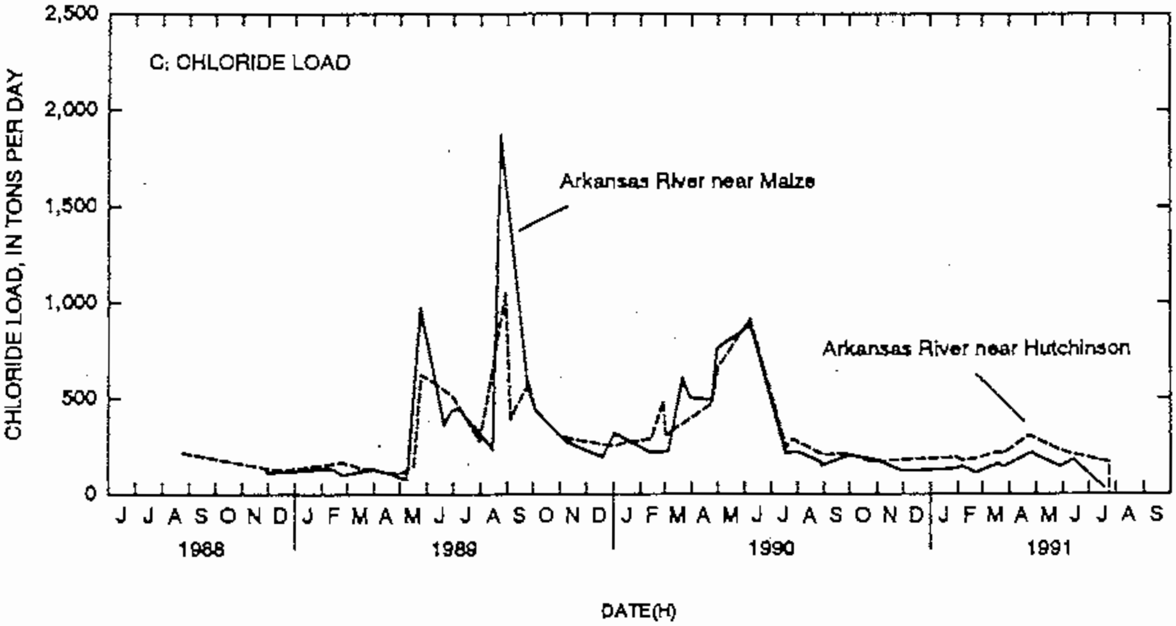



Figure A-6c.—Load calculated from streamflow and chloride concentration data (figures a. and b.) (Myers et al., in review).

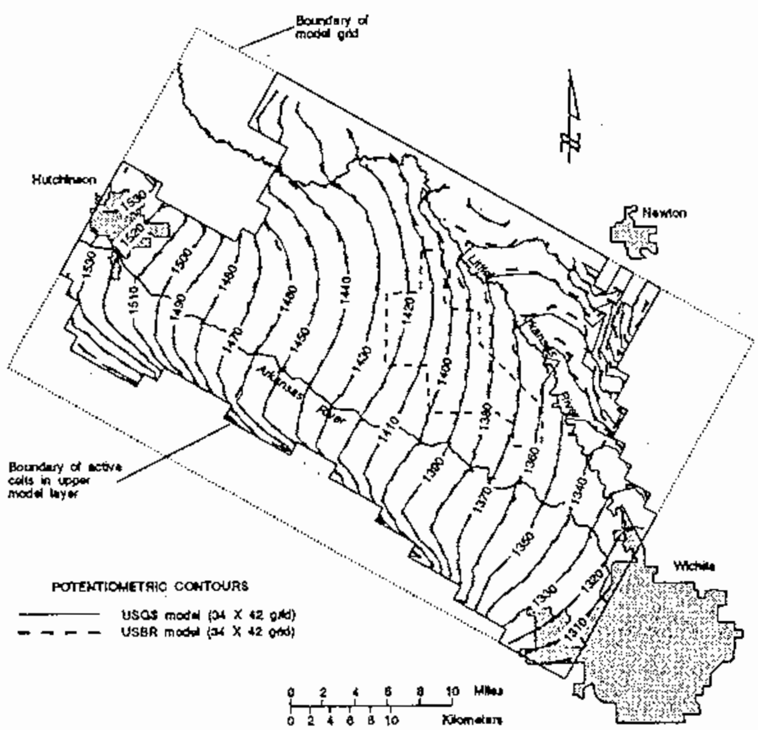



Figure A-7a.—Comparison of steady-state predicted heads by the U.S. Geological Survey flow model and regridded flow model for the upper model layer, 1940.

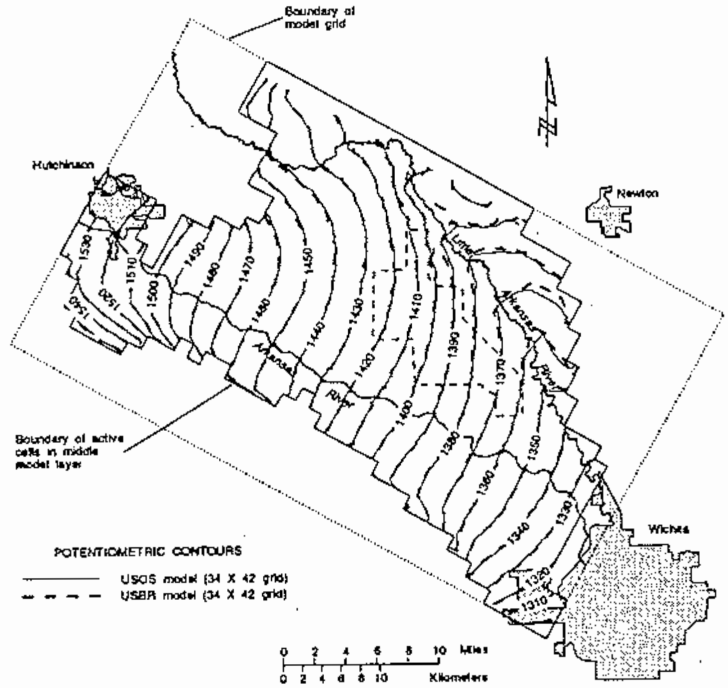



Figure A-7b.—Comparison of steady-state predicted heads by the U.S. Geological Survey flow model and regridded flow model for the middle model layer, 1940.

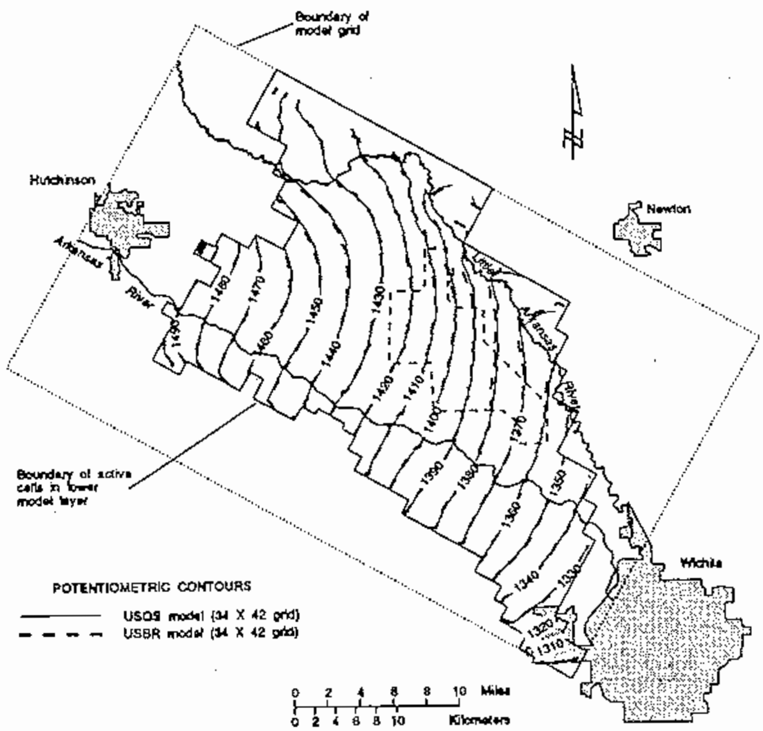



Figure A-7c.—Comparison of steady-state predicted heads by the U.S. Geological Survey flow model and regridded flow model for the lower model layer, 1940.

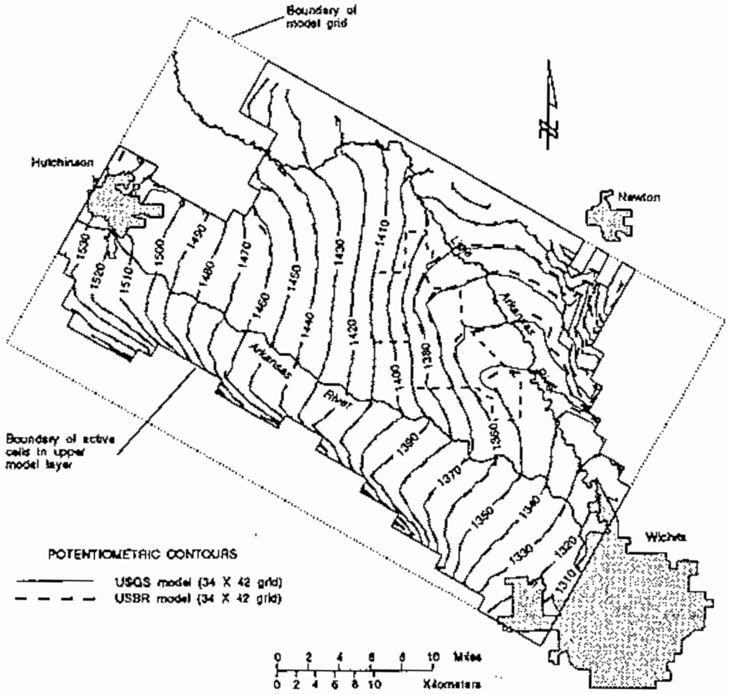



Figure A-8a.—Comparison of transient predicted heads by the U.S. Geological Survey flow model and regridded flow model for the upper model layer, 1989.

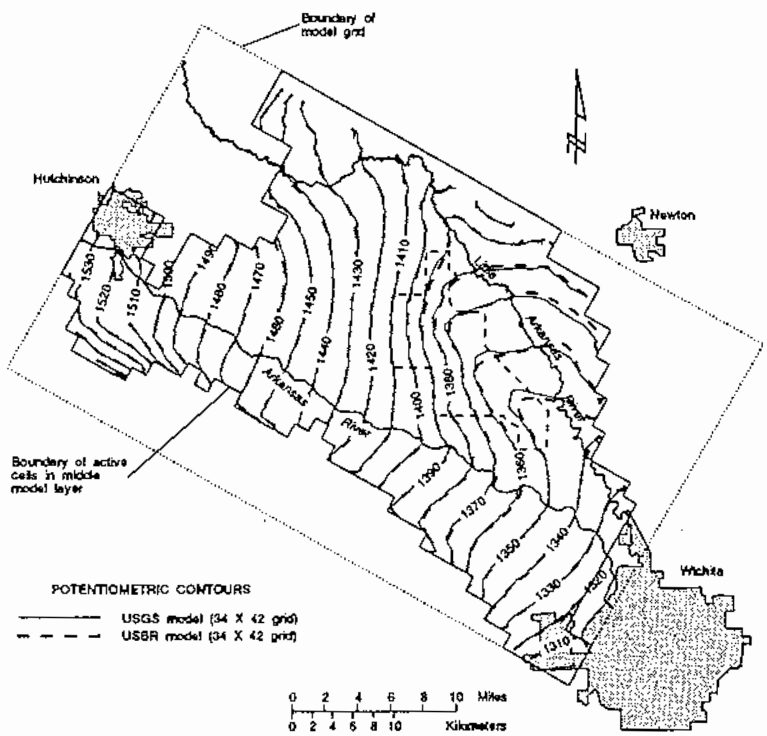



Figure A-8b.—Comparison of transient predicted heads by the U.S. Geological Survey flow model and regridded flow model for the middle model layer, 1989.

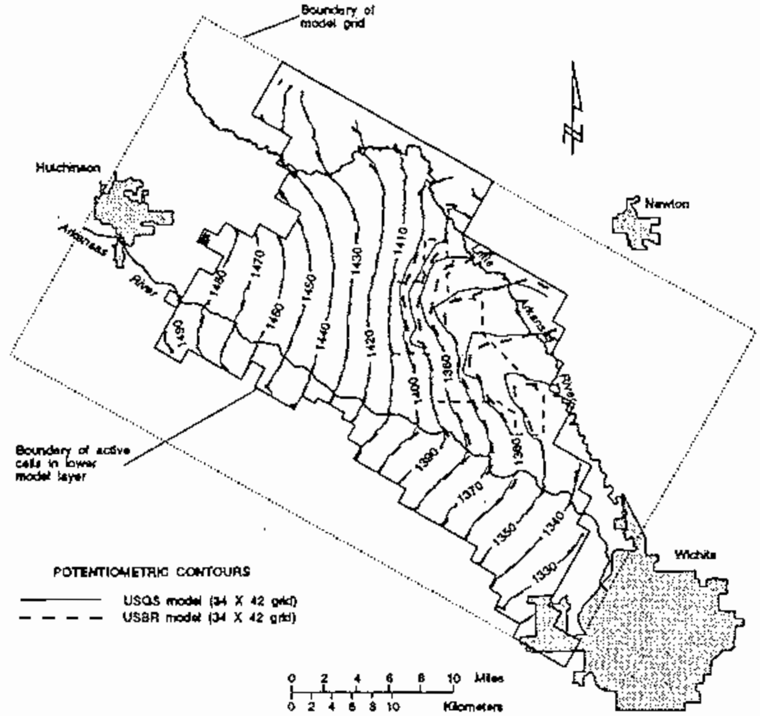



Figure A-8c.—Comparison of transient predicted heads by the U.S. Geological Survey flow model and regridded flow model for the lower model layer, 1989.

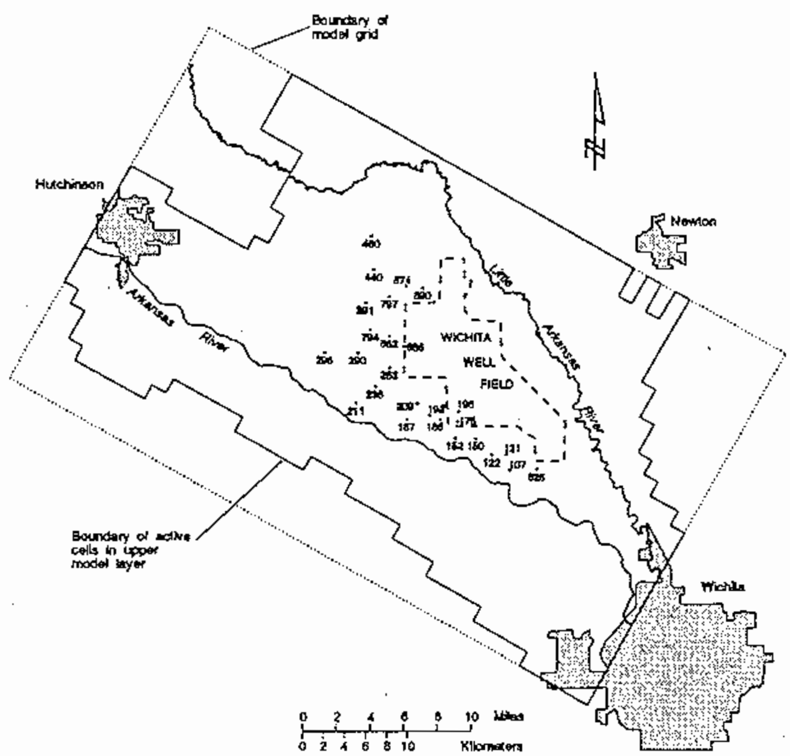



Figure A-9a.—Locations having well data used in the model calibration for the upper model layer.

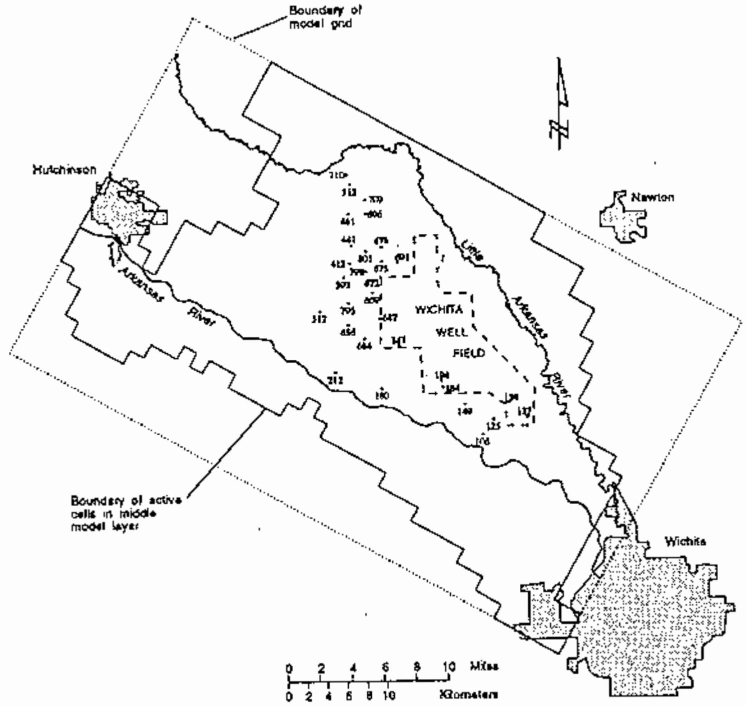



Figure A-9b.—Locations having well data used in the model calibration for the middle model layer.

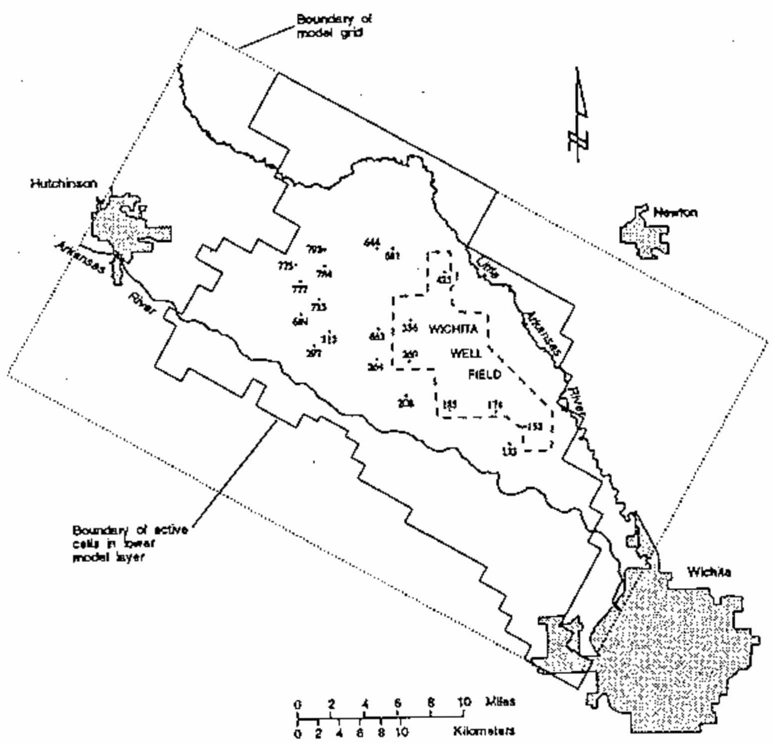



Figure A-9c.—Locations having well data used in the model calibration for the lower model layer.

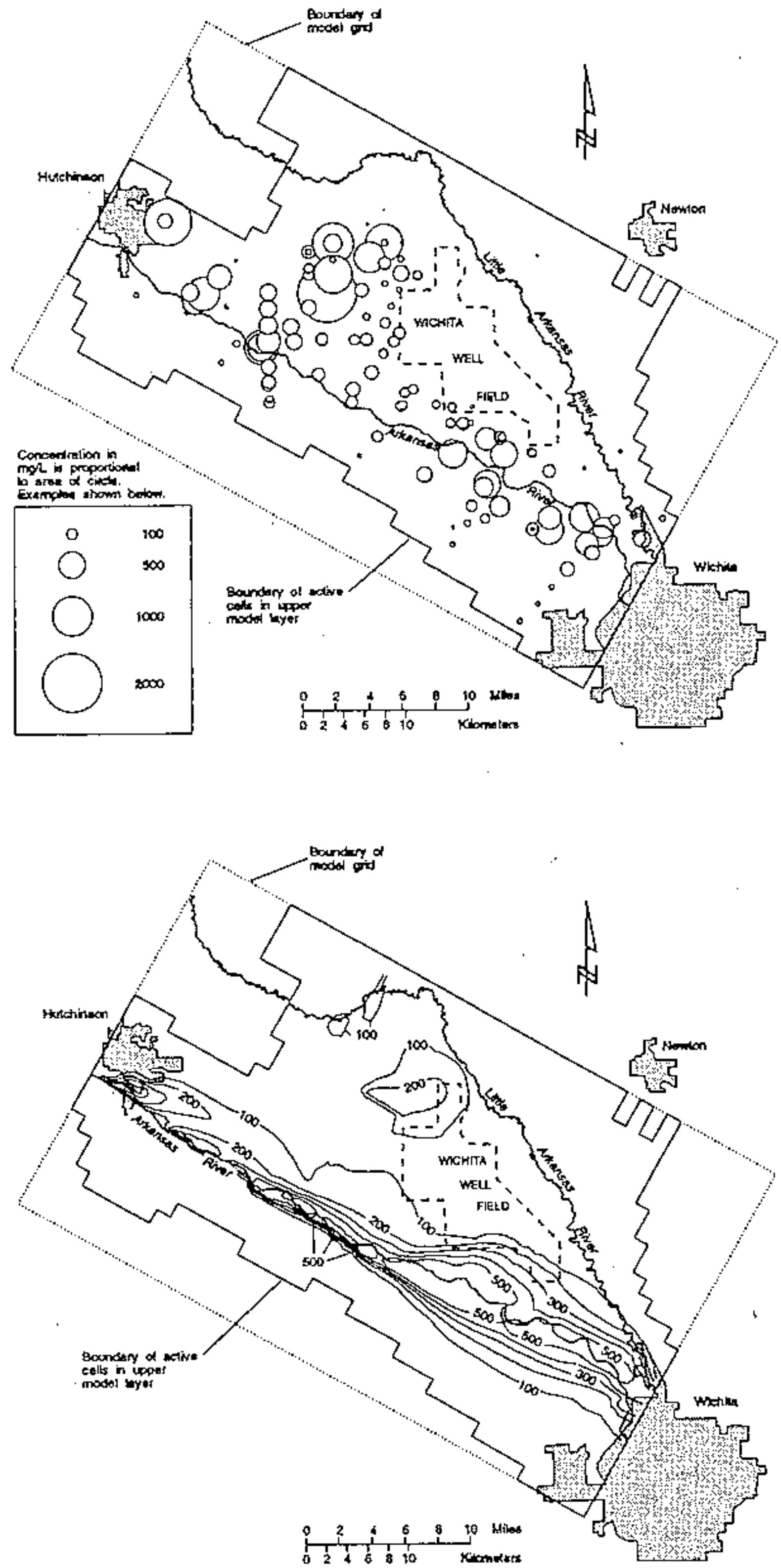



Figure A-10a.—Average chloride concentrations of measured data in (1986-1992) in the Equus Beds aquifer and predicted chloride distribution for the upper model layer.

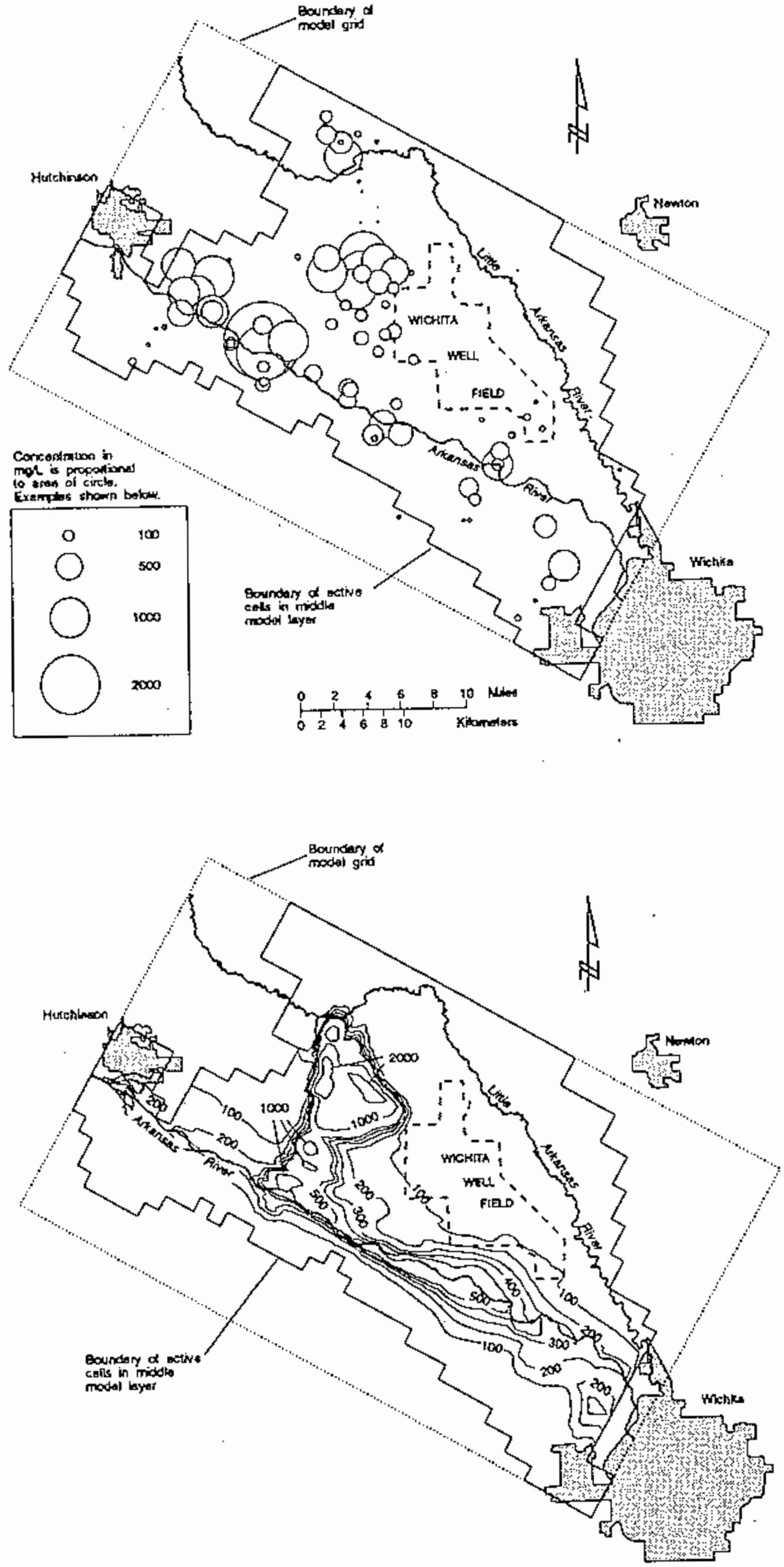
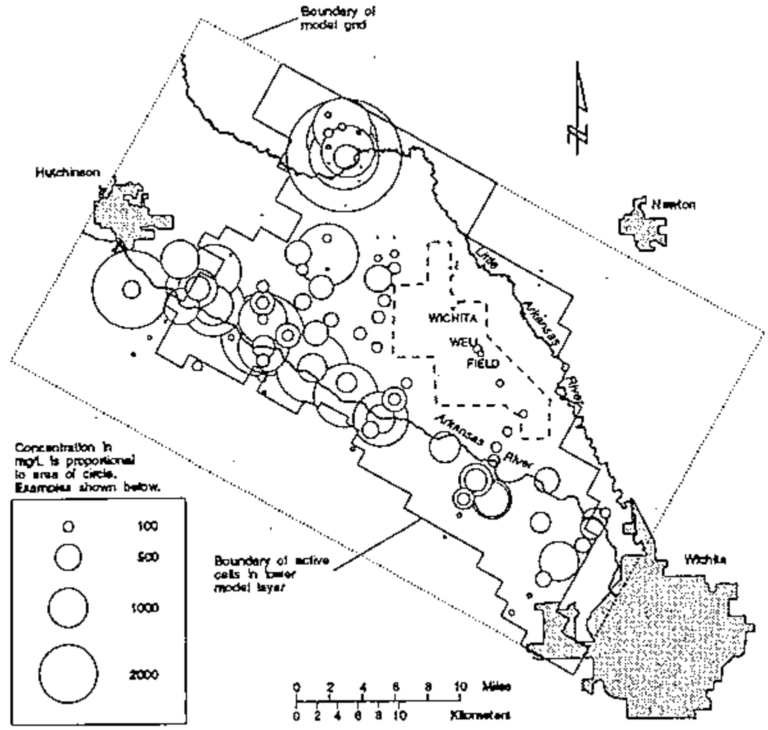



Figure A-10b.—Average chloride concentrations of measured data in (1986-1992) in the Equus Beds aquifer and predicted chloride distribution for the middle model layer.



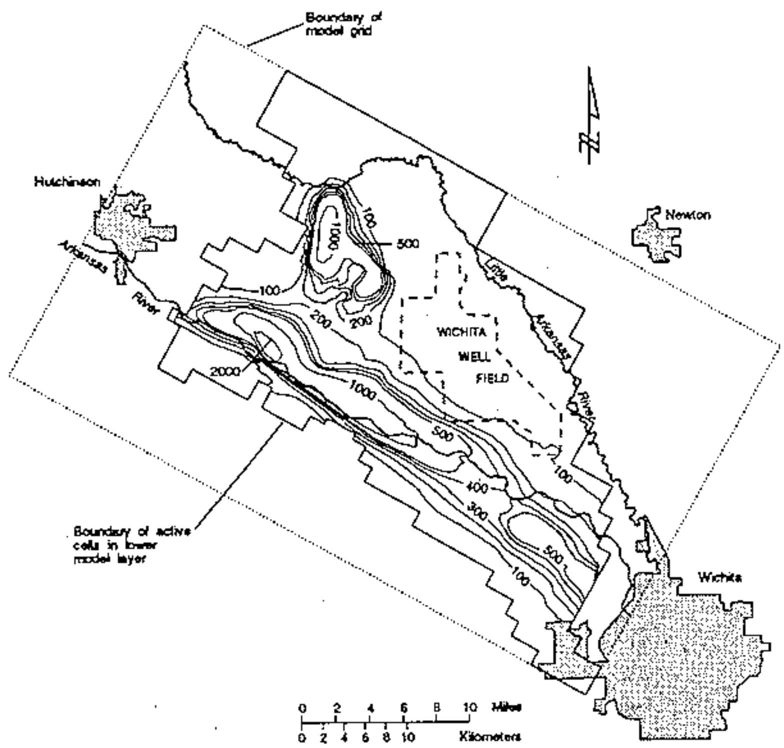




Figure A-10c.—Average chloride concentrations of measured data in (1986-1992) in the Equus Beds aquifer and predicted chloride distribution for the lower model layer.

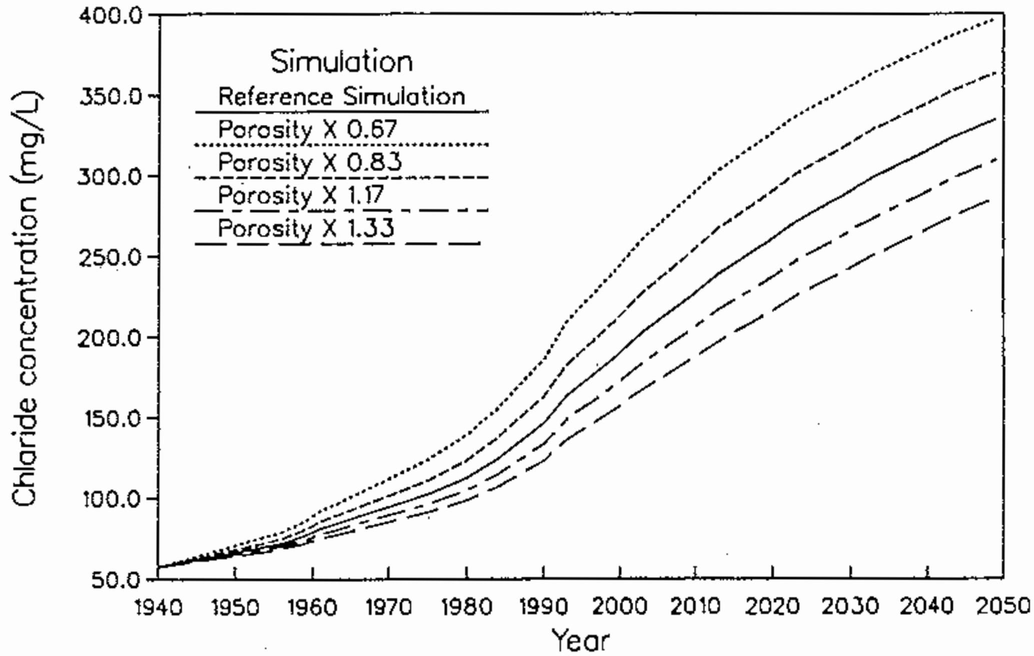



Figure A-11a.—Predicted average chloride concentration in the river zone for varying effective porosity values.

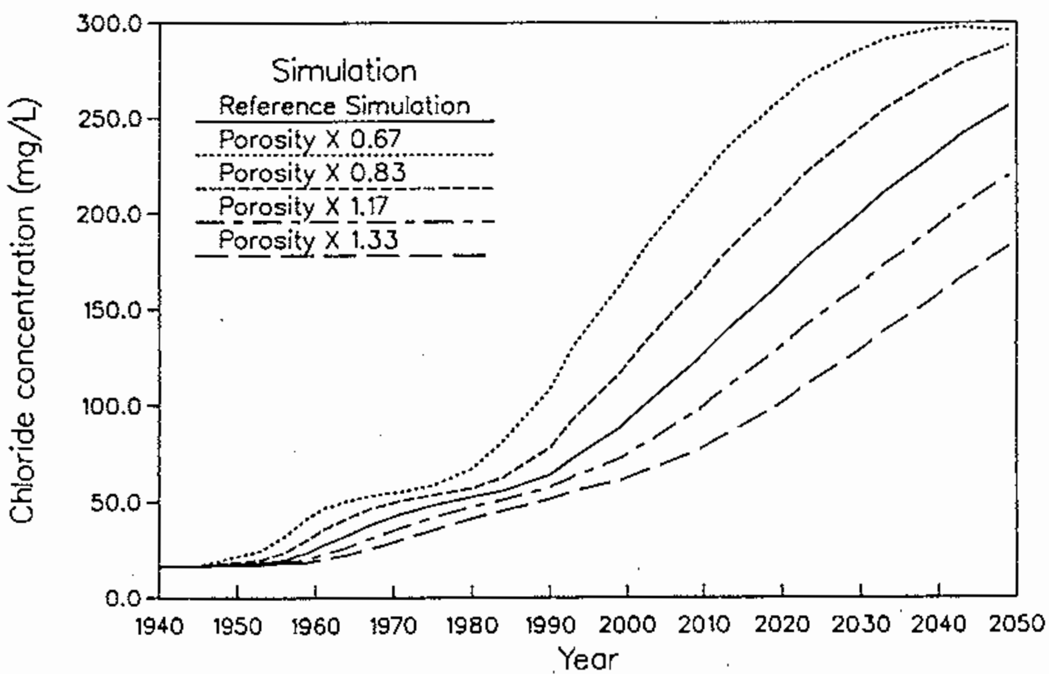



Figure A-11b.—Predicted average chloride concentration in the brine zone for varying effective porosity values.

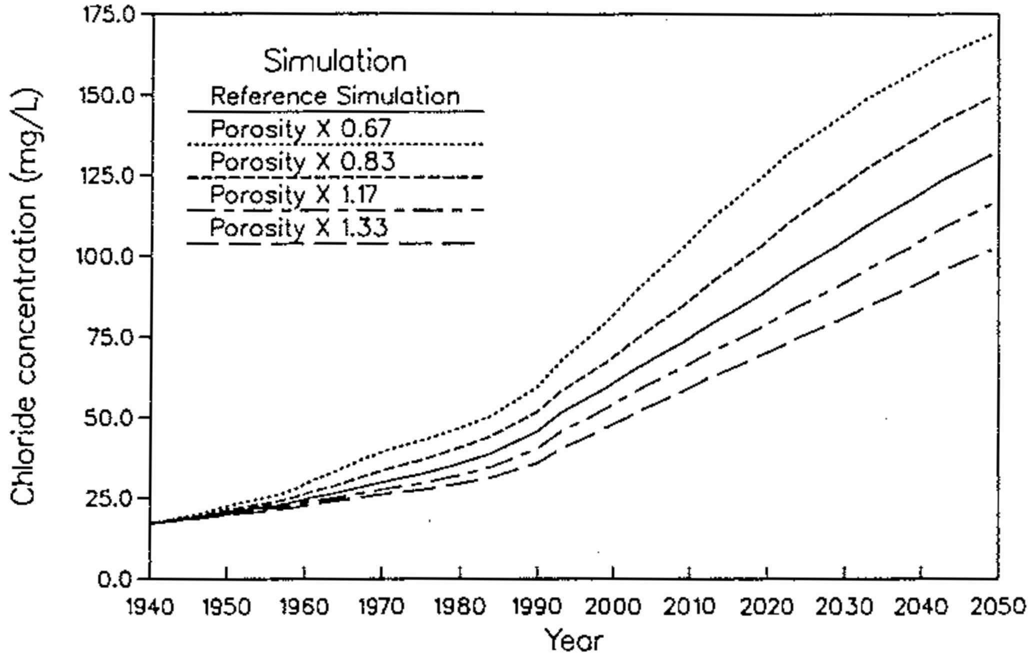



Figure A-11c.—Predicted average chloride concentration in the Wichita well field area for varying effective porosity values.

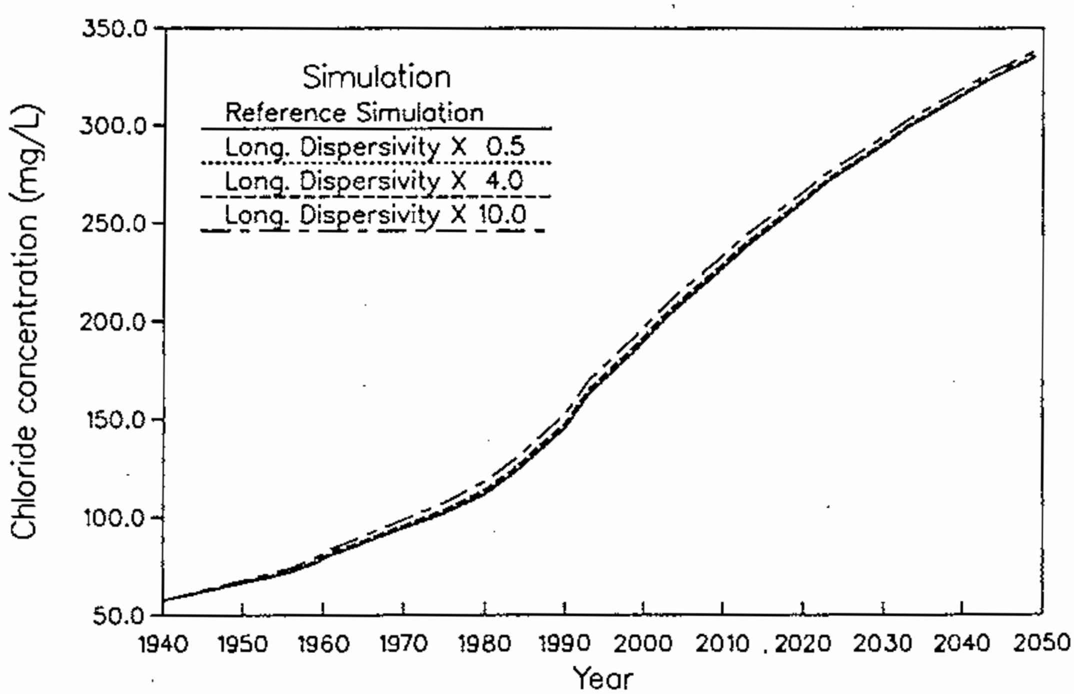



Figure A-12a.—Predicted average chloride concentration in the river zone for varying longitudinal dispersivity values.

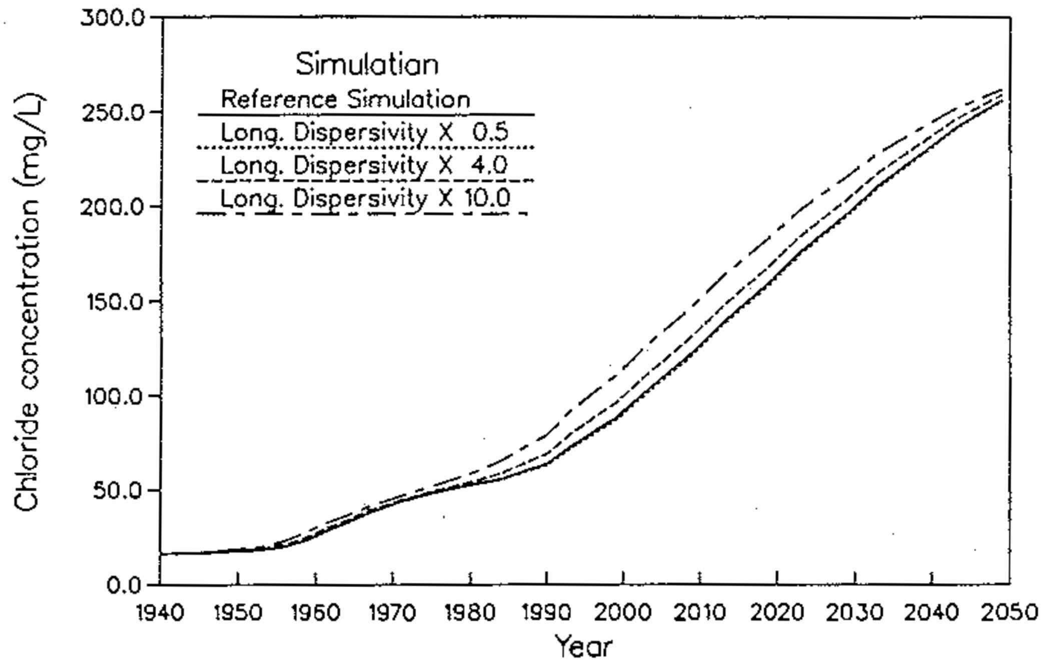



Figure A-12b.—Predicted average chloride concentration in the brine zone for varying longitudinal dispersivity values.

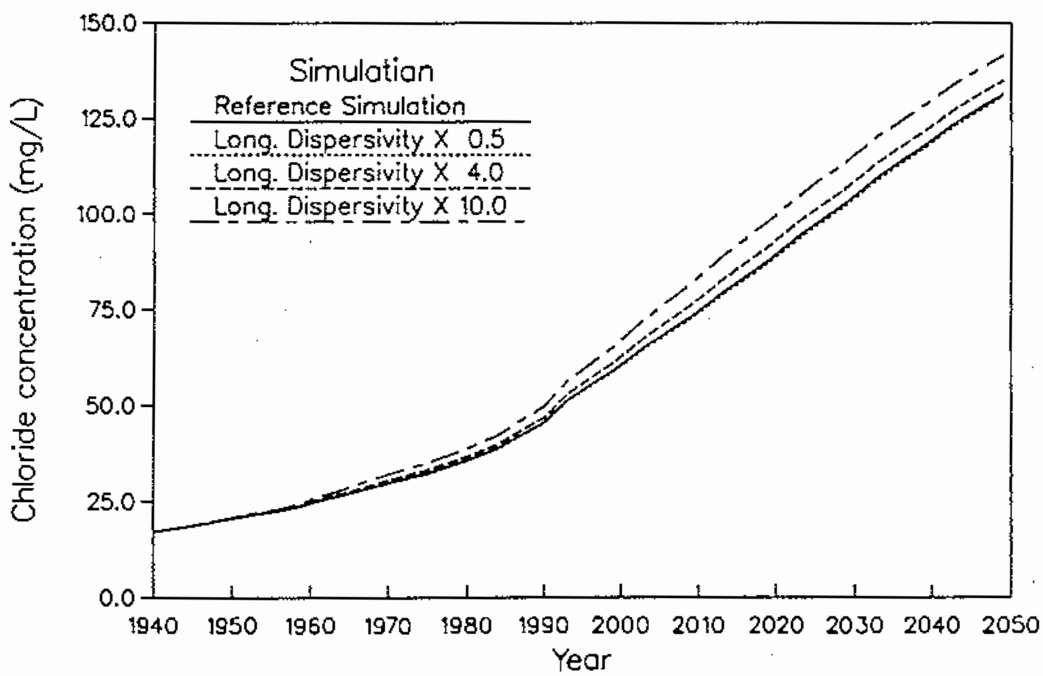



Figure A-12c.—Predicted average chloride concentration in the Wichita well field area for varying longitudinal dispersivity values.

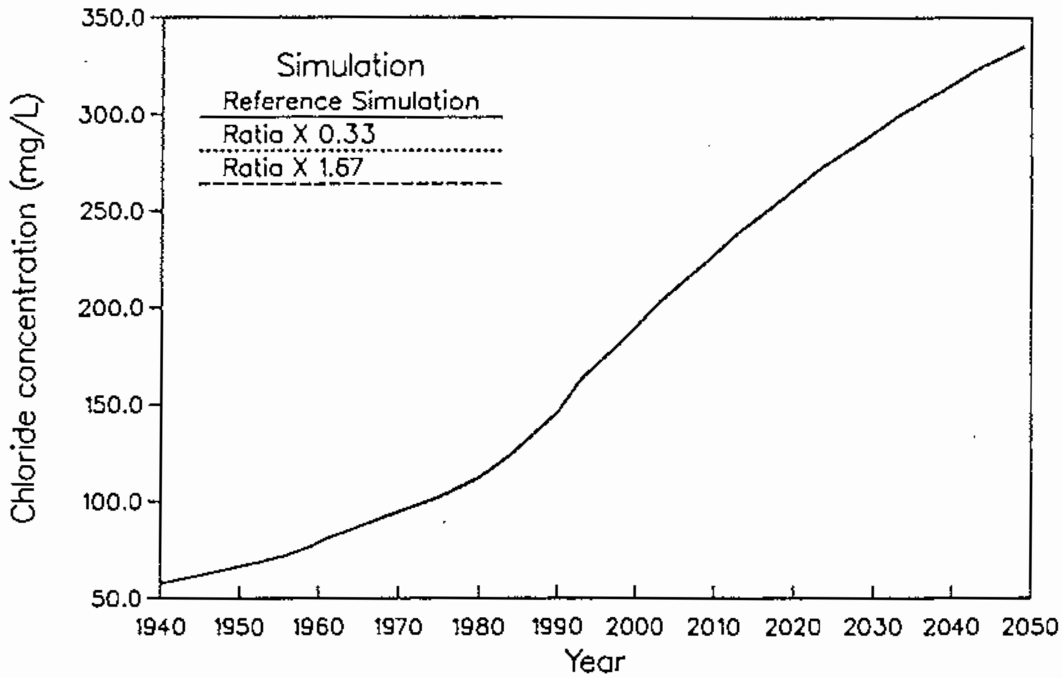



Figure A-13a.—Predicted average chloride concentration in the river zone for varying the ratio of lateral to longitudinal dispersivity values.

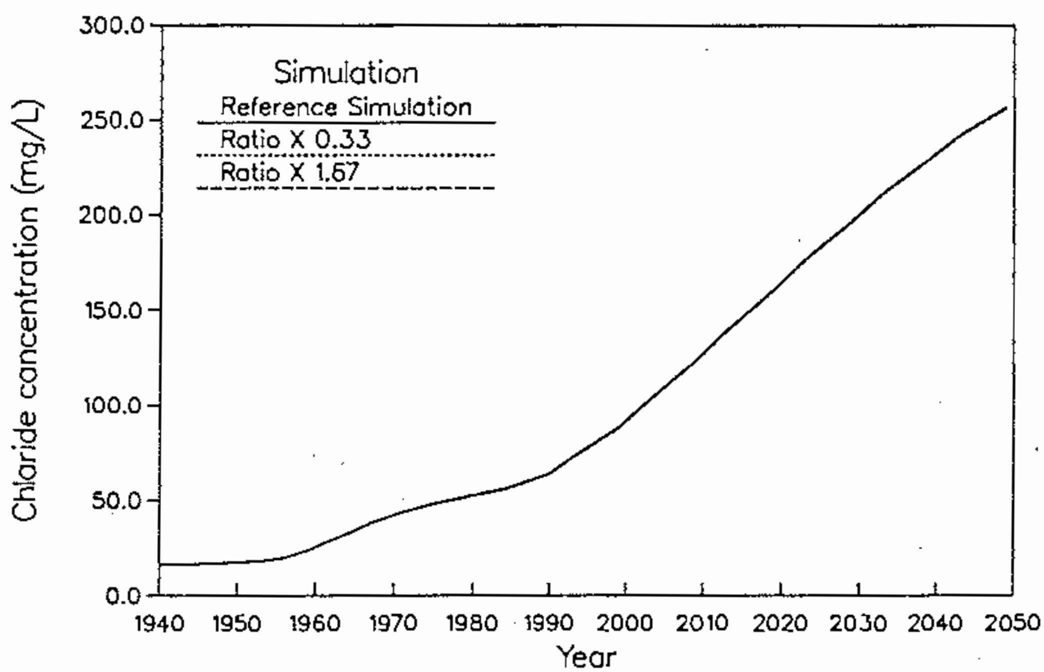



Figure A-13b.—Predicted average chloride concentration in the brine zone for varying the ratio of lateral to longitudinal dispersivity values.

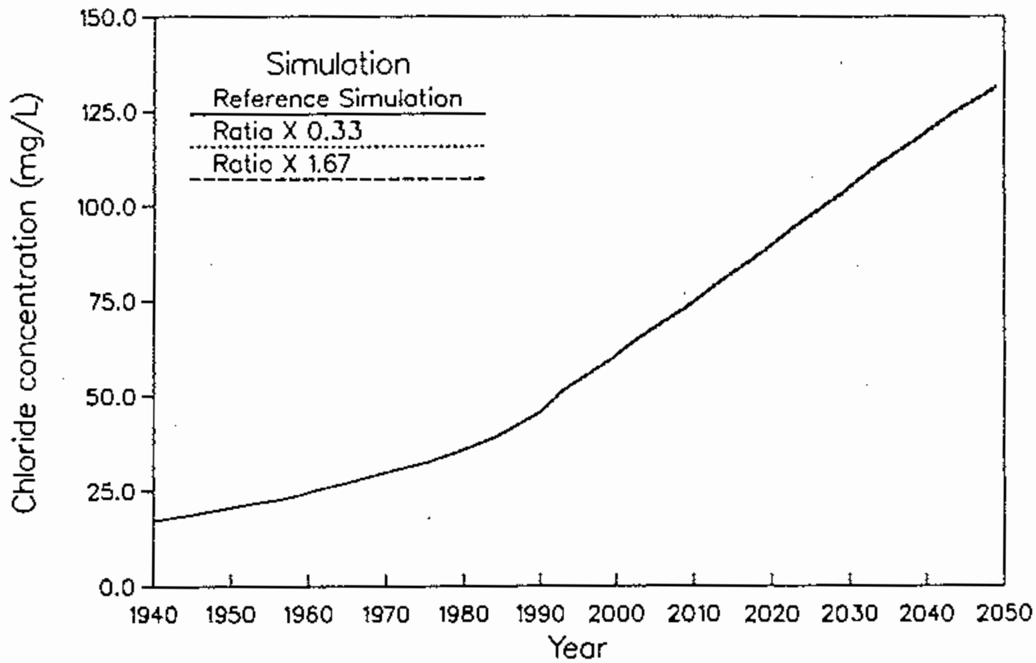



Figure A-13c.—Predicted average chloride concentration in the Wichita well field area for varying the ratio of lateral to longitudinal dispersivity values.

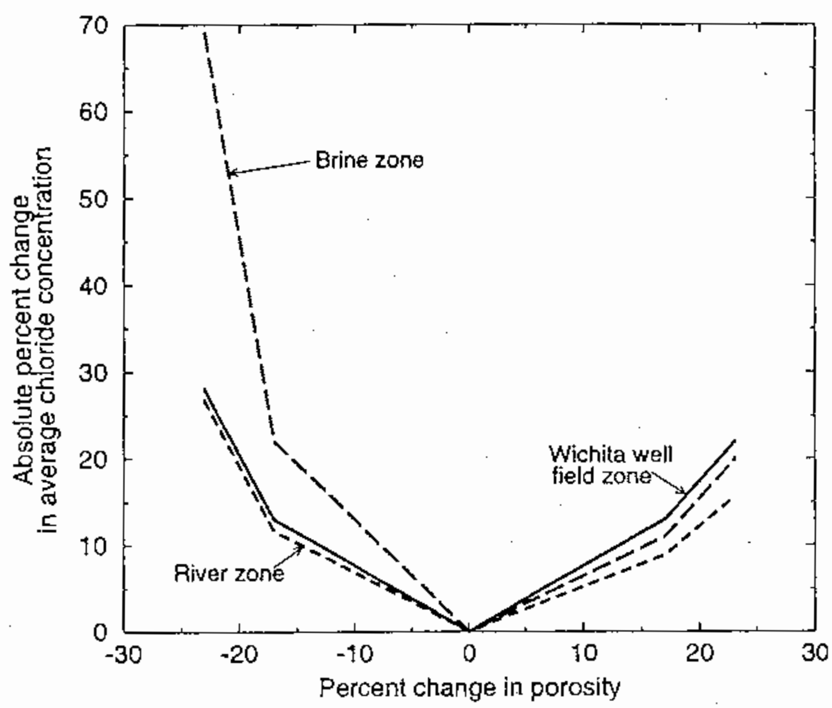



Figure A-14a.—Absolute percent change in predicted average chloride concentration versus percent change in porosity, 1989.

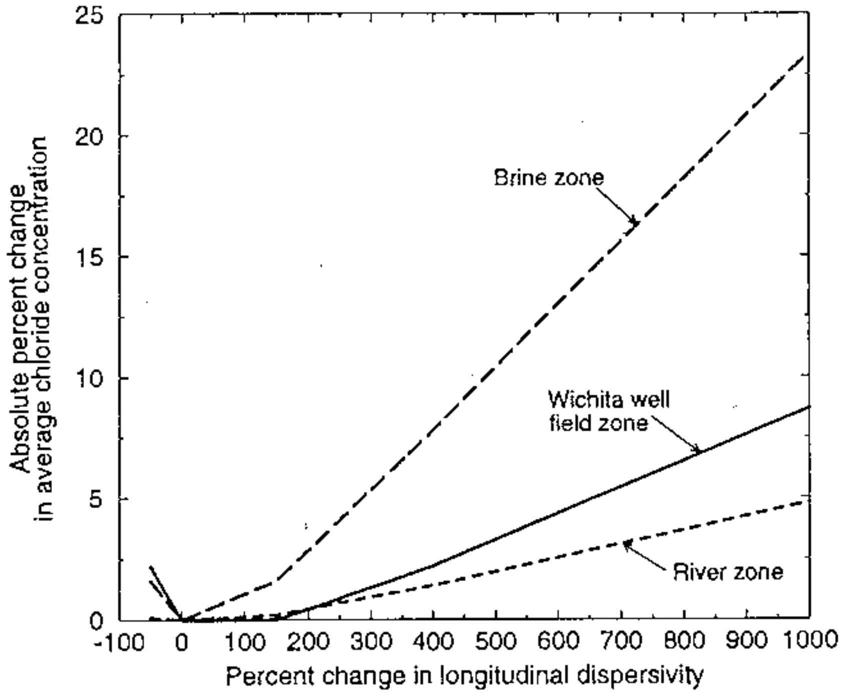



Figure A-14b.—Absolute percent change in predicted average chloride concentration versus percent change in longitudinal dispersivity, 1989.

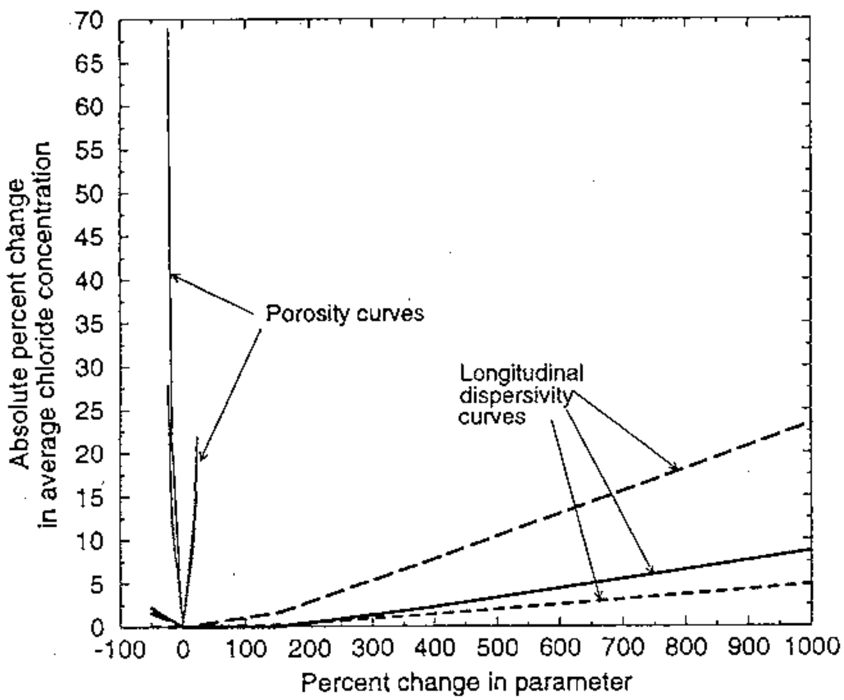



Figure A-14c.—Absolute percent change in predicted average chloride concentration versus percent change in porosity and longitudinal dispersivity, 1989.

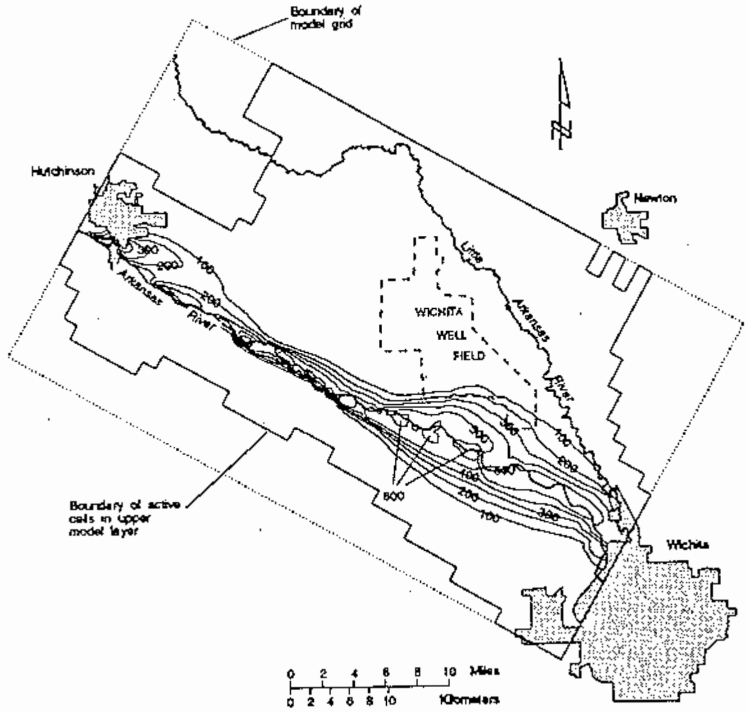



Figure A-15a.—Predicted chloride distribution in 1989 with the Arkansas River as the only chloride source for the upper model layer.

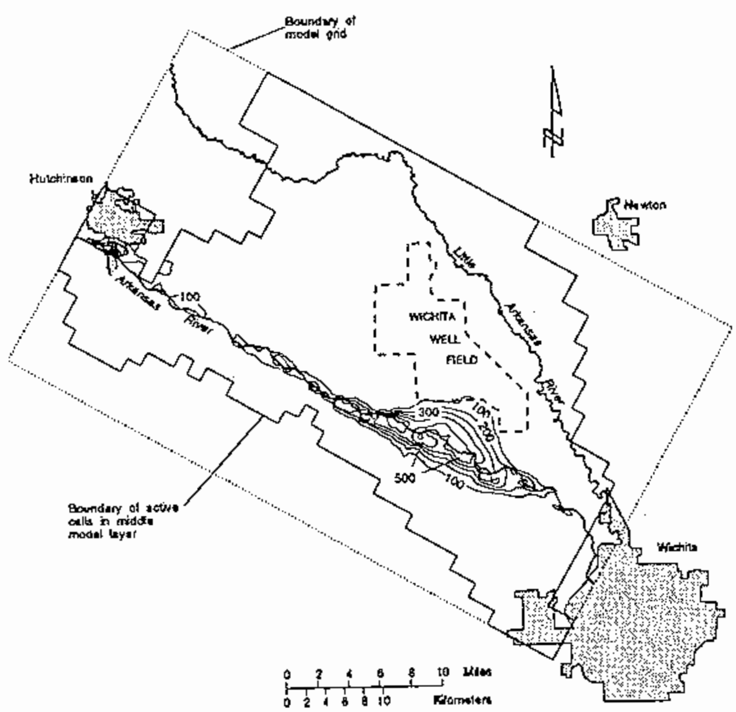



Figure A-15b.—Predicted chloride distribution in 1989 with the Arkansas River as the only chloride source for the middle model layer.

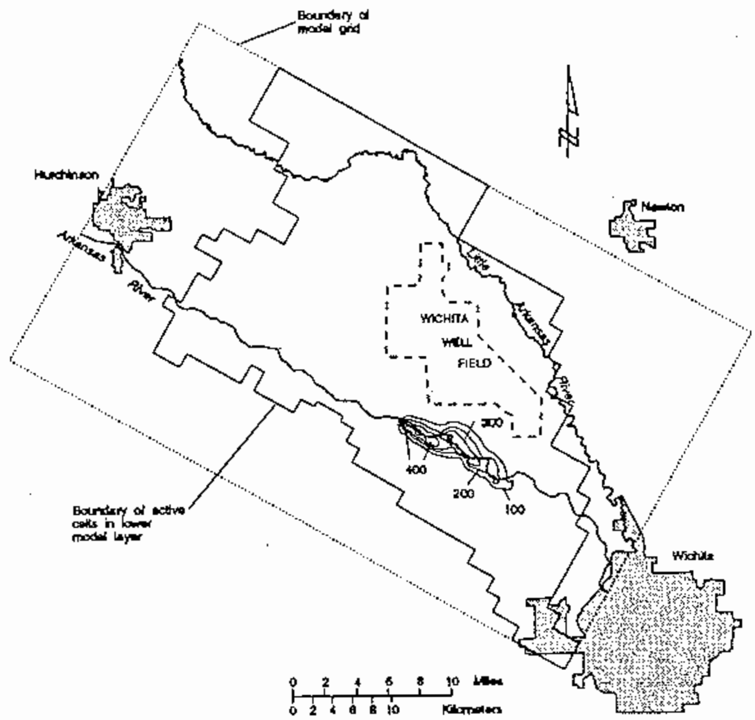



Figure A-15c.—Predicted chloride distribution in 1989 with the Arkansas River as the only chloride source for the lower model layer.

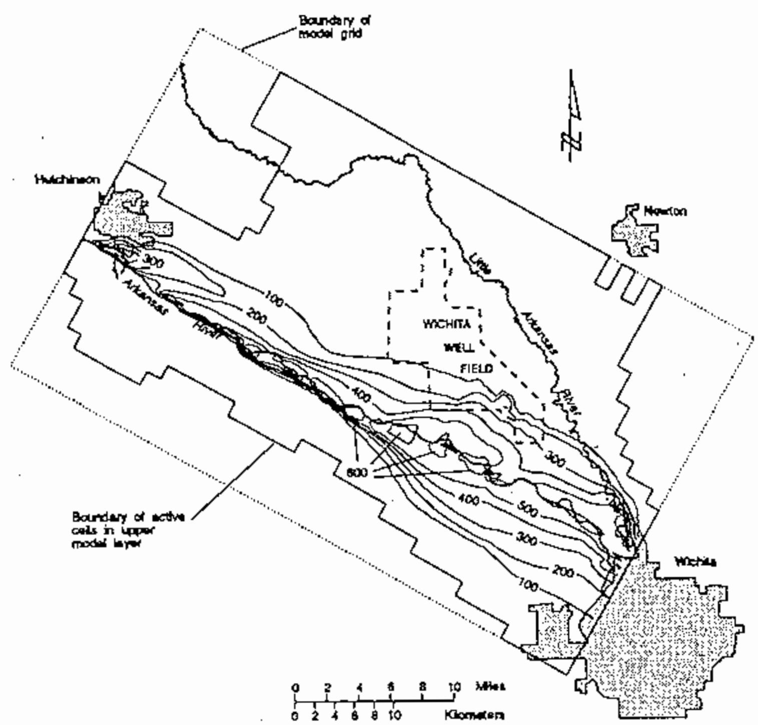



Figure A-16a.—Predicted chloride distribution in 2049 with the Arkansas River as the only chloride source for the upper model layer.

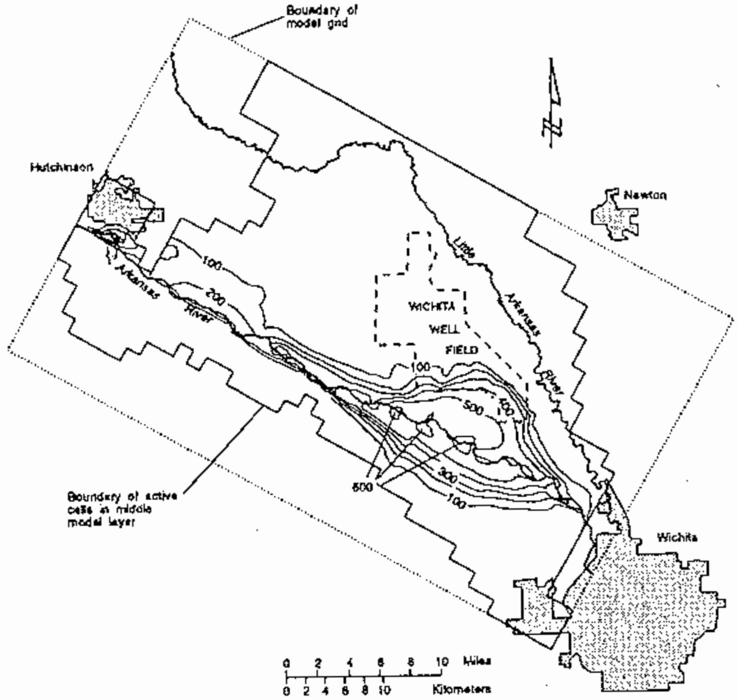



Figure A-16b.—Predicted chloride distribution in 2049 with the Arkansas River as the only chloride source for the middle model layer.

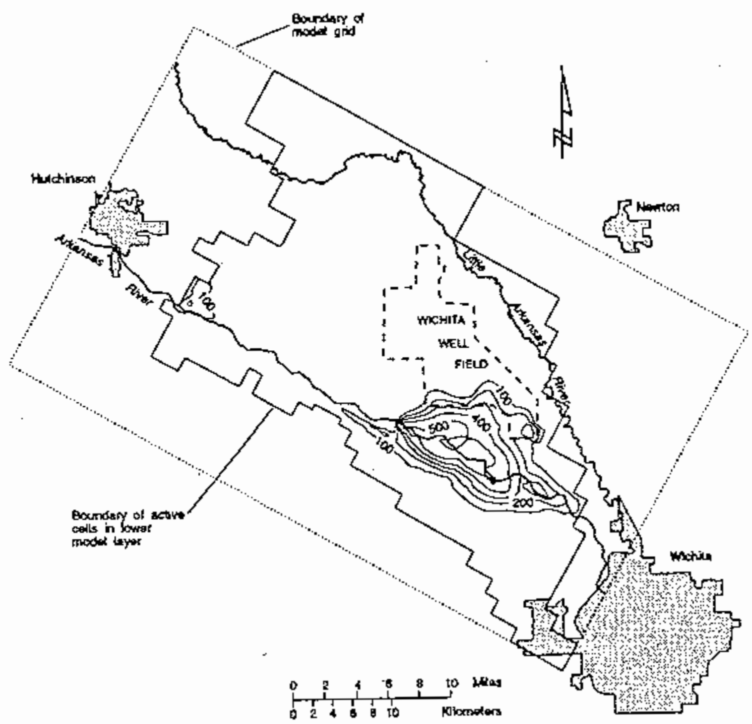



Figure A-16c.—Predicted chloride distribution in 2049 with the Arkansas River as the only chloride source for the lower model layer.

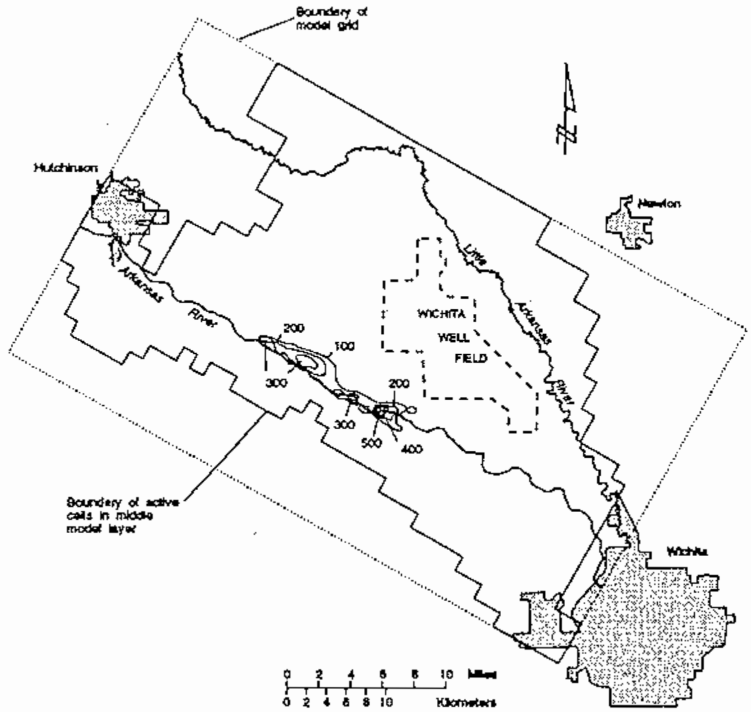



Figure A-17a.—Predicted chloride distribution in 1989 with saltwater intruding from the deep natural saltwater as the only chloride source for the middle model layer.

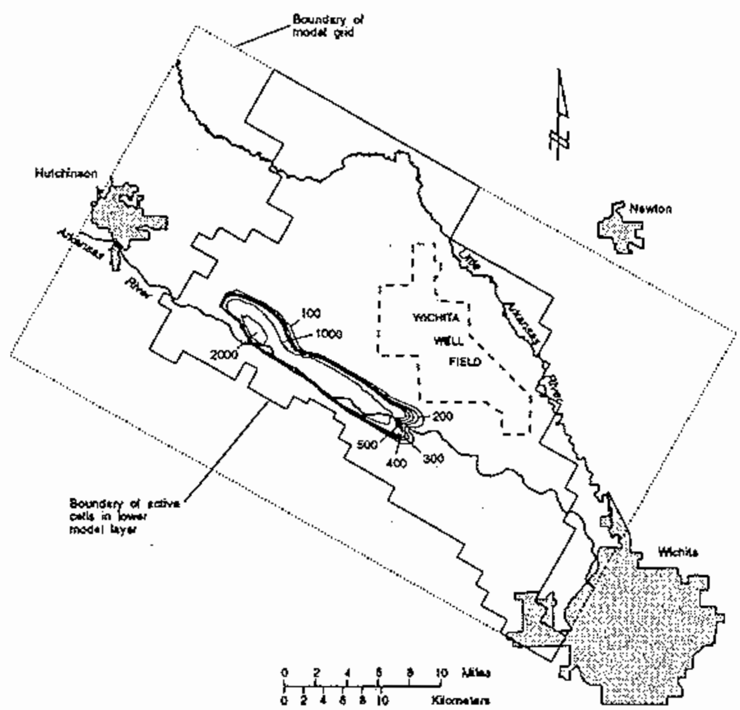



Figure A-17b.—Predicted chloride distribution in 1989 with saltwater intruding from the deep natural saltwater as the only chloride source for the lower model layer.

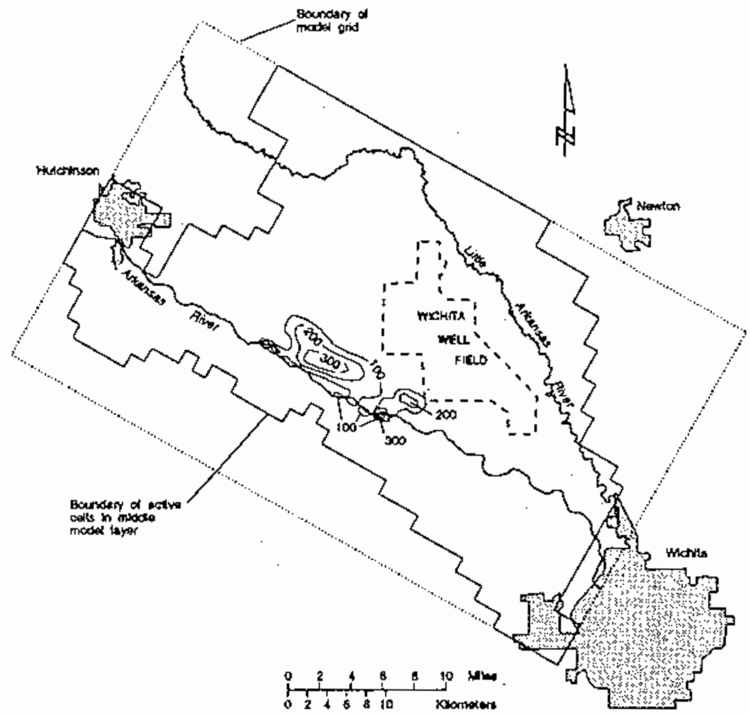



Figure A-18a.—Predicted chloride distribution in 2049 with saltwater intruding from the deep natural saltwater as the only chloride source for the middle model layer.

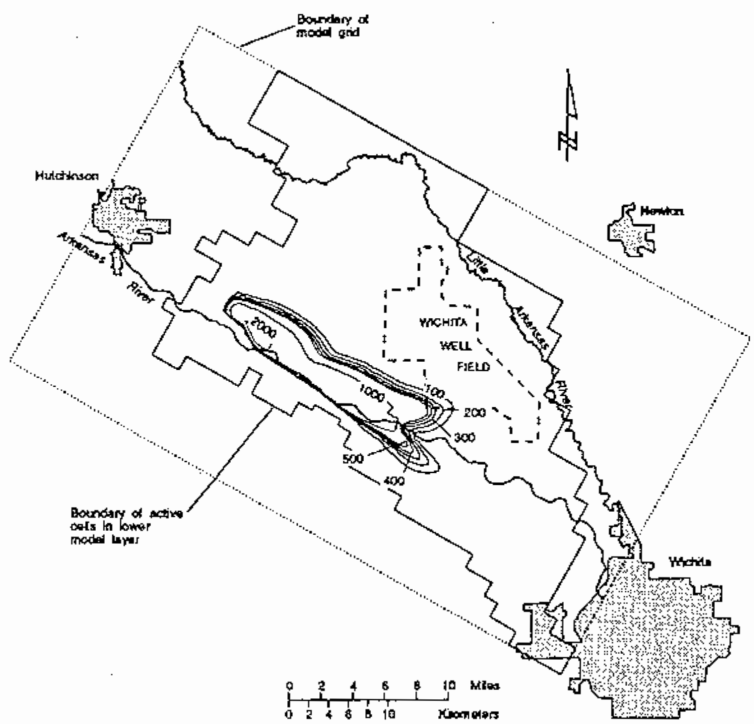



Figure A-18b.—Predicted chloride distribution in 2049 with saltwater intruding from the deep natural saltwater as the only chloride source for the lower model layer.

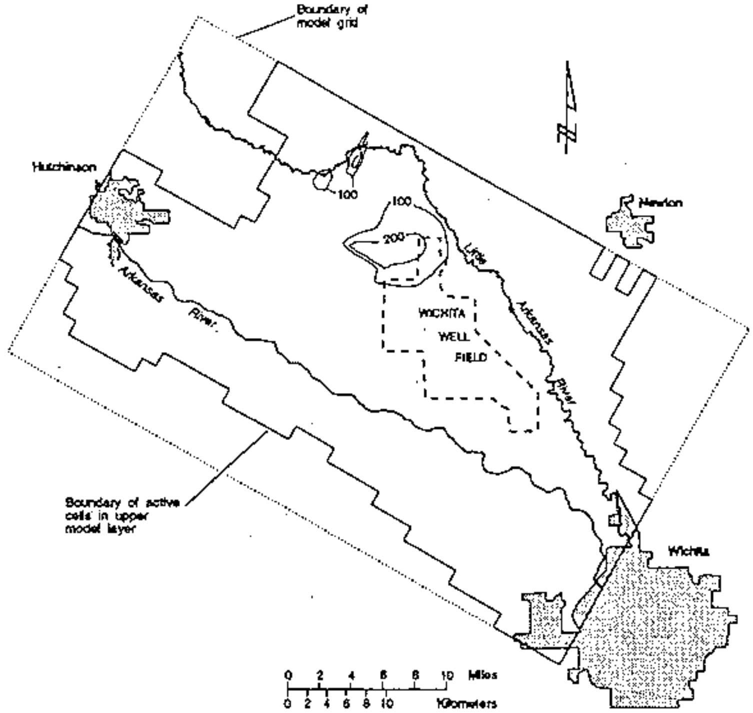



Figure A-19a.—Predicted chloride distribution in 1989 with oil field brine as the only chloride source for the upper model layer.

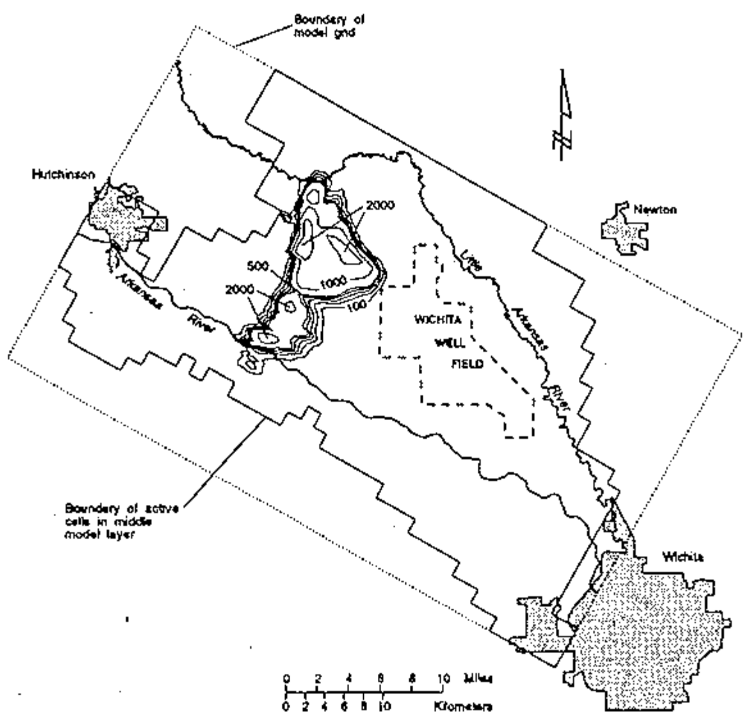



Figure A-19b.—Predicted chloride distribution in the 1989 with oil field brine as the only chloride source for the middle model layer.

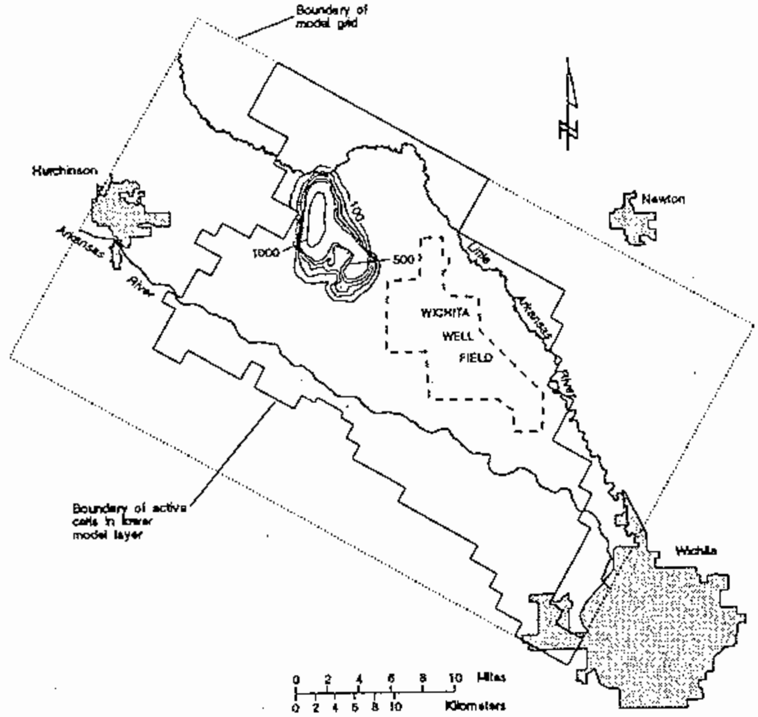



Figure A-19c.—Predicted chloride distribution in 1989 with oil field brine as the only chloride source for the lower model layer.

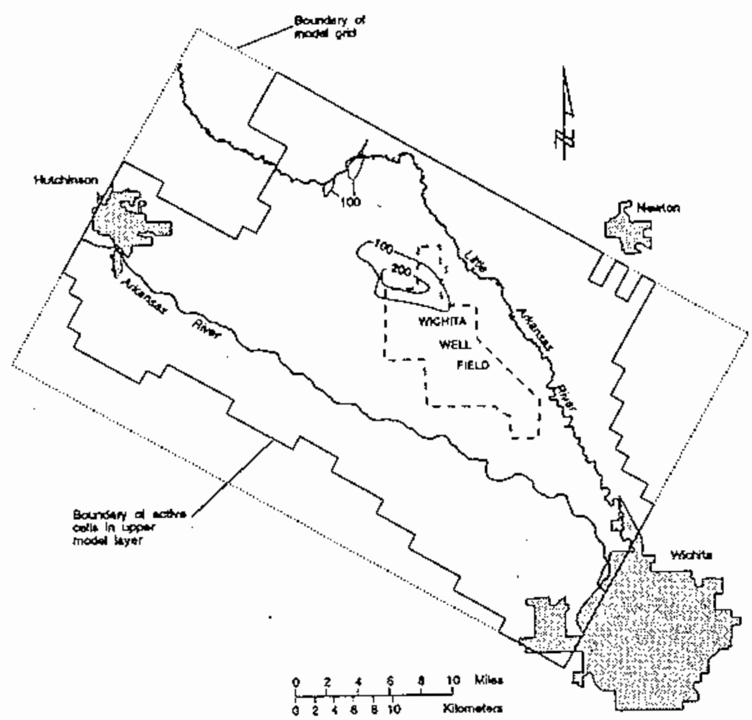



Figure A-20a.—Predicted chloride distribution in 2049 with oil field brine as the only chloride source for the upper model layer.

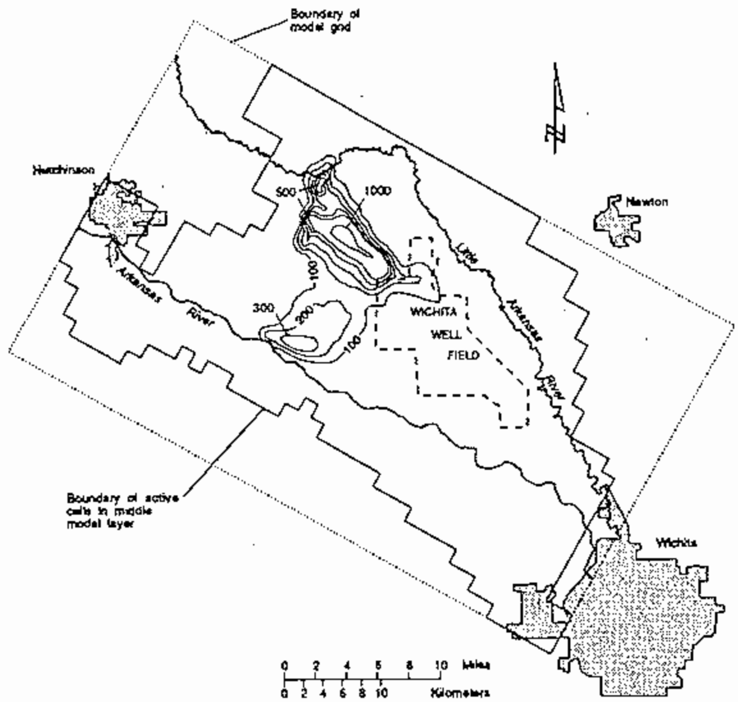



Figure A-20b.—Predicted chloride distribution in 2049 with oil field brine as the only chloride source for the middle model layer.

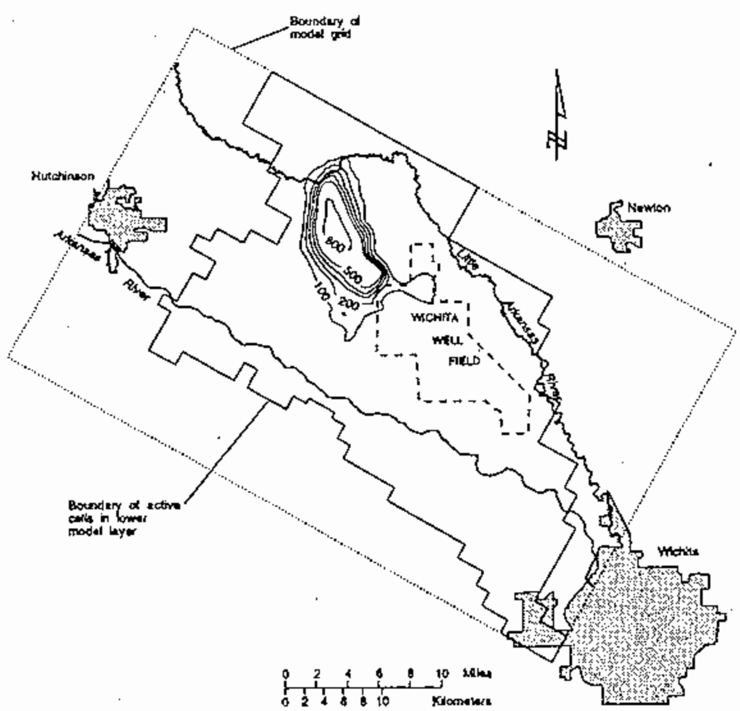



Figure A-20c.—Predicted chloride distribution in 2049 with oil field brine as the only chloride source for the lower model layer.

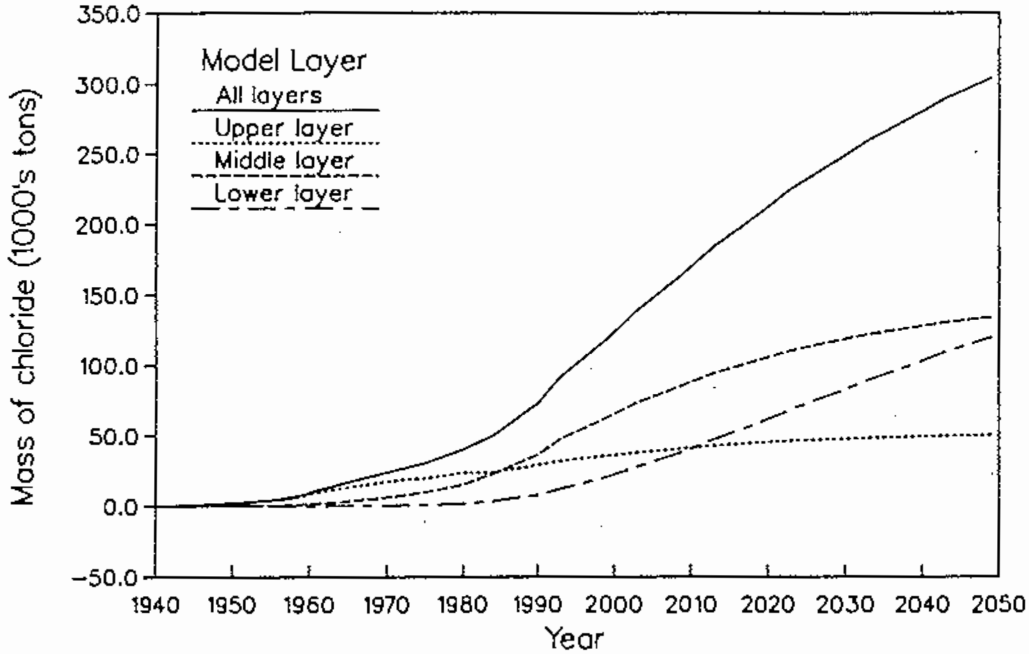



Figure A-21a.—Predicted chloride mass in the river zone with the Arkansas River as the only chloride source.

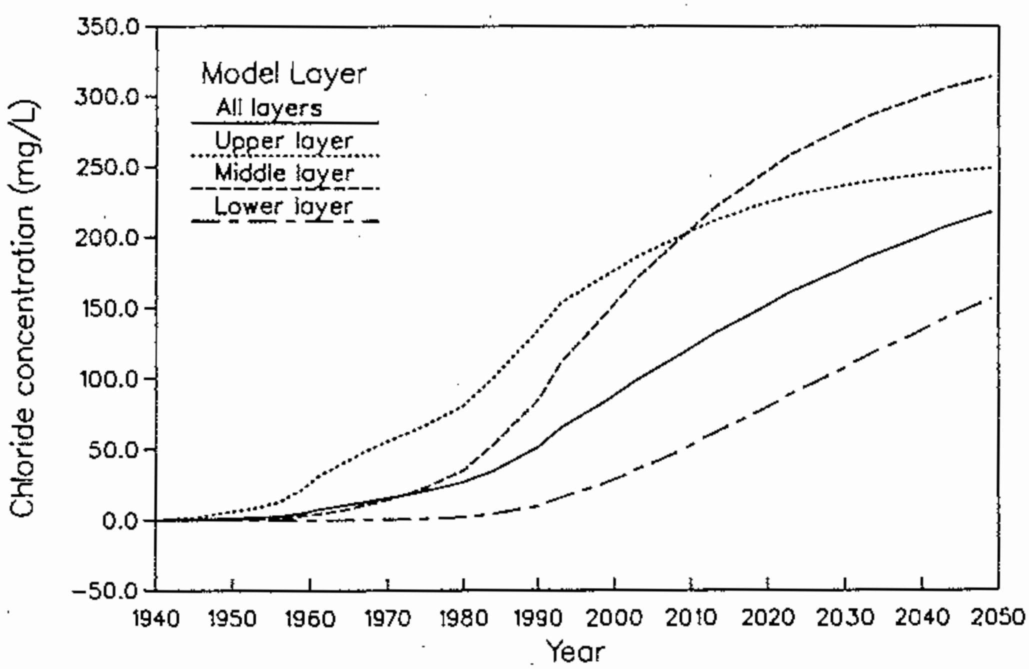



Figure A-21b.—Predicted average chloride concentration in the river zone with the Arkansas River as the only chloride source.

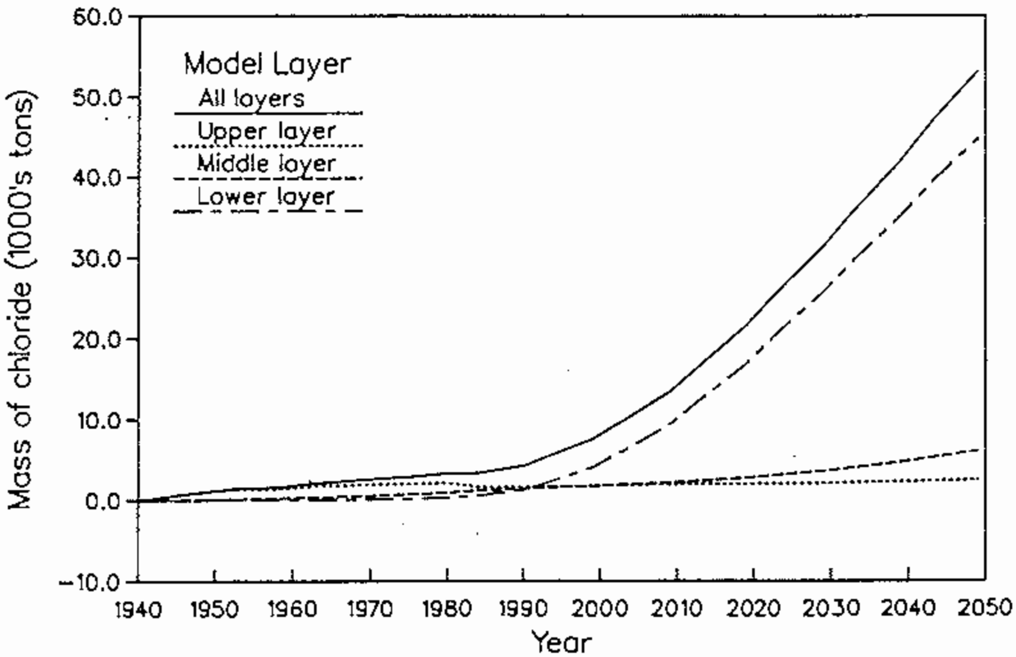



Figure A-22a.—Predicted chloride mass in the river zone with saltwater intruding from the deep natural saltwater as the only chloride source.

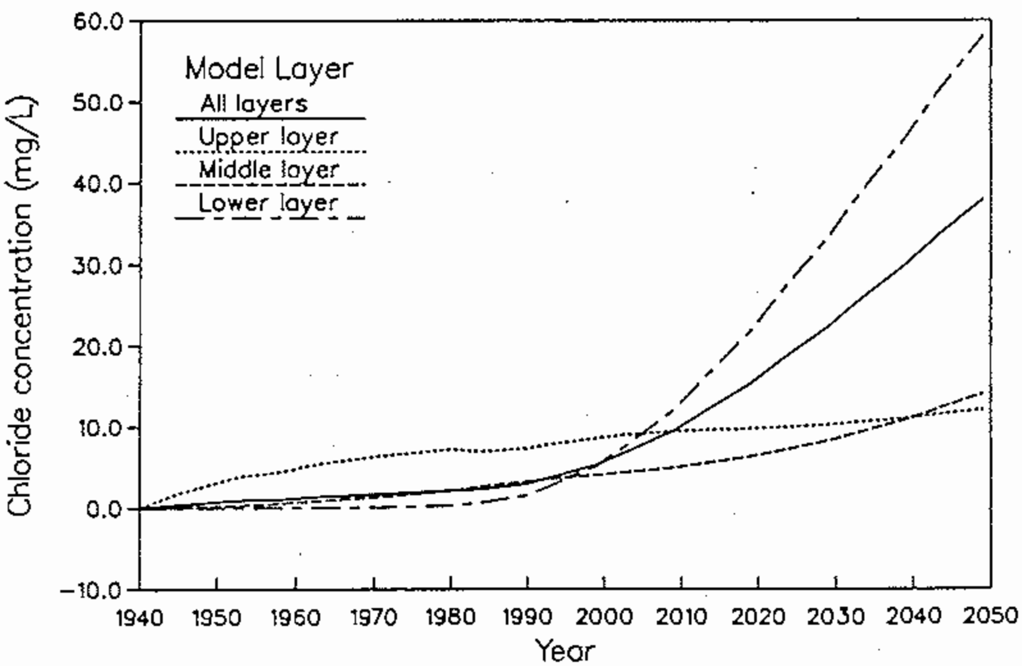



Figure A-22b.—Predicted average chloride concentration in the river zone with saltwater intruding from the deep natural saltwater as the only chloride source.

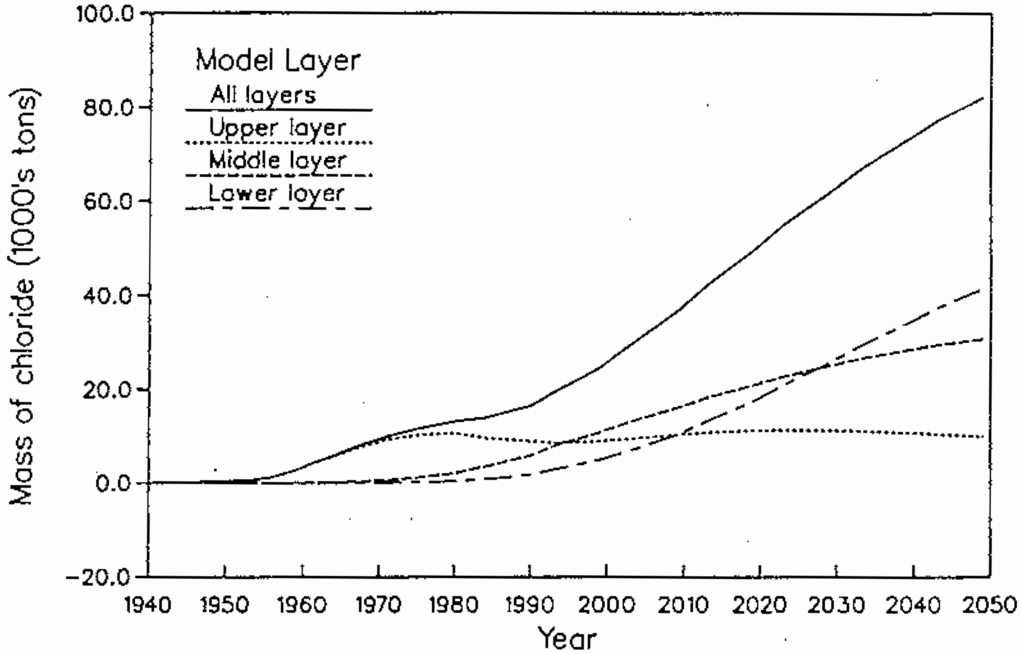



Figure A-23a.—Predicted chloride mass in the brine zone with oil field brine as the only chloride source.

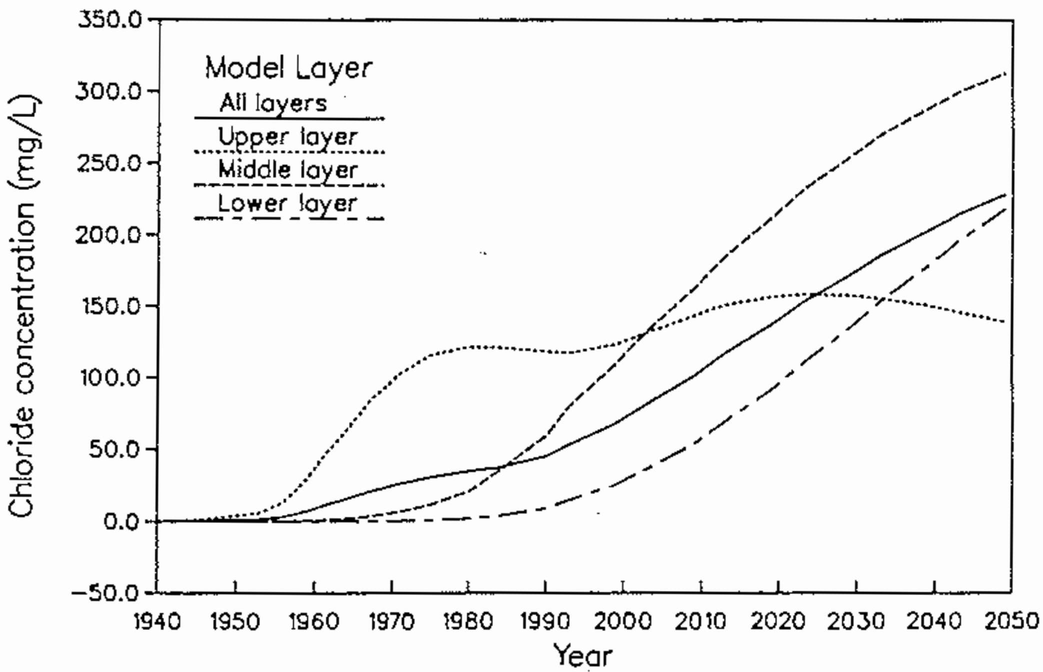



Figure A-23b.—Predicted average chloride concentration in the brine zone with oil field brine as the only chloride source.

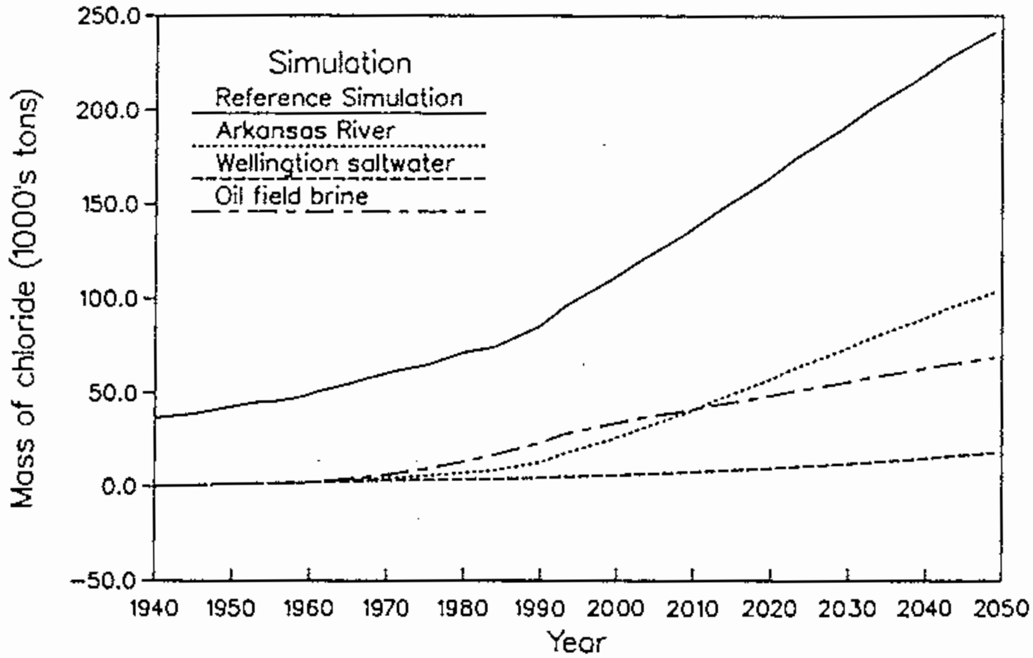



Figure A-24a.—Predicted chloride mass in the Wichita well field area for specific chloride source simulations.

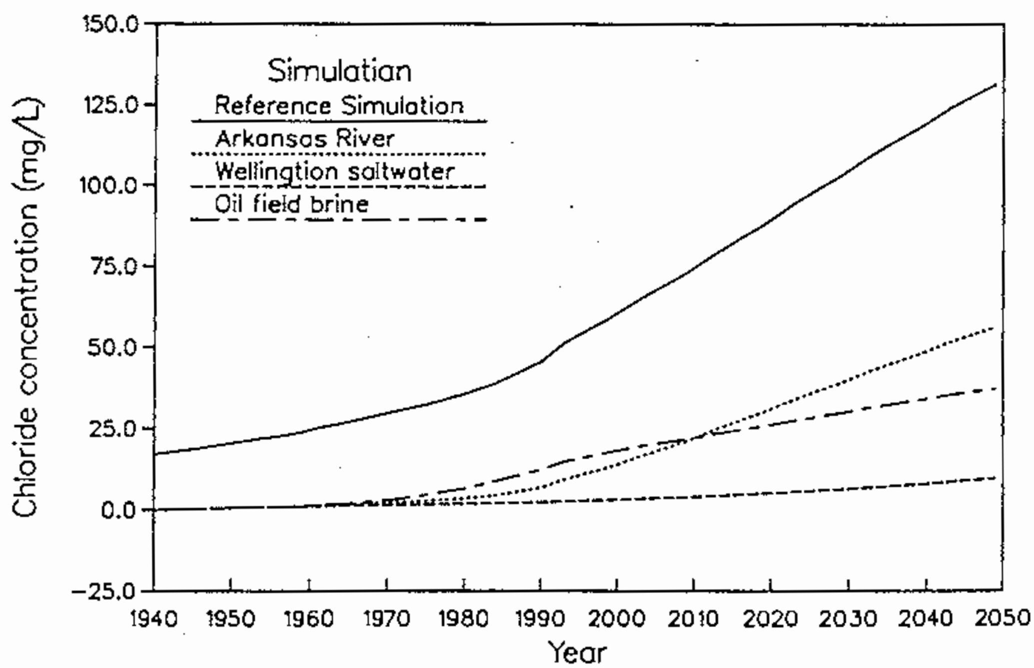



Figure A-24b.—Predicted average chloride concentration in the Wichita well field area for specific chloride source simulations.

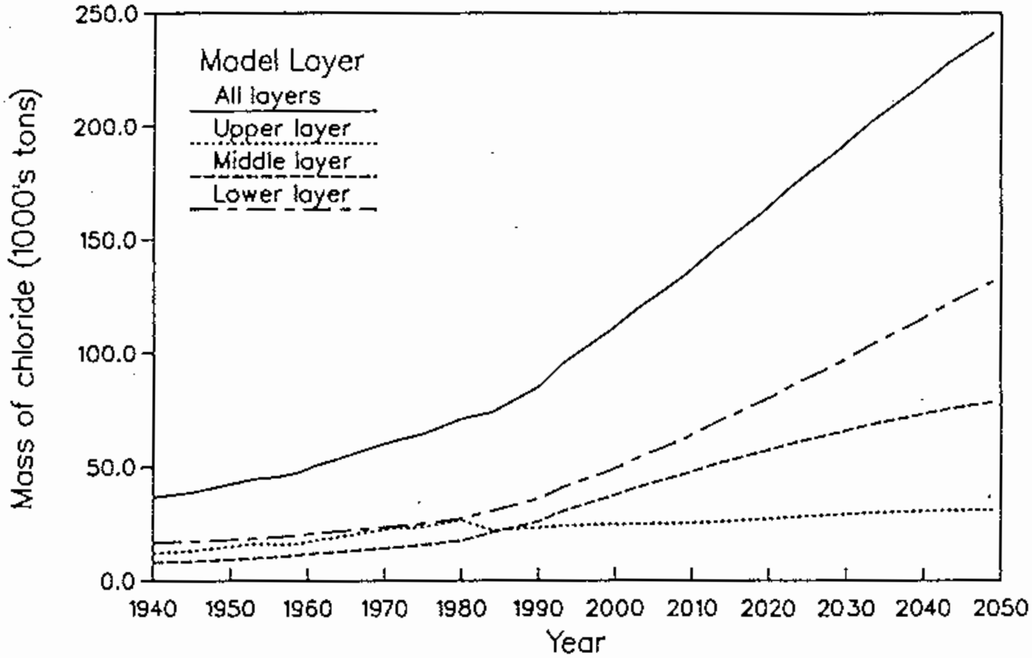



Figure A-25a.—Predicted chloride mass in the Wichita well field area for the reference simulation.

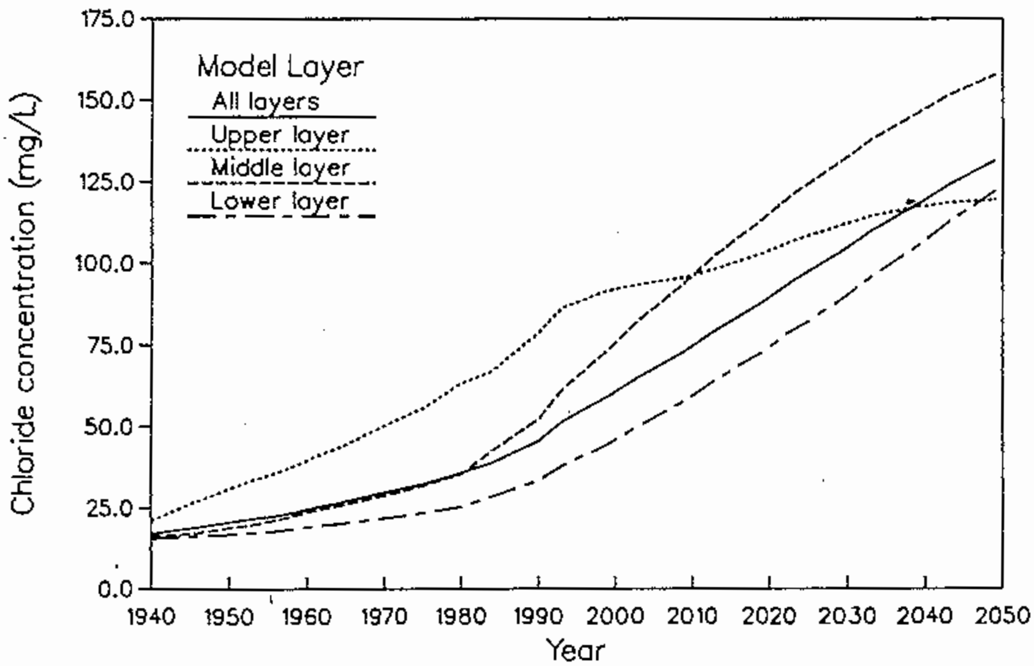



Figure A-25b.—Predicted average chloride concentration in the Wichita well field area for the reference simulation.

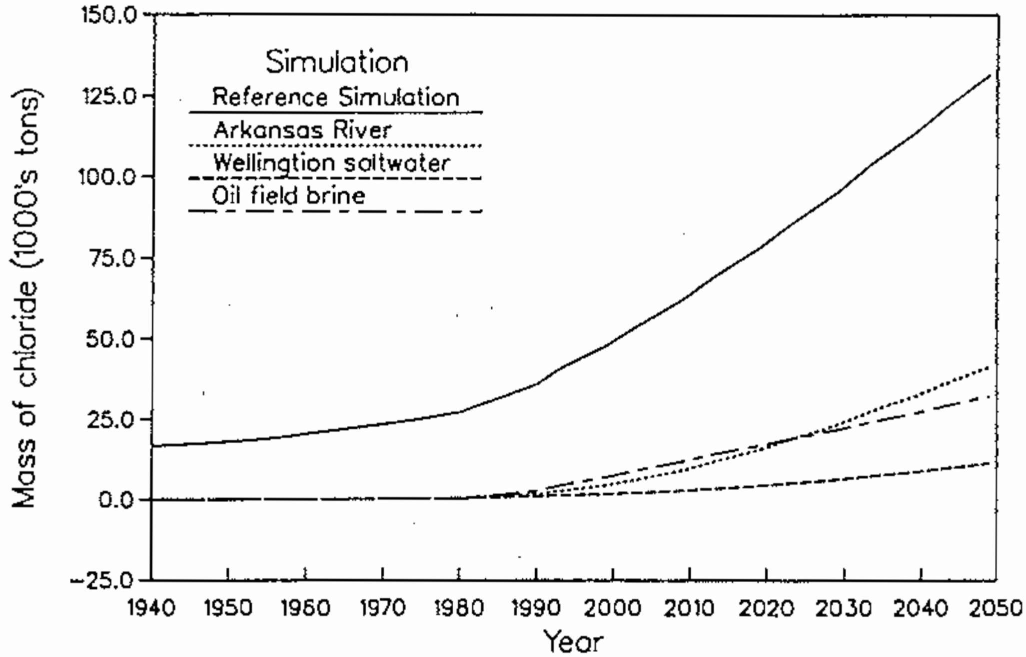



Figure A-26a.—Predicted chloride mass in the lower model layer of the Wichita well field zone for Arkansas River flow simulations.

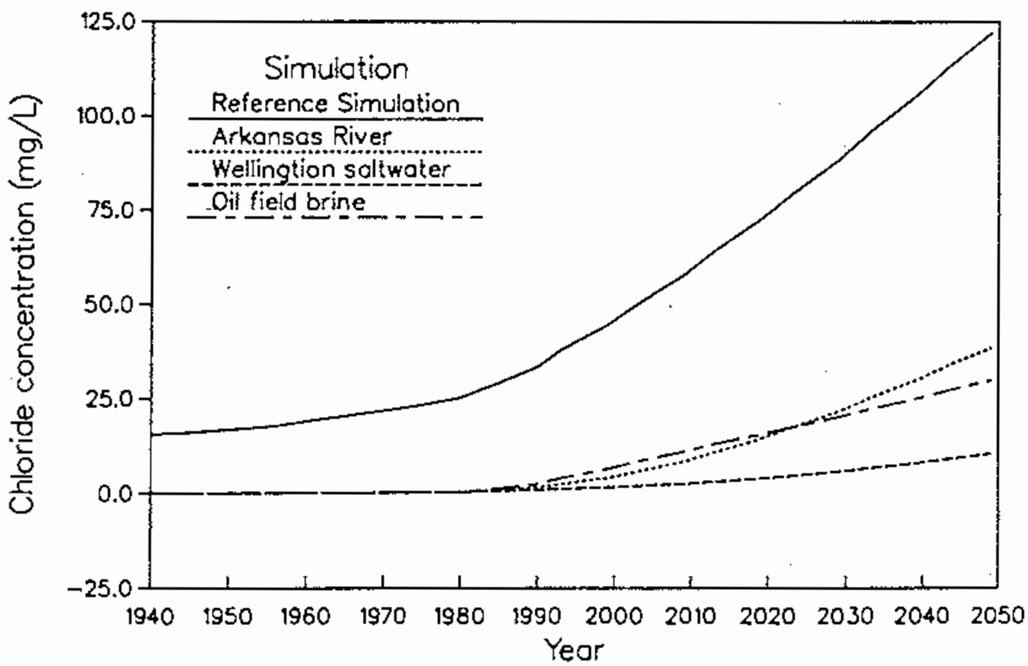



Figure A-26b.—Predicted average chloride concentration in the lower model layer of the Wichita well field zone for the Arkansas River flow simulations.

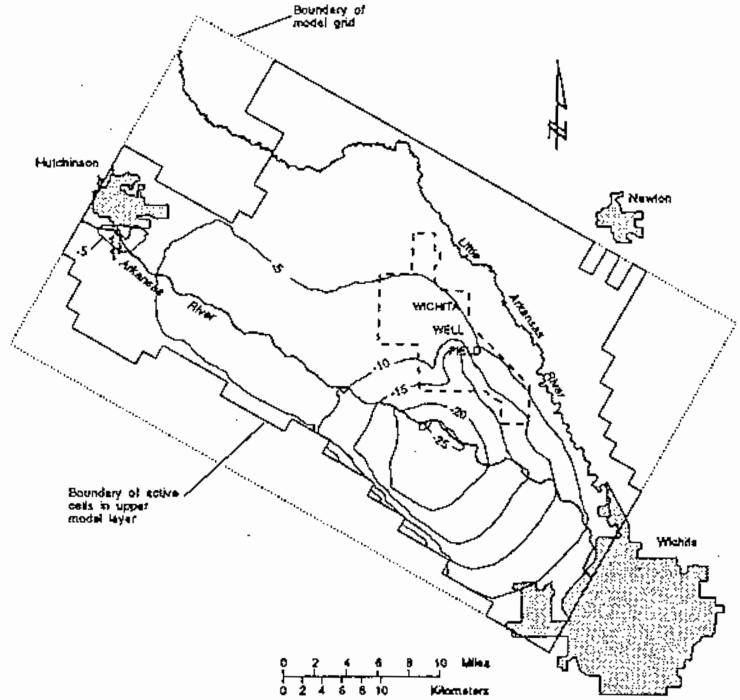



Figure A-27a.—Predicted water table elevation difference from the reference simulation for simulations: Arkansas River streamflow set to zero.

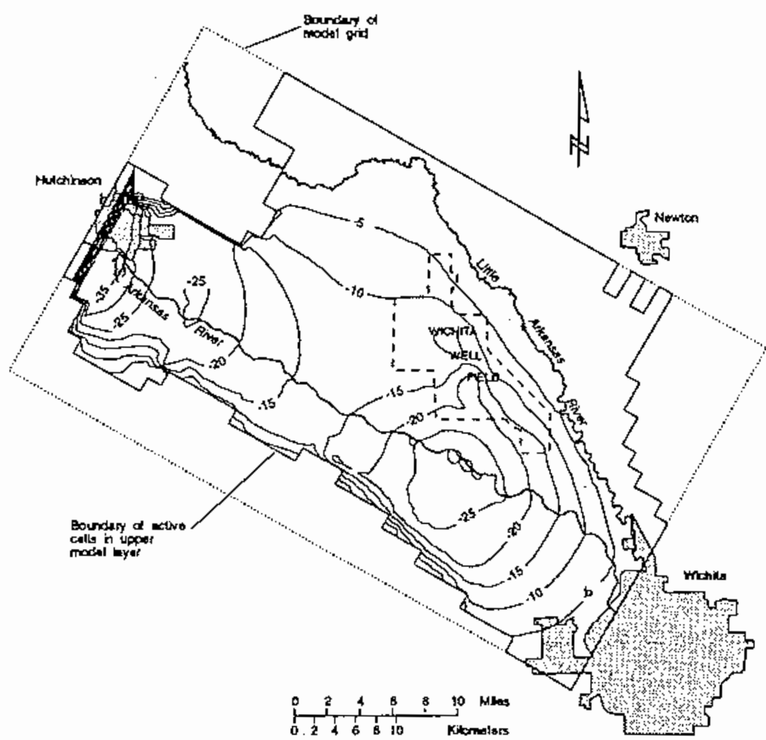



Figure A-27b.—Predicted water table elevation difference from the reference simulation for simulations: No-flow boundary and Arkansas River streamflow set to zero.

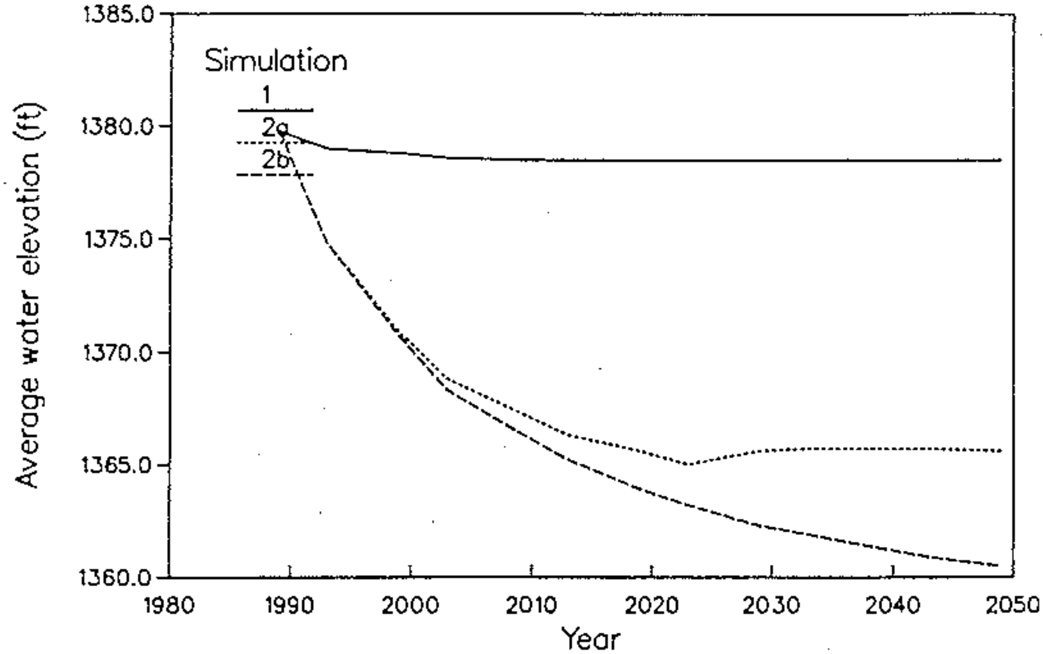



Figure A-28a.—Predicted average water table elevation for river zone for Arkansas River flow simulations.

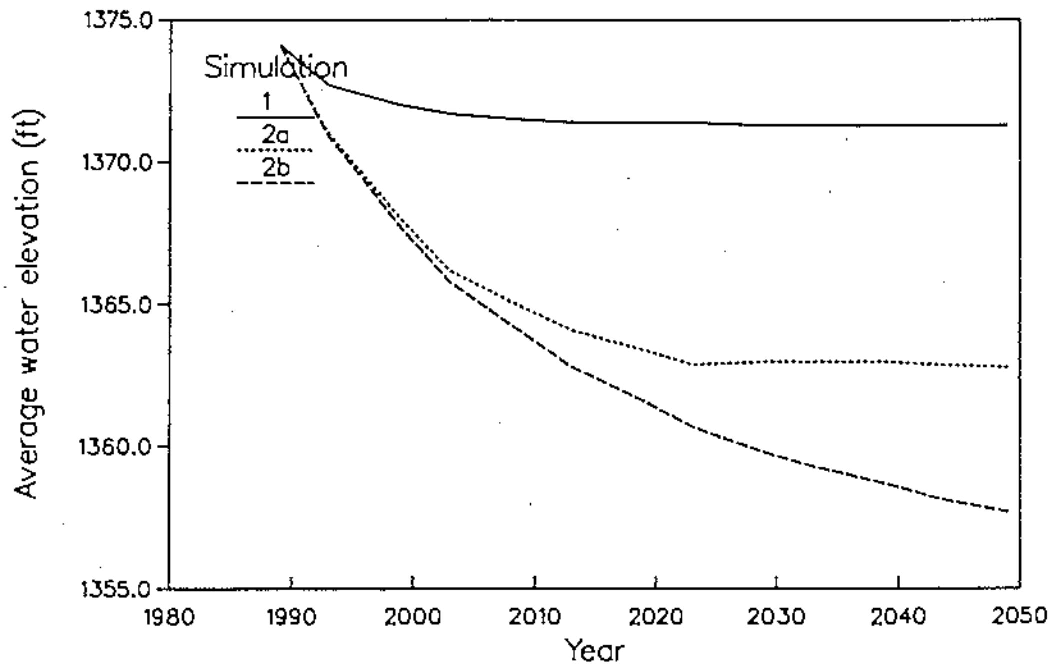



Figure A-28b.—Predicted average water table elevation for Wichita well field area for Arkansas River flow simulations.

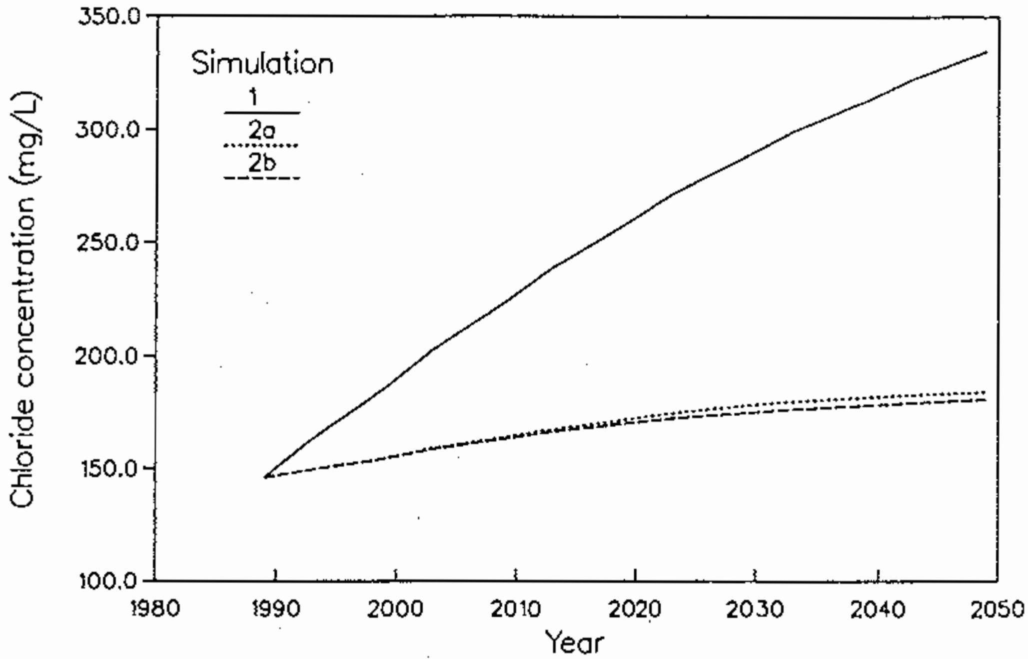



Figure A-29a.—Predicted average chloride concentration for river zone for Arkansas River flow simulations.

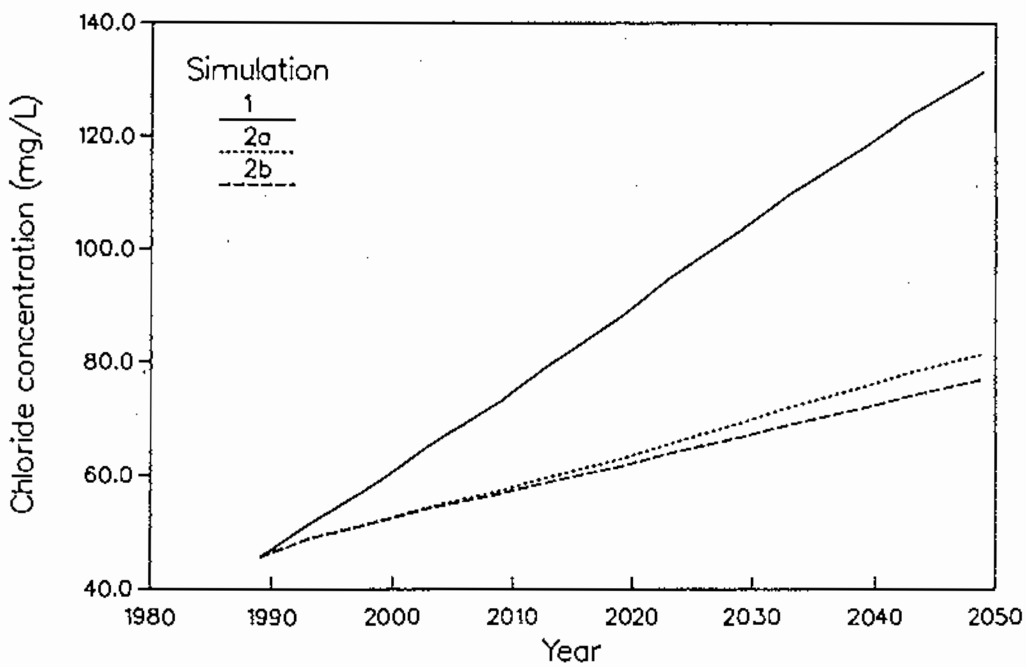



Figure A-29b.—Predicted average chloride concentration flow Wichita well field area for Arkansas River flow simulations.

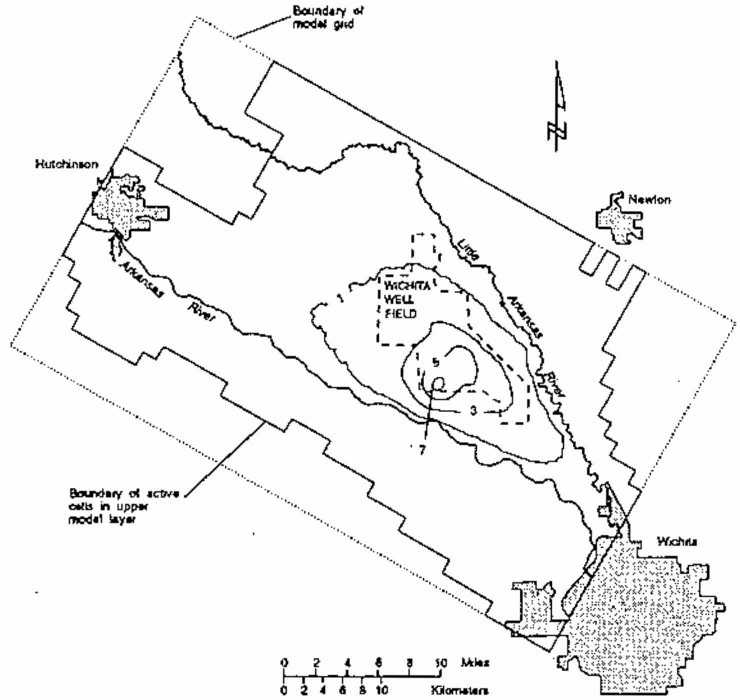



Figure A-30a.—Predicted water table elevation difference from the reference simulation for simulations: no pumping in upper model layer near the Arkansas River.

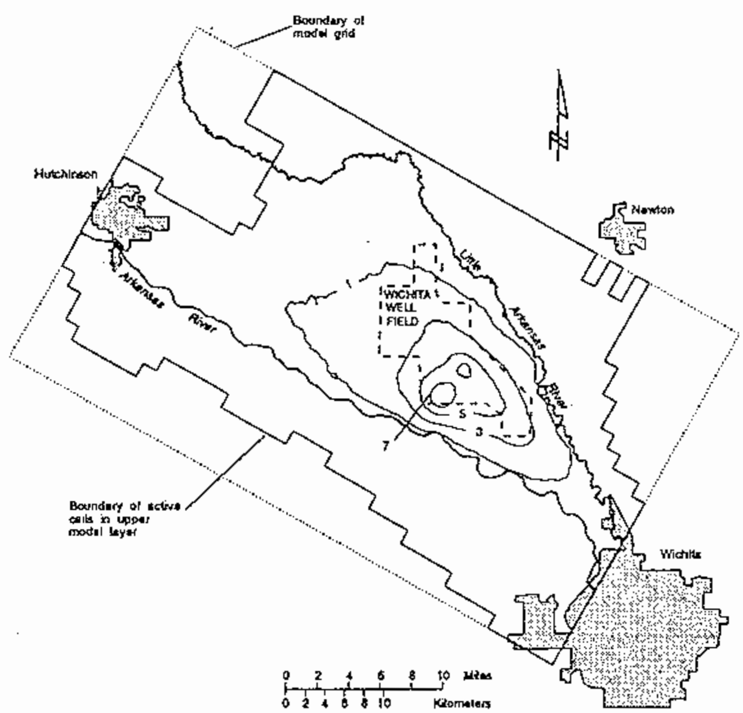



Figure A-30b.—Predicted water table elevation difference from the reference simulation for simulations: no pumping in upper and middle model layers near the Arkansas River.

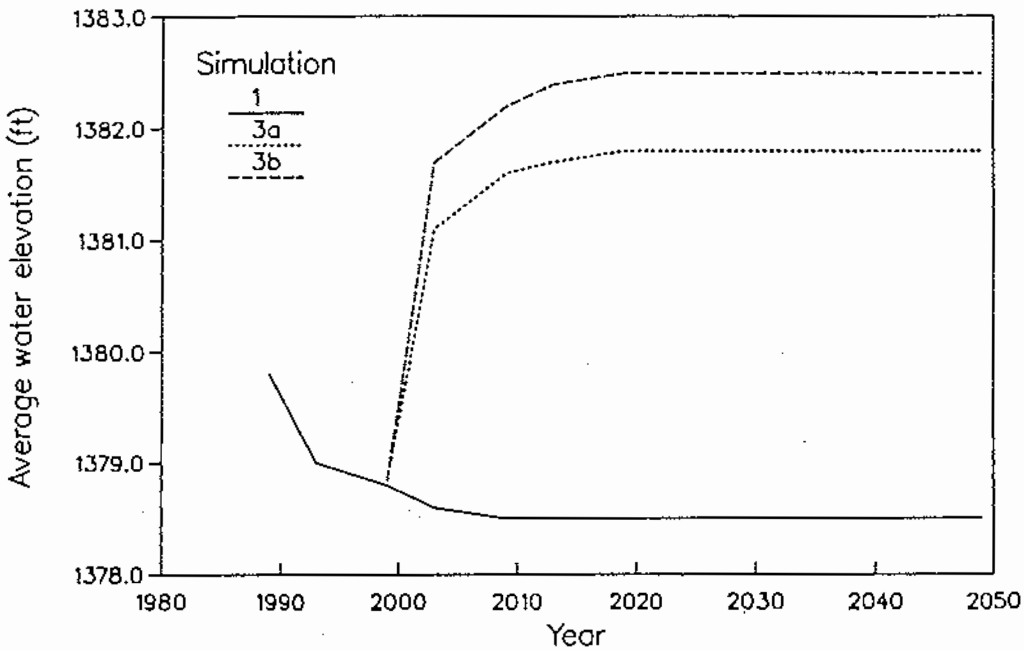



Figure A-31a.—Predicted average water table elevation in river zone for pumping near Arkansas River simulations.

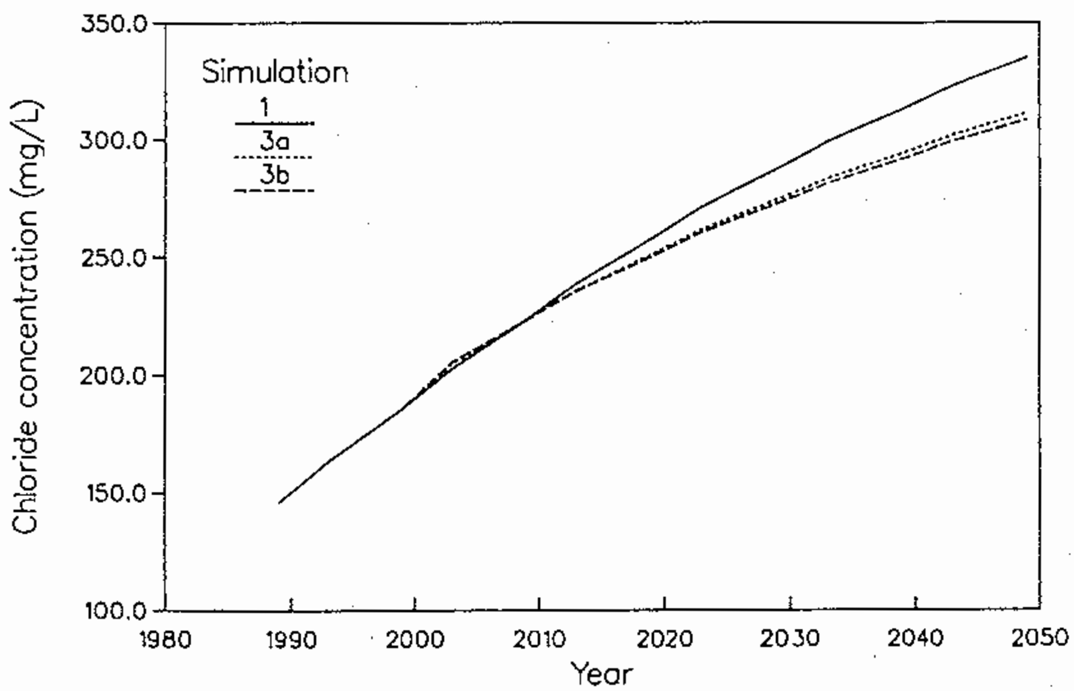



Figure A-31b.—Predicted average chloride concentration in river zone for pumping near Arkansas River simulations.

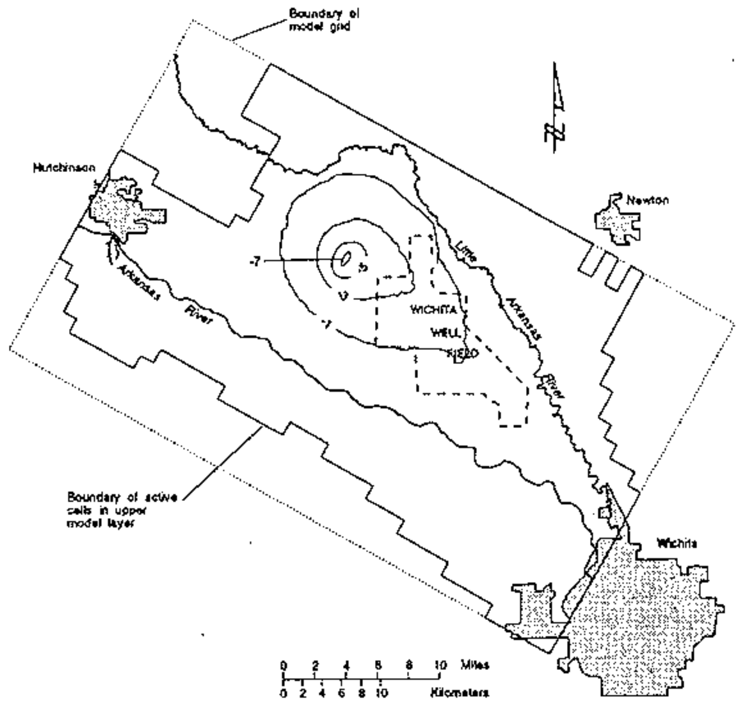



Figure A-32a.—Predicted water table elevation difference from the base projection for brine interception well withdrawal rates per well of 50 gpm.

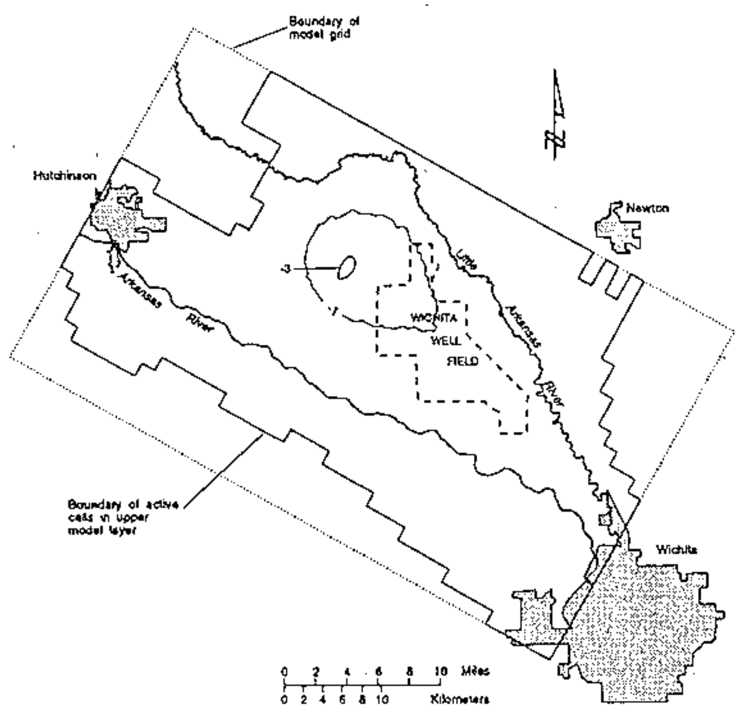



Figure A-32b.—Predicted water table elevation difference from the base projection for brine interception well withdrawal rates per well of 100 gpm.

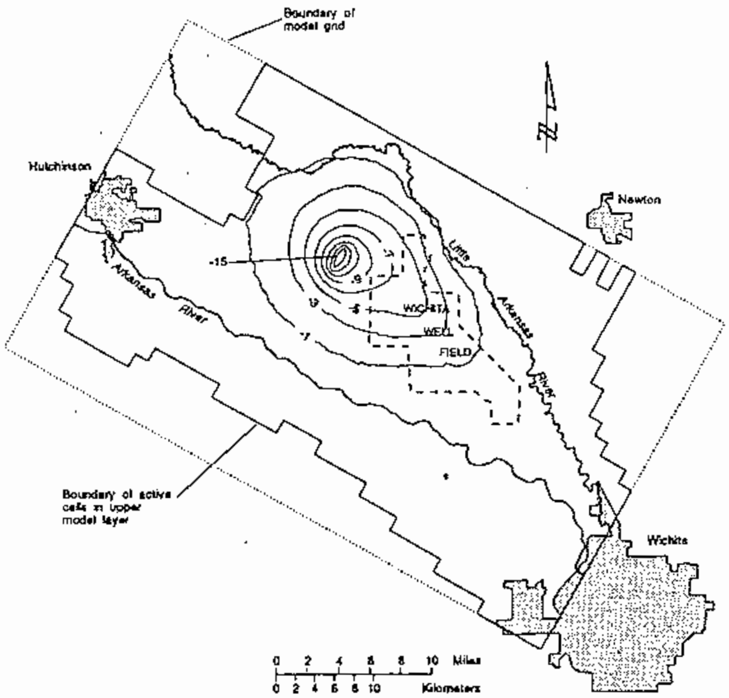



Figure A-32c.—Predicted water table elevation difference from the base projection for brine interception well withdrawal rates per well of 200 gpm.

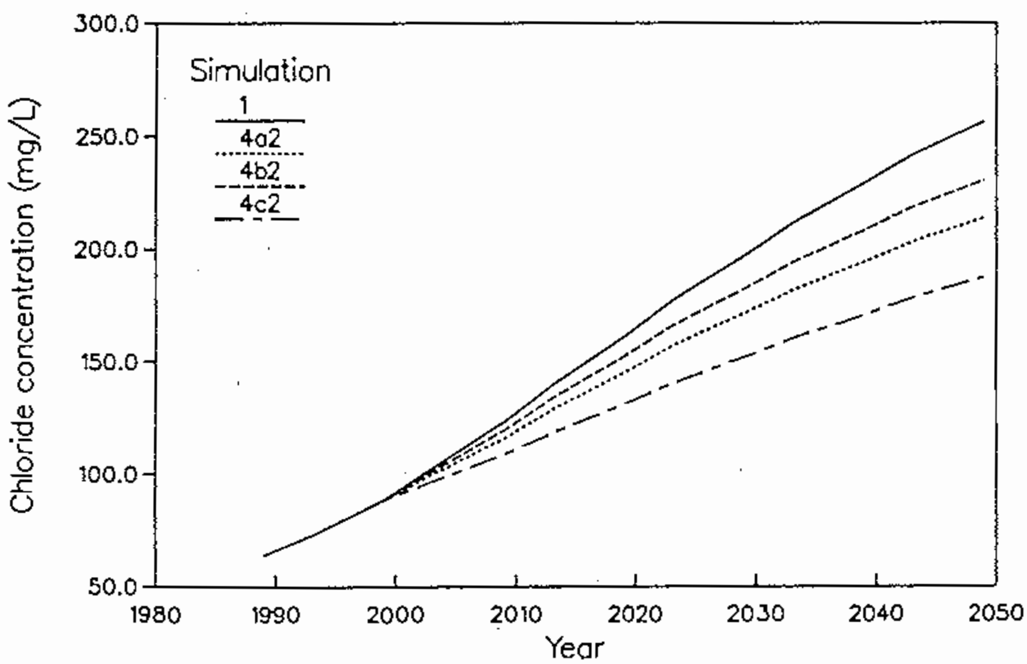



Figure A-33a.—Predicted average chloride concentration for the upper model layer in the brine zone for brine interception well simulations.

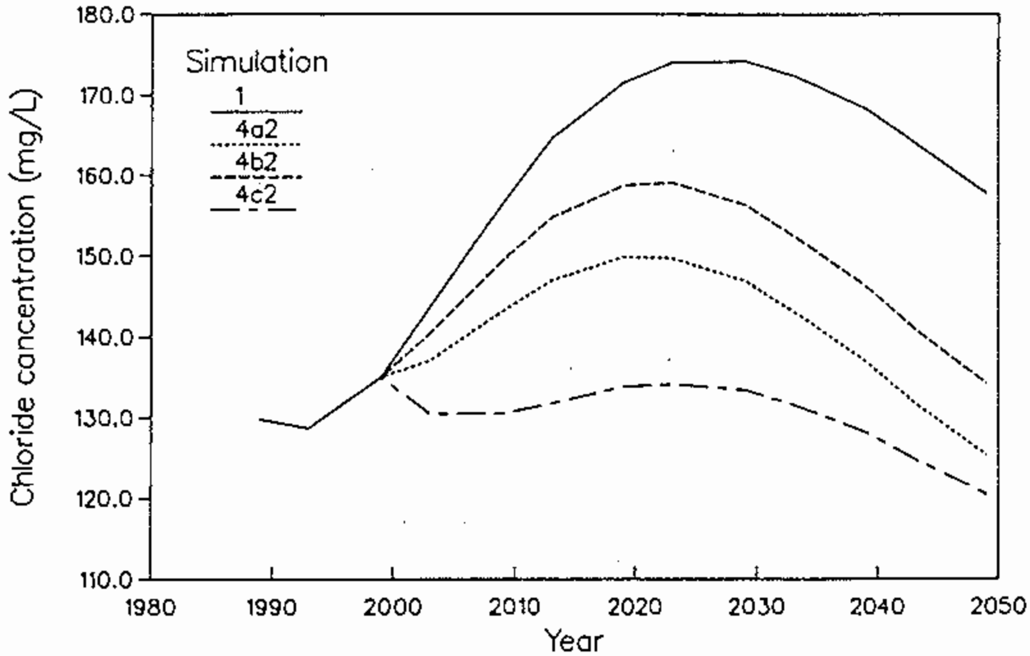



Figure A-33b.—Predicted average concentration for the middle model layer in the brine zone for brine interception well simulations.

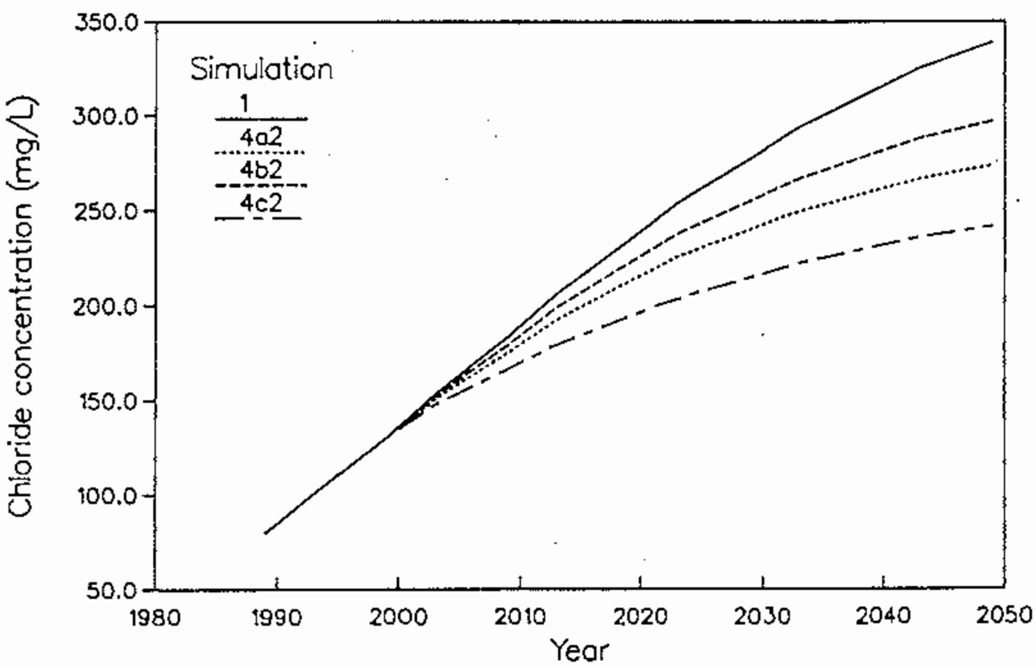



Figure A-33c.—Predicted average concentration for the lower model layer in the brine zone for brine interception well simulations.

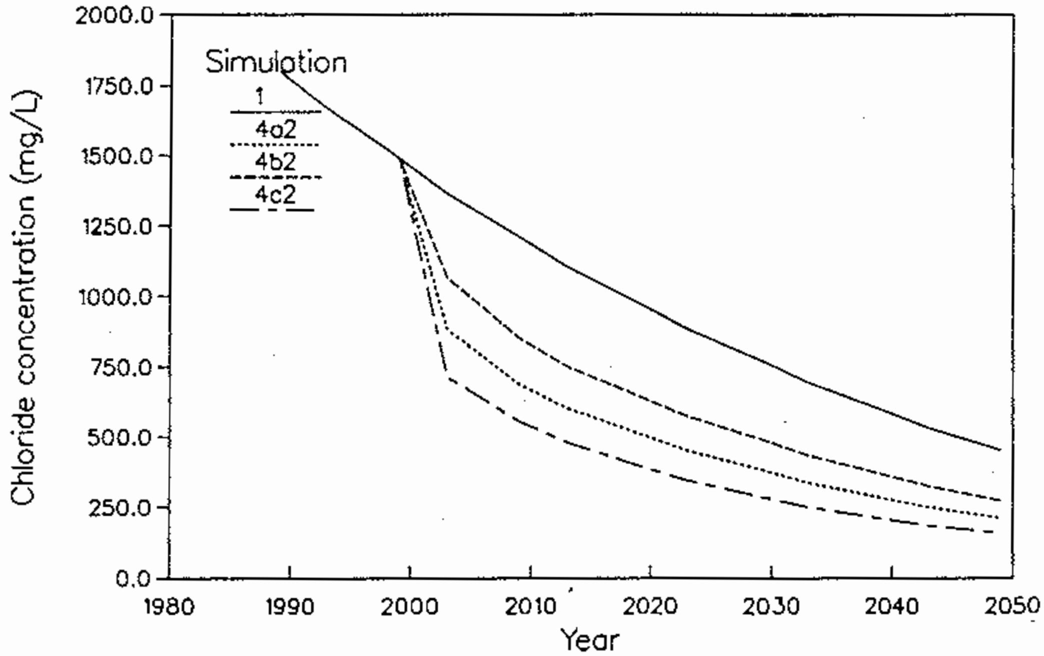



Figure A-34a.—Estimated average chloride concentration of water from brine interception wells installed in the middle model layer.

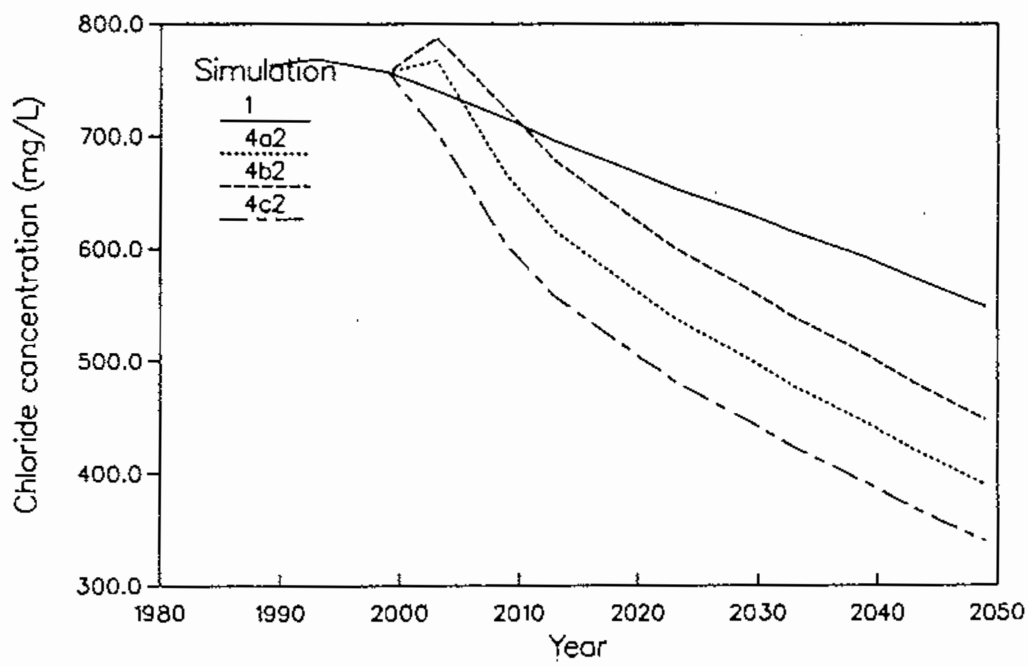



Figure A-34b.—Estimated average chloride concentration of water from brine interception wells installed in the lower model layer.

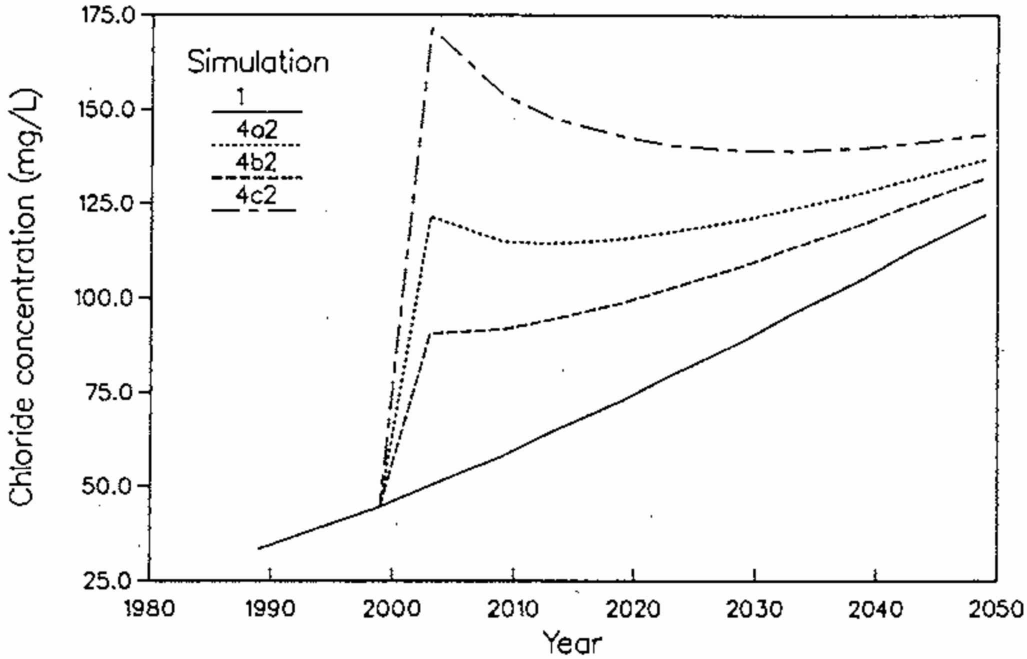



Figure A-34c.—Estimated average chloride concentration of water from blending brine interception well production with Wichita well field production.

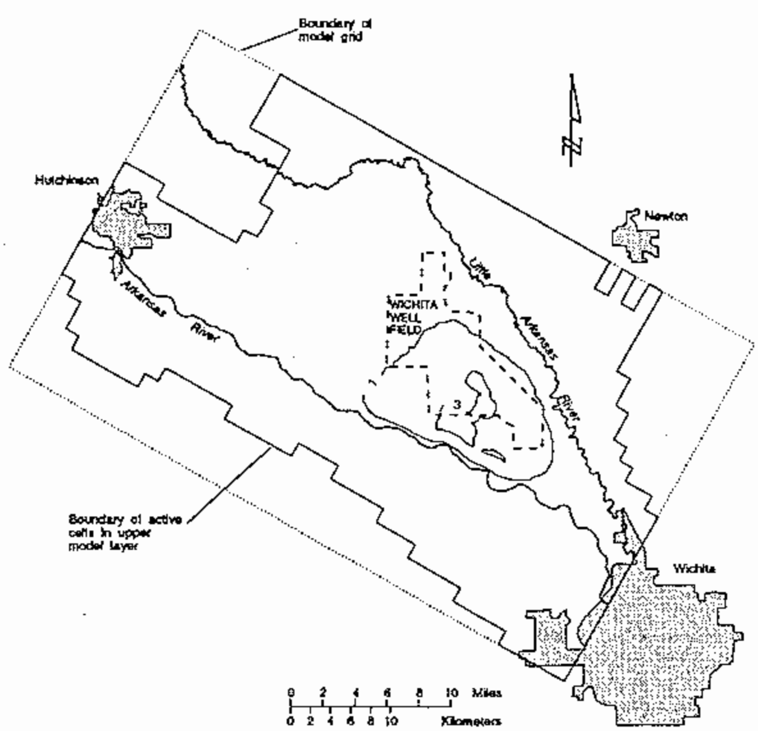



Figure A-35.—Predicted water table elevation difference from the reference simulation for simulation: hydraulic barrier at location nearest the river with recharge of 11,300 acre-feet/year.

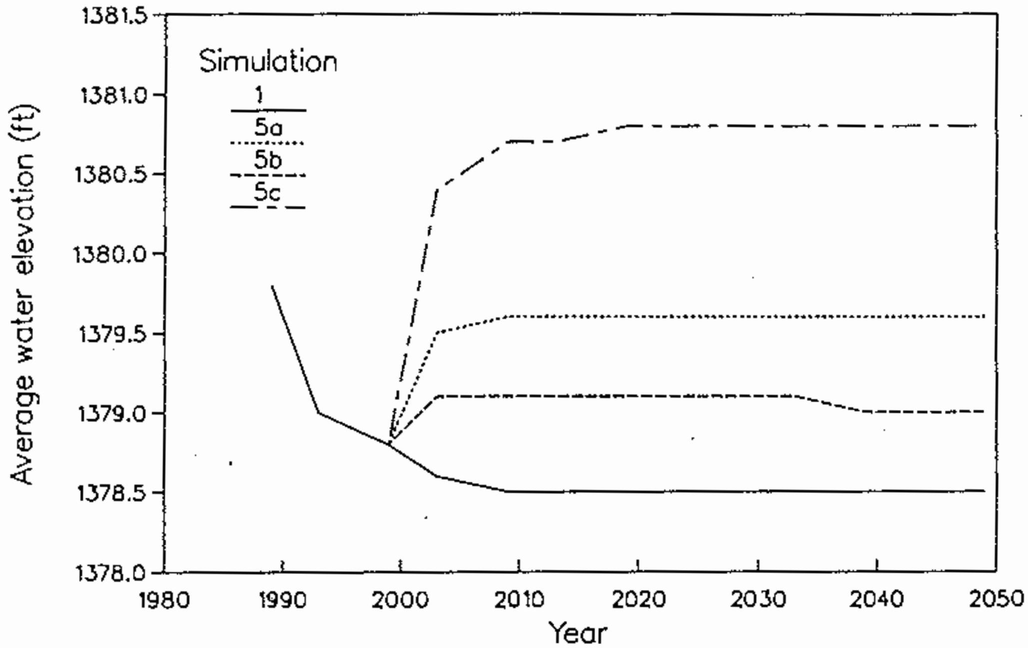



Figure A-36.—Predicted average water table elevation in the river zone for hydraulic barrier simulations at location nearest the river.

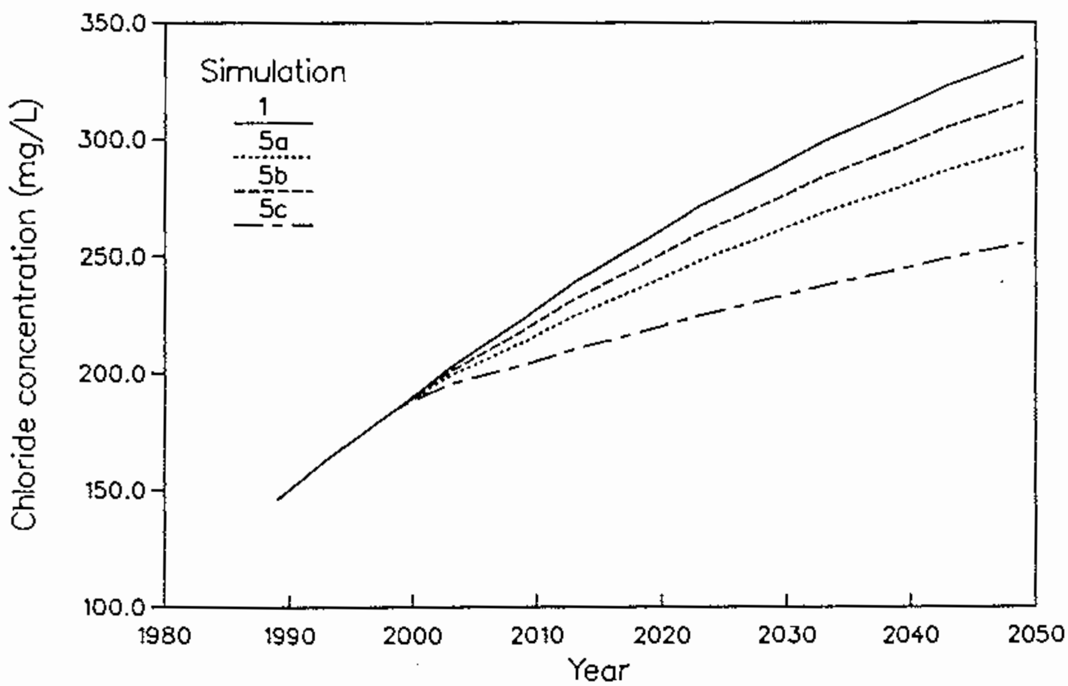



Figure A-37a.—Predicted average chloride concentration in river zone for hydraulic barrier simulations at location nearest the river.

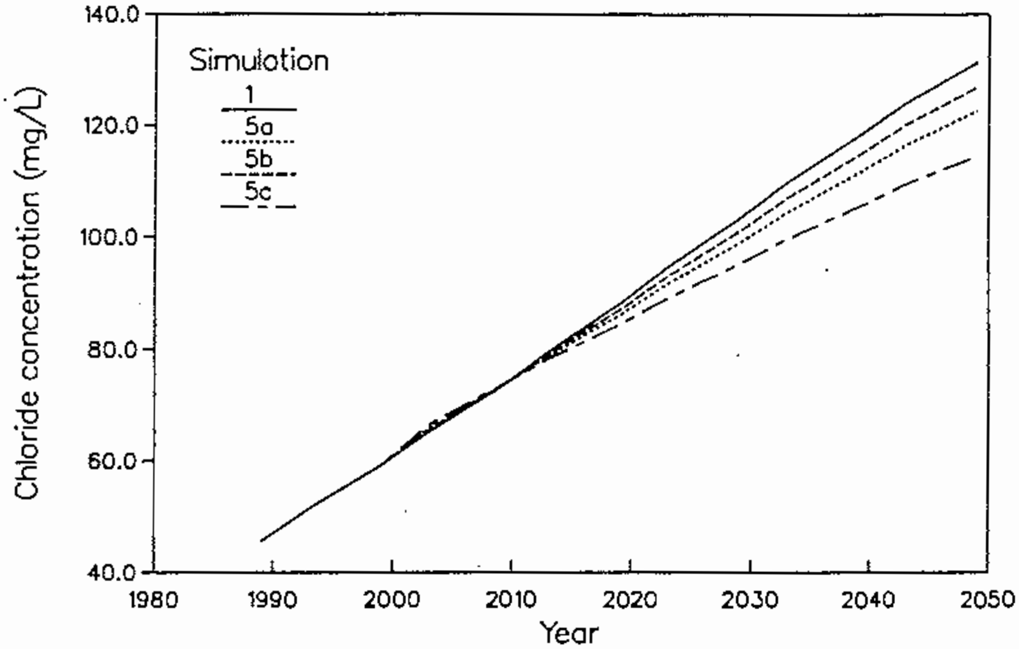



Figure A-37b.—Predicted average chloride concentration in Wichita well field zone for hydraulic barrier simulations at location nearest the river.

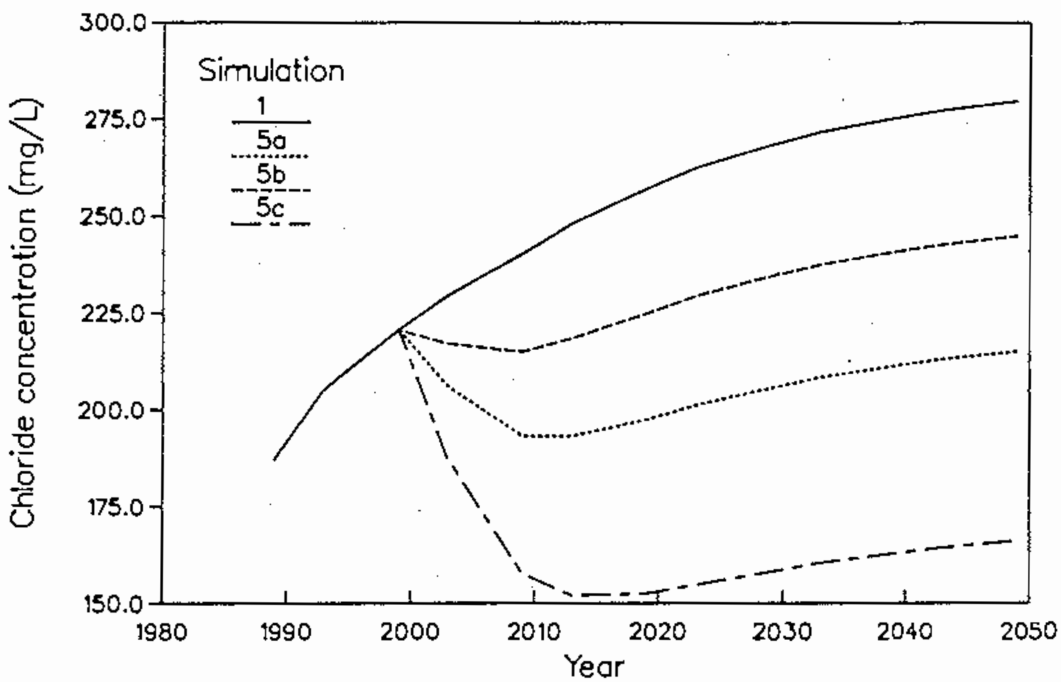



Figure A-38a.—Predicted average chloride concentration in the river zone for the upper model layer. Hydraulic barrier simulations at location nearest the river.

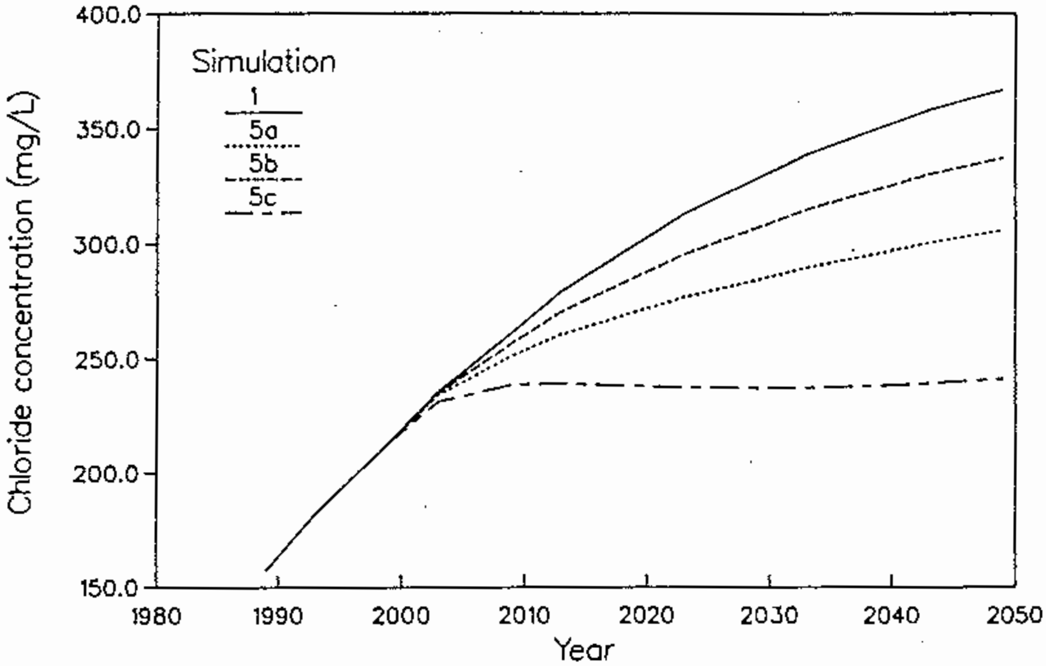



Figure A-38b.—Predicted average chloride concentration in the river zone for middle model layer. Hydraulic barrier simulations at location nearest the river.

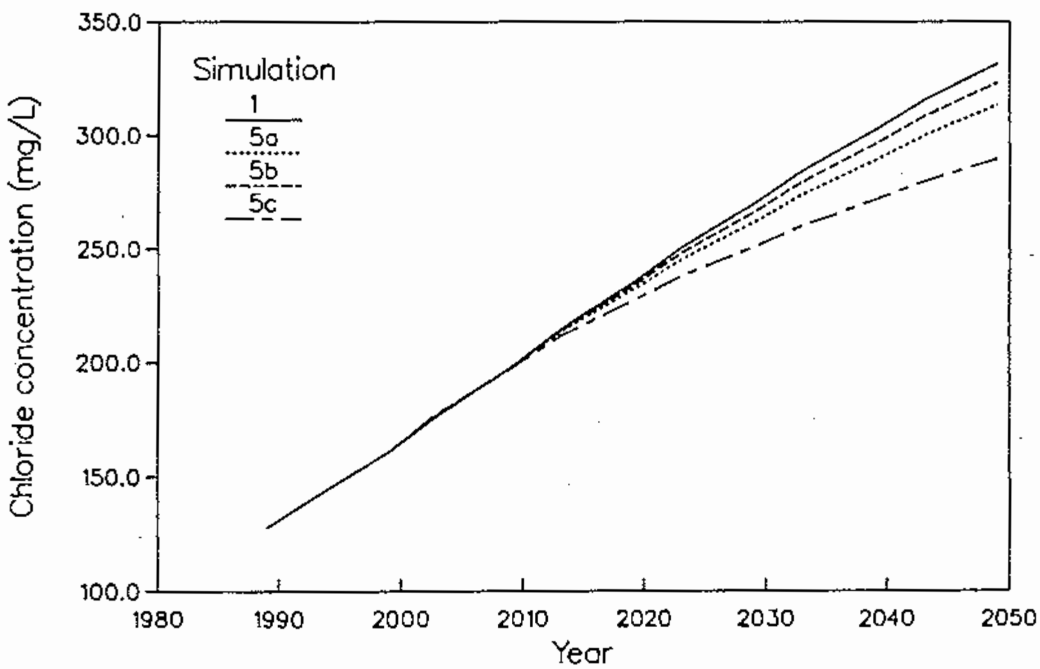



Figure A-38c.—Predicted average chloride concentration in the river zone for lower model layer. Hydraulic barrier simulations at location nearest the river.

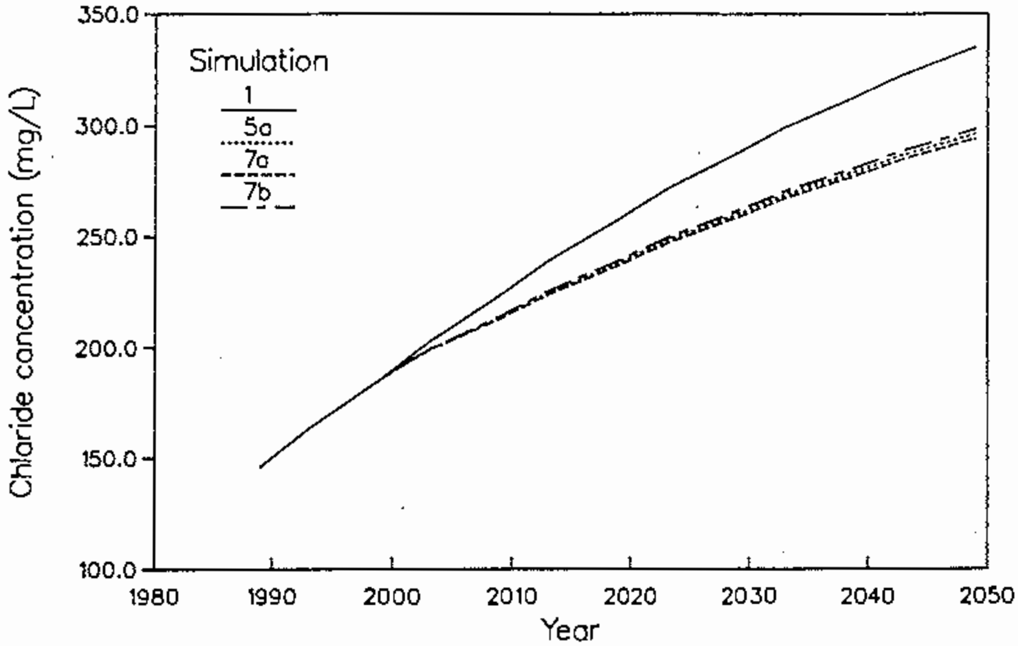



Figure A-39a.—Predicted average chloride concentration in the river zone for varying recharge water chloride concentration. Hydraulic barrier simulations at location nearest the river.

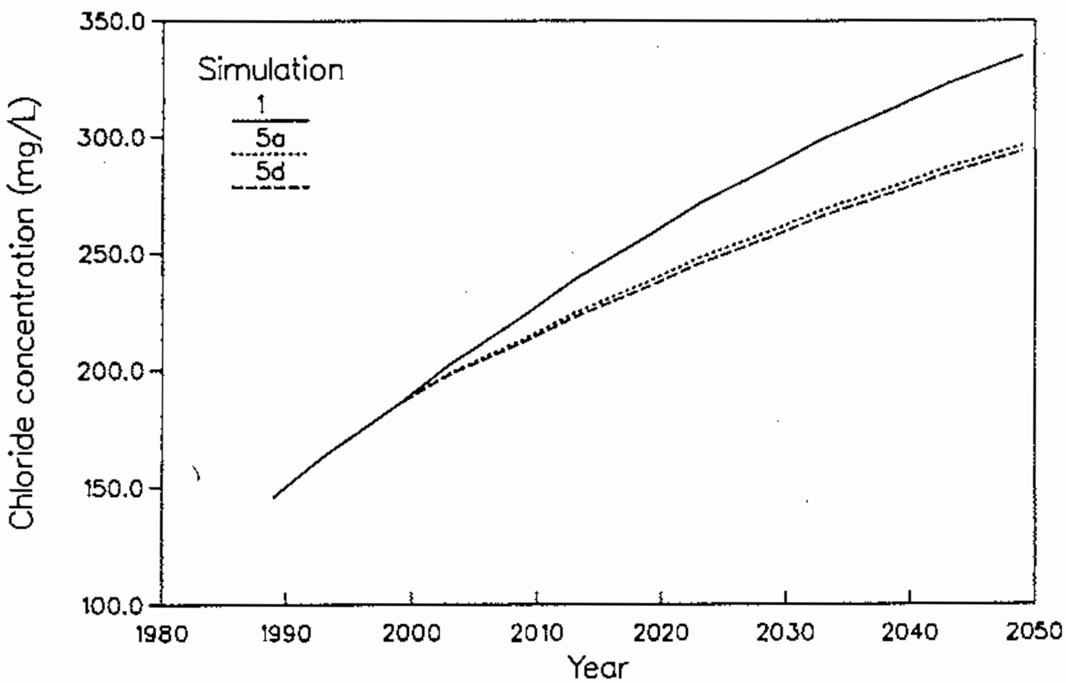



Figure A-39b.—Predicted average chloride concentration in the river zone for the two hydraulic barrier locations.

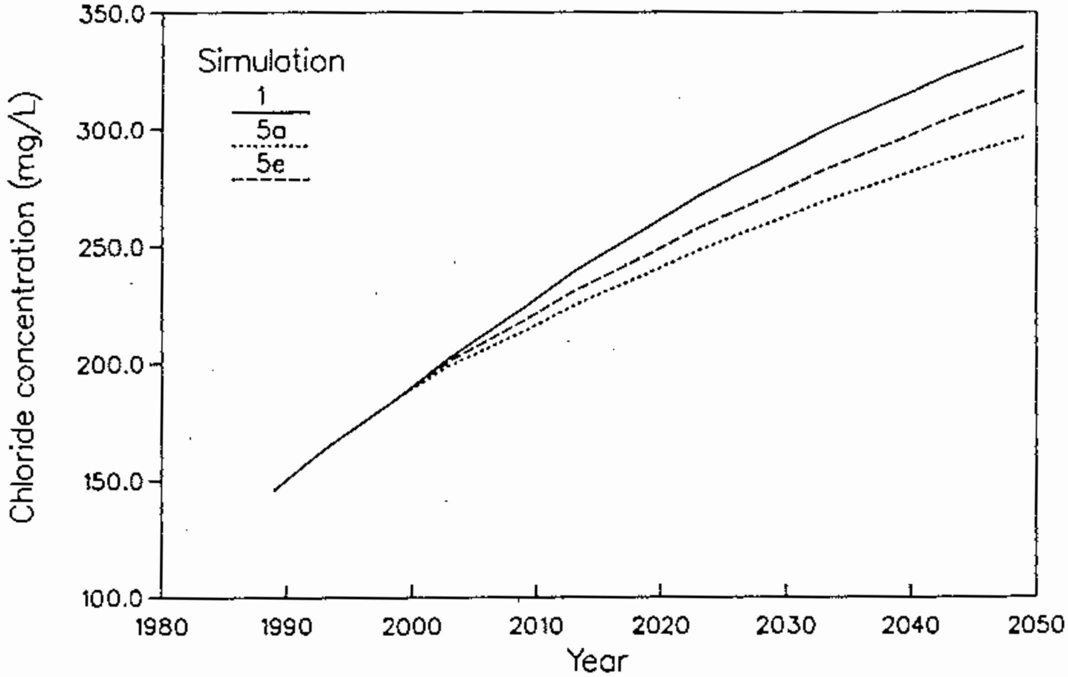



Figure A-40a.—Predicted average chloride concentration in the river zone. Comparison of hydraulic barrier and reduced pumping.

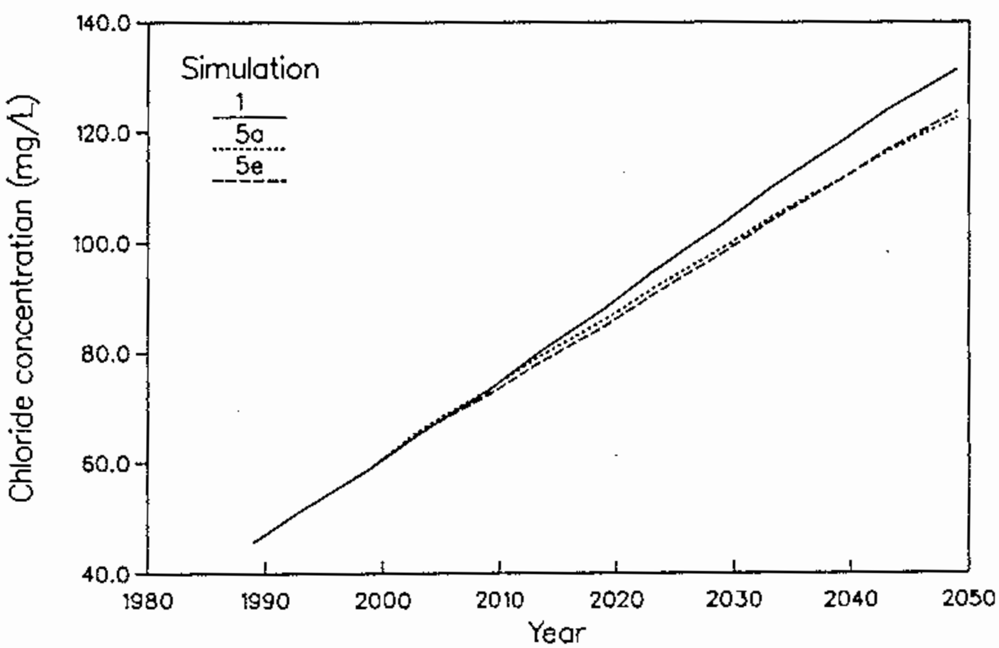



Figure A-40b.—Predicted average chloride concentration in the Wichita well field area. Comparison of hydraulic barrier and reduced pumping.

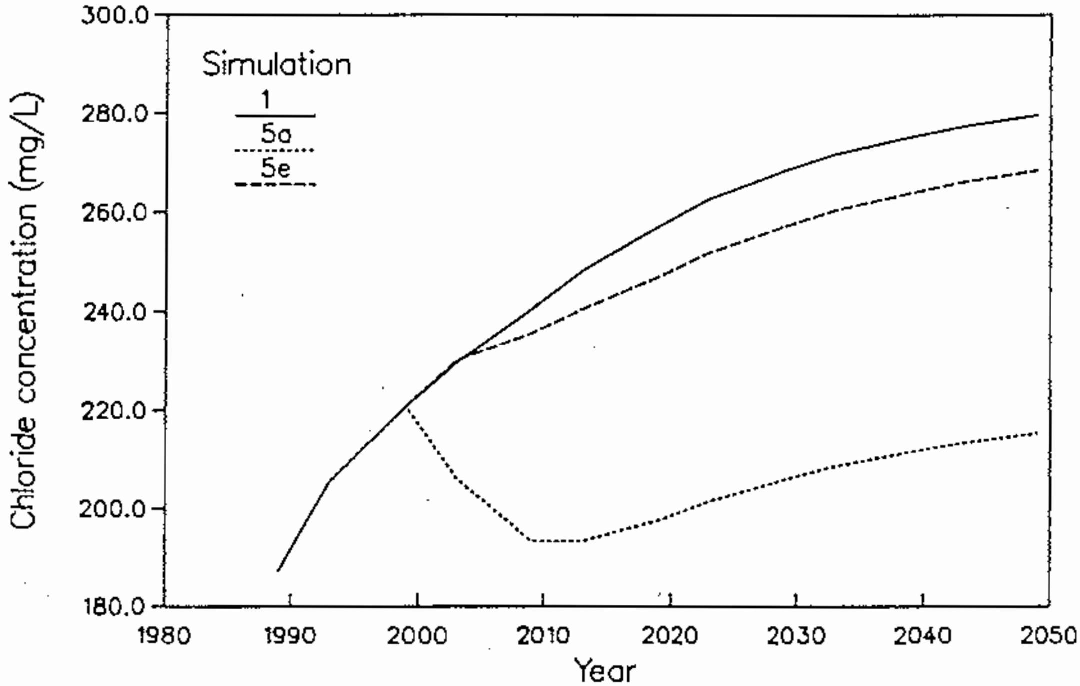



Figure A-41a.—Predicted average chloride concentration in the river zone for the upper model layer. Comparison of hydraulic barrier and reduced pumping.

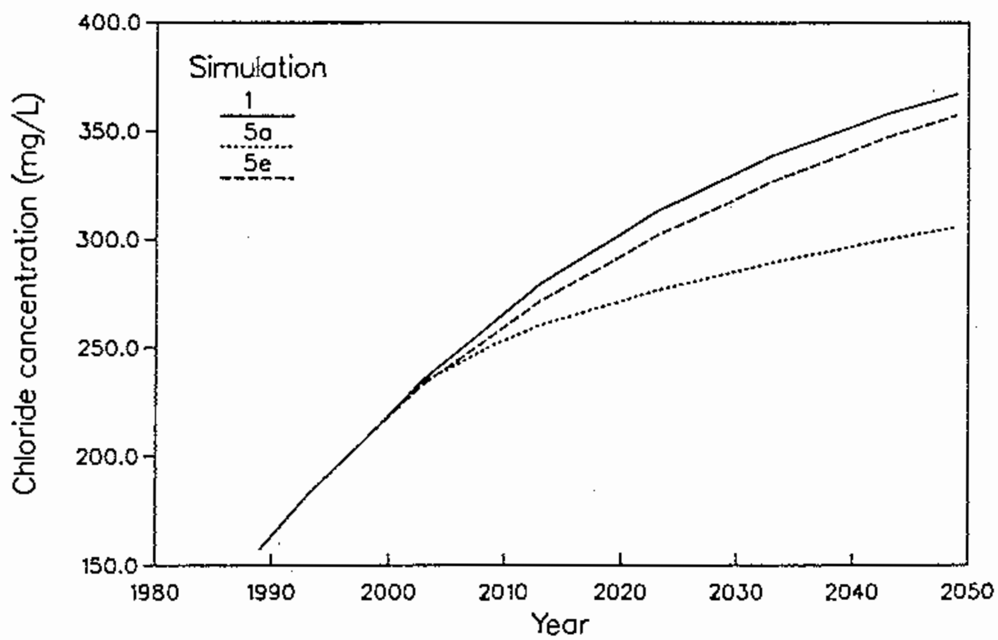



Figure A-41b.—Predicted average chloride concentration in the river zone for the middle model layer. Comparison of hydraulic barrier and reduced pumping.

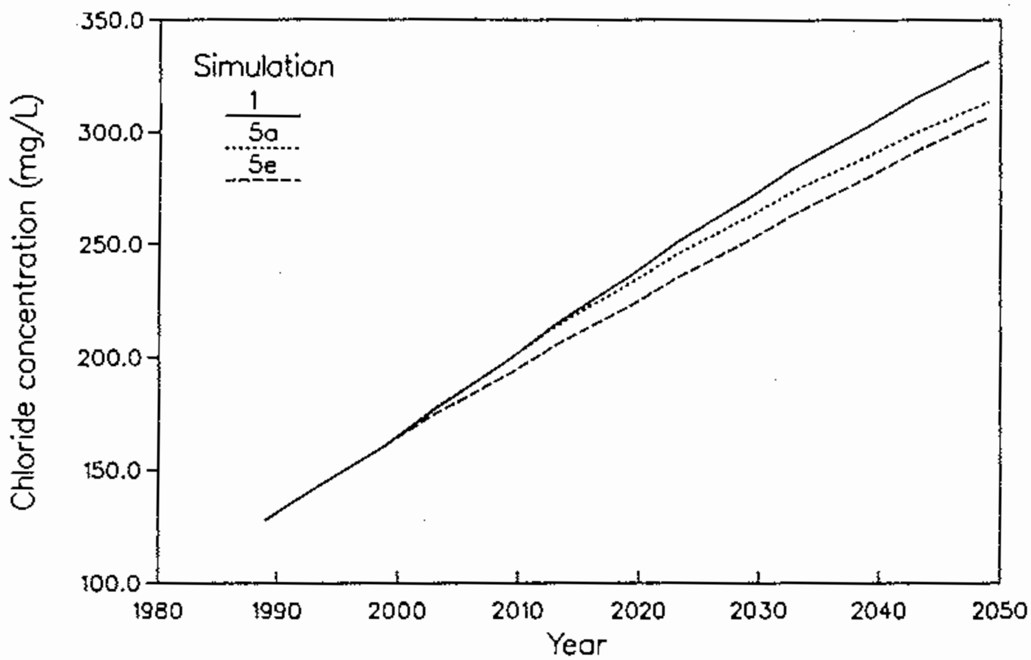



Figure A-41c.—Predicted average chloride concentration in the river zone for the lower model layer. Comparison of hydraulic barrier and reduced pumping.

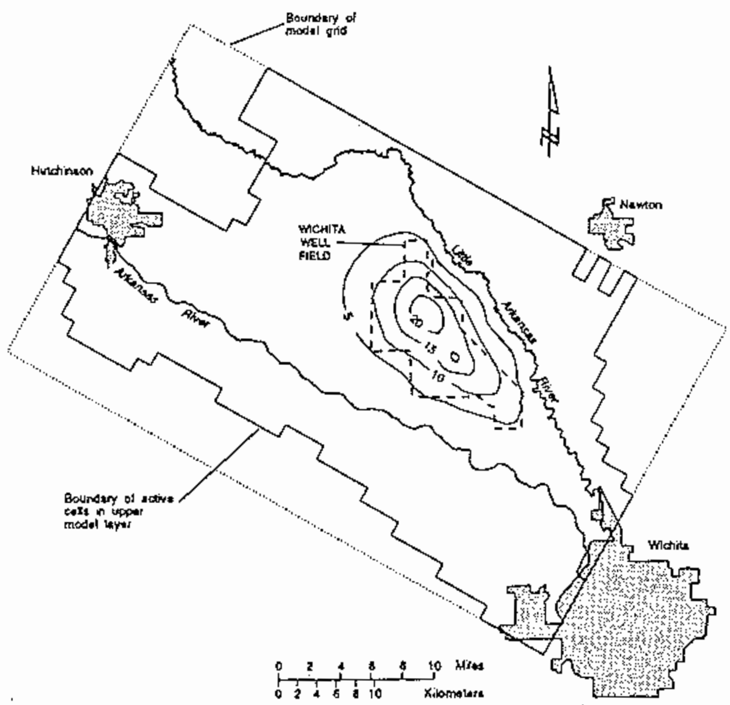



Figure A-42.—Predicted water table elevation difference from the base projection for reducing pumping by 22,400 acre-feet/year in the lower model layer.

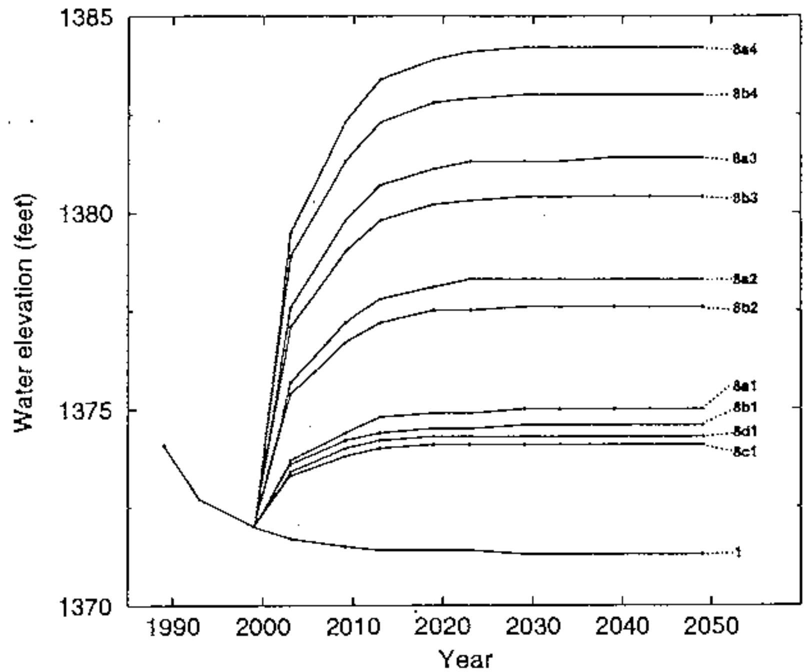



Figure A-43.—Predicted average water table elevation in the Wichita well field zone for reduction in pumpage simulations.

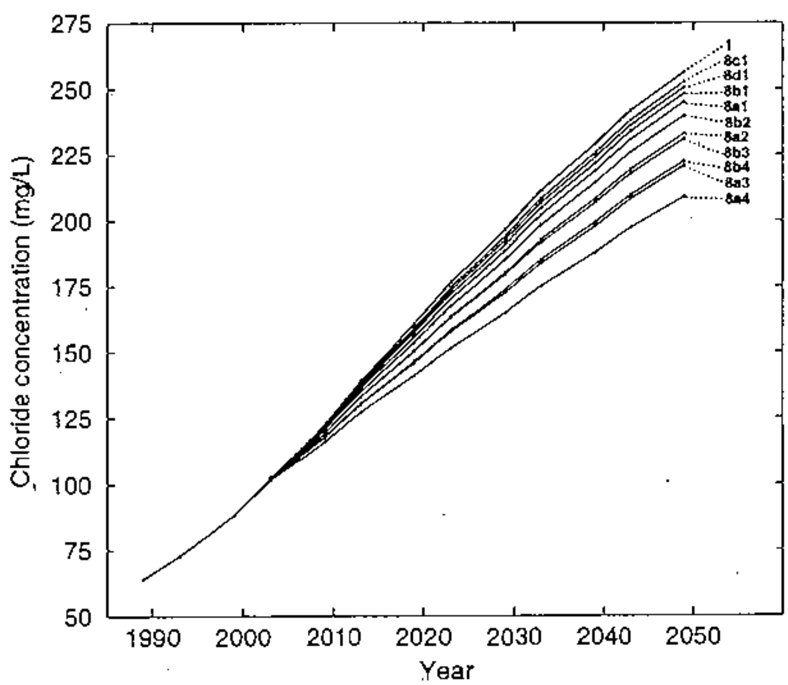



Figure A-44a.—Predicted average chloride concentration in the brine zone for reduction in pumpage simulations.

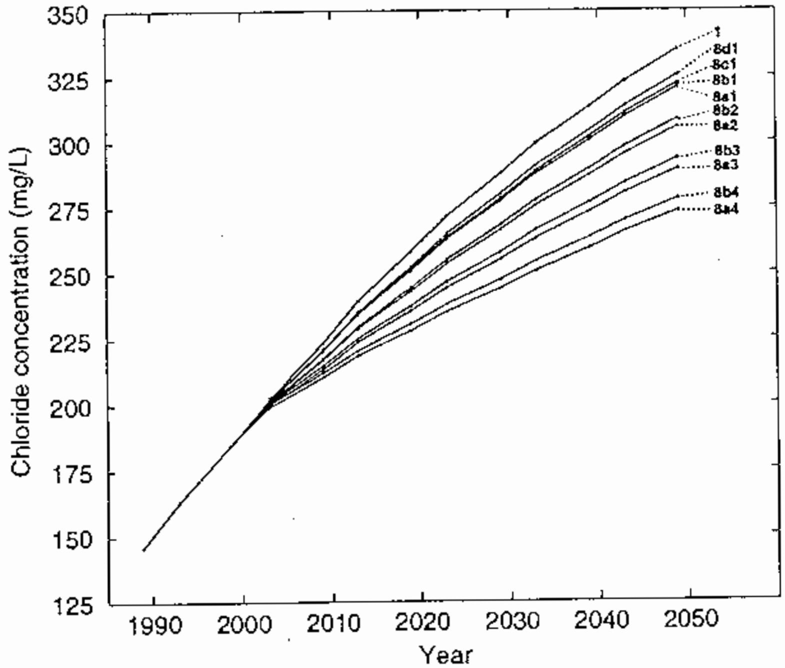



Figure A-44b.—Predicted average chloride concentration in the river zone for reduction in pumpage simulations.

# APPENDIX B

Maps Displaying Model Geometry, Boundary Conditions, Properties, and Stresses of USGS Flow Modeling (from Myers et al., in review)

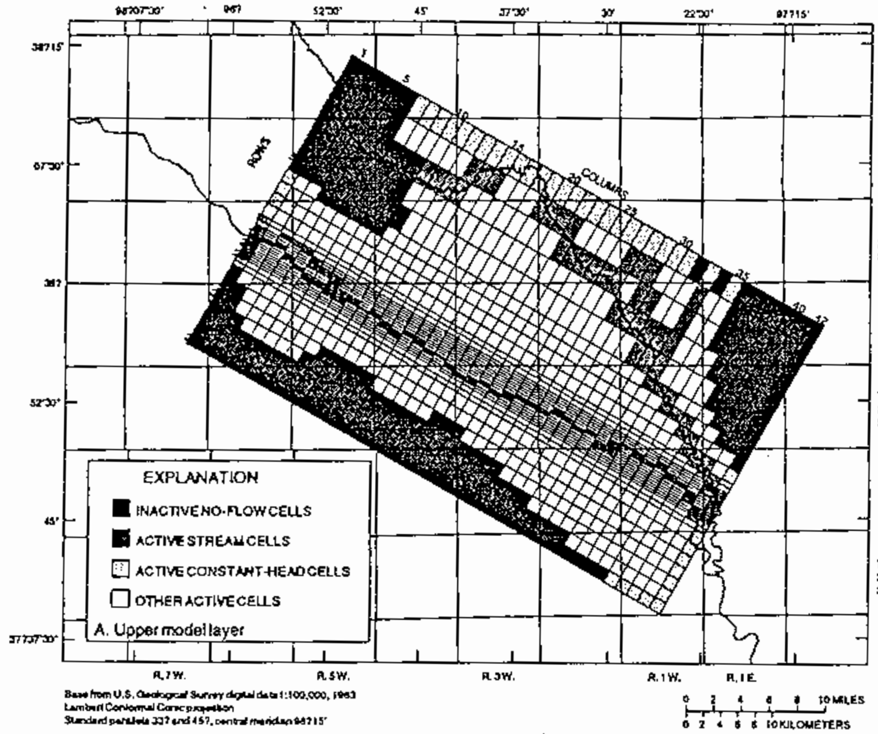



Figure B-1a.—Model grid and boundary conditions for the upper model layer of the USGS flow model (Myers et al., in review).

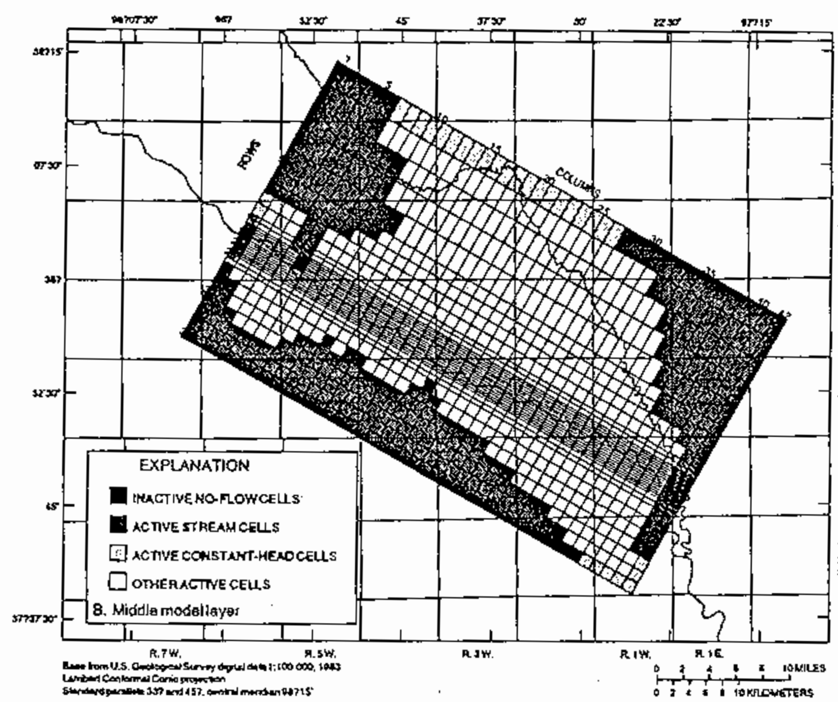



Figure B-1b.—Model grid and boundary conditions for the middle model layer of the USGS flow model (Myers et al., in review).

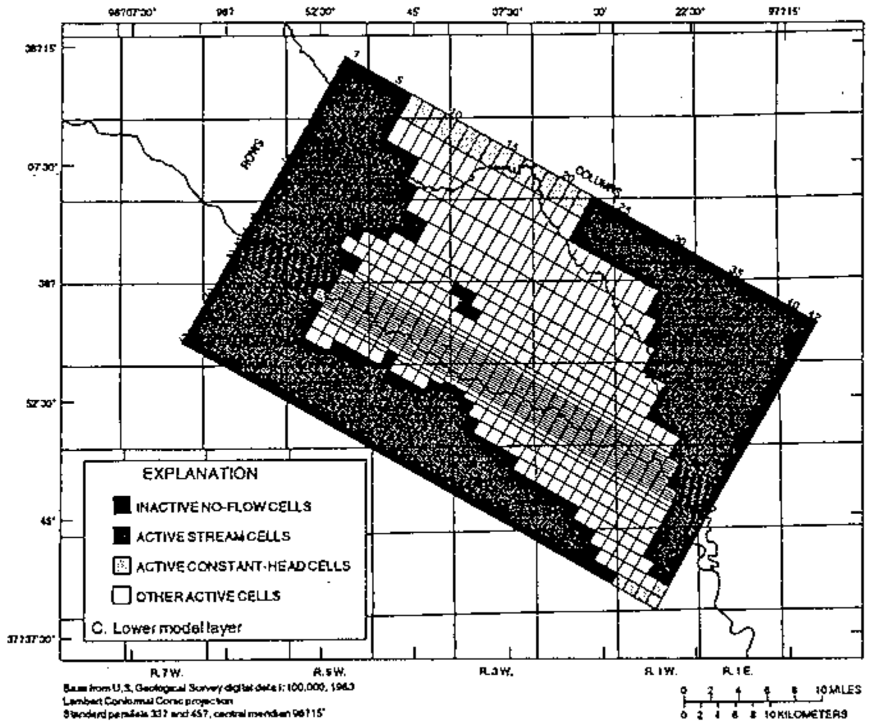



Figure B-1c.—Model grid and boundary conditions for the lower model layer of the USGS flow model (Myers et al., in review).

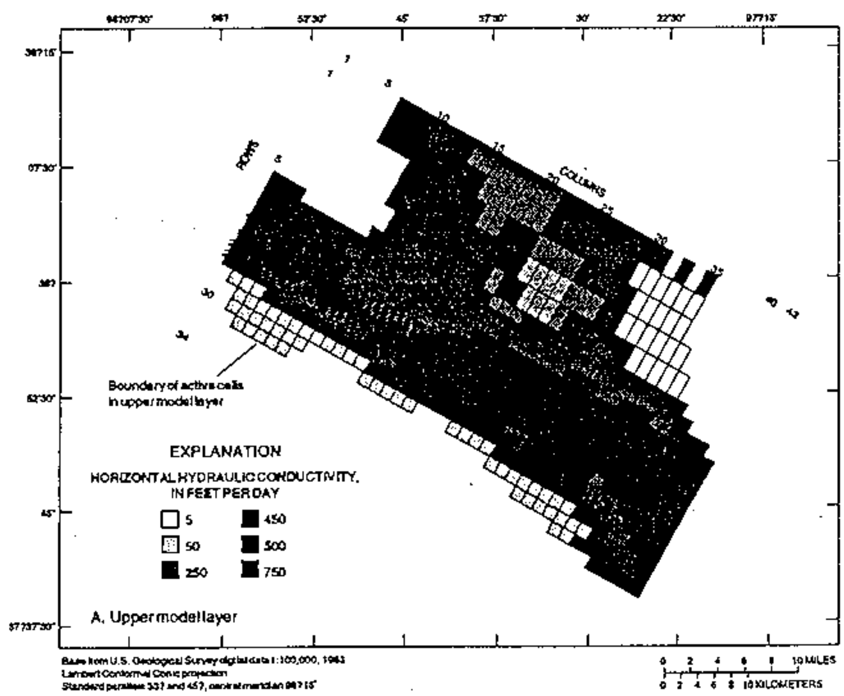



Figure B-2a.—Distribution of horizontal hydraulic conductivity in the upper model layer of the USGS flow model (Myers et al., in review).

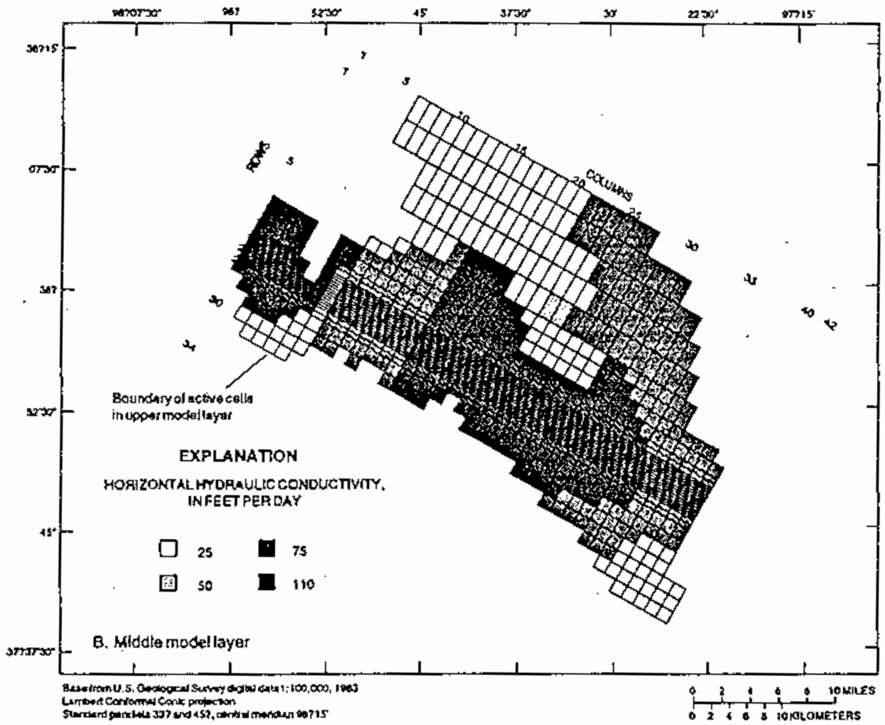



Figure B-2b.—Distribution of horizontal hydraulic conductivity in the middle model layer of the USGS flow model (Myers et al., in review).

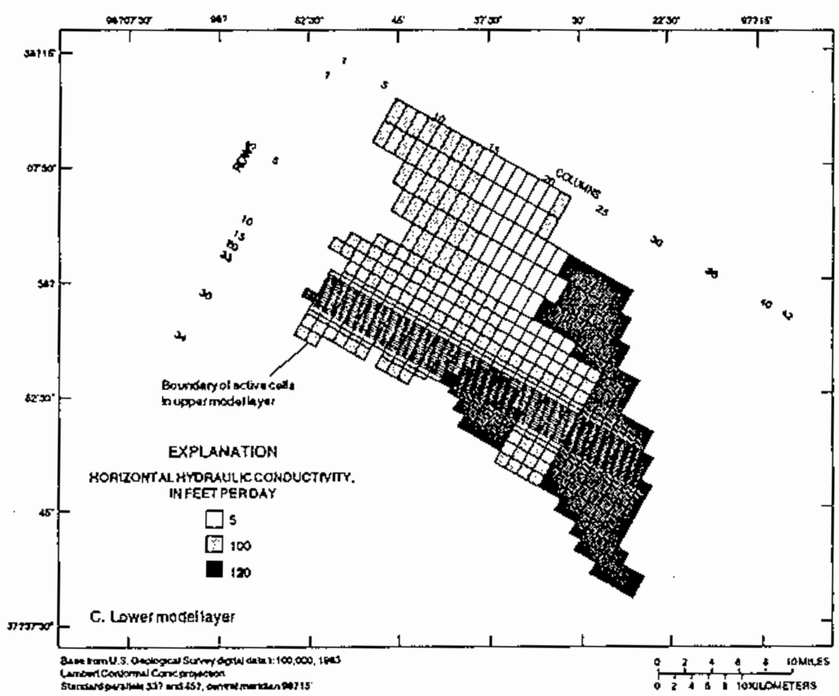



Figure B-2c.—Distribution of horizontal hydraulic conductivity in the lower model layer of the USGS flow model (Myers et al., in review).

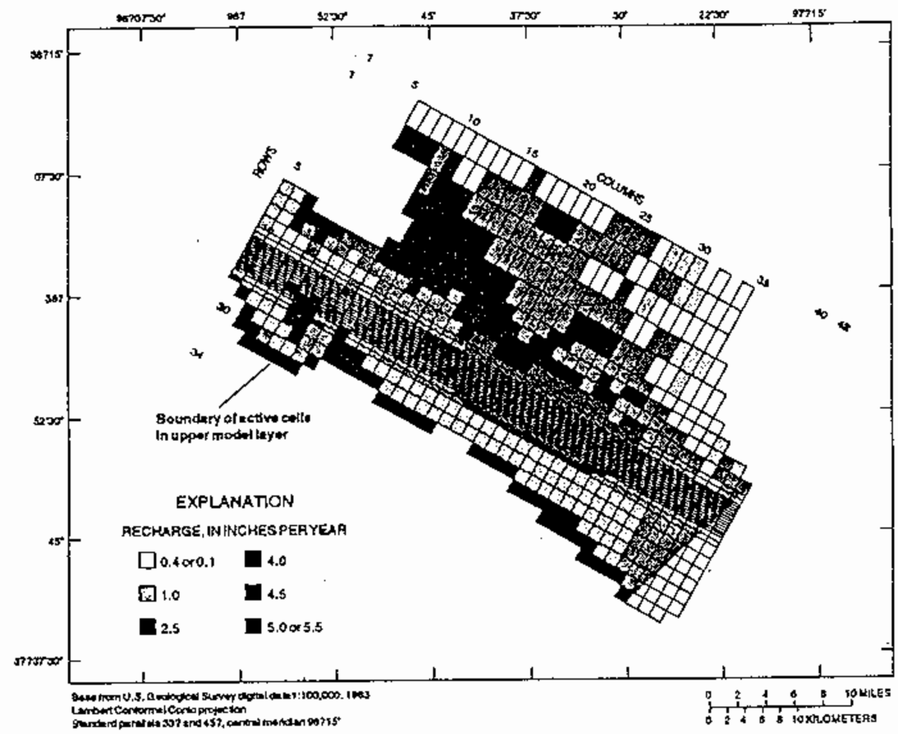
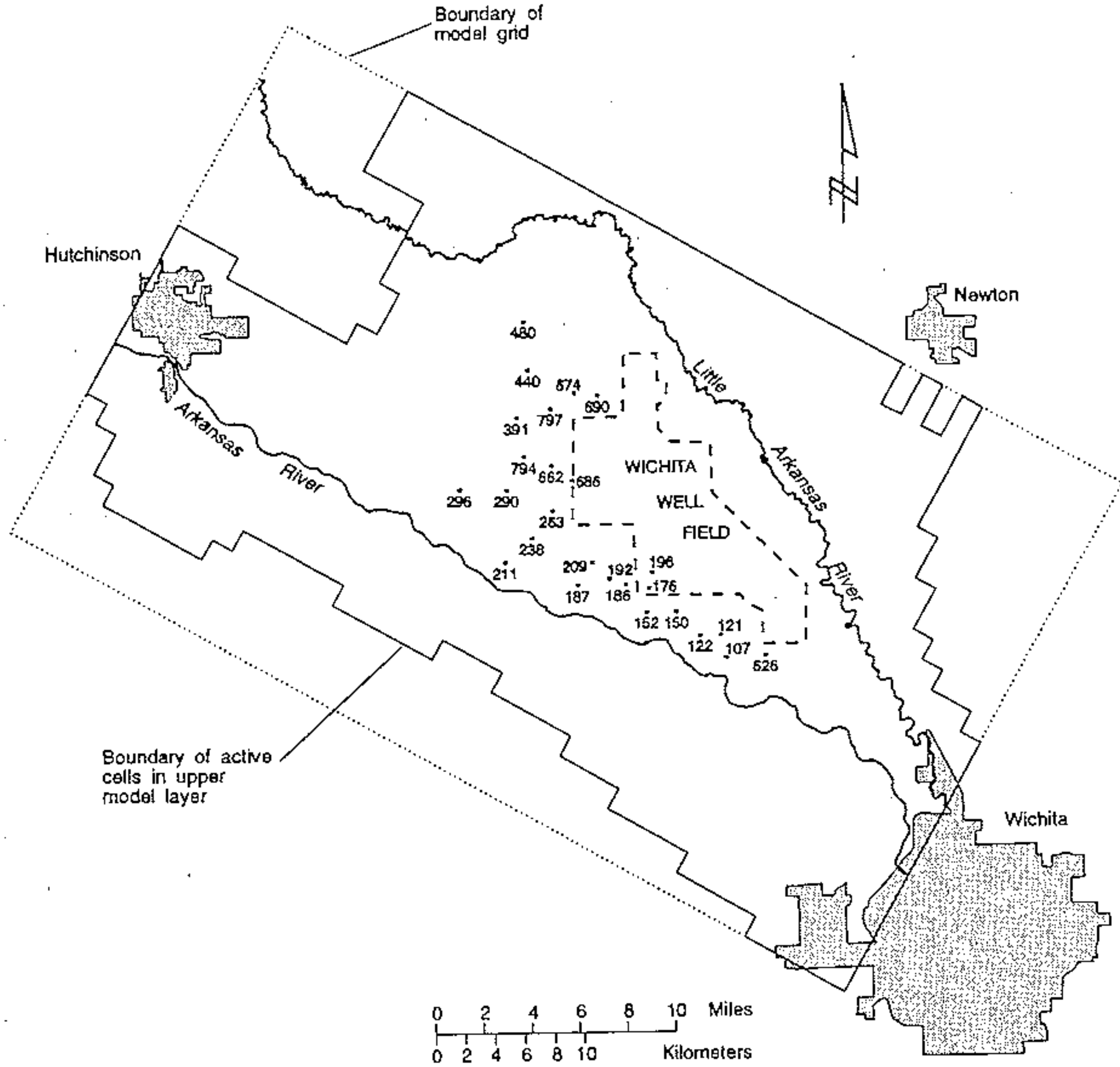


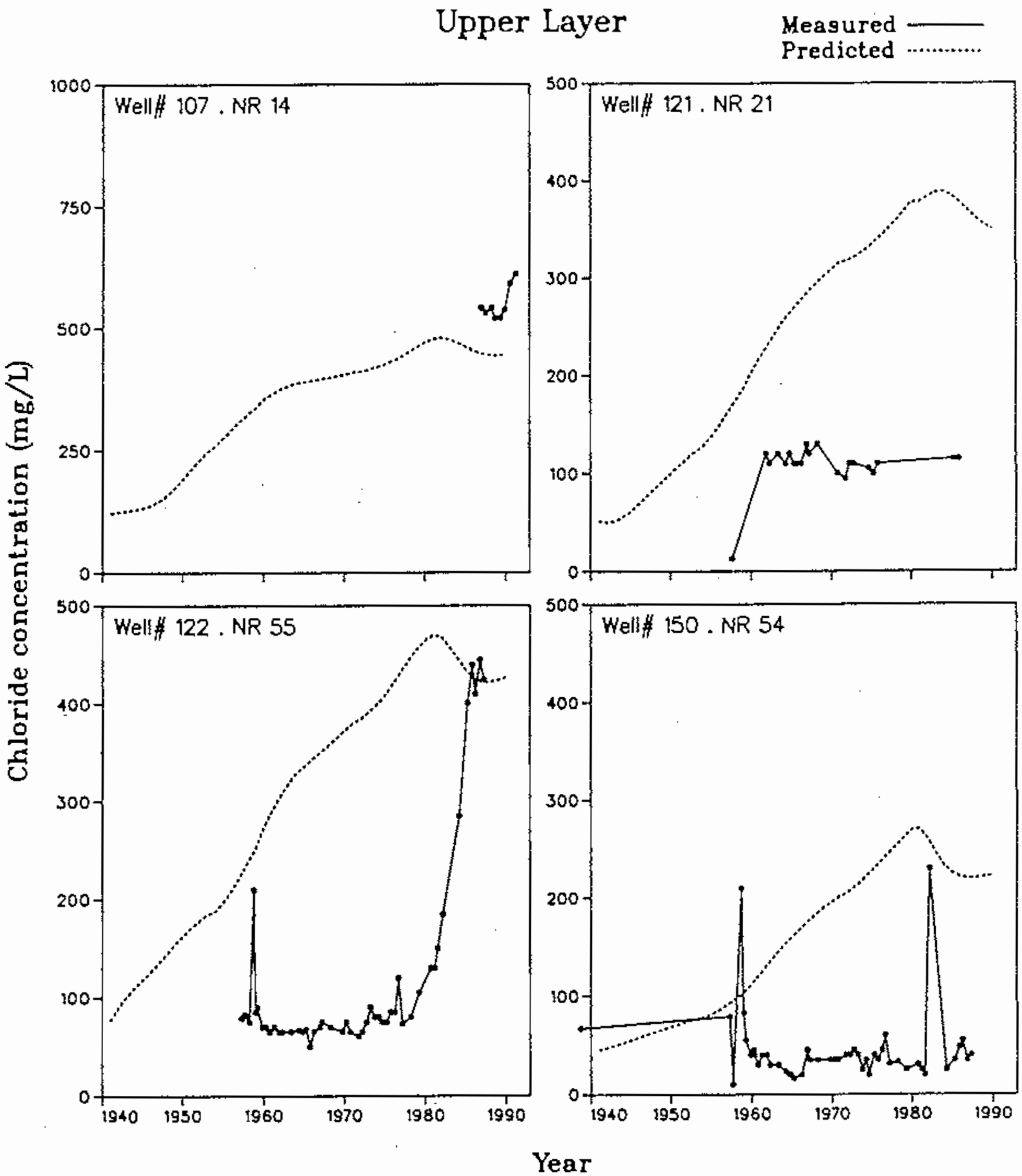

Figure B-3.---Ground-water recharge rates of the USGS steady-state flow model (Myers et al., in review).

# APPENDIX C

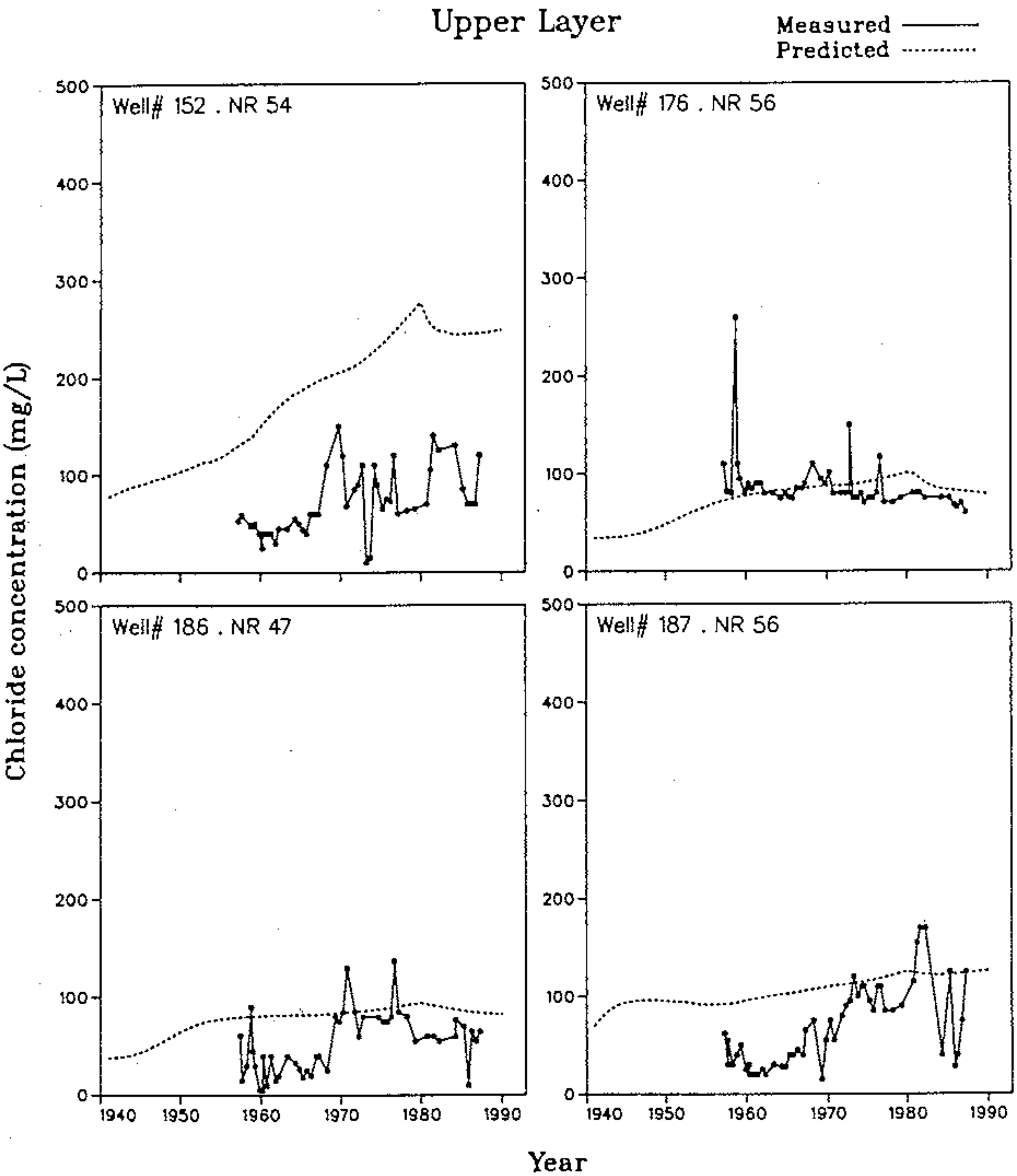
## Graphs of Measured and Predicted Chloride Concentration Used in the Model Calibration

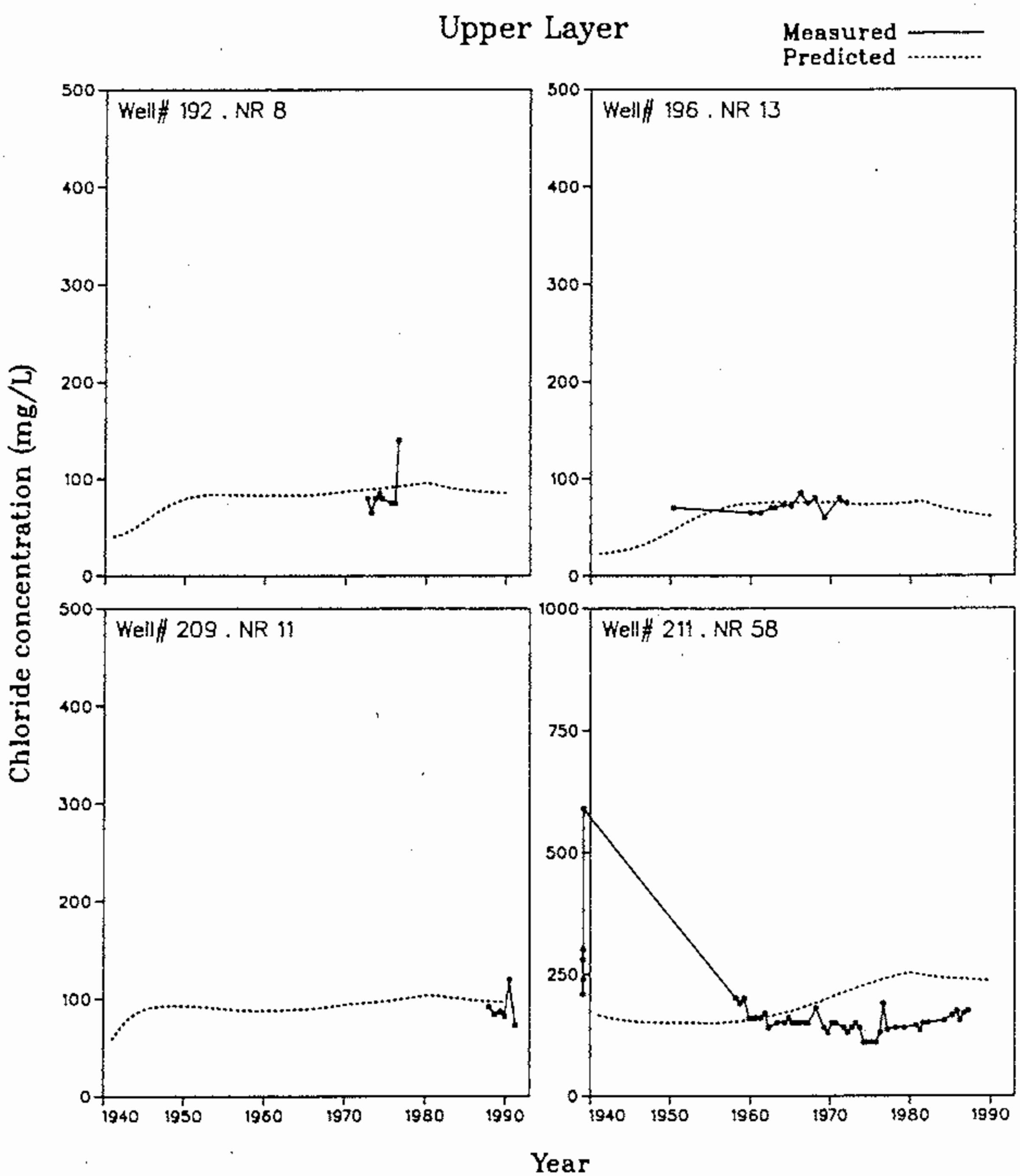



Locations having well data used in the model calibrations for the upper model layer. Graphs of measured and predicted chloride concentration for each well, referenced by number, follow.

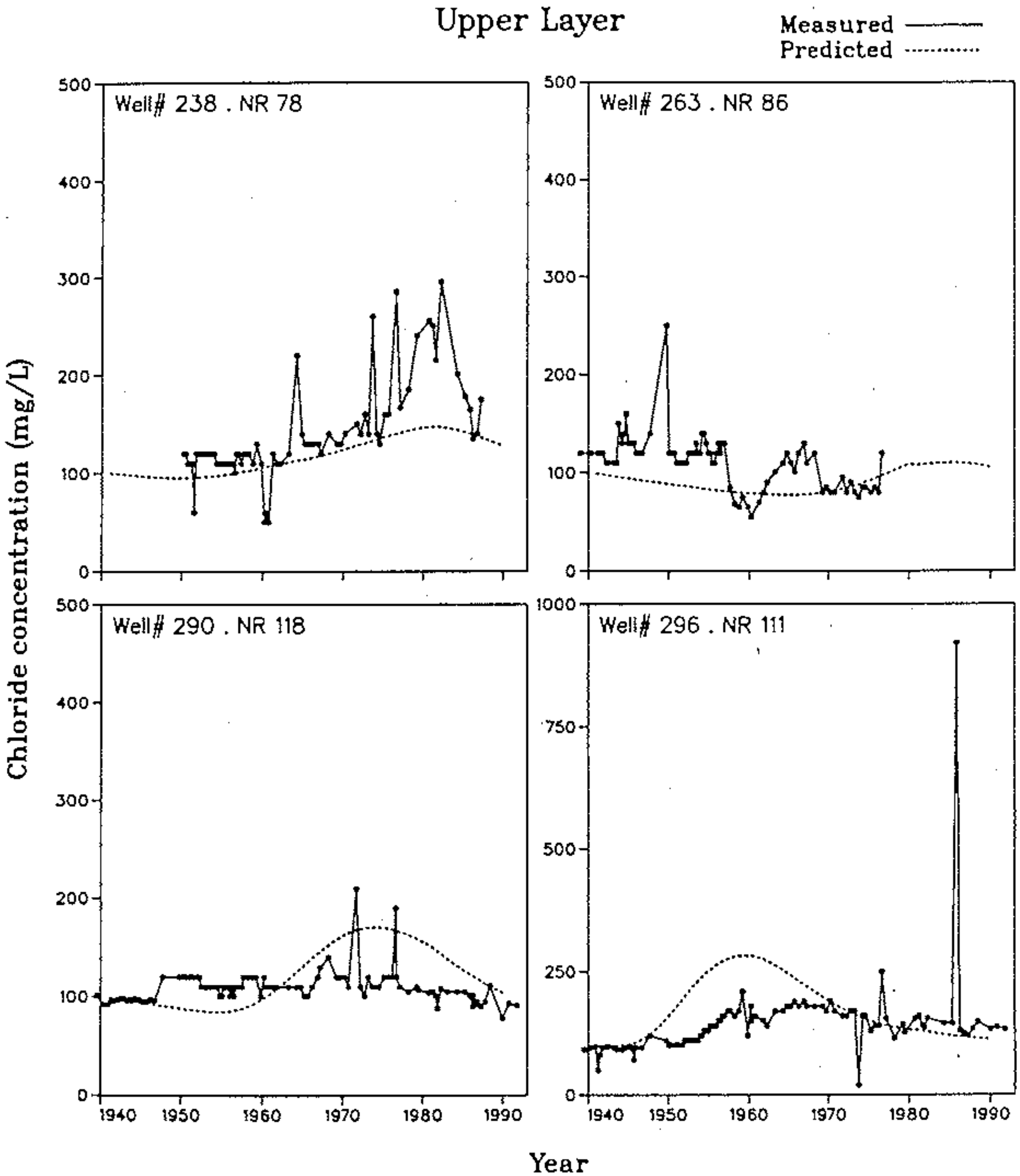


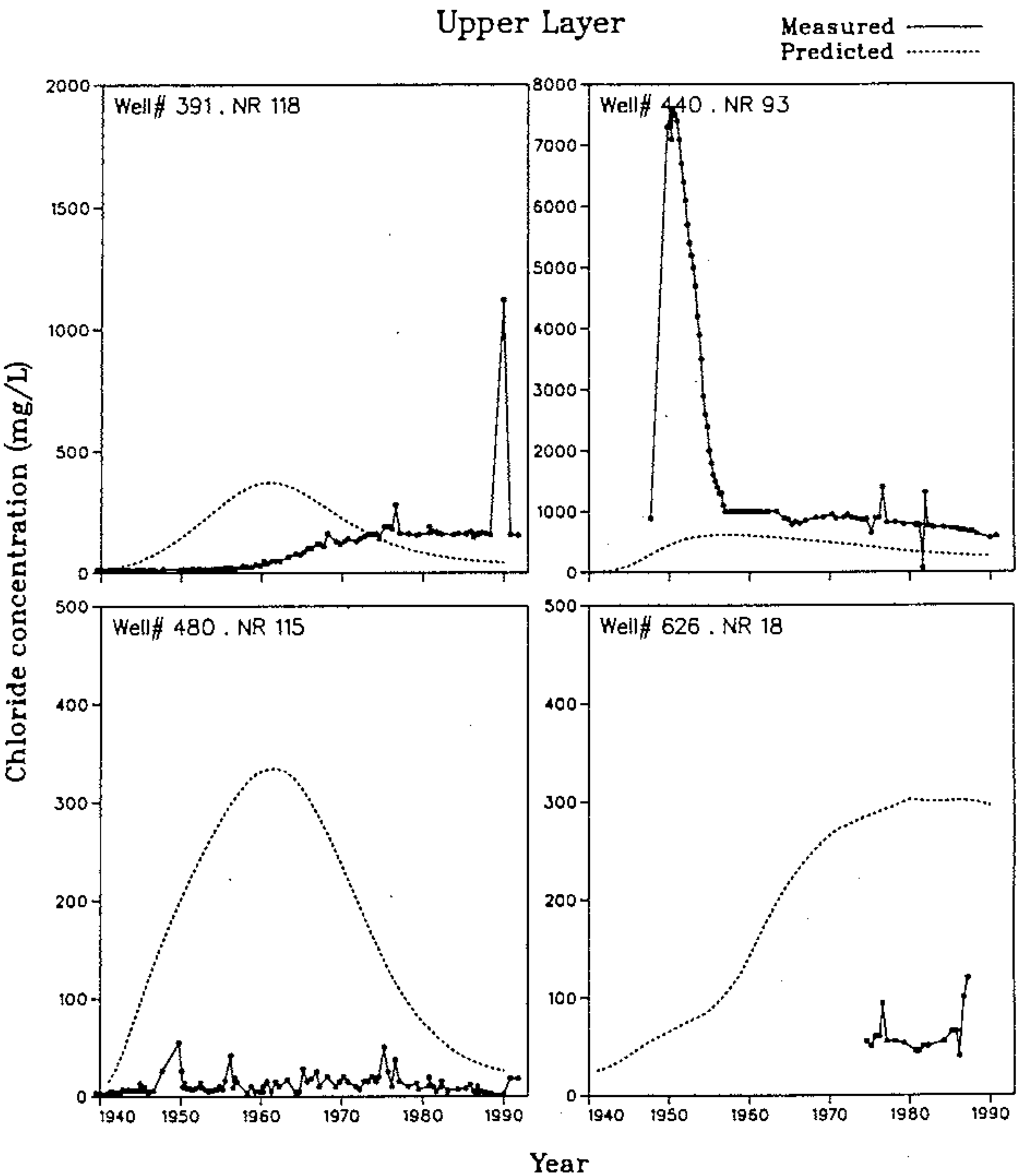
Upper Layer
Measured
Predicted
Well# 107 . NR 14
Well# 121 . NR 21
Well# 122 . NR 55
Well# 150 . NR 54
Chloride concentration (mg/L)
1000
750
500
250
0
400
300
200
100
1940
1950
1960
1970
1980
1990
Year

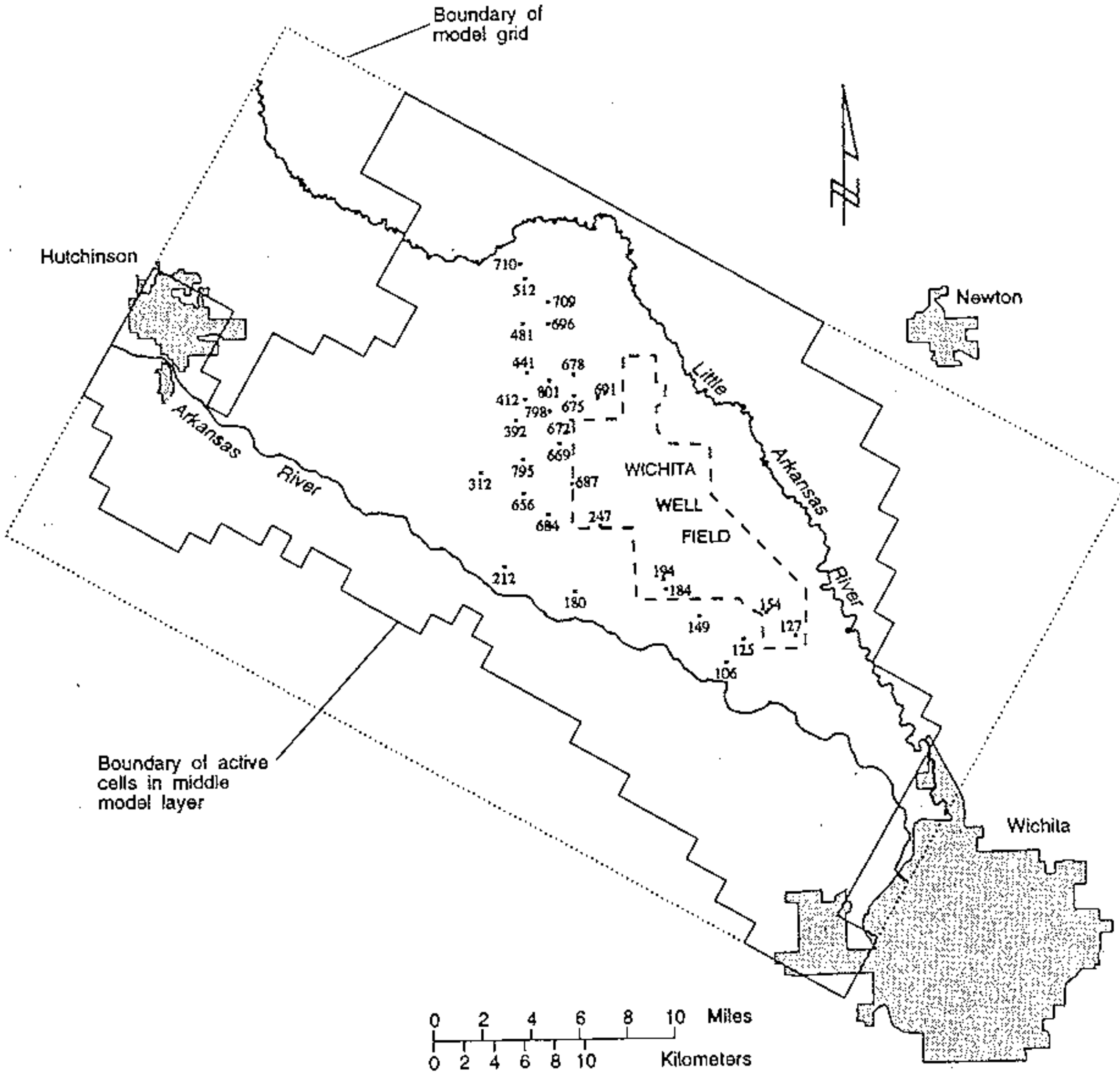

Upper Layer
Measured
Predicted
Well# 152 . NR 54
Well# 176 . NR 56
Well# 186 . NR 47
Well# 187 . NR 56
Chloride concentration (mg/L)
0
100
200
300
400
500
1940
1950
1960
1970
1980
1990
Year



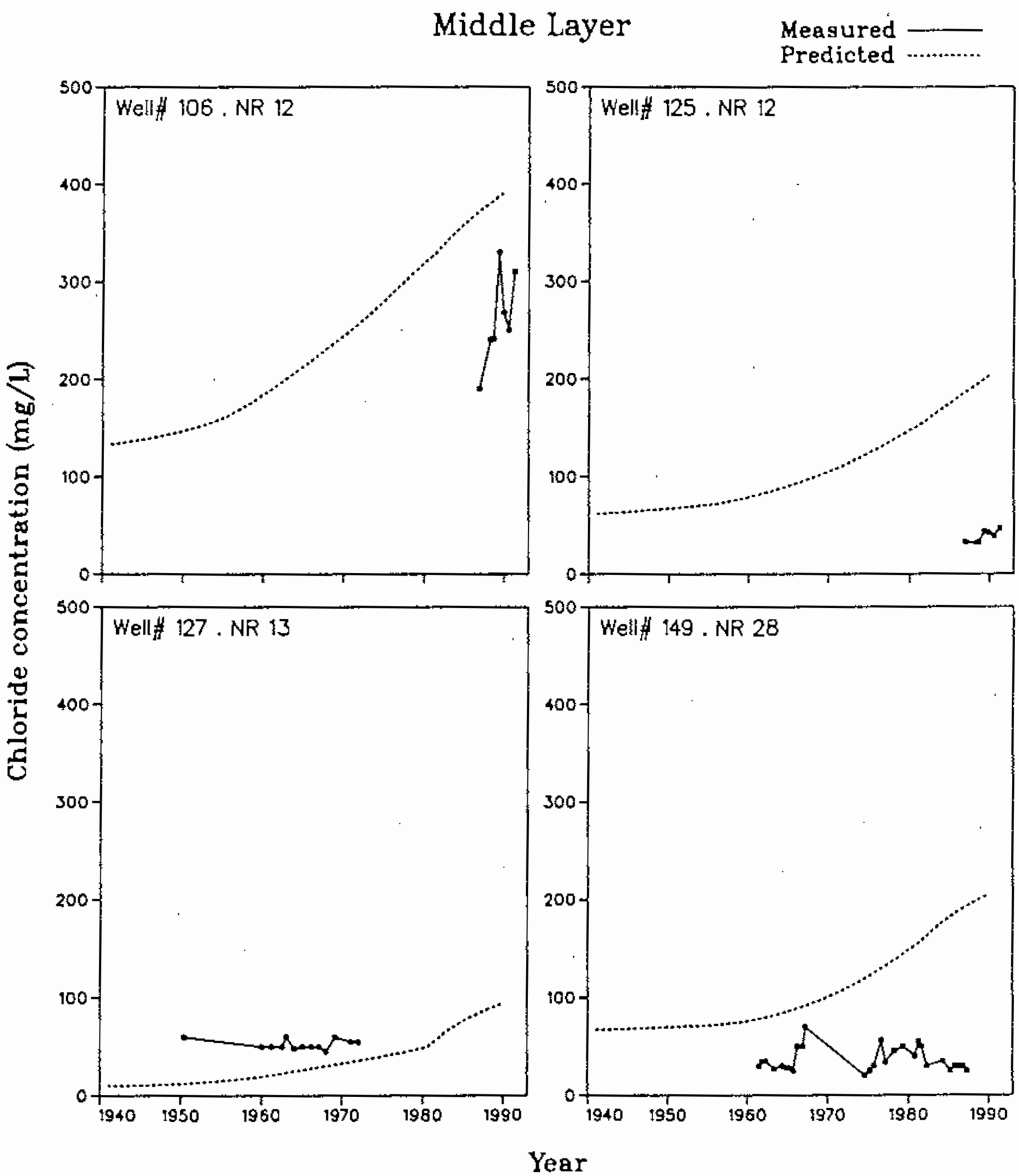
Upper Layer
Measured
Predicted
Chloride concentration (mg/L)
Well# 192 . NR 8
Well# 196 . NR 13
Well# 209 . NR 11
Well# 211 . NR 58
0
100
200
300
400
500
750
1000
250
1940
1950
1960
1970
1980
1990
Year

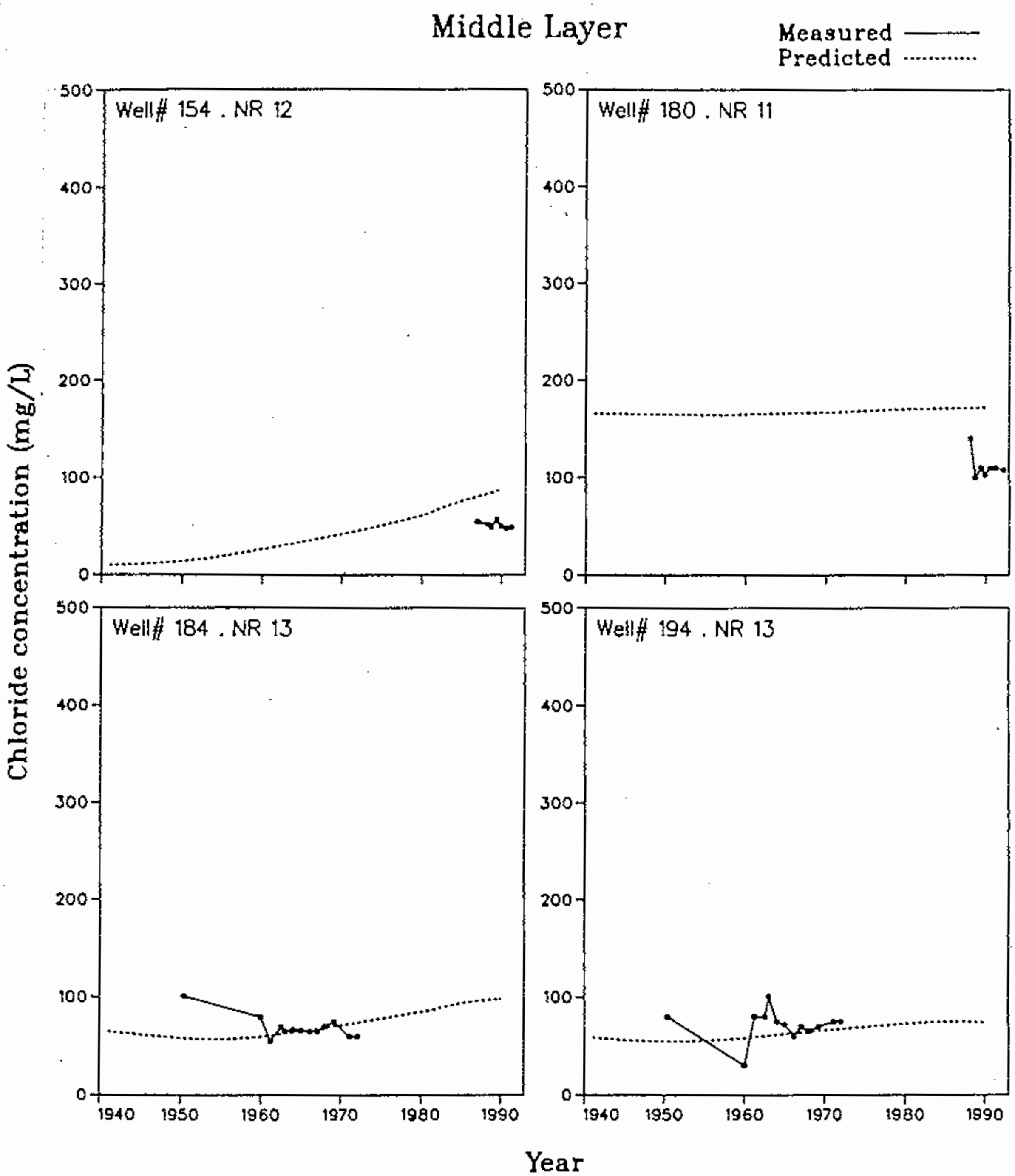

Upper Layer
Measured
Predicted
Well# 238 . NR 78
Well# 263 . NR 86
Well# 290 . NR 118
Well# 296 . NR 111
Chloride concentration (mg/L)
Year
0
100
200
300
400
500
250
750
1000
1940
1950
1960
1970
1980
1990

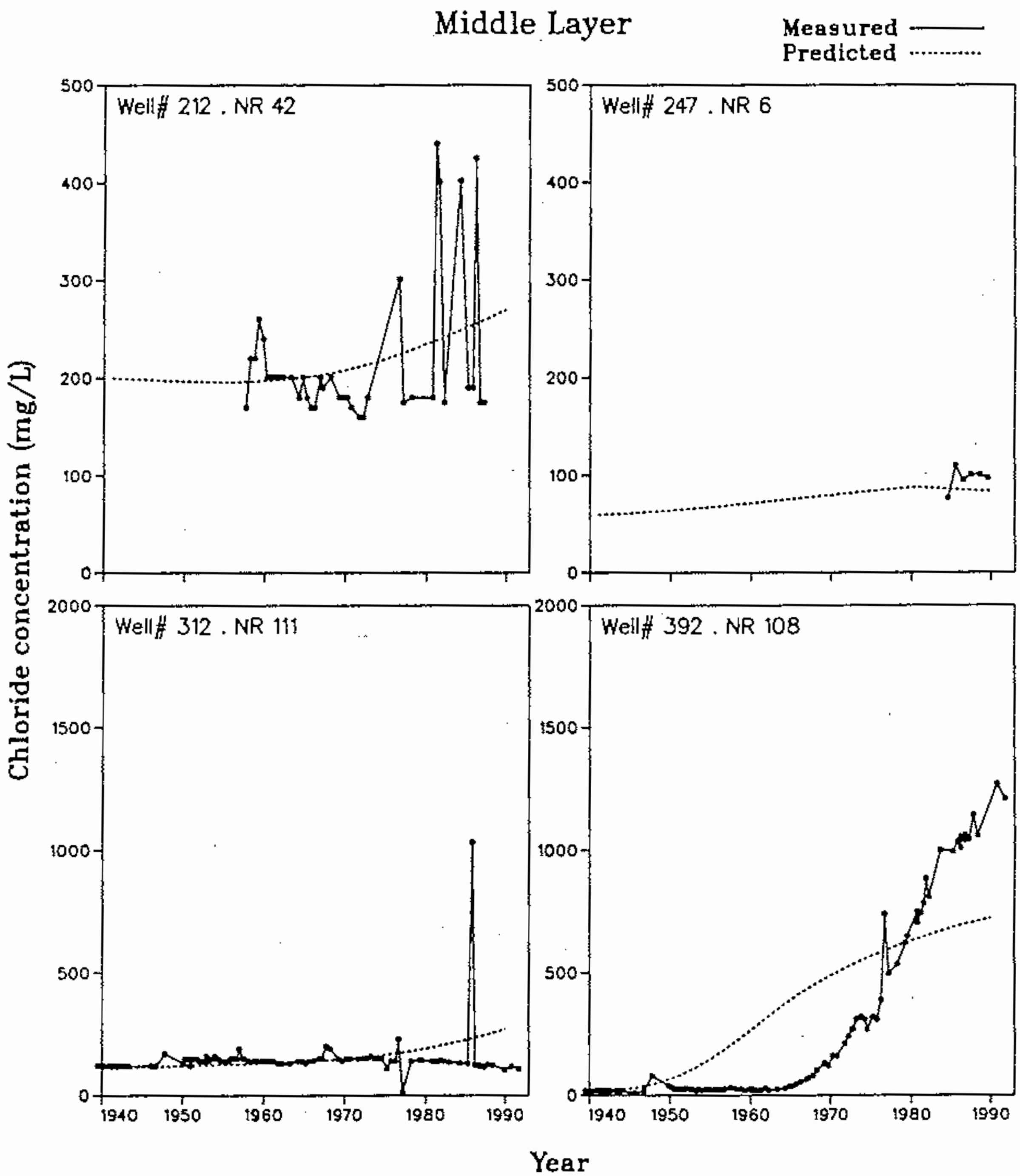

Upper Layer
Measured
Predicted
Well# 391 . NR 118
Well# 440 . NR 93
Well# 480 . NR 115
Well# 626 . NR 18
Chloride concentration (mg/L)
Year
0
500
1000
1500
2000
1000
2000
3000
4000
5000
6000
7000
8000
100
200
300
400
500
1940
1950
1960
1970
1980
1990

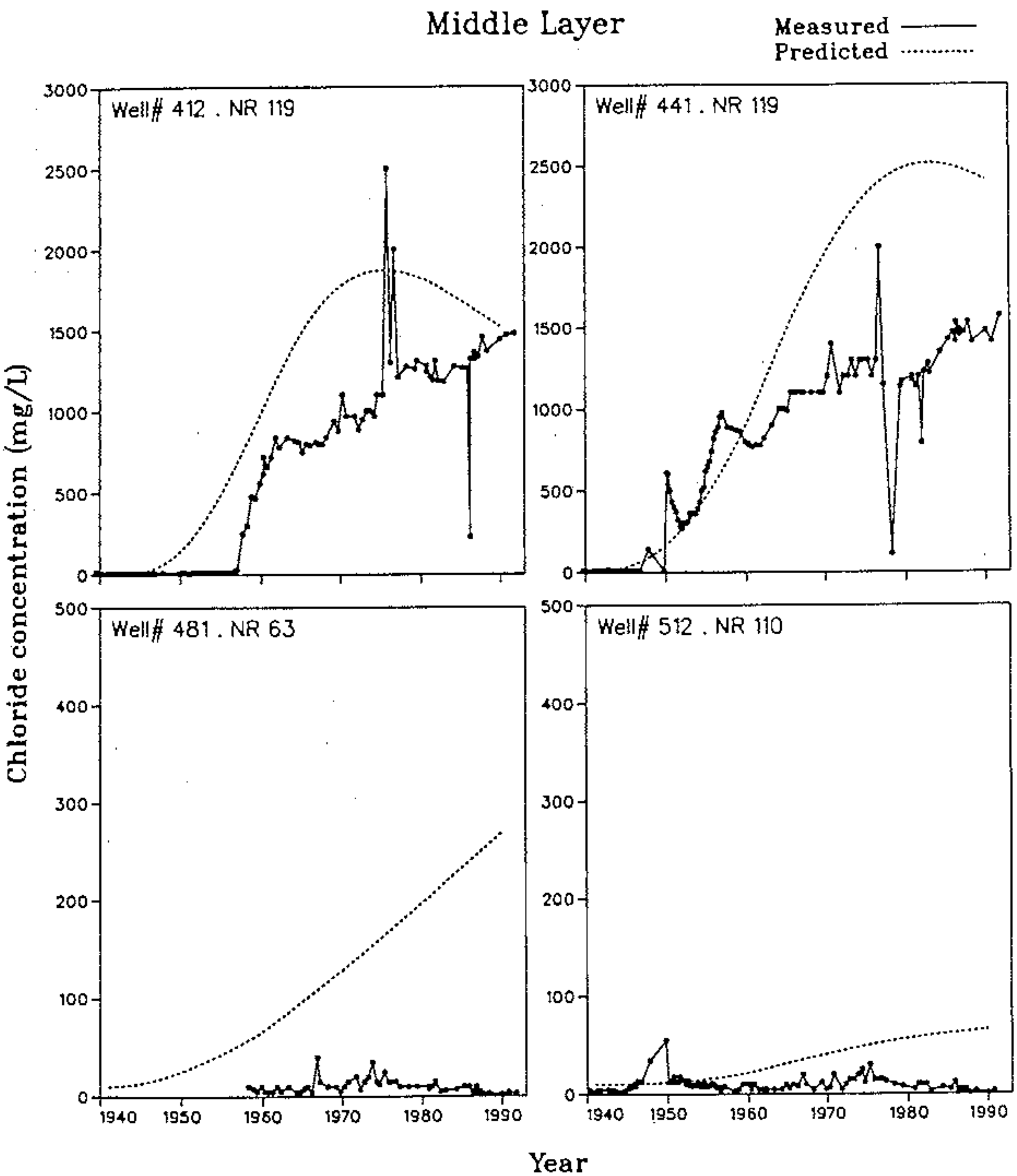



Locations having well data used in the model calibrations for the middle model layer. Graphs of measured and predicted chloride concentration for each well, referenced by number, follow.

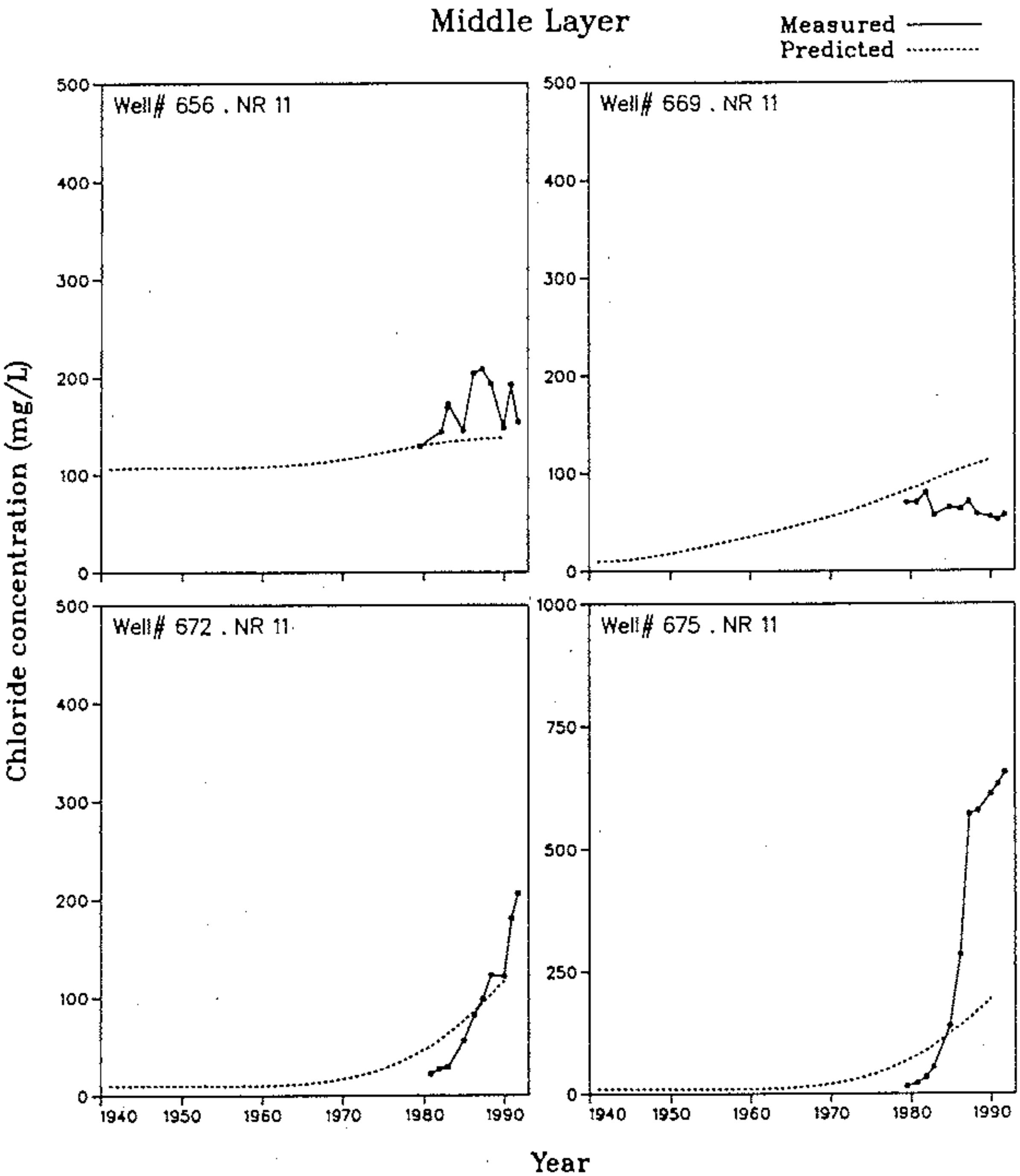

Middle Layer
Measured
Predicted
Well# 106 . NR 12
Well# 125 . NR 12
Well# 127 . NR 13
Well# 149 . NR 28
Chloride concentration (mg/L)
500
400
300
200
100
0
1940
1950
1960
1970
1980
1990
Year


Middle Layer
Measured
Predicted
Well# 154 . NR 12
Well# 180 . NR 11
Well# 184 . NR 13
Well# 194 . NR 13
Chloride concentration (mg/L)
Year
0
100
200
300
400
500
1940
1950
1960
1970
1980
1990

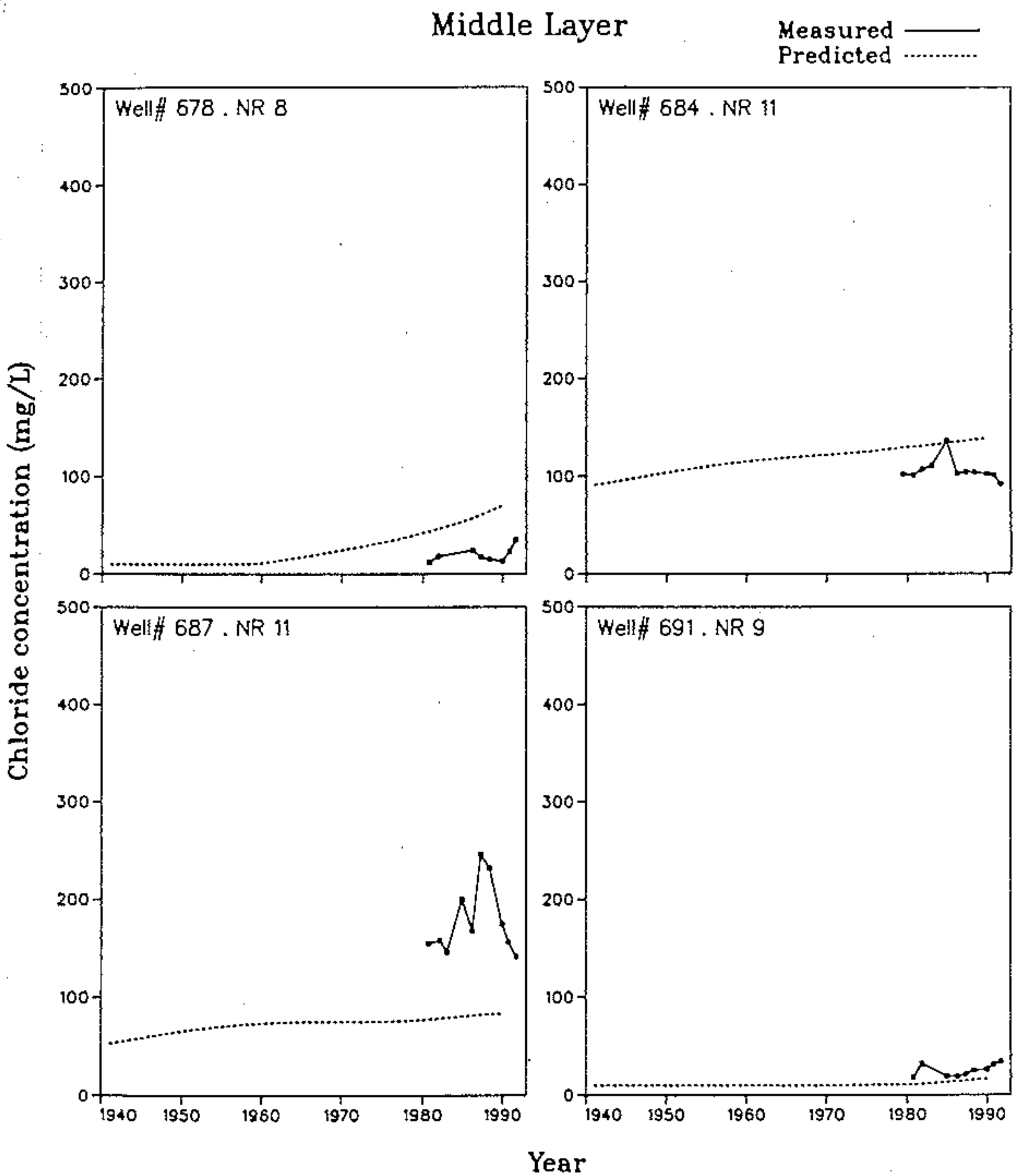

Middle Layer
Measured
Predicted
Well# 212 . NR 42
Well# 247 . NR 6
Well# 312 . NR 111
Well# 392 . NR 108
Chloride concentration (mg/L)
Year
0
100
200
300
400
500
1000
1500
2000
1940
1950
1960
1970
1980
1990



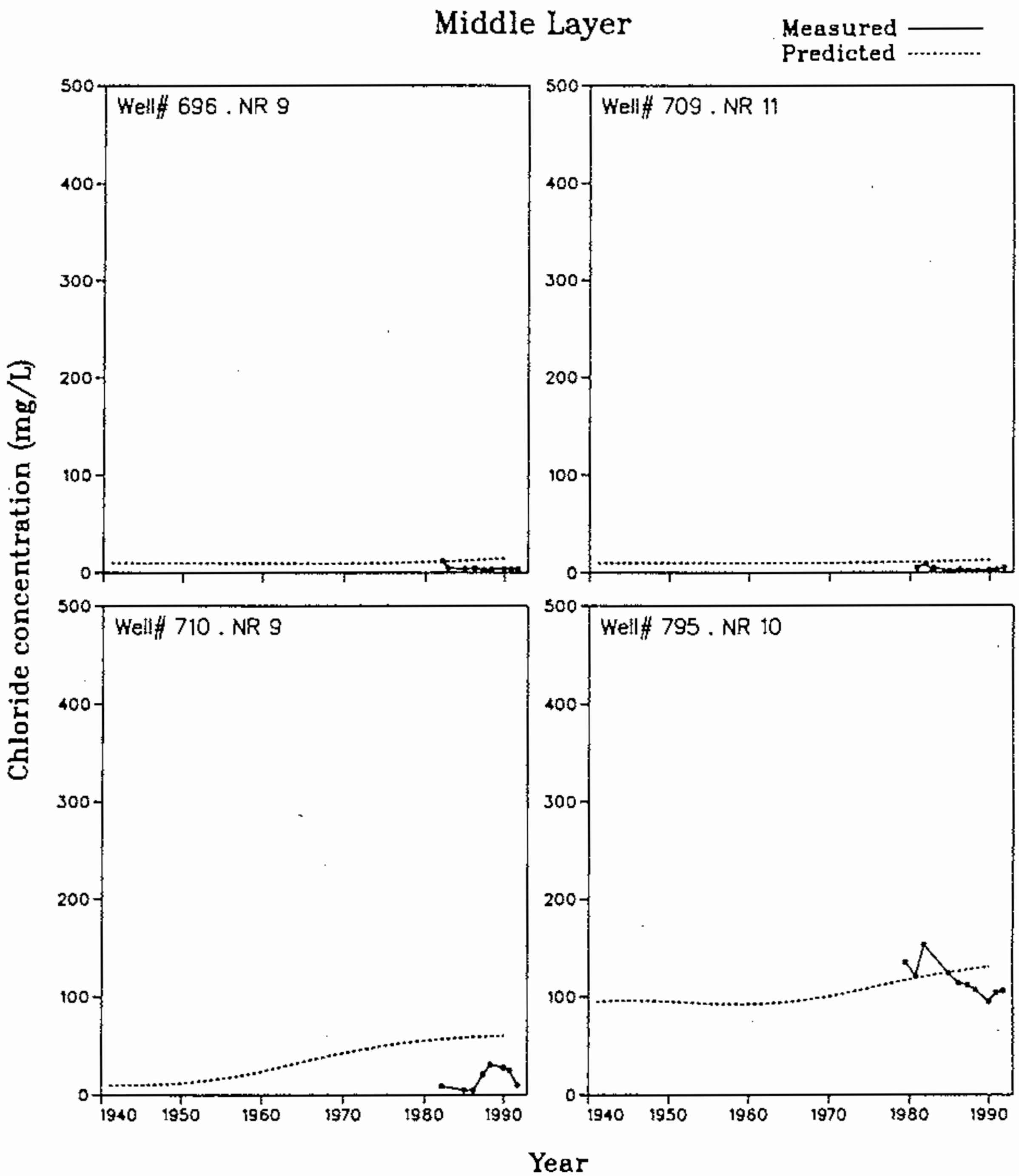
Middle Layer
Measured
Predicted
Well# 412 . NR 119
Well# 441 . NR 119
Well# 481 . NR 63
Well# 512 . NR 110
Chloride concentration (mg/L)
Year



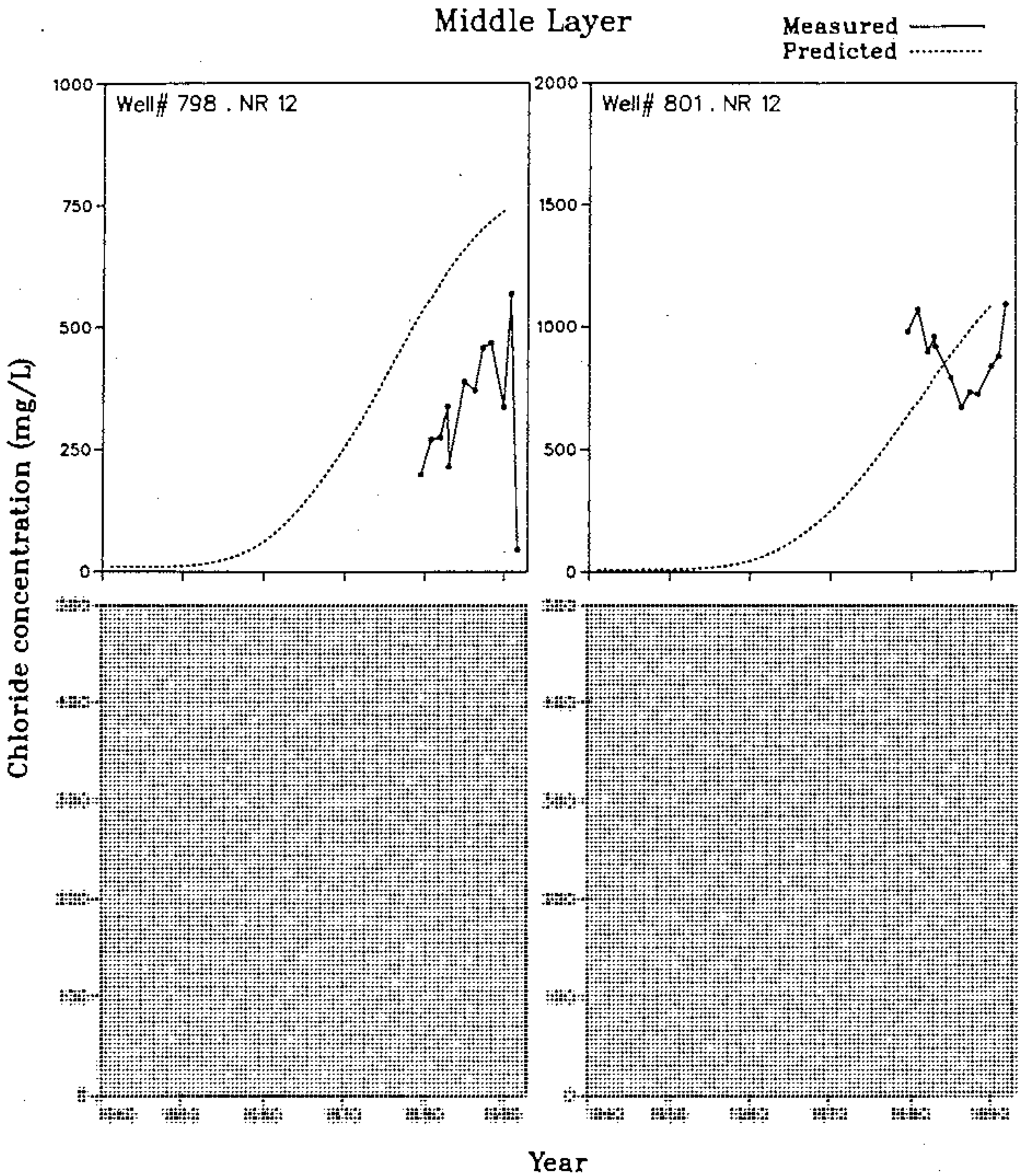
Middle Layer
Measured
Predicted
Well# 656 . NR 11
Well# 669 . NR 11
Well# 672 . NR 11
Well# 675 . NR 11
Chloride concentration (mg/L)
500
400
300
200
100
0
1000
750
500
250
1940
1950
1960
1970
1980
1990
Year



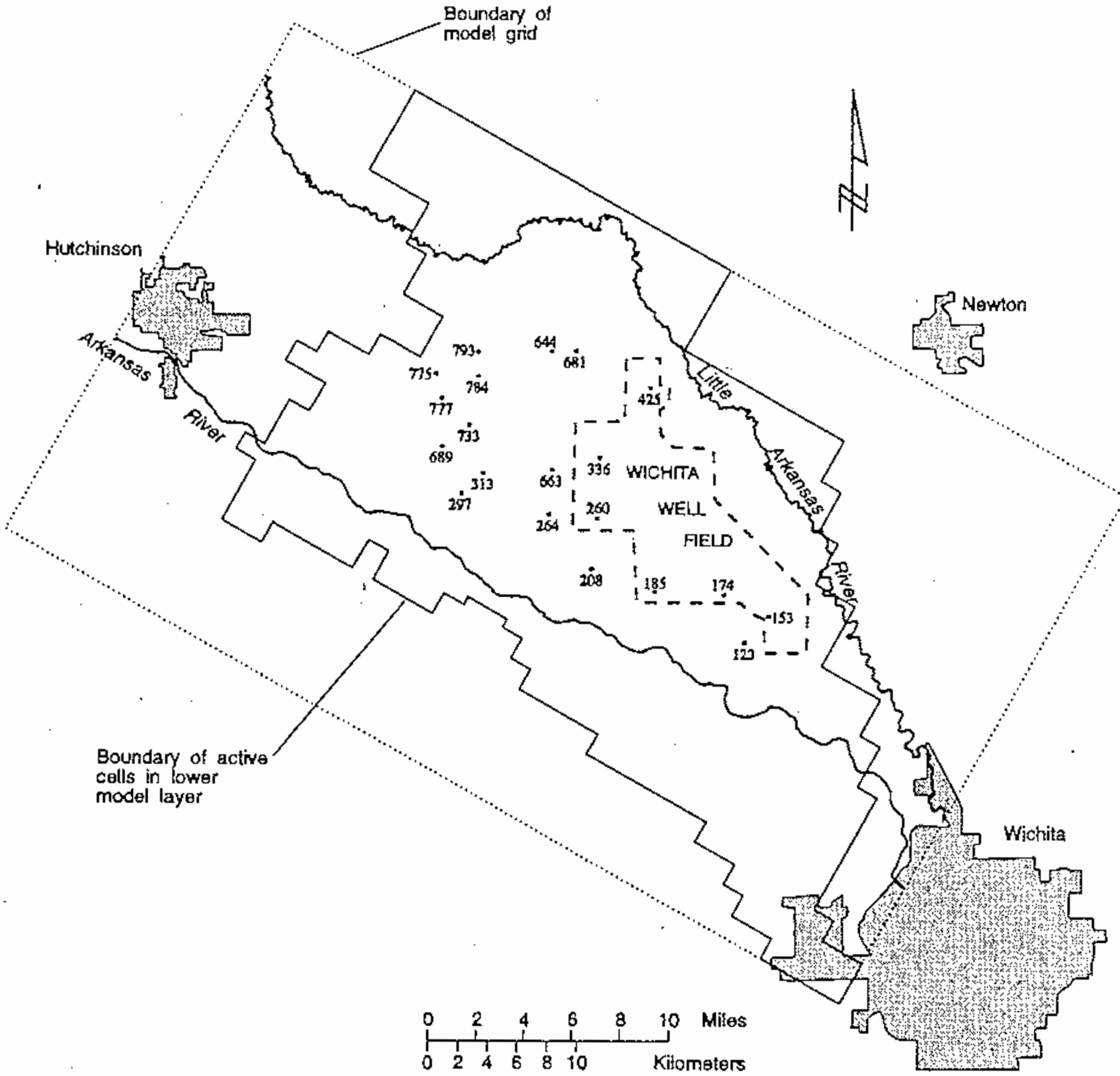
Middle Layer
Measured
Predicted
Chloride concentration (mg/L)
Well# 678 . NR 8
Well# 684 . NR 11
Well# 687 . NR 11
Well# 691 . NR 9
0
100
200
300
400
500
1940
1950
1960
1970
1980
1990
Year



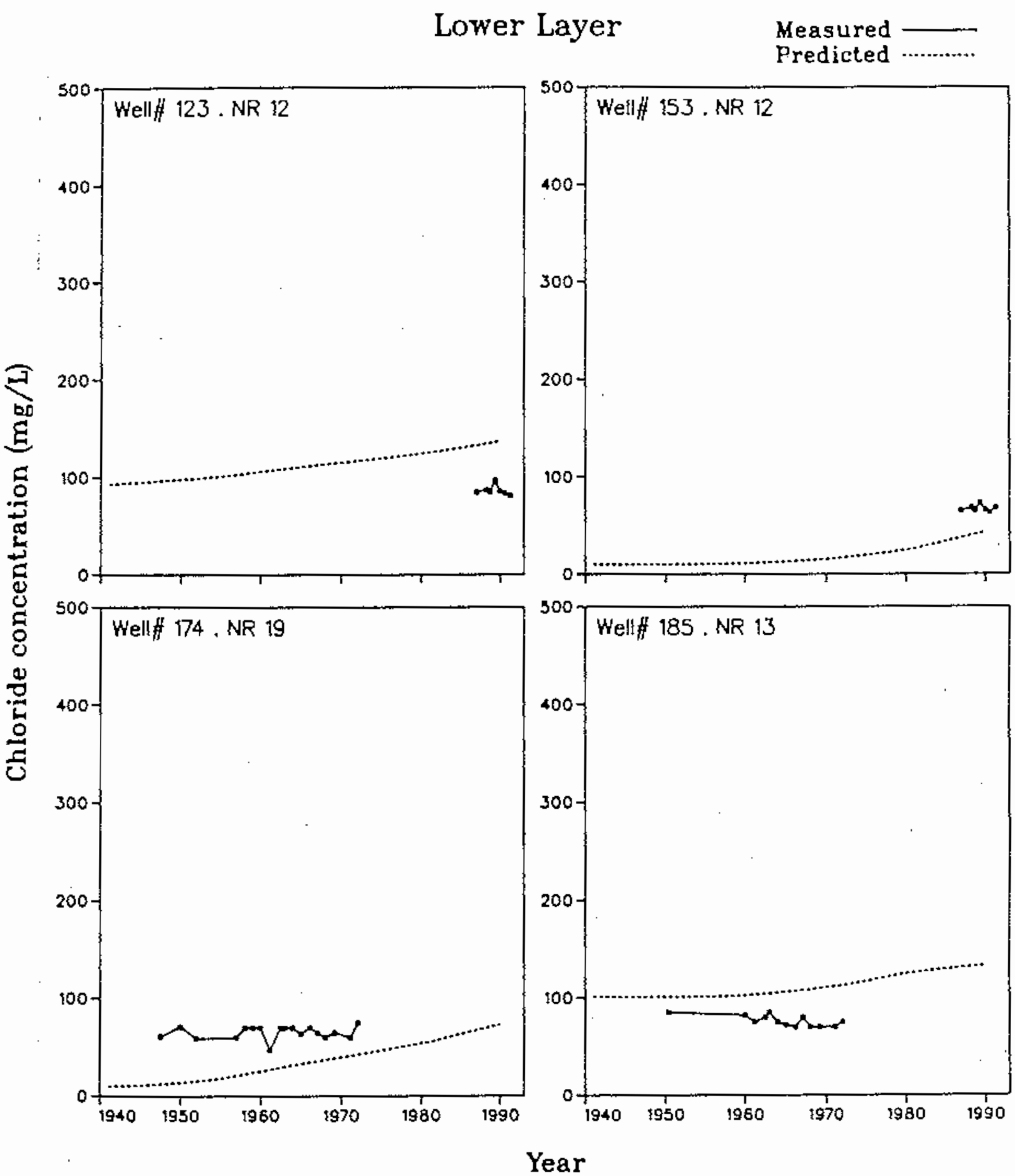
Middle Layer
Measured
Predicted
Chloride concentration (mg/L)
Well# 696 . NR 9
Well# 709 . NR 11
Well# 710 . NR 9
Well# 795 . NR 10
0
100
200
300
400
500
1940
1950
1960
1970
1980
1990
Year



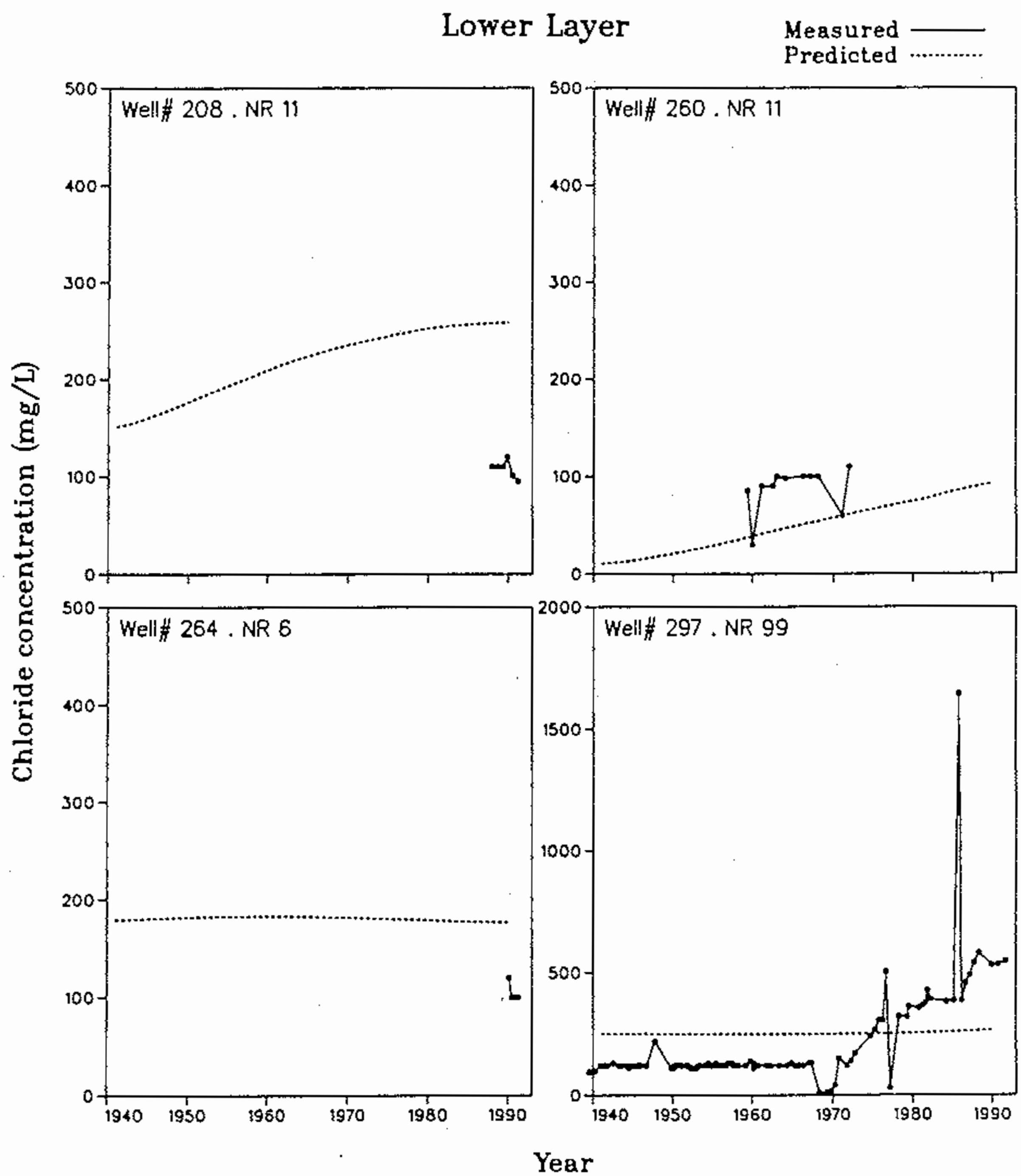
Middle Layer
Measured
Predicted
Well# 798 . NR 12
Well# 801 . NR 12
Chloride concentration (mg/L)
1000
750
500
250
0
2000
1500
1000
500
0
Year

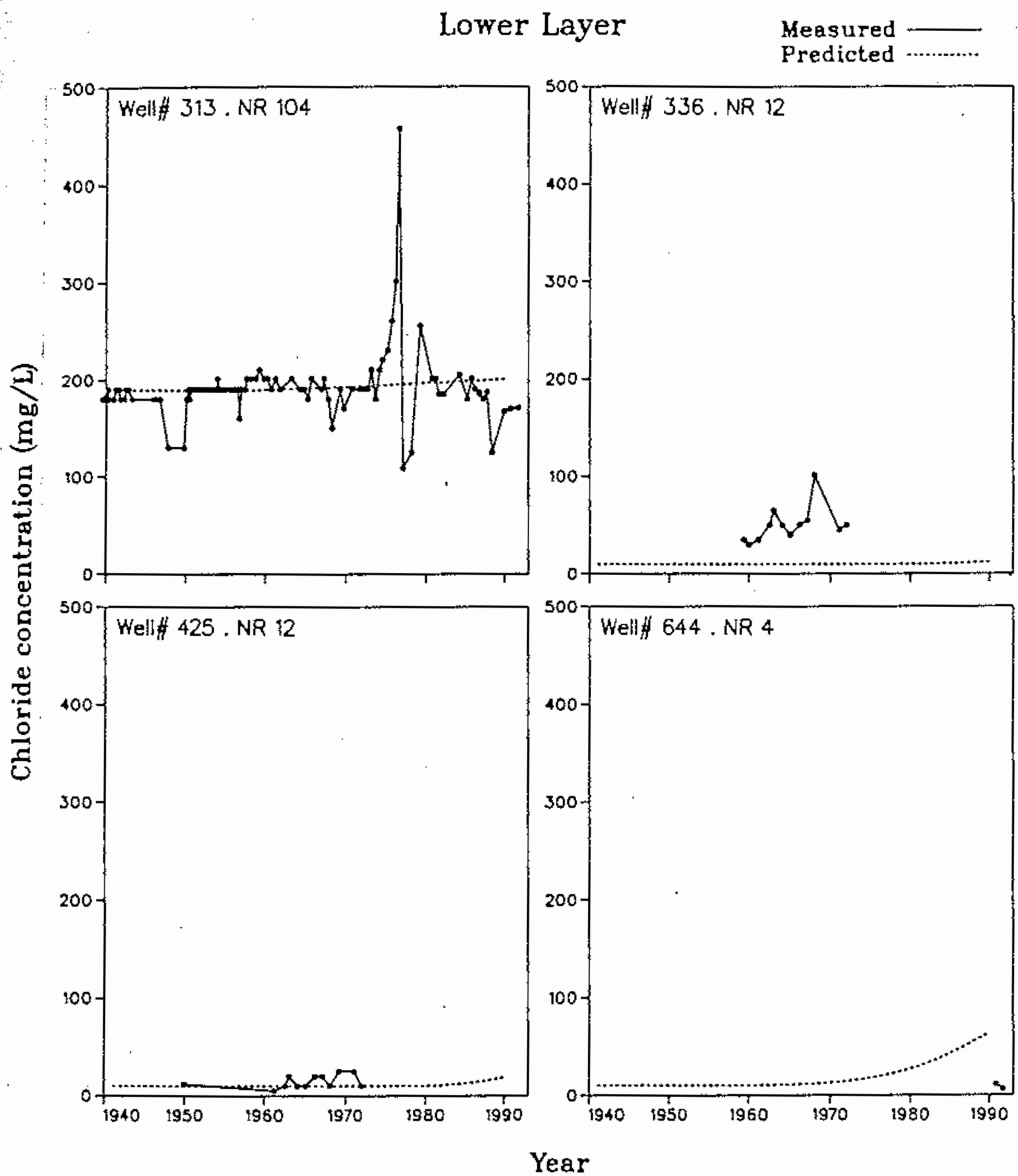


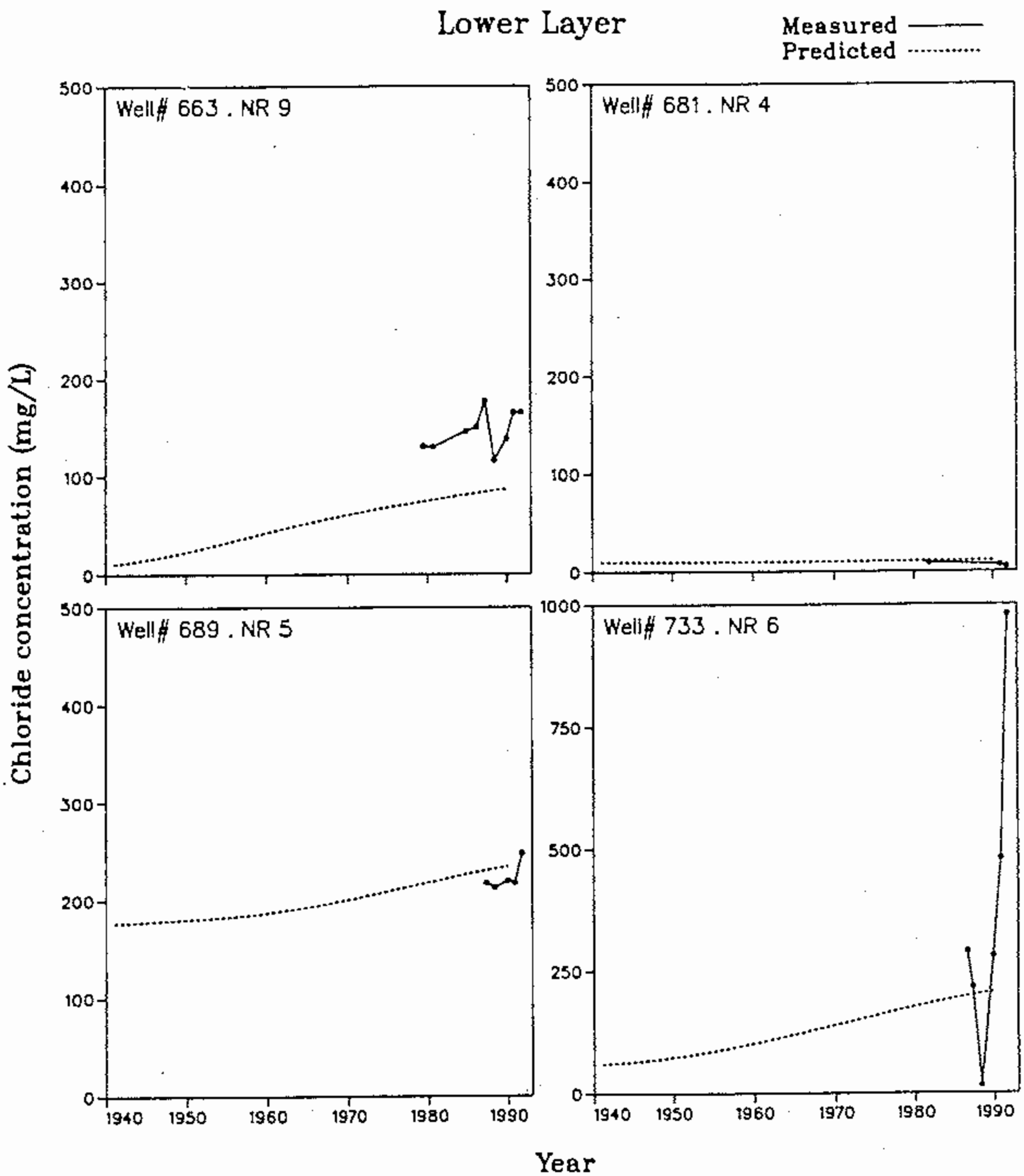

Locations having well data used in the model calibrations for the lower model layer. Graphs of measured and predicted chloride concentration for each well, referenced by number, follow.



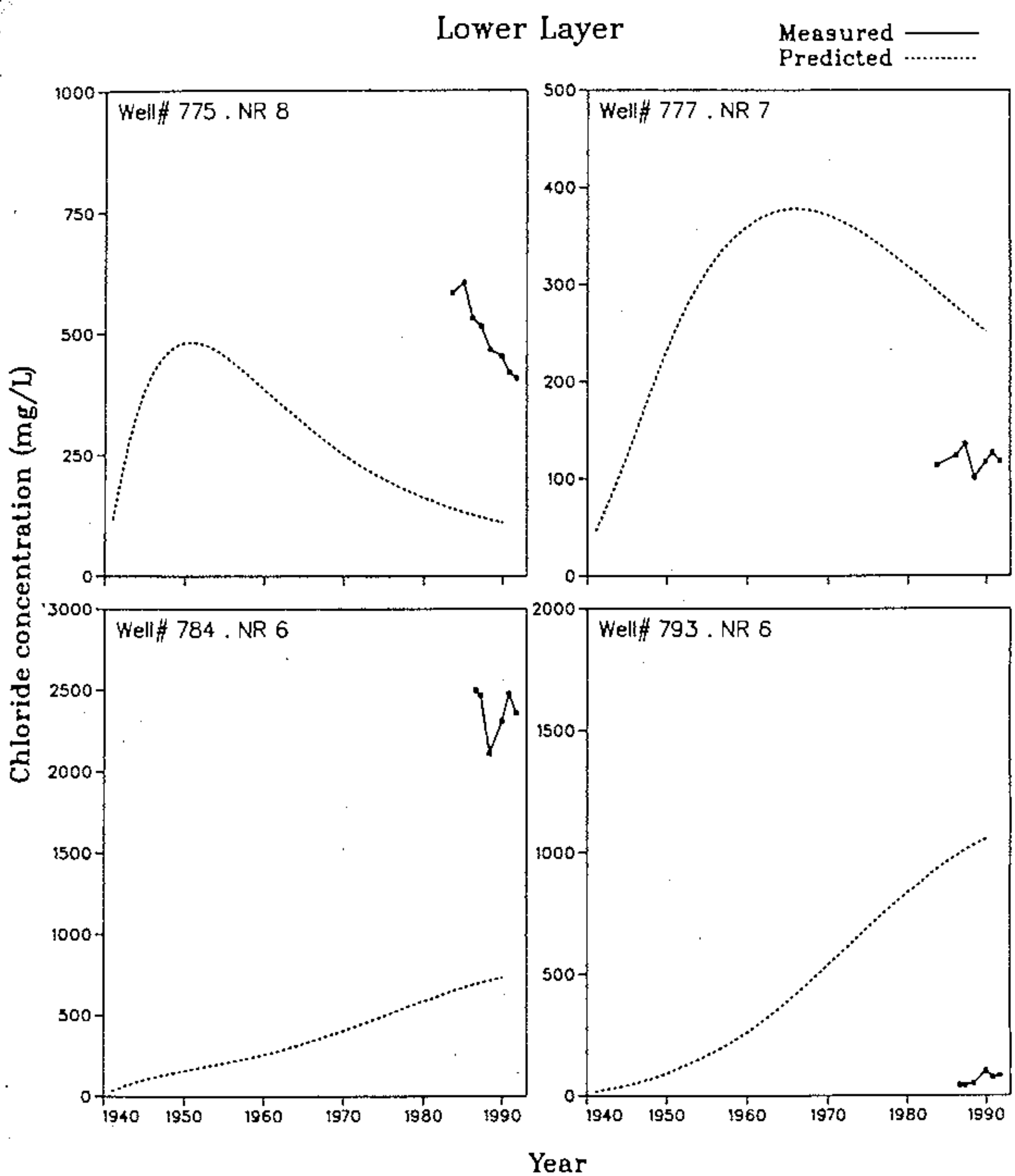
Lower Layer
Measured
Predicted
Well# 123 . NR 12
Well# 153 . NR 12
Well# 174 . NR 19
Well# 185 . NR 13
Chloride concentration (mg/L)
0
100
200
300
400
500
1940
1950
1960
1970
1980
1990
Year


Lower Layer
Measured
Predicted
Well# 208 . NR 11
Well# 260 . NR 11
Well# 264 . NR 6
Well# 297 . NR 99
Chloride concentration (mg/L)
0
100
200
300
400
500
1000
1500
2000
1940
1950
1960
1970
1980
1990
Year


Lower Layer
Measured
Predicted
Well# 313 . NR 104
Well# 336 . NR 12
Well# 425 . NR 12
Well# 644 . NR 4
Chloride concentration (mg/L)
0
100
200
300
400
500
1940
1950
1960
1970
1980
1990
Year



Lower Layer
Measured
Predicted
Well# 663 . NR 9
Well# 681 . NR 4
Well# 689 . NR 5
Well# 733 . NR 6
Chloride concentration (mg/L)
Year
500
400
300
200
100
0
1000
750
500
250
1940
1950
1960
1970
1980
1990


Lower Layer
Measured
Predicted
Chloride concentration (mg/L)
Well# 775 . NR 8
Well# 777 . NR 7
Well# 784 . NR 6
Well# 793 . NR 6
0
250
500
750
1000
100
200
300
400
500
1000
1500
2000
2500
3000
1940
1950
1960
1970
1980
1990
Year

# APPENDIX D

## Water Quality

# Water Quality Data

## Introduction

The complete set of water quality data collected during the period 1988 through 1990 was reviewed. Several tasks were undertaken in the data analysis. The initial task involved the development of a spreadsheet that was used for statistical analysis and comparison of observed values with water quality standards. Of the data available in the data set, there are standards for chloride (Cl), sulfate ($SO_4$), ($NO_3$), fluoride (F), iron (Fe), and manganese (Mn).

Specific conductance, which is also known as electrical conductivity (EC), is a measure of the total dissolved solids (TDS) in water. There is a standard for TDS, but not for EC. A gross estimate of the TDS in water is often made using a factor of 0.7, which is multiplied times the EC. Frequently the dominant ions in water are also highly correlated with EC as well. Because the major concern of the Arkansas River Water Management Improvement Study (ARWMIS) is Cl, possible correlations of Cl on EC were investigated.

Regressions of chloride on specific conductance were derived for the complete data set and for several subsets of the data collected throughout the sampling period of 1986 through 1990. The regression were derived using a LOTUS 123, Version 3.1+ spreadsheet. A regression of sodium (Na) on chloride (Cl) was also calculated to evaluate whether the components of salt were behaving similarly or differently.

## Comparison to Water Quality Standards

The comparison to water quality standards is summarized in Table 1. It should be noted that all of the standards shown are secondary drinking water standards and do not represent a level of the substances shown that relate to public health. The standards are based on levels that are related to the acceptability of the water by the public, primarily based on taste or undesirable effects on various domestic uses.

Table 1: Comparison of Water Quality Data for 1988 through 1990 from Well in Groundwater Management District Number 2 to Drinking Water Standards

| | Cl | $SO_4$ | $NO_3$ | F | Fe | Mn |
|---|---|---|---|---|---|---|
| Standard (mg/L) | 250 | 250 | 10 | 2 | 0.3 | 0.05 |
| % > standard | 40.8 | 8.9 | 2.6 | 0 | 85.4 | 76.8 |

There are a total of 574 well samples were analyzed for chloride, which is the most of any of the dissolved solids shown. The fewest are for Fe and Mn, which were analyzed only in 1988 and 1989 and have a total of 328 analyses. Because of the varying number of samples, the comparisons are based on percentages.

The standards that are most frequently exceeded are those for the metals Fe and Mn. Fe gives the water a rusty flavor. Mn gives water a somewhat metallic taste, but of more concern is that at a concentration only slightly greater than the standard, it will stain laundered fabrics black or dark brown. Fe is easily removed from most waters by simple settling; Mn is difficult to treat and is most often removed by in-line adsorption on activated charcoal. The standard that is exceeded next most often is Cl, which is the major subject being addressed in the ARWMIS. The only way to remove Cl is to evaporate (distill) the water.

## Regression Relationships

The EC-Cl regressions are summarized in Table 2. All of the regressions appear to be quite useable based on their $R^2$ values (Table 2). However, when predicted values are generated using the regression equations, the results are not very satisfactory. As can be seen from the $b_0$ values shown in the table, all are negative and for the most part relatively large, *i.e.* near 200. Since most of the $b_1$ coefficients are on the order of 0.3, conductivities less than 600 yield negative chloride estimates. At lower conductivities and chloride concentrations, the addition of the standard error to the final estimate yields a much more usable value; at higher chlorides, such an adjustment makes little difference in the final estimate. For estimating purposes this procedure could be used.

Table 2: Parameters of Regressions of Chloride (mg/L) on Specific Conductance (µS/cm) by Cross-Section and Depth Interval

| Data Set | $R^2$ | Std. Err. of Y-Est. | $b_1$ | $b_0$ |
|---|---|---|---|---|
| All Data | 0.981 | 94.1 | 0.310 | -194.3 |
| Cross-section: | | | | |
| Hutchinson | 0.994 | 39.0 | 0.308 | -162.9 |
| Haven | 0.987 | 122.8 | 0.324 | -219.6 |
| Mt. Hope | 0.962 | 94.9 | 0.289 | -176.7 |
| Bentley | 0.908 | 73.1 | 0.221 | -85.2 |
| Maize | 0.986 | 38.3 | 0.318 | -192.5 |
| Depth: | | | | |
| A-Wells | 0.958 | 76.7 | 0.310 | -190.2 |
| B-Wells | 0.990 | 64.6 | 0.331 | -211.9 |
| C-Wells | 0.982 | 119.4 | 0.305 | -196.4 |

The slopes of the regression lines for 4 of the 5 cross-sections are around 3. The $b_1$ value for the Bentley cross-section is nearer to 2 than to 3. The associated $R^2$ values show the same relationship as the $b_1$ values, as would be expected since the 2 are calculated from similar data. The decrease in the $b_1$ values indicates that chloride accounts for a decreasing amount of the variation in the EC. However, the Bentley cross-section has the smallest $b_1$ value, but sits somewhat in the center of the set of cross-sections. Dilution by water lower in chloride is indicated, but the pattern is not entirely consistent with the pattern of ground water flow.

The regression of Cl on Na is also very highly significant. The $r^2$ is 0.93, indicating that 93 % of the variation in Na is reflected in that of Cl. The slope of the regression line is 1.7. If the Na and Cl were completely related the slope would be 1.5. The slope of 1.7 indicates that there is some reduction of Na relative to the Cl concentration, but any loss is relatively small. Na undergoes ion exchange reactions, but like Cl it behaves conservatively for the most part.

## Chloride Data

Attached is a set of plots of all of the chloride data for the major cross-sections broken down by individual well. The sections are arranged from west to east in the general direction of the Arkansas River. Each plot shows the northern end of the cross-section on the left and the south end to the right. The main three layers are shown on each plot.

Figure 1 shows the Cl concentrations in the Hutchinson cross-section wells. The highest Cl concentrations are from wells in the north-central part of the cross-section. The northernmost well (EB228) shows little Cl at any depth. Immediately to the south, well EB229 shows the greatest Cl of any well in the cross-section in the C-well, with Cl decreasing in the B-well and at its lowest in the A-well. Continuing to the south, EB230 shows the greatest Cl in the B-well; the A-well has Cl concentrations nearly the same as the B-well. In both cases the Cl are at approximately the same concentration as the EB229, B-well. The greatest Cl in both EB231 and EB232 decrease with decreasing depth. EB232 is slightly lower in Cl in the C-well and B-well than the more northerly EB231 and much lower in the A-well. EB233, EB234, and EB235 are relatively low in Cl at all depths.

The peak Cl in the Haven cross-section is in the C-well near the center of the cross-section (Figure 2). The highest concentration in the shallow wells is in well 216, which is located immediately adjacent to the Arkansas River. The peak Cl in the B-wells in the cross-section occur near the C-well peak.

Figures 3 through 5 show similar information for the remaining cross-sections. Each section shows a peak in the Cl concentration at the approximate location of the river in the cross-section. In the Mt. Hope section (Figure 3), the peak Cl is in the EB210 C-well; there is a smaller peak in the A- and B-wells also in EB210. In the Bentley cross-section (Figure 4), the peak is also in the C-well (EB205), which is also located adjacent to the river. Smaller peak are present in the shallow (A-wells) at EB203 and EB204. The Cl in the Bentley cross-section appears more complicated than that in the other sections. The Cl in the Maize cross-section is very similar to that in the Mt. Hope cross-section. The peak at all depths is in the well near the river, with the maximum Cl in the C-well.

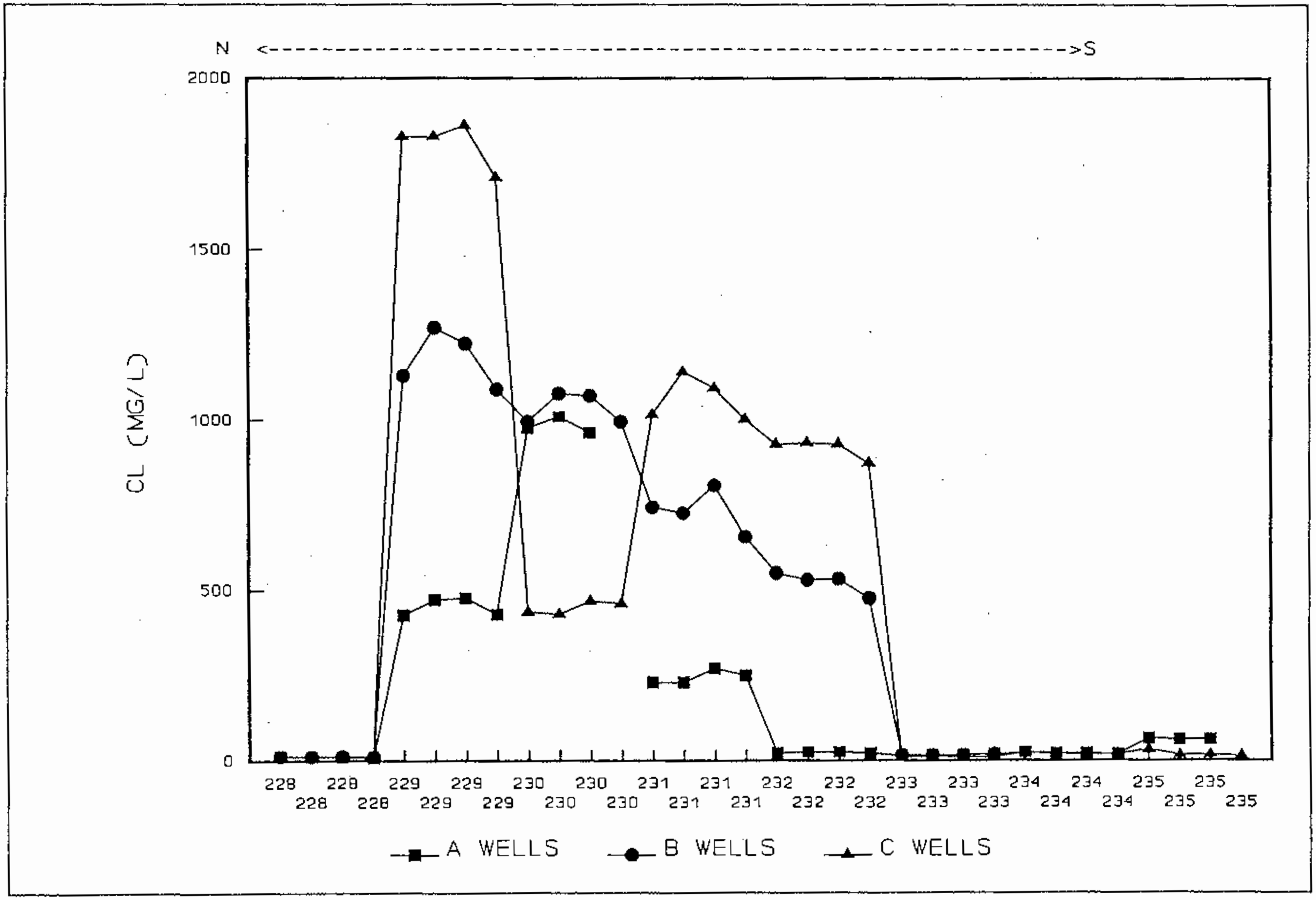



**Figure 1:** Chloride Concentrations by Layer in the Hutchinson Cross-Section Wells

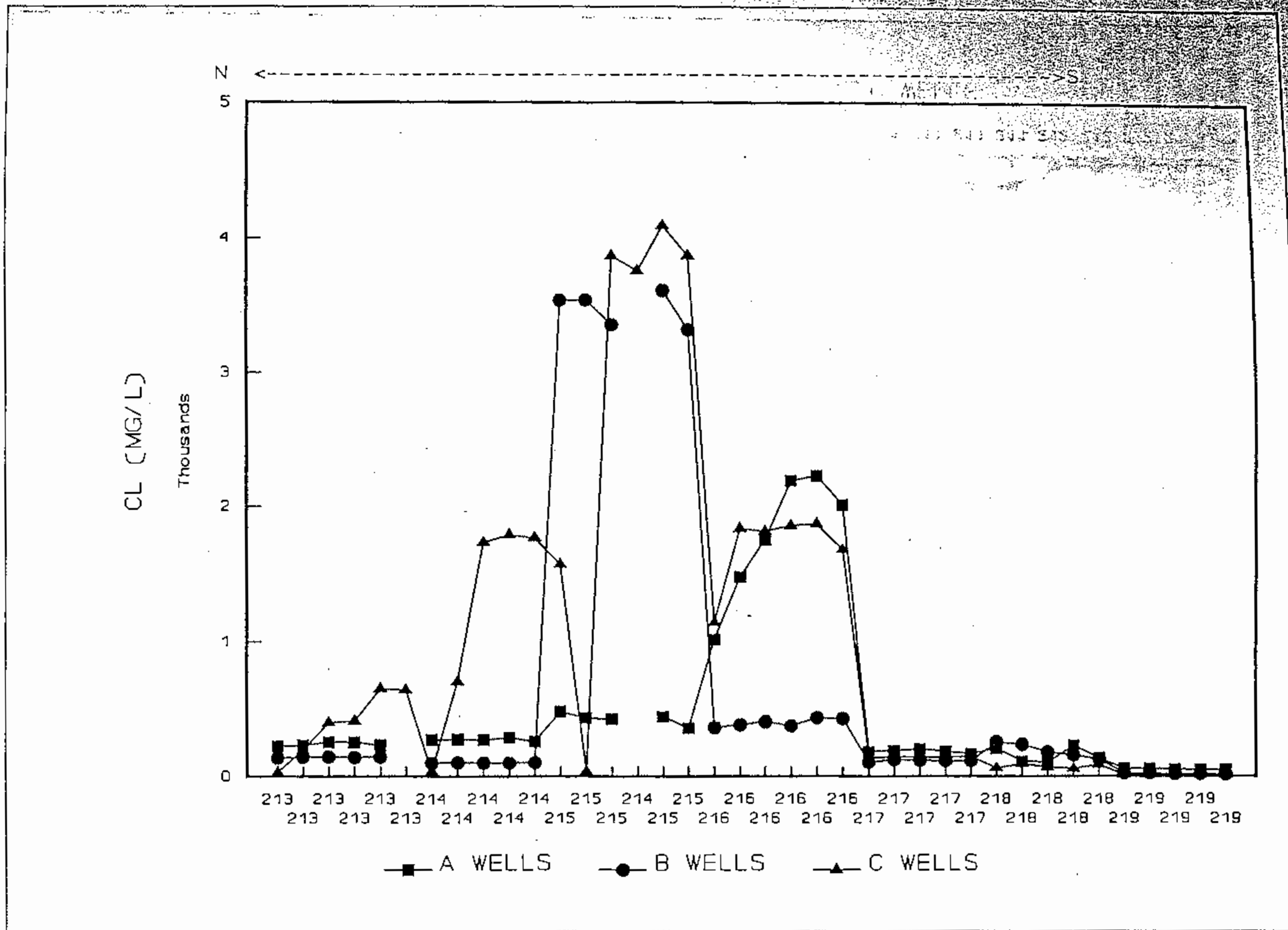



**Figure 2:** Chloride Concentrations by Layer in the Haven Cross-Section Wells

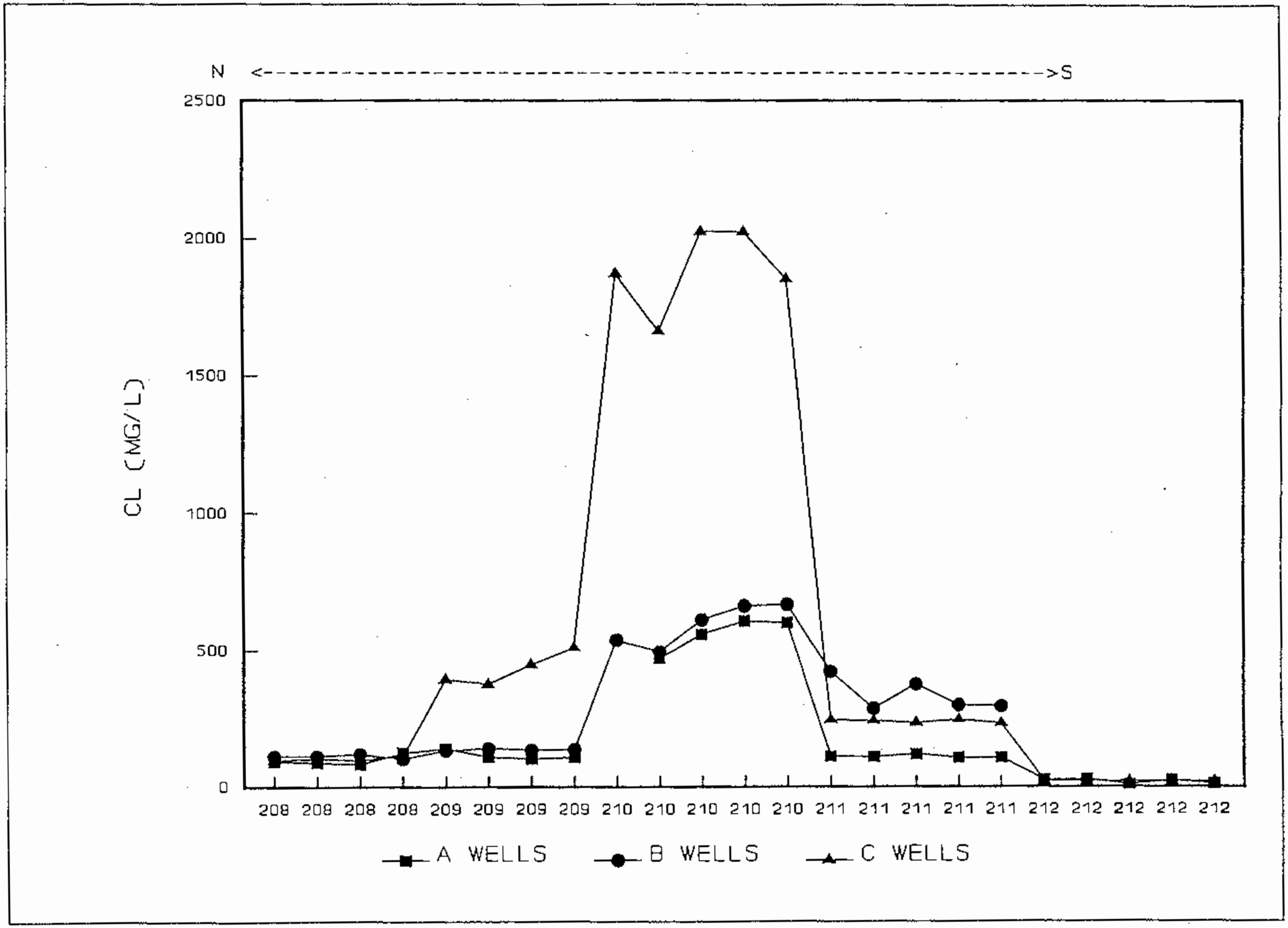



**Figure 3:** Chloride Concentrations by Layer in the Mt. Hope Cross-Section Wells

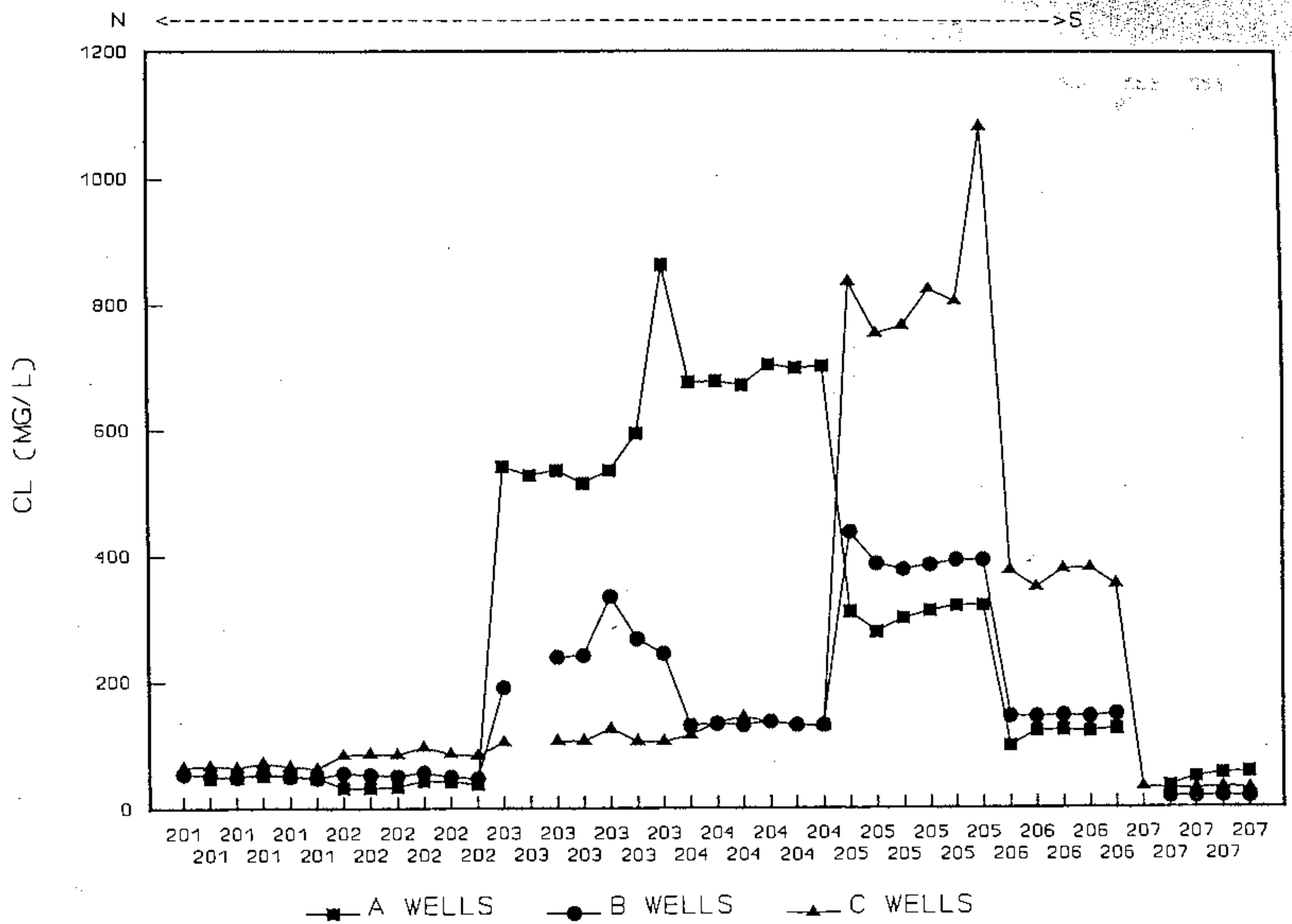



**Figure 4:** Chloride Concentrations by Layer in the Bentley Cross-Section Wells

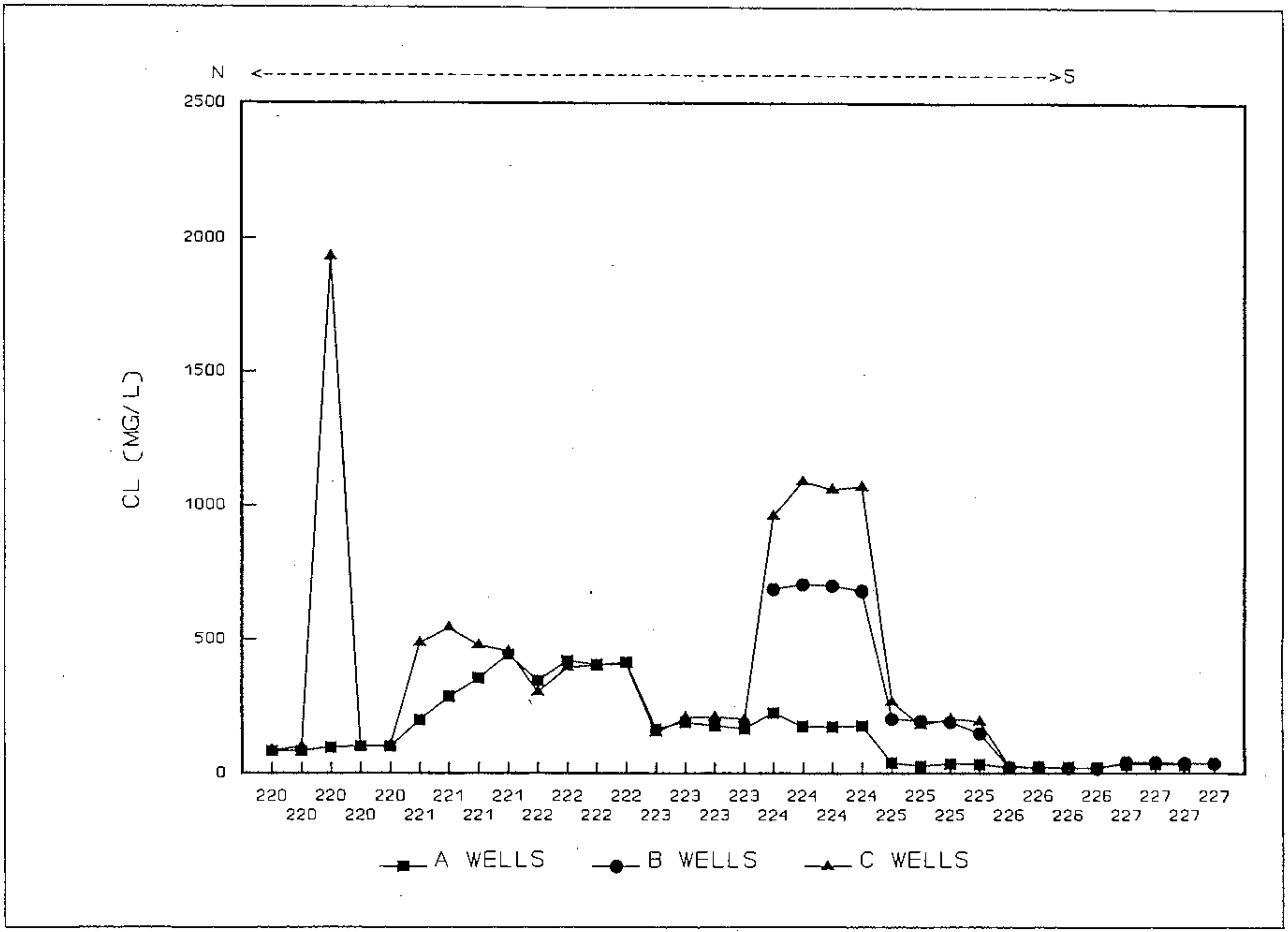



**Figure 5:** Chloride Concentrations by Layer in the Maize Cross-Section Wells

# EXHIBIT K

# Hydrobiological Monitoring Plan

# for the

# Integrated Local Water Supply Project

**Prepared for**

CITY OF WICHITA

**October 2004**

Burns & McDonnell
SINCE 1898

# Hydrobiological Monitoring Plan

for the

# Integrated Local Water Supply Project

Prepared for

CITY OF WICHITA

October 2004

Project Number 34256

Burns & McDonnell SINCE 1898

002010

## TABLE OF CONTENTS

## LIST OF FIGURES

## LIST OF TABLES



## REFERENCES



## APPENDICES

# 1.0 INTRODUCTION

## 1.1 PURPOSE AND NEED

The City of Wichita (City) has committed to developing and implementing a Hydrobiological Monitoring Program (HBMP) as part of the mitigation described in the 2003 Final Environmental Impact Statement (EIS) for the Integrated Local Water Supply Project (ILWSP).

The HBMP will help identify and describe a process whereby the possible environmental impacts to existing natural resources resulting from implementation and operation of the ILWSP can be monitored. The HBMP has two basic goals:

- Establish baseline environmental conditions prior to starting construction and operation of the ILWSP
- Evaluate if flows in the Little Arkansas or Arkansas rivers fluctuate to the extent that water quality parameters, or flora, fauna or threatened or endangered species communities, habitat, or populations are either adversely or beneficially impacted

The HBMP is designed to be a flexible plan, one that can be revised as necessary to address changing environmental conditions and the beneficial or adverse impacts that may be a result of the construction or operation of the ILWSP. Much of the information contained within this HBMP has been obtained directly or derived from the Final EIS that was generated for the ILWSP in 2003, or from the periodic HBMP development meetings with participating agencies in 2003 and 2004.

Many of the state and federal agencies that either have been or are currently conducting programs that collect biological or chemical data in the project area have been contacted. The objectives are to supplement the existing available data set and analyses, to avoid unnecessary duplication, and to concentrate, at least initially, on resources that are believed to be most likely impacted by the project. These programs and the data being collected and analyzed are described in Section 6.0 of the HBMP. By being aware of what information or data is or will be available, the City is able to design a HBMP that directly focuses on specific biological or physical parameters that may be affected by the ILWSP.

As mentioned above, the environmental impacts that may be associated with ILWSP construction and operation may not always be adverse. For example, the hydrologic model used in the ILWSP to predict stream flow impacts indicated that the water surface elevations in Cheney Reservoir and downstream flow volumes in the North Fork of the Ninnescah River would not be reduced with the Project in place. In fact, water surface elevations in the reservoir may be slightly higher, thereby decreasing surface water fluctuations that are currently observed and expected to occur in the future. As indicated in the City's EIS, no adverse impacts are predicted for the reservoir or in the North Fork of the Ninnescah River; therefore, no monitoring is proposed as part of the HBMP.

The HBMP is an environmental monitoring program that is being developed in cooperation with several federal and state agencies. The agencies currently involved with developing and implementing the HBMP for the ILWSP are:

- City of Wichita
- Kansas Department of Wildlife and Parks (KDWP)
- U.S. Fish and Wildlife Service (FWS)
- U.S. Bureau of Reclamation (BOR)
- U.S. Geological Survey (USGS)

Other agencies, groups or individuals may be invited or may request to participate in future HBMP refinement, the analysis of data, and the development of recommendations for future activities as conditions warrant and interest is expressed.

## 1.2 PLAN OBJECTIVES

The objectives of the HBMP are as follows:

- Document the existing environmental conditions in the Little Arkansas and Arkansas rivers
- Detect if changes in the existing environmental conditions occur
- Determine if any detected environmental changes are caused by the ILWSP or other unrelated causes
- Provide a scientifically defensible means to evaluate whether the ILWSP is causing or significantly contributing to the observed beneficial or adverse environmental changes
- Recommend management actions or operational changes to mitigate adverse or enhance beneficial environmental impacts if they occur or are expected to occur

## 1.3 BACKGROUND

Even though no lead federal agency was identified, the City proactively developed and completed an EIS for the ILWSP in 2003 that followed the National Environmental Policy Act (NEPA) process. This EIS discloses the environmental impacts that could occur if the City develops and expands multiple local water sources to meet the increased water demands that are expected to occur within the greater metropolitan area of Wichita, Kansas by the year 2050.

The City carefully considered the public and agency comments received during the scoping process, comments received from review of the draft EIS and the NEPA process, and regulatory requirements to determine the range of water supply alternatives to be addressed in the final EIS. The alternatives considered met the following two goals:

- Provide water supply plans capable of supplying the year 2050 projected average and maximum daily demands of 112 and 223 million gallons per day (MGD), respectively, and
- Help protect the Equus Beds aquifer's water quality

With respect to the first goal, the City identified 27 water supply sources or alternatives that were evaluated using conceptual design and operating protocols, estimated project construction and operation costs, and water quality parameters. These potential alternatives were screened using the following criteria: water supply capability, water quality, future availability, legal issues, policy and political issues, planning horizons, environmental issues, and costs. Ultimately, three alternatives were identified as best meeting the first goal: the Milford Reservoir Plan, the ILWSP with 250 MGD Diversion Option, and the ILWSP with 150 MGD Diversion Option.

These three alternatives were then evaluated to meet the second goal – the capability to protect the Equus Beds aquifer's water quality. The Milford Reservoir Plan alternative does not provide any protection to the aquifer, and was eliminated from further consideration. The remaining two alternatives were compared and refined based on more detailed engineering studies and a demonstration project. Each of the two remaining alternatives satisfied the second goal of providing protection for the Equus Beds aquifer water quality. Refinements ultimately resulted in a reduction in the water quantity each alternative would be required to provide. The result was that the two ILWSP alternatives were renamed – the ILWSP 150 MGD Diversion and the ILWSP 100 MGD Diversion. These two alternatives and the No-Action alternative are considered in detail in the EIS and are summarized below.

## No-Action Alternative

Under this alternative, the City would not construct nor provide an expanded water supply to meet projected population growth needs of the Wichita metropolitan area. As with the two water supply alternatives, water conservation is included as a component of the No-Action alternative due to public and agency input received during project scoping process. The No-Action alternative reduces the net water need through self-imposed growth limitations. The City would continue water service to existing retail and wholesale customers, but would not serve any additional wholesale customers. In addition, the City would not provide a water supply for projected population increases outside of their existing service area.

## ILWSP 150 MGD Diversion

The ILWSP 150 MGD Diversion alternative would capture water from the Little Arkansas River using a surface water intake and induced filtration wells adjacent to the river. In addition to the surface water intake and induced infiltration wells, facilities to transfer and recharge the captured water to the Equus Beds aquifer, and to recover the stored water (ASR system) would be included in the plan. A pre-sedimentation plant is proposed to treat surface water before recharging into the aquifer or piping to the City's water treatment plants. As with the No-Action alternative, water conservation was an integral part of the ILWSP 150 MGD Diversion alternative. Three options for capturing 150 MGD of water were considered; each option was considered with and without diverting 60 MGD of treated surface water to the City water treatment facilities. The three options were:

- 60/90 ASR Option – Capture of 60 MGD of induced infiltration water for recharge and 90 MGD of surface water for treatment and recharge with an additional option to capture, pre-treat, and convey 60 MGD of surface water direct to the City's water treatment facilities
- 75/75 ASR Option – Capture of 75 MGD of induced infiltration water for recharge and 75 MGD of surface water for treatment and recharge with additional option to capture, pre-treat, and convey 60 MGD of surface water direct to the City's water treatment facilities, and
- 100/50 ASR Option – Capture of 100 MGD of induced infiltration water for recharge and 50 MGD of surface water for treatment and recharge with additional option to capture, pre-treat, and convey 60 MGD of surface water direct to the City's water treatment facilities

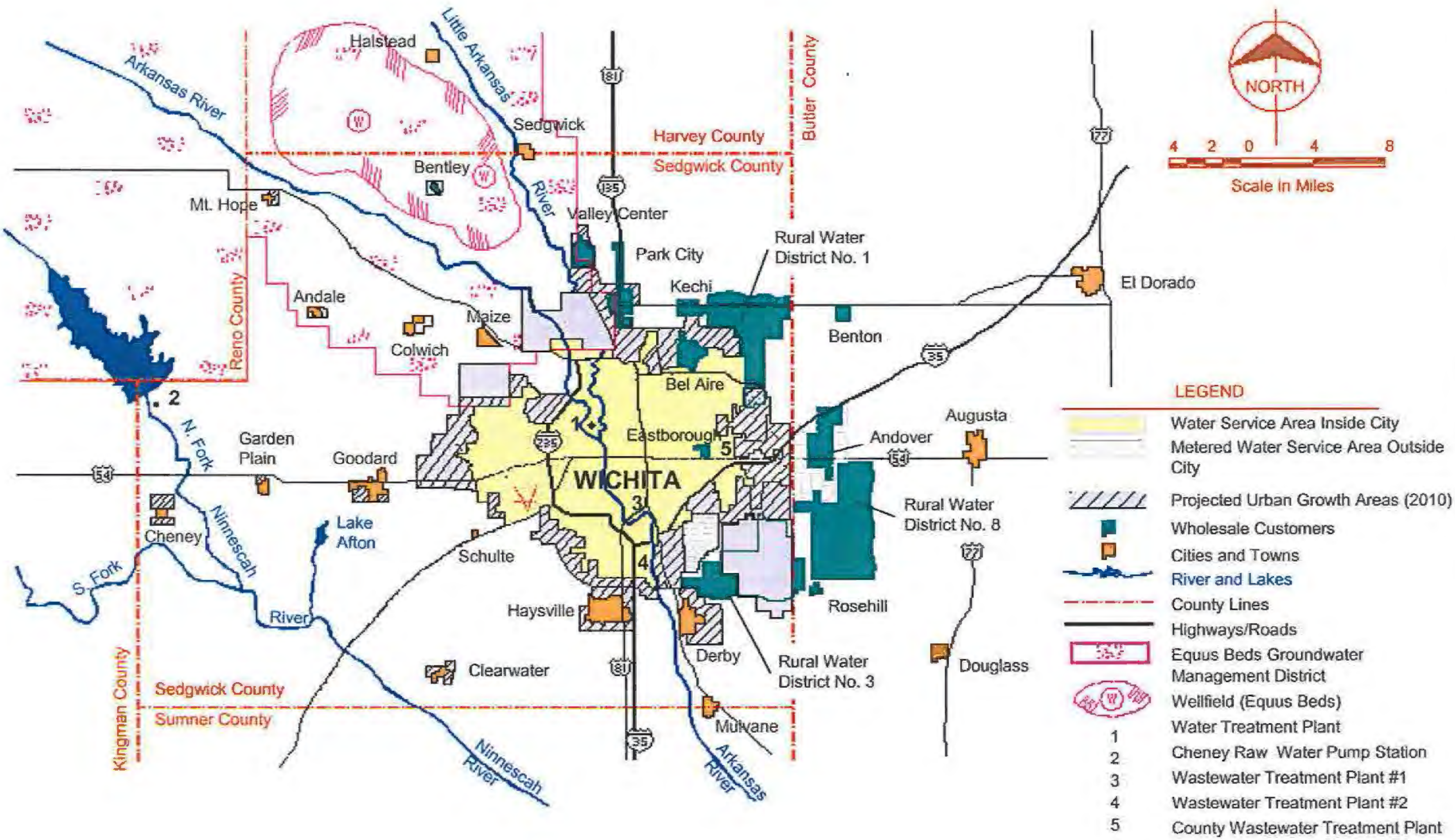
## ILWSP 100 MGD Diversion

The ILWSP 100 MGD Diversion alternative would capture 100 MGD of water from the Little Arkansas River using a surface water intake and induced infiltration wells adjacent to the river. As with the preceding alternative, project facilities would include a surface water intake, induced infiltration wells, facilities to transfer and recharge the captured water to the aquifer, and an ASR system. In addition, a pre-sedimentation plant is proposed to treat surface water before recharging into the aquifer or piping to the City's water treatment facilities. Water conservation was again an integral part of this alternative. Once again, three options for capturing 100 MGD of water were considered; each option was considered with and without diverting 60 MGD of treated surface water to the City water treatment facilities. The three options were:

- 60/40 ASR Option – Capture of 60 MGD of induced infiltration water for recharge and 40 MGD of surface water for treatment and recharge with additional option to capture, pre-treat and convey 60 MGD direct to the City water treatment facilities
- 75/25 ASR Option – Capture of 75 MGD of induced infiltration water for recharge and 25 MGD of surface water for treatment and recharge with additional option to capture, pre-treat and convey 60 MGD direct to the City water treatment facilities, and
- 100/0 ASR Option – Capture of 100 MGD of induced infiltration water for recharge and no surface water; however, there is an additional option to capture, pre-treat and convey 60 MGD of surface water direct to the City water treatment facilities; the pre-sedimentation plant with this option could be located adjacent to the City's Central Water Treatment Plant in Wichita

Following detailed alternative screening and comparison, the City selected the ILWSP 100 MGD alternative with the ASR 75/25 option as their preferred alternative. The ILWSP Project location map, as depicted in the 2003 EIS, is shown in Figure 1-1.

## Figure 1–1 ILWSP Project Location Map




Note: Projected growth areas from information provided by the Wichita-Sedgwick County Metropolitan Area Planning Department
Source: EIS ILWSP for the City of Wichita 2003

# 2.0 EVALUATION OF ECOLOGICAL IMPACTS

The information obtained from implementing the HBMP will be used by the City of Wichita and federal and state agencies to evaluate if adverse or beneficial impacts have occurred to the environment as a result of the ILWSP implementation and operation. During the alternative comparison process and in the EIS, impacts were evaluated to a wide variety of natural resources (land, water, air, noise, wetlands, vegetation, wildlife, threatened or endangered species, socioeconomics, recreation, cultural resources, and hazardous wastes). Except for water quality, wetlands, and threatened or endangered species in and on the Little Arkansas and Arkansas rivers, implementation and operation of the ILWSP is not anticipated to significantly impact the natural environment.

As mentioned in Section 1.3 above, the ILWSP 100 MGD Diversion alternative with the 75/25 ASR Option is the City's environmentally preferred alternative. NEPA defines the environmentally preferable alternative as "*. . . the alternative that will promote the national environmental policy as expressed in NEPA. Ordinarily, this means the alternative that causes the least damage to the biological and physical environment; it also means the alternative which best protects, preserves, and enhances historic, cultural, and natural resources.*" It is implicit in NEPA that the environmentally preferable alternative must be reasonable and feasible to implement.

Both of the goals established for the project will be met – providing for increased water supply needs for the Wichita metropolitan area through the year 2050 and protection of the Equus Beds aquifer's water quality. If No-Action were taken, the existing water supply sources would be unable to meet the maximum daily needs for the expected future growth of metropolitan Wichita. Without additional capacity, the City would be required to limit new customers as much as possible by not providing water to customers outside its present service area boundaries. This action would limit, but not completely stop, growth in demand because the Department is required by statute to serve new customers within its service area boundaries. Eventually, the City would not be able to maintain system pressure during maximum use periods.

According to the 2003 EIS, with the ILWSP in place, the water levels and water stored in Cheney Reservoir will be slightly increased, compared to the No-Action alternative, maintaining and slightly improving recreation opportunities, fish habitat, and water quality. A slight increase in the flow regime and improvement in water quality is expected in the North Fork of the Ninnescah River below Cheney Reservoir, perhaps resulting in a slight improvement in fish habitat in the North Fork.

In the Little Arkansas River above Wichita, low or base flow will increase over time as aquifer recharge occurs; high flows in the river will be unchanged. With the exception of May and June, median flows in the river are expected to increase and no change in water quality is expected. Below the Local Well Field within the City, flow in the Little Arkansas River in the last mile above the confluence with the Arkansas River is expected to decrease when the ILWSP is operating. As stated in the 2003 EIS, the total dissolved solids, suspended sediment, and chloride concentration in the Arkansas River is expected to increase by six, four, and seven percent respectively below the confluence with the Little Arkansas River. A slight decrease in the Arkansas River flow is expected in June when the ILWSP is likely to be operating.

## 2.1 WATER LEVELS AND WATER QUALITY

Equus Beds aquifer groundwater levels within the City's well field area are expected to be higher and recover faster following dry periods. Groundwater levels along the Little Arkansas River will be lower in the immediate vicinity of each induced infiltration well during pumping periods; recovery will occur quickly once pumping ceases. Similar reductions in groundwater levels and quick recovery will occur in the Arkansas River alluvium when the Bentley Reserve Well Field is operating. Water quality in the Equus Beds aquifer will improve as infiltration and salinity content rates decrease with rising groundwater levels in the aquifer due to ILWSP operation. If no action was taken by the

City, water levels in the aquifer would decrease, with little hopes of recovering. Also, with no action, the water quality in the aquifer would become worse over time as a result of chloride migration, thus increasing salinity.

## 2.2 NATURAL RESOURCES

Wetland disturbance resulting from the phased construction of the ILWSP will be avoided and minimized. When avoidance is not possible, permits will be obtained from the U.S. Army Corps of Engineers, Kansas City District. Approximately 266 acres of vegetation will be permanently lost as project facilities are constructed. Of this amount, about 75 acres of row crops, hay fields, and pasture would also be lost. The agricultural use of 65 acres of prime farmland would be lost for the life of the project. Wildlife species may be temporarily displaced during construction and a slight decrease in fishery habitat in the Little Arkansas River may occur due to water diversions. Threatened and endangered species or other species of special concern could be temporarily affected by construction if they are in the area. Wildlife would be displaced at the pre-sedimentation plant site for the life of the project. Fish habitat in the Arkansas River may be slightly decreased. No known cultural resource properties will be affected; unknown sites that are discovered later will be avoided. Surveys to identify, avoid, and mitigate cultural resource properties will occur as phased project facility construction occurs; coordination with the Kansas State Historic Preservation Office to obtain needed clearances will be maintained.

## 2.3 SOCIOECONOMICS

Temporary increases in employment will be expected during individual construction phases for the ILWSP. The current trend of local economic expansion in the City and region will be facilitated with a dependable water supply; with the ILWSP in place, projected increases in population growth and new housing starts are expected to continue. A temporary increase in traffic density, noise and dust levels in rural areas of Sedgwick and Harvey counties would be expected during construction. Development of the ILWSP project facilities will result in an increase in the number of industrial structures visibly present in a rural landscape for the life of the project and in the amount of night lighting. A temporary increase in traffic density on urban streets in the Local Well Field vicinity within the City would also be expected. Vehicular access to residences and businesses would be temporarily disrupted in the immediate vicinity of the pipeline construction for a short period of time.

# 3.0 AGENCY REVIEW AND COORDINATION

For purposes of the HBMP, the City and participating state and federal agencies attended periodic meetings to discuss and identify the following:

- specific beneficial or adverse environmental impacts that could be expected to occur
- specific natural resources that should be evaluated and how
- environmental and natural resource data that is currently available and being collected
- environmental data that should be collected
- appropriate methods for data collection
- analysis and evaluation methods to be used in data evaluation
- necessary coordination, communication, and reporting requirements

The cooperating federal and state agencies played an important role in assisting the City in developing the 2003 EIS and the HBMP, and will continue to play an important role in reviewing, altering, and implementing the HBMP as the ILWSP continues to be implemented and operation begins.

City and agency review and coordination efforts should continue after the HBMP has been implemented. HBMP participants should meet following review of a draft annual report to discuss current assessments and any need to revise any portion of the HBMP. This annual meeting should be tentatively scheduled to occur in March of each year, following the analysis of the previous year's data and distribution of the draft HBMP report.

## 4.0 REVISIONS TO THE HYDROBIOLOGICAL MONITORING PLAN

The City may revise the HBMP any time during the implementation and operation of the ILWSP as long as there is reasonable technical evidence that revision of the HBMP is warranted. These revisions may be necessary, for example, if data collection locations, the timing of collections, or the specific resources being monitored are not providing the ecological information necessary to make reasonable determinations regarding impacts that may be caused by the ILWSP. The HBMP may also be revised when the City and the cooperating agencies conclude that specific resources that are not being monitored are impacted. Processes within the HBMP may also be revised to provide for more efficient coordination efforts between the City and cooperating federal and state agencies. All proposed revisions or other modifications to the HBMP will be documented by the City in writing, and maintained in HBMP files.

For the assessment of environmental, natural resource, or ecological relationships relative to possible beneficial or adverse project impacts, the City may need to evaluate available information from other sources. The City may conduct these additional assessments at its discretion at any time. The cooperating agencies may request in writing that the City consider other available sources of information or data in the HBMP analysis of relationships or evaluation of impacts.

# 5.0 REPORT REQUIREMENTS

Reports will be submitted by the City to the cooperating agencies typically in five-year cycles as described in the following paragraphs. For reporting purposes, the data collection year extends from January 1 through December 31. Annual reports for years 1, 2 and 4 will generally be summary reports that basically document the data collected during the 12-month period only; these reports will not be submitted to the cooperating agencies as drafts. Reports for years 3 and 5 will contain much more analysis and evaluation of the data collected during the previous 3- and 5-year periods; these reports will be submitted to the cooperating agencies as drafts for review and comment. Please see additional discussion below for more detail about each report type.

Reports for years 1, 2 and 4 will be provided to the cooperating agencies within 90 days (or March 31) of the close of the data collection period. For the 3- and 5-year reports, draft reports will be provided to the cooperating agencies within 120 days (or April 30) of the conclusion of the data collection period. The cooperating agencies will have 45 days to provide written review comments to the City; the City will have 60 days to incorporate comments, make revisions, and distribute final reports. Each report will be distributed in hard copy and on digital format (CD). Each successive annual report will be added to a single CD, so that one CD contains 5 separate reports at the end of the 5-year reporting period. It is also recommended to make the final reports available on the City and/or participating agency website.

## 5.1 YEAR ONE REPORT

The Year One Report will be prepared by the City and provided to the cooperating agencies within 90 days (March 31) following the end of the data collection year (December 31). The Year One Report will contain all of the raw data collected during that year. The report will be mostly a tabular presentation with text limited to technical explanation of important observations, problems encountered, or other description important to the HBMP.

## 5.2 YEAR TWO REPORT

The Year Two Report will be a data report similar to the Year One Report. The first two years of data collection will be presented on a CD.

## 5.3 YEAR THREE REPORT

Following the third year of data collection, the City will prepare an expanded, mid-term data report that contains the raw data for the third year. The report will contain basic figures, tables and summaries of data for the pervious three years of data collection. Interpretative text in the Year Three Report will include a description of monitoring process and progress, any observed changes in parameters being monitored, summaries for the three years of data collection, and recommendations for either continuance of monitoring without change and/or discussions of modifications to address observed changes. At a minimum, the Year Three Report should specifically include in a preliminary fashion the following:

- analysis of current conditions
- comparison of current conditions to baseline conditions
- data collection methodologies, locations, and frequencies
- professional opinion of project induced impacts, if any exist, including beneficial or adverse impacts
- recommendations for the HBMP regarding data collection, report requirements, agency involvement, etc.

## 5.4 YEAR FOUR REPORT

The Year Four Report will be similar to the reports for years one and two.

## 5.5 YEAR FIVE REPORT

The Year Five Report will be a comprehensive, interpretative report that analyzes all continuing data collected to that point of time in the HBMP. All data including that of the preceding five year period will be included in the Year Five Report. This report will examine the long-term trends for specific project resources and their relationship to beneficial or adverse terrestrial or aquatic impacts. The report will present analyses that document the status of monitored parameters and determine if the health and productivity of the project area resources are showing signs of improvement or stress due to the construction and operation of the ILWSP. For example, changes in freshwater flows or water elevations will be evaluated to determine if any impact to the ecological resources is observable.

The design of the HBMP will be reviewed and re-evaluated in each Year Five Report. Modifications to the HBMP can be recommended in this report, or at an interim time if approved by the City and cooperating agencies. The Year Five Reports will be the primary documents for evaluating the presence or absence of beneficial or adverse ecological impacts, the significance of such impacts, and the environmental considerations for continuing construction of additional project phases or continued project operation. The effectiveness of the specific operational criteria relative to the initiation or cessation of project operations or the mixing of surface and groundwater to maintain water quality and the original project goals will be evaluated.

# 6.0 DATA COLLECTION

The HBMP will be used as a repository for the assimilation of data from historic, current and future data collection programs in the Project area. This data will be used to satisfy environmental, natural resource, and ecological objectives identified in Sections 1.0 and 3.0. The City and the cooperating agencies may need to perform additional studies of limited duration to evaluate specific relationships that would be used to evaluate certain ecological parameters or revise the design or operation of the ILWSP. In this way, both the City and the cooperating agencies would be involved in the design and operation of the ILWSP, the collection and interpretation of limited duration data and studies within the HBMP framework, and in scientific peer review.

The data that has been, is or will be collected for, used in, or required for the HBMP is described in the following sections and paragraphs. The data analyses that the City is expected to perform are also described. Lastly, cooperating agencies can request reasonable additional analyses to be performed as a result of the draft report review process of the more detailed reports described in Section 5.0.

## 6.1 AVAILABLE HYDROLOGICAL AND BIOLOGICAL DATA

Information and data used in the HBMP report described in Section 5.0 will be collected from a variety of sources. Some of these sources will include ongoing and future monitoring programs by the City and various state and federal agencies such as the USGS, KDHE, and the Groundwater Management District No. 2 (GMD2) to address various regulatory responsibilities. Each of these entities has specific monitoring programs in place that are responsible for evaluating groundwater and/or surface water systems, using both hydrological and biological components. Some of these programs have been in operation for several years and are anticipated to remain so indefinitely. Additional data may be available from the FWS and KDWP for purposes of the HBMP; however, much of the data is limited as it is typically collected for short-term special projects when funding is available. Maps showing existing stream and groundwater data collection and monitoring locations for the various agencies and the City are presented in Appendices A and B.

As an example, the City is currently conducting a Bio-Monitoring program administered by the Water and Sewer Department, Sewage Treatment Division. As part of the program, a water quality specialist with the City, has been extensively studying and sampling fish and benthic macro-invertebrates, where the Arkansas River is the primary concern. Physical habitat studies, a new component of the monitoring program, were added in the year 2000 for tributaries to the Arkansas River within the City of Wichita. Chemical monitoring has been an on-going program at several sites on many tributaries and the main stem of the Arkansas River. Limited data has been collected along the Little Arkansas River.

## 6.1.1 Groundwater Elevation Data

### 6.1.1.1 Available USGS Groundwater Elevation Data

The USGS has been cooperatively working with the City and GMD2 to monitor wells in the project area for several years. Data has been collected and analyzed to determine water storage capacities in the Equus Beds for the ILWSP. Some of the City and GMD2 groundwater elevation records date back to the 1940s. A map depicting wells that are currently being monitored in the ILWSP area is located in Appendix B. Groundwater elevation change data for the project area is available from the USGS and the GMD2. Much of this data can also be retrieved at the following website: http://ks.water.usgs.gov/Kansas/studies/equus/equus_gwstorage.html.

## 6.1.2 Stream Flow Data

### 6.1.2.1 Available USGS Stream Flow Monitoring Data

The USGS has operated and is currently operating stream gaging stations at several locations in the Project area. Many of these gaging stations were of vital importance in the 2003 EIS and the associated hydrologic modeling, and will likely continue to be important for the HBMP. These recommended gaging stations are listed in Table 6-1 and were derived from the gaging station list contained in the EIS. Per HBMP discussions with the USGS, stations 07143665 Little Arkansas River at Alta Mills, Kansas and 07144200 Little Arkansas River at Valley Center, Kansas should be maintained, as water quality consistently varies between the two stations. A summary of available USGS stream flow and water quality data from 1973 to 2003 has been compiled by HDR Engineering, Inc.; a compact disk (CD) containing this information is included in the HBMP in Appendix E. At the present time, the USGS plans to continue stream flow and water quality data collection at these stations, and will make the data available to the City for use in the HBMP.

**Table 6-1. Recommended USGS Stream Gages**

| Station Number & Name | Location (Latitude/ Longitude) | Drainage Area (miles$^2$) | Period of Record |
|---|---|---|---|
| 07143330<br>Arkansas R near Hutchinson, KS | 37° 56' 47"<br>97° 45' 29" | 38,910 | 10/01/59–present |
| 07143375<br>Arkansas R near Maize, KS | 37° 46' 53"<br>97° 23' 33" | 39,110 | 03/01/87–present |
| 07143665<br>Little Arkansas R at Alta Mills, KS | 38° 06' 44"<br>97° 35' 30" | 736 | 06/06/73–present |
| 07143672<br>Little Arkansas R at Halstead, KS* | 38° 01' 43"<br>97° 32' 25" | 759 | 05/95 - present |
| 07144100<br>Little Arkansas R near Sedgwick, KS* | 37° 52' 59"<br>97° 25' 27" | 1,239 | 10/01/93–present |
| 07144200<br>Little Arkansas R at Valley Center, KS | 37° 49' 56"<br>97° 23' 16" | 1,327 | 06/10/22–present |
| 07144550<br>Arkansas R at Derby, KS | 37° 32' 34"<br>97° 16' 31" | 40,830 | 10/01/68–present |
| 07144300<br>Arkansas R at Wichita, KS | 37° 38' 41"<br>97° 20' 06" | 40,490 | 10/01/34–present |

Source: EIS for the ILWSP Wichita, KS 2003 and USGS website 2003 (http://water.usgs.gov).
* These sites are only monitored for water quality.

### 6.1.3 Stream Quality Data

#### 6.1.3.1 Available KDHE Stream Chemistry Data

Beginning in 1990, bimonthly samples were taken at all of KDHE's routine permanent (every year) and rotational (every fourth year) stream chemistry monitoring stations. The parameters that are sampled include a wide spectrum of physical, inorganic, organic (every quarter) and bacteriological water quality constituents. The physiochemical parameters that are monitored are listed in Table 6-2, as provided by KDHE in January 2004. Per KDHE, the monitoring schedule for all routine stations is fixed and scheduled one year in advance of the sampling event.

The ambient stream chemistry data is tentatively available two months following sampling and is electronically available in spreadsheet or database formats. The data is recorded with remark codes, where the "<" value is the Method Reporting Limit (MRL). The MRL is the "less than" value reported when a specific analyte either is not detected or is detected at a concentration less than the MRL. Per KDHE, all of the monitoring stations included in Table 6-3 will be monitored on a bimonthly basis for the foreseeable future.

**Table 6-2. KDHE Stream Chemistry Program Monitored Physiochemical Parameters**

| Routine Inorganic Parameters | Routine Organic Parameters |
|---|---|
| Alkalinity, total (as CaCO3) | 2,4-D as acid (phenoxychlorine herbicide) |
| Aluminum, total recoverable | 2,4, 5-T as acid (phenoxychlorine herbicide) |
| Ammonia, total (as N) | 2,4,5-TP as acid - Silvex (phenoxypropionic herbicide) |
| Antimony, total recoverable | Acetochlor (chloroacetanilide herbicide) |
| Arsenic, total recoverable | Alachlor (chloroacetanilide herbicide) |
| Barium, total recoverable | Aldrin (cyclodiene insecticide) |
| Beryllium, total recoverable | Atrazine (chlorotriazine herbicide) |
| Biochemical oxygen demand (Ended Y2000) | Butachlor (chloracetanilide herbicide) |
| Boron, total recoverable | Carbofuron – Furadan (cabamate insecticide) |
| Bromide | Chlordane (cyclodiene insecticide) |
| Cadmium, total recoverable | Cyanazine - Bladex (chlorotriazine herbicide) |
| Calcium, total recoverable | DCPA - Dacthal (phthalic acid herbicide) |
| Chloride | p,p'-DDD (organochlorine insecticide) |
| Chromium, total recoverable | p,p'-DDE (organochlorine insecticide) |
| Cobalt, total recoverable | p,p'-DDT (organochlorine insecticide) |
| Copper, total recoverable | Dieldrin (cyclodiene insecticide) |
| Dissolved oxygen | Endosulfan I (organochlorine acaricide, cyclodiene insecticide) |
| Fluoride | Endosulfan II (organochlorine acaricide, cyclodiene insecticide) |
| Hardness, total (as CaCO3) | Endosulfan Sulfate (organochlorine acaricide, cyclodiene insecticide) |
| Iron, total recoverable | Endrin (cyclodiene insecticide) |
| Kjeldahl nitrogen, total (Began Y2000) | alpha-BHC isomer (organochlorine acaraicide, insecticide, rodenticide) |
| Lead, total recoverable | beta-BHC isomer (organochlorine acaraicide, |

| Routine Inorganic Parameters | Routine Organic Parameters |
|---|---|
| | insecticide, rodenticide) |
| Magnesium, total recoverable | delta-BHC isomer (organochlorine acaraicide, insecticide, rodenticide) |
| Manganese, total recoverable | gamma-BHC- Lindane (organochlorine acaraicide, insecticide, rodent) |
| Mercury, total | Heptachlor (cyclodiene insecticide) |
| Molybdenum, total recoverable | Heptachlor epoxide - oxidation prod of heptachlor (cyclodiene insect) |
| Nickel, total recoverable | Hexachlorobenzene (aromatic fungicide) |
| Nitrate (as N) (Began Y1968-1977) (1995-current) | Hexachlorocyclopentadiene |
| Nitrite (as N) (Began Y1995) | Methoxychlor (organochlorine insecticide) |
| Nitrate-Nitrite (as N) (June 1977 through 1994) | Metolachlor - Dual (chloroacetanilide herbicide) |
| pH (field) | Metribuzin - Sencor (triazinone herbicide) |
| Phosphate, ortho- (as P) | PCB-1016 Polychlorinated Biphenyls (containing 41.5% chlorine) |
| Phosphorus, total (as P) | PCB-1221 Polychlorinated Biphenyls (containing 21% chlorine) |
| Potassium, total recoverable | PCB-1232 Polychlorinated Biphenyls (containing 32% chlorine) |
| Selenium, total recoverable | PCB-1242 Polychlorinated Biphenyls (containing 42% chlorine) |
| Silica, total recoverable (as SiO2) | PCB-1248 Polychlorinated Biphenyls (containing 48% chlorine) |
| Silver, total recoverable | PCB-1254 Polychlorinated Biphenyls (containing 54% chlorine) |
| Sodium, total recoverable | PCB-1260 Polychlorinated Biphenyls (containing 60% chlorine) |
| Specific conductance | Picloram - Tordon (picolinic acid herbicide) |
| Sulfate | Propachlor – Ramrod (chloracetanilide herbicide) |
| Strontium, total recoverable (Began Y2002) | Propazine - Milogard (chloracetanilide herbicide) |
| Thallium, total recoverable | Simazine (chlorotriazine herbicide) |
| Total dissolved solids | Toxaphene (organochlorine acaricide,insecticide) |
| Total organic carbon (Began Nov.Y2000) | |
| Total suspended solids | **Non-Routine Reported Organic Parameters** |
| Turbidity | Diazinon (organophosphate insecticide) |
| Vanadium, total recoverable | Deethylatrazine (chlorotriazine herbicide) atrazine metabolite |
| Zinc, total recoverable | Deisopropylatrazine (chlorotriazine herbicide) atrazine metabolite |
| Temperature (field) | Prometon - Pramitol (triazine herbicide) |
| | Dursban – Chlorpyrifos |
| **Routine Microbiological Parameters** | |
| Fecal coliform bacteria (Ended Y2003) | |
| Fecal streptococcus bacteria (Ended Y1999) | |
| E. Coli (Began July 2003) | |

Source: KDHE Correspondence January 2004

KDHE's ambient stream chemistry monitoring program has a quality assurance management plan that defines the agency's standard operating procedures for the collection, preservation, transport and analysis of environmental samples. This plan also provides information regarding water quality monitoring and assessment of the surface waters in the State of Kansas. This document can be found at the KDHE website, http://www.kdhe.state.ks.us/environment/qmp_2000/download/SCMP_QAMP.pdf.

**Table 6-3 KDHE Stream Chemistry Sampling Locations**

| Site Number | General Location/Name | Latitude/Longitude | Period of Record |
|---|---|---|---|
| SC281 | Arkansas R at Derby | NA | Active – 1973 |
| SC524 | Arkansas R near Yoder | 37.98468<br>97.86682 | Active – 1990 |
| SC536 | Arkansas R near Maize | 37.81035<br>97.42687 | Active – 1990 |
| SC729 | Arkansas R in Wichita | NA | Active – 2000 |
| SC246 | Little Arkansas R at Alta Mills | 38.11244<br>97.59198 | Active – 1975 |
| SC282 | Little Arkansas R at Valley Center | 37.81035<br>97.38802 | Active – 1973 |
| SC728 | Little Arkansas R in Wichita | NA | Active – 2000 |

Source: KDHE Correspondence January 2004

### 6.1.3.2 Available Stream Chemistry Data from the City's Bio-Monitoring Program

The chemical monitoring being conducted as part of the Bio-Monitoring Program includes stations on several tributaries to and the main stem of the Arkansas River. These locations, along with sampling frequencies, are listed in Table 6-4. The chemical monitoring locations are as far north as the Harvey-Sedgwick county line on the Little Arkansas River and north of Mt. Hope on the Arkansas River. According to the City, monitoring sites were established to assess the waters entering the county and the City, and waters exiting the City. Sampling is set up on a monthly collection schedule with 11 sites on the Arkansas River and five sites on the Little Arkansas River. Samples are analyzed for:

- pH
- temperature
- dissolved oxygen
- conductivity

- ammonia
- nitrates
- phosphates
- bacteria

Additional analyses are performed at specific locations for:

- chlorophyll A
- chlorides
- metals
- cyanide
- total suspended solids (TSS)
- nitrites
- total kjeldahl nitrogen (TKN)
- hardness

Please refer to Appendix D for more detail on the Bio-Monitoring Program. Bacteria source tracking and hydrographic assessment are also part of the program.

**Table 6-4. Wichita's Current Bio-Monitoring Schedule**

| General Location | River | Type | Frequency |
|---|---|---|---|
| **Mt. Hope** | Arkansas R | Chemical | Monthly and Field Visit |
| **Bentley** | Arkansas R | Fish | Annually |
| | | Benthic | Biannually |
| | | Phy-Hab | Biannually |
| **53rd St. N.** | Arkansas R | Chemical | Monthly and Field Visit |
| | | Fish | Annually |
| | | Benthic | Biannually |
| | | Phy-Hab | Biannually |
| **Harvey/Sedgwick** | Little Arkansas R | Chemical | Monthly and Field Visit |
| **109th St. N.** | Little Arkansas R | Chemical | Monthly and Field Visit |
| **85th St. N.** | Little Arkansas R | Chemical | Monthly and Field Visit |
| **53rd St. N.** | Little Arkansas R | Chemical | Monthly and Field Visit |
| | | Benthic | Biannually |
| **Seneca** | Arkansas R | Chemical | Monthly and Field Visit |
| **Central** | Little Ark. River | Chemical | Monthly and Field Visit |
| **Twin Lakes** | Arkansas R | Fish | Annually |
| | | Benthic | Biannually |
| **Lincoln Street** | Arkansas R | Fish | Annually |
| | | Benthic | Biannually |
| | | Phy-Hab | Biannually |
| **Herman Hill Park** | Arkansas R | Fish | Annually |
| | | Chemical | Field Visit |
| **Lewis** | Arkansas R | Chemical | Monthly and Field Visit |
| **Hydraulic** | Arkansas R | Chemical | Monthly and Field Visit |
| **47th St. South** | Arkansas R | Chemical | Monthly |

| General Location | River | Type | Frequency |
|---|---|---|---|
| | | Fish | Annually |
| | | Benthic | Biannually |
| | | Phy-Hab | Biannually |
| **63rd St. South** | Arkansas R | Chemical | Monthly |
| | | Fish | Annually |
| | | Benthic | Biannually |
| | | Phy-Hab | Biannually |
| **Pawnee** | Arkansas R | Chemical | Monthly |
| **Derby** | Arkansas R | Chemical | Monthly and Field Visit |
| | | Fish | Annually |
| | | Benthic | Biannually |
| | | Phy-Hab | Biannually |
| **Mulvane** | Arkansas R | Chemical | Monthly and Field Visit |
| | | Fish | Annually |
| | | Benthic | Biannually |
| | | Phy-Hab | Biannually |
| **55 HWY** | Arkansas R | Chemical | Monthly and Field Visit |
| | | Fish | Annually |
| | | Benthic | Biannually |
| | | Phy-Hab | Biannually |
| **K-96** | Arkansas R | Chemical | Monthly and Field Visit |
| | | Fish | Annually |
| | | Benthic | Biannually |

Source: City of Wichita, HBMP Meetings 2003/2004

### 6.1.3.3 Available USGS Stream Chemistry Monitoring Data

As reported, the USGS conducts routine monitoring of fecal coliform bacteria (FCB) at specific locations along the Arkansas and Little Arkansas rivers. The summary of USGS data that was compiled by HDR Engineering, Inc. as part of the Phase II Report includes bacterial mass loading probability curves from 1990-2003 historical data by sampling location. KDHE ceased routine monitoring of fecal streptococcus bacteria and fecal coliform bacteria in 1999 and 2003, respectively (KDHE website, http://www.kdhe.state.ks.us). The USGS expects to continue monitoring for FCB since portions of the Arkansas and Little Arkansas rivers have exceeded established FCB water quality standards and have been placed on the KDHE 303 (d) impairment list. The CD containing the USGS data can be found in Appendix E of this report.

### 6.1.3.4 Available KDHE Fish Tissue Sampling Data

As shown in their correspondence, KDHE has collected annual composite samples for fish tissue analysis at three locations in the ILWSP project area. Additional sample locations were established for screening purposes or as special project sites that were sampled for a period of one to three years. Some of the tissue samples were analyzed as whole fish while others were analyzed as fillets with the skin removed. All fish tissue samples were analyzed for a suite of long-lived organochlorine pesticides, a group of selected toxic metals and other organic contaminants. As provided by the agency, KDHE's monitoring locations and the types of samples obtained are summarized in Table 6-5. In addition, a summary of KDHE's stream chemistry monitoring program can be found at their website, http://www.kdhe.state.ks.us/environment/qmp_2000/qmp_2000.htm#BEFS.

**Table 6-5. KDHE Fish Tissue Monitoring Locations**

| Site Number | General Location/Name | Latitude/Longitude | Whole Fish | Fillet |
|---|---|---|---|---|
| SB281 | Arkansas River at Derby (Washington St.) | 37.54292 97.27561 | 82-94,96,98,02 | 88,90-96, 98, 99,02 |
| SB282 | Little Arkansas River 0.5 West of Valley Center | 37.83215 97.38802 | 82 | NA |
| SB283 | Arkansas River near Haven (3 Mi. North) | 37.94641 97.77510 | 82-87 | NA |
| No ID | Little Arkansas River near 13th St. in Wichita | NA | NA | 94,96-98 |
| No ID | Arkansas River at Wichita near US54/Kellog St. (upstream of the Lincoln St. dam) | NA | 86 | 90,91,96,97,00, 01 |
| No ID | Arkansas River upstream of Wichita (2 Mi. East and 2 Mi.North of Maize) | NA | 92,93 | NA |
| No ID | Arkansas River near Belle Plaine (East of Belle Plaine) | NA | 92,93 | NA |

Source: KDHE Correspondence January 2004

### 6.1.4 Stream Macroinvertebrate/Benthic Data

#### 6.1.4.1 Available KDHE Stream Macroinvertebrate Sampling Data

KDHE has also collected annual samples of macroinvertebrates from approximately 1980 to 2003. The locations used for macroinvertebrate data collection are considered to be long-term and will likely be sampled into the future. A list of these sample locations along with their sample history is provided in Table 6-6. The KDHE stream biological monitoring program is summarized on the following website, http://www.kdhe.state.ks.us/environment/qmp_2000/qmp_2000.htm#BEFS.

**Table 6-6. KDHE Stream Macroinvertabrate Monitoring Locations**

| Site Number | General Location/Name | Latitude/Longitude | Period of Record |
|---|---|---|---|
| SB281 | Arkansas River at Derby (Washington St.) | 37.54292<br>97.27561 | 1980 – 2003 |
| SB282 | Little Arkansas River 0.5 West of Valley Center | 37.83215<br>97.38802 | 1981 – 2003 |
| SB283 | Arkansas River near Haven (3 Mi. North) | 37.94641<br>97.77510 | 1982 – 2003 |

Source: KDHE Correspondence January 2004

#### 6.1.4.2 Available Benthic Data from the City's Bio-Monitoring Program

According to the City, benthic data has been collected as part of the Bio-Monitoring Program implemented by the Water and Sewer Department, Sewage Treatment Division. Sample locations along major tributaries to the Arkansas River were initially established for the biannual collections. Locations along the Little Arkansas River have not been sampled for benthics for the last six years. Please refer to Table 6-4 for the City's sampling locations and collection frequencies. Sampling typically consists of scavenging and D-net sweeps through all possible habitat niches at a given location. A standardized collection time of three hours per location has been established.

### 6.1.5 Fish Sampling

#### 6.1.5.1 Available Fish Sampling Data from the City's Bio-Monitoring Program

The City conducts fish collections annually through their existing Bio-Monitoring Program. Currently, 11 locations along the Arkansas River are sampled, primarily to assess pollutant effects and concerns relative to the effluent discharge from the City's Sewage Treatment Plant #2. One new sample location has been added at the request of the City's Environmental Health Department to assess the effluent from the new ground water treatment facility. Sampling methods used for collection include electroshocking and seining. Sampling locations and collection frequencies as provided by the City are presented in Table 6-4.

### 6.1.6 Physical Habitat Data

#### 6.1.6.1 Available Physical Habitat Data from the City's Bio-Monitoring Program

According to the City, nine of the established locations along the Arkansas River were sampled in 2003 using a physical habitat measurement system similar to that recommended by the EPA's Environmental Monitoring and Assessment Program protocols. As of 2004, no physical habitat measurements have been made at any location along the Little Arkansas River. Physical habitat sampling was proposed in order to help determine if benthic and fish population differences among sample locations were associated with habitat availability and site heterogeneity. Physical habitat data has been collected for some tributaries of the Arkansas River, such as Gypsum and Cowskin creeks. Data collected at established sample locations along the Arkansas River are scheduled to be analyzed and summarized in 2004. As mentioned earlier, established sampling locations and collection frequencies are shown in Table 6-4 in Section 6.1.3.2.

## 6.2 BASELINE ECOLOGICAL CONDITIONS

### 6.2.1 Data Obtained from Current Agency and City Monitoring Programs

Data obtained from past and present monitoring programs, investigations, and studies will be used to help determine baseline ecological conditions for the ILWSP. The only studies that are needed at this time, besides those that are currently being conducted by federal and state agencies or the City, are those that are necessary to determine baseline conditions for fisheries, benthics, and physical habitats along the Little Arkansas River. Details of these additional studies proposed at five sample locations on the Little Arkansas River are provided below in Section 6.2.1.4. Biological Conditions, of this HBMP.

#### 6.2.1.1 Groundwater Elevation

As previously described in Section 6.1.1, the USGS has cooperatively worked with the City and GMD2 to monitor existing groundwater wells and elevations in the ILWSP project area (specifically, the Equus Beds). This groundwater data has been used to model and evaluate the water storage capacities available in the Equus Beds aquifer for recharge with implementation of the ILWSP. Groundwater elevation records date back from the 1940s; groundwater wells that are being monitored are shown graphically in Appendix B. An adequate baseline for groundwater conditions for the Equus Beds aquifer can be derived from the existing data, which can be obtained directly from the USGS and/or GMD2. A limited amount of this data can also be retrieved at the following website: http://ks.water.usgs.gov/Kansas/studies/equus/equus_gwstorage.html.

#### 6.2.1.2 Stream Flow

As mentioned earlier in the HBMP, the USGS maintains and operates several established stream gage stations in the ILWSP project area (Table 6-7). This stream flow data was used to develop a historic record from 1923 to1996 as a basis for evaluating the ILWSP. As shown in the 2003 EIS, monthly median flow data (Table 6-8) at specific stream gage locations (Figure 6-1) provide a good representation of the seasonal variability of stream discharge in the ILWSP project area. Since median flows are those that fall in the statistical middle of the historic range, actual daily stream flow discharges will be higher than the median flow half the time and less half of the time.

The Kansas Water Office (KWO), Division of Water Resources, KDWP, and the KDHE, established minimum desirable stream flows (MDS) for many of the streams and rivers in Kansas. Several of these streams and rivers were located in the Little Arkansas and Ninnescah river basins.

**Table 6-7. Project Vicinity USGS Stream Gages**

| Station Number & Name | Location (Lat/Long) | Drainage Area (miles$^2$) | Period of Record |
|---|---|---|---|
| 07143330<br>Arkansas R near Hutchinson, KS | 37° 56' 47"<br>97° 45' 29" | 38,910 | 10/01/59–present |
| 07143375<br>Arkansas R near Maize, KS | 37° 46' 53"<br>97° 23' 33" | 39,110 | 03/01/87–present |
| 07143400<br>Arkansas R near Wichita, KS | 37° 42' 30"<br>97° 21' 50" | 39,072 | 10/01/21–03/31/35 |
| 07143665<br>Little Arkansas R at Alta Mills, KS | 38° 06' 44"<br>97° 35' 30" | 736 | 06/06/73–present |
| 07143672<br>Little Arkansas R at Halstead, KS* | 38° 01' 43"<br>97° 32' 25" | 759 | 05/95 - present |
| 07144100<br>Little Arkansas R near Sedgwick, KS* | 37° 52' 59"<br>97° 25' 27" | 1,239 | 10/01/93–present |
| 07144200<br>Little Arkansas R at Valley Center, KS | 37° 49' 56"<br>97° 23' 16" | 1,327 | 06/10/22–present |
| 07144300<br>Arkansas R at Wichita, KS | 37° 38' 41"<br>97° 20' 06" | 40,490 | 10/01/34–present |
| 07144550<br>Arkansas R at Derby, KS | 37° 32' 34"<br>97° 16' 31" | 40,830 | 10/01/68–present |
| 07144780<br>NF Ninnescah R above Cheney R, KS | 37° 43' 17"<br>97° 47' 39" | 787 | 07/01/65–present |
| 07144800<br>NF Ninnescah R near Cheney, KS | 37° 40' 00"<br>97° 46' 00" | 930 | 10/01/50–09/30/64 |
| 07145500<br>Ninnescah R near Peck, KS | 37° 27' 26"<br>97° 25' 20" | 2,129 | 04/01/38–present |
| 07146500<br>Arkansas R at Arkansas City, KS | 37° 03' 23"<br>97° 03' 32" | 43,713 | 10/01/21–present |

Source: EIS for the ILWSP, Wichita, KS, 2003 and USGS website (http://water.usgs.gov).
* These sites are only monitored for water quality.

**Table 6-8. Median Flow by Month for Project Area Streams (cfs)**

| Month | Arkansas River | | | Little Arkansas River | |
|---|---|---|---|---|---|
| | Hutchinson | Wichita | Arkansas City | Alta Mills | Valley Center |
| Jan | 124.9 | 249.9 | 571.1 | 23.3 | 53.8 |
| Feb | 169.4 | 327.1 | 645.5 | 26.0 | 61.1 |
| Mar | 207.2 | 387.7 | 801.0 | 31.0 | 70.4 |
| Apr | 216.8 | 459.7 | 947.1 | 35.0 | 76.4 |
| May | 273.5 | 573.4 | 1,198.2 | 45.5 | 107.6 |
| Jun | 405.1 | 825.1 | 1,515.8 | 57.0 | 129.4 |
| Jul | 248.4 | 504.5 | 959.6 | 31.5 | 75.6 |
| Aug | 166.5 | 321.6 | 659.7 | 22.7 | 54.7 |
| Sep | 150.0 | 293.2 | 555.5 | 21.6 | 53.5 |
| Oct | 117.6 | 226.9 | 520.6 | 18.7 | 49.6 |
| Nov | 149.6 | 306.0 | 634.2 | 26.0 | 58.8 |
| Dec | 142.3 | 287.8 | 595.8 | 24.5 | 58.4 |

Source: EIS for the ILWSP, Wichita, KS, 2003 and USGS website (http://water.usgs.gov).

**Table 6-9. Minimum Desirable Streamflow Values (cfs)**

| Month | Little Arkansas River | |
|---|---|---|
| | at Alta Mills | at Valley Center |
| Jan | 8 | 20 (34) |
| Feb | 8 | 20 (34) |
| Mar | 8 | 20 (34) |
| Apr | 8 | 20 (60) |
| May | 8 | 20 (60) |
| Jun | 8 | 20 (60) |
| Jul | 8 | 20 (34) |
| Aug | 8 | 20 (34) |
| Sep | 8 | 20 (34) |
| Oct | 8 | 20 (34) |
| Nov | 8 | 20 (34) |
| Dec | 8 | 20 (34) |

Source: EIS for the ILWSP City of Wichita, KS, 2003 and Kansas Water Office, 1983 and 1985. Values in parentheses are values recommended by Kansas Department of Wildlife and Parks

The MDS values established by the State of Kansas for streams and rivers in the ILWSP project area, as presented in the 2003 EIS, are listed in Table 6–9. As an example, the official MDS at Valley Center is a flow of 20 cubic feet per second (cfs) year-round. However, KDWP originally recommended a stream flow of 60 cfs during April, May and June at Valley Center, and a 34 cfs stream flow for the remainder of the year (KWO 1983, 1985).

**Figure 6-1. USGS Stream Gage Locations**


Source: Delorme Street Atlas 8.0

### 6.2.1.3 Stream Quality

Surface water quality in streams and rivers in the ILWSP project area can vary significantly with time and location. A summary of surface water quality data used for the ILWSP that has heen collected by the USGS is presented in Table 6-10. Although the number of samples and their respective collection periods vary, the surface water quality data shown in Table 6-10 is considered representative of conditions in the ILWSP area (EIS 2003).

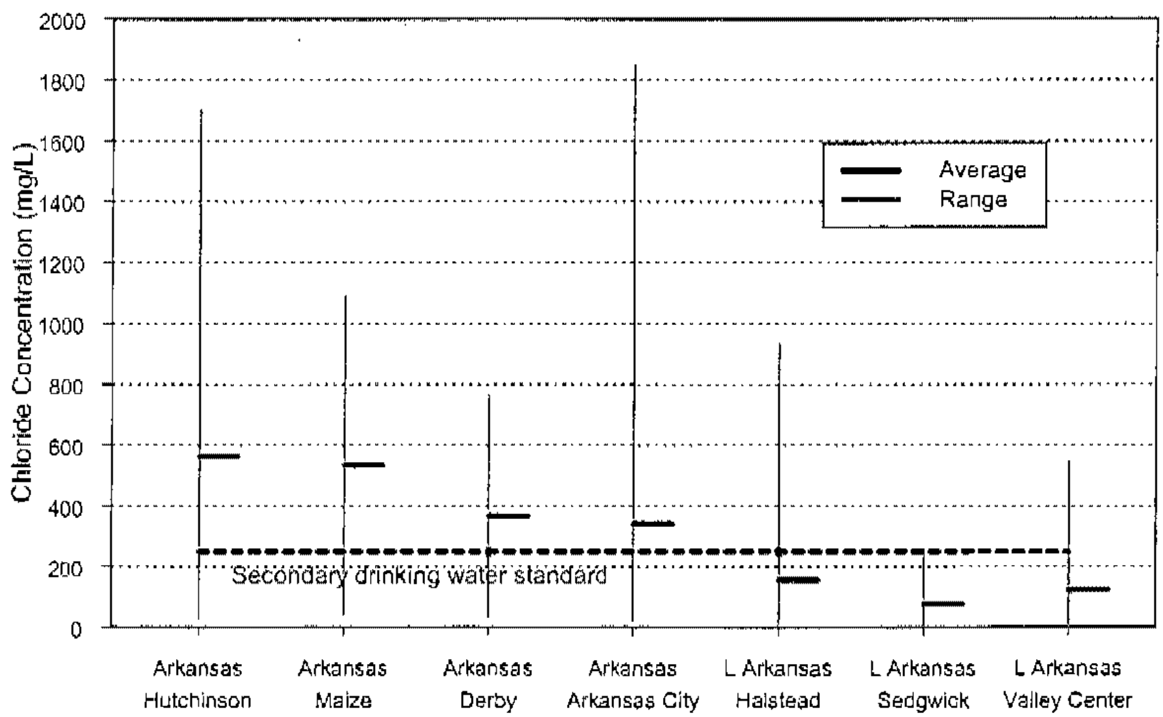
Though moderately hard, the quality of the water from these streams meets established standards for domestic and municipal use. The only exception to this condition is the elevated salinity levels that are historically found in the Arkansas River. Several natural and man-made saline sources upstream of Wichita contribute to these observed elevated levels in the Arkansas River in the ILWSP project area.

The concentration of chloride ions in the Arkansas River, which is a measure of salinity, can range up to 1,700 milligrams per liter (mg/L) upstream of Wichita (see Table 6-10). The U.S. Environmental Protection Agency (EPA) has established secondary drinking water standards that recommend limiting chloride concentrations to 250 mg/L (40 CFR 143). The contaminants that are included in the secondary drinking water standards, like chloride, are those that primarily affect the aesthetic qualities of drinking water, such as taste, odor and color.

As in the 2003 EIS, Figure 6-2 in the HBMP illustrates the range and average of chloride concentrations for those stations listed in Table 6-10 that have at least 50 data points. The data in Figure 6-2 also illustrates that surface water in the Little Arkansas River has significantly lower chloride concentrations than that of the Arkansas River. A comparison of average chloride concentrations in the Arkansas River surface water just above Wichita near Maize, and just below Wichita near Derby, provides evidence of a distinct water quality improvement.

Other compounds and chemicals such as herbicides and pesticides often affect surface water quality in streams and rivers, especially in areas where agricultural crops are concentrated. In the ILWSP project area, the herbicide atrazine is typically applied to agricultural crops in the spring and fall months. Coincidentally, this application occurs when precipitation is most intense and surface runoff can be the greatest. Atrazine concentrations and loading in the Little Arkansas River is typically greatest during the spring and early summer months (May through July).

**Figure 6-2. Surface Water Chloride Concentrations**




Source: Final EIS for the ILWSP, Wichita, KS 2003 and USGS website (http://water.usgs.gov).

### 6.2.1.4 Biological Conditions

The City has collected fisheries, benthic, and physical habitat data on both the Arkansas and Little Arkansas rivers for several years. In addition, KDHE has also collected stream macroinvertebrate data on both of these rivers. The data collected by both the City and

## Table 6-10. Surface Water Quality Data

| Station | Conductivity | Dissolved Oxygen | pH | Dissolved Concentrations | | | | | | | | | Suspended Solids | Sample Dates |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Hardness | Calcium | Magnesium | Sodium | Potassium | Chloride | Sulfate | Fluoride | Dissolved Solids | | |
| | µsiemens | mg/l | | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | |
| **Arkansas River** | | | | | | | | | | | | | | |
| 07143330 near Hutchinson, KS | 300 - 5900 | 1.3 - 13.6 | 6.9 - 9.1 | 0 - 805 | 22 - 214 | 3.5 - 72 | 23 - 1110 | 6.2 - 23 | 27 - 1700 | 18 - 918 | 0.2 - 1.2 | 208 - 3470 | 5 - 6120 | 1961-2002 |
| 07143375 near Maize, KS | 235 - 4150 | | 7.1 - 9.4 | | 19 - 160 | 3.9 - 70 | 26 - 500 | 6.5 - 13 | 45 - 1088 | 11 - 800 | | 162 - 1750 | | 1987-2002 |
| 07144300 at Wichita, KS | 200 - 2620 | | 6.8 - 9.2 | | | | | | | | | | 76 - 2500 | 1958-2002 |
| 07144550 at Derby, KS | 185 - 3560 | 5.8 - 13.4 | 6.8 - 8.9 | 80 - 717 | 25 - 187 | 3.4 - 64 | 22 - 536 | 4 - 16 | 33 - 765 | 20 - 738 | 0.3 - 1 | 193 - 2150 | 1340 - 1560 | 1961-2002 |
| 07146500 at Arkansas City, KS | 213 - 6540 | 1 - 17.1 | 6.6 - 10 | 24 - 760 | 17 - 216 | 3.5 - 56 | 18 - 1180 | 0.6 - 28 | 20 - 1850 | 15 - 630 | 0 - 1.1 | 132 - 4090 | 0.8 - 74 | 1943-2002 |
| **Little Arkansas River** | | | | | | | | | | | | | | |
| 07143665 at Alta Mills, KS | 105 - 3200 | | 7 - 8.7 | 330 - 452 | 105 - 142 | 17 - 24 | 152 - 258 | 5.3 - 6 | 274 - 532 | 54 - 125 | 0.4 | 820 - 1380 | 9 - 2130 | 1959-2002 |
| 07144100 near Sedgwick, KS | 40 - 1580 | 3.6 - 18.7 | 6.1 - 8.7 | 180 - 320 | 9.63 - 128 | 1.67 - 23.9 | 2.54 - 132 | 4.43 - 10.6 | <5 - 256 | <5 - 211 | 0.10 - 0.82 | 233-1630 | <4-1600 | 1995-2003 |
| 07143672 near Halstead, KS | 99 - 3550 | 2.5 - 16.2 | 6.2 - 8.5 | 210 - 460 | 8.19 - 174 | 1.54 - 36.2 | 4.38 - 498 | 4.4 - 18.1 | 8 - 932 | <5 - 312 | 0.05 - 2.74 | 308-2970 | <4-2240 | 1994-2003 |
| 07144200 at Valley Center, KS | 79 - 7300 | 5.7 - 14.6 | 6.6 - 8.7 | 1 - 474 | 9.6 - 142 | 0.2 - 32 | 3 - 260 | 3.3 - 10 | 5 - 545 | 5 - 110 | 0.1 - 0.8 | 64 - 1250 | 9 - 9990 | 1944-2002 |
| **North Fork of the Ninnescah River** | | | | | | | | | | | | | | |
| 07144780 above Cheney Reservoir, KS | 152 - 1560 | 7.5 - 10.4 | 7.2 - 9.1 | 188 - 266 | 54 - 83 | 9.1 - 16 | 137 - 190 | 3.6 - 8.2 | 196 - 282 | 49 - 88 | 0.4 - 0.5 | 628 - 776 | 1 - 2460 | 1967-2002 |
| 07144800 near Cheney, KS | 260 - 1770 | | 7.2 - 8.3 | 84 - 307 | 26 - 87 | 4.6 - 30 | 16 - 265 | 1.6 - 8 | 23 - 402 | 11 - 85 | 0.2 - 0.5 | 158 - 967 | 27 - 1740 | 1958-1965 |
| **Ninnescah River** | | | | | | | | | | | | | | |
| 07145500 near Peck, KS | 15 - 4020 | | 6.8 - 8.8 | 48 - 320 | 14 - 99 | 3.2 - 23 | 7.5 - 273 | 1.4 - 8.2 | 12 - 421 | 6 - 82 | 0 - 0.7 | 95 - 936 | 11 - 4000 | 1940-2002 |

Source: http://nwis.waterdata.usgs.gov

KDHE should be combined and used as an initial baseline for the HBMP of the ILWSP. The five locations along the Little Arkansas River that were previously sampled by the City for fisheries, macroinvertebrate, and physical habitat from 1995 through 1997 should be the starting point for collecting baseline data and to monitor if changes as a result of ILWSP operation appear to be occurring. Since the ILWSP will be constructed in phases and will take several years to be fully operational, ample time should be available to collect and analyze supplemental data for the intervening period between 1997 and 2004. It is recommended that the five sites be in addition to the City's existing program and be sampled at least twice per year beginning in the year 2005. The collected data should be analyzed, compared, and reported in the third year and fifth year reports, beginning in 2008 and continuing until five years after project implementation.

Since stream flow and conditions can be extremely variable from year to year, sampling should be conducted in the summer or winter on a consistent basis when flow parameters are likely to be most similar. Prior to determining sampling times, it is highly recommended to take advantage of "sametime" data or hourly flow data from the USGS to determine existing stream conditions.

The combination of the previously collected data and additional sampling at the five locations, along with the City's and KDHE's current data collection on the Little Arkansas River, should provide sufficient data for an accurate baseline and for comparative analyses. These five sample locations are graphically illustrated on the HBMP Monitoring Location Map in Appendix B.

This routine monitoring should be continued as part of the HBMP for five years after ILWSP implementation is completed or until a specific project impact as a result of ILWSP operation has been detected. Once all cooperating parties and the City agree that an impact appears to be occurring, the monitoring schedule can be modified and conducted as agreed by the cooperating agencies and the City.

## Table 6-11. Recommended Biological Monitoring Locations Along the Little Arkansas River

| Site Name | General Location Description |
|---|---|
| AQM-1 | Near NW 12 Rd. in Halstead Township |
| AQM-6 | Near NW 48 Rd. in Lakin Township |
| AQM-9 | Near S Emma Creek Rd. in Sedgwick Township |
| AQM-12 | Near 55th St West in Valley Center Township |
| AQM-13 | Near 24th St W and 69th St N in Park Township |

Source: Aquatic Monitoring Report - Little Arkansas River, Equus Beds Groundwater Recharge Project for the City of Wichita, 1995-1997.

### 6.2.2 Available Studies and Reports for Reference

Existing studies and reports should be used as references for the development and implementation of the HBMP. A partial list of these available documents is provided in Table 6-12. Additional reports and materials that were provided for reference material by the KDWP are located in the reference section of the HBMP and are listed under Additional References Provided by KDWP.

## Table 6-12. Available Studies and Reports

| Title | Organization | Year |
|---|---|---|
| Water Supply Study | Burns & McDonnell | 1993 |
| Environmental Assessment for the Equus Beds Groundwater Recharge Demonstration Project | Burns & McDonnell | 1994 |
| Annual Aquatic Monitoring Report for Little Arkansas River | Burns & McDonnell | 1995 |
| Annual Aquatic Monitoring Report for Little Arkansas River | Burns & McDonnell | 1996 |
| Local Well Field Feasibility Study Data Review and Initial Work Plan | Burns & McDonnell | 1996 |
| Equus Beds Groundwater Recharge Demonstration Project, Summary of Activities for Calendar Year 1996 | Burns & McDonnell | 1997 |
| Annual Aquatic Monitoring Report for Little Arkansas River | Burns & McDonnell | 1997 |
| Customer and Water Demand Projection Reevaluation | Burns & McDonnell | 1997 |
| Quality Assurance Plan for Water Quality Sampling Analysis, Equus Beds Groundwater Recharge Demonstration Project | Burns & McDonnell | 1997 |
| State and Federal and Agency Update Meeting, Raw Water Supply Projects, City of Wichita, Kansas | Burns & McDonnell | 1997 |
| Local Well Field Expansion Test Well Project, Final Environmental Assessment | Burns & McDonnell | 1997 |
| Aquatic Monitoring Report for Little Arkansas River | Burns & McDonnell | 1995-97 |
| Annual Aquatic Monitoring Report for the North Fork of the Ninnescah | Burns & McDonnell | 1997 |
| Equus Beds Groundwater Recharge Demonstration Project, | Burns & McDonnell | 1998 |

| Title | Organization | Year |
|---|---|---|
| Summary of Activities for Calendar Year 1997 | | |
| Annual Aquatic Monitoring Report for the North Fork of the Ninnescah and the Ninnescah Rivers | Burns & McDonnell | 1998 |
| Aquatic Monitoring Report for the North Fork of the Ninnescah and the Ninnescah Rivers | Burns & McDonnell | 1997-98 |
| Report on Pipeline Improvements at Key Locations Along City's 48-Inch Well Field Supply Main | Burns & McDonnell | 1998 |
| Operation and Testing Manual for the Equus Beds Groundwater recharge Demonstration Project | Burns & McDonnell | 1998 |
| Equus Beds Groundwater Recharge Demonstration Project, Summary of Activities for Calendar Year 1998 | Burns & McDonnell | 1998 |
| Cheney Reservoir Field Study | Burns & McDonnell | 1998 |
| Atrazine in Source Water Intended for Artificial Groundwater Recharge, South-Central Kansas | US Geological Survey | 1998 |
| Changes in Groundwater Levels and Storage in the Wichita Well Field Area, South-Central Kansas | US Geological Survey | 1998 |
| Status of Groundwater Levels and Storage in the Wichita Well Field Area, South-Central Kansas | US Geological Survey | 1998 |
| Report on Raw Water Delivery With 48-Inch Pipeline Replacement | Burns & McDonnell | 1999 |
| Local Well Field Concept Development Study | Burns & McDonnell | 1999 |
| Baseline Water Quality and Preliminary Effects of Artificial Recharge on Groundwater, South-Central KS | US Geological Survey | 1999 |
| Aquatic Monitoring Report for the Little Arkansas River | Burns & McDonnell | 2000 |
| Aquatic Monitoring Report for the North Fork of the Ninnescah and the Ninnescah Rivers | Burns & McDonnell | 2000 |
| Concept Design Study of the Equus Beds Aquifer Recharge, Storage and Recovery | Burns & McDonnell | 2000 |
| Instream Flow Incremental Modeling Report – Little Arkansas River | Burns & McDonnell | 2000 |
| 080-LARB-00 Cowskin Creek, Sedgwick County | Kansas Department of Wildlife & Parks | 2000 |
| 081-LARB-00 Ninnescah River, Sedgwick County | Kansas Department of Wildlife & Parks | 2000 |
| 086-LARB-00 Little Arkansas River, Sedgwick County | Kansas Department of Wildlife & Parks | 2000 |
| 088-LARB-00 Arkansas River, Sedgwick County | Kansas Department of Wildlife & Parks | 2000 |
| 089-LARB-00 Arkansas River, Sumner County | Kansas Department of Wildlife & Parks | 2000 |
| 090-LARB-00 Arkansas River, Cowley County | Kansas Department of Wildlife & Parks | 2000 |
| Instream Flow Incremental Modeling Report – North Fork of the Ninnescah River | Burns & McDonnell | 2001 |
| Effects of Artificial Recharge on Water Quality in the Equus Beds Aquifer, South-Central Kansas, 1995-2000 | U.S. Geologic Survey | 2001 |
| Significant Findings of Water-Quality Studies and Implications for Cheney reservoir Watershed, South-Central Kansas, 1996-2001 | U.S. Geologic Survey | 2002 |
| HDR Water Quality Report Summary – Phase II | HDR Engineering, Inc | 2003 |
| Status of Groundwater Levels and Storage Volume in the Equus Beds Aquifer Near Wichita, KS, Jan. 2000 – Jan. 2003 | U.S. Geologic Survey | 2003 |

## 6.3 PROJECT IMPLEMENTATION CONCERNS

Several potential issues and concerns have been identified by cooperating agencies and the public either during the NEPA EIS process or during the HBMP development meetings in 2003 and 2004. The basic objective of the HBMP is to be able to recognize and address beneficial or adverse project impacts (or issues and concerns) early-on. General issues and concerns expressed during the NEPA and HBMP processes have been related to stream flows, water quality, and the overall condition of the aquatic biological community. A brief discussion of each of these items follows.

### 6.3.1 Stream Flows

As mentioned in the 2003 EIS, the median stream flows of the Little Arkansas River have historically been near 60 cubic feet second (cfs) April through June and near 35 cfs the remaining time of the year. With implementation of the preferred ILWSP 100 MGD Diversion Alternative, base flows in the Little Arkansas River above Wichita are expected to increase over a period of about 15 years, while high stream flows are expected to remain relatively unchanged.

Median stream flows are expected to increase, except in the months of May and June when the median stream flow is expected to decrease slightly. Median stream flow in the Arkansas River is expected to remain essentially the same, except during June when stream flows would decrease slightly as a result of ILWSP operation increasing the upstream diversion of water for aquifer recharge in the Little Arkansas drainage. Stream flow is not expected to change significantly downstream of Cheney Reservoir in the Ninnescah River basin as a result of ILWSP implementation. A slight increase in the water surface elevation of Cheney Reservoir is expected.

The FWS and KDWP would prefer that stream flows remain within 80 percent of the historical median flows instead of the MDS of 20 cfs that was adopted by the State of Kansas for the Little Arkansas River. Both agencies believe that it is more important to monitor median flows than flows during more infrequent or rare wet or dry years. In addition, lower stream flows appear to create a more significant stressful situation to the existing biological community than would be expected to occur with higher stream flows.

### 6.3.2 Surface Water Quality

In 1998, EPA approved the Section 303(d) list that identified 129 river segments, as well as 24 lakes, in the lower Arkansas River basin as "water quality impaired" (KDHE website: http://www.kdhe.state.ks.us), which includes portions of the Arkansas and Little Arkansas rivers.

High levels of FCB were the most common reason for stream water quality impairment. However, eutrophic conditions were the primary reason for lake impairment. Additional pollutants that are limiting the use of the stream or river segments include:

- Chlordane
- Selenium
- Chloride
- Fluoride
- Ammonia
- Sulfate
- Nutrient oxide demand
- Sediment
- Dissolved oxygen depletion

Additional impairments to lakes occurred as a result of:

- Chloride
- Sulfate
- Dissolved oxygen depletion
- Selenium
- Siltation
- pH
- Excessive aquatic plants

A Total Daily Maximum Load (TMDL) has been developed by KDHE for each pollutant or parameter causing impairment to a stream or lake and has been given a high, medium, or low priority ranking. As of 2004, the TMDL's with a high priority implementation ranking for portions of the Arkansas and Little Arkansas rivers in the HBMP area of interest include FCB, sediment, nutrients, and chloride. The watershed above Cheney Reservoir is on the high priority list for TMDL's for siltation and eutrophication (nutrients); however, plans to include Cheney Reservoir or the Ninnescah River are not part of the HBMP, since ILWSP impacts are not anticipated to occur. It is also unlikely that the ILWSP would have significant impacts on water quality in either the Arkansas or Little Arkansas rivers as project operation is not expected to introduce additional or remove existing pollutants.

### 6.3.3 Aquatic Biological Community

During the development of the HBMP, cooperating agencies discussed their concerns that significant alteration to existing stream flow and water quality could result in adverse impacts to the aquatic biological community including fisheries, macroinvertebrates, and physical habitats. These impacts could adversely affect sensitive species populations, as well as general species populations. The two species of concern mentioned were the Arkansas River shiner (*Notropis girardi*) and the speckled chub (*Macrhybopsis aestivalis tetranemus*).

As indicated by FWS, critical habitat for the Arkansas River shiner (shiner) is no longer designated at the Federal level in the Arkansas and Ninnescah rivers in the State of Kansas. However, KDWP recognizes critical habitat for the shiner from Great Bend, Kansas to the Kansas – Oklahoma stateline. FWS indicated that a final determination to redesignate critical habitat for the Arkansas River shiner has not been completed. The Arkansas River shiner has not been found in the Arkansas or Little Arkansas river basins in Kansas since the late 1980s; however, the species is on the Kansas endangered list and on the Federal threatened list. KDWP indicated that the State of Kansas threatened and endangered species list is up for review in 2004.

The BOR and FWS are expecting a final report from Texas Tech University regarding Arkansas River shiner studies on the North Canadian River in Texas. Previously, it was believed that the Arkansas River shiner populations would remain stable in a river system if the speckled chub (*Macrhybopsis aestivalis tetranemus*) and silver chub (*Macrhybopsis storeiana*) populations remained stable. Changes to this concept have occurred, for it is now believed that length of contiguous unobstructed river segments is extremely important for the well-being of the Arkansas River shiner according to the unpublished results of the Texas Tech study. The reasoning for this need is that the Arkansas River shiner eggs float downstream and must have time to develop for successful reproduction. The Arkansas River shiner's breeding period typically commences in May when stream flow is relatively high or near its seasonal peak.

A second species, the speckled chub, is a state-listed endangered species where critical habitat has been designated; the species is known to occur in both the Arkansas and Ninnescah river basins. This species prefers currents over clean, fine sand, avoiding calm water and silt bottoms (from KDWP County T&E List and Species Data Sheets).

## 6.4 SUMMARY

In summary, both hydrological and biological data will be collected by the City of Wichita and by and with assistance from federal, state, and local cooperating agencies. Historic resource data, along with that data currently being collected, can be easily used to establish adequate baseline conditions that are representative of the ILWSP prior to operation. Continuing these existing programs using the recommended schedule and reporting requirements will provide the avenue to determine if ILWSP operation will potentially create either beneficial or adverse environmental impacts or effects that will need to be recognized and addressed in the future.

**Table 6-13. Data Collection by Entity**

| Data Type | USGS | KDHE | GMD2 | City |
|---|---|---|---|---|
| Groundwater | X | | X | X |
| Stream Flow | X | | | |
| Stream Quality | X | X | | X |
| Benthic or Macroinvertebrate | | X | | X |
| Fisheries | | | | X |
| Physical Habitat | | | | X |

# 7.0 HBMP RESPONSIBILITIES FOR DATA COLLECTION

To address the concerns of groundwater, stream flow, quality, and biological community, the HBMP recommends continuation of on-going data collection programs. The data collection procedures, responsibilities, and reporting requirements in the HBMP were agreed upon by the City and the participating agencies. The subsequent sections will summarize in detail the data collection procedures and responsibilities associated with the HBMP.

## 7.1 GROUNDWATER ELEVATION DATA COLLECTION

The City currently works with the USGS and GMD2 to collect groundwater data; however, it will be the City's responsibility for gathering the data from the necessary entities and including it in the HBMP annual reports. As described in Section 5.0, the data will be tabulated and briefly analyzed in the three-year reports, while the detailed analysis results and recommendations will be provided within the five-year HBMP reports. Recommended sampling locations are identified on the HBMP Groundwater Monitoring Location Map in Appendix B.

## 7.2 STREAM FLOW DATA COLLECTION

Since the USGS has hourly stream flow monitoring records and are projected to use existing sampling sites well into the future, it is recommended to use their existing locations and data for purposes of the HBMP. The City is responsible for collecting the stream flow data from the USGS and providing it in the annual reports. The data will be tabulated and preliminarily analyzed in the three-year reports, while the detailed analysis results and recommendations will be included in the five-year reports. Recommended sampling locations and data collection include the same gaging stations listed in Table 6-1 and depicted on the HBMP Monitoring Location Map in Appendix B.

## 7.3 STREAM QUALITY DATA COLLECTION

Since the KDHE, USGS, and the City have stream quality records and are projected to use existing sampling sites into the future, it is recommended to use the combination of the collected data for purposes of the HBMP. The City is responsible for collecting the data from KDHE and USGS, as well as from other departments in the City, on an annual basis for inclusion in the annual reports. The data will then be tabulated and analyzed in the three-year reports, while analysis results and specific recommendations will be included within the five-year reports. Recommended sampling locations and data collection, include the same monitoring sites listed in Tables 6-1, 6-3, and 6-5, as well as the City's detailed sampling schedule provided in Appendix D. All of the stream quality locations are also depicted on the HBMP Monitoring Location Map in Appendix B.

## 7.4 STREAM MACROINVERTEBRATE/BENTHIC DATA COLLECTION

Stream macroinvertebrate and benthic data from the KDHE and City is limited for the Little Arkansas River. For purposes of the HBMP, it is recommended that a combination of sampling sites and data collection from both the KDHE and the City be used, including the five additional sites on the Little Arkansas River as identified in Section 6.2.1.4, Biological Conditions. For purposes of monitoring as part of the HBMP, these biological sites can be monitored twice per year for five years after project implementation or until a project impact has been detected. Depending on the impacts observed, the appropriate monitoring schedules can be determined by the participating agencies and the City. The City is responsible for collecting the data from KDHE and conducting the necessary studies for the additional sites. The raw data will be provided in the annual reports; however, tabulated data and analysis results will be provided in the three- and five-year reports, respectively. The recommended monitoring locations include the same sites listed in Tables 6-4, 6-6, and 6-11. All of the biological monitoring locations are depicted on the HBMP Monitoring Location Map included in Appendix B.

## 7.5 FISHERIES DATA COLLECTION

It is recommended that the City of Wichita's current data collection methods and sampling locations, as identified in Appendix D Wichita's Current Bio-Monitoring Schedule, continue to be used to determine impacts to the fish populations within the Arkansas and Little Arkansas Rivers. It is also recommended that five additional sites on the Little Arkansas River be monitored, as described in Section 6.2.1.4 Biological Conditions. For purposes of the HBMP, these additional biological sites can be monitored twice per year for five years after project implementation or until a project impact has been detected; at that point, the City and participating agencies can determine an appropriate monitoring schedule. The City is responsible for collecting this data and providing it in annual reports. The tabulated data will be provided in the three-year reports. Current and historic trends of fish populations should be analyzed and compared to project operation schedules to determine if there are signs of impacts, either adverse or beneficial to the fish populations. The results are to be provided within the five-year reports. The recommended monitoring locations include the sites listed in Tables 6-4 and 6-11. The monitoring locations are also depicted on the HBMP Monitoring Location Map in Appendix B.

## 7.6 PHYSICAL HABITAT

It is recommended that the City's current data collection methods and sampling locations as identified in Table 6-4 Wichita's Current Monitoring Schedule be used to determine impacts to physical habitat within the Arkansas and Little Arkansas rivers. It is also recommended to monitor the five additional sites on the Little Arkansas River, as described in Section 6.2.1.4 Biological Conditions and shown in Table 6-11. For purposes of monitoring as part of the HBMP, these additional biological sites can be monitored twice per year for five years after project implementation or until a project impact has been detected; at this point, the City and participating agencies can determine a more appropriate monitoring schedule. The City is responsible for collecting this data and providing it in annual reports. The tabulated data will be provided in the three-year reports. Physical habitat studies will be reviewed and compared to past records and the results are to be provided within the five-year reports. The monitoring locations are also depicted on the HBMP Monitoring Location Map in Appendix B.

## 8.0 DATA COLLECTION COORDINATION RESPONSIBILITIES

The City will be responsible for coordinating and collecting the pertinent data from the participating agencies that will be used to generate the annual HBMP reports. The City will also be responsible for conducting any additional studies or monitoring additional sites per recommendations made within this HBMP. The City will provide reports to the participating agencies for review and coordinate any follow-up meetings regarding the HBMP.

# 9.0 SCIENTIFIC PEER REVIEW

With the recommendation and concurrence of the City and the cooperating agencies, a "scientific peer review" panel may convene to review the progress and findings of the HBMP. The panel will provide non-binding technical input to the City regarding the HBMP. The panel will consist of five members to be selected from the scientific community who have expertise in terrestrial and aquatic ecosystems found within the ILWSP project area and surrounding region. Two of the panel members will be selected by the City, two by the cooperating agencies, and one by the City and cooperating agencies. The City will by responsible for scheduling meetings, maintaining files, and generally coordinating the logistics of the panel.

The cost associated with compensating the scientific peer review panel will be shared equally by the City and the cooperating agencies. Prior to each budget year, the City and the cooperating agencies shall agree on the reasonable and effective budgeted amount for compensating the panel for the following year. Agreement will not be unreasonably withheld by either party. Any change in the panel composition, structure, or scope of review may be made in writing with the City and the cooperating agencies.

# 10.0 QUALITY ASSURANCE MANUAL

The water quality or water chemistry analyses included in the HBMP should be performed using established procedures included in the ILWSP Quality Control Manual prepared by the City, EPA, and the USGS. This manual, the *Quality Assurance Plan for Water Quality Sampling Analysis, Equus Beds Groundwater Recharge Demonstration Project*, was completed in 1997 and remains in effect today. All field and laboratory methods used in the HBMP must be as described in the 1997 manual. If modifications to the procedures are required, these procedural changes should be approved by the City, EPA, USGS, and cooperating agencies before being implemented. Documentation of the changes should be appended to the HBMP as they occur.

# REFERENCES

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http://www.water.usgs.gov
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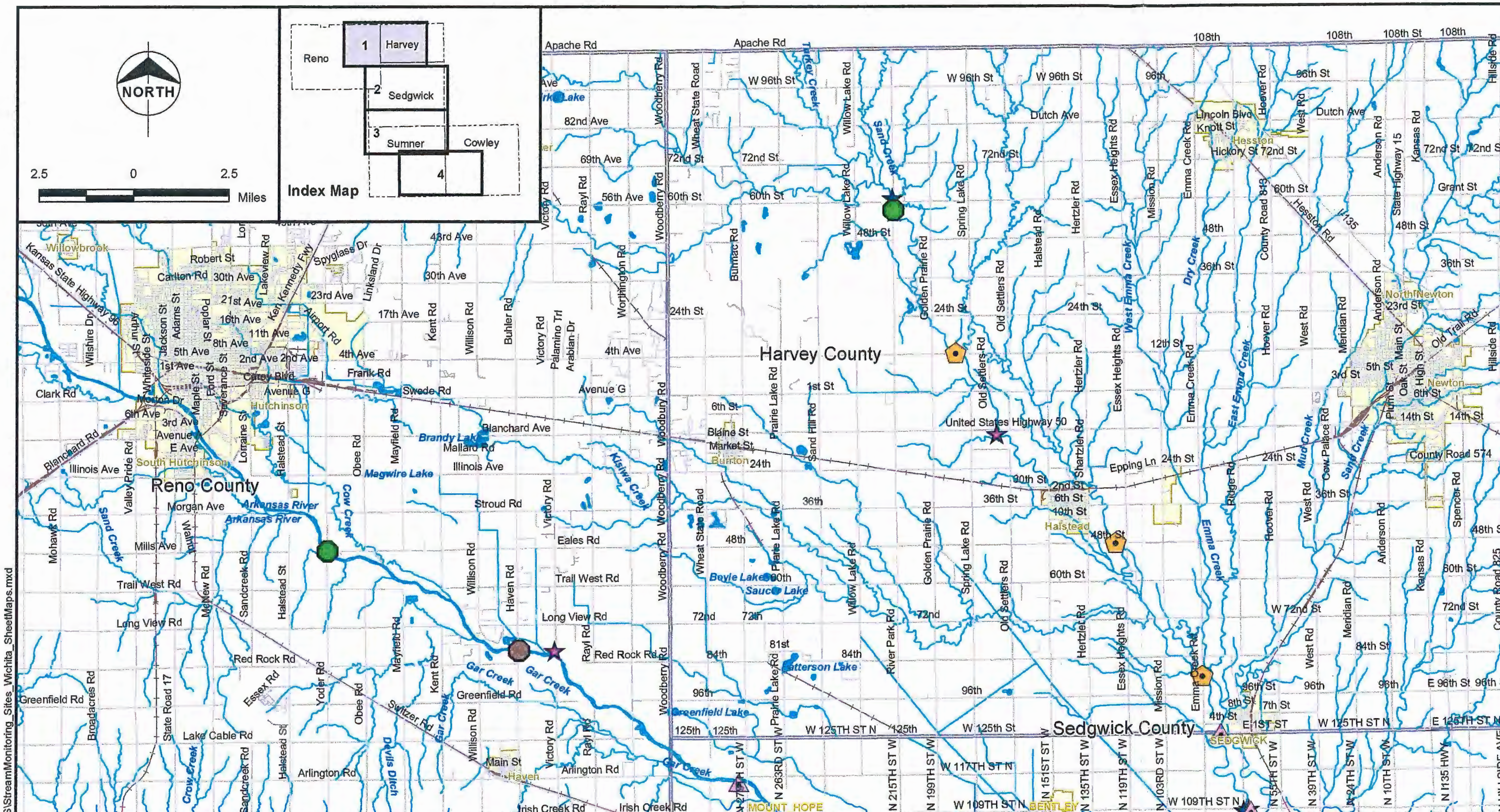
# APPENDICES

# Appendix A

Stream Monitoring Test Sites Near Wichita




## LEGEND

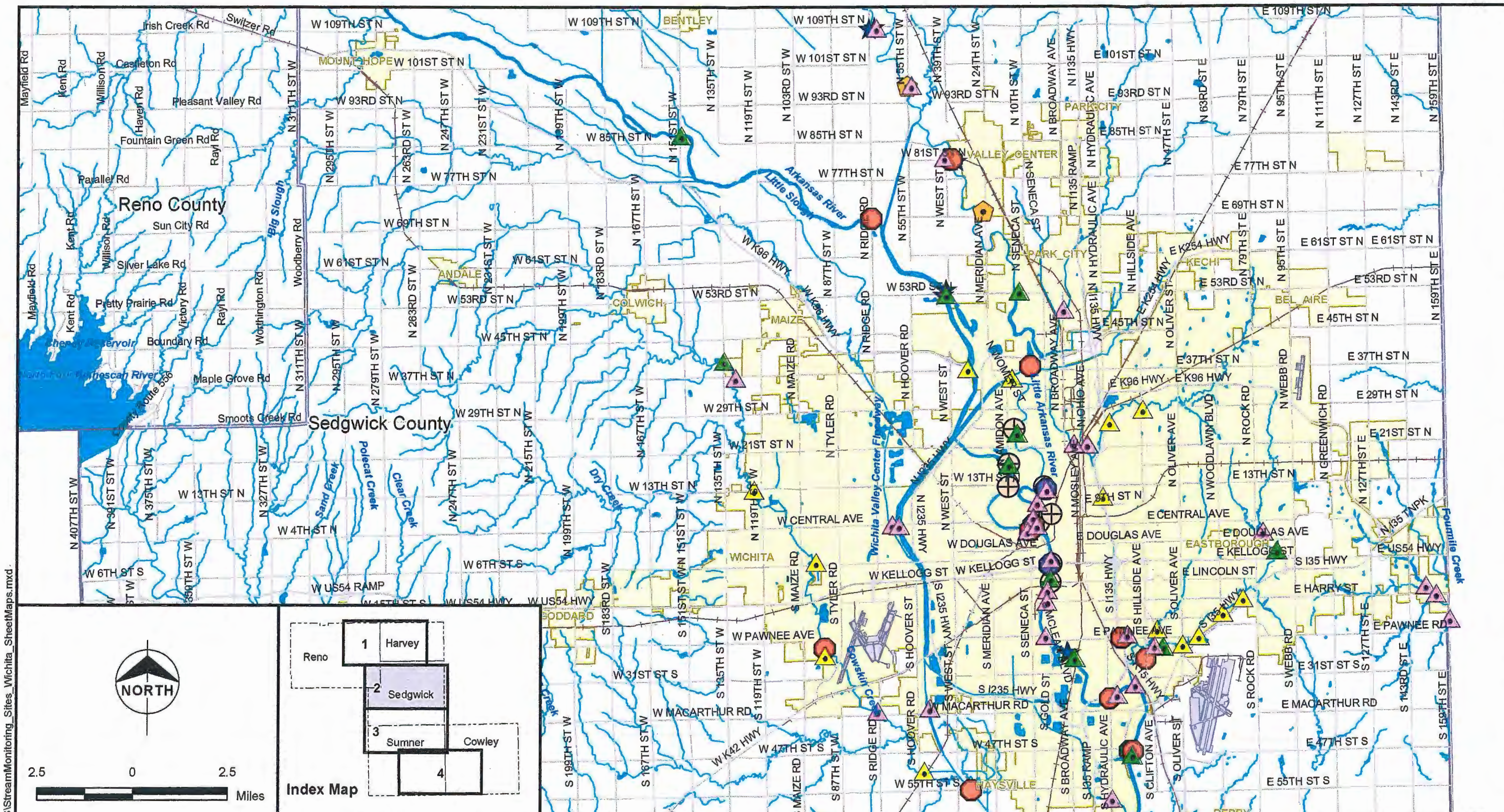
- City Biological Test Sites
- City Chemical Test Sites
- City Chemical & Biological Test Sites
- Health Department Test Sites
- City Aquatic Monitoring Sites (1995-1997)
- USGS Flow Stations
- USGS Stream Flow Test Sites
- KDHE Test Sites
- KDHE Fish Tissue Sampling Sites
- KDHE Stream Chemistry Test Sites
- KDHE Macro-Invertebrate Sampling Sites

CITY OF WICHITA

Stream Monitoring Test Sites Near Wichita
Wichita Hydrobiological Monitoring Plan
Sheet 1 of 4

V:\WICHITA\34256-HBMP\GIS\StreamMonitoring_Sites_Wichita_SheetMaps.mxd

Revised September 14, 2004




## LEGEND

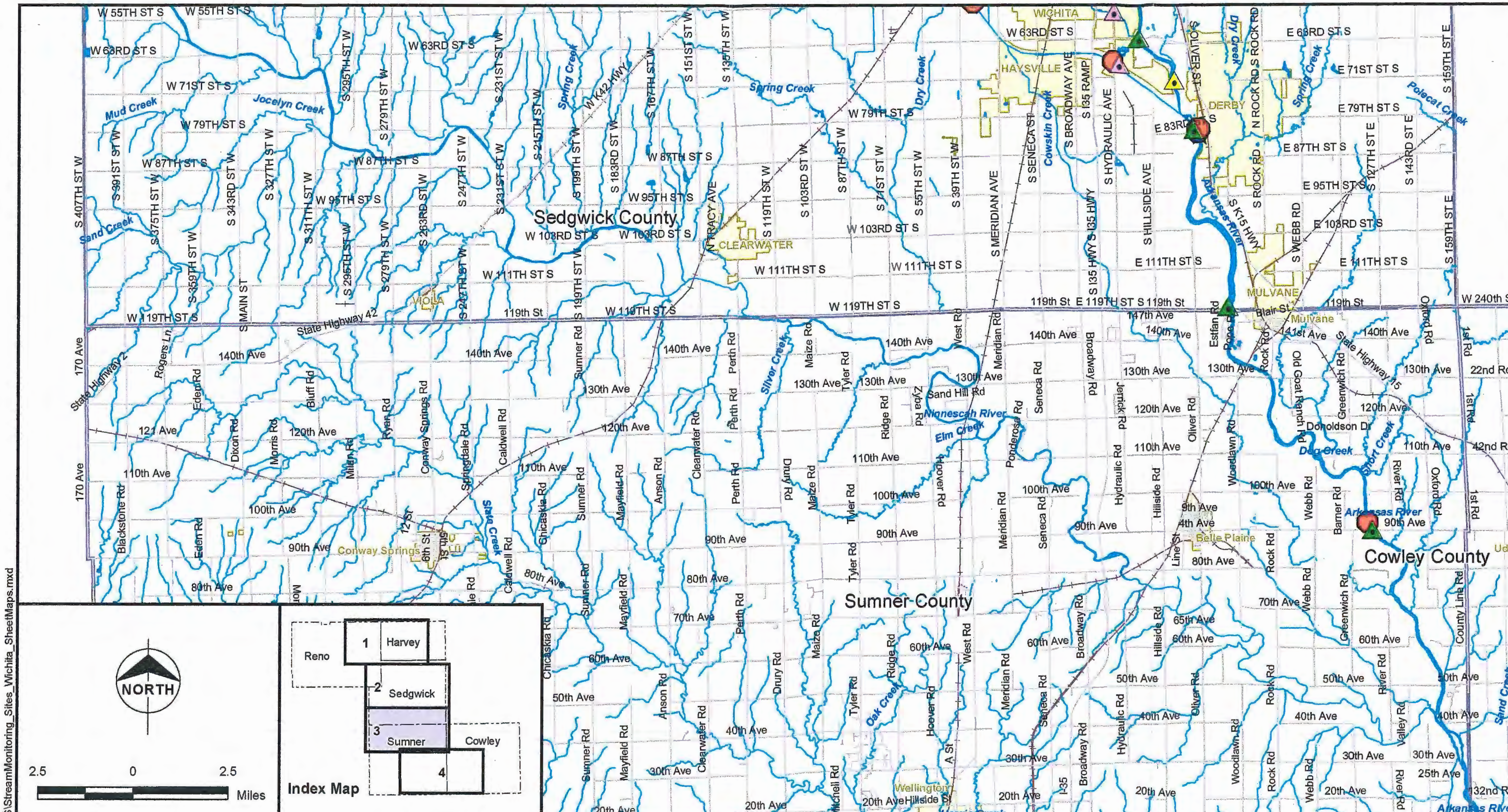
- City Biological Test Sites
- City Chemical Test Sites
- City Chemical & Biological Test Sites
- Health Department Test Sites
- City Aquatic Monitoring Sites (1995-1997)
- USGS Flow Stations
- USGS Stream Flow Test Sites
- KDHE Test Sites
- KDHE Fish Tissue Sampling Sites
- KDHE Stream Chemistry Test Sites
- KDHE Macro-Invertebrate Sampling Sites

CITY OF WICHITA

Stream Monitoring Test Sites Near Wichita
Wichita Hydrobiological Monitoring Plan
Sheet 2 of 4

V:\WICHITA\34256-HBMP\GIS\StreamMonitoring_Sites_Wichita_SheetMaps.mxd

Revised September 14, 2004




## LEGEND

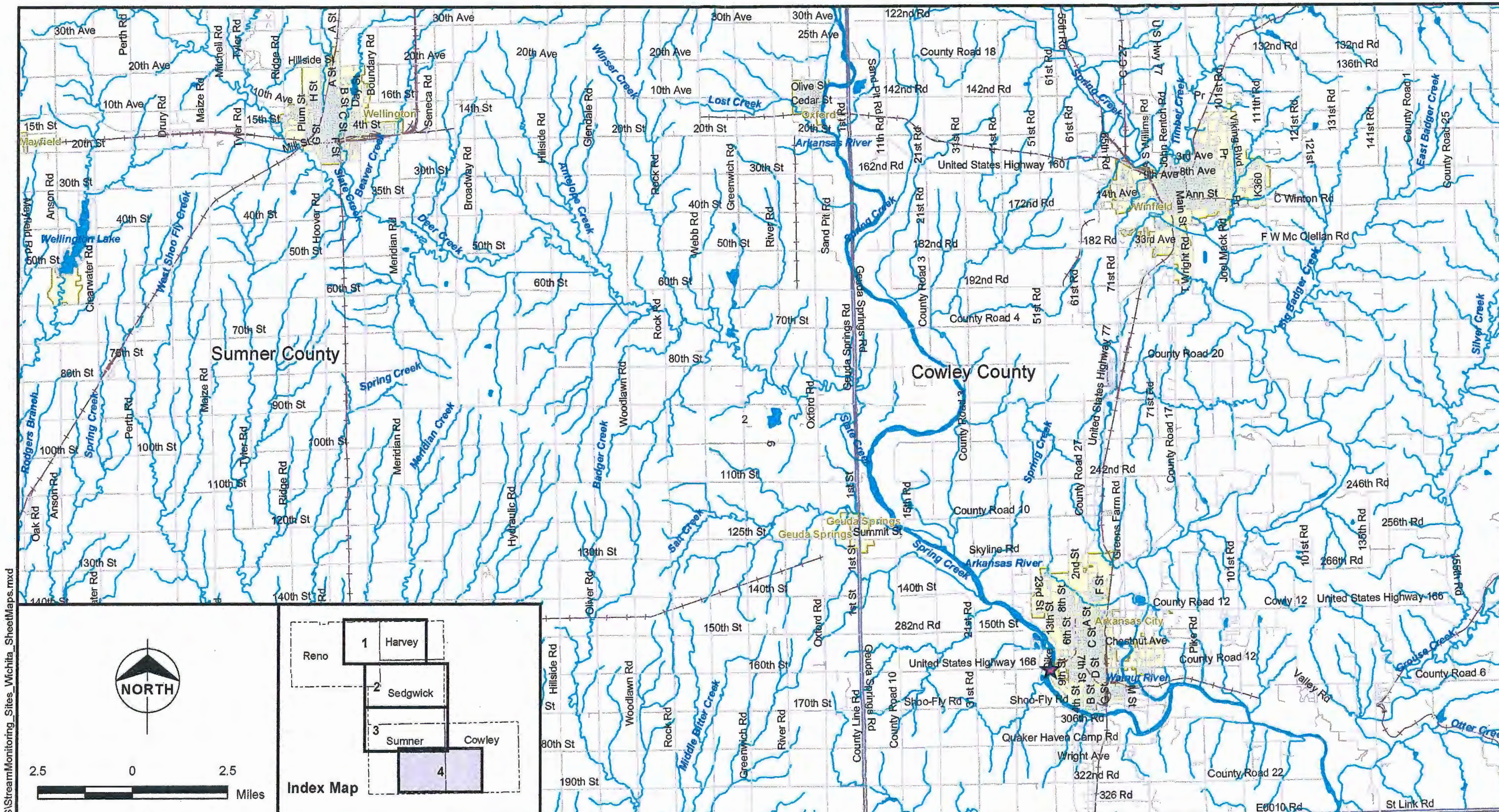
- City Biological Test Sites
- City Chemical Test Sites
- City Chemical & Biological Test Sites
- Health Department Test Sites
- City Aquatic Monitoring Sites (1995-1997)
- USGS Flow Stations
- USGS Stream Flow Test Sites
- KDHE Test Sites
- KDHE Fish Tissue Sampling Sites
- KDHE Stream Chemistry Test Sites
- KDHE Macro-Invertebrate Sampling Sites

CITY OF WICHITA

Stream Monitoring Test Sites Near Wichita
Wichita Hydrobiological Monitoring Plan
Sheet 3 of 4

V:\WICHITA\34256-HBMP\GIS\StreamMonitoring_Sites_Wichita_SheetMaps.mxd

Revised September 14, 2004




## LEGEND

- City Biological Test Sites
- City Chemical Test Sites
- City Chemical & Biological Test Sites
- Health Department Test Sites
- City Aquatic Monitoring Sites (1995-1997)
- USGS Flow Stations
- USGS Stream Flow Test Sites
- KDHE Test Sites
- KDHE Fish Tissue Sampling Sites
- KDHE Stream Chemistry Test Sites
- KDHE Macro-Invertebrate Sampling Sites

CITY OF WICHITA

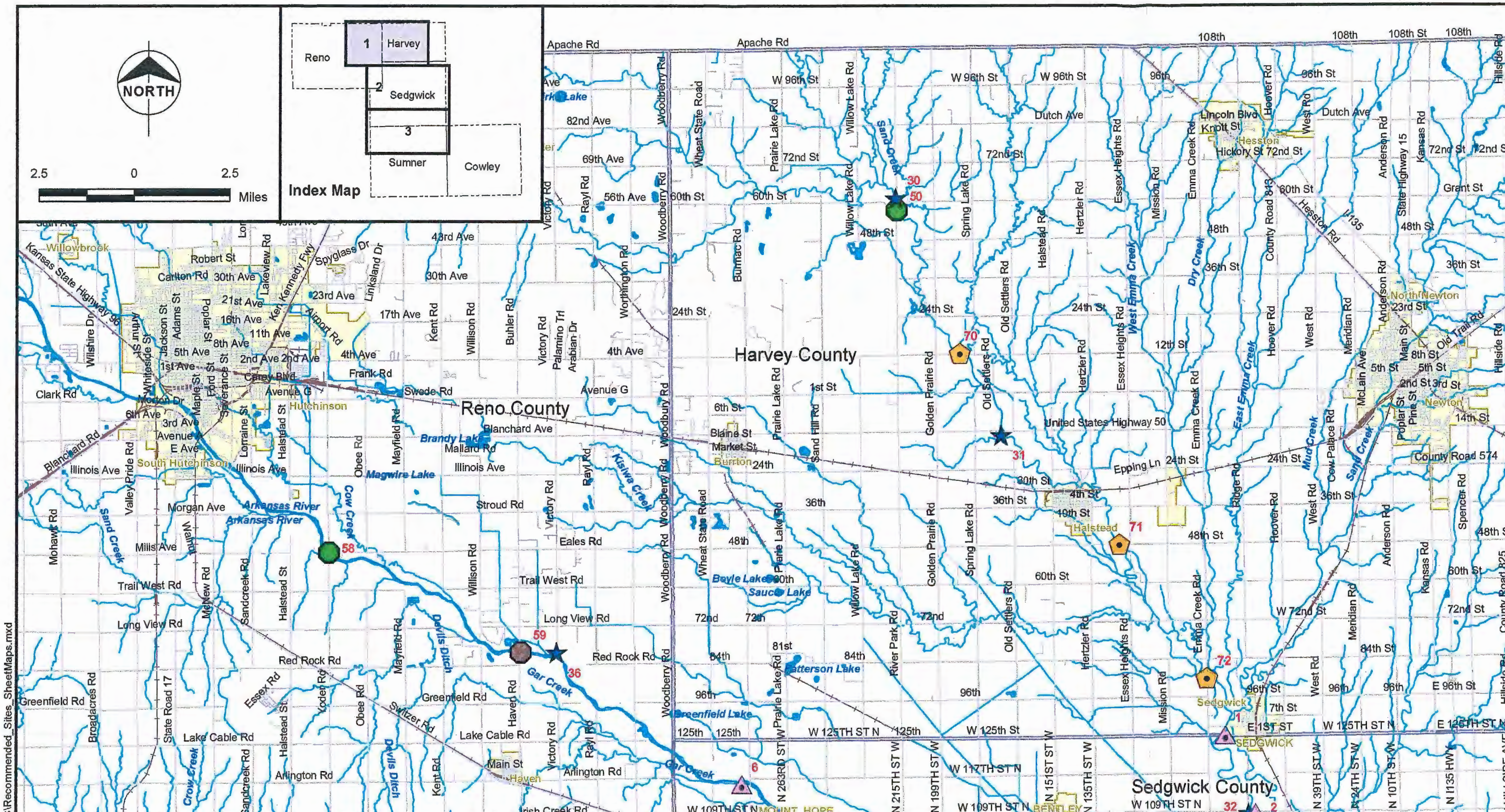
Stream Monitoring Test Sites Near Wichita
Wichita Hydrobiological Monitoring Plan
Sheet 4 of 4

V:\WICHITA\34256-HBMP\GIS\StreamMonitoring_Sites_Wichita_SheetMaps.mxd

Revised September 14, 2004

# Appendix B

# Recommended HBMP Stream Monitoring Test Sites




## LEGEND

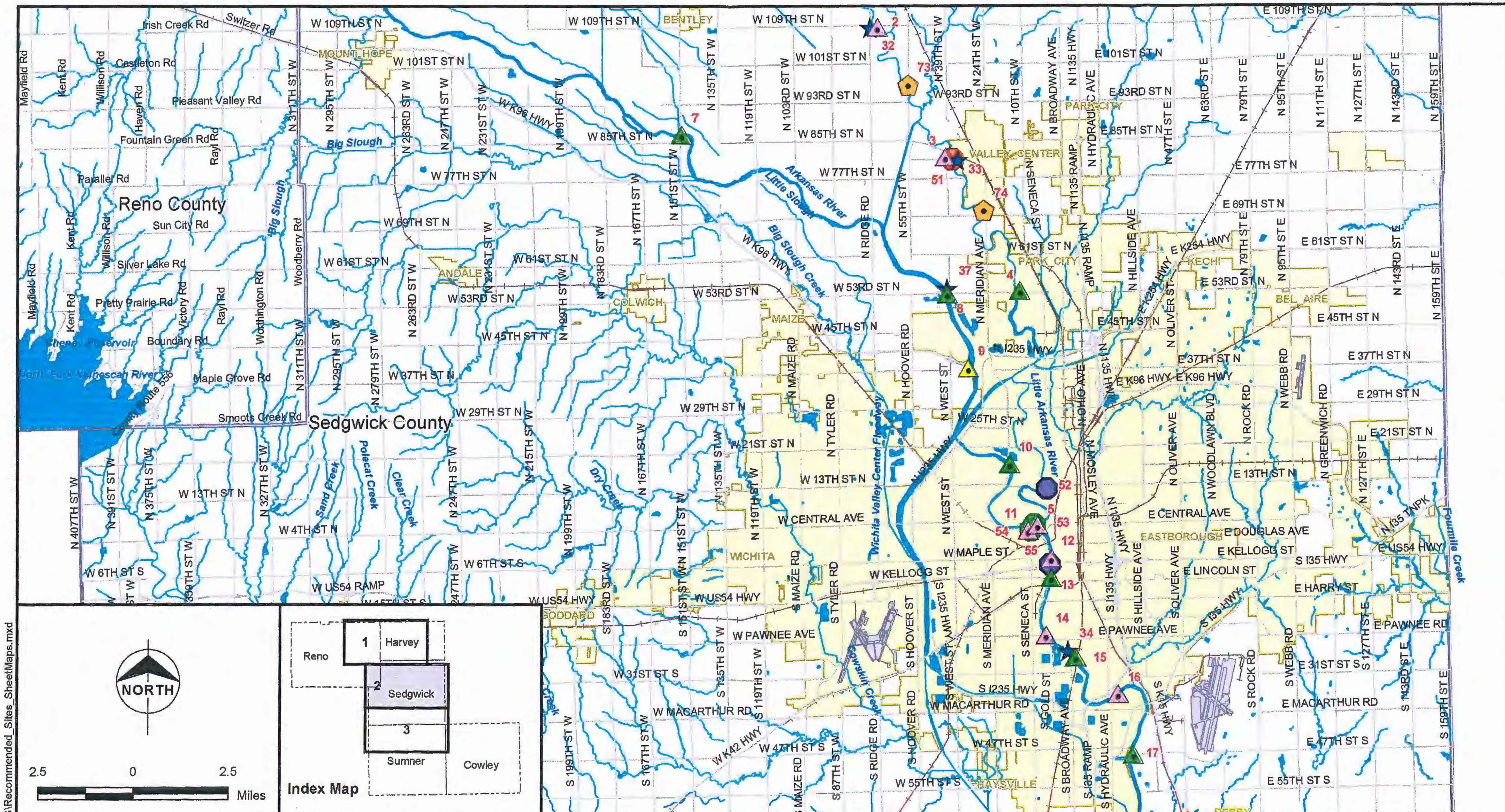
- City Biological Test Sites
- City Chemical Test Sites
- City Chemical & Biological Test Sites
- City Aquatic Monitoring Sites (1995-1997)
- USGS Flow Stations
- KDHE Test Sites (Contains Chemical, Fish Tissue, & Macro-Invertebrate)
- KDHE Fish Tissue
- KDHE Chemical Test Sites
- KDHE Fish Tissue & Macro-Invertebrate
- KDHE Fish Tissue & Stream Chemistry

CITY OF WICHITA

Recommended Stream Monitoring Test Sites
Wichita Hydrobiological Monitoring Plan
Sheet 1 of 3

V:\WICHITA\34256-HBMP\GIS\Recommended_Sites_SheetMaps.mxd

Revised September 13, 2004



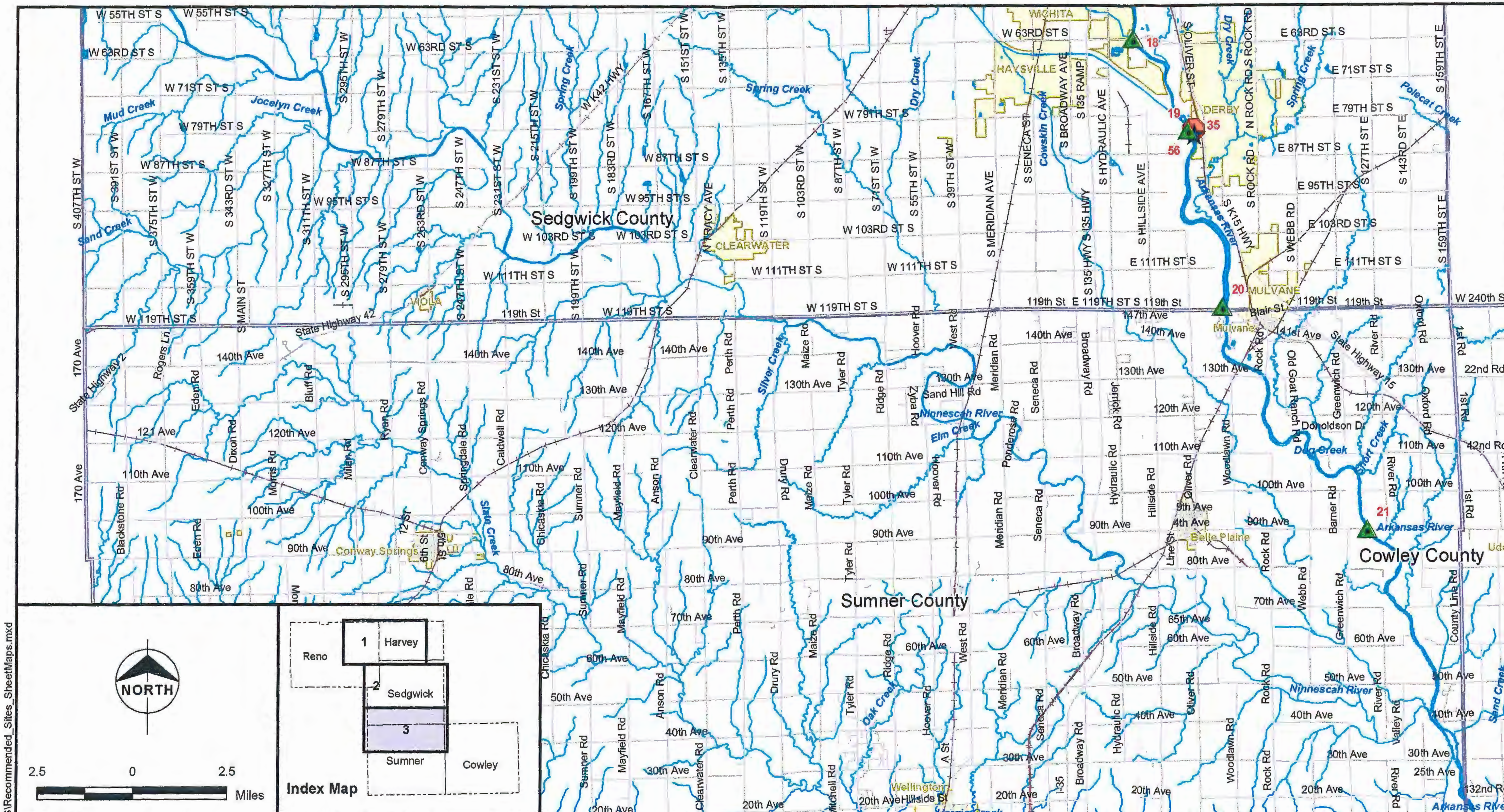

## LEGEND

- City Biological Test Sites
- City Chemical Test Sites
- City Chemical & Biological Test Sites
- City Aquatic Monitoring Sites (1995-1997)
- USGS Flow Stations
- KDHE Test Sites (Contains Chemical, Fish Tissue, & Macro-Invertebrate)
- KDHE Fish Tissue
- KDHE Chemical Test Sites
- KDHE Fish Tissue & Macro-Invertebrate
- KDHE Fish Tissue & Stream Chemistry

CITY OF WICHITA

Recommended Stream Monitoring Test Sites
Wichita Hydrobiological Monitoring Plan
Sheet 2 of 3

Revised September 13, 2004




## LEGEND

- City Biological Test Sites
- City Chemical Test Sites
- City Chemical & Biological Test Sites
- City Aquatic Monitoring Sites (1995-1997)
- USGS Flow Stations
- KDHE Test Sites (Contains Chemical, Fish Tissue, & Macro-Invertebrate)
- KDHE Fish Tissue
- KDHE Chemical Test Sites
- KDHE Fish Tissue & Macro-Invertebrate
- KDHE Fish Tissue & Stream Chemistry

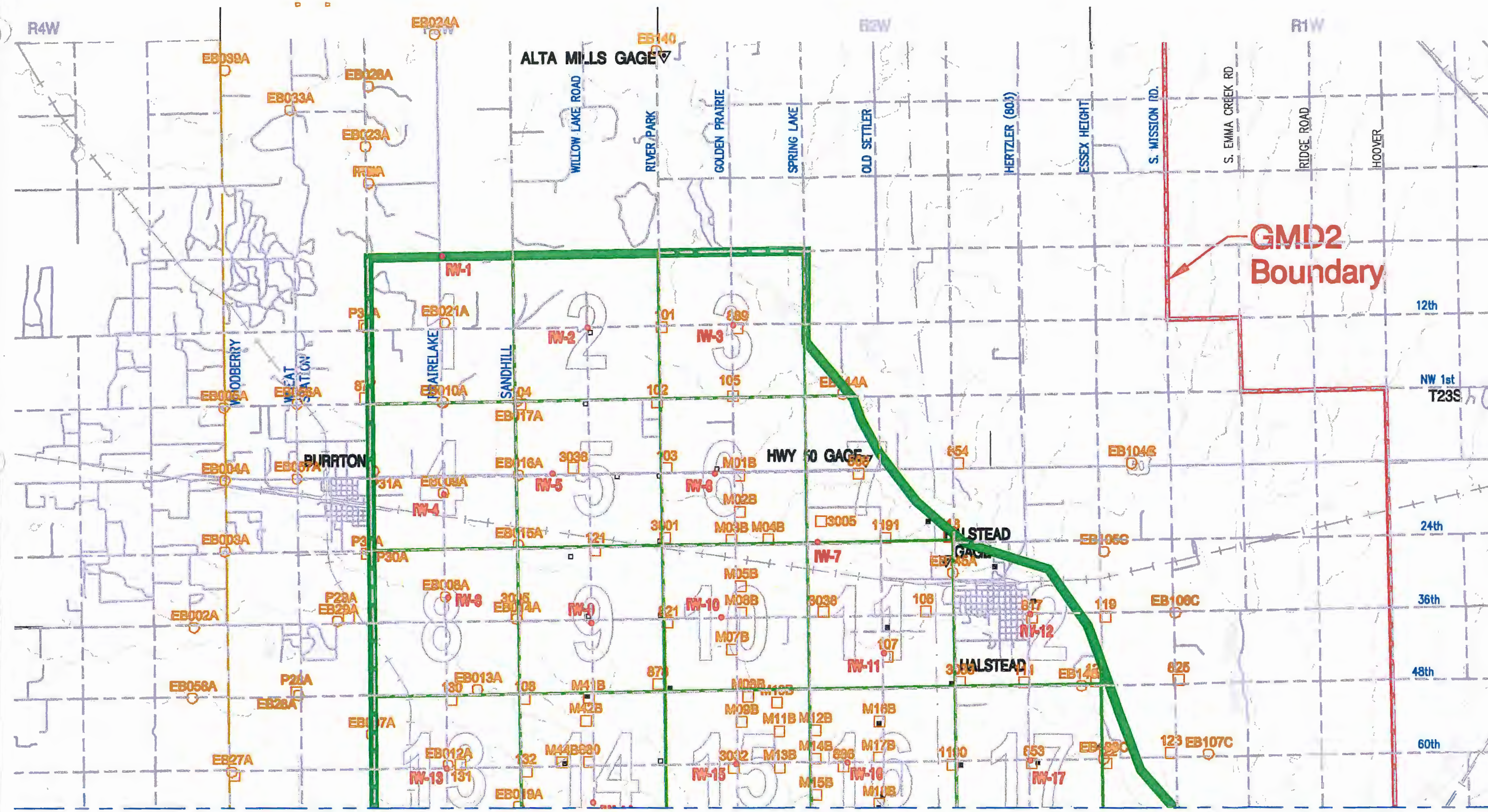
CITY OF WICHITA

Recommended Stream Monitoring Test Sites
Wichita Hydrobiological Monitoring Plan
Sheet 3 of 3

V:\WICHITA\34256-HBMP\GIS\Recommended_Sites_SheetMaps.mxd

Revised September 13, 2004

# Recommended HBMP Groundwater Monitoring Test Sites




**NOTE:**

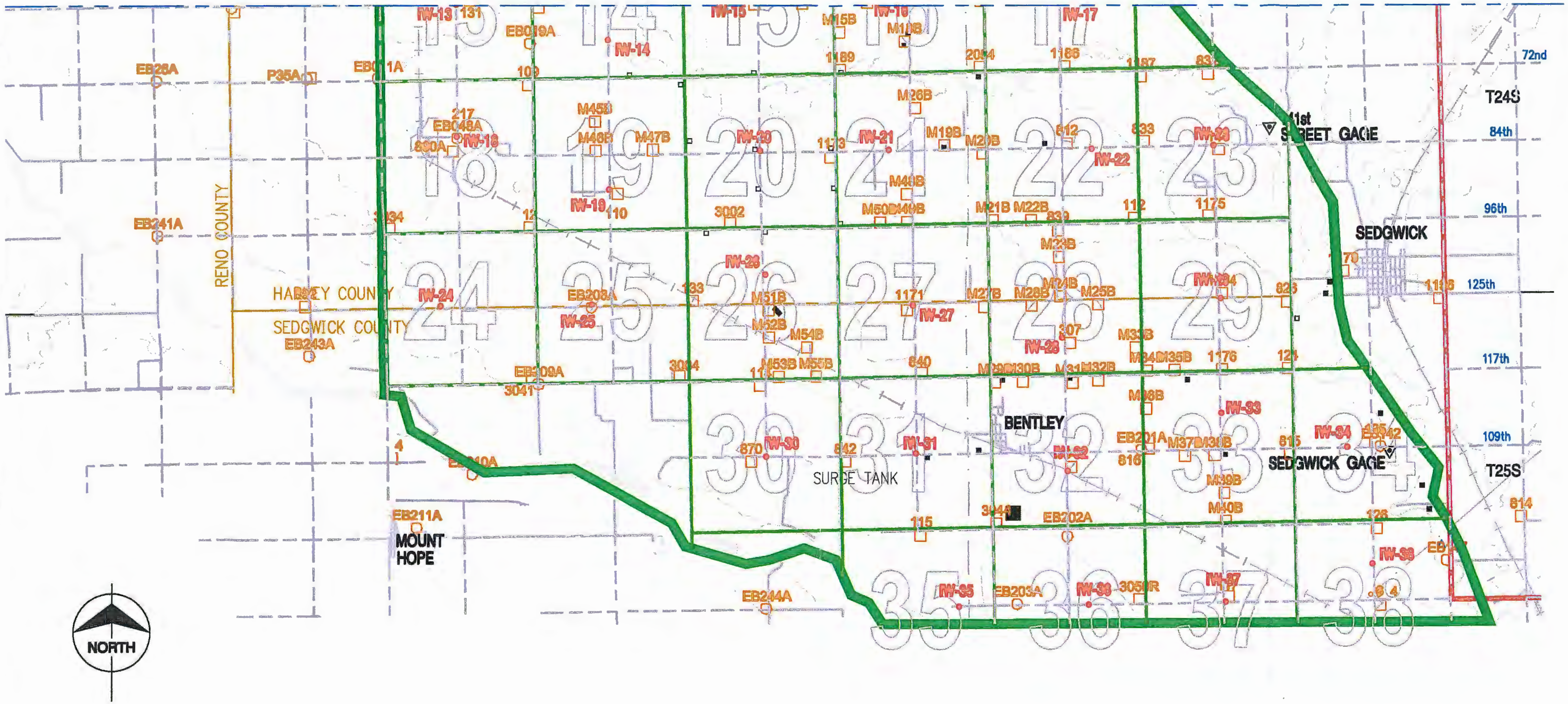
"EB" WELLS ARE PART OF THE GROUNDWATER MANAGEMENT DISTRICT MONITORING SYSTEM.

CITY OF WICHITA

# Monitoring Well Locations

## SHEET 1 OF 2

Burns & McDonnell SINCE 1898




## LEGEND

HISTORICAL MONITORING WELL

INDEX WELL LOCATION (CONSTRUCTED 2001)

STUDY AREA BOUNDARY

35 INDEX AREA

CITY OF WICHITA

# Monitoring Well Locations

## SHEET 2 OF 2

Burns & McDonnell SINCE 1898

Appendix C

Recommended HBMP Monitoring Locations Table

## HBMP Recommended Monitoring Sites

| Map Site No. | Station or ID No. | General Location | Stream Flow | Stream Quality/ Chemistry | Stream Macroinvert./ Benthic | Fisheries | Physical Habitat |
|---|---|---|---|---|---|---|---|
| **City Monitoring Sites** | | | | | | | |
| 1 | NA | Little Arkansas R near Sedgwick-Harvey County Line, KS | | X | | | |
| 2 | NA | Little Arkansas R near 109th N. St., Wichita, KS | | X | | | |
| 3 | NA | Little Arkansas R near 85th N. St., Wichita, KS | | X | | | |
| 4 | NA | Little Arkansas R near 53rd N. St., Wichita, KS | | X | X | | |
| 5 | NA | Little Arkansas R near Central St., Wichita, KS | | X[1] | | | |
| 6 | NA | Arkansas R near Mt. Hope, KS | | X | | | |
| 7 | NA | Arkansas R near Bentley, KS | | X | X | X | X |
| 8 | NA | Arkansas R near 53rd N. St., Wichita, KS | | X | X | X | X |
| 9 | NA | Arkansas R near K-96, Wichita, KS | | X | X | X | |
| 10 | NA | Arkansas R near Twin Lakes, Wichita, KS | | X | X | X | |
| 11 | NA | Arkansas R near Seneca St., Wichita, KS | | X | | | |
| 12 | NA | Arkansas R near Lewis St., Wichita, KS | | X[1] | | | |
| 13 | NA | Arkansas R near Lincoln St., Wichita, KS | | X | X | X | X |
| 14 | NA | Arkansas R near Pawnee St., Wichita, KS | | X[1] | | | |
| 15 | NA | Arkansas R near Herman Hill, Wichita, KS | | X[1] | | X | |
| 16 | NA | Arkansas R near Hydraulic St., Wichita, KS | | X | | | |
| 17 | NA | Arkansas R near 47th St., Wichita, KS | | X | X | X | X |
| 18 | NA | Arkansas R near 63rd St., Wichita, KS | | X | X | X | X |
| 19 | NA | Arkansas R near Derby, KS | | X | X | X | X |
| 20 | NA | Arkansas R near Mulvane, KS | | X | X | X | X |
| 21 | NA | Arkansas R near Hwy 55, Belle Plaine, KS | | X | X | X | X |
| **USGS Gaging Stations** | | | | | | | |
| 30 | 7143665 | Little Arkansas R near Alta Mills, KS | X | X[2] | | | |
| 31 | 7143672 | Little Arkansas R near Hwy 50, Halstead, KS | X | X[2] | | | |
| 32 | 07144100 | Little Arkansas R near Sedgewick, KS | X | X[2] | | | |
| 33 | 07144200 | Little Arkansas R near Valley Center, KS | X | X[2] | | | |
| 34 | 07144300 | Arkansas R near Wichita, KS | X | X[2] | | | |
| 35 | 07144550 | Arkansas R near Derby, KS | X | X[2] | | | |
| 36 | 07143330 | Arkansas R near Hutchison, KS | X | X[2] | | | |
| 37 | 07143375 | Arkansas R near Maize, KS | X | X[2] | | | |

## HBMP Recommended Monitoring Sites

| Map Site No. | Station or ID No. | General Location | Stream Flow | Stream Quality/ Chemistry | Stream Macroinvert./ Benthic | Fisheries | Physical Habitat |
|---|---|---|---|---|---|---|---|
| **KDHE Monitoring Stations** | | | | | | | |
| 50 | SC246 | Little Arkansas R near Alta Mills, KS | | X[3] | | | |
| 51 | SC282 | Little Arkansas R near Valley Center, KS | | X[3] | X | | |
| 52 | No ID | Little Arkansas R near 13th St. in Wichita, KS | | X[4] | | | |
| 53 | SC728 | Little Arkansas R near Wichita, KS | | X[3] | | | |
| 54 | SC729 | Arkansas R near Wichita, KS | | X[3] | | | |
| 55 | No ID | Arkansas R near US54/Kellog St. Wichita, KS | | X[4] | | | |
| 56 | SC281 | Arkansas R near Derby, KS | | X | X | | |
| 57 | No ID | Arkansas R near Belle Plaine, KS | | X[4] | | | |
| 58 | SC524 | Arkansas R near Yoder, KS | | X[3] | | | |
| 59 | SB283 | Arkansas R near Haven, KS (3 Mi. North) | | X[4] | X | | |
| 60 | SC536 | Arkansas R near Maize, KS | | X | | | |
| **Burns & McDonnell Aquatic Monitoring Sites** | | | | | | | |
| 70 | AQM1 | Little Arkansas R near NW 12 Rd. in Halstead Township | | | X | X | X |
| 71 | AQM6 | Little Arkansas R near NW 48 Rd. in Lakin Township | | | X | X | X |
| 72 | AQM9 | Little Arkansas R near S Emma Creek Rd. in Sedgwick Township | | | X | X | X |
| 73 | AQM12 | Little Arkansas R near 55th St. West in Valley Center Township | | | X | X | X |
| 74 | AQM13 | Little Arkansas R near 24th St. W/69th St. N in Park Township | | | X | X | X |

X[1] - Bacteria testing only

X[2] - Sampling schedule varies annually

X[3] - Stream chemistry sampling only

X[4] - Fish tissue sampling only

Appendix D

City's Detailed Current Bio-Monitoring Schedule

## City of Wichita's BioMonitoring Detailed Schedule
(as of January 16, 2004)

| | | Chemical | | | | | | | | | | | | | | Biological | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| * Site No. | Site Location | pH | Temp | D.O. | Conductivity | Ammonia | Nitrates | TKN | Chlorophyll A | Chlorides | Phosphorous | Hardness | Bacteria | Metals | Cyanide | Fish | Benthic | Phy-Hab |
| 1 | Little Arkansas R near Sedgwick-Harvey County Line, KS | x | x | x | x | x | x | | | | x | | x | | | | | |
| 2 | Little Arkansas R near 109th N. St., Wichita, KS | x | x | x | x | x | x | | | | x | | x | | | | | |
| 3 | Little Arkansas R near 85th N. St., Wichita, KS | x | x | x | x | x | x | | | | x | | x | | | | | |
| 4 | Little Arkansas R near 53rd N. St., Wichita, KS | x | x | x | x | x | x | | x | | x | | x | | | | x | |
| 5 | Little Arkansas R near Central St., Wichita, KS | | | | | | | | | | | | x | | | | | |
| 6 | Arkansas R near Mt. Hope, KS | x | x | x | x | x | x | | | | x | | x | | | | | |
| 7 | Arkansas R near Bentley, KS | x | x | x | x | | | | | | | | | | | x | x | x |
| 8 | Arkansas R near 53rd N. St., Wichita, KS | x | x | x | x | x | x | | x | x | x | x | x | x | x | x | x | x |
| 9 | Arkansas R near K-96, Wichita, KS | x | x | x | x | | | | | | | | x | | | x | x | |
| 10 | Arkansas R near Twin Lakes, Wichita, KS | x | x | x | x | | | | | | | | | | | x | x | |
| 11 | Arkansas R near Seneca St., Wichita, KS | x | x | x | x | x | x | | | | x | | x | | | | | |
| 12 | Arkansas R near Lewis St., Wichita, KS | | | | | | | | | | | | x | | | | | |
| 13 | Arkansas R near Lincoln St., Wichita, KS | x | x | x | x | | | | | | | | | | | x | x | x |
| 14 | Arkansas R near Pawnee St., Wichita, KS | | | | | | | | | | | | x | | | | | |
| 15 | Arkansas R near Herman Hill, Wichita, KS | | | | | | | | | | | | x | | | x | | |
| 16 | Arkansas R near Hydraulic St., Wichita, KS | x | x | x | x | x | x | | | | x | | x | | | | | |
| 17 | Arkansas R near 47th St., Wichita, KS | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| 18 | Arkansas R near 63rd St., Wichita, KS | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| 19 | Arkansas R near Derby, KS | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| 20 | Arkansas R near Mulvane, KS | x | x | x | x | | | | | | | | | | | x | x | x |
| 21 | Arkansas R near Hwy 55, Belle Plaine, KS | x | x | x | x | | | | | | | | | | | x | x | x |
| | **Sampling Frequency** | F | F | F | F | M | M | M | M | M | M | M | M | M | M | A | B | B |

M=monthly; B=bi-annual; A=annual; F=any field visit

LA = Little Arkansas River

BA = Arkansas River above confluence with the Little Arkansas River

AR = Arkansas River below confluence with Little Arkansas River

" * " Denotes that site numbers correspond with the HBMP Recommended Monitoring Sites Map.

Appendix E

Water Quality Study of the Arkansas River
Phase II Report November 2003 (CD)

THIS EXHIBIT CONTAINS A DISK RELATED TO THE HYDROBIOLOGICAL MONITORING PLAN FOR THE INTEGRATED LOCAL WATER SUPPLY PROJECT

COPIES OF THIS DISK ARE NOT BEING DISTUBUTED TO THE PARTIES BUT CAN BE MADE AVAILABLE ON REQUEST

# EXHIBIT L

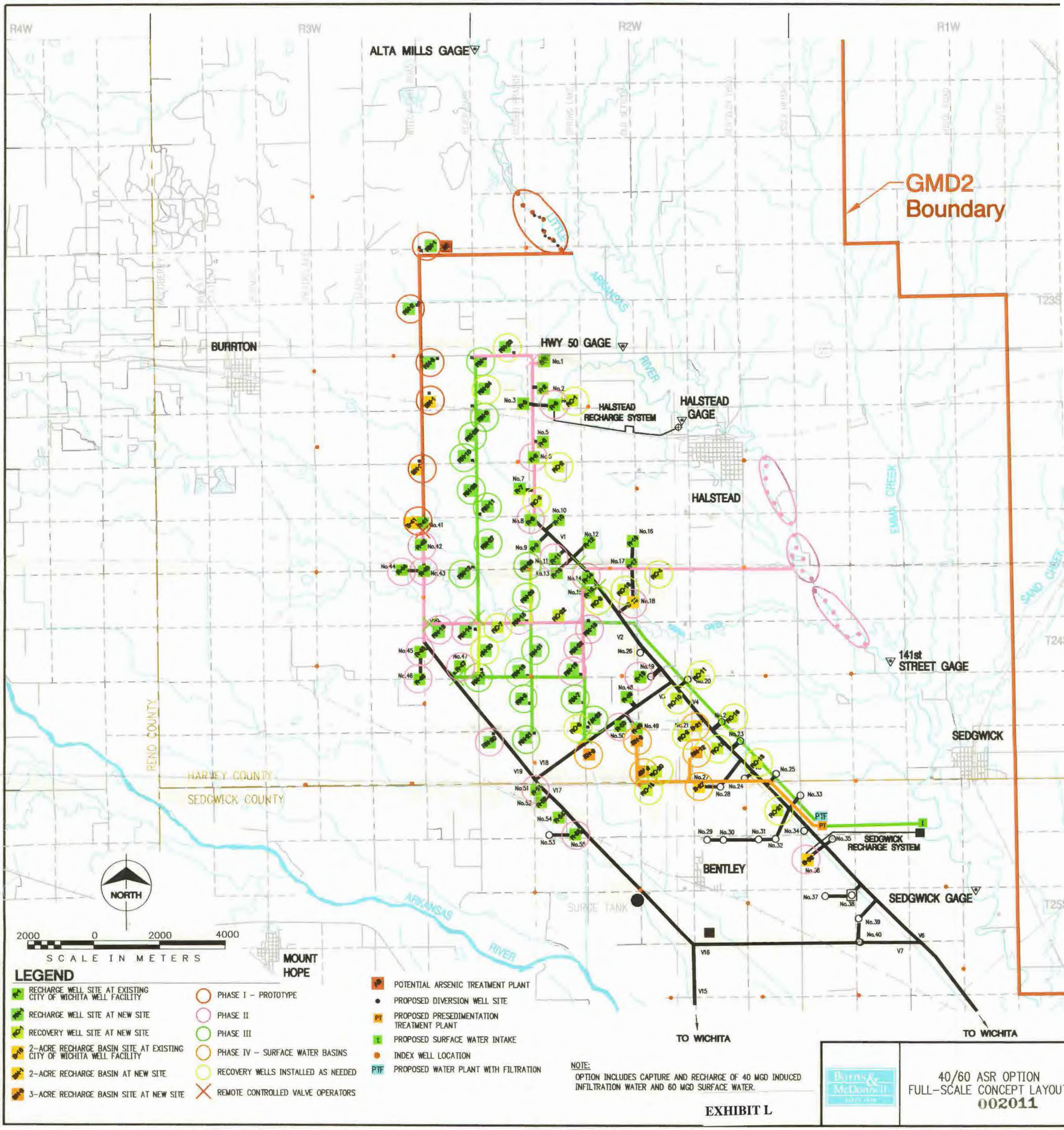
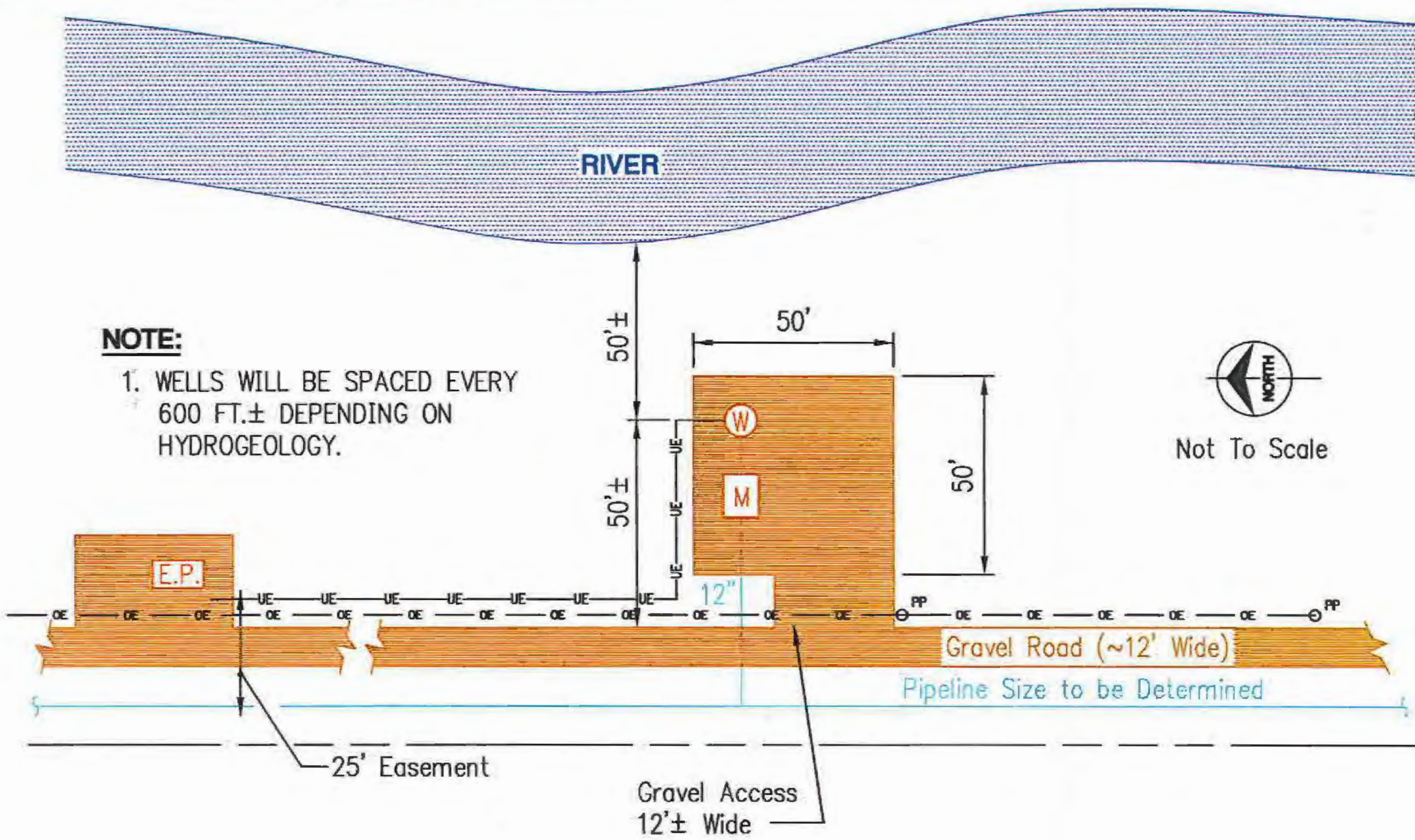

R4W
R3W
R2W
R1W
ALTA MILLS GAGE
GMD2 Boundary
HWY 50 GAGE
BURRTON
HALSTEAD RECHARGE SYSTEM
HALSTEAD GAGE
HALSTEAD
ARKANSAS RIVER
LITTLE ARKANSAS RIVER
EMMA CREEK
SAND CREEK
141st STREET GAGE
SEDGWICK
RENO COUNTY
HARVEY COUNTY
SEDGWICK COUNTY
SEDGWICK RECHARGE SYSTEM
BENTLEY
SURGE TANK
SEDGWICK GAGE
MOUNT HOPE
TO WICHITA
TO WICHITA
NORTH
2000 0 2000 4000
SCALE IN METERS
LEGEND
RECHARGE WELL SITE AT EXISTING CITY OF WICHITA WELL FACILITY
RECHARGE WELL SITE AT NEW SITE
RECOVERY WELL SITE AT NEW SITE
2-ACRE RECHARGE BASIN SITE AT EXISTING CITY OF WICHITA WELL FACILITY
2-ACRE RECHARGE BASIN AT NEW SITE
3-ACRE RECHARGE BASIN SITE AT NEW SITE
PHASE I - PROTOTYPE
PHASE II
PHASE III
PHASE IV - SURFACE WATER BASINS
RECOVERY WELLS INSTALLED AS NEEDED
REMOTE CONTROLLED VALVE OPERATORS
POTENTIAL ARSENIC TREATMENT PLANT
PROPOSED DIVERSION WELL SITE
PROPOSED PRESEDIMENTATION TREATMENT PLANT
PROPOSED SURFACE WATER INTAKE
INDEX WELL LOCATION
PROPOSED WATER PLANT WITH FILTRATION
NOTE:
OPTION INCLUDES CAPTURE AND RECHARGE OF 40 MGD INDUCED INFILTRATION WATER AND 60 MGD SURFACE WATER.
Burns & McDonnell
40/60 ASR OPTION
FULL-SCALE CONCEPT LAYOUT
002011

EXHIBIT L

# EXHIBIT M



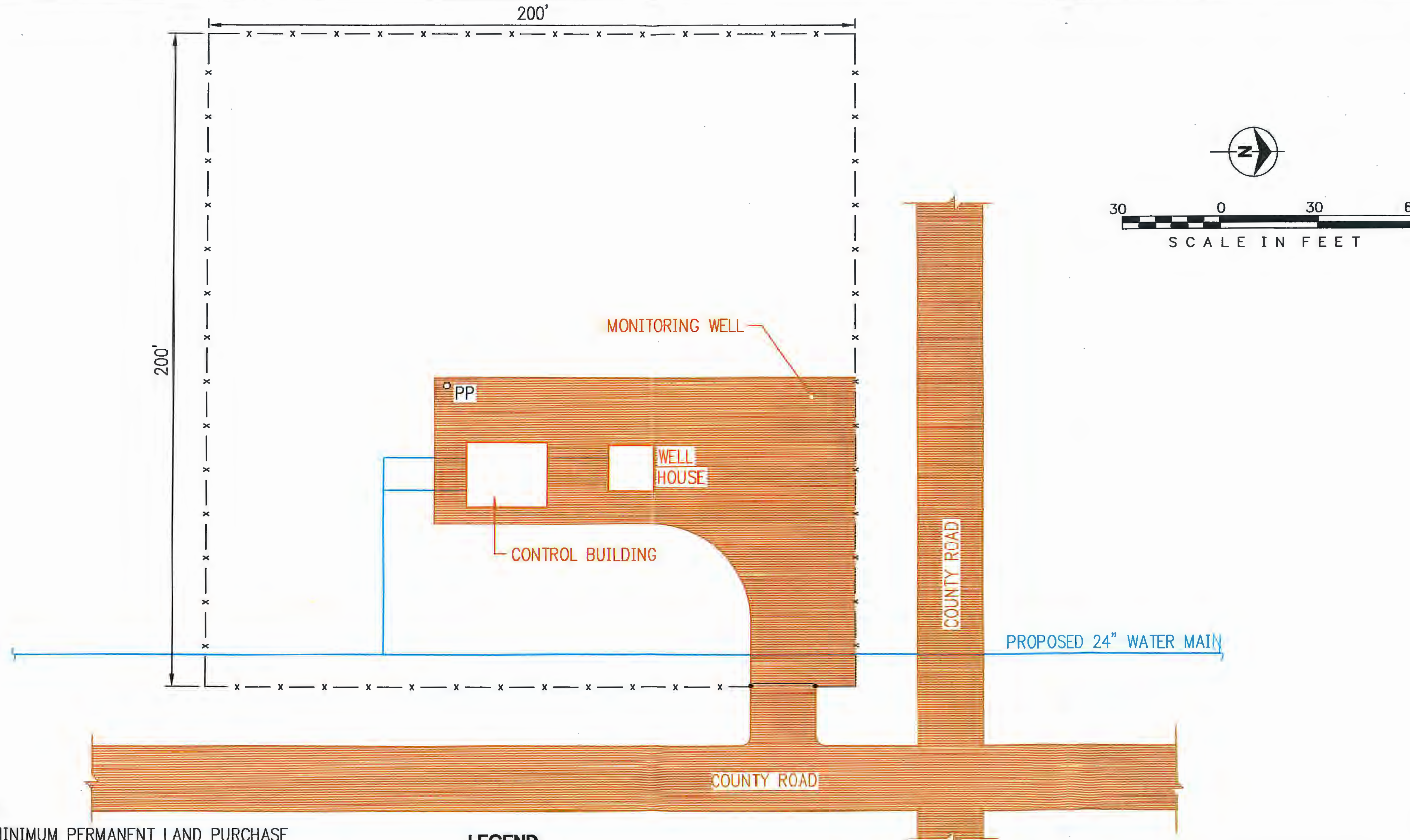

## LEGEND

| | |
|---|---|
| GRAVEL | — OE — OVERHEAD ELECTRIC |
| (W) WELL (SUBMERSIBLE PUMP) | — UE — UNDERGROUND ELECTRIC |
| [M] METER VAULT | — x — FENCE |
| [E.P.] ELEVATED PLATFORM | |

Burns & McDonnell
SINCE 1898

PRELIMINARY
DIVERSION WELL
SITE SCHEMATIC

# EXHIBIT N




**NOTE:**

1. MINIMUM PERMANENT LAND PURCHASE OF APPROXIMATELY 1/4 ACRE.
2. CONSTRUCTION EASEMENT OF AN ADDITIONAL 1/4 ACRE.
3. WELLHEAD PROTECTION RULES REQUIRES MINIMUM OF 100 FEET CONTROL AREA AROUND WELLS

**LEGEND**

— x — x — FENCE / PROPERTY LINE

GRAVEL

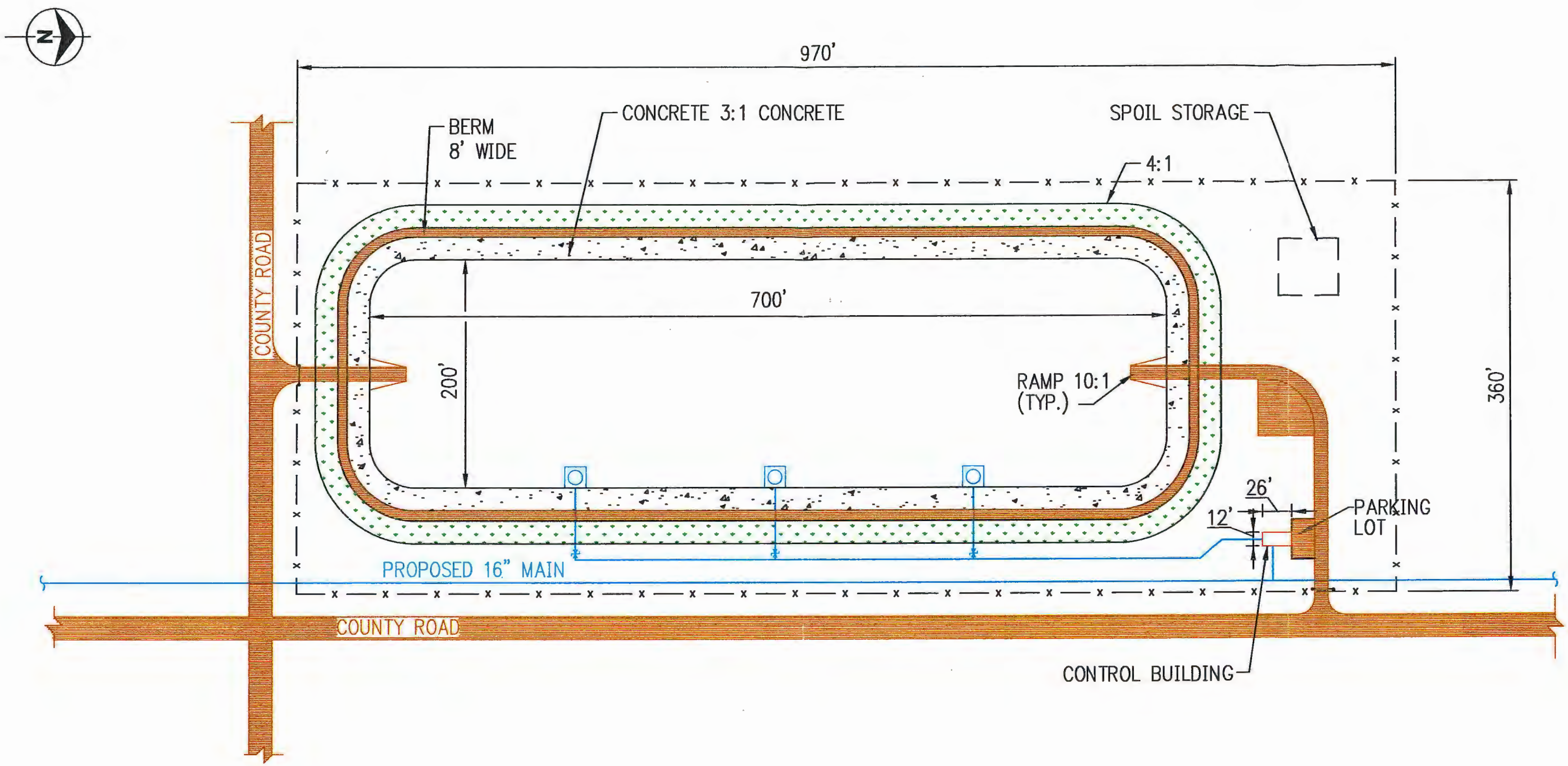
Burns & McDonnell SINCE 1898

TYPICAL RECHARGE WELL SITE SCHEMATIC

J:\WI... TA\29886 ASR-P1\procws\FIG_2.dwg 12-18-2002 09:40 A...

002013

# EXHIBIT O




**LEGEND**

- GRAVEL
- GRASS
- CONCRETE
- FENCE / PROPERTY LINE
- INLET STRUCTURE

100 0 100 200
SCALE IN FEET

Burns & McDonnell SINCE 1898

TYPICAL RECHARGE BASIN SITE SCHEMATIC

FIG_3.d 01-17-2003 14:12 mjc

002014

# EXHIBIT P
# [VACANT]

# EXHIBIT Q

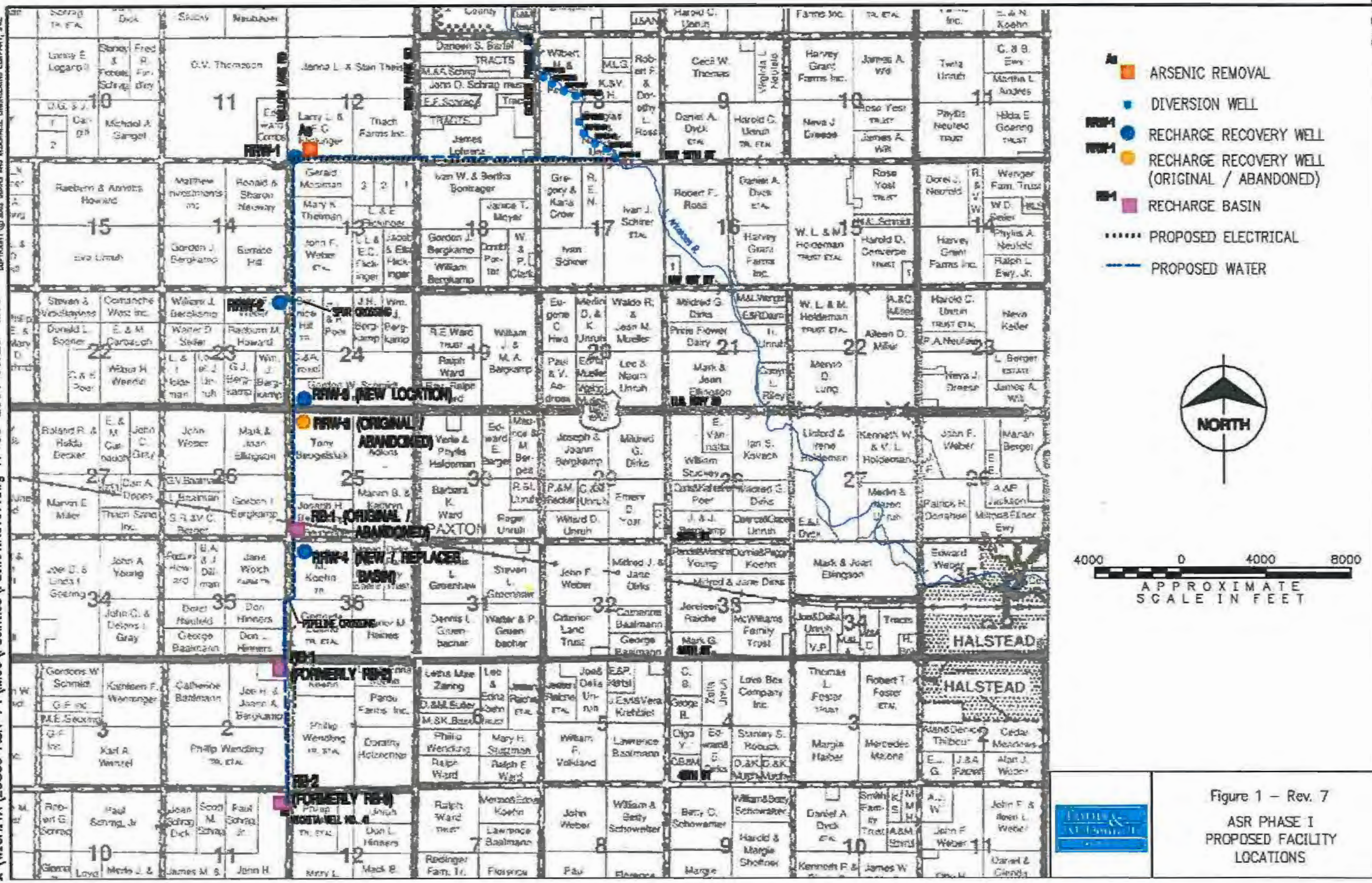



Figure 1 – Rev. 7
ASR PHASE I
PROPOSED FACILITY LOCATIONS

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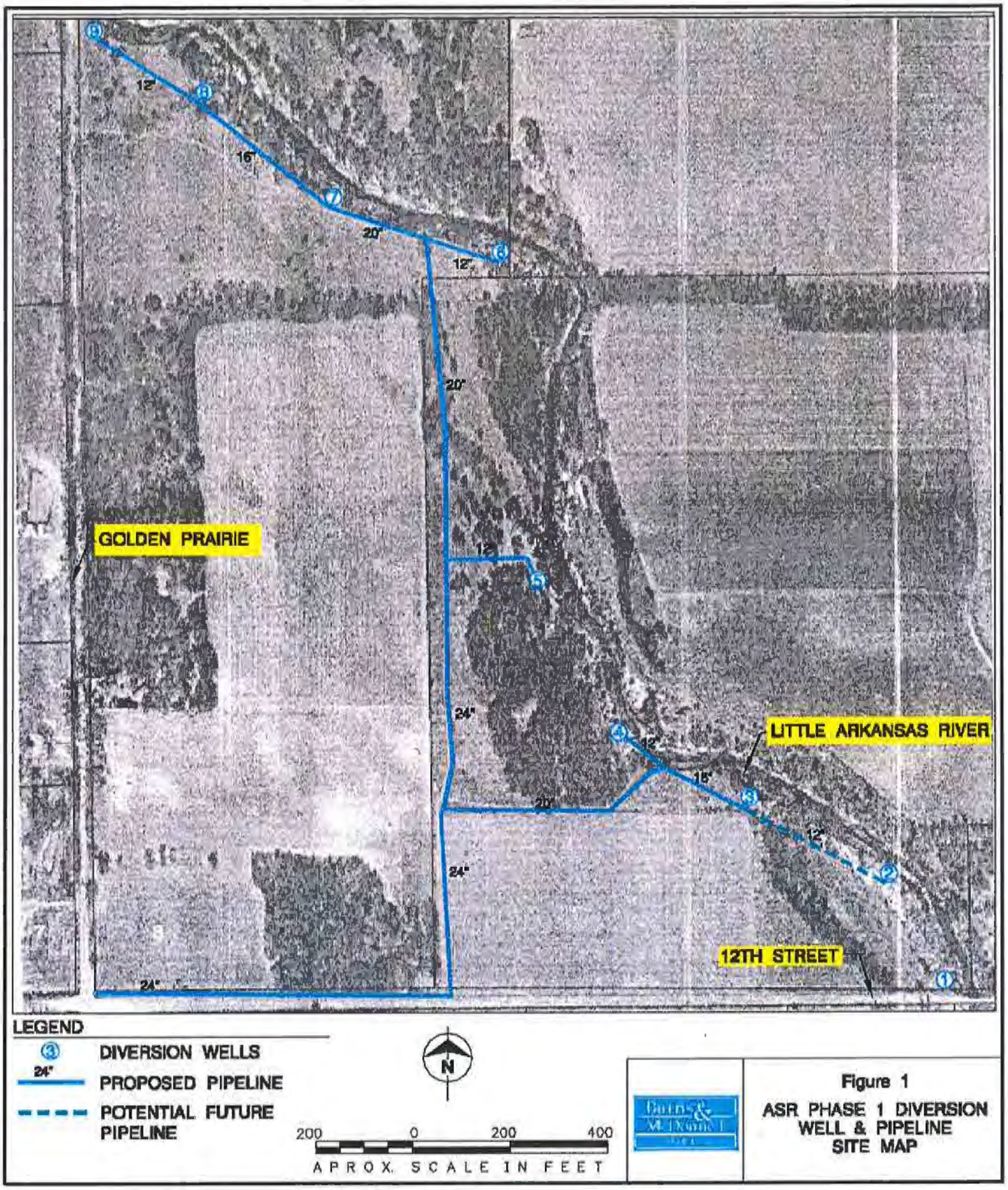
0002016

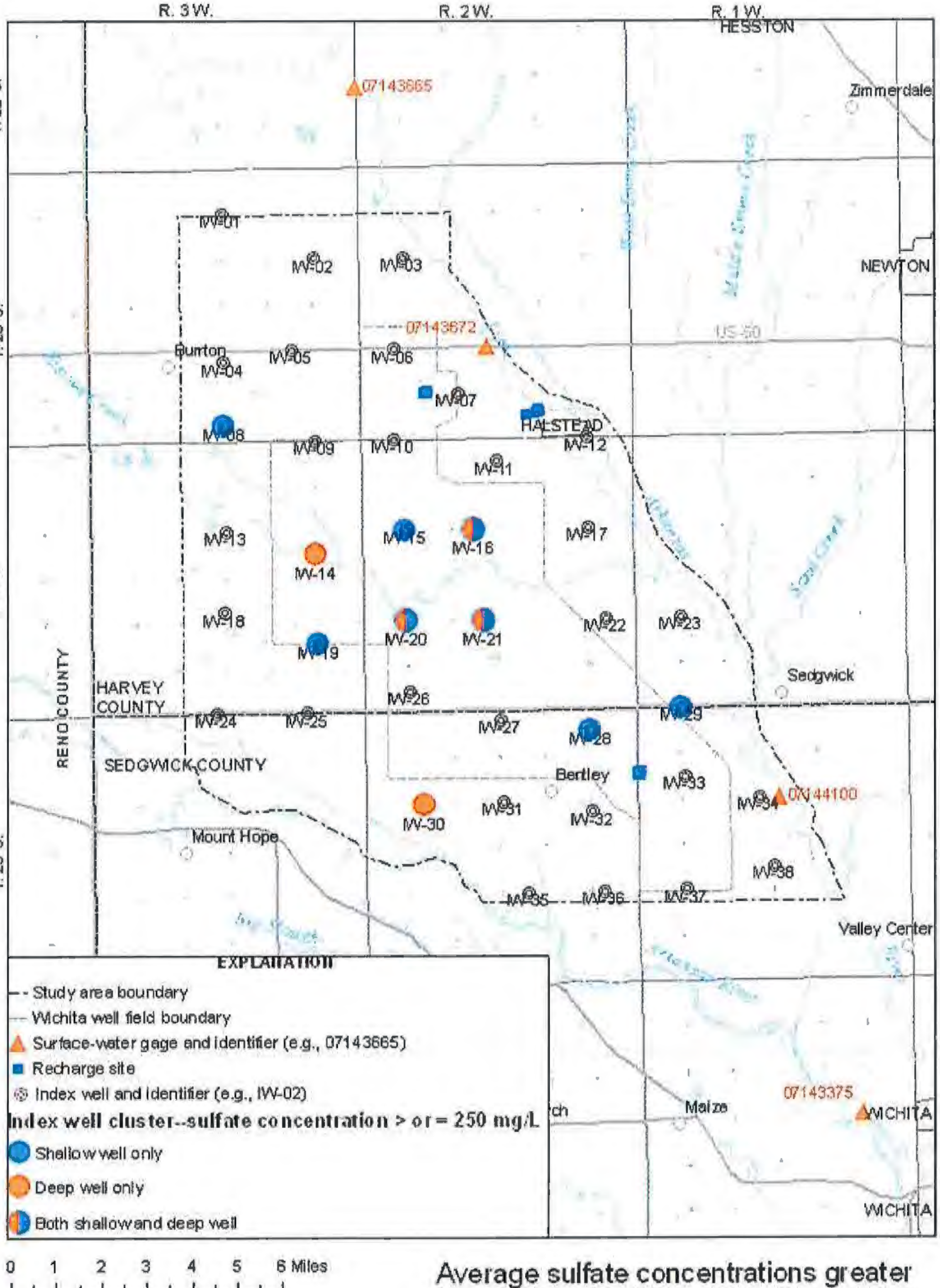
# EXHIBIT R




J:\WICHITA\29886 ASR-P1\Misc\Facilities\wichimage1.dwg 11-03-2004 11:09 MJC
13" X 11"

PLOT AT 11" X 17" TO KEEP CORRECT SCALE. CUT AT ABOVE CUTLINE FOR MOUNT BOARD

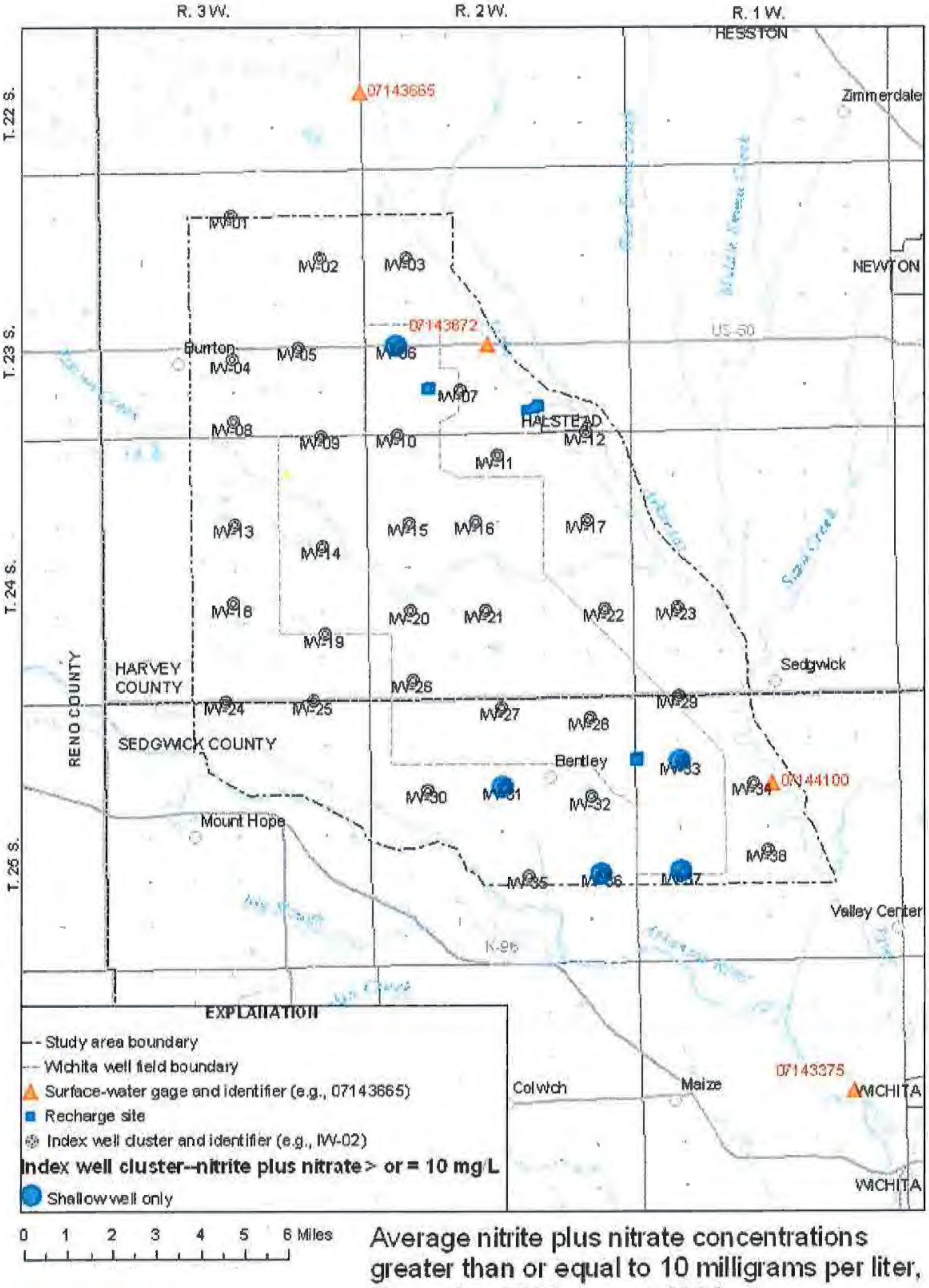
# EXHIBIT S




Average sulfate concentrations greater than or equal to 250 milligrams per liter, November 2001-August 2004

USGS

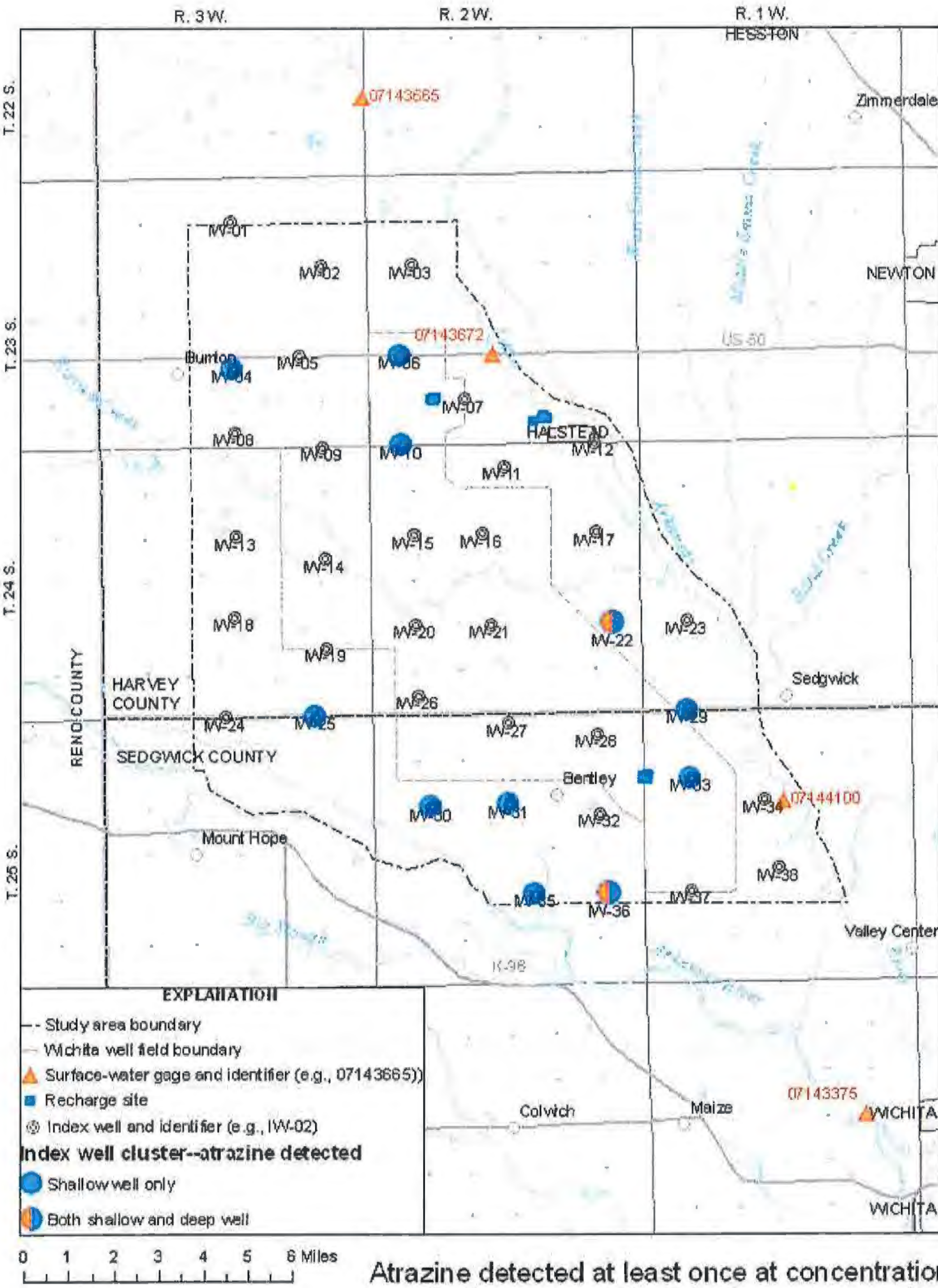
# EXHIBIT T




Average nitrite plus nitrate concentrations greater than or equal to 10 milligrams per liter, November 2001-August 2004.

USGS

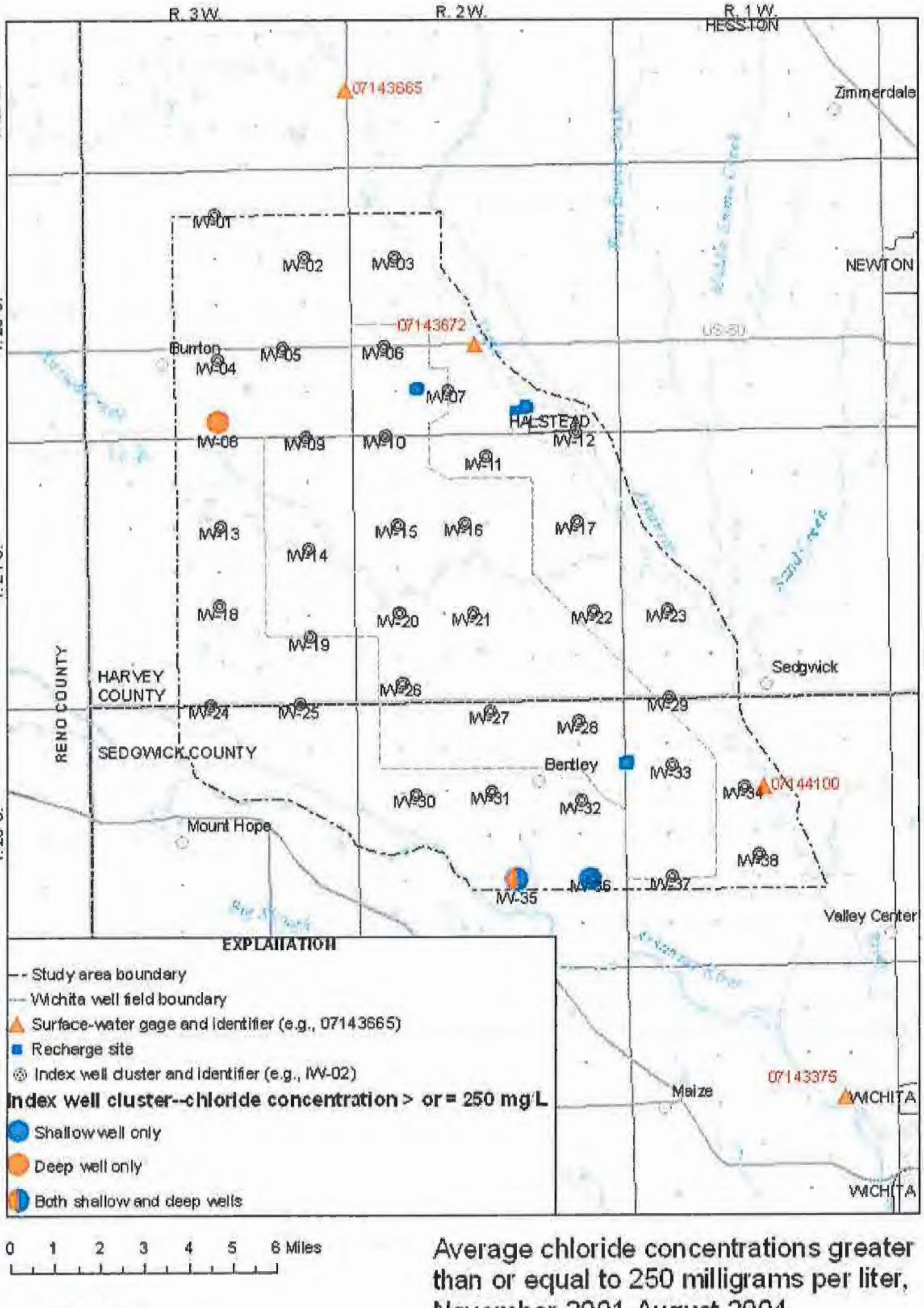
# EXHIBIT U




Atrazine detected at least once at concentrations greater than or equal to 0.1 micrograms per liter, November 2001-August 2004.

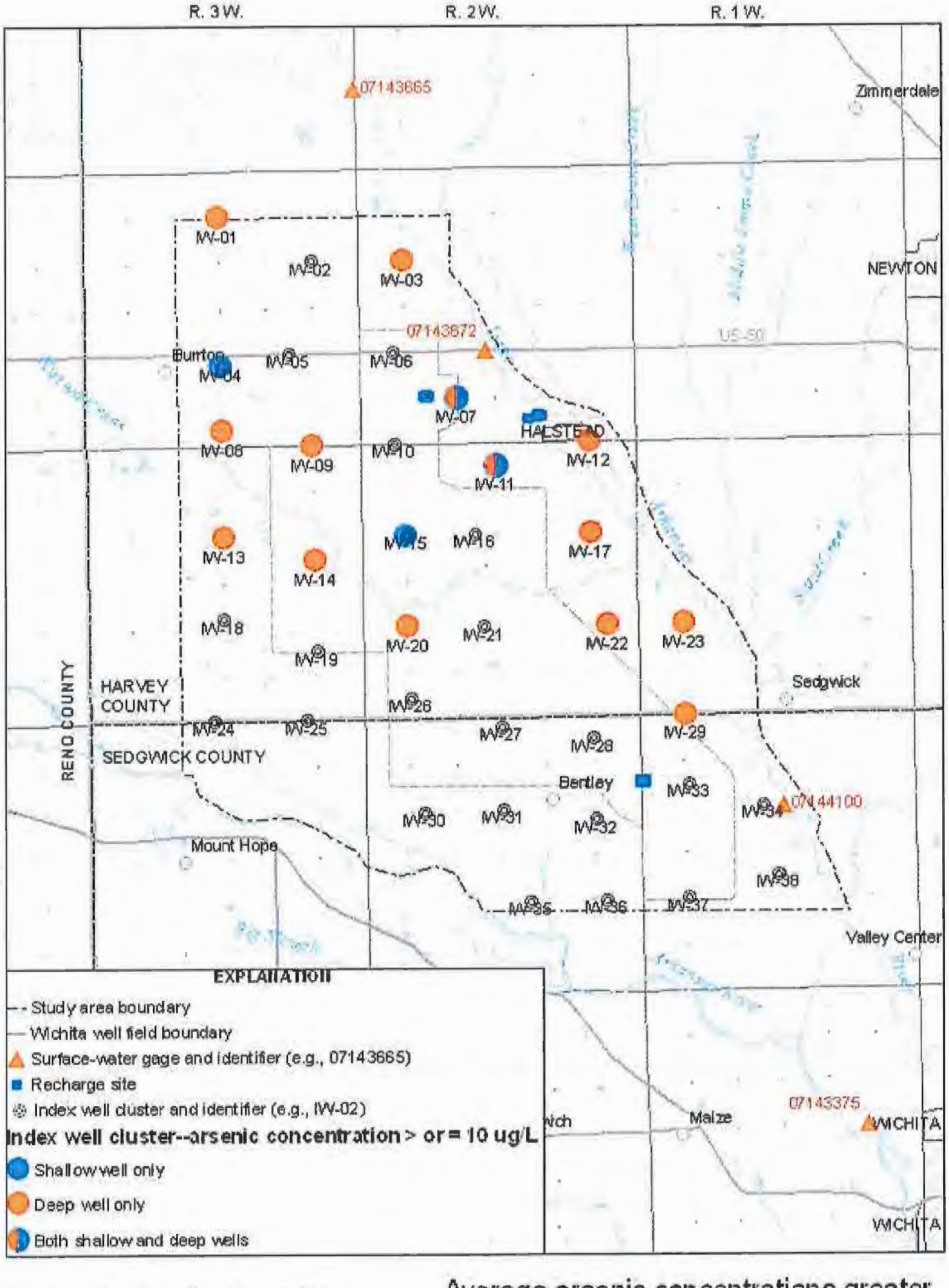
USGS

# EXHIBIT V




Average chloride concentrations greater than or equal to 250 milligrams per liter, November 2001-August 2004.

# EXHIBIT W

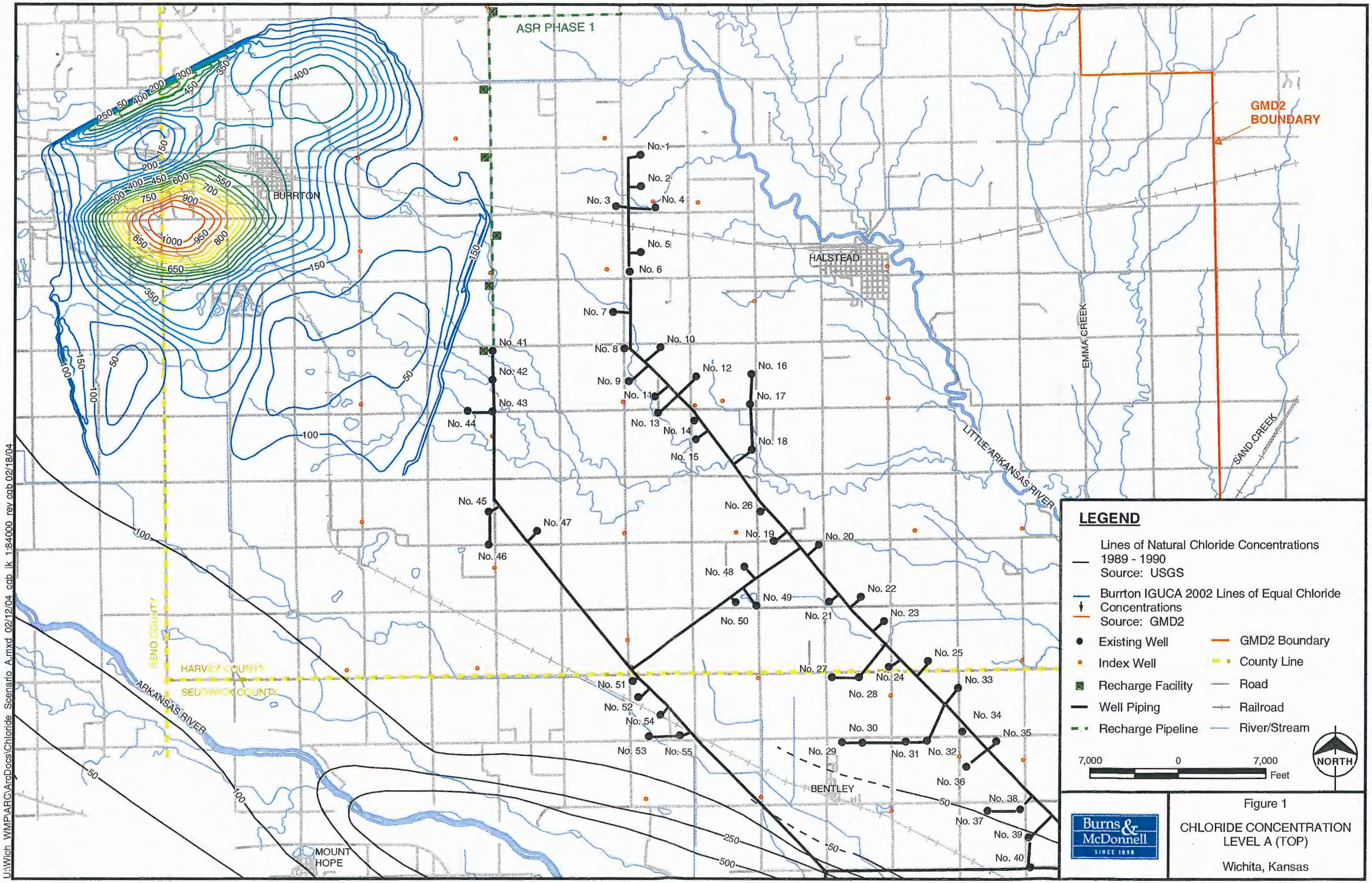



≋USGS

Average arsenic concentrations greater than or equal to 10 micrograms per liter, November 2001-August 2004.

002022

# EXHIBIT X

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002023

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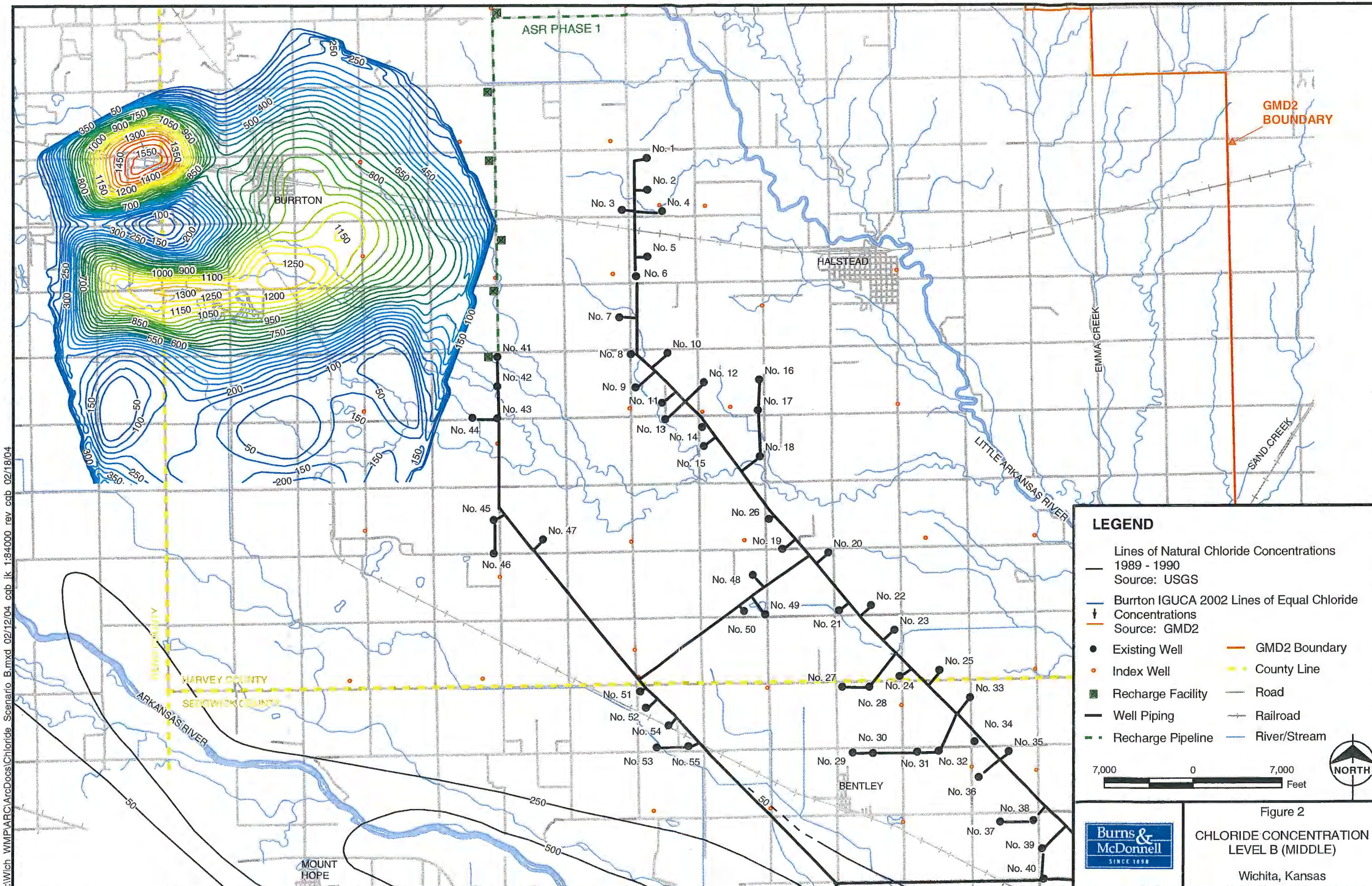


Figure 2
CHLORIDE CONCENTRATION LEVEL B (MIDDLE)
Wichita, Kansas

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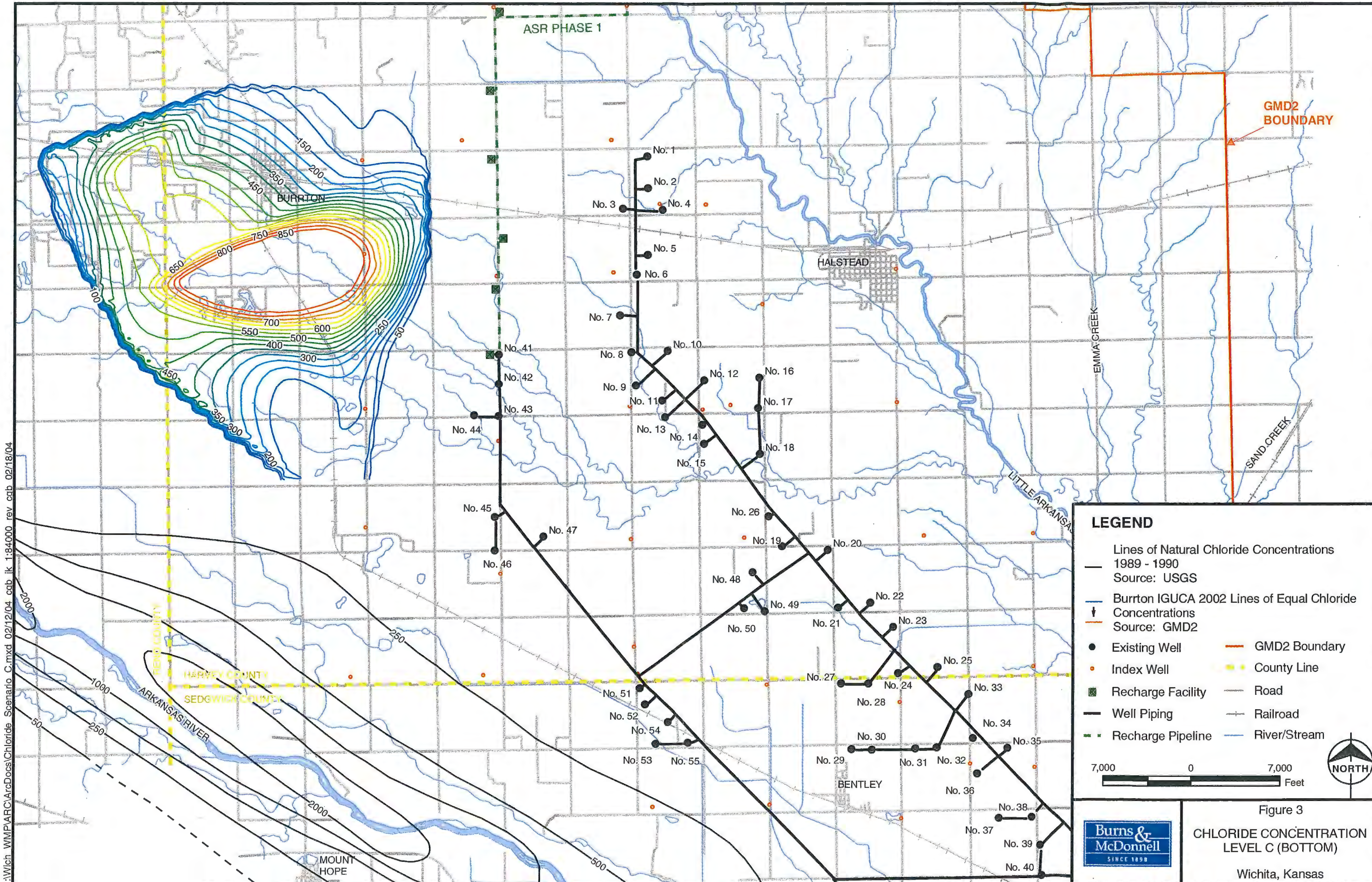
# EXHIBIT Z


U:\Wich WMP\ARC\ArcDocs\Chloride Scenario C.mxd 02/12/04 cab ik 1:84000 rev cab 02/18/04
ASR PHASE 1
GMD2 BOUNDARY
BURRTON
HALSTEAD
BENTLEY
MOUNT HOPE
EMMA CREEK
SAND CREEK
LITTLE ARKANSAS
ARKANSAS RIVER
HARVEY COUNTY
SEDGWICK COUNTY
No. 1
No. 2
No. 3
No. 4
No. 5
No. 6
No. 7
No. 8
No. 9
No. 10
No. 11
No. 12
No. 13
No. 14
No. 15
No. 16
No. 17
No. 18
No. 19
No. 20
No. 21
No. 22
No. 23
No. 24
No. 25
No. 26
No. 27
No. 28
No. 29
No. 30
No. 31
No. 32
No. 33
No. 34
No. 35
No. 36
No. 37
No. 38
No. 39
No. 40
No. 41
No. 42
No. 43
No. 44
No. 45
No. 46
No. 47
No. 48
No. 49
No. 50
No. 51
No. 52
No. 53
No. 54
No. 55
LEGEND
Lines of Natural Chloride Concentrations 1989 - 1990 Source: USGS
Burrton IGUCA 2002 Lines of Equal Chloride Concentrations Source: GMD2
Existing Well
Index Well
Recharge Facility
Well Piping
Recharge Pipeline
GMD2 Boundary
County Line
Road
Railroad
River/Stream
7,000 0 7,000 Feet
NORTH
Burns & McDonnell SINCE 1898
Figure 3
CHLORIDE CONCENTRATION LEVEL C (BOTTOM)
Wichita, Kansas

# EXHIBIT AA

CITY OF WICHITA

INTEROFFICE MEMORANDUM

**TO:** Chris Cherches, City Manager

**FROM:** David Warren, Dir. of Water and Sewer

**SUBJECT:** Water Supply Plan Workshop Summary

**DATE:** July 31, 2001

In response to a recommendation by the Staff Screening and Selection Committee, on July 10 and 11 we hosted a workshop/idea exchange on the City's Water Supply Plan. The City used the services of a man with an outstanding national reputation, Mr. Rob Renner, Deputy Executive Director of the American Waterworks Association, as the facilitator of the workshop. The City invited a number of nationally recognized experts in water supply planning, water treatment, and hydrology, to serve on this blue ribbon panel, and finally secured the participation of six exceptional individuals. Participants in the workshop included Mr. Peter Binney, Mr. Yasser Abou-Aish, Dr. John Bredehoeft, Dr. Jeff Featherstone, Dr. Neil Grigg, and Mr. Mike Personnett.

The goal of the workshop was to review all of the components of our water supply plan and to stimulate a brainstorming session to rate the ideas currently in the plan, and to see if there are other options that we should be pursuing that are currently not in the plan.

To facilitate those discussions, the workshop began with a presentation from Burns & McDonnell, who helped to create the existing Plan. That presentation was followed by a presentation from Camp Dresser and McKee, who has developed some other water supply concepts that they would like the City to consider. These presentations provided a strong starting point for the panel's evaluations.

I feel that the panel held very insightful discussions about the City's existing water supply plan, and also about other alternatives that the City might want to pursue. As a result of their discussions, the panel developed a number of recommendations to the City. Key among the recommendations was an overall affirmation of the City's existing Plan. The panel recommended that the City proceed with the initial projects identified in the Plan. They recommended doing the first phase of the Aquifer Storage and Recovery Project, so that the City can develop more knowledge on the best components of the full-scale ASR project, and to begin to form a hydraulic barrier to the salt-water contamination from the Burton area. They also recommended that the City proceed with Phase One of the Local Wellfield expansion, and the redevelopment of the Bentley Reserve Wellfield. They felt that all of these projects are essential to meeting the City's future water supply needs.

The panel felt that recent improvements in technology, particularly the reverse osmosis membrane process, could play a role in improving the existing plan. However they felt that additional research would be needed before the City should commit to that technology. They therefore recommended that the City complete a feasibility project to evaluate the use of reverse osmosis technology. They recommend that this occur concurrently with the first phase projects so that the City will be in position to decide if, and how, to use this technology for the next phase of the project.

The panel also recommended a number of other items to investigate, including doing an operations study of Cheney Reservoir to see how its usage can be enhanced as part of the Water Supply Plan, and investigating if irrigation demand management in the Equus Beds could be a successful component of the Plan.

In general, the panel expressed that the City's plan appears to be an innovative, and viable, way to meet the City's future water supply needs. They emphasized that the City should remain flexible as it follows the Plan, and be ready and able to take advantage of any new technologies that might be developed that could enhance the Plan, and to continue to build the facilities in as small of stages as possible so that the Plan can remain as flexible as possible for as long as possible. I feel that this recommendation serves as an affirmation of the approach that our staff has been following. We intend to use the Plan as a map, with many potential routes, and not as a single path that should be followed exactly.

Before we started the workshop, we had estimated that the workshop would cost $25,000 to $30,000. I am happy to report that the expenses and professional fees for the workshop totaled just under $24,000. One of the reasons we were able to meet our expense goal was because the American Water Works Association paid the professional fees and expenses for Mr. Renner to participate in the workshop.

This workshop represented a new approach to reviewing major project commitments, and I think it was a very sound investment by the City.

I have attached a copy of the recommendations generated by the workshop.

xc: Jerry Blain, Superintendent of Production and Pumping

# Recommendations RE: Wichita Water Supply Plan (7/11/01)

* Should be initial Phase of Plan (Focus is E.B.A. Management)

* Near-term objectives
    - Protect Quality of E.B.A. and increase water levels of E.B.A.
    - Incease supply availability to City
    - Defer decisions/investments in additional ASR or surface water development

## Near-Term Plan

* Implement
    - Phase I ASR to block salt plume & add water to E.B.A.
    - Increase use of Cheney Reservoir supply to conserve/bank E.B.A. supply
    - Conservation/demand management
    - Develop local and Bentley reserve well fields
    - Apply for Big Ark water rights

* Investigate (By end of 2003)
    - Irrigation Demand Management (Options, cost, acceptability, etc)
    - Reuse and non-potable sources (Opportunities, costs, pricing, etc).
    - Cheney Reservoir Operations Study
        - Historic Inflows/Outflows
        - Minimize spills
        - Drop levels after recreational season
        - Try not to encroach on flood pool
    - Why E.B.A. has recovered since 1993?
    - R.O. Feasibility (Treatability, cost, etc)
        - Bentley Well Field as source
    - ASR (If, when, how, what sources; Water Quality; anticipated regulations)
    - Technical Peer Review/Audit
        - Compliments internal program management
    - Systems Operations/System Capacity Expansion Study

(e.g., How much can existing supply & infrastructure provide; when is additional resource development and/or infrastructure development needed?)

How do you balance projects with different unit costs to obtain a true I.R.P.?

RFP would include:

*Linear optimization/hydrologic water balance model including all sources of potential supply/demand based on current sources/infrastructure

*Consider individual project element unit cost versus quantity relationships

*Would not be issued until other studies are completed (Cheney, E.B.A., etc.)

*Use decision support modeling techniques to develop alternative plans and risk assessments under a range of hydrologic conditions

*Describe a preferred plan that best meets the City's needs to 2050

<u>Long-term Issues/Decisions</u>

* If, when, how (sources) do you expand E.B.A. ASR?

* If, when, how do you develop Big Ark surface water supply?

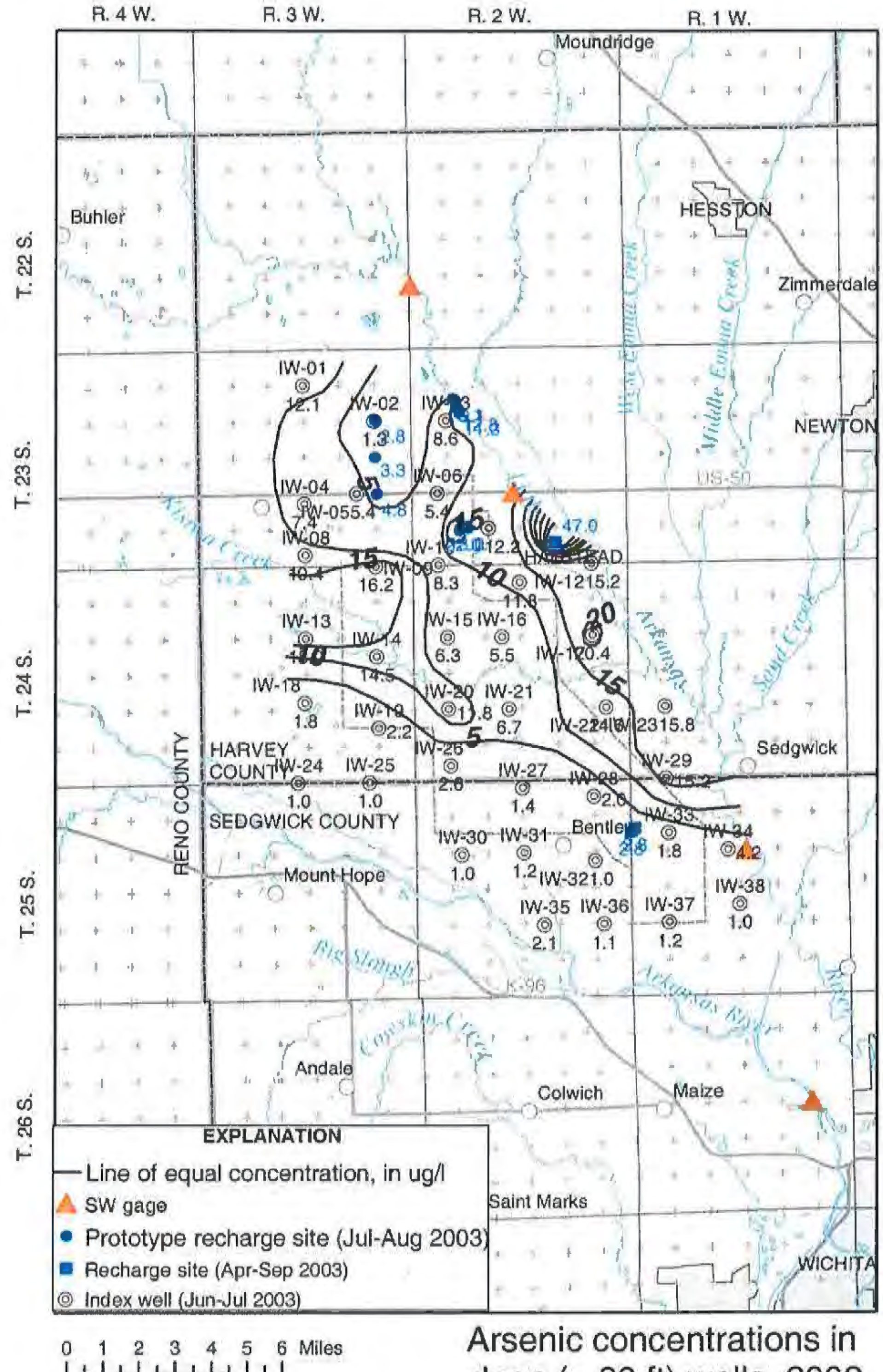
* When/how do you expand or develop new infrastructure?
  Production/delivery capacity of E.B.A.
  Water treatment capacity/location
  Conveyance of water from Cheney Reservoir (e.g., parallel existing line, convey to E.B.A.)

*Reuse - If, when, how (e.g., reclaimed water, stormwater, other) sources for non-potable uses

*Drought Management -

How much risk is city/public willing to accept?
How much/often curtailment is acceptable?
How much are folks willing to pay for a given level of supply reliability?
What % of demand will we meet in Drought of Record with supply strategies?
How much with Demand Management?

# EXHIBIT BB




Arsenic concentrations in deep (> 80 ft) wells, 2003

# EXHIBIT CC

RECEIVED
OCT 4 7 2002
EQUUS BEDS GROUNDWATER MANAGEMENT DISTRICT NO. 2

NARRATIVE

On August 27, 2002 I received an e-mail requesting assistance with a row of trees that had died next to a City of Wichita groundwater recharge demonstration project located southeast of the town of Halstead. A meeting was to be held at the Groundwater Management District No. 2 office in Halstead on August 29, 2002 at 8:00 A.M. I was requested to be at the meeting to discuss the issue and perform a site visit. I called Jim Foster, another Investigator with the Kansas Department of Agriculture to also be present at the meeting.

On August 29, 2002 at about 8:00 A.M. Jim Foster and I met at the GMD No. 2 office located at 313 Spruce, Halstead, Kansas 67056. Also present were Dennis Carlson, a District Forester for the Kansas Forest Service and Michael Dealy, Manager for GMD No. 2. We presented our credentials and offered our business cards to Dennis and Mike. We began with Mike giving us an overview of the project and explaining the problem with the trees to us.

Mike explained that the site located southeast of Halstead was used to recharge water back into the equus beds. The water used for this project was drawn from the Little Arkansas River and piped approximately three miles to the site. Mike explained that Powder Activated Carbon (P.A.C.) was added to the water after it is pumped from the river. When the water reaches the recharge site it goes into a presedimentation basin before being pumped into one of three final recharge basins. Mike said that the water was cleaned up to drinking water quality before being recharged into the ground. Mike went on to explain that there are numerous monitoring wells around the project that are sampled by the United States Geological Survey (USGS) and that the records indicate that there is some atrazine present in the groundwater in small amounts but that no other chemicals they have checked for have been present and that records of all water testing was available if needed.

I asked when the facility was constructed and when did they notice damage to the trees and Mike replied in September 1997 the project was completed and turned over to the city. The trees to his knowledge began to die about 1 ½ years ago (spring of 2001). We then drove to the site for a site visit.

When we arrived we drove to the gate at the center of the project. The project is located at 11414 N 119th St. West in Sedgwick County. We immediately noticed the dead trees to the south of the project. The recharge project was not in operation at the time. I asked how long it had been since the recharge was in use. Mike replied that the city had not run the site in 2001 or 2002. Mike, Dennis Jim and I walked to the south end of the project and walked along the outside of the fence inspecting the tree row. The tree row was Siberian Elms in two parallel rows. Directly south of the recharge project both rows of elms were dead. When we reached the back of the project the north row of elms was dead for about 100 - 150 feet farther but the south row of trees was still alive. The farther east we walked the trees looked better. In the tree row at the east end of the project it appeared that a ridge of soil existed between the rows of trees. I asked Dennis if this was natural and he replied that he has seen soil particles that tree rows slow down through the years fall out and form a ridge in the tree rows.

As we walked back to the back fence of the recharge project the soil ridge ended. As we walked we discussed several other points of the project. Could the water level underground had raised and damaged the root systems of the trees. Mike replied that at any time the water level was about 25 feet beneath the surface. When the roject was in operation about 1000 gallons of water per minute was being recharged into the soil and the recharge ponds would barely maintain six inches of water in them because the soil is so sandy in the area. Mike also said that the water level in the test wells never raised by more than six to twelve inches, which would have

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EQUUS BEDS GROUNDWATER
MANAGEMENT DISTRICT NO. 2

kept the water level far below level of the feeder roots of trees.

Mike asked about the possibility of agricultural chemical damaging the trees. To the north and east of the recharge was milo and soybeans were planted south of the tree row. I explained to Mike that I felt an agricultural herbicide like atrazine, (commonly used in corn and milo) could not have been applied at a high enough rate to damage the trees without doing damage to the crops and if crops would have been damaged our department would probably have been notified.

Also in the tree row was new growth of trees mainly elms and hackberrys. These elms were about 8-10 feet tall. Dennis Carlson took out a saw and cut several of the young trees and estimated their age at 3-4 years. When we arrived back near the road at the west end of the row we observed one siberian elm that was still alive. As we looked around it there also appeared to be a ridge of soil to the north and east sides of it. At this point Dennis, Jim and I all agreed that we felt there had been a soil sterilant type herbicide applied to the recharge site that might have moved off target with heavy rainfall and ended up killing the trees, with the soil ridges at the east end and by the road protecting the trees that were still alive.

Dennis Carlson also made several other points about the dead trees:

1. There were no fire scars on the trees.
2. If a natural cause would have damaged the trees there would be resprouting. There is none.
3. The volunteer trees cut are 3-4 years old. All undergrowth is the same size.
4. Possibly a herbicide 3-4 years ago. The dead trees had the small twigs broken off and the bark was falling off. This would indicate that the trees had been dead several years.

Mike Dealy asked us whether a product like this could have been applied to the tree row intentionally and we agreed that it could have been, but would be impossible to confirm. Mike asked whether soil samples could confirm what kind of herbicide had been used. I told Mike that since we all felt it had been so long and the soil was very sandy, that the herbicide was likely gone and we would not be able to find it in a soil sample.

We then walked into the soybean field on the south side of the tree row. The soybeans appeared to be Roundup Ready soybeans, the weeds appeared to have been sprayed. As we walked along the row we observed much the same as the north side of the row. When we reached the back edge of the recharge site the elms started to have a few live limbs in them and then gradually returned to normal.

I asked Mike who all would have been to the site to look at the trees and who from the water department for the city maintains the site. Mike told us that a city forester had been out to look at the site about a year ago and that Gerald Blain, the Water Projects Supply Manager, and Rich Robinson, who worked at the water department field office near Halstead would have the most knowledge about maintenance at the site.

Mike then asked how he could receive a copy of my report and I advised him to call the KDA Topeka office and request a copy after the case is reviewed and closed out. Dennis Carlson said that he would send to me a copy of his report. Jim and I thanked Mike and Dennis for their time. They then left the property.

I proceeded to take several photographs of the site and the tree row from the north and south sides. Shortly thereafter we left the site. I then drove to the City of Wichita Water Dept. field office located 2 miles west and 2 miles south of Halstead. When I arrived I did not find anyone at the facility. I then left the area.

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OCT 7 2002
EQUUS BEDS GROUND MANAGEMENT DISTRICT NO.



On September 3rd I spoke with Rich Robinson by phone. I first asked Rich if he had been with this project for all five years and he said yes, since it had been built. We then discussed when Rich had noticed the trees dying and Rich thought he remembered the trees dying about 2 years ago. I asked Rich what herbicides had been applied to the site through the years. Rich replied that no herbicides, including Roundup had been applied to the site. It was their standard practice to mow and string trim the fencelines. Rich said that USGS had recommended that no herbicides be applied to the site since there was monitoring wells present, to mow and trim only. Rich went on to say that it meant string trimming the inside of the recharge ponds and hand pulling the weeds sometimes. I also asked Rich whether a herbicide had been applied by the original contractor and he said to his knowledge none had been applied.

I then tried to talk to Gerald Blain. I was informed that he would be out of the office for the week but that a message would be left for him to call next Monday. I talked to Tim Martz, the City of Wichita Superintendent for Parks and Recreation. Tim said that Craig Steward, the city arborist or Jim Smith, the General Supervisor had been out to look at the trees. He would have Craig give me a call.

On September 4th I spoke with Craig Steward. Craig said that Jim Smith had been out to the site a little over a year ago. Jim told him that he felt a soil type herbicide had been applied to the trees killing them.

On September 9th I spoke with Gerald Blain. Gerald said that he remembers trees dying about two years ago in the summer of 2000. He said that after the trees started looking bad that they died within about two weeks.

In conclusion, from the evidence seen and the individuals talked to, the trees appeared to have been killed by a soil sterilant type herbicide anywhere from two to four years ago, depending on the source of the estimate. No respondent has been identified as having made the application of herbicide in the case.

Shawn Hackett (signature) 9-9-2002

Shawn Hackett
Investigator
Kansas Department of Agriculture

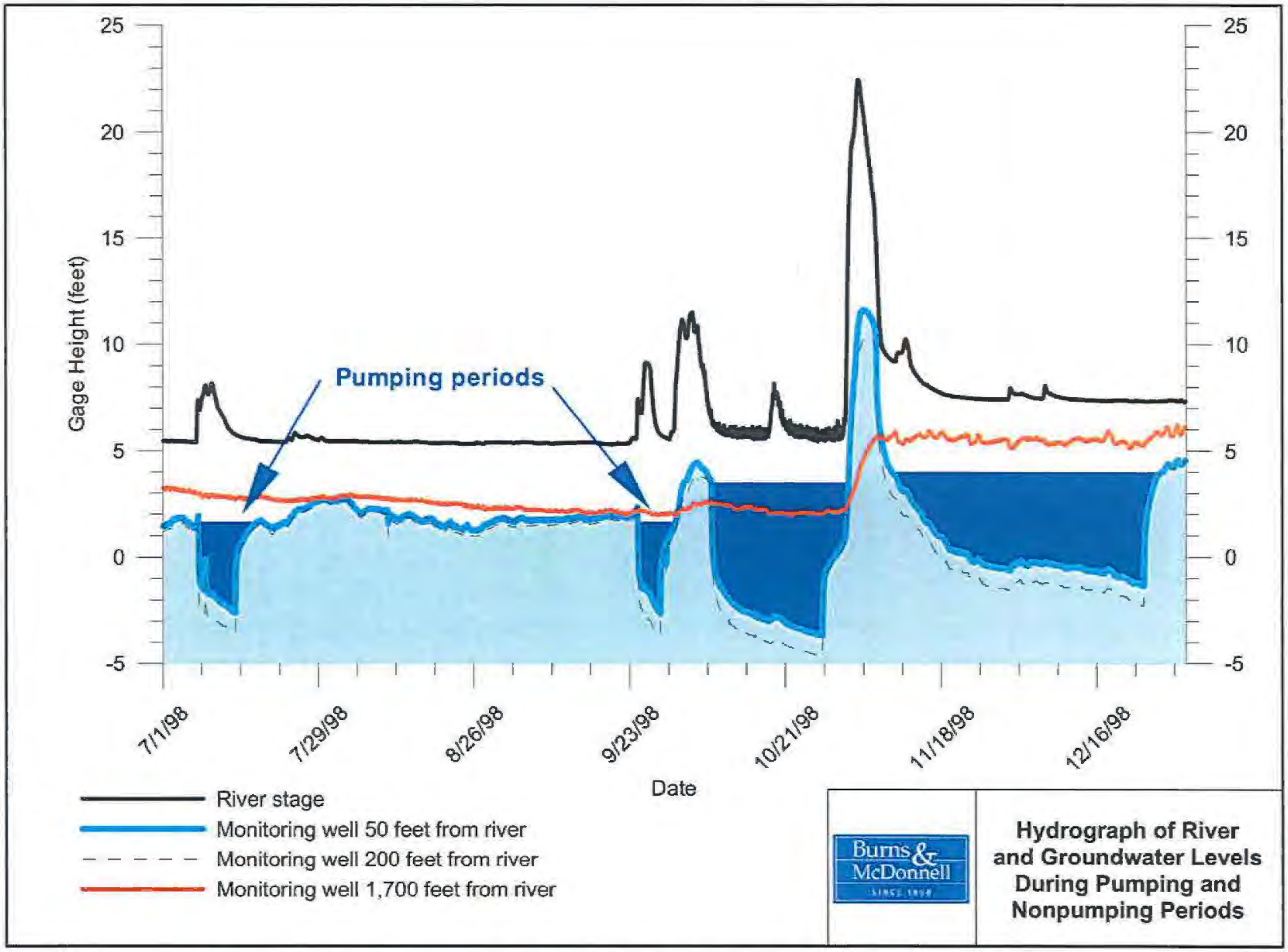
Date

Attachments:
Site Diagram - 2 pages
Photographs - 8
letter from Dennis Carlson, Kansas Forest Service - 2 pages
letter from Michael Dealy, Manager, GMD No. 2

# EXHIBIT DD

002029

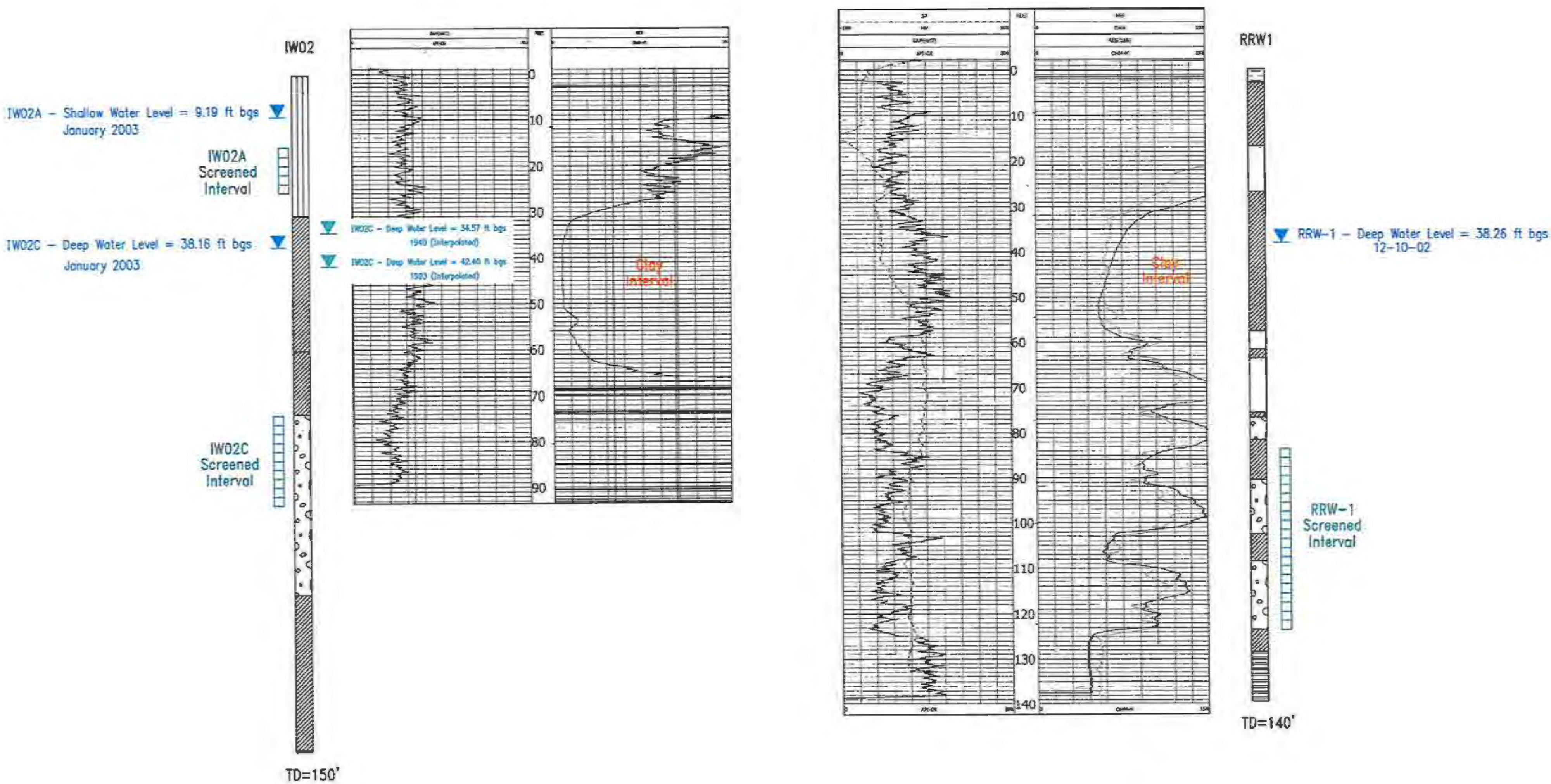
## Hydrograph of Little Arkansas River
## 1998




Note: Pumping was started on September 23, 1998 and ended on December 17, 1998.
Well pumped a total of 117 million gallons over 86 consecutive days.
Groundwater Levels were 3 feet higher than before pumping started.
All water levels were recorded and reported by U S personnel.

# EXHIBIT EE

## Groundwater Levels and Geology at Index Well No. 2

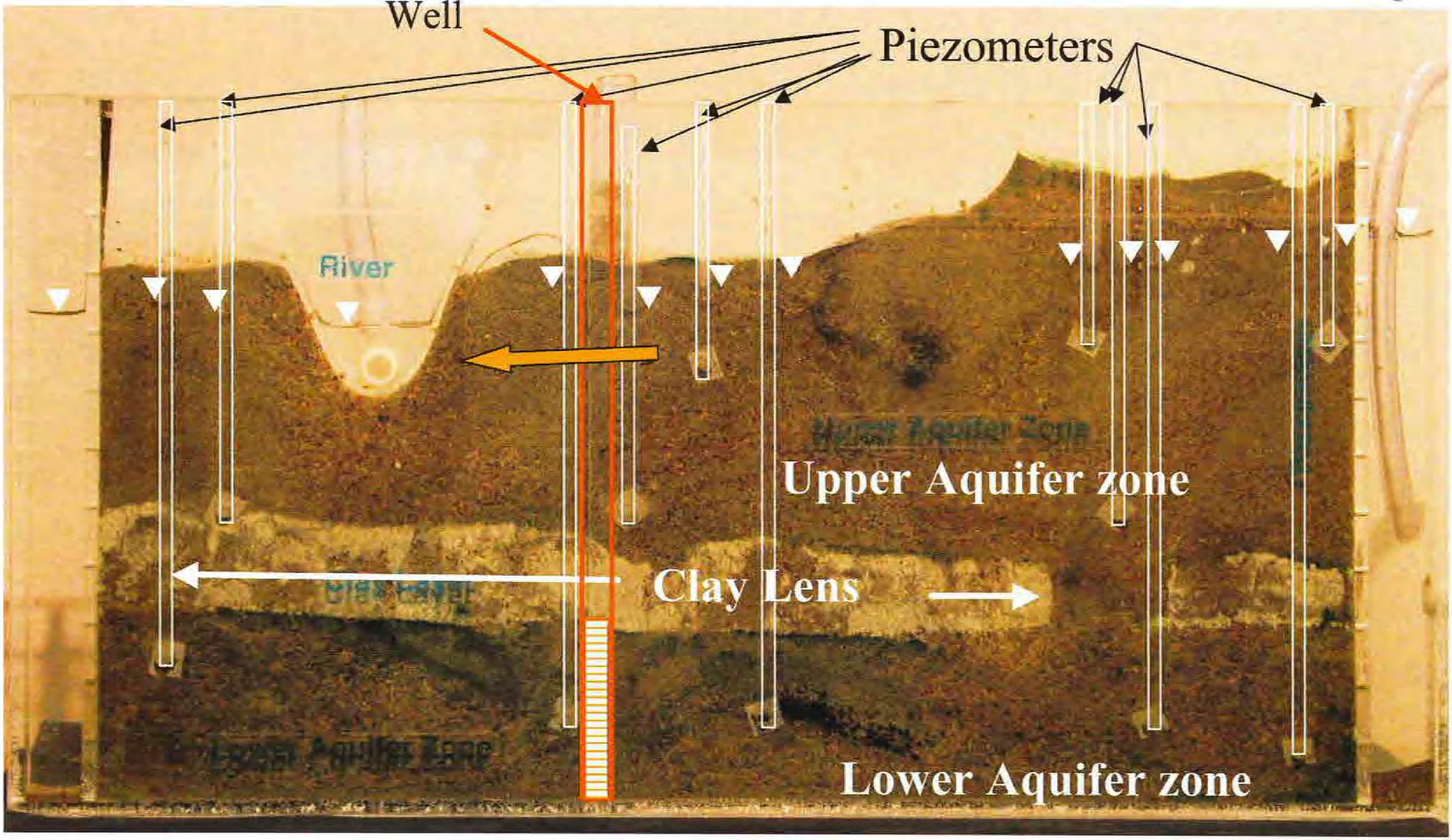



002030

# EXHIBIT FF

# Physical Model Set Up
## Halstead Test Well

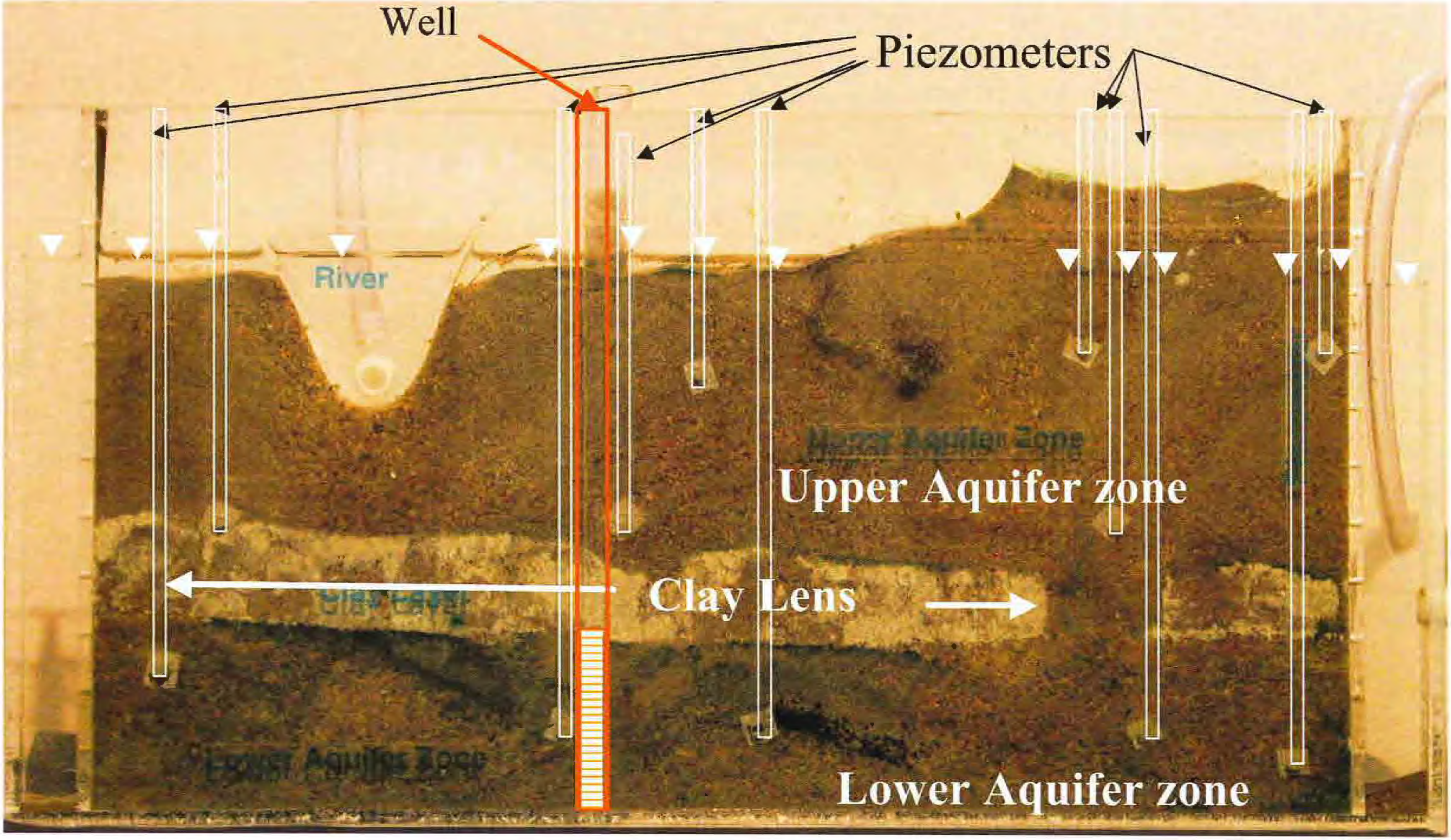
002031




Normal Base Flow

002032

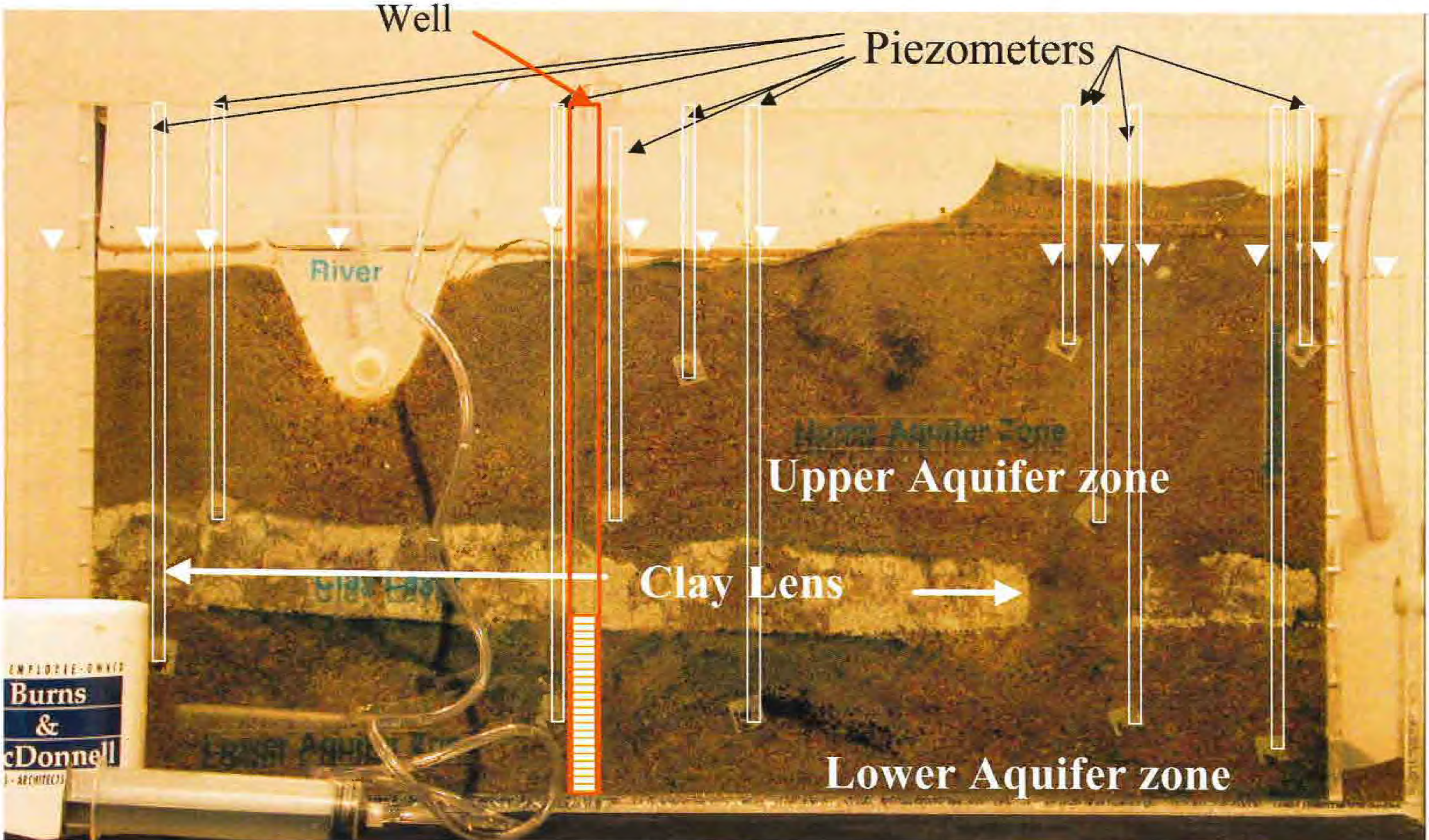
# Physical Model Set Up
## Halstead Test Well




Above Base Flow

Physical Model Set Up

Halstead Test Well

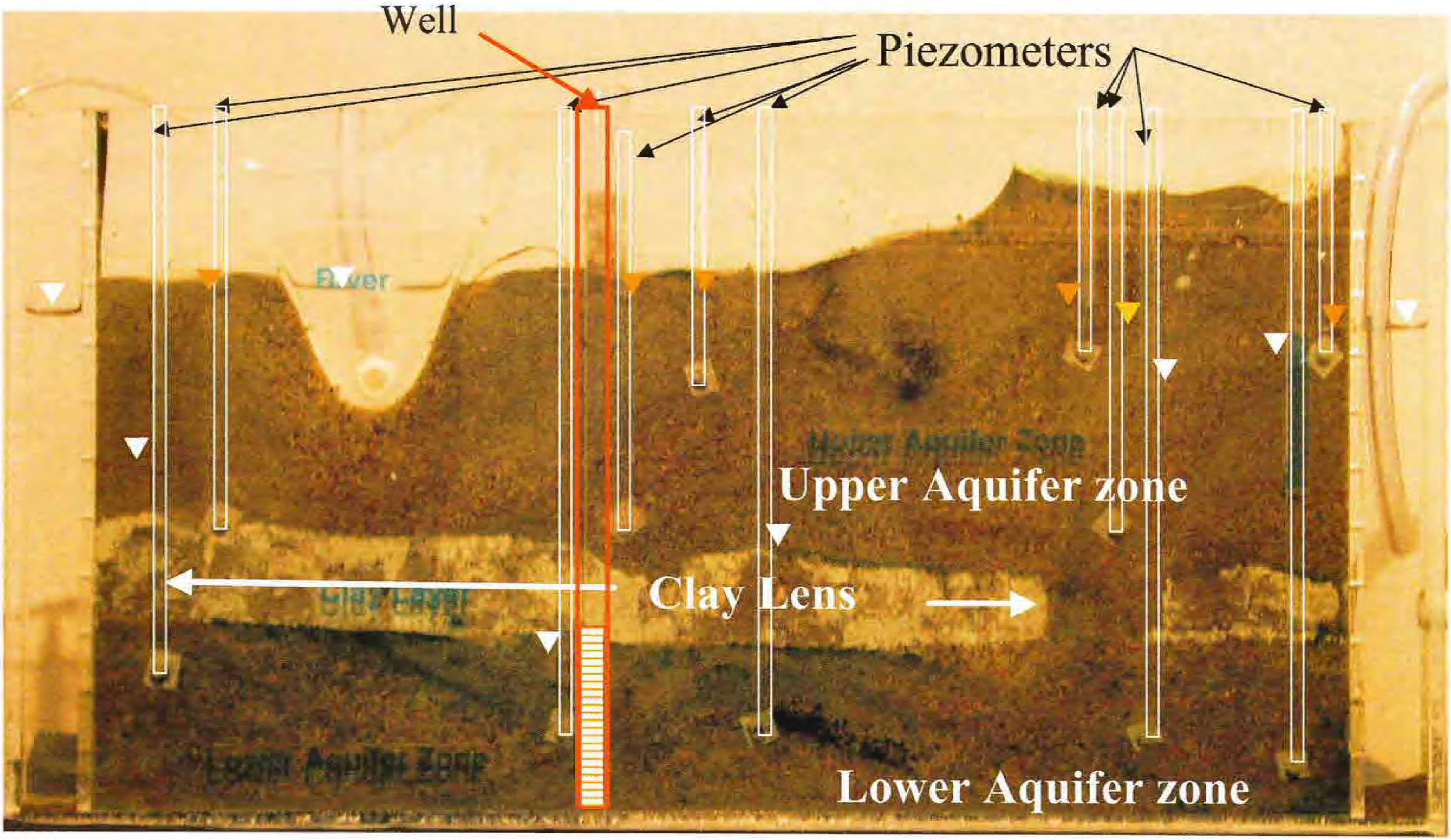



Above Base Flow - Pump Installed

# Physical Model Set Up

## Halstead Test Well

002034

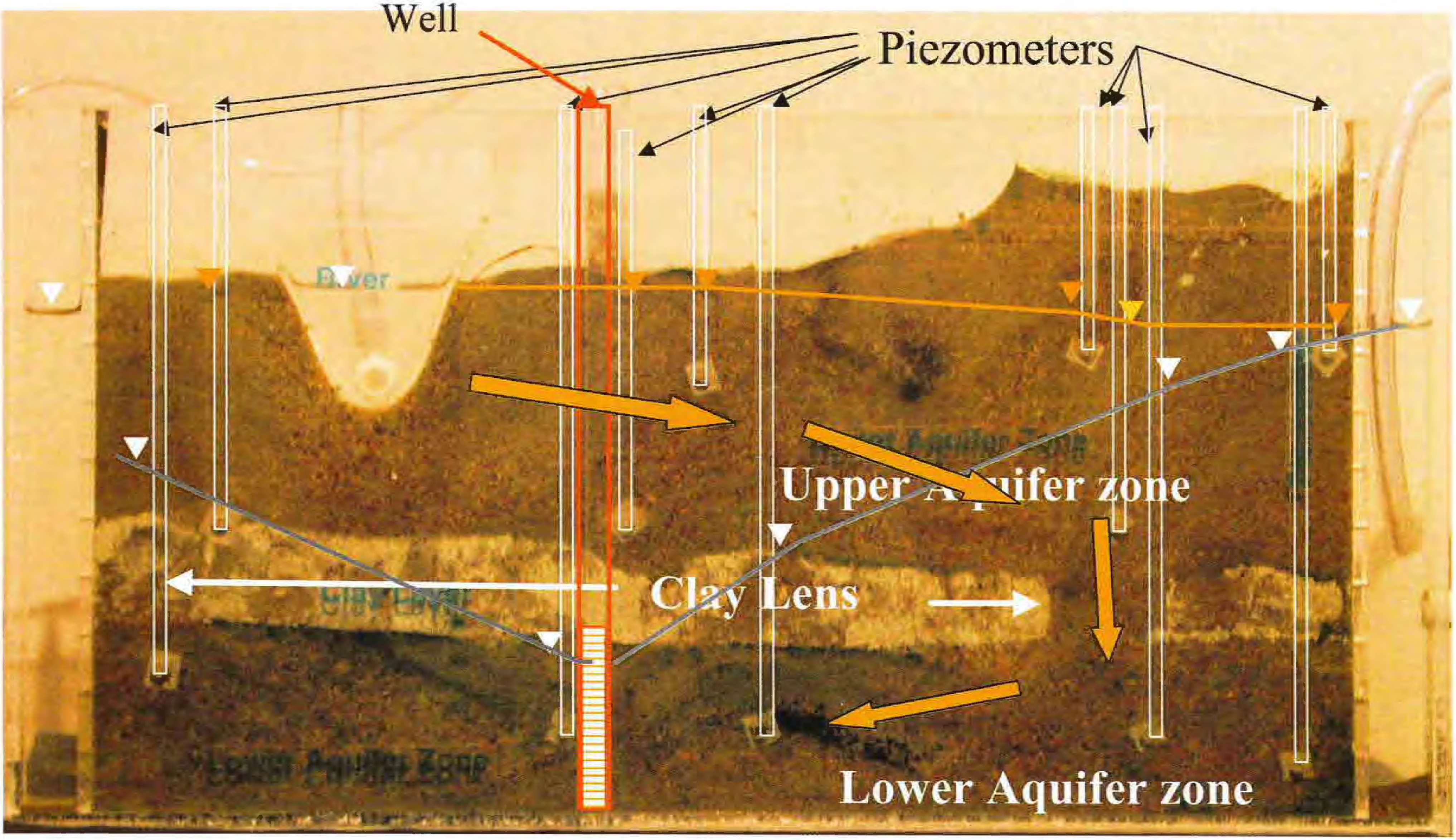



Above Base Flow - Pumping

002035

Physical Model Set Up

Halstead Test Well




Above Base Flow - Pumping

# EXHIBIT GG

# Recharge

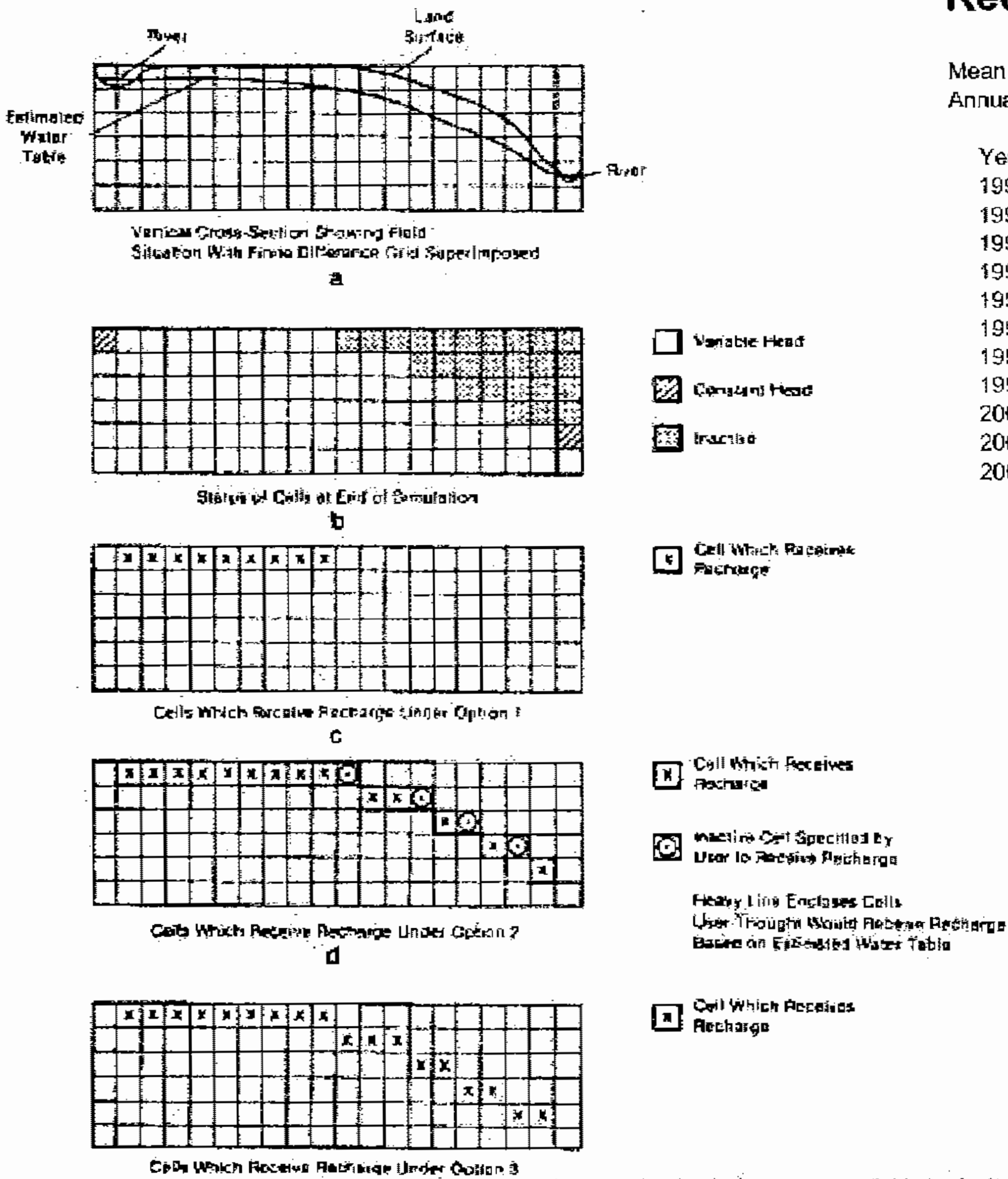



Figure 38.-Hypothetical problem showing which cells receive recharge under the three options available in the Recharge Package.

## Recharge Factors Used in Model

Mean annual precipitation for stress period 1935-1939 = 29.71 (USGS)
Annual average for Hutch, Mt. Hope, and Wichita

| Year | 1935-1939 | Annual Average | Rech. Factor |
|---|---|---|---|
| 1992 | 29.71 | 33.38 | 1.124 |
| 1993 | 29.71 | 42.72 | 1.438 |
| 1994 | 29.71 | 25.41 | 0.855 |
| 1995 | 29.71 | 36.28 | 1.221 |
| 1996 | 29.71 | 29.94 | 1.008 |
| 1997 | 29.71 | 26.44 | 0.890 |
| 1998 | 29.71 | 33.95 | 1.143 |
| 1999 | 29.71 | 37.55 | 1.264 |
| 2000 | 29.71 | 33.05 | 1.113 |
| 2001 | 29.71 | 25.47 | 0.857 |
| 2002 | 29.71 | 32.58 | 1.096 |

# EXHIBIT HH

002037

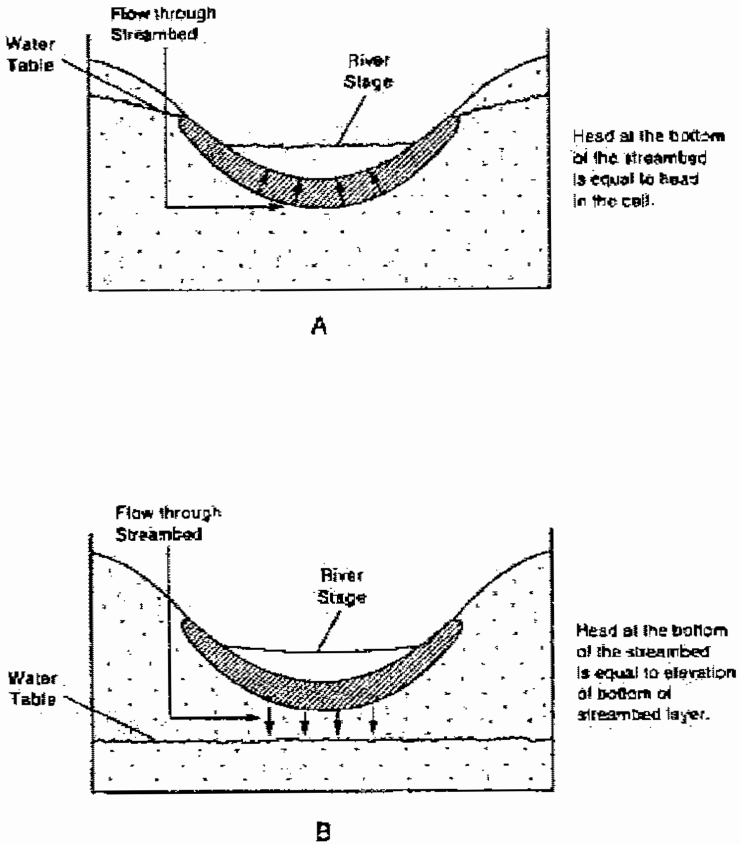



Figure 35.-Cross sections showing the relation between head at the bottom of the streambed layer and head in the cell. Head in the cell is equal to the water-table elevation.

Vertical hydraulic conductivity of the stream bed are:

0.5 ft/day for Emma, East Emma, and Sand Creeks
5 ft/day for the Little Arkansas River
50 ft/day for the Arkansas River

Streambed thickness assumed to be
1 ft for all streams and creeks.

**Streamflow that was exceeded 70 percent of the time was used to simulate streamflow in the Arkansas and Little Arkansas River.**

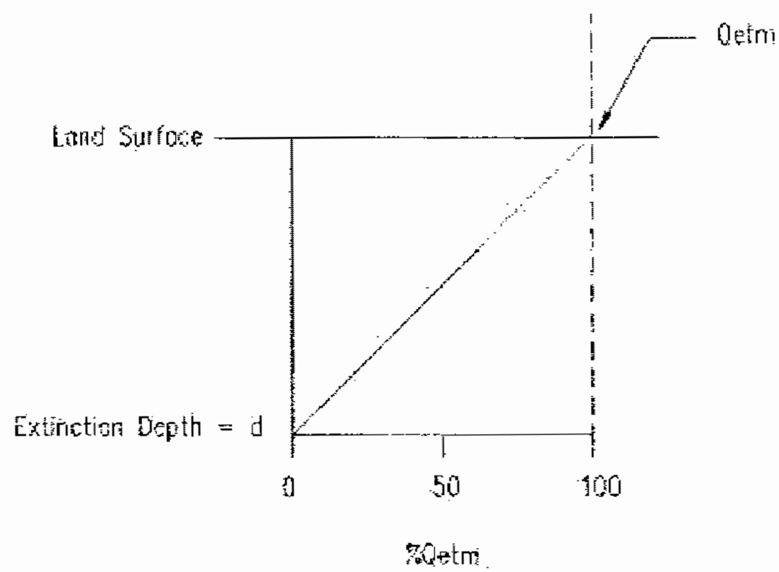
| | | | Little Ark. at Valley Center | | | | | Arkansas at Hutchinson | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| YEAR | MONTH | DAY | cfs | Cumul | Excedence | (cfd) | | cfs | Cumul | Excedence | cfd |
| 1990 | 11 | 23 | 17 | 256 | 70.14% | 1,468,800 | | 136 | 256 | 70.14% | 11,750,400 |
| 1991 | 12 | 4 | 11 | 256 | 70.14% | 950,400 | | 54 | 256 | 70.14% | 4,665,600 |
| 1992 | 2 | 17 | 28 | 257 | 70.22% | 2,419,200 | | 76 | 257 | 70.22% | 6,566,400 |
| 1993 | 1 | 1 | 91 | 256 | 70.14% | 7,862,400 | | 495 | 256 | 70.14% | 42,768,000 |
| 1994 | 12 | 6 | 22 | 256 | 70.14% | 1,900,800 | | 110 | 256 | 70.14% | 9,504,000 |
| 1995 | 10 | 17 | 39 | 256 | 70.14% | 3,369,600 | | 144 | 256 | 70.14% | 12,441,600 |
| 1996 | 3 | 22 | 44 | 257 | 70.22% | 3,801,600 | | 152 | 257 | 70.22% | 13,132,800 |
| 1997 | 11 | 16 | 67 | 256 | 70.14% | 5,788,800 | | 398 | 256 | 70.14% | 34,387,200 |
| 1998 | 2 | 22 | 111 | 256 | 70.14% | 9,590,400 | | 862 | 256 | 70.14% | 74,476,800 |

# EXHIBIT II

# Evapotranspiration Package

## Conceptualization and Implementation

The Evapotranspiration (ET) Package simulates the effects of plant transpiration and direct evaporation in removing water from the saturated ground water regime. The approach is based on the following assumptions: (1) when the water table is at or above a specified elevation, termed the "ET surface" in this report, evapotranspiration loss from the water table occurs at a maximum rate specified by the user; (2) when the depth of the water table below the ET surface elevation exceeds a specified interval, termed the "extinction depth" or "cutoff depth" in this report, evapotranspiration from the water table ceases; and (3) between these limits, evapotranspiration from the water table varies linearly with water table elevation.




d = extinction depth = 10 feet
Qet = Evapotranspiration Rate = 0.0007991 cubic feet per day
Qetm= Maximum Evapotranspiration Rate

# EXHIBIT JJ

THE STATE OF KANSAS

**KANSAS DEPARTMENT OF AGRICULTURE**
Jamie Clover Adams, Secretary of Agriculture

**DIVISION OF WATER RESOURCES**
David L. Pope, Chief Engineer

File Number ____________________
This item to be completed by the Division of Water Resources.

## APPLICATION FOR PERMIT TO APPROPRIATE WATER FOR BENEFICIAL USE

Filing Fee Must Accompany the Application
(Please refer to Fee Schedule attached to this application form.)

ASR Project RW-1

*To the Chief Engineer of the Division of Water Resources, Kansas Department of Agriculture, 109 SW 9th Street, Second Floor, Topeka, KS 66612-1283:*

1. Name of Applicant (Please Print): City of Wichita, Water & Sewer Dept.
   Address: 455 N. Main
   City: Wichita State KS Zip Code 67202
   Telephone Number: (316) 268-4504

2. The source of water is: G surface water in ____________ (stream)
   OR ✓ groundwater in Equus Beds, Arkansas River Basin (drainage basin)

   Certain streams in Kansas have minimum target flows established by law or may be subject to administration when water is released from storage for use by water assurance district members. If your application is subject to these regulations on the date we receive your application, you will be sent the appropriate form to complete and return to the Division of Water Resources.

3. The maximum quantity of water desired is 43 acre-feet OR ________ gallons per calendar year, to be diverted at a maximum rate of 1,500 gallons per minute OR ________ cubic feet per second.

   Once your application has been assigned a priority, the requested maximum rate of diversion and maximum requested quantity of water under that priority number can **NOT** be increased. Please be certain your requested maximum rate of diversion and maximum quantity of water are appropriate and reasonable for your proposed project and are in agreement with the Division of Water Resources' requirements.

4. The water is intended to be appropriated for **(Check use intended)**:
   (a) G Artificial Recharge (c) G Irrigation Use (e) G Recreational Use (g) G Water Power use
   (b) G Industrial Use (d) ✓ Municipal Use (f) G Stockwatering Use

YOU **MUST** COMPLETE AND ATTACH ADDITIONAL DIVISION OF WATER RESOURCES FORM(S) PROVIDING INFORMATION TO SUBSTANTIATE YOUR REQUEST FOR THE AMOUNT OF WATER FOR THE INTENDED USE REFERENCED ABOVE.

| **For Office Use Only: Code** REG **Fee $** ________ **TR #** __________ **Receipt Date** __________ **Check #** ________ |
|---|

File No. ____________

5. The location of the proposed wells, pump sites or other works for diversion of water is:

**Note:** For the application to be accepted, the point of diversion location must be described to at least a 10 acre tract, unless you specifically request 60 days in which to locate the site within a quarter section tract. Any request for an extension of time in which to locate the point of diversion shall include a contract with a well driller or a contractor for the necessary test holes.

(A) One in the NW quarter of the NW quarter of the NW quarter of Section 36, more particularly described as being near a point 5170 feet North and 5170 feet West of the Southeast corner of said section, in Township 23 South, Range 3 East/West (circle one), Harvey County, Kansas.

(B) One in the ______ quarter of the ______ quarter of the ______ quarter of Section ______, more particularly described as being near a point ______ feet North and ______ feet West of the Southeast corner of said section, in Township ______ South, Range ____ East/West (circle one), ____________ County, Kansas.

(C) One in the ______ quarter of the ______ quarter of the ______ quarter of Section ______, more particularly described as being near a point ______ feet North and ______ feet West of the Southeast corner of said section, in Township ______ South, Range ____ East/West (circle one), ____________ County, Kansas.

(D) One in the ______ quarter of the ______ quarter of the ______ quarter of Section ______, more particularly described as being near a point ______ feet North and ______ feet West of the Southeast corner of said section, in Township ______ South, Range ____ East/West (circle one), ____________ County, Kansas.

If the source of supply is groundwater, a separate application shall be filed for each proposed well or battery of wells, except that a single application may include up to four wells within a circle with a quarter (¼) mile radius in the same local source of supply which do not exceed a maximum diversion rate of 20 gallons per minute per well and which are operated by means of submersible pumps.

A battery of wells is defined as two or more wells connected to a common pump by a manifold; or not more than four wells in the same local source of supply within a 300 foot radius circle which are being operated by pumps not to exceed a total maximum diversion rate of 800 gallons per minute and which supply water to a common distribution system.

6. The proposed project for diversion of water will consist of one recharge well
(number of wells, pumps or dams, etc.)

and (was/will be) completed (by) November 30, 2005
(Month/Day/Year - each was or will be completed)

7. The first actual application of water for the proposed beneficial use was or is estimated to be 03/01/06
(Mo/Day/Year)

8. Will pesticide, fertilizer, or other foreign substance be injected into the water pumped from the diversion works?

Yes G No G ✓ If "yes", a check valve shall be required.

All chemigation safety requirements must be met including a chemigation permit and reporting requirements.

002040

File No. ____________

9. If you are planning to impound water, please contact the Division of Water Resources for assistance, prior to submitting the application. Please attach a reservoir area capacity table and inform us of the total acres of surface drainage area above the reservoir.

Have you also made an application for a permit for construction of this dam and reservoir with the Division of Water Resources? G Yes G No

! If yes, show the Water Structures permit number here ____________

! If no, explain here why a Water Structures permit is not required ____________

10. The application must be supplemented by a U.S.G.S. topographic map, aerial photograph or a detailed plat showing the following information. On the topographic map, aerial photograph, or plat, identify the center of the section, the section lines or the section corners and show the appropriate section, township and range numbers. Also, please show the following information:

(a) The location of the proposed point(s) of diversion (wells, stream-bank installations, dams, or other diversion works) should be plotted as described in Paragraph No. 5 of the application, showing the North-South distance and the East-West distance from a section line or southeast corner of section.

(b) If the application is for groundwater, please show the location of any existing water wells of any kind within ½ mile of the proposed well or wells. Identify each existing well as to its use and furnish the name and mailing address of the property owner or owners. If there are no wells within ½ mile, please advise us.

(c) If the application is for surface water, the names and addresses of the landowner(s) ½ mile downstream and ½ mile upstream from your property lines must be shown.

(d) The location of the proposed place of use should be shown by crosshatching on the topographic map, aerial photograph or plat.

(e) Show the location of the pipelines, canals, reservoirs or other facilities for conveying water from the point of diversion to the place of use.

A 7.5 minute U.S.G.S. topographic map may be obtained by providing the section, township and range numbers to: Kansas Geological Survey, 1930 Constant, Campus West, University of Kansas, Lawrence, Kansas 66047.

11. List any application, appropriation of water, water right, or vested right file number that covers the same diversion points or any of the same place of use described in this application. Also list any other recent modifications made to existing permits or water rights in conjunction with the filing of this application.

Part of City of Wichita's ASR project. Water will be used to maintain recharge well and can only be withdrawn when recharge credits are available.

File No. ____________

12. Furnish the following well information if the proposed appropriation is for the use of groundwater. If the well has not been completed, give information obtained from test holes, if available.

Information below is from: Test holes G ✓ Well as completed G Drillers log attached G

| Well location as shown in paragraph No. | (A) | (B) | (C) | (D) |
| --- | --- | --- | --- | --- |
| Date Drilled | 07-15-03 | | | |
| Total depth of well | 244 | | | |
| Depth to water bearing formation | 16 | | | |
| Depth to static water level | 30 | | | |
| Depth to bottom of pump intake pipe | — | | | |

13. The relationship of the applicant to the proposed place where the water will be used is that of agent.
(owner, tenant, agent or otherwise)

14. The owner(s) of the property where the water is used, if other than the applicant, is (please print):

______________________________
(name, address and telephone number)

______________________________
(name, address and telephone number)

15. The undersigned states that the information set forth above is true to the best of his/her knowledge and that this application is submitted in good faith.

Dated at Wichita, Kansas, this 3rd day of November (month), 2004 (year)

______________________________
(Applicant Signature)

APPLICANT(S) SOCIAL SECURITY IDENTIFICATION NUMBER(S)

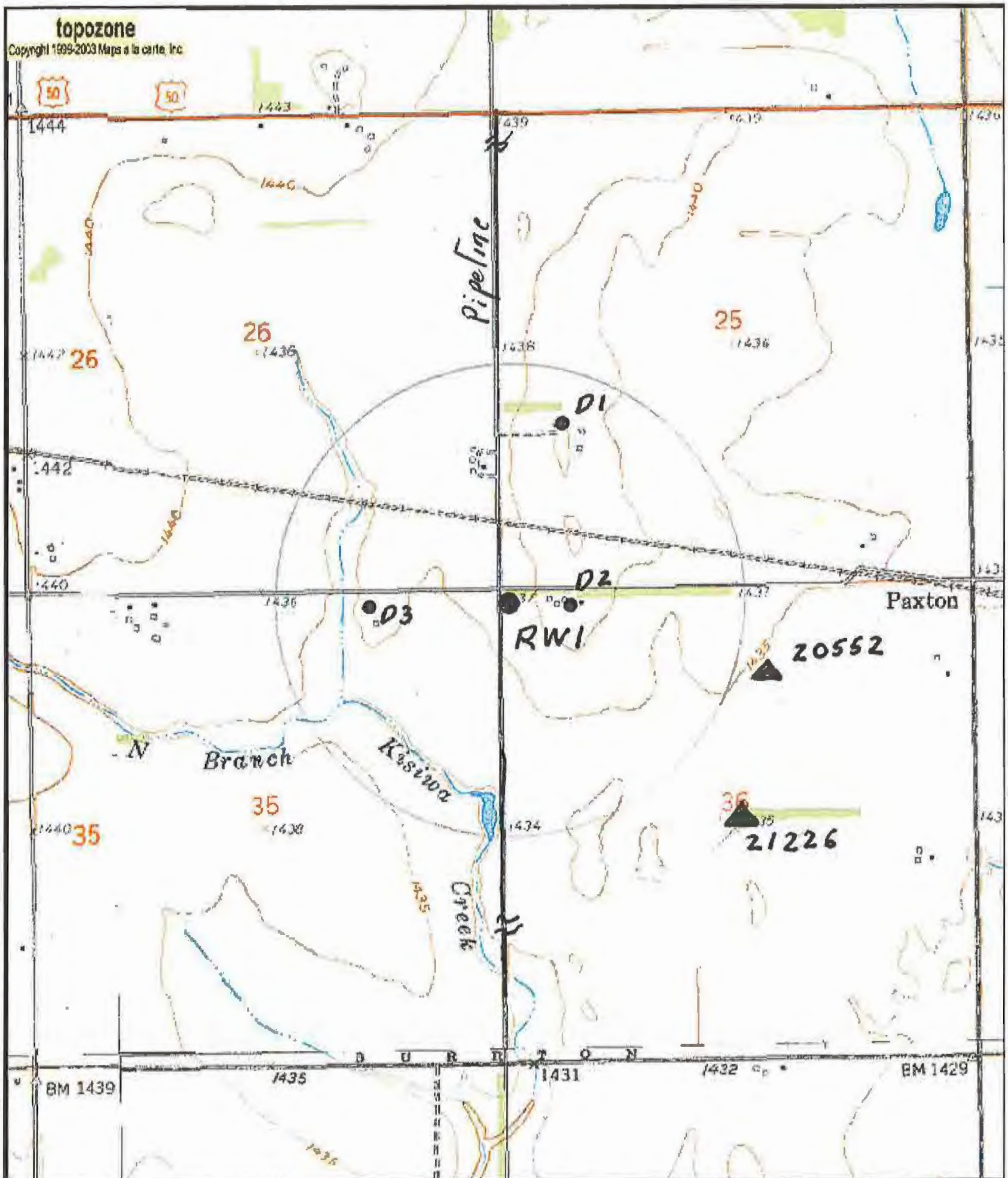
By Gerald T. Blain
(Agent or Officer Signature)

48-6000653
and/or
APPLICANT(S) TAXPAYER I.D. NO.(S)

Gerald T. Blain
(Agent or Officer - Please Print)

Assisted by ______________ ______________ Date: ______________
(office/title)

002042




0 0.3 0.6 0.9 1.2 1.5 km
0 0.2 0.4 0.6 0.8 1 mi

T 23 S
R 3 W

Map center is UTM 14 622012E 4208266N (WGS84/NAD83)
**Halstead** quadrangle
Projection is UTM Zone 14 NAD83 Datum

M=5.381
G=0.856

002043

Recharge Well No. 1
5,170 ft. N. and 5,170 ft. W. of SE Corner of Sec. 36, T 23 S, R 3 W.

Diversions within 1/2 mile:

Irrigation Wells –

# 21226
Leo & Edna Koehn Trust
8935 SW 24th St.
Halstead, KS 67056

# 20552
Marvin and Betty Baehr
Address not available

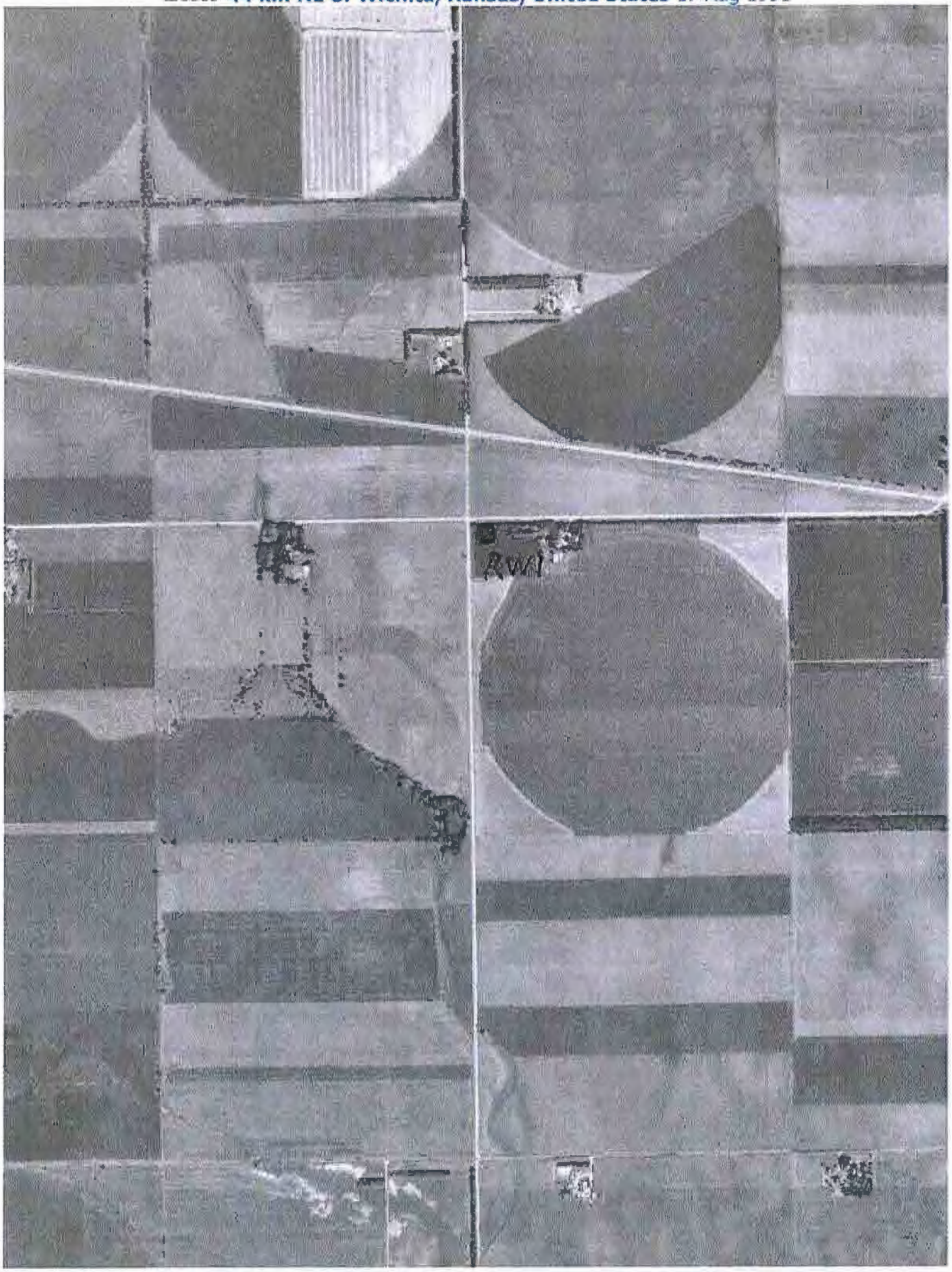
Domestic Wells
D1
Joe and Joanna Bergkamp
2004 S. Willow Lake Rd.
Halstead, KS

D2
Larry Koehn
8935 SW 24th St.
Halstead, KS 67056

D3
JC Welch
18307 SW 24th St.
Burrton, KS 67020

Send To Printer Back To TerraServer Change to 11x17 Print Size Show Grid Lines Change to Landscape

USGS **44 km NE of Wichita, Kansas, United States** 17 Aug 1991




0 .5Km 0 .25Mi

Image courtesy of the U.S. Geological Survey



002045

# EXHIBIT KK

**LAND ACQUISITION DOCUMENTATION**
**CITY OF WICHITA**

***Documents included**

**Diversion Well Sites**:

- Wilbert H. and Eileen Penner: Letter of Intent signed*. Agreement under attorney's review
- Doug and Nancy Unruh: Agreement under land owner's review

**Recharge/Recovery Well and Arsenic Removal Site**:

RRW-1: Larry and E.C. Flickinger: Permanent Easement Agreement*. Signed by property owner; pending City Council approval

**Recharge/Recovery Well Site:**

| | | |
|---|---|---|
| RRW-2 | John Weber: | Agreement provided to land owner and under review |
| RRW-3 | Gordon Schmidt and Christine Downey-Schmidt | Letter of Intent signed*.<br>Agreement under land owner's review |
| RRW-4 | Gary and Carol Koehn Trust | Letter of Intent signed*.<br>Agreement under land owner's review |

**Recharge Basin Site:**

| | | |
|---|---|---|
| RB-1 | City of Wichita | Warranty Deed*<br>City ownership final. |
| RB-2 | John Stutzman, et al | Contract for purchase*.<br>Signed by owner; pending City Council Approval. |

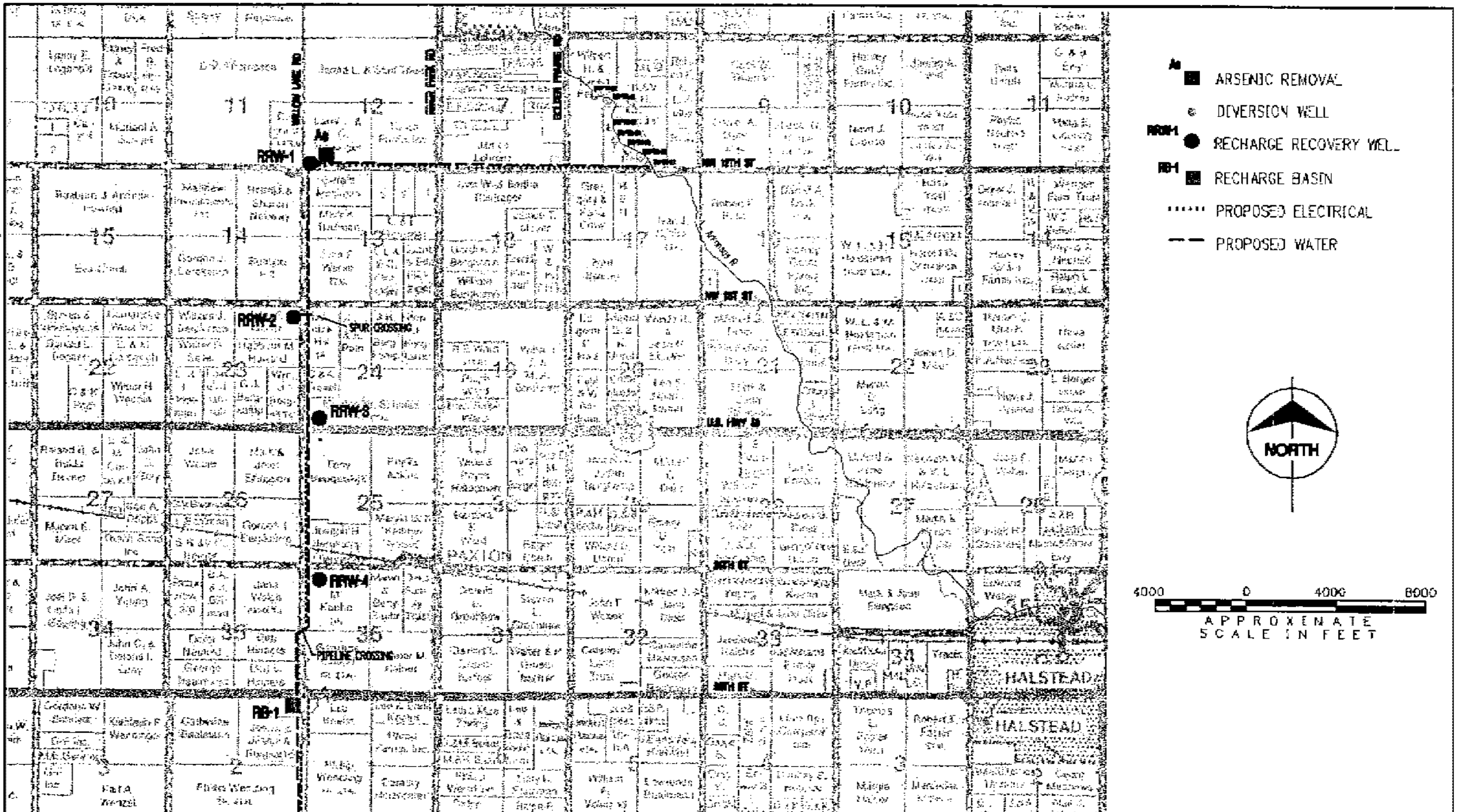



Figure 1 - Rev. 7
ASR PHASE 1
PROPOSED FACILITY
LOCATIONS

**LETTER OF INTENT**
**EQUUS BEDS AQUIFER STORAGE AND DISCOVERY PROJECT**

To Whom It May Concern:

We/I have been contacted by representatives of the City of Wichita, requesting access to my property for the placement wells as part of the City of Wichita's project. Subject to the satisfactory completion of negotiations and the execution of the appropriate documents, it is our/my intent to [sell] [lease] the property below to the City of Wichita for the purpose of installation, operation, and accessing wells.

Property description:

NW 1/4 SEC 8 T23S R2W

Property owner:

Name(s): WILBERT H PENNER
EILEEN PENNER
Address: 14935 NW 24TH
BURRTON, KS 67020

Signature(s) Wilbert H. Penner
Eileen Penner

Date:
11/3/04

## Agreement for Permanent Easement

THIS AGREEMENT, Made and entered into this____ day of ________________, 2004 by and between Larry L. Flickinger & EC Flickinger party of the First Part, hereinafter referred to as "Seller," whether one or more, and City of Wichita, party of the Second Part, hereinafter referred to as "Buyer," whether one or more.

**WITNESSED:** That for and in consideration of the mutual promises, covenants and payments hereinafter set out, the parties hereto do hereby contract to and with each other, as follows:

1. The Seller does hereby agree to sell and convey to the Buyer a permanent easement for the following described real property, situated in Harvey County, Kansas, to wit:

> Generally described as a site of no more than two acres located in the SW Corner of the SW ¼ of Sec. 12, TWP. 23-S, R-3-W of the 6th P.M., Harvey County, Kansas and a 30' pipeline easement to be located adjacent to existing road-right-of-way along NW 12th Street in Sec. 12, TWP. 23-S, R-3-W of the 6th P.M., Harvey County, Kansas.
>
> See Exhibit A
>
> *(Specific location, size, and description shall be determined in the future and with agreement by both Seller and Buyer. Legal description, as determined by survey will be completed and approved by both the Buyer and Seller, will appear on document granting permanent easement)*

2. The Buyer hereby agrees to purchase, and pay to the Seller, as consideration for the permanent easement of the above-described real property, the sum of !

in the manner following, to-wit: cash at closing.

3. The Seller, as a condition of the sale, agrees to allow access to the Buyer, its agents and assigns, access over, under, through, in and across the real property described above and made a part hereof by this reference in order to construct, install, maintain, operate, test, repair, replace, and/or remove monitoring wells, recharge/recovery wells, flow meters, pipelines, water treatment equipment, and other operations and associated instrumentation to collect and transmit data and water for the Equus Beds Groundwater Recharge Project (hereinafter "Project").

4. A title insurance company's commitment to insure, to the above described real

property, showing a merchantable title vested in the seller, subject to easements and restrictions of record is required. The Title Evidence shall be sent to for examination by the Buyer as promptly and expeditiously as possible, and it is understood and agreed that the Seller shall have a reasonable time after said Title Evidence has been examined in which to correct any defects in title.

5. A duly executed copy of this Agreement shall be delivered to the parties hereto.

6. It is further agreed by and between the parties hereto that all rentals, insurance (if policies acceptable to Buyer), and interest, if any shall be adjusted and prorated as of the closing date.

7. The Seller further agrees to convey the above described premises with all the improvements located thereon and deliver possession of the same in the same condition as they now are, reasonable wear and tear excepted.

8. It is understood and agreed between the parties hereto that time is of the essence of this contract, and that this transaction shall be consummated on or before February 28, 2005.

9. Possession to be given to Buyer on or before closing date .

10. In the event an Owners title insurance policy is furnished, the total cost of the commitment to insure and the title insurance policy will be paid by Buyer. The Buyer will pay 100 % of all closing costs.

11. Buyer may enter upon property prior to closing for the sole purpose of obtaining, at its sole expense, such engineering reports, soil tests, percolating studies, or other evaluation of such property which Buyer deems necessary. Buyer agrees that the firm(s) which will conduct the tests and studies must be approved by Seller prior to conducting the same. Seller agrees that it shall not unreasonably withhold or delay such approval. Buyer agrees to indemnify Seller with respect to personal injury, including death, to any person or physical damage to said property that may occur as a result of Buyer's acts or omission in the exercise of any of the rights granted under this paragraph. Pending closing, Buyer agrees to keep the information obtained from its test and studies confidential; and to disclose such information only to its attorney, agents, and staff.

12. Seller makes no representations or warranties, expressed or implied, as to the condition, including the environmental condition, of subject property and the surrounding property, including all facilities, improvements, structures, and equipment thereon, surface water thereon or adjacent thereto, including soil and groundwater thereunder. Any information, reports or records, (Disclosures") provided or made by Seller to Buyer concerning the environmental condition of property shall not be deemed representations or warranties. Buyer shall not rely on such disclosures, but rather rely only on its own

inspection of property. Seller does not assume an obligation to remedy environmental problems, if any.

13. The Buyer, at its sole expense, agrees to remove and relocate said equipment, components and systems, if the Project should not prove successful and be discontinued or abandoned by the Buyer.

14. Buyer further agrees that the installation, maintenance, operation, repair replacement, relocation or removal shall be done in a careful and workmanlike manner in accordance with sound engineering practices and in a manner not to endanger persons or property and in such a manner so as to not impair or impede the use of said property for roads, ditches, drains, and borrow pits and to maintain said equipment, components and systems at such depth as will not impair or obstruct drainage.

15. Buyer agrees to seek and obtain such reviews, approvals, permits as may be required prior to the construction, installation, and operation of the groundwater recharge, storage and recovery project and to obtain all such reviews, approvals and permits as may be required for the continuing operation of the project.

16. Seller and Buyer acknowledge that Buyer has been provided a full opportunity to inspect the premises. Buyer takes the premises "as is," with all faults and conditions thereon.

17. <u>Site Assessment</u>

A. At any time prior to the closing of this agreement, the buyer shall have the right to conduct or cause to be conducted an environmental site assessment and/or testing on the property. If an environmental audit or test reveals the presence of a hazardous substance or waste, as defined by federal or state law, or that there has been a spill or discharge of a hazardous substance or waste on the property, the buyer shall have the right to void this agreement upon notice to the seller, in which event neither party shall be under any further obligation to the other, with the exception that seller shall return to buyer any deposit made hereunder.

B. The buyer or its agents shall have the right, without the obligation, to enter upon the property prior to closing to undertake an environmental site assessment or testing of the property, at the buyer's sole expense.

C. Provided, however, buyer shall in no event be obligated to close before the completion of a site assessment made pursuant to Paragraphs A and B above. If a site assessment is completed after the closing date set herein, then the buyer and seller shall close or the buyer shall advise seller that this agreement is being voided pursuant to said paragraph within ten (10) days of the completion of the site assessment. The buyer shall, if buyer determines a site assessment is necessary, exercise good faith in commencing and diligently completing such site assessment after this agreement is executed by all parties.

18. Buyer agrees and covenants to protect and hold harmless the Seller, its successors, and assigns, from any and all losses, damages or expenses of any kind growing out of any and all claims, demands, or causes of action for injury or damages to persons or property arising out of this authorization to cross over, under, above, through in and across the subject property (including all facilities, improvements, structures, and equipment thereon, surface water thereon or adjacent thereto, and soil or groundwater thereunder) under the ownership and control of Seller.

19. Buyer hereby releases and discharges the Seller, agents and assigns, from and against any and all suits, claims, demands, causes of action, damages, consequential damages, losses, costs and expenses of any kind, whether known or unknown, which Buyer had, has or at any time may have, based on (i) any environmental law, including any cost recovery claim under common law, the Comprehensive Environmental Response, Compensation and Liability Act of 1980, 42 U.S.C. 6901 et seq., as amended by the Resource Conservation and Recovery Act (RCRA), 42 U.S.C. 6901 et seq., as amended by the Hazardous and Solid Waste Amendments of 1984, or comparable state law; (ii) any release of any hazardous material on, at, to or from the described easement including with respect to the easement, all facilities, improvements, structures, and equipment thereon, surface water thereon or adjacent thereto, and soil or groundwater thereunder); (iii) any conditions whatsoever on, under, or in the vicinity of the easement, including the presence of hazardous materials, such as asbestos, on said easement.

20. INDEMNIFICATION:

A. To the extent allowed by law and as additional consideration herein, the Buyer agrees to indemnify and hold harmless the Seller and its assigns from any and all liability, loss or damages Seller may suffer as a result of claims, demands, costs, orders or judgments against it arising from the installation, operation, maintenance, testing, and construction of a water facility of any kind, water lines, power lines, measuring wells, monitoring wells, pumping wells, flow meter, injection wells, recharge wells, recharge basins, meters, etc. that are place in, on or under the above described real property or immediately adjacent property, whether owned by Seller or others.

B. Buyer also agrees to return the real property to the condition as it existed at and before approval of this agreement. Including, but not limited to, any and all cost, expenses, or judgments that may arise as a result of any adverse environmental condition as a result of the installation, operation, maintenance, and removal of the water treatment facility, pipeline, poles, wells, meters, etc. that are in place in, on or under the above described real property or immediately adjacent property, whether owned by Seller or others.

C. The agreements to indemnify specifically includes any claims, demands, cost, orders or judgments which might be made by any governmental agency or private party relating to pollution, contamination, or hazardous substances which might leach from the real property during the installation, construction, maintenance, and removal of said facility this excludes such substances which exist at the property before or at the time of the approval of this agreement and leach there from at a later date).

D. Seller shall notify Buyer of any claims made against it which are covered by this agreement within a reasonable time of the claims being made. Notice shall be made in writing and served upon the Clerk of the City of Wichita, Kansas.

E. Upon receiving notice from the Seller of a claim covered by this agreement, the Buyer shall defend and indemnify the Seller from that claim, and Buyer shall bear all legal and other expenses in regard to the claim.

F. If it is necessary for the Seller to enforce the indemnity provision of this agreement, the Seller, if successful, shall be entitled to collect from the Buyer all costs incurred in obtaining the enforcement, including reasonable attorney's fees.

G. These provisions for indemnification shall inure to the benefit of any party which might obtain a consensual lien upon the property with the consent of the Seller. Seller benefits under this agreement shall automatically be transferred and assigned to any subsequent transferees of the property.

H. Seller agrees to cooperate with Buyer in connection with any response to a claim covered by these indemnity provisions. Buyer shall be granted reasonable access to the property for the purpose of responding to such a claim, so long as such activity does not unreasonably interfere with Seller's use of the property.

21. Items numbered 13, 14, 15, 16, 18, 19, 20, 22, as paragraphs of this Agreement shall survive the closing

22. Buyer shall not assign its rights hereunder without the prior written consent of Seller, which consent shall not be unreasonably with held.

**WITNESS OUR HANDS AND SEALS** the day and year first above written.

**SELLER:**

Larry L. Flickinger

EC Flickinger

**002053**

**BUYER:**

**Approved as to Form:**

______________________________
Carlos Mayans, Mayor

______________________________
Gary E. Rebenstorf, Director of Law

**ATTEST:**

______________________________
Karen Sublett, City Clerk

**LETTER OF INTENT**
**EQUUS BEDS AQUIFER STORAGE AND DISCOVERY PROJECT**

To Whom It May Concern:

We/I have been contacted by representatives of the City of Wichita, requesting access to my property for the placement of a well as part of the City of Wichita's project. Subject to the satisfactory completion of negotiations and the execution of the appropriate documents, it is our/my intent to [sell] [lease] the property below to the City of Wichita for the purpose of installation, operation, and accessing a well.

Property description: Generally described as a site located in the SW Corner of 1/4 of Sec. 24, TWP. 23-S, R-3-W of the 6th P.M., Harvey County, KS.

Property owner:

Name(s): Gordon Schmidt and Christine Downey-Schmidt
Address: 10320 N. Wheat State Rd.
Inman, KS 67546

Signature(s) Gordon Schmidt Christine Downey-Schmidt

Date:

Nov. 2, '04

[illegible]

**LETTER OF INTENT**
**EQUUS BEDS AQUIFER STORAGE AND DISCOVERY PROJECT**

To Whom It May Concern:

We/I have been contacted by representatives of the City of Wichita, requesting access to my property for the placement of a well as part of the City of Wichita's project. Subject to the satisfactory completion of negotiations and the execution of the appropriate documents, it is our /my intent to [sell] [lease] the property below to the City of Wichita for the purpose of installation, operation, and accessing a well

Property description:
NW 1/4 Sec 26 Twp 23 S R-3 W 6th PM Harvey County Kansas

Property owner:

Name(s): [illegible] Trust

Address: [illegible]
[illegible]

Signature(s): [illegible] Trustee

Date: 11-4-04

BOOK 209 PAGE ~~612~~ 646

1-14-03

acq of Integrated Local Water Supply Plan

088928

HARVEY COUNTY, STATE OF KANSAS
This instrument was filed for record on the 19 day of May AD, 2003 at 8:00 o'clock A M and duly recorded in book 209 of Deeds on Page 612-613 Fees $ 12.00

Margaret A Hermstein
Register of Deeds

By ______________ Deputy

040 013610

ORIGINAL COMPARED WITH RECORD

Entered in Transfer Record in my office this 19 day of May A.D. 2003
Margaret Wright
County Clerk

REFILED
WARRANTY DEED

*** This deed is refiled to correct the legal description.

Refile
089125

HARVEY COUNTY, STATE OF KANSAS
This instrument was filed for record on the 23 day of May AD, 20 03 at 3:45 o'clock P M and duly recorded in book 209 of Deeds on Page 646-647 Fee $ 12.00

Margaret A Hermstein
Register of Deeds
By Michelle Schroeder Deputy

ORIGINAL COMPARED WITH RECORD

Grantor: Tammy Arlene Huneycutt, a single person

Warrants and Conveys to City of Wichita

the following described premises, to-wit:

See Exhibit A attached hereto and made a part hereof.

for the sum of One Dollar and other good and valuable consideration, the receipt of which is hereby acknowledged. This conveyance is made subject to easements and restrictions of record, if any.

Dated this 16th day of May, 2003.

Entered in Transfer Record in my office this 23 day of May A.D. 2003
Roberta Schroeder
Dep County Clerk

Tammy Arlene Huneycutt
Tammy Arlene Huneycutt

D1112

State of Kansas, County of Harvey : ss:

Be it remembered that before me, a notary public in and for the State and County aforesaid, personally appeared

Tammy Arlene Huneycutt, a single person

002057

**Exhibit A**

*** 1471.34

A tract of land in the Northeast Quarter (NE/4) of Section Two (2), Township Twenty-four (24) South, Range Three (3) West of the 6th P.M., Harvey County, Kansas. Beginning at the Northeast corner of said Northeast Quarter (NE/4); thence North 90 degrees 00 minutes 00 seconds West (assumed) along the North line of said Northeast Quarter (NE/4) for 935.55 feet; thence South 00 degrees 12 minutes 14 seconds East for ***1471.34*** feet; thence South 90 degrees 00 minutes 00 second East for 136.52 feet; thence North 00 degrees 12 minutes 14 seconds for 101.34 feet; thence South 90 degrees 00 minutes 00 seconds East for 757.23 feet to the East line of said Northeast Quarter; thence North 00 degrees 12 minutes 14 seconds West for 1370.01 feet feet to the point of beginning.EXCEPT Commencing at the Northeast Corner of said Northeast Quarter (NE/4); thence North 90 degrees 00 minutes 00 seconds West (assumed) along the North line of said Northeast Quarter (NE/4) for 739.52 feet to the point of beginning; thence South 00 degrees 32 minutes 30 seconds East for 1370.06 feet; thence North 90 degrees 00 minutes 00 seconds West for 40.00 feet; thence North 00 degrees 32 minutes 30 seconds West for 1370.06 feet to the North line of said Northeast Quarter (NE/4); thence South 90 degrees 00 minutes 00 seconds East for 40.00 feet to the point of beginning.

# REAL ESTATE PURCHASE CONTRACT

THIS AGREEMENT, Made and entered into this 3 day of Nov. , 2004 by and between John Stutzman, party of the First Part, hereinafter referred to as "Seller," whether one or more, and the City of Wichita, party of the Second Part, hereinafter referred to as "Buyer," whether one or more.

**WITNESSETH:** That for and in consideration of the mutual promises, covenants and payments hereinafter set out, the parties hereto do hereby contract to and with each other, as follows:

1. The Seller does hereby agree to sell and convey to the Buyer by a good and sufficient warranty deed the following described real property, situated in Harvey County, Kansas, to-wit:

   A tract of land in the Northeast Quarter of Section 11, Township 24 South, Range 3 West of the 6th P.M., Harvey County, Kansas. Said tract roughly described as the all land lying approximately 25 feet northeasterly of the east edge of a dry creek running from the northwest to southeast, less existing Road Right-of-Way. **Said tract containing 12.5 acres, more or less. Exact legal description to be determined by survey.**

2. The Buyer hereby agrees to purchase, and pay to the Seller, as consideration for the conveyance to him of the above-described real property, the sum of
   in the manner following to-wit: cash at closing.

3. The Buyer hereby agrees that while property is owned by City of Wichita, excess land not used for water utility purposes will be placed in conservation measures. Excess land will not be sold or leased for residential or crop land. If Buyer should decide to sell the land sold and purchased under this contract, Buyer hereby grants Seller or successors the right of first refusal to purchase all or any part of the property owned by the Buyer and purchased under this contract. If Buyer receives an offer acceptable to Buyer for all or any part of such adjoining property, Buyer shall provide written notice to Seller of the price, terms and conditions of the offer. Such written notice shall be sent by certified mail, return receipt requested, to the Seller. Seller shall have twenty (20) days afer its receipt of the written notice to decide whether to purchase the property, and if so, it shall give written notice to buyer of its decision to do so. This right of first refusal shall survive this closing.

4. A complete abstract of title certified to date, or a title insurance company's commitment to insure, to the above described real property, showing a merchantable title vested in the seller, subject to easements and restrictions of record is required. The Title Evidence shall be sent to Property Management Division for examination by the Buyer as promptly and expeditiously as possible, and it is understood and agreed that the Seller shall have a reasonable time after said Title Evidence has been examined in which to correct any defects in title.

5. A duly executed copy of this Purchase Agreement shall be delivered to the parties hereto.

6. It is further agreed by and between the parties hereto that all costs and income, if any shall be adjusted and prorated as of the closing date. Taxes shall be pro-rated for calendar year on the basis of 100% of taxes levied for the prior year.

7. The Seller further agrees to convey the above described premises with all the improvements located thereon and deliver possession of the same in the same condition as they now are,

reasonable wear and tear excepted.

8. It is understood and agreed between the parties hereto that time is of the essence of this contract, and that this transaction shall be consummated on or before February 28, 2005.

9. Possession to be given to Buyer at time of closing.

10. In the event an Owners title insurance policy is furnished, the total cost of the commitment to insure and the title insurance policy will be paid 0 % by seller and 100% by buyer. Buyer will pay 100% closing costs.

11. Site Assessment

A. At any time prior to the closing of this agreement, the buyer shall have the right to conduct or cause to be conducted an environmental site assessment and/or testing on the property. If an environmental audit or test reveals the presence of a hazardous substance or waste, as defined by federal or state law, or that there has been a spill or discharge of a hazardous substance or waste on the property, the buyer shall have the right to void this agreement upon notice to the seller, in which event neither party shall be under any further obligation to the other, with the exception that seller shall return to buyer any deposit made hereunder.

B. The buyer or its agents shall have the right, without the obligation, to enter upon the property prior to closing to undertake an environmental site assessment or testing of the property, at the buyer's sole expense.

C. Provided, however, buyer shall in no event be obligated to close before the completion of a site assessment made pursuant to Paragraphs A and B above. If a site assessment is completed after the closing date set herein, then the buyer and seller shall close or the buyer shall advise seller that this agreement is being voided pursuant to said paragraph within ten (10) days of the completion of the site assessment. The buyer shall, if buyer determines a site assessment is necessary, exercise good faith in commencing and diligently completing such site assessment after this agreement is executed by all parties.

**WITNESS OUR HANDS AND SEALS** the day and year first above written.

By Direction of the City Council

Carlos Mayans, Mayor

John Stutzman

**ATTEST:**

Karen Sublett, City Clerk