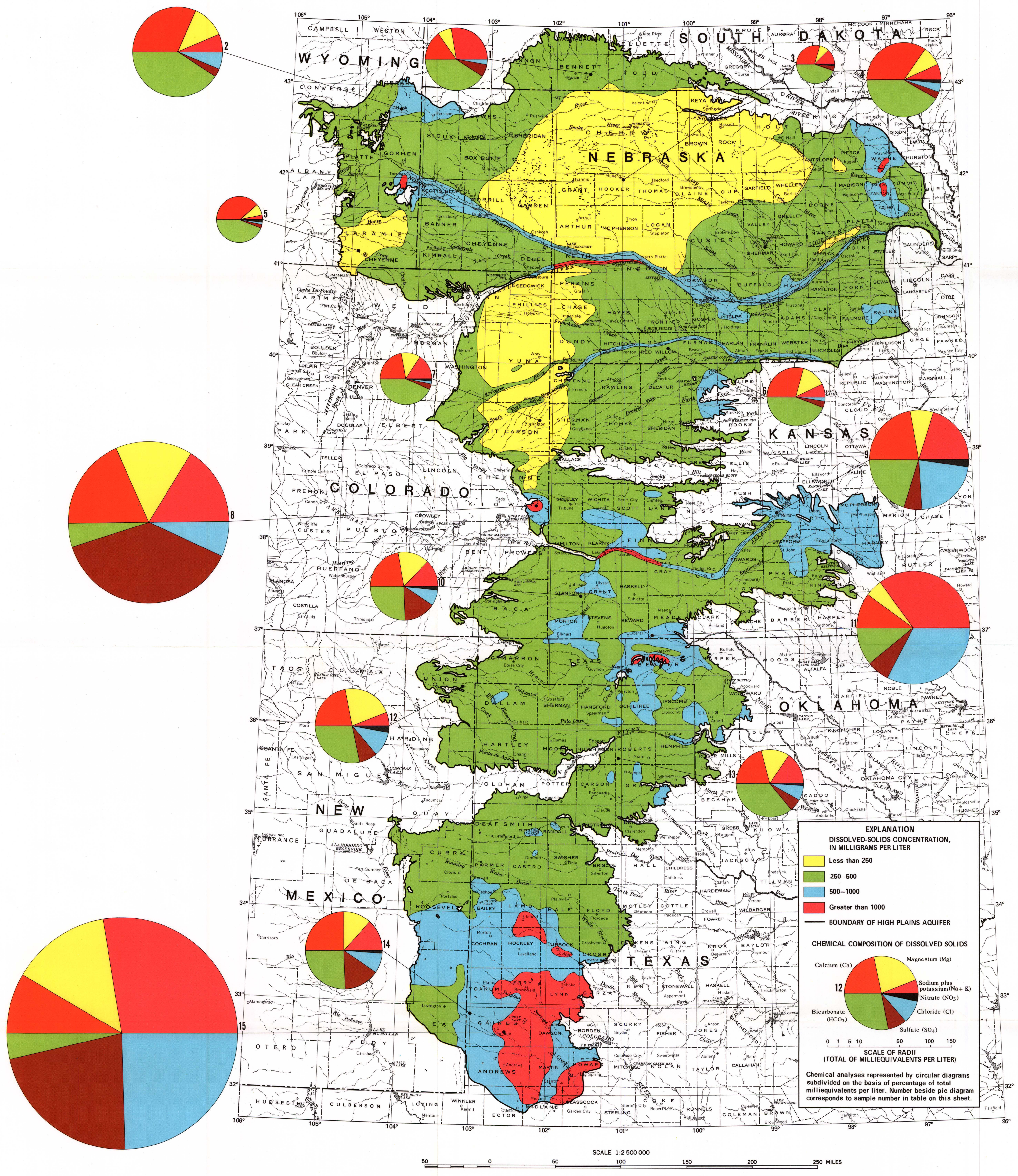
DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

HYDROLOGIC INVESTIGATIONS
ATLAS HA-658 (SHEET 1 OF 2)



CONCENTRATION OF DISSOLVED SOLIDS IN GROUND WATER

INTRODUCTION

In 1978, the U.S. Geological Survey initiated a 5-year study of the High Plains regional aquifer to provide: (1) Hydrologic information needed to evaluate the effects of continued ground-water development; and (2) computer models to predict aquifer response to changes in ground-water development. The plan of study for the High Plains Regional Aquifer-System Analysis was described by Weeks (1978). A description of the High Plains aquifer and a map of the 1978 water table were presented by Gutentag and Weeks (1980). Maps of the bedrock geology, altitude of aquifer base, and saturated thickness of the High Plains aquifer were published by Weeks and Gutentag (1981). Water-level and saturated-thickness changes, from predevelopment to 1980, were mapped by Luckey, Gutentag, and Weeks (1981). This report describes the areal distribution of dissolved solids and sodium in water of the High Plains aquifer. Data used in this study were provided by the U.S. Geological Survey and State agencies in each of the eight States in the High Plains. Their contribution is an integral part of this investigation.

The High Plains aquifer underlies about 174,000 square miles in eight States--Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming. The aquifer consists mainly of sediments of Tertiary and Quaternary age. In ascending order, the Tertiary rocks consist of the Brule Formation, Arikaree Formation (or Group in Nebraska where it is subdivided), and Ogallala Formation. The upper part of the Brule Formation is included in the High Plains aquifer where it contains interconnected fractures in parts of northeastern Colorado, western Nebraska, and southeastern Wyoming. The Arikaree Formation or Group is part of the aquifer where it underlies northeastern Colorado, western Nebraska, southern South Dakota, and southeastern Wyoming. The principal geologic unit in the High Plains aquifer is the Ogallala Formation which underlies 156,000 square miles of the study area in New Mexico, Oklahoma, Texas, and parts of Colorado, Kansas, Nebraska, South Dakota, and Wyoming.

The Quaternary deposits included in the High Plains aquifer consist of alluvial, dune-sand, and valley-fill deposits. Alluvial deposits comprise the aquifer in eastern Nebraska and the Great Bend area in central Kansas. In many areas of the High Plains, saturated alluvial deposits overlie the Ogallala Formation to form one aquifer. Wind-blown dune-sand deposits are part of the aquifer in an area of about 20,000 square miles in west-central Nebraska and smaller areas in Kansas. Valley-fill deposits along present streams also are part of the aquifer. A more detailed description of the geology of the High Plains aquifer was presented by Gutentag and Weeks (1980) and Weeks and Gutentag (1981).

The High Plains region is an important agricultural area that includes about 16 million acres of irrigated land. The High Plains aquifer is the only source of water for irrigation in most of the High Plains. In part, the economy of the High Plains depends on the availability of suitable quality water for irrigation. The suitability of water for irrigation is determined largely by the concentrations of dissolved solids (salinity hazard) and sodium (sodium hazard). The purpose of this report is to describe the areal variations in dissolved solids and sodium in water from the High Plains aquifer, relate the concentrations of dissolved solids and sodium to salinity and sodium hazards, and determine the suitability of the water for irrigation. The concentration of dissolved solids in water of the High Plains aquifer is described on sheet 1 of this report; sodium concentrations and salinity and sodium hazards are described on sheet 2.

DISSOLVED SOLIDS

As a result of geochemical and biochemical interactions between water and the geologic materials through which it flows, ground water contains a variety of dissolved inorganic chemical constituents. The concentration of dissolved solids in ground water can vary by many orders of magnitude. A simple method for categorizing ground water based on dissolved-solids concentration is presented below (Winslow and Kister, 1956):

Category	Concentration of dissolved solids, in milligrams per liter
Fresh	Less than 1,000
Slightly saline	1,000 - 3,000
Moderately saline	3,000 10,000
Very saline	10,000 35,000
Brine	More than 35,000

To put the concentration ranges in perspective, water containing more than 2,000 to 3,000 mg/L (milligrams per liter) dissolved solids generally is too mineralized to drink (Freeze and Cherry, 1979). The U.S. Environmental Protection Agency (1977) recommended limit for dissolved solids in drinking-water supplies is 500 mg/L. Dissolved-solids concentrations also provide a measure of the salinity hazard of water used for irrigation. Most crops can tolerate water containing as much as 500 mg/L dissolved solids without adverse effects; if leaching or drainage is adequate, concentrations of 500 to 1,500 mg/L are not likely to be harmful (U.S. Salinity Laboratory Staff, 1954).

On this sheet, the map shows the areal distribution of dissolved-solids concentrations found in water from the High Plains aquifer. Each interval on the map shows the range in concentration of dissolved solids that predominates in that area. The dissolved-solids map is based on several thousand reported chemical analyses of water samples. Because of map scale, it is not possible to show small areas within or between intervals where the dissolved-solids concentration may be more or less than that indicated. More detailed information about the quality of ground water is available in reports from various Federal, State, and County agencies.

The chemical composition of ground water at selected sites is shown on the map by 15 circular or "pie" diagrams. The pie diagrams are based on the concentrations of dissolved constituents expressed as milliequivalents per liter. The concentration of each ion, in milligrams per liter, is converted to milliequivalents per liter by dividing by the combining weight of that ion (Hem, 1970). Milliequivalents per liter expresses the concentration of chemical constituents in terms of chemical equivalence, and more accurately describes the composition of water and the relationship between ions in solution. One milliequivalent of a cation (positively charged ion) will react with one milliequivalent of an anion (negatively charged ion).

Each pie diagram is constructed so that the area of the circle is proportional to the concentration of dissolved solids, in milliequivalents per liter. Thus, the larger the diagram, the larger the concentration at that site. For example, the area of pie diagram 15 is about 40 times larger than the area of pie diagram 3, which indicates that the concentration of dissolved solids in ground water at site 15 is about 40 times greater than at site 3.

Each pie diagram also shows the proportion of cations and anions that comprise the concentration of dissolved solids in ground water at that location. Only the concentrations of the most common ions were used to construct the diagrams. The numerous other ions found in ground water make up a very small percentage of the dissolved-solids concentrations. The cations, including calcium (Ca), magnesium (Mg), and combined sodium (Na) plus potassium (K), comprise one-half of the pie diagram. The anions, including bicarbonate (HCO_3), sulfate (SO_4), chloride (Cl), and nitrate (NO_3), comprise the other one-half.

The 15 chemical analyses from which these diagrams were constructed are presented in the table below. These analyses were selected because they are representative of the variation in concentration of dissolved solids and the chemical composition of water in the High Plains aquifer. Concentrations of chemical constituents exceeding U.S. Environmental Protection Agency (1976, 1977) primary and secondary drinking-water regulations are indicated in the table. The concentrations of sulfate, chloride, fluoride, nitrate, and dissolved solids in several samples exceed the regulations. Feder and Krothe (1981) noted that selenium exceeded the regulations in a water sample from Kiowa County, Colorado.

The chemical composition of water in the High Plains aquifer is related to the concentration of dissolved solids. In general, water in the High Plains aquifer containing less than 250 mg/L dissolved solids is a calcium bicarbonate type water. Sodium and sulfate become more prevalent where the concentration of dissolved solids is 250 to 500 mg/L. The chemical character of water in the High Plains aquifer that exceeds 500 mg/L dissolved solids is mixed, with the ions calcium, sodium, sulfate, and chloride most prevalent.

Most of the High Plains aquifer is composed of sand and gravel usually mixed with silt, clay, and caliche. The chemical composition of water from the aquifer is predominately calcium bicarbonate type water derived from the solution of calcium carbonate cementing the sand and gravel. About 62 percent of the area of the High Plains aquifer contains water with 250 to 500 mg/L dissolved solids, 19 percent of the area of the aquifer contains water with less than 250 mg/L dissolved solids, and 19 percent of the area of the aquifer contains water exceeding 500 mg/L dissolved solids. Only 3 percent of the area of the aquifer contains water with more than 1,000 mg/L dissolved solids, most of which is in Texas. Generally, the maximum concentrations of dissolved solids in water from the High Plains aquifer are less than 3,000 mg/L except where the aquifer has been contaminated by saline water.

In parts of Colorado, Kansas, Nebraska, and Wyoming, water in the High Plains aquifer contains less than 250 mg/L dissolved solids as shown on the map. A large part of this area in Colorado and Nebraska is covered by sandy soils and dune sands. The concentration of dissolved solids in the area covered by sand is less than 250 mg/L because recharge to the aquifer from precipitation is relatively large and most soluble material already has been removed from the sand.

In several areas where water in the aquifer contains more than 500 mg/L dissolved solids, the water chemistry appears to be related to bedrock geology. Except south of the Canadian River, the age of the geologic units underlying the High Plains aquifer increases from north to south and from west to east (Weeks and Gutentag, 1981). The age of the bedrock ranges from Tertiary to Permian and, in general, the older rocks contain more soluble minerals than the younger rocks.

The bedrock can affect the chemical composition of water in the aquifer in several ways. Water at the base of the aquifer in contact with the bedrock can dissolve minerals and transport solutes through the aquifer by flow and diffusion. Water containing large concentrations of solutes within the bedrock can flow from the bedrock into the aquifer in response to hydraulic-head differences. Water chemistry also can be affected by dissolution of minerals from reworked bedrock material contained in the aquifer since deposition.

The concentration of dissolved solids in water from the High Plains aquifer exceeds 1,000 mg/L near outcrops of Late Cretaceous age in Goshen County, Wyoming. The bedrock units underlying the aquifer in Goshen County are the Lance Formation of Late Cretaceous age and the Chadron and Brule Formations of Tertiary age. Rapp, Visher, and Littleton (1957) reported that the dissolved-solids concentration in water from the Lance Formation ranged from 416 to 1,250 mg/L and exceeded 1,000 mg/L in 2 of 7 water samples. Water in the Lance Formation usually is under artesian pressure (Rapp and others, 1957) and may be moving upward into the High Plains aquifer.

In northeastern Nebraska, the High Plains aquifer includes interfingering glacial till deposits. The till deposits consist of reworked Cretaceous bedrock material of marine origin. Wells in the till do not yield adequate quantities of water for irrigation. Where the aquifer includes till deposits, the dissolved-solids concentration in ground water usually exceeds 500 mg/L and, in parts of Stanton and Wayne Counties, the concentration exceeds 1,000 mg/L. The maximum reported concentration of dissolved solids in water from the till was 2,120 mg/L (R. A. Engberg, U.S. Geological Survey, oral commun., 1981).

In Kiowa County, Colorado, the concentration of dissolved solids in water from the aquifer exceeds 1,000 mg/L. The maximum concentration of dissolved solids reported by Boettcher (1964) in Kiowa County was 2,560 mg/L. In this area, the aquifer is underlain by the Smoky Hill Marl Member of the Niobrara Formation of Late Cretaceous age. The Smoky Hill Marl Member is "practically impermeable" and contains gypsum (calcium sulfate) crystals according to Boettcher (1964). Water in the High Plains aquifer in Kiowa County commonly contains sulfate as the dominate anion (pie diagram 8), which is attributed to gypsum in the bedrock. Because the Smoky Hill Marl Member is not known to yield water to wells, the chemistry of water in the High Plains aquifer probably is affected by solution of gypsum at the bedrock contact or in wells that are drilled through the aquifer into bedrock.

Extending from McPherson to Pratt Counties in central Kansas, the High Plains aquifer is underlain by Permian bedrock containing salt beds and saline water. In this area, water in the aquifer contains 500 to 1,000 mg/L dissolved solids and large proportions of sodium and chloride (pie diagram 9) indicating that water from the Permian bedrock may be entering the aquifer.

Permian bedrock also underlies the High Plains aquifer in Beaver County, Oklahoma. Water in the aquifer in this area typically contains 500 to 1,000 mg/L dissolved solids but exceeds 1,000 mg/L near the Permian outcrops in Beaver County. As shown by pie diagram 11, water in the aquifer is a sodium chloride type with nearly equal proportions of sodium and chloride, which indicates that saline water from the Permian bedrock is entering the aquifer. The maximum reported dissolved-solids concentration in water from the aquifer in this area was 6,200 mg/L.

South of the Canadian River, in New Mexico and Texas, the High Plains aquifer is underlain by Triassic, Jurassic, and Lower Cretaceous bedrock. The Lower Cretaceous rocks were deposited in a deep-water marine environment. Water in these rocks is highly mineralized and probably is moving into the High Plains aquifer in response to hydraulic-head differences. As shown on the map and pie diagrams 14 and 15, water in the aquifer in the southern High Plains contains large concentrations of dissolved solids and unusually large proportions of magnesium, sodium, chloride, and sulfate. This probably is caused by the movement of solutes from the marine bedrock into the aquifer. Also, Reeves and Miller (1978) proposed that seepage from saline lakes or playas contributes to the relatively large dissolved-solids concentrations found in water from the aquifer in the southern High Plains of Texas. The maximum concentration of dissolved solids in water from the aquifer noted during this study was 20,200 mg/L reported by Rettman and Leggat (1966, p. 169) in Gaines County, Texas. This anomalously large concentration was caused by contamination from disposal of oil-field brines in surface pits. Generally, the dissolved-solids concentration in water from the High Plains aquifer in southern Texas is less than 3,000 mg/L.

The concentration of dissolved solids in water in the High Plains aquifer near major streams is affected by irrigation practices. Salts that accumulate in the soil because of evapotranspiration are dissolved and flushed with irrigation water. In stream valleys where the water table is near land surface, the salts that were dissolved from the soil are carried to the aquifer. As shown on the map, the concentration of dissolved solids in ground water along the Arkansas, Platte, and Republican Rivers generally is 500 to 1,000 mg/L and exceeds 1,000 mg/L along parts of the South Platte and Arkansas Rivers.

CHEMICAL ANALYSES OF SELECTED WATER SAMPLES FROM THE HIGH PLAINS AQUIFER

[Values are in milligrams per liter except as indicated; values in blue are in milliequivalents per liter; values in red exceed U.S. Environmental Protection Agency regulations (1976, 1977); µmho = micromhos per centimeter at 25 degrees Celsius]

Map number	Site number	Geologic unit[1]	Well depth (feet)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium + Potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (sum)	pH (units)	Specific conductance (µmho)	Predominate	
																Cation	Anion
1	4312571012815	ARKR	96	77	28 1.4	8 .7	66 2.6	230 3.8	28 .6	8.5 .2	0.1 ---	1.9 ---	332	7.6	446	Na	HCO_3
2	4244261042007	ARKR	100	54	122 6.1	29 2.4	38 1.3	446 7.3	24 .5	40 1.1	.5 ---	--- ---	678	7.5	926	Ca	HCO_3
3	4200401005902	SDGV	245	58	20 1.0	3.3 .3	12 .4	94 1.5	5.0 .1	.3 ----	.2 ---	3.0 ---	148	8.1	158	Ca	HCO_3
4	4114520984721	OGLL	200	63	94 4.7	14 1.2	21 .9	336 5.5	18 .4	18 .5	--- ---	7.6 .1	403	7.7	605	Ca	HCO_3
5	4109391045801	OGLL	250	28	45 2.2	5.5 .5	6.4 .2	157 2.6	6.5 .1	2.8 .1	.4 ---	7.0 .1	191	7.4	281	Ca	HCO_3
6	4011081001734	OGLL	200	58	56 2.8	15 1.2	19 .7	200 3.3	13 .3	3.9 .1	.8 ---	--- ---	273	7.7	420	Ca	HCO_3
7	3918061021418	OGLL	321	36	30 1.5	10 .8	27 1.1	181 3.0	10 .2	3.0 .1	1.8 .1	7.6 .1	214	8.0	325	mixed	HCO_3
8	3824481020652	OGLL	100	22	228 11.4	114 9.4	226 9.8	184 3.0	1,170 24.4	143 4.0	4.0 .2	3.9 .1	2,140	7.7	2,630	mixed	SO_4
9	3816540985512	SDGV	100	20	108 5.4	21 1.7	114 4.9	248 4.1	94 2.0	177 5.0	1.0 .1	32 .5	694	7.5	1,235	mixed	mixed
10	3725431013338	OGLL	40	20	51 2.5	20 1.6	35 1.5	180 3.0	8.1 1.7	30 .8	1.4 .1	12 .2	339	7.6	555	mixed	HCO_3
11	3700591003420	OGLL	260	23	63 3.1	19 1.6	245 10.6	210 3.4	94 2.0	350 9.9	1.0 .1	1.7 ---	900	7.7	1,650	Na	Cl
12	3627141031104	OGLL	170	38	56 2.8	34 2.8	17 .7	215 3.5	49 1.0	46 1.3	1.6 .1	24 .4	372	7.4	628	mixed	HCO_3
13	3543091010043	OGLL	569	27	46 2.3	18 1.5	37 1.6	243 4.0	32 .7	28 .8	.8 ---	3.9 .1	312	8.0	507	mixed	HCO_3
14	3255461030251	OGLL	150	58	72 3.6	20 1.6	44 1.9	221 3.6	104 2.2	43 1.2	1.5 .1	5.6 .1	507	7.3	675	Ca	HCO_3
15	3239241023450	OGLL	104	64	231 11.5	225 18.5	845 36.8	282 4.6	1,351 28.1	1,109 31.3	4.0 .2	4.2 .1	3,970	7.4	5,350	Na	mixed

[1] ARKR-Arikaree Formation; OGLL-Ogallala Formation; SDGV-Quaternary sand and gravel deposits.

Base from U. S. Geological Survey
United States base map, 1972

INTERIOR—GEOLOGICAL SURVEY, RESTON, VIRGINIA—1982—W82171

DISSOLVED SOLIDS AND SODIUM IN WATER FROM THE HIGH PLAINS AQUIFER IN PARTS OF COLORADO, KANSAS, NEBRASKA, NEW MEXICO, OKLAHOMA, SOUTH DAKOTA, TEXAS, AND WYOMING

By

Noel C. Krothe, Joseph W. Oliver, and John B. Weeks

1982

For sale by Branch of Distribution, U.S. Geological Survey
Box 25286, Federal Center, Denver, CO 80225