2-1990

Bazile Triangle Groundwater Quality Study

David C. Gosselin
University of Nebraska-Lincoln, dgosselin2@unl.edu

Gosselin, David C., "Bazile Triangle Groundwater Quality Study" (1990). *Conservation and Survey Division*. 321.
http://digitalcommons.unl.edu/conservationsurvey/321

Bazile Triangle Groundwater Quality Study

David C. Gosselin
Project Coordinator

Conservation and Survey Division
Institute of Agriculture and Natural Resources
The University of Nebraska-Lincoln

February, 1990

Final Report for Contract 89-2
Submitted to the
Nebraska Department of Environmental Control

TABLE OF CONTENTS

ABSTRACT i

ACKNOWLEDGMENTS ii

INTRODUCTION 1

- Purpose and Scope 1
- Previous Work 2

GEOGRAPHY 3

- Topographic Region 3
- Soils 3
- Climate 4
- Land Use 5

GEOLOGY and HYDROGEOLOGY 5

- Geology 5
- Hydrogeology 7

METHODS 8

- Site Selection and Sampling Techniques 8
- Analytical Techniques and Quality Control 9

RESULTS 10

- Domestic Wells 11
- Irrigation Wells 11
  - Plio-Pleistocene Hydrostratigraphic Unit 11
  - Ogallala Hydrostratigraphic Unit 12
  - Combined Ogallala/Plio-Pleistocene Hydrostratigraphic Unit 12

DISCUSSION 13

- General Water Chemistry 13
- Nitrate-Nitrogen Contamination 13

SUMMARY, CONCLUSIONS, and RECOMMENDATIONS 17

REFERENCES 19

ABSTRACT

The Bazile Triangle Water Quality Study in northeast Nebraska is a cooperative effort involving the Upper Elkhorn, Lower Elkhorn, Lower Niobrara, and Lewis and Clark natural resource districts, and the Conservation and Survey Division, University of Nebraska-Lincoln. Groundwater in the study area occurs in predominantly unconfined water-bearing units consisting of the Ogallala Group and Plio-Pleistocene sand and gravel. The three general groundwater flow areas in the study area are related to drainage basins of Verdigre Creek, Bazile Creek, and the North Fork of the Elkhorn River.

One-hundred-seventeen irrigation wells and 8 domestic wells were sampled from July 24 to August 8, 1989. The NO_3-N content in the domestic wells ranged from 0.66 to 38.6 ppm; only the 38.6 ppm value exceeded the recommended 10 ppm level. Groundwater samples were obtained from irrigation wells that were screened in either the Ogallala Group or Plio-Pleistocene sand and gravel, the principal water-bearing hydrostratigraphic units; or in a combination of the two principal water-bearing units. Only 25 percent of the irrigation-well samples had NO_3-N values greater than the 10 ppm, the highest value being 25.0 ppm. An additional 45 percent had values that ranged from 5 to 10 ppm, with the majority of these exceeding 7 ppm, indicating that groundwater probably has been contaminated to varying degrees. Apparent contamination in the Ogallala appears to be due to direct hydraulic connection with overlying Plio-Pleistocene sand and gravel, which provides the contaminated water. This relationship suggests that the Ogallala is still relatively uncontaminated. Contamination in samples where both the Ogallala and the Plio-Pleistocene sand and gravel are screened is being derived from Plio-Pleistocene sand and gravel.

Glacial till appears to inhibit vertical migration of contamination as indicated by the association of 0 to 5 ppm NO_3-N values in the vicinity of the till. The majority of samples with NO_3-N values greater than 10 ppm occur in the vicinity of local and regional drainage divides, which serve as the dominant net-recharge areas. A strong relationship between the NO_3-N and Cl concentrations indicates that the source of groundwater contamination is most likely related to fertilizer application practices.

Although there are indications of groundwater contamination, the data presented represent only a glimpse of the contamination at one moment. More work is required to evaluate short-term and seasonal variations to determine how well the data acquired here represent the degree to which the subsurface has been contaminated. It is necessary to determine the extent of contaminant stratification and whether most of the contamination occurs in a particular unit(s). The susceptibility of recharge areas to contamination has been suggested; however, in order to protect these areas more detailed knowledge of the hydrogeologic system is required.

ACKNOWLEDGMENTS

The author is grateful to P. Wigley, V. Dreeszen, J. Ayers, D. Pederson, J. Swinehart, C. Flowerday, and the staff of the Groundwater Section, Nebraska Department of Environmental Control (NDEC; D. Ehrman, unit supervisor) for thoughtful reviews that improved the manuscript significantly. Special thanks to D. Schueth, S. Kahler, and G. Howey for their assistance during sampling, without which this study could not have been completed; Roy Spalding for technical advice; A. Mack for her patience and expertise in drafting the diagrams; and L. Eckmann for technical support. This study was supported by a grant from U.S. Environmental Protection Agency administered by NDEC; by the Lower Elkhorn, Upper Elkhorn, Lower Niobrara, and Lewis and Clark Natural Resources Districts, and by the Conservation and Survey Division, University of Nebraska-Lincoln.

INTRODUCTION

Purpose and Scope

Groundwater is one of Nebraska's most precious natural resources providing potable water to more than 95 percent of the state's rural population. Groundwater is never pure and always carries dissolved solids and gases. These dissolved constituents are the result of natural physical and chemical interactions between water and the biologic and geologic materials (soils, rocks etc.) as the water moves from the land surface to subsurface aquifers. Unfortunately, over the past 15 years, the reported number of incidents of contaminated groundwater in domestic and municipal supplies has increased significantly.

The most commonly reported type of contamination in Nebraska is nitrate. Nitrate (NO_3) is a normal part of the nitrogen cycle in nature, and is relatively non-toxic. Although nitrate itself is relatively harmless, nitrate is converted to nitrite within the human body, and nitrite at high levels can cause the blood abnormality, methemoglobinemia (blue baby syndrome), in infants (rarely in older individuals), and form potentially cancer-causing N-nitroso compounds (WHO, 1978). Nitrates are common in food products with vegetables, accounting for 90 percent of daily ingested nitrate, which is about 86 mg NO_3 per person per day (White, 1975). Water is consumed in larger amounts than any other food. For this reason, a high nitrate content in water has a great impact on the total amount of nitrates consumed. The U.S. Public Health Service and the World Health Organization have recommended that drinking water not exceed 10 mg/l (ppm) NO_3-N (National Interim Primary Drinking Water Regulations, 1975). Cities in Nebraska with concentrations that consistently exceed 10 ppm are required to supply bottled water to families with infants and pregnant women.

The Bazile Triangle Grounwater Quality Study was the result of growing concern about groundwater contamination in northeastern Nebraska, which has affected municipal wells in Osmond, Creighton, Royal, and Orchard, and the mandate given to Nebraska's natural resource districts (NRDs) in 1984 by LB 1106 to develop policies and programs for the management of groundwater quality and quantity (fig. 1). The study area centered on the Bazile Creek drainage area (fig. 2), is located in Township 27 N. and 28 N. of Antelope and Pierce County and portions of Township 29 N. Range 3 W., 4 W., 5 W., and 6 W. of Knox County . This study is unique in that it involves the cooperation of the Upper Elkhorn, Lower Elkhorn, Lower Niobrara, and Lewis and Clark NRDs, along with the Conservation and Survey Division, University of Nebraska-Lincoln. Although each of the NRDs have groundwater quality monitoring programs of some sort, none have the resources to do a detailed evaluation of the potential contamination in this relatively small area centered on the Bazile Creek drainage. The purpose of this study is to begin assessing the nature, extent, and magnitude of nitrate contamination in major groundwater-bearing units in this area.

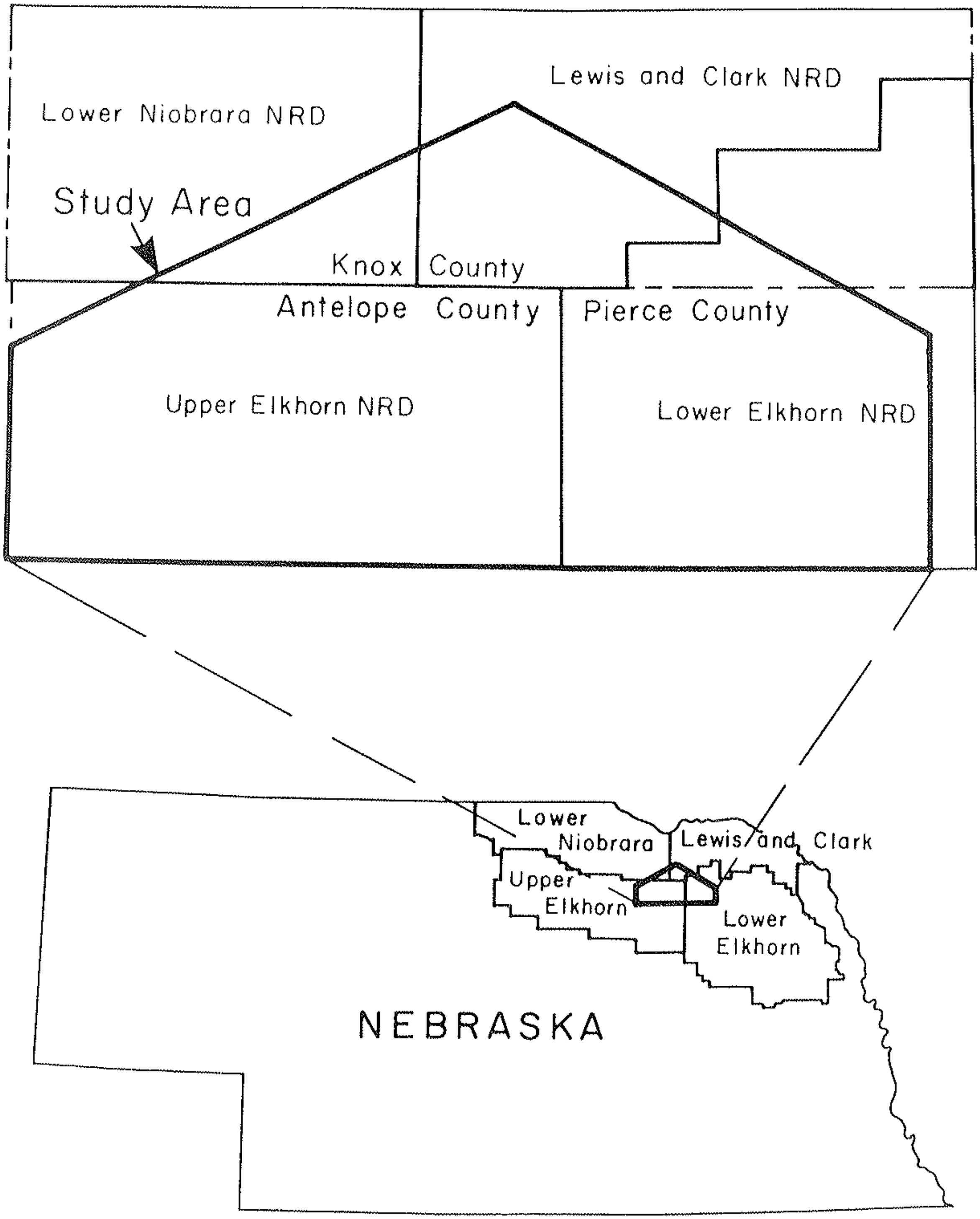

Figure 1. Location of Bazile Triangle Groundwater Quality Study area.

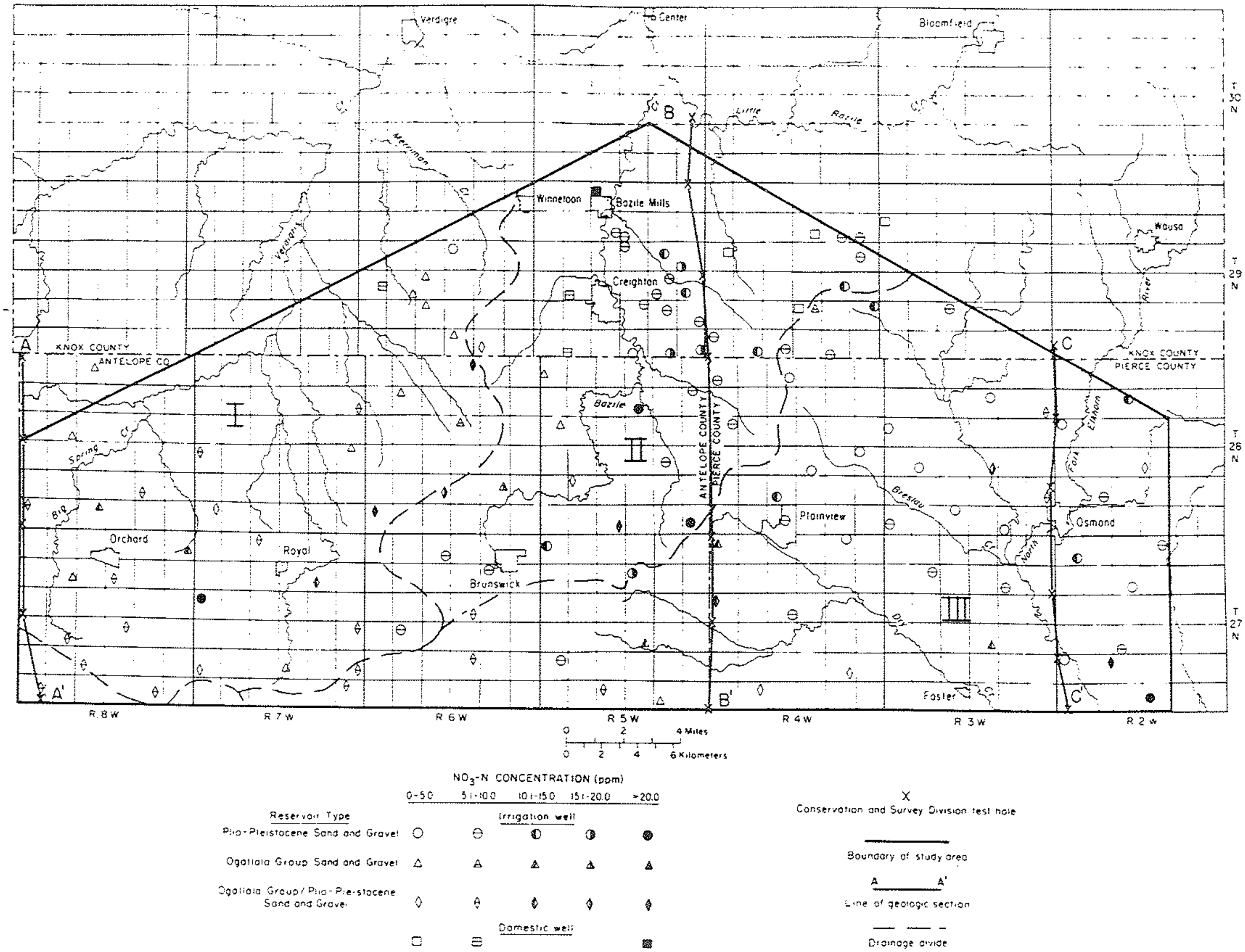

Figure 2. Sample locations with approximate nitrate concentrations of the groundwater. I = Verdigre Creek drainage basin; II = Bazile Creek drainage basin; III = North Fork, Elkhorn River drainage basin

In addition, the study provides basic information on the dissolved substances that occur in the highest concentrations in water and are most likely to affect water use.

Previous Work

Available information on the water quality in the Bazile Triangle and, in general, northeastern Nebraska is scarce. Only six wells had been analyzed in the Triangle prior to 1969, according to the National Water-Data System operated by the U. S. Geological Survey (USGS),. The only high volume well (> 100 gallons per minute, gpm) analyzed, a municipal well at Plainview, had a NO_3-N value of 2.1 ppm in 1958 The other wells tested during this period included four domestic supplies and one stock well. During 1969 to 1979, an additional eight domestic wells (<0.01 to 9.6 ppm NO_3-N), two stock wells (6.4 and 10.4 ppm NO_3-N), and two unused irrigation wells (<0.01 and 1.0 ppm NO_3-N) were sampled. The Plainview municipal well was sampled in 1969 and 1975, yielding values of 3.4 and 3.6 ppm NO_3-N, respectively.

The increasing concern and speculation about the potential of nitrate contamination in Pierce County led to the sampling of 156 irrigation and municipal wells in 1980, 1981, and 1982 (Hanson, 1983). The reported NO_3-N values ranged from less than 0.01 to 53.7 ppm. Twenty six of the 135 samples collected in 1980 exceeded the public health standard of 10 ppm. Resampling 14 of the 26 wells with high values in 1981 indicated no significant change from 1980 to 1981 (Hanson, 1983). Hanson (1983) compared the 1980 data from 17 samples to those reported previously by the Nebraska Department of Health, USGS, and the University of Nebraska Cooperative Extension Service. This comparison indicated that NO_3-N values had risen since 1970, but predicting future trends was impossible due to the small number and the potential internal variability of the samples.

As part of their mission to protect and manage groundwater, the Upper Elkhorn (UE), Lower Elkhorn (LE), and Lewis and Clark (LC) NRDs sampled 16 irrigation wells from 1986 to 1988 that were analyzed by the Nebraska Department of Health. The NO_3-N values ranged from 4.0 to 21.9 ppm. A comparison of the data from five wells that were sampled at least twice in the LE and LC portions of the Triangle indicates that three samples have apparent NO_3-N increases, one has an apparent decrease of 4 ppm, and one had no change. Domestic and stock well samples tested in the Lower Niobrara (LN) NRD adjacent to the Triangle during January 1988 using a HACH kit indicated values that range from <0.2 to 155 ppm NO_3-N. The 155 ppm sample was taken from a well located in the middle of a periodically used barnyard where the potential for nitrate contamination is extremely high.

During 1985 and 1986, the City of Osmond municipal water system exceeded the 10 ppm NO_3-N limit 12 of the 23 times it was sampled. The recognition of a problem led to a detailed hydrogeologic study of the local groundwater flow system at Osmond, Nebraska (Alix, 1987). This site specific study involved the installation of 20 shallow and deep monitoring wells at 10 locations in and adjacent to Osmond. Alix

(1987) concluded that, in general, the top of the aquifer was contaminated, as 5 of the 10 shallow monitoring wells showed evidence of contamination. He suggested that the contamination was entering the city from the northeast and was possibly related to agricultural practices (Alix, 1987). In a follow up to this study, the LENRD sampled 56 domestic wells within a 4 mile radius of Osmond. Eighteen of the 56 wells (32 percent) exceeded 8.0 ppm NO_3-N; however, 16 of these 18 wells were located adjacent to active barnyards or animal confinement buildings. One well (no longer being used) had a NO_3-N value of 222 ppm. This well is located next near the farm house septic system. It appears that many of the contamination problems in these rural domestic supplies are related to point sources.

GEOGRAPHY

Topographic Region

The Bazile Triangle study area consists of three distinct topographic regions; These are the "Plains," "Dissected Plains,", and "Rolling Hills" as described by Dreeszen (1973). The following descriptions are from Dreeszen (1973). The Plains region comprises a large part of western and eastern Antelope County, western Pierce County, and the majority of Knox County. This area consists of flat-lying land which lies above valleys and is underlain by stream-deposited silt, clay, and sand and gravel overlain by wind deposited silt (loess). The Dissected Plains occur in Antelope County in the western part of the area associated with the Verdigree Creek drainage basin (Fig. 2). This region consists of hilly land with moderate to steep slopes, sharp ridge crests, and remnants of the old, nearly level plains. This region formed as the result of water and wind erosion of old plains. The Rolling Hills region comprises the eastern part of Pierce County and is characterized by hilly land with moderate to steep slopes and rounded ridge crests. The Rolling Hills consist dominantly of eroded glacial till that is mantled by loess. The boundary between the Rolling Hills and Plains regions follows the North Fork of the Elkhorn River. The land-surface elevation in the study area ranges from about 1,450 to 2,100 feet above mean sea level. The area is drained by Bazile Creek, Verdigree Creek, and the North Fork of the Elkhorn River and its tributaries (fig. 2).

Soils

Soils in the Triangle can be divided into 10 associations (fig. 3). The five dominant associations are described as follows (number in parenthesis refers to association on fig. 3):

1. Bazile-Paka-Thurman Association (5)-deep, nearly level to gently sloping, well and somewhat excessively drained silty, loamy, and sandy soils formed in loess overlying sandy sediments, weathered

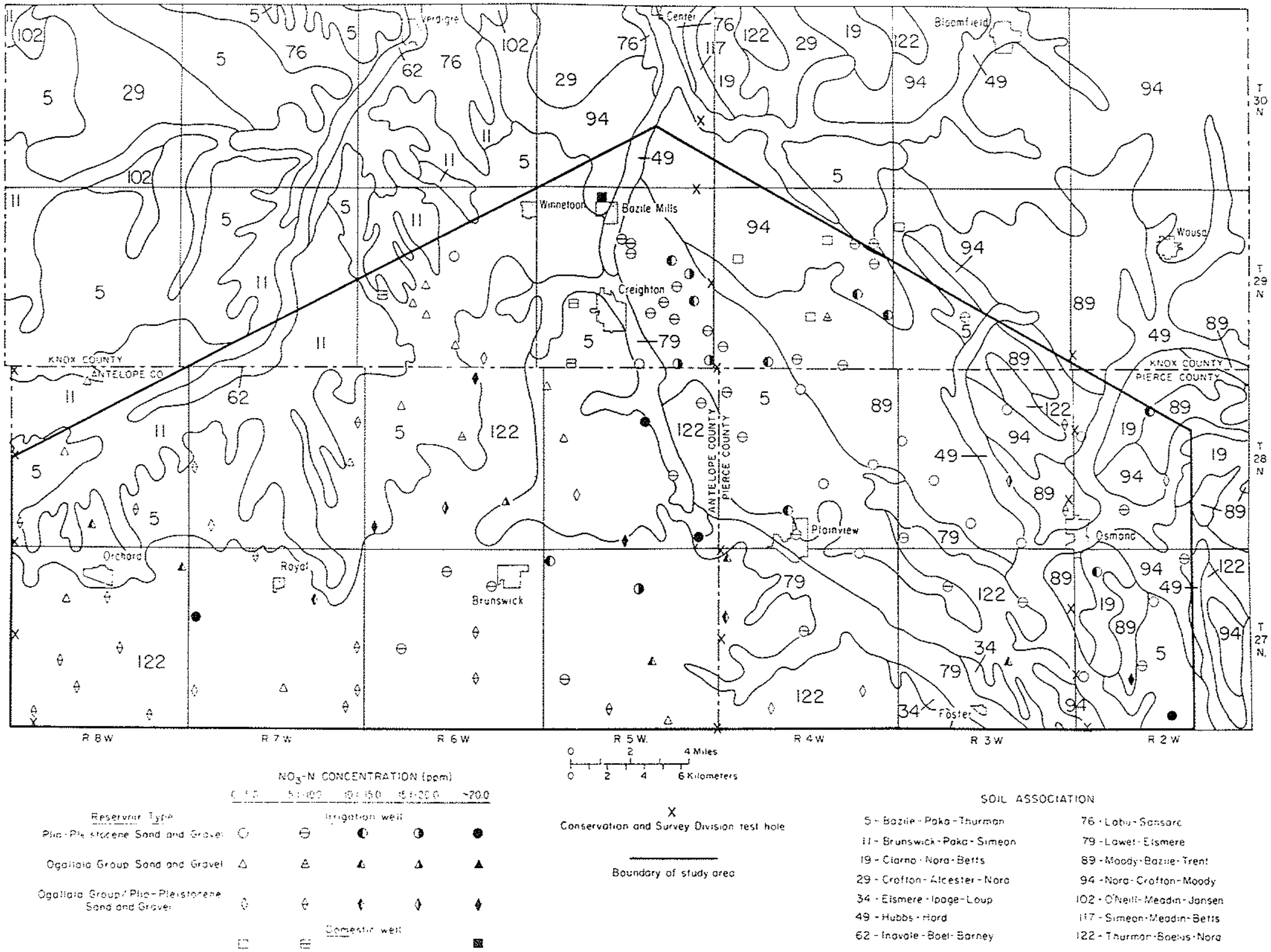

Figure 3. Soil associations in and adjacent to the Bazile Triangle study area. See text for description of major soil types. Source: General 1° x 2° soil maps for Sioux City (1980), and O'Neill (1981).

siltstone, and eolian sands on upland areas. Absorbs most or all of light precipitation, which is retained as soil moisture, but produces much runoff when precipitation is heavy. Five to 10 percent of annual precipitation transmitted to water table (Souders and Shaffer, 1969);

2. Brunswick-Paka-Simeon Association (11)-moderately deep, gently sloping to steep, well to excessively drained, loamy and sandy soils formed in weathered sandstone and siltstone, and sandy sediments on upland areas. Absorbs very little of moderately heavy and heavy precipitation, so much runoff is produced. Little or no precipitation transmitted to water table (Souders and Shaffer, 1969);

3. Moody-Bazile-Trent Association (89)-deep, nearly level to gently sloping, well and moderately well drained, silty soils formed in loess and outwash sand on uplands terraces, and upland swales. Absorbs most light precipitation and heavy precipitation produces significant runoff. Ten to 15 percent of annual precipitation transmitted to water table (Brogden et al., 1976);

4. Nora-Crofton-Moody Association (94)-deep, gently sloping to steep, well and somewhat excessively drained, silty soils formed in loess on uplands. Absorbs most light precipitation and heavy precipitation produces significant runoff. Ten to 15 percent of annual precipitation transmitted to water table (Brogden et al., 1976);

5. Thurman-Boelus-Nora Association (122)-deep, nearly level to strongly sloping, somewhat excessively and well drained, sandy and silty soils formed in eolian sand, eolian sand over loess, and loess on uplands. Rapidly absorbs most or all the precipitation so rarely produces runoff. Probably transmits 20 to 25 percent of annual precipitation to water table (Souders and Shaffer, 1969).

The proportion of water transmitted to the water table (recharge) given above may be underestimated by two or three times (Dreeszen, personal communication) For additional information on other soil associations present the reader is referred to the Antelope County and Pierce County soil surveys (Mahnke et al., 1978; Schulte et al., 1976).

Climate

The climate in the Bazile Triangle is typical of the interior of large continents in midlatitudes, being normally subhumid, but in extreme years it has been arid to humid (Souders and Shaffer, 1969; Brogden et al., 1976). The following climatic information is summarized from Souders and Shaffer, 1969 and Brogden et al., 1976. Average annual precipitation ranges from 23 inches in western Antelope County to 26 inches in eastern Pierce County. Average rainfall during the growing season (May through September) ranges from 15 inches in the west to 17.5 inches in the east. The annual average temperature is near 48.7° F with a growing season average of 68.7° F. Wind directions frequently change, and strong winds are common in early spring and late fall. Occasionally, pastures and crops may be damaged by hot, high velocity winds during the growing season. These winds associated with high temperatures will contribute significantly to evapotranspiration and reduce the amount of water available to crops and to the subsurface.

Land Use

Data from the U. S. Department of Agriculture Soil Conservation Service (SCS) indicates that 90 to 95 percent of the land in the Bazile Triangle is used for agriculture. Approximately 85 percent of the land in Knox and Pierce Counties is cropland; the remainder being classified as rangeland or pastureland. Rangeland and pastureland is more common in Antelope County (about 32 percent) whereas nearly 68 percent is cropland. In Knox and Antelope Counties there is approximately equal proportions of irrigated and dryland farming, whereas in Pierce County 40 percent of the cropland is irrigated. Other land uses include feedlots, gravel pits, roads, farmsteads, towns, and forested areas.

Data from the SCS indicates that corn and soybeans account for at least 80 percent of the total amount of crop production; small grains (e.g., oats, rye), alfalfa, and forage crops account for the remaining portion. Anhydrous ammonia is the dominant fertilizer used. Annual applications vary from 50 to 250 lbs per acre with typical applications being between 150 to 200 lbs N per acre.

GEOLOGY and HYDROGEOLOGY

Geology

To understand the areal and vertical distribution of water-bearing units in the subsurface and the distribution and movement of groundwater and chemical contaminants requires an understanding of geology. The geologic units currently suppling the groundwater for domestic, irrigation, and municipal use are unconsolidated sand and gravel deposits and the semi-consolidated Ogallala Group (Table 1). The Pierre Shale of Late Cretaceous age is the lower limit of drilling for fresh water in the Triangle. The Niobrara Formation and Dakota Sandstone, which are older than and underlie the Pierre Shale, are potential sources for groundwater, but presently are not known to supply water to any wells in the study area.

The top of the Pierre Shale was modified by erosion prior to the deposition of the Ogallala sediments. Contours on top of the Pierre Shale, based on test drilling by the Conservation and Survey Division (Souders and Shaffer, 1969; Brogden et al., 1976; Dreeszen, unpublished data), indicate a series of southeast-trending valleys and intervening ridges through Antelope, Pierce and Knox counties; the maximum relief exceeds 200 feet (fig. 4a-c). These valleys were formed by tributaries of a major easterly flowing river (Brogden et al., 1976).

The Ogallala Group underlies the entire area except for the northeastern corner of Antelope County, northwestern corner of Pierce County and an area extending north into Knox County. This group consists of strata composed of fine to medium silty sand and sandstone, siltstone, and sandy and clayey silt, and lesser

Table 1

Summary of geologic and hydrostratigraphic framework (Modified from Lawton and Hiergesell, 1988)

ERATHEM	SYSTEM	SERIES	GROUP OR FORMATION	HYDROSTRATIGRAPHIC UNIT AS USED IN THIS REPORT		LITHOLOGY	WATER-YIELDING PROPERTIES
Cenozoic	Quaternary	Holocene 0.01		H1	H1a Alluvial Fill H1b Surficial Sand	H1a - sand, gravel, silt, clay H2b - eolian and alluvial sand	PRINCIPAL GROUNDWATER RESERVOIR Provides moderate to large well yields. High-capacity wells penetrate H3 and commonly H4. Some low-capacity wells penetrate H1 and H2.
		Pleistocene 1.6		H2	Undifferentiated Quaternary	Sand, silt, sandy and clayey silt, and sandy clay	
	Tertiary	Pliocene 5		H3	Plio-Pleistocene Sand and Gravel S&G A S&G B	Sand, gravel, interbedded silt within gravels, and brown silt between gravels A and B	
		Miocene 24	Ogallala 19	H4	Ogallala Group	Sand, silty sand, sandy and clayey silt, sandstone, siltstone, and some gravel	
		Oligocene 38	Arikaree-? White River-?	H5	Pre-Ogallala Tertiary/ Older Ogallala	Clayey and sandy silt and siltstone, sandy and silty clay	Not an aquifer.
		Eocene	Rocks of this age are not known to be present in study area.				
		Paleocene 65					
Mesozoic	Cretaceous	Upper Cretaceous	Pierre	H6	Pierre Shale	Shale	Not an aquifer.
			Niobrara			Shaley chalk and limestone	Secondary aquifer where fractured.
			Carlile			Shale, some sandstone	Not an aquifer.
		98	Greenhorn-Graneros			Limestone and shale	Not an aquifer.
		Lower Cretaceous 144	Dakota			Sandstone and shale	Secondary aquifer; water may be highly mineralized.

Note: Approximate age of boundaries given in million years.

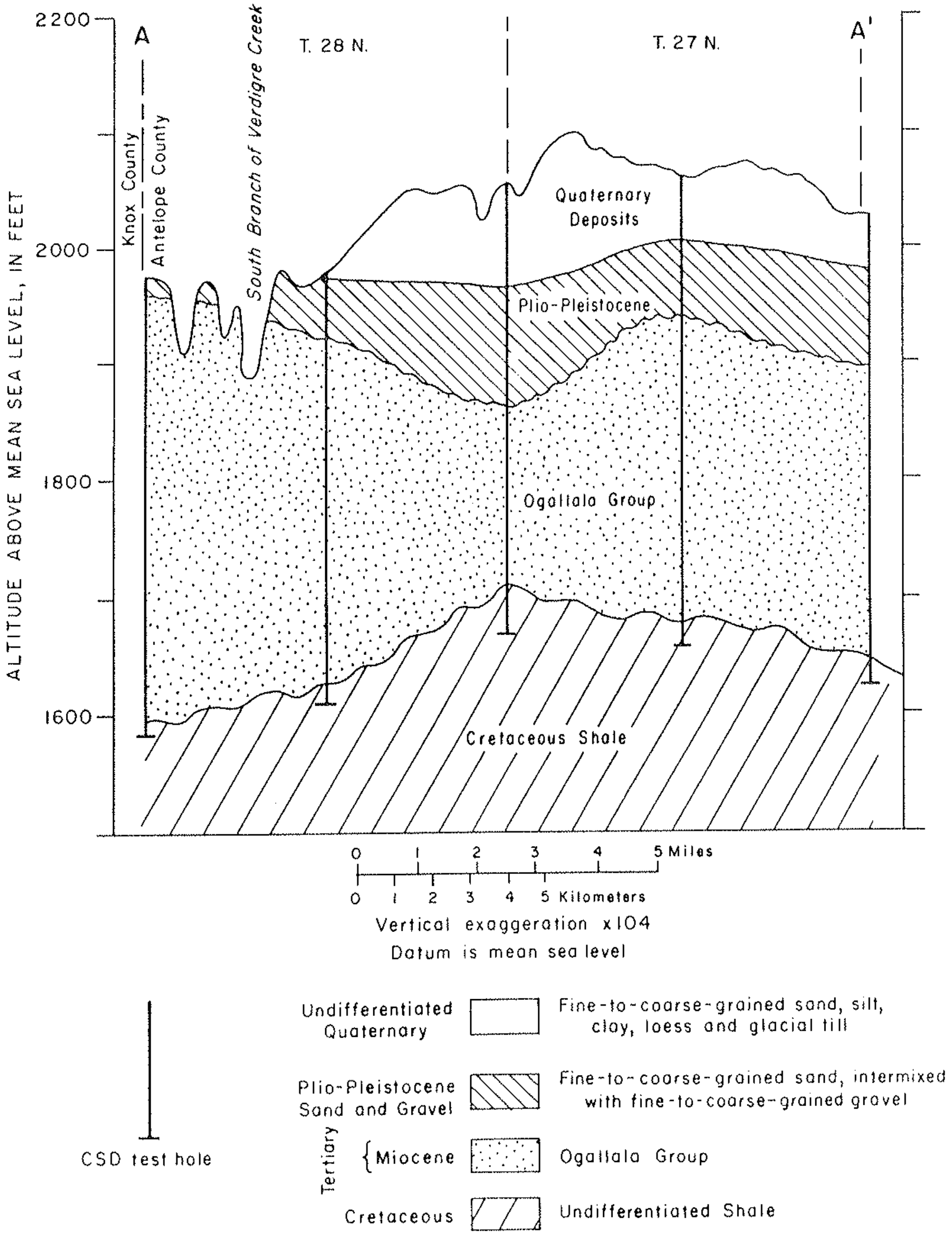

Figure 4a. Geologic cross section A-A'; Cross section locatio on figure 2. (Modified from Souders and Shaffer, 1969)

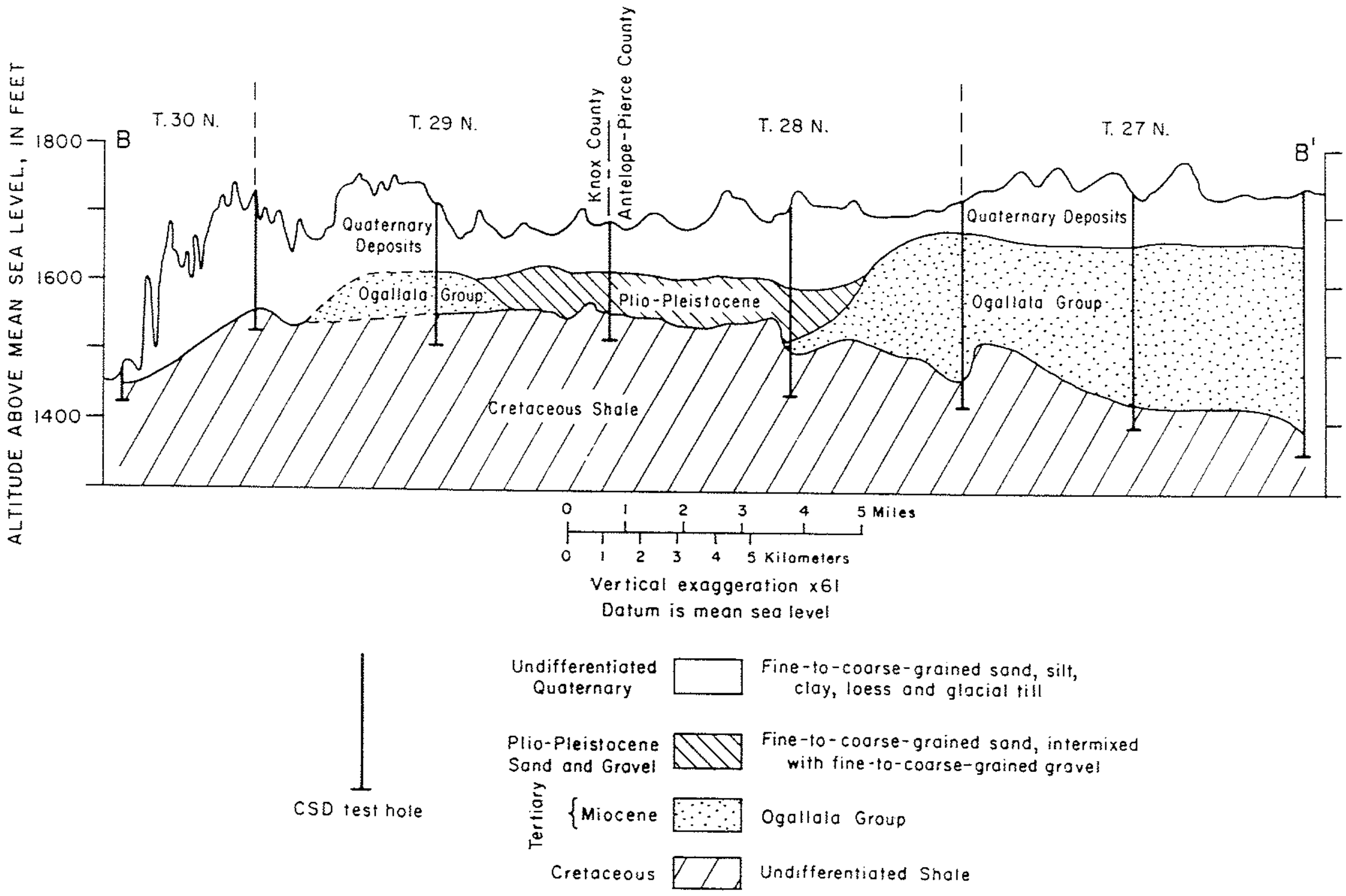

Figure 4b. Geologic cross section B-B'; Cross section location on figure 2.

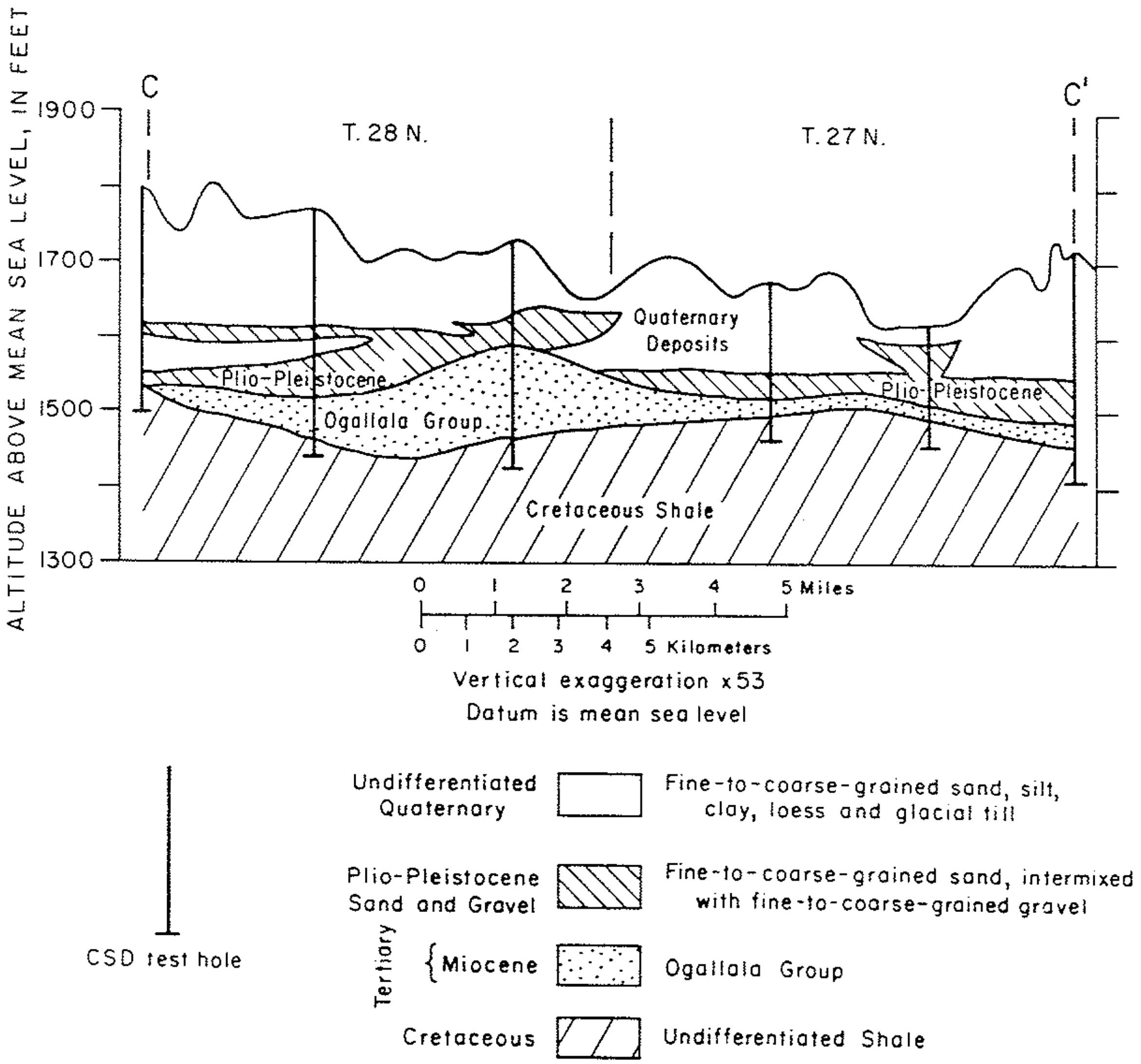

Figure 4c. Geologic cross section C-C'; Cross section location on figure 2. Modified from Brogden et al. (1976)

amounts of volcanic ash and diatomite (Lawton and Hiergesell, 1988; Swinehart and Diffendal, 1989). The sand is dominantly very fine to fine, but locally is well-sorted, medium- to coarse-grained sand and fine gravel. In other areas in Nebraska, it has been possible to differentiate the Ogallala Group into three formations (e.g., Lugn, 1939; Swinehart et al., 1985). Voorhies (1973) divided the Ogallala Group exposed along the Middle Branch of Verdigree Creek, about 8 miles southeast of Verdigre, into the Ash Hollow and Valentine formations. No attempt has been made to divide the Ogallala Group in formations in this report because of the lack of outcrop and detailed subsurface information.

The Ogallala Group was deposited between 19 and 5 million years ago by eastward-flowing streams carrying sediment primarily derived from the Rocky Mountains. The preserved strata represent complex episodes of valley erosion and filling by streams (Diffendal, 1982; Swinehart and Diffendal, 1989). After deposition of the Ogallala ceased, erosion by later streams created an irregular upper surface. Because of this complex sequence of erosion and deposition, the Ogallala may be absent or may attain thicknesses of more than 400 feet (fig.4 a-c).

The unconformity (a surface representing a missing interval in the rock record) created during post-Ogallala erosion may represent up to 1.5 million years (Swinehart and Diffendal, 1989). The next sediments were river-deposited, fine- to coarse-grained sand intermixed with fine- to coarse-grained gravel. The age of these deposits is not well constrained, but their deposition probably occurred from the middle Pliocene into the Pleistocene (Swinehart and Diffendal, 1989; Swinehart, personal communication). Hence, they are referred to as Plio-Pleistocene sand and gravel (Table 1; fig. 4a-c). The source of the sand and gravel was probably from the Rocky Mountains in Colorado and Wyoming (Swinehart and Diffendal, 1989). However, during the late Pliocene into the early Pleistocene streams carrying runoff from glaciers, moving down from the north, probably can account for some of the sand and gravel deposits, but no distinction has been attempted. The Plio-Pleistocene deposits are absent locally, but attain thicknesses that may exceed 150 feet (fig. 4a-c).

Overlying and interbedded with the sand and gravel deposits is a complex sequence of undifferentiated, interbedded fine- to coarse-grained sand, silty and clayey sand, sandy and clayey silt, and silty clay, representing material deposited by water and wind during the Quaternary (table 1). Except where removed by erosion, these deposits are present throughout the area. Till, a glacially deposited mixture of clay, silt, sand, gravel and boulders, occurs in the eastern part of the area (fig. 5) and in places may be more than 250 ft thick (Brogden et al., 1976). Wind-deposited silt (loess) blankets the till and the Plio-Pleistocene sand and gravel and may be as much as 75 feet thick in eastern Pierce County (Brogden et al., 1976).

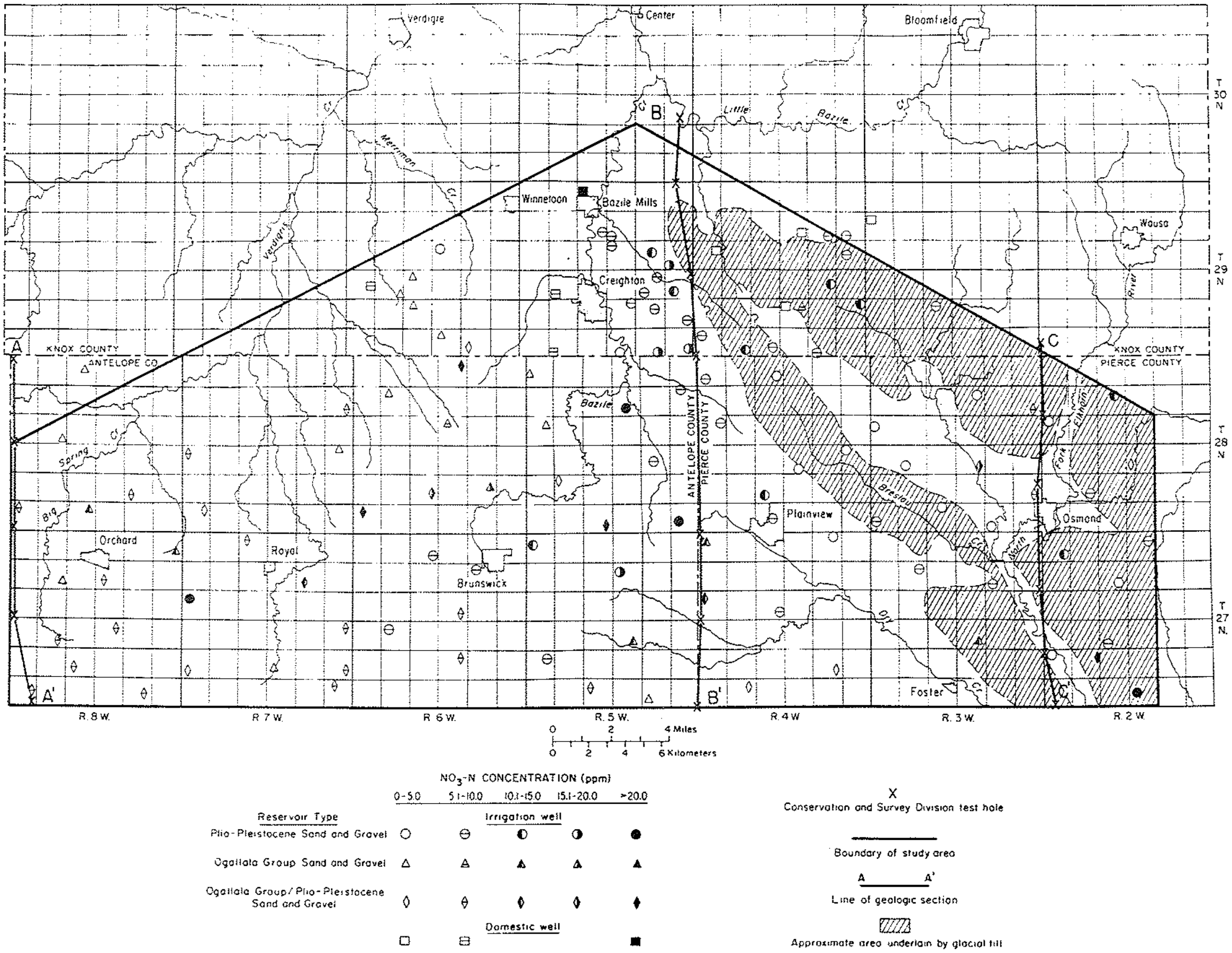

Figure 5. Approximate distribution of glacial till. Isolated bodies of till may occur beyond boundary given on this map. Data from Brogden et al. (1976) and Dreeszen (1970).

Hydrogeology

To describe the relationship between geology and the occurrence of groundwater, the term "hydrostratigraphic unit" is used. Boundaries of a hydrostratigraphic unit are related to the similarities in the water-yielding characteristics of the geologic material. In the Bazile Triangle, the primary sources of usable water are the water-bearing hydrostratigraphic units consisting of Plio-Pleistocene sand and gravel and the Ogallala Group. These units are part of the "High Plains Aquifer," which extends from South Dakota to Texas underlying parts of eight states, as defined by the U.S. Geological Survey (Gutentag and Weeks, 1980; Weeks and Gutentag, 1981). This aquifer predominantly consists of the Ogallala Group, but in most of Nebraska younger and older water-bearing units are hydraulically connected with the Ogallala Group and are considered to be part of this aquifer. Locally, clay lenses hydraulically isolate these water-bearing units into distinct aquifers. The majority of irrigation wells in the area derive water from the Plio-Pleistocene sand and gravel; however, where these deposits are thin or absent irrigation wells may derive all or part of their water from the Ogallala Group. Some domestic and stock wells may obtain water from local sand and gravel intervals within the Quaternary deposits associated with the glacial till.

The water resources in Antelope and Pierce counties have been described by Souders and Shaffer (1969) and Brogden et al. (1976), respectively, and the following discussion is based on their work except where indicated. The saturated thickness of the of the Plio-Pleistocene and Ogallala Group deposits ranges from less than 100 feet to more than 400 feet. Depth to water, based on water level measurements made by the NRDs in the Fall, 1989 on wells sampled in this study, varies from less than 6 feet to more than 185 feet. The greatest depths to water are associated with upland areas, whereas the shallowest depths are generally in the valleys of principal streams.

Gravity is the principal force controlling groundwater movement. In the Triangle, groundwater moves from upland interstream areas towards streams and bottomlands. Thus, groundwater flow is principally controlled by topography (i.e. configuration of the land surface) indicating that the water-bearing units are predominantly unconfined (i.e. water only partly fills the water-bearing unit and the water level is free to rise and decline as the amount of water in the aquifer increases or decreases). The presence of relatively low permeability clay layers will cause the water-bearing units to be confined locally (i.e. water completely fills the water-bearing unit and the water level in a well stands at some height above the top of this unit). Because of topographic control, the three distinct drainages in the Triangle (I, II, III, fig. 2) also represent three groundwater flow areas. In areas I and II, groundwater flows in a northerly direction, following the Verdigre and Bazile Creek, respectively. In area III, groundwater flow is east to southeast, depending on the influence of the local drainage.

The rate at which groundwater moves from the uplands to the discharge areas depends upon the slope of the water table (hydraulic gradient) and the water transmitting characteristics of the reservoir material

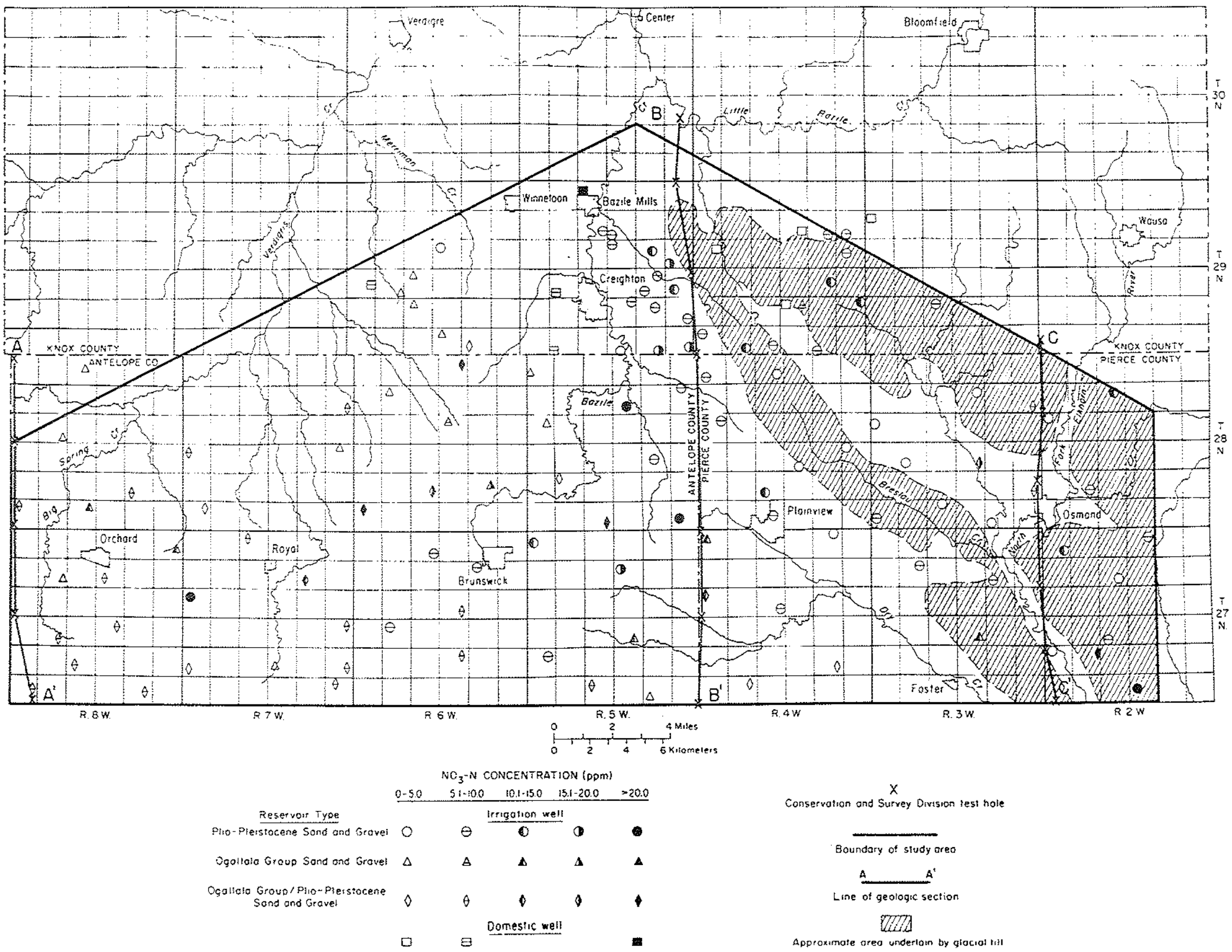

Figure 5. Approximate distribution of glacial till. Isolated bodies of till may occur beyond boundary given on this map. Data from Brogden et al. (1976) and Dreeszen (1970).

(i.e. hydraulic conductivity). Souders and Shaffer (1969) suggested that in most places in Antelope County the rate of movement is probably less than 1 foot per day, or about 1 mile in 15 years. Chen and Druliner (1987) estimated a range of groundwater flow rates in six areas of the High Plains aquifer in Nebraska from 0.06 to 1.50 feet per day and an average of about 0.38 feet per day (1 mile every 38 years). Similar rates are assumed for the Bazile Triangle. Pumping large volumes of water from high capacity irrigation wells will alter hydraulic gradients near the wells, thereby disturbing groundwater flow patterns and velocity.

Perched water conditions occur in the areas underlain by glacial till. Water from precipitation or applied through irrigation moves readily through loess but not through glacial till. As a result water saturates sediments above the till and a perched water table forms (Dreeszen, personal communication). Farm wells yielding small quantities of water have been developed in these perched water bodies. Significant water-level changes occur between wet and dry seasons; lateral water movement is slow, and the direction of flow is controlled by the slope of the land surface, as well as by the slope of the buried till surface (Dreeszen, personal communication).

METHODS

Site Selection and Sampling Techniques

Groundwater samples were collected from 117 irrigation wells and 8 domestic wells over the period of July 24 to August 8, 1989. The irrigation wells were selected from a pool of potential wells submitted by each of the NRDs. Well registrations for each potential site were examined to determine the screened interval and water-bearing hydrostratigraphic unit intersected by the well. This examination resulted in wells being selected that had screened intervals restricted to either the Ogallala Group or the Plio-Pleistocene sand and gravel units; and wells that had screened intervals that included both water-bearing hydrostratigraphic units. The sampled sites were then selected from the registrations that had the appropriate information and provided for the best areal distribution over the particular NRD. During the field sampling, two selected wells were not being pumped because of mechanical difficulties. Two replacement wells were selected without consulting their well registrations, and it was later apparent that the necessary well information was not available (see below). Domestic wells were sampled only in Knox County where two few irrigation wells to assure a broad areal distribution. These domestic wells were selected to fill gaps where irrigation wells were not available.

Prior to sampling each irrigation well, each cooperator was contacted the evening before sampling to determine when the well(s) would be pumping. All wells had been pumped at least 4 hours and typically 8 hours prior to sampling. Site specific data was collected for each well and from the well registrations (see appendix A for site-evaluation sheet). In addition, each cooperator was contacted via mail or phone to obtain cropping, fertilizer-use, and pesticide-use histories. However, numerous cooperators contacted by mail did not reply to the survey.

A tap or outlet was located as close as possible to the pump. If a hose or tube were found connected to the outlet or tap, they were disconnected to eliminate a potential source of contamination. The tap was opened and allowed to run at least 5 minutes prior to sampling. Domestic wells were sampled from the outlet closest to the well after the water had run at least 15 minutes and in a several cases more than 2 hours. This period was considered sufficient to purge the system of stagnant water and ensure the water sample represented that in the local aquifer. Site specific data was collected on each domestic well, but information on the type of water-bearing unit usually was not available.

Field conductivity was measured using Hanna Instruments 8033 conductivity meter that was periodically calibrated with a 1000 µmho/cm @ 25° C standard solution. Field pH and temperature were measured using a Fisher Accumet Mini pH meter Model 955 that was calibrated prior to each measurement using certified pH 7 and pH 10 solutions. Field temperature was measured using a mercury-filled thermometer. All measurements were taken using a Thermos container, and then the sample was discarded.

At each site, two 500 ml polyethylene screwtop sample bottles were thoroughly rinsed and completely filled. One bottle was preserved with 2 ml of HNO_3 for analysis of the major cations (calcium, magnesium, iron, sodium, and potassium). The other bottle was filled completely as possible with a concerted effort to eliminate air bubbles. This bottle was used for the analysis of anions (nitrate, sulfate, chloride, and alkalinity). Samples were placed on ice and transported to the LENRD office in Norfolk where they were refrigerated at about 4°C. Upon reaching the LENRD office alkalinity analyses were performed by the author using a standard potentiometric titration technique to a pH of 4.3 to 4.5 (APHA, 1985). The titrant was 0.04N H_2SO_4 obtained from IME Inc. Although Langmuir (1971) recommends that the alkalinity determinations be done on-site, Spalding and co-workers (Exner and Spalding, 1979; personal communication) indicate that no significant error results from the delay. Samples were sent by bus (Arrow Stage Lines) in three batches in ice-packed coolers to Harris Environmental Technologies Inc., Lincoln, Nebraska.

Analytical Techniques and Quality Control

Cations were analyzed by Inductively Coupled Plasma Spectroscopy using EPA Method SW 846 for metals in water. An EPA 987 check sample was used as a quality control (QC) monitor. This QC sample was run at the beginning, after every 10 samples, and at the end of the run. The values obtained for the cations in the QC sample had to be within 15 percent of the given value; otherwise the instrument was recalibrated and the samples reanalyzed. Anions were analyzed by Ion Chromatography using EPA Method 300.0 for inorganic anions in water. A QC standard was again run at the beginning, end, after every 10 samples, and at the end of the run. Values obtained for the anions in the QC standard had to be within 10 percent of the given value; otherwise the instrument was recalibrated and the samples reanalyzed.

Each batch of samples sent to Harris Labs contained one or two blanks of distilled water, and two sets of duplicates or triplicates were included to monitor the reliability of the Harris Lab data. The data on the replicate samples indicated reproducibility within the lab's stated analytical error except in the case of one iron value, which appeared to be due to some unknown source of contamination. Ten, 20, and 50 ppm standards of NO_3-N were included in each batch of samples to ensure the accuracy of the NO_3-N data. The results for these standard samples were within 4 percent of the given value. An additional check of the data quality included the examination of the cation-anion charge balance in each sample. Natural waters are electrically neutral; therefore, the abundance of the positively charged cations should be equivalent to the abundance of negatively charged anions. This relationship between anions and cations can be presented as a percentage of the difference between the ions of different charges and is referred to as the analysis of error. The analysis of error for each of the batches is as follows: Batch 1, 40 samples from the LENRD, had cation-anion balances all less than +5.0 percent, except for four values, the highest of which was +7.6 percent, and an overall average of +4.0 percent; Batch 2, 50 samples from UENRD, had a range of values from -11.0 percent to +7.7 percent, with an average of +4.5 percent. Batch 3, 35 samples from the LCNRD and LNNRD, had a range of values from +4.1 percent to +26.3 percent, with an average, excluding the unexplainably high 26.3 percent, of 7.3 percent. The majority of the balances are positive indicating an underestimation of the anions, which is attributed to errors in the alkalinity measurements. These errors are attributed to the use of the 0.04N sulfuric acid titrant whose normality (N) was not precisely known. Overall, the errors in the cation-anion balances are well within the lab's analytical error, indicating acceptable data.

RESULTS

Appendix B contains the data collected on the 125 wells sampled. The data are reported in parts per million (ppm), which is equivalent to milligrams per liter (mg/l). Figures 2, 3, and 5 illustrate the distribution of sample locations with respect to drainage basins, soil associations, and occurrence of glacial till. The results have been divided according to domestic (n = 8) versus irrigation wells (n = 117). The irrigation wells are subdivided according to the type of water-bearing unit from which the water was derived. These include: the Ogallala Group (n = 20); the Plio-Pleistocene sand and gravel (n = 61), and a combination of the Ogallala/Plio-Pleistocene units (n = 34). Two samples, BT-21-UE and BT-28-LC, are from unregistered wells, but are assumed to be from the Ogallala and Plio-Pleistocene water-bearing units, respectively. However, they are not included in the following discussions because the type of water-bearing unit cannot be definitely identified.

Domestic Wells

The fundamental purpose of this study was to address the nature and extent of groundwater contamination in the major water-bearing units. The general lack of information about domestic wells (e.g. screened interval, material screened, depth to water, etc.) does not allow for the assessment of the hydrostratigraphic unit from which water is being derived. In addition, contamination in domestic wells is typically correlated to a point source (Exner and Spalding (1985); LENRD, unpublished data) which inhibits their usefulness in assessing nonpoint source contamination.

The NO_3-N content ranged from 0.66 to 38.6 ppm; only the 38.6 value exceeded the recommended 10 ppm level. The 38.6 ppm value is associated with the highest Cl (33.8 ppm) and SO_4 (172.9 ppm) values in the area. This contamination is almost certainly due to point source contamination considering that the well is in the middle of an intermittently used barnyard. The well has not been used for domestic purposes for at least 2 years. Of the remaining wells, the highest NO_3-N value is 6.7 ppm with an average of 3.8 ppm. The remaining chemical constituents have concentrations within the range found in natural waters (table 2). The total hardness ranges from 183 to 583 ppm $CaCO_3$, indicating very hard water (table 2).

Irrigation Wells

Plio-Pleistocene Hydrostratigraphic Unit

The water from the Plio-Pleistocene sand and gravel unit is of the calcium-bicarbonate type and exhibits a relatively narrow range in the proportion of the cations, calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K) (fig. 6A). There is more variation in the proportion of the anions, bicarbonate (HCO_3), nitrate (NO_3), sulfate (SO_4), and chloride (Cl), which is primarily a function of the variable amounts of NO_3 in the groundwater (fig. 6A). The range in the values for Na (6.7 to 24.4 ppm; ave. = 13.9 ppm), K (3.4 to 7.7 ppm; ave. = 5.1 ppm), and Mg (6.6 to 24.2 ppm; ave. = 13.4 ppm) are typical of the ranges found in natural waters (table 2; Engberg, 1984). Ca contents, which account for the majority of the hardness of the water in the areas, average 84.2± 16.6 ppm and range from 53.0 to 123.9 ppm; the highest values were found in Pierce and Knox counties associated with areas of glacial till. The total hardness values range from 160 to 404 ppm $CaCO_3$, averaging 265 ppm indicating this water is very hard. Iron concentrations are all less than 0.01 ppm, except for one sample that has a value of 0.05 ppm.

The dominant anion is HCO_3; it ranges from 139 to 368 ppm and averages 262 ppm. Chloride values range from 0.71 to 5.7 ppm (ave. = 2.2 ppm) and SO_4 values range from 4.4 to 75.2 ppm (ave. = 24.9 ppm), all of which are in the range of natural concentrations (table 2). Nitrate-nitrogen contents range

Table 2
Concentration Range of Chemical Constituents in Natural Water*

Constituents	Range (ppm)	
Sodium	0-50	
Potassium	0-10	
Calcium	10-100	
Magnesium	0-200	
Chloride	0-30	
Sulfate	0-100	
Total Hardness	0-60	"soft"
	61-120	"moderately hard"
	121-180	"hard"
	>181	"very hard"

---

* Data from Davis and Dewiest, 1966; Driscoll, 1986; Engberg and Spalding, 1978

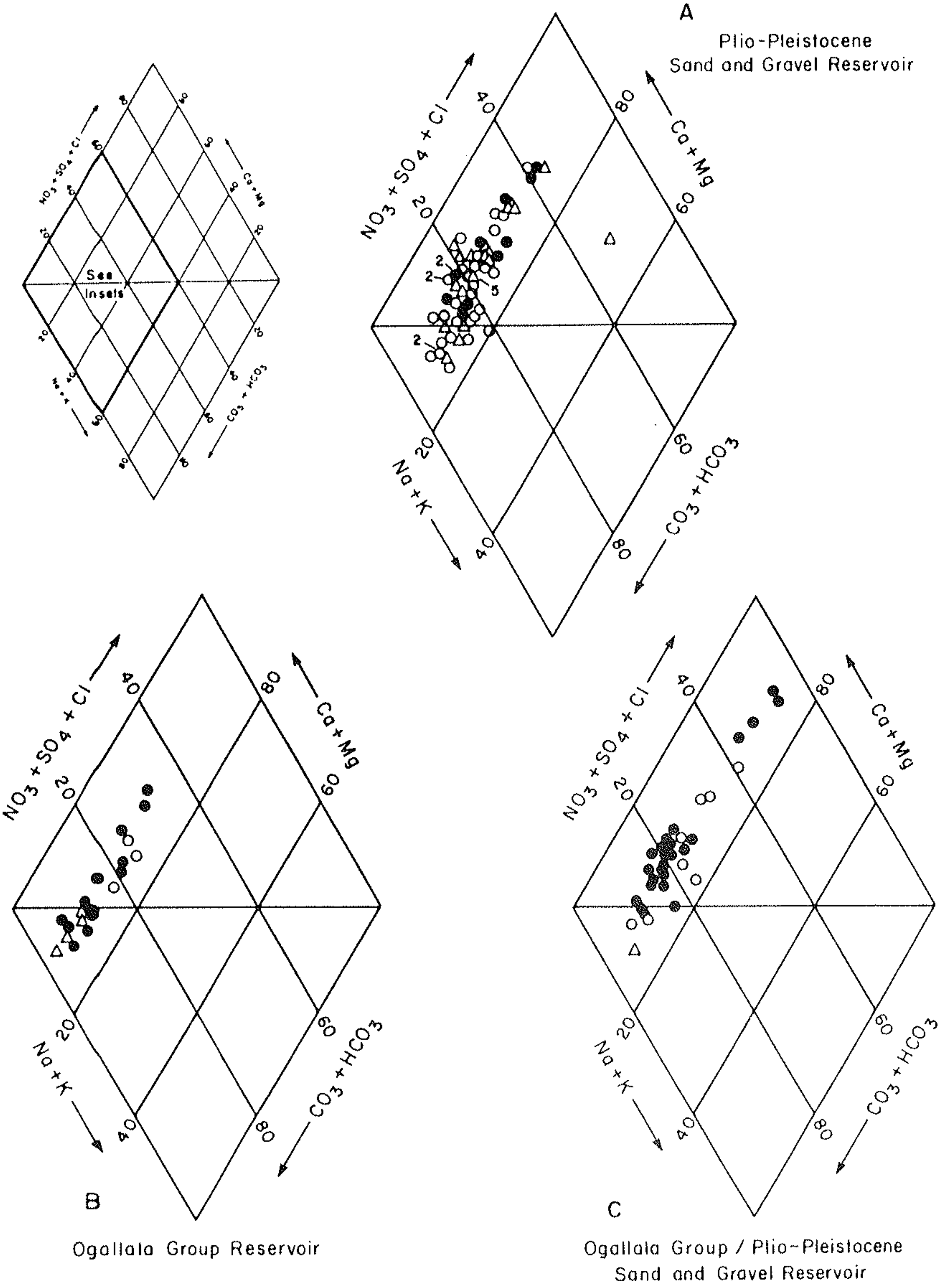

Figure 6. Summary of the chemical composition of the principal groundwater units. See appendix B for data.

from less than 0.02 to 25.0 ppm with an average value of 8.5 ppm. Seventy-two percent of the wells (n = 44) have less than the recommended 10 ppm level (fig. 7). Only 13 percent (n = 8) exceed 15 ppm, and removal of these values results in an overall average NO_3-N content of 6.8 ppm. Fifty percent of the samples fall within the range of 5 to 10 ppm.

Ogallala Hydrostratigraphic Unit

The water from the Ogallala is of the calcium-bicarbonate type. The cation proportions occur within a restricted range and the anions have more variable proportions than that observed in the water-bearing units in the Plio-Pleistocene sand and gravel (fig. 6B). This similarity is not surprising considering that their lithologic composition is nearly the same and that a good hydraulic connection exists, except where separated by localized clay lenses (Souders and Shaffer, 1969; Bentall et al., 1971; Brogden et al., 1976). The absolute concentrations of the chemical constituents in water from the Ogallala and the Pleistocene sand and gravel are distinctly different, except for K and Cl. The average concentrations for the other constituents are distinctly less in waters from the Ogallala than those in the Plio-Pleistocene sand and gravel. Calcium averages 61.3 ppm with a range of 38 to 94 ppm; Mg averages 8.8 ppm with a range of 3.9 to 17.2 ppm; K averages 5.2 ppm with a range of 3.6 to 7.8 ppm; Na averages 8.7 ppm with a range of 5.6 to 17.4 ppm; Cl averages 1.4 ppm with a range of <0.02 to 4.1 ppm; and SO_4 averages 9.3 ppm with a range of 1.7 to 33.8 ppm; HCO_3 averages 197 ppm with a range of 122 to 317 ppm. The total hardness of the water ranges from 114 to 305 ppm $CaCO_3$ indicating the water varies from hard to very hard (table 2). These values are consistent with those reported by Engberg (1984).

The NO_3-N content of the Ogallala ranges from 0.35 to 15.4 ppm, averaging 6.0 ppm. Seventy percent (n = 14) of the values are less than the recommended 10 ppm level with only one value exceeding 15 ppm (fig. 8). Fifty-five percent (n = 11) of the samples have values less than 6.0 ppm.

Combined Ogallala/Plio-Pleistocene Hydrostratigraphic Unit

The water from this reservoir is of the calcium-bicarbonate type as would be expected from the results presented for the individual water-bearing units (fig. 6C). The concentrations of the individual constituents should be intermediate, on average, between the two end member units, because these samples represent a mixing of water from the two individual units. This is in fact the case for five of the eight constituents; the exceptions are Cl, K, and NO_3-N. Calcium averages 71.8; Mg averages 10.8 ppm, Na averages 10.6 ppm; SO_4 averages 17.4 ppm; and HCO_3 averages 219 ppm. Hardness values are also intermediate with an average of 224 ppm $CaCO_3$, but the range, 106 to 419 ppm $CaCO_3$, is more extreme.

Nitrate-nitrogen values range from 0.98 to 25.4 ppm, averaging 9.6 ppm. Seventy-six percent (n = 26) of the NO_3-N values are less than the recommended 10 ppm level whereas only 18 percent (n = 6) of the values exceed 15 ppm (fig. 9). A significant number of samples (n = 20; 59 percent) fall within the 5

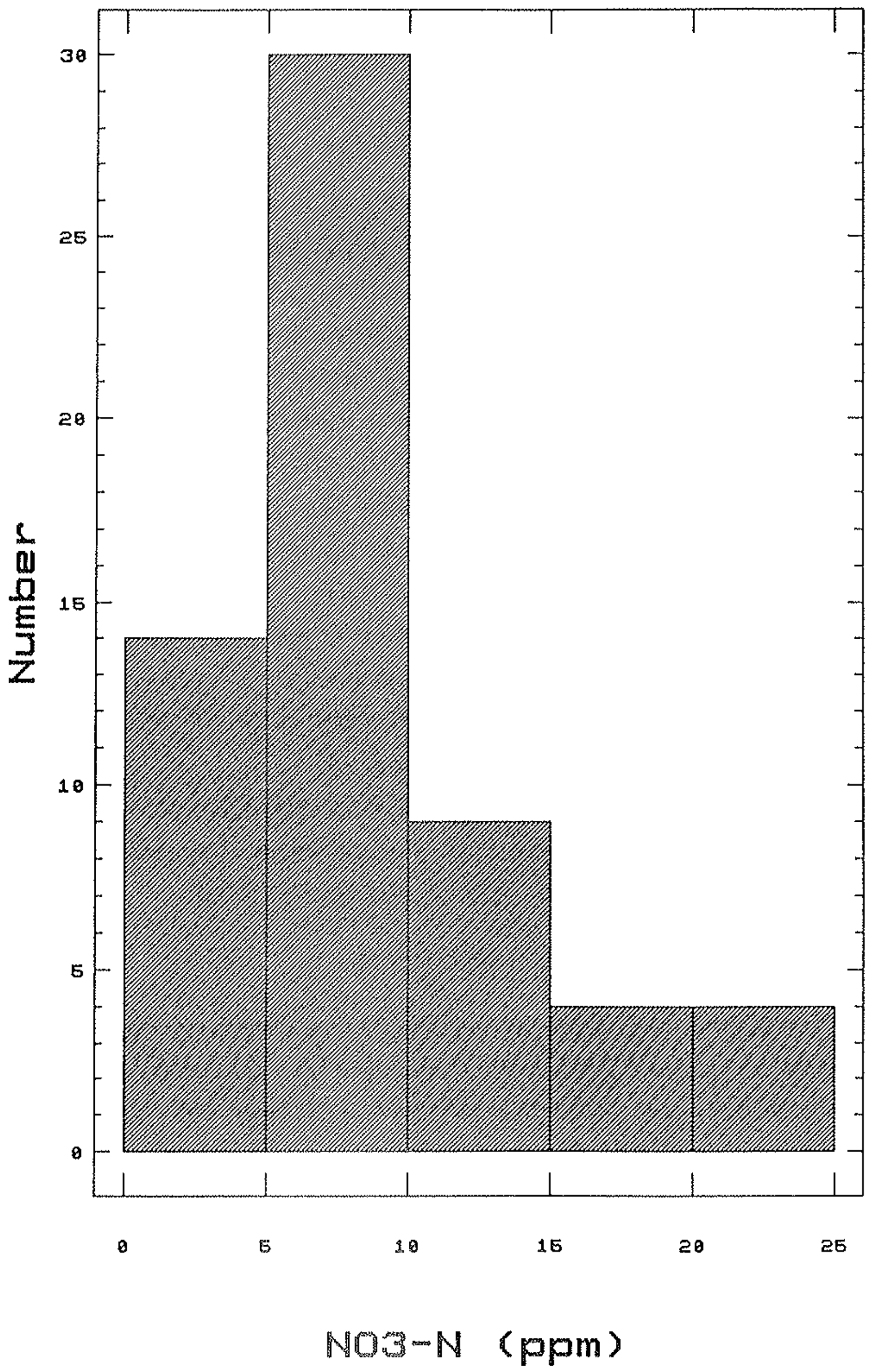

Figure 7. Histogram of NO_3-N contents for the Plio-Pleistocene Hydrostratigraphic unit. Number of samples = 61

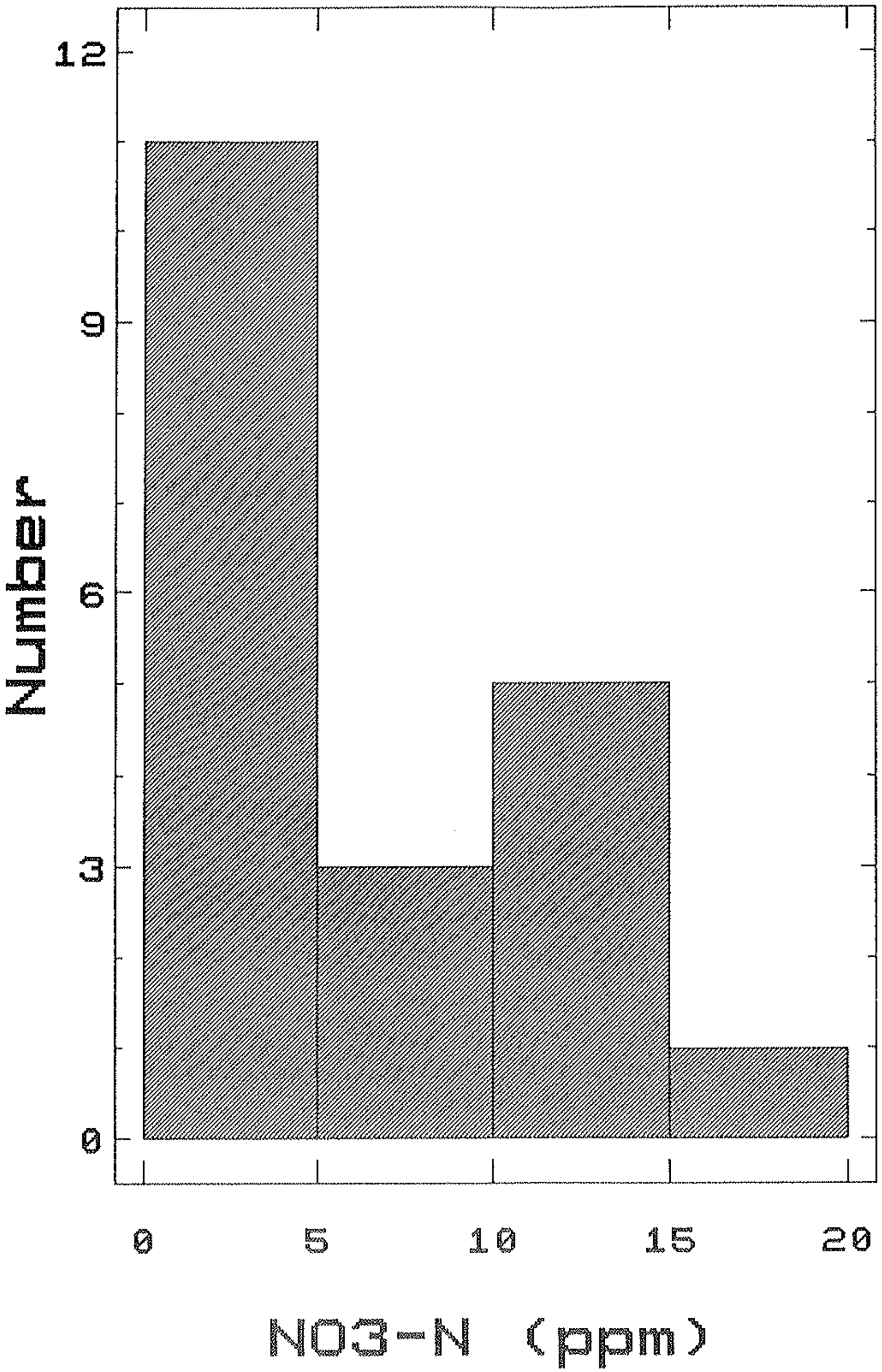

Figure 8. Histogram of NO_3-N contents for the Ogallala Hydrostratigraphic unit. Number of samples = 20

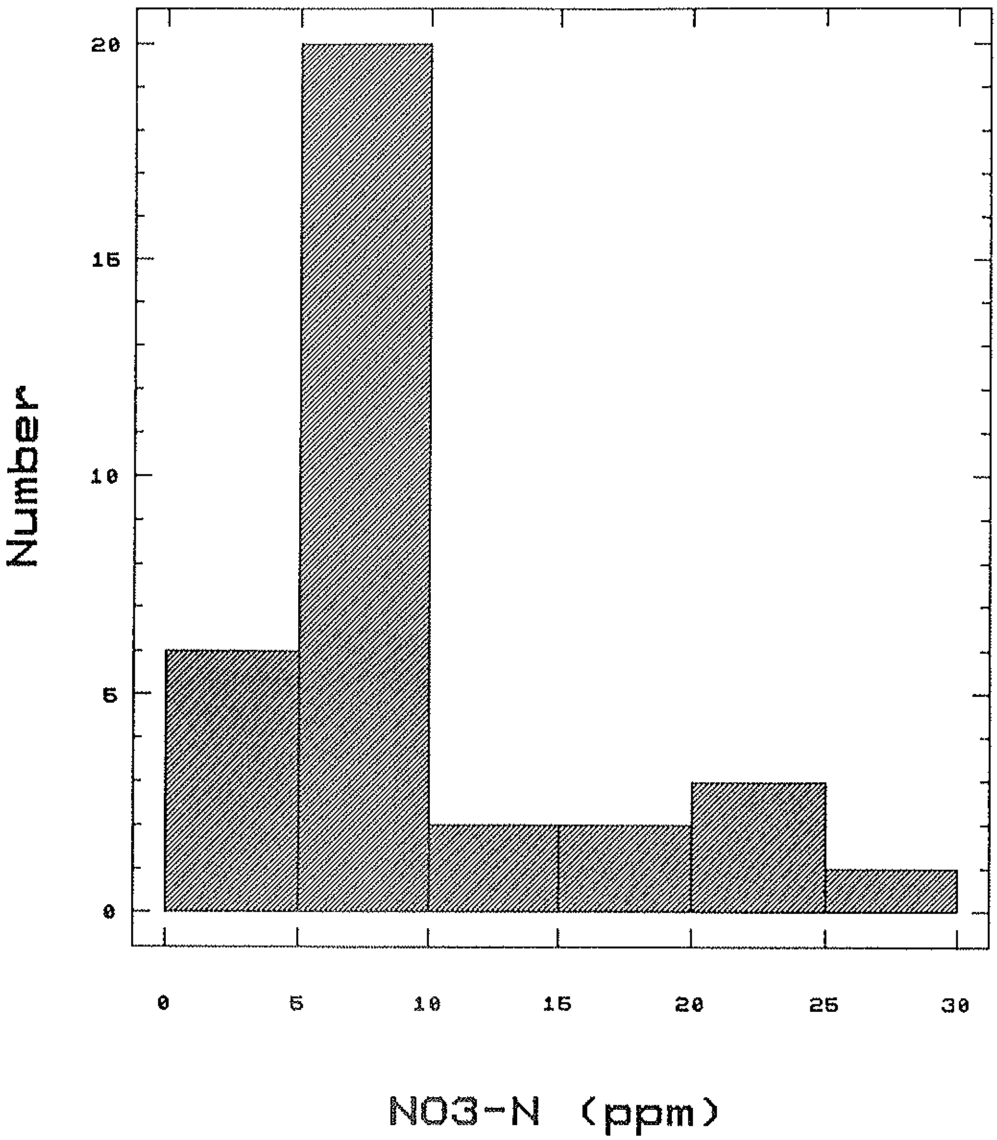

Figure 9. Histogram of NO_3-N for water derived from both the Plio-Pleistocene and Ogallala Hydrostratigraphic units. Number of samples = 34

to 10 ppm range, as was the case with the Plio-Pleistocene sand and gravel unit (fig. 7), and contrasting with the NO_3-N distribution in the Ogallala.

DISCUSSION

General Water Chemistry

Water quality is the result of the physical, chemical, and biological interactions between water and the material with which it comes into contact. The groundwater in the Bazile Triangle is hard to very hard. In general, the concentrations of the chemical constituents are within the range of those observed in natural water from other areas in Nebraska (Engberg and Spalding, 1978; Engberg, 1984). Variations in concentration, within a particular reservoir and between reservoirs, are to be expected because of local and regional variations in the composition of the material with which the water has interacted. For example, water from the Plio-Pleistocene sand and gravel in Pierce and Knox counties generally has higher Ca and Mg contents than its counterpart in Antelope County, primarily because the water has interacted with glacial till that contains an abundant supply of these elements (appendix B). Glacial till also contains an abundant supply of sulfate (Bentall et al., 1971; Engberg and Spalding, 1978; Engberg, 1984) that contributes to the distinctly higher concentrations in the eastern and northeastern parts of the Triangle relative to those in Antelope County. The concentrations of the individual naturally occurring constituents in any of the water-bearing units are primarily controlled by mineral solubility and chemical equilibrium. These natural abundances, however, can be modified by the introduction of chemicals into the system via human activities. This results in contamination of the groundwater. The remainder of this report will discuss contamination and emphasize the NO_3-N problem.

Nitrate-Nitrogen Contamination

A variety of sources provide NO_3-N to groundwater. Natural processes, which include bacterial activity and the growth of certain plants, remove nitrogen from the air and fix it in the modern soils. This fixed nitrogen occurs in a variety of forms that can be oxidized to nitrate by bacterial activity. This naturally produced nitrate can potentially reach the groundwater. Human-induced or human-made sources of nitrate include fertilizers, barnyards and feedlots, septic systems, and range animal waste.

If we are to assess the extent to which groundwater has been contaminated by human activity, we must know the concentrations of the naturally produced NO_3 (background level) prior to contamination. However, assessment of the background levels is very difficult. It is commonly assumed that NO_3-N background levels of Nebraska's groundwater are no more than 1 ppm (Exner and Spalding, 1979;

Dreeszen, personal communication). Water from observation wells on the Gudmundsen Ranch in the Sand Hills have NO_3-N values from 1-3 ppm in the Ogallala Group at depths greater than 100 feet that cannot be attributed to cultivation or irrigation activity and are probably due to buried soil horizons within the Ogallala (Goeke, personal communication). Heaton et al. (1983) indicated the possibility that confined aquifers on the arid western margin of the Khalahari Desert of southern Africa may have had initial NO_3-N concentrations, prior to denitrification, ranging from 6.9 to 22.0 ppm. This nitrate was probably generated within the soil of the recharge area by bacterial activity (Heaton et al., 1983). These studies, in addition to the report on the potential availibility and leaching of geologic nitrate from loess deposits to the groundwater (Boyce et al., 1976), suggest that background NO_3-N levels are not necessarily less than 1 ppm and could vary throughout Nebraska. We do not know the background NO_3-N level in the Bazile Triangle. Nitrate-nitrogen values exceeding 5 ppm have been arbitrarily selected as being representative of areas where contamination has most likely occurred so the variables that may control the degree of contamination can be more readily evaluated. Nitrogen-nitrogen values less than 5 ppm may have been affected by contamination, but to a lesser degree, and in particular values less than 3 ppm may represent background levels. Evaluating the actual background NO_3-N level is definitely an area for future work.

Figure 10 illustrates that of the 117 irrigation wells sampled, about 25 percent of the samples exceed the recommended 10 ppm NO_3-N level, whereas an additional 45 percent had values that ranged from 5 to 10 ppm. The majority of these exceeded 7 ppm indicating that the groundwater has probably been contaminated to varying degrees. There are many factors that control the potential for contaminating groundwater with agricultural chemicals including hydrogeologic, climatic, soil, and land use variables. Figures 7 and 8 indicate that this contamination has not effected the Ogallala and Pleistocene sand and gravel water-bearing units to the same extent. The Ogallala has a much larger percentage of samples with less than 5.0 ppm NO_3-N, compared to the Plio-Pleistocene unit. This may be due to the smaller number and location of samples from the Ogallala; however, as discussed below, the differences are real and can be explained by local hydrogeologic conditions.

The probability of higher contaminant concentration in an unconfined system is greater at shallow depths for two reasons. First, a contaminant will enter an unconfined system from the top, and as it moves vertically it will usually become diluted and dispersed with depth (contaminant-dependent). Secondly, the vertical movement of the contaminant is inhibited by the strong influence of horizontal transport in groundwater systems. Of the samples with NO_3-N values greater than about 5.0 obtained from screened intervals in the Ogallala, all, except one, have at least 25 feet of what is inferred to be Plio-Pleistocene sand and gravel directly overlying the Ogallala. These Plio-Pleistocene units are not screened. If contamination is most likely to occur at relatively shallow depth, then contamination would more likely occur in the overlying and shallower Plio-Pleistocene water-bearing units. This suggests that the apparently high NO_3-N values in the Ogallala may be not due to actual contamination but are the result of contaminated water being drawn in from the Plio-Pleistocene units. The Plio-Pleistocene sand and gravel

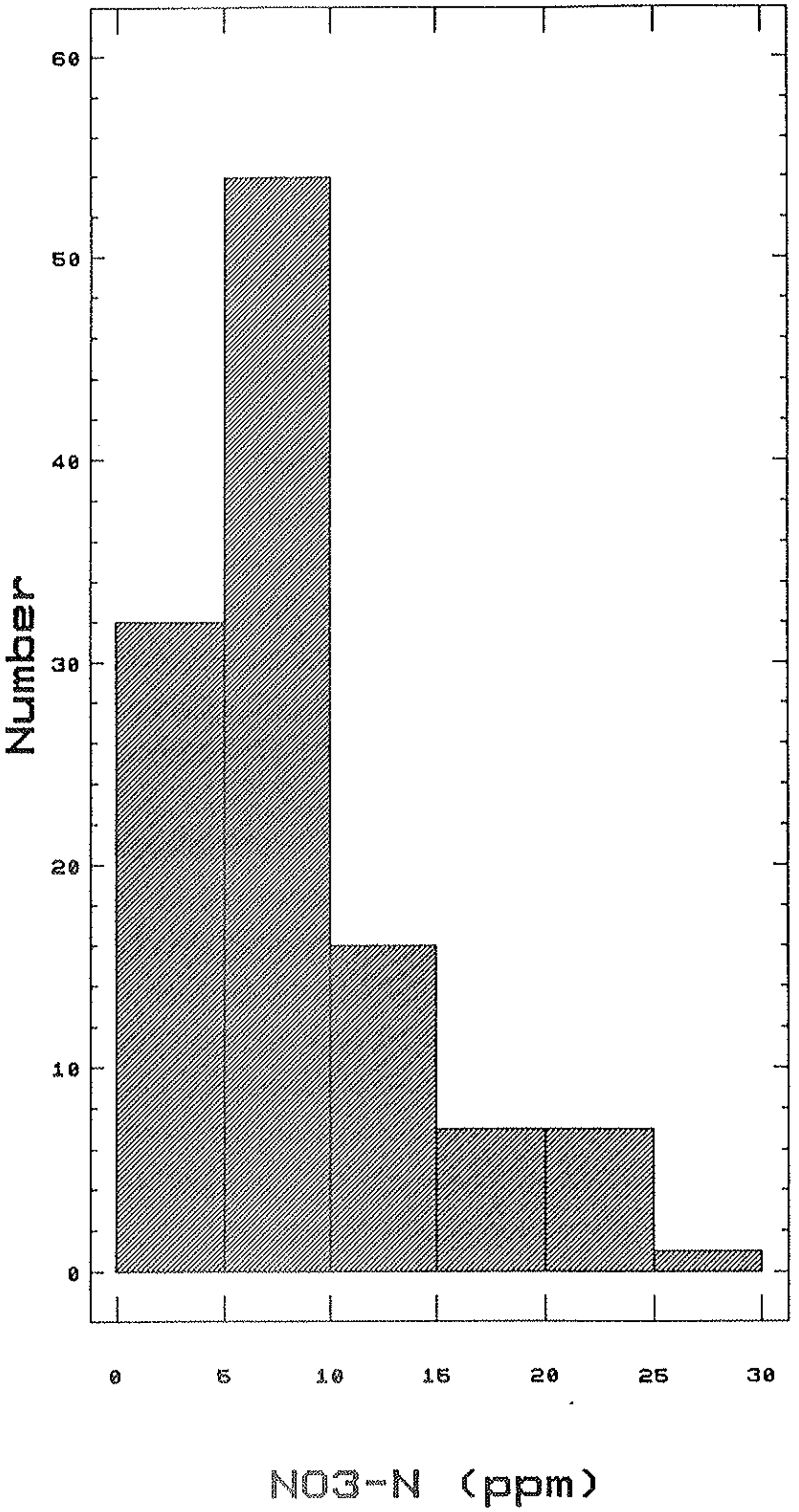

Figure 10. Histogram of NO_3-N for irrigation-well samples from the Bazile Triangle Groundwater Quality study. Number of samples = 117

units transmit water much more readily than the semi-consolidated, fine- to medium-grained sand of the Ogallala, so that during pumping these two units become hydraulically connected. Sample BT-8-LE has 42 feet of medium-grained gravel that is separated from the Ogallala by 40 feet of blue clay, according to the drillers' log; however, considering the intermittent nature of these clay lenses, there could be a hydraulic connection with the Ogallala at a relatively short distance. The fact that apparent contamination in the Ogallala is due to the presence of Plio-Pleistocene units, suggests that, for the most part, the Ogallala water-bearing units are relatively uncontaminated. Based on this conclusion, the observed NO_3-N contamination in samples from wells screening both the Plio-Pleistocene and Ogallala is probably derived from the Plio-Pleistocene units in these wells. At present, not enough information exists to determine the extent to which the pumping influences the natural hydraulic gradient between these two hydrostratigraphic units.

The key question becomes, what influences the NO_3-N content of the Plio-Pleistocene water-bearing units? Many of the Plio-Pleistocene samples with NO_3-N values between 0 and 5 ppm occur near or under glacial till (fig. 5), suggesting that this clay-rich material may provide an effective impermeable layer that inhibits vertical movement of contamination to the groundwater. This relationship may only apply to the Triangle because in the Pierce-Weetown area, a few miles to the south, glacial tills are associated with high NO3-N values (Hanson, 1983). This case of high values in glacial till indicates that the presence of glacial till does not necessarily mean low NO_3-N values, but it stresses the need for site-specific information when evaluating water chemistry data.

The majority of the samples with NO_3-N concentrations greater than 10 ppm occur in the vicinity of local and regional drainage divides where the slopes are slight to moderate (fig. 2). Although in an unconfined groundwater system, recharge occurs over the entire flow system, the net recharge will be much greater in these upland areas relative to areas dominated by discharge. In these upland areas, water has a greater tendency to percolate into and through the soil, transporting contaminants to the groundwater. As water moves from recharge to discharge areas in an area that is completely cultivated, the apparent NO_3-N contamination should increase. This is not the case in the Bazile Creek drainage basin near Creighton, where groundwater flows toward the northwest to Bazile Mills. Nitrate-nitrogen concentration decreases from between 15 and 20 ppm near the intersection of Antelope/Knox/Pierce counties to about 6.0 ppm southeast of Bazile Mills (fig. 2). A possible reason for the decrease is that the area is not completely under cultivation and the volume of water entering the system in the uncultivated areas will have little or no NO_3-N content and dilute the NO_3-N contamination entering the groundwater from fertilized and irrigated ground. Other factors that may influence the extent of contamination entering the system are local fertilization and irrigation practices, the timing of fertilizer application relative to precipitation events, and irrigation-well density. If the most susceptible areas to contamination are those where there is net recharge is dominant, then it is these areas that should be protected. Unfortunately, sufficient hydrogeologic information does not exist to document areas dominated by net recharge.

The type of soil and its infiltration characteristics may influence the movement of contamination to the subsurface. A relationship of soil type to NO_3-N content is not apparent on Figure 3, which may reflect the generalized nature of the soil association map. In fact, the variability in soil permeability within the associations given is often greater than between associations (Ehrman, personal communication). Placing the data in the framework of detailed soil surveys may indicate a soil-contamination relationship, but this has not been done yet and should be the subject of future work. Another factor commonly suggested as a control of contamination is depth to water. A analysis of the correlation of NO_3-N content to depth of water indicated absolutely no relationship.

The nitrate contamination in agricultural areas is typically attributed to septic tank systems, feedlots, or over-application of fertilizer. A well located in sec. 29 T.29N R.5W, which is within a 100 feet of a hog confinement facility, and another in sec. 36 T.29N R.5W, which is within 200 feet from a farm house and along the road leading to the farmstead, appear to be affected by point sources. A strong correlation between NO_3-N and Cl, which are both readily soluble in groundwater and conservative in their movement. Potash (KCl) as well as NO_3-N are found in starter fertilizers. This suggests that the leaching of commercial fertilizers may be responsible for the contamination. In samples from Plio-Pleistocene units and wells screened in both Plio-Pleistocene and Ogallala units that have NO_3-N contents greater than about 6.0 ppm, Cl is strongly correlated to NO_3-N as indicated by the correlation coefficients (r) of 0.82 and 0.90, respectively (i.e. $r = 1$ indicates a perfect linear relationship). This correlation has also been observed in Holt County (Exner and Spalding, 1979) and indicates that although some of the Cl in these groundwaters is almost certainly natural, the proportion of Cl that is probably the result of contamination increases as the NO_3-N concentration increases. Nitrate and Cl may also be correlated if animal or human waste was the source of contamination; however, significant correlations between NO_3:Na and Cl:Na should exist (Exner and Spalding, 1979), but these are not observed.

A comparison of results from this study with data previously collected on wells used in the Bazile Triangle study yield equivocal results (table 3). Except for the value given for sec. 33 T.28N R.4W, the samples taken by Hanson in 1980 (Hanson, 1983) were collected after the irrigation well had only been pumping 10 to 15 minutes. The remaining samples listed in table 3 were collected after several hours of pumping. Only for wells that were sampled using similar sampling protocol can a valid comparison can be made. Of the 15 wells that can be compared, nine show an increase, three show a decrease, and six show no change. The six that show no change were collected over the past 3 years. A comparison of samples collected at least seven years apart suggest that the NO_3-N in the groundwater may be on the increase as indicated by 5 of the 6 samples showing increases ranging from about 1 to 15 ppm. However, this small number of samples and the potential variability in the composition of water samples, as discussed below, does not allow for statistically significant arguments as to past and future trends.

The interpretation of NO_3-N data acquired from samples of irrigation wells must be considered in light of the inherent problems in acquiring samples that are representative of contamination in the

Table 3

Comparison of Previous NO3-N Concentrations (ppm) with Bazile Triangle Results

		Sample Year		
	1986	1987	1988	1989
Upper Elkhorn				
127N R7W 18b		21.9		21.2
127N R7W 25d		8.2		9.5
127N R8W 8d		3.5		3.3
128N R5W 12b		5.6		5.8
128N R8W 12d		8.1		8.3
Lewis and Clark				
129N R5W 9d		7.7	6.7	6.6
129N R5W 13c		11.7	15.9	18.2
129N R5W 27a			7.0	8.0
129N R5W 34c		3.8	3.6	4.2
Lower Elkhorn				
127N R3W 22d	10.1		17.6	10.9
129N R3W 12d		18.6	12.0	6.5

Hanson (1983)	1958	1969	1970	1975	1978	1980	1981	1982	1989
127N R2W 3b						12.9		14.2	7.6
127N R2W 21c						17.7	4.5		7.3
127N R2W 29a						10.2	10.2		25.5
127N R2W 30b						3.2			3.2
127N R3W 8c						7.9			6.5
127N R3W 22c						1.0			10.9
127N R4W 26d						8.2			2.6
127N R4W 32a					1.8*	0.55			4.2
128N R2W 22c						9.4			5.0
128N R3W 10a						1.1			1.7
128N R3W 22d						8.0			15.9
128N R3W 33b			<0.01*		16.0*	9.4			1.1
128N R4W 6c						6.9			8.7
128N R4W 33d	2.1*		3.2*	3.6*		5.4			6.6

* Data from U. S. Geological Survey Water Resources Data.

subsurface. Irrigation wells have screened intervals that extend over several hundred feet and possibly intersecting distinctly different water-bearing units. The resulting sample is a mixture composed of varying proportions of contaminated and uncontaminated water, as is argued above for water from the Ogallala. This mixing results in the dilution of the contamination, leading to samples having concentrations potentially biased towards low values. This is not acceptable for evaluating potential health risks and water management. Concentration of NO_3-N in a sampled well has the potential to vary considerably depending on when the well was sampled, relative to the time elapsed since pumping was initiated (minutes versus many hours). These variations are the result of vertical stratification in water quality, variations in the ability of the different units to transmit water, differences in the source of recharge for different water-bearing units, radial changes in water chemistry with distance from the well, and changes in the hydraulic head during pumping (Schmidt, 1977; Nightingale and Bianchi, 1980). In addition to these relatively short-term variations, seasonal variations will almost certainly exist depending on land use, rainfall etc. Combining all these variations may result in compositional changes that are on the order of a couple of ppm or up to tens of ppm (Saffigna and Keeney, 1977; Schmidt, 1977; Nightingale and Bianchi, 1980; Spalding and Exner, 1980). Therefore, one sample represents only an estimate of the contaminant level at one moment. The potential for variation is significant and must be considered when evaluating data on contaminants acquired using an irrigation well.

SUMMARY, CONCLUSIONS, and RECOMMENDATIONS

The Bazile Triangle is a complex geologic and hydrogeologic area. Groundwater occurs in predominantly unconfined water-bearing hydrostratigraphic units consisting of the Ogallala Group and Plio-Pleistocene sand and gravel, which are part of the areally extensive High Plains Aquifer. The saturated thickness of these deposits range from less than 100 feet to more than 400 feet and depth to water varies from 6 to 185 feet. There are three general groundwater flow areas that are related to the Verdigre Creek, Bazile Creek, and the North Fork of the Elkhorn River drainage basins. The estimated rate of groundwater movement is on the order of 0.5 to 1.5 feet per day.

One hundred seventeen irrigation wells and 8 domestic wells were sampled from July 24 to August 8, 1989. The NO_3-N content in the domestic wells ranged from 0.66 to 38.6 ppm; only the 38.6 ppm value exceeded the recommended 10 ppm level. Groundwater samples were obtained from irrigation wells that were screened in two distinct water-bearing hydrostratigraphic units, the Ogallala Group and Plio-Pleistocene sand and gravel, or were screened in both the Ogallala and Plio-Pleistocene sand and gravel. Only 25 percent of the samples had NO_3-N values that were greater than 10 ppm; the highest value being 25.0 ppm. An additional 45 percent had values that ranged from 5 to 10 ppm; the majority of these exceeded 7 ppm indicating that groundwater has probably been contaminated to varying degrees. Apparent contamination in water from the Ogallala appears to be related to direct hydraulic conductivity with overlying Plio-Pleistocene sand and gravel. This suggests that the Ogallala is still relatively uncontaminated. Contamination in the water derived from wells that screened both hydrostratigraphic units probably resides in the Plio-Pleistocene sand and gravel.

Glacial till appears to inhibit vertical migration of contamination in the Bazile Triangle as indicated by the number of samples with 0 to 5 ppm near till occurrences, but this relationship may vary with variations in the composition of the till. The majority of samples with NO_3-N values greater than 10 ppm occur in the vicinity of local and regional drainage divides with slight to moderate slopes that are areas of net recharge. A strong relationship between the NO_3-N and Cl concentrations indicate that the source of groundwater contamination is most likely related to fertilizer-application practices.

There is insufficient data to implement a specific groundwater management or protection strategy even though the groundwater appears to be contaminated to varying degrees. The data presented represent only a glimpse at the contamination at one moment. Short-term and seasonal variations need to be evaluated to determine how well the data acquired here represent the degree to which the subsurface has been contaminated. This can only be done with additional sampling. If there is vertical stratification of the contamination as suggested, additional research should examine the extent of this stratification and whether the contamination predominantly occurs in a particular unit(s). Assessing vertical stratification will require nested monitoring wells equipped with dedicated sampling systems and pressure transducers to record hydraulic head data. Pump tests could also be done to test the hydraulic connection between the the Ogallala and the Plio-Pleistocene sand and gravel. More specific information needs to be acquired to identify the areas dominated by net recharge and evaluate the relationship of soil types and their ability to transmit water and contamination. A concerted effort by landowners should be made to protect Nebraska's greatest natural resource. This can be done by encouraging deep soil profiling and efficient irrigation water management to reduce the potential for future contamination.

REFERENCES

Alix, J. J. (1987) A hydrogeologic study of the local groundwater flowsystem at Osmond, Nebraska. University of Nebraska, Department of Geology, M. S. Thesis Lincoln, Nebraska, 267 p.

American Public Health Association (APHA) (1985) Standard methods for the examination of water and wastewater, 16th Ed.

Bentall, R. (1971) The Elkhorn River basin of Nebraska. Resource Atlas No. 1, Conservation and Survey Division, University of Nebraska, Lincoln, Nebraska, 51p.

Boyce, J. S., J. Muir, A. P. Edwards, E.C. Seim, and R. A. Olson (1976) Geologic Nitrogen in Pleistocene Loess of Nebraska. Journal of Environmental Quality, v.5, p. 93-96.

Brogden, R. E., F. B. Shaffer, and R. A. Engberg (1976) Water resources of Pierce County, Nebraska. Nebraska Water Survey Paper Number 41, Conservation and Survey Division, University of Nebraska, Lincoln, Nebraska, 35 p.

Chen, H-H. and A. D. Druliner (1987) Nonpoint-source agricultural chemicals in ground water in Nebraska -- Preliminary results for six areas of the High Plains Aquifer. U.S. Geological Survey Water Resources Investigations Report 86-4338, 68 p.

Davis, S. N. and R. DeWeist (1966) Hydrogeology. John Wiley and Sons.

Driscoll, F. (1986) Groundwater and wells, 2nd ed., Johnson Division, UOP Inc., St. Paul, Minnesota.

Diffendal, R. F. (1982) Regional implications of the geology of the Ogallala Group (upper Tertiary) of southwestern Morrill County, Nebraska, and adjacent areas. Geological Society of America Bulletin, v. 93, p. 964-976.

Dreeszen, V. H. (1970) The stratigraphic framework of Pleistocene glacial and periglacial deposits in the Central Plains. *In* Pleistocene and Recent Environments of the Central Great Plains, Special Publication 3, Department of Geology, University of Kansas, p. 9-22.

Dreeszen, V. H. (1973) Topographic regions of Nebraska. Conservation and Survey Division, University of Nebraska, Lincoln, Nebraska.

Engberg, R. A. (1984) Appraisal of data for ground-water quality in Nebraska. U. S. Geological Survey Water Supply Paper 2245, 54 p.

Engberg, R. A. and R. F. Spalding (1978) Groundwater Quality Atlas of Nebraska. Resource Atlas No. 3, Conservation and Survey Division, University of Nebraska, Lincoln, Nebraska, 38 p.

Exner, M. E. and R. F. Spalding (1979) Evolution of contaminated groundwater in Holt County, Nebraska. Water Resources Research, v. 15, p. 139-146.

Exner, M. E. and R. F. Spalding (1985) Groundwater contamination and well construction in southeast Nebraska. Ground Water, v. 23, p. 26-34.

Gutentag, E.D. and J.B. Weeks (1980) Water table in the High Plains aquifer in 1978 in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming. U.S. Geological Survey Hydrologic Investigations Atlas HA-642, 1 plate.

Hanson, B.V. (1983) Nitrate in the groundwater of Pierce County - Summers 1980 and 1981: A base line study. Conservation and Survey Division Open File Report, University of Nebraska-Lincoln, 34 p.

Heaton T. H. E., A. S. Talma and J. C. Vogel (1983) Origin and history of nitrate in confined groundwater in the western Khalahari. Journal of Hydrology, v. 62, p. 243-262.

Langmuir, D. (1971) The geochemistry of some carbonate waters in central Pennsylvania. Geochimica et Cosmochimica Acta, v. 435, p. 1023-1045.

Lawton, D. R. and R. A. Hiergesell (1988) Hydrogeology of Garfield and Wheeler Counties, Nebraska. Nebraska Water Survey Paper Number 63. Conservation and Survey Division, University of Nebraska, Lincoln, Nebraska, 164p.

Lugn, A. L. (1939) Classification of the Tertiary system in Nebraska. Geological Society of America Bulletin, v. 50, p. 1245-1276.

Mahnke, C., R. Hammer, C. Hammond and R. Schulte (1978) Soil survey of Antelope County, Nebraska. Soil Conservation Service, U.S. Department of Agriculture, 128 p.

National Interim Primary Drinking Water Regulations (1975) U. S. Environmental Protection Agency, Federal Register, v. 40, p. 59566-59588.

Nightingale, H. I. and W. C. Bianchi (1980) Well-water quality changes correlated with well pumping time and aquifer parameters - Fresno, California. Groundwater, v. 18, p. 274-280.

Saffigna, P. G. and D. R. Keeney (1977) Nitrate and chloride in ground water under irrigated agriculture in central Wisconsin. Ground Water, v. 15, p. 170-177.

Schmidt, K. D. (1977) Water quality variations for pumping wells, Ground Water, v. 15, p. 130-137.

Schulte, R. B., C. L. Hammond and C. F. Mahnke (1976) Soil survey of Pierce County, Nebraska, Soil Conservation Service, U.S. Department of Agriculture, 106p.

Souders, V. L. and F. B. Shaffer (1969) Water Resources of Antelope County, Nebraska. U.S. Geological Survey Hydrologic Investigations Atlas HA-316.

Spalding, R. F. and M. E. Exner (1980) Areal, vertical, and temporal differences in groundwater chemistry: I. Inorganic constituents. Jour. Environmental Quality, v. 9, p. 466-479.

Swinehart, J. B. and R. F. Diffendal (1989) Geology of the pre-dune strata, *In* An Atlas of the Sand Hills (ed. A. Bleed and C. Flowerday), Resource Atlas No. 5. Conservation and Survey Division, University of Nebraska, Lincoln, Nebraska, p. 29-42.

Swinehart, J. B., V. L. Souders, H. M. DeGraw and R. F. Diffendal (1985) Cenozoic paleogeography of western Nebraska. *In* Cenozoic Paleogeography of West-Central United States (ed. R. M. Flores and S. S. Kaplan) Rocky Mountain Section - S.E.P.M., p. 209-229.

United States Geological Survey Water Resources Data - Nebraska Water Years 1966-1988.

Voorhies, M. R. (1973) Early Miocene mammals from northeast Nebraska, Contributions to Geology, v. 12, p. 1-10.

Weeks, J. B. and E. D. Gutentag (1981) Bedrock geology, altitude of base, and saturated thickness of the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming. U. S. Geological Survey Hydrologic Investigation Atlas HA-648, 2 plates.

White, J. W., Jr. (1975) Relative significance of dietary sources of nitrate and nitrite. Journal of Agriculture and Food Chemistry, v. 23, p. 886-891.

World Health Organization (WHO)(1978) Nitrates, nitrites, and N-nitroso compounds. Environmental Health Criteria 5, Geneva. WHO.

Appendix A

SAMPLE SITE DATA

Well Location: T._____N, R._____E or W, Sec._____, _____1/4 _____1/4
Registration #:____________________ Sample #:________________________
Sampling Date:_____________Time:______________Sampled by:_____________
Well Data:
Type: Irrigation Household Stock Municipal Monitoring
Elevation: __________ ft. (AMS)
Depth: Total ________ft; To Water: ________ft.
Casing: Concrete Steel Plastic Transite Brick Other
Screened Interval: ____________ft. Type of Screen: ____________
Reservoir Material:____
Location: Pit Lowlying area Near drainage
Age: __________yrs.
Construction: Drilled Driven Dug
Output: __________gpm
Pumping Duration Prior to Sampling:__________________________________
Additional Comments:____
____
Sample Area: Soil Type(s)____

Location Description:

Comments:____
____

Point Sources:
Barnyard__________ft.__________of well Active Inactive
Septic tank __________ft. __________ of well
Other:
____

Nonpoint Sources: describe crops, direction and distance from well

Crop Rotation (Last 5 years) _______________________________________
Pesticides used on these fields? Y N
Which ones and rates:____
____
Nitrogen fertilizer, manure used on these fields? Y N
Rate(s):____
____

Groundwater Data

Field Parameters:

Temperature: ____________ C
Conductivity: ___________umho/cm
mV_________________________
Nitrate-nitrogen, ppm: ___________
pH, S.U.:__________________________

Laboratory Parameters:

Analytical Facility____

CATIONS	ppm	meq/l	ANION	ppm	meq/l
Calcium			Bicarbonate		
Iron					
Magnesium			Nitrate-Nitrogen		
Potassium			Sulfate		
Sodium			Chloride		
Total			Total		

Triazines, ppb: _______________________
Pesticides: Type: ________________________, _____________________ppb
________________________, _____________________ppb
Total coliform 100 ml:_____________________

Comments:____

____

____

Owner:
Name:
Address:
Phone:

Results sent: Y N

Appendix B

Sample Locations and Chemical Data for Bazile Triangle Groundwater Quality Study.

Chemical Data for Domestic and Unregistered Wells (n = 10)

Knox County Legal Location	Sample Number (BT-)	Temperature (°C)	pH	Conductivity µmhos @ 25°C	Chemical Data (ppm) HCO3	Cl	NO3-N	SO4	Ca	Fe	Mg	K	Na	TDS
29N3W7b	BT-1-LC	12.1	7.4	546	301	1.30	0.7	24.4	88.4	<0.01	15.6	3.9	13.1	295
29N5W4c	BT-27-LC	13.0	7.2	1481	501	33.80	38.6	172.9	185.0	<0.01	29.5	5.3	116.2	828
29N4W10d	BT-5-LC	13.2	7.5	685	324	1.46	4.2	39.5	105.9	<0.01	16.7	6.5	11.1	345
29N4W18a	BT-35-LC	11.9	7.4	592	312	1.34	1.6	36.3	104.0	0.23	14.7	8.1	7.4	327
29N4W27b	BT-37-LC	14.0	7.5	527	279	1.30	2.6	11.1	79.3	<0.01	8.9	5.8	14.3	260
29N5W10c	BT-28-LC*	11.7	7.7	547	244	1.56	5.5	35.7	83.8	<0.01	13.7	4.8	11.8	277
29N5W20c	BT-32-LC	12.9	7.6	518	245	1.32	6.7	11.1	83.5	<0.01	12.3	9.1	10.3	255
29N5W32c	BT-34-LC	13.0	7.7	387	191	0.82	5.1	6.8	62.5	<0.01	6.6	4.7	11.2	192
29N6W28b	BT-17-LC	12.7	7.5	471	227	2.63	5.6	13.2	87.0	<0.01	7.1	3.4	5.0	236
Antelope County														
27N7W27c	BT-21-UE*	14.4	7.4	605	338	<0.02	2.8	28.1	99.9	0.01	13.5	8.4	13.4	332

* = Unregistered Well

Antelope County sampled 7/31/89 to 8/3/89
Knox County sampled 8/7/89 to 8/9/89
Pierce County sampled 7/24/89 to 7/28/89

Chemical Data for Plio-Pleistocene Sand and Gravel Reservoir (Continued)

Knox County (Continued)

Sample Location	Sample Number (BT-)	Registration Number	Temperature (°C)	pH	Conductivity µmhos@25°C	Chemical Data (ppm)									
						HC03	Cl	N03-N	S04	Ca	Fe	Mg	K	Na	TDS
29N6W15b	25-LC	G54099	11.9	7.7	435	139	0.71	4.2	4.4	65.3	<0.01	7.9	4.8	13.4	169
Pierce County															
27N2W3a	37-LE	G48718	11.8	7.2	578	262	2.57	7.6	18.2	71.0	<0.01	12.2	4.6	24.4	269
27N2W6d	32-LE	G51088	11.0	7.4	735	305	2.08	12.4	32.0	95.4	<0.01	15.3	4.2	18.6	330
27N2W9d	33-LE	G46764	11.5	7.6	723	317	1.69	4.0	61.1	99.3	<0.01	18.7	4.5	15.9	361
27N2W21c	39-LE	G57761	11.7	7.4	556	250	1.52	7.3	17.9	76.2	<0.01	13.7	4.7	8.4	253
27N2W30b	31-LE	G49988	10.7	7.8	583	279	2.34	3.2	28.8	78.1	<0.01	13.6	4.4	13.9	282
27N2W34b	40-LE	G55194	12.0	7.6	700	219	5.09	25.0	26.0	84.5	<0.01	18.5	4.5	11.1	282
27N3W8a	19-LE	G45496	11.8	7.7	525	280	0.92	6.5	6.7	78.6	<0.01	11.6	5.4	15.6	263
27N3W11d	42-LE	G48524	11.7	7.6	575	262	2.11	8.4	25.5	80.2	<0.01	13.6	4.5	13.1	276
27N4W16d	24-LE	G50483	11.8	7.3	639	284	1.85	7.7	19.8	81.1	<0.01	13.4	7.0	17.7	288
27N4W2a	28-LE	G55019	12.4	7.6	510	257	1.28	3.4	7.2	69.6	<0.01	8.9	4.8	16.5	238
28N2W9a	5-LE	G45683	11.0	7.6	1030	356	3.96	13.0	65.8	122.1	<0.01	24.2	4.3	19.2	428
28N2W18b	15-LE	G5151	12.5	7.5	690	354	1.02	0.76	30.0	91.9	<0.01	21.3	5.0	14.2	338
28N2W29d	34-LE	G5110	NA	NA	757	361	1.37	5.3	51.3	101.1	<0.01	20.1	4.9	23.0	384
28N3W10a	11-LE	G50845	12.4	7.6	745	332	2.18	1.7	66.8	103.2	<0.01	23.6	5.1	8.6	374
28N3W18b	6-LE	G50512	12.0	7.3	NA	322	1.11	<0.02	17.5	83.5	<0.01	14.3	5.9	14.4	295
28N3W20c	13-LE	G50528	11.8	7.7	686	322	2.67	1.4	40.3	89.5	<0.01	15.4	5.5	20.1	333
28N3W31c	1-LE	G69033	12.5	7.6	587	244	2.09	5.8	7.5	68.7	<0.01	9.7	4.1	17.6	235
28N3W33b	22-LE	G42529	11.5	7.5	709	327	3.12	1.1	51.4	93.3	<0.01	16.6	6.9	23.1	356
28N3W35c	20-LE	G62205	11.0	7.5	731	368	1.53	<0.02	26.0	99.3	0.05	16.2	5.2	19.9	349
28N4W4d	3-LE	G50375	12.5	7.7	592	258	0.83	2.2	14.7	77.5	<0.01	11.2	5.4	13.1	252
28N4W6c	4-LE	G32659	12.4	7.8	510	202	1.36	8.7	8.9	61.2	<0.01	9.0	4.3	11.1	204
28N4W18a	2-LE	G46233	12.2	7.5	595	232	0.94	6.6	8.5	69.9	<0.01	9.6	4.8	12.8	227
28N4W22d	23-LE	G67252	12.2	7.9	596	310	0.76	4.1	7.8	85.4	<0.01	10.7	4.5	17.2	283
28N4W24b	10-LE	G46275	12.4	7.6	741	293	3.30	0.14	56.2	91.6	<0.01	14.3	4.6	15.8	330
28N4W28c	29-LE	G34919	12.2	7.5	613	237	2.97	12.8	14.4	74.2	<0.01	11.3	5.3	14.9	252
28N4W33d	30-LE	G28162	13.1	7.4	595	254	5.74	6.6	17.5	78.9	<0.01	11.7	5.9	12.3	263

Antelope County sampled 7/31/89 to 8/3/89

Knox County sampled 8/7/89 to 8/9/89, except 7-LE, 9-LE, 35-LE collected with Pierce County samples

Pierce County sampled 7/24/89 to 7/28/89

NA =Not available due to equipment malfunction

Chemical Data for Plio-Pleistocene Sand and Gravel Reservoi (n = 61)

Legal Location	Sample Number (BT-)	Registration Number	Temperature (°C)	pH	Conductivity µmhos @ 25°C	HC03	Cl	N03-N	S04	Ca	Fe	Mg	K	Na	TDS
					Chemical Data (ppm)										
Antelope County															
27N5W6b	55-UE	G39140	12.7	7.5	526	227	4.99	13.6	23.0	82.7	<0.01	11.8	5.1	16.2	269
27N5W10b	44-UE	G53502	12.2	7.0	522	230	2.83	15.1	11.1	80.1	<0.01	12.2	5.3	14.3	254
27N5W30a	49-UE	G40204	12.7	7.5	494	235	1.11	8.9	13.2	73.8	<0.01	12.8	7.0	10.5	243
27N6W4d	4-UE	G42888	12.5	7.2	356	155	0.97	9.8	7.5	57.0	<0.01	7.6	3.9	6.7	170
27N6W11b	29-UE	G45812	12.9	7.0	407	196	0.84	8.0	7.2	64.4	<0.01	8.2	4.2	7.1	196
27N6W20b	3-UE	G51326	12.5	7.0	424	278	0.82	8.9	6.6	70.0	<0.01	8.7	4.6	7.1	243
27N7W18b	18-UE	G26306	12.8	7.5	578	223	4.29	21.2	11.5	87.1	<0.01	13.5	6.5	10.0	257
28N5W10c	53-UE	G34896	12.7	7.6	536	182	5.21	22.2	12.2	79.5	<0.01	10.0	5.6	10.9	235
28N5W12b	52-UE	G48093	12.3	7.6	355	163	0.99	5.8	7.9	53.0	<0.01	6.6	3.4	8.9	167
28N5W23b	45-UE	G64964	12.2	7.3	454	224	0.78	6.7	9.5	69.9	<0.01	8.4	4.9	13.1	224
28N5W36b	51-UE	G13029	12.5	7.2	510	166	5.60	21.7	13.6	74.3	<0.01	11.6	4.8	11.6	225
Knox County															
29N3W28b	35-LE	G42642	11.4	7.5	678	321	3.20	7.0	27.6	94.7	<0.01	16.6	4.8	12.8	324
29N4W12a	2-LC	G34684	11.3	7.6	757	352	1.33	7.8	47.2	121.5	<0.01	19.7	3.9	9.9	385
29N4W13b	3-LC	G56579	12.1	7.4	648	310	1.59	6.2	31.5	103.7	<0.01	16.7	5.4	13.2	331
29N4W23d	4-LC	G46918	12.3	7.6	680	304	2.71	10.3	39.5	102.8	<0.01	16.3	6.7	18.6	346
29N4W25a	7-LE	G50808	12.2	7.5	935	327	2.49	12.5	69.2	114.6	<0.01	21.6	6.9	14.5	402
29N4W35c	9-LE	G37673	11.8	7.6	644	300	2.40	5.3	14.9	84.3	<0.01	15.4	6.4	12.1	288
29N4W31a	9-LC	G35730	12.4	7.7	462	206	1.38	8.7	13.0	70.6	<0.01	9.6	4.4	10.3	219
29N4W32d	7-LC	G40860	12.5	7.7	451	190	1.49	11.3	12.2	69.4	<0.01	9.7	5.6	8.8	212
29N4W33d	6-LC	G45036	12.4	7.6	577	294	1.39	6.6	10.6	87.3	<0.01	11.9	5.7	19.4	281
29N5W9d	40-LC	G60715	12.2	7.8	583	272	1.28	6.6	28.9	87.4	<0.01	13.7	5.3	12.2	289
29N5W11c	31-LC	G54607	11.8	7.4	751	354	2.46	8.2	43.6	122.6	<0.01	19.6	5.1	13.1	388
29N5W13c	21-LC	G40674	12.1	7.2	629	338	3.83	18.2	66.5	123.9	<0.01	19.2	7.7	20.6	426
29N5W14c	20-LC	G31840	12.2	7.4	804	317	1.67	13.6	75.2	121.6	<0.01	18.2	7.2	18.5	398
29N5W15b	19-LC	G32291	11.9	7.7	554	248	1.58	5.7	36.0	82.5	<0.01	14.1	4.7	11.7	278
29N5W23a	38-LC	UNREG	12.1	7.6	536	219	1.46	8.4	29.1	75.8	<0.01	12.1	5.0	12.3	252
29N5W23c	36-LC	G40673	12.1	7.6	536	240	1.36	6.4	17.2	77.8	<0.01	11.8	5.4	13.0	251
29N5W24c	30-LC	G67283	11.6	7.7	540	227	2.65	11.5	16.4	79.8	<0.01	11.6	5.1	12.0	251
29N5W25d	24-LC	G47323	11.7	7.6	680	235	2.83	8.0	18.2	80.8	<0.01	11.4	4.9	12.7	255
29N5W26c	10-LC	G44833	11.3	7.8	391	202	1.09	8.2	14.3	75.0	<0.01	10.6	4.3	13.1	225
29N5W27a	22-LC	G69058	12.1	7.9	477	219	1.29	8.0	13.4	73.8	<0.01	10.5	4.0	11.6	230
29N5W34c	8-LC	G29546	11.8	7.6	493	267	1.00	4.2	11.6	82.4	<0.01	10.3	5.9	11.6	258
29N5W35d	29-LC	G30717	11.7	7.6	453	139	3.10	19.6	12.2	64.8	<0.01	8.5	3.5	9.5	189
29N5W36a	23-LC	G49985	11.5	7.7	NA	183	3.15	16.4	12.9	74.9	<0.01	10.0	3.6	11.1	222

Chemical Data for Ogallala Reservoir (n = 20)

Legal location	Sample Number (BT-)	Registration Number	Temperature (°C)	pH	Conductivity µmhos @ 25°C	HCO3	Cl	NO3-N	SO4	Ca	Fe	Mg	K	Na	TDS
Antelope County															
27N5W22d	46-UE	G30984	11.9	7.2	640	280	2.64	10.6	33.8	94.0	<0.01	17.2	7.0	11.8	315
27N5W35c	47-UE	G31695	12.4	7.2	586	293	2.00	9.1	13.3	90.9	<0.01	15.8	7.8	12.1	295
27N8W1d	14-UE	G42594	13.2	7.3	400	163	1.67	13.6	8.7	61.0	<0.01	9.6	5.4	7.9	188
28N5W6b	42-UE	G47147	13.3	7.9	245	126	0.71	2.8	3.1	39.2	<0.01	3.9	3.6	5.7	121
28N5W18a	41-UE	G57398	13.5	7.6	313	178	0.74	1.6	4.1	53.0	<0.01	6.4	4.5	6.9	165
28N6W8b	8-UE	G38143	13.4	7.8	255	139	0.66	2.4	2.6	37.7	<0.01	4.9	4.7	5.6	127
28N6W15b	7-UE	G67259	12.9	7.5	265	122	0.60	5.5	5.9	38.3	<0.01	5.4	4.4	5.9	126
28N6W26c	37-UE	G54904	12.1	7.4	457	171	2.23	15.4	11.4	66.8	<0.01	12.4	4.3	8.9	205
28N7W24b	30-UE	G65929	13.6	7.5	264	139	0.59	3.3	4.2	40.9	<0.01	5.0	4.3	6.0	133
28N8W4a	17-UE	G68606	13.7	7.4	314	195	1.06	1.0	4.2	53.8	<0.01	5.3	5.2	7.6	174
27N8W8d	27-UE	G52952	14.0	7.6	427	256	0.81	3.3	3.4	72.4	0.10	9.6	6.0	7.9	229
28N8W17d	28-UE	G68607	13.8	7.2	352	208	0.66	4.8	5.2	57.8	<0.01	5.8	5.2	7.2	189
28N8W33a	16-UE	G48037	13.0	7.0	502	248	2.48	10.7	13.8	82.5	<0.01	10.9	6.6	12.7	261
Knox County															
29N4W27a	8-LE	G36549	11.9	7.5	708	317	4.06	7.4	25.2	94	<0.01	16.3	7.4	17	327
29N6W20d	26-LC	A15760B	12.3	7.8	300	168	0.65	0.35	1.7	49.0	<0.01	5.7	4.0	5.7	150
29N6W21b	14-LC	G51600	12.5	7.7	314	211	1.39	1.7	12.4	66.6	<0.01	8.1	5.8	7.6	207
29N6W28b	18-LC	G41778	13.0	7.7	322	171	0.92	1.6	3.1	51.9	<0.01	5.8	4.3	5.9	158
29N6W34b	13-LC	G66165	12.2	7.8	226	140	<.02	2.7	3.0	46.4	<0.01	5.4	4.1	5.7	136
Pierce County															
27N3W22a	16-LE	G59084	11.7	7.5	487	195	1.54	10.9	11.3	60	<0.01	11.3	4.6	14	209
27N4W6b	14-LE	G19656b	11.9	7.5	563	217	2.25	11.5	14.8	70	<0.01	11.6	5.6	11	233

Chemical Data (ppm): HCO3 through TDS.

Antelope County sampled 7/31/89 to 8/3/89
Knox County sampled 8/7/89 to 8/9/89, except 8-LE collected with Pierce County samples
Pierce County sampled 7/24/89 to 7/28/89

Chemical Data for Combined Plio-Pleistocene Sand/Gravel and Ogallala Reservoir (n = 34)

Antelope County

Location	Sample Number (BT-)	Registration Number	Temperature (°C)	pH	Conductivity µmhos @ 25°C	Chemical Data (ppm) HCO_3	Cl	NO_3-N	SO_4	Ca	Fe	Mg	K	Na	TDS
27N5W33b	48-UE	G53529	12.7	7.4	610	308	1.30	8.9	17.2	92.4	<0.01	15.7	7.9	16.0	311
27N6W15d	26-UE	G33333	13.2	7.6	395	182	0.95	8.9	7.3	58.7	<0.01	9.1	4.7	6.6	186
27N6W27a	23-UE	G44250	12.8	7.6	368	195	0.55	5.2	9.0	58.8	<0.01	9.5	5.3	7.0	191
27N7W4b	32-UE	G40440	12.6	7.4	340	158	1.13	8.6	8.7	38.3	<0.01	5.6	3.4	6.6	150
27N7W11c	43-UE	G54359	12.9	7.5	493	216	1.85	11.7	9.7	79.2	<0.01	10.4	4.4	8.4	232
27N7W24a	25-UE	G68882	12.8	7.9	371	179	0.89	8.2	6.7	59.8	<0.01	6.6	3.7	6.0	180
27N7W25d	24-UE	G50784	13.0	7.6	512	240	2.21	9.5	6.5	77.8	<0.01	11.2	6.1	6.6	238
27N7W30c	33-UE	G40072	13.3	7.4	440	240	0.46	4.1	9.5	75.4	<0.01	8.4	7.1	7.8	231
27N7W36b	22-UE	G59519	13.7	7.6	445	240	0.74	8.4	5.8	74.8	<0.01	10.2	5.8	6.8	231
27N8W10c	13-UE	G61978	13.7	7.6	440	212	1.02	8.4	8.3	69.6	<0.01	10.0	6.6	8.9	217
27N8W20d	11-UE	G32350	12.8	7.6	439	196	1.40	9.2	9.4	67.0	<0.01	10.9	7.0	5.9	207
27N8W22a	12-UE	G64508	13.1	7.5	480	245	0.92	8.7	6.3	74.0	<0.01	10.5	6.6	8.7	236
27N8W28c	2-UE	G46740	12.6	7.1	403	193	1.40	8.5	7.3	63.7	<0.01	10.3	6.6	6.0	199
27N8W31a	34-UE	G50426	12.8	7.4	377	162	1.24	8.4	6.6	54.2	<0.01	8.2	4.5	5.7	169
27N8W35a	35-UE	G28703	NA	NA	NA	285	0.86	5.8	6.5	84.6	<0.01	9.6	9.1	11.0	268
28N5W29b	40-UE	G48764	13.0	7.4	440	224	0.98	4.0	19.8	67.1	<0.01	9.8	8.4	14.4	235
28N5W33d	50-UE	G48482	12.1	7.3	532	174	6.98	24.7	13.7	81.9	<0.01	11.6	4.7	11.8	241
28N6W3a	6-UE	G35641	13.5	7.2	475	118	6.79	25.4	11.5	65.2	<0.01	8.2	5.6	9.2	165
28N6W28d	5-UE	G62098	12.5	6.8	370	106	6.30	16.4	11.5	48.7	<0.01	9.1	3.3	8.4	156
28N6W31b	36-UE	G28485	NA	NA	NA	101	3.95	21.5	12.9	52.5	<0.01	8.2	3.9	9.8	163
28N7W12d	9-UE	G29299	13.4	7.6	290	127	1.09	8.3	5.4	45.4	<0.01	5.3	4.5	6.1	138
28N7W19b	31-UE	G41489	12.7	7.3	364	187	1.34	8.5	8.5	54.9	<0.01	7.2	4.3	7.6	184
28N7W31a	54-UE	G41551	13.6	7.4	365	189	0.79	4.0	3.9	57.7	<0.01	6.8	5.0	7.1	178
28N8W6c	15-UE	G60774	12.2	6.7	335	171	1.20	6.2	7.3	50.2	<0.01	7.2	5.0	6.7	168
28N8W31b	10-UE	G62797	12.7	7.5	420	199	1.09	7.4	7.0	64.8	<0.01	6.9	4.4	8.3	198
Knox County															
29N6W35c	33-LC	G45061	13.9	7.7	240	123	0.53	1.0	1.8	36.2	<0.01	3.90	4.3	5.8	114

Chemical Data for Combined Plio-Pleistocene Sand/Gravel and Ogallala Reservoir (Continued)

Pierce County						Chemical Data (ppm)									
Location	Sample Number (BT-)	Registration Number	Temperature (°C)	pH	Conductivity µmhos @ 25°C	HC03	Cl	N03-N	S04	Ca	Fe	Mg	K	Na	TDS
27N2W29a	38-LE	G42574	11.8	7.5	647	204	5.90	24.5	20.0	83.4	<0.01	12.0	3.2	16.9	266
27N4W18b	25-LE	G43651	12.0	7.5	669	278	1.91	11.2	22.4	88.0	<0.01	14.8	6.7	18.1	300
27N4W26c	27-LE	G28379	12.8	7.8	562	293	0.84	2.6	8.8	76.0	<0.01	13.0	6.9	9.8	262
27N4W32a	26-LE	G56159	12.4	7.4	592	293	1.04	4.2	13.1	77.4	<0.01	14.7	8.1	13.0	275
28N2W22c	36-LE	G29719	11.3	7.4	851	371	3.30	5.0	67.9	102.7	<0.01	21.2	4.7	31.6	419
28N3W12d	21-LE	G37072	12.0	7.5	803	319	2.91	6.5	54.9	103.4	<0.01	20.4	3.6	16.4	365
28N3W22d	12-LE	G59936	11.0	7.4	1020	339	6.50	15.9	64.7	131.7	<0.01	16.4	5.5	18.6	426
28N3W25d	43-LE	G1554	11.7	7.3	887	366	2.94	6.9	111.9	125.6	<0.01	25.7	5.7	23.5	482

Antelope County sampled 7/31/89 to 8/3/89
Knox County sampled 8/7/89 to 8/9/89
Pierce County sampled 7/24/89 to 7/28/89

NA = Not Available due to equipment malfunction