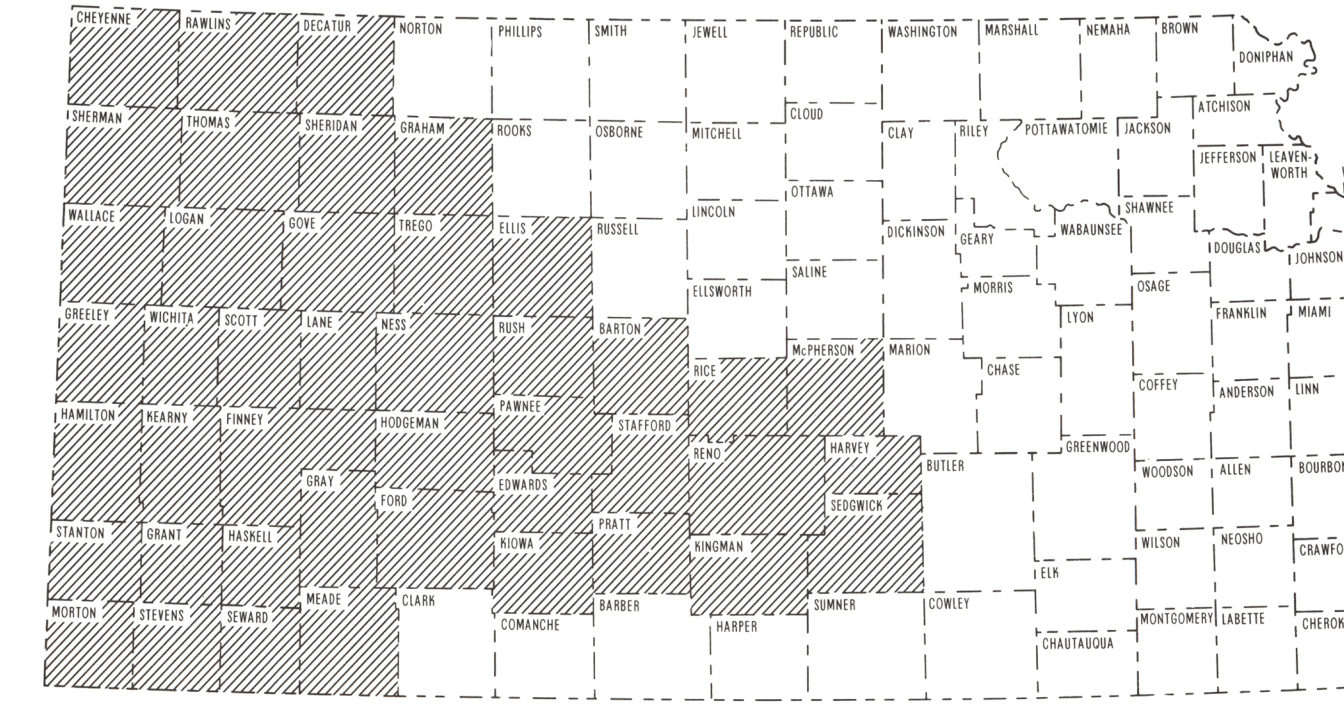
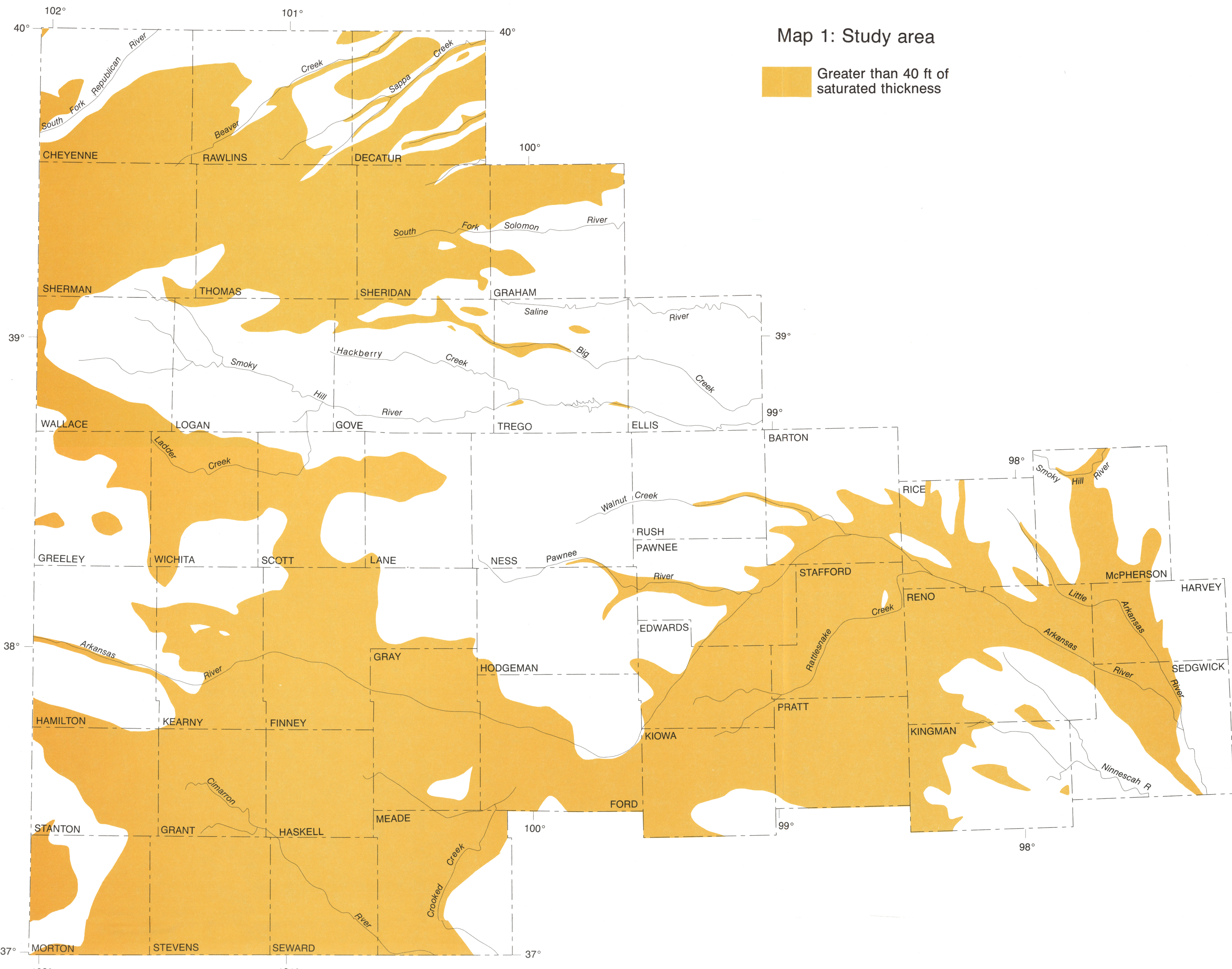


Atlas of chemical-quality data for irrigation waters of western Kansas

by
L. R. Hathaway and L. M. Magnuson
Kansas Geological Survey
1985

Map 1: Study area

Greater than 40 ft of saturated thickness



Index map of study area.

Water-bearing unconsolidated sediments of Quaternary and Tertiary age serve as the major source of freshwater in the irrigated croplands of western and south-central Kansas where annual rainfall averages range from about 16 to 30 inches, respectively. Bedrock underlying these sediments varies from units of Cretaceous age in northwestern Kansas to units of Permian age in southwestern and south-central Kansas. Within the area of study (Map 1), the water table tends to parallel the eastward-sloping land surface. Thus, ground-water movement is in a general easterly direction.

The surficial topography of this part of the state is relatively flat, sloping gently eastward. Three principal drainage systems—the Cimarron River, the Arkansas River, and the Smoky Hill River—make eastward to southeastward trending incisions into the land's surface within the study area. The soil cover throughout much of the region is derived from a loess mantle which covers the unconsolidated aquifer. Dunes and sandy soils cover extensive regions south of both the Arkansas and Cimarron rivers. Patches of saline and/or sodic soils may be found within the alluvium of the drainageways or within areas of restricted surface drainage and shallow water-table conditions.

The information displayed in Map 1 is taken from Kansas Geological Survey Map M-5. The simplified drainage depicted for the study area represents for the most part continuous-flow segments of drainageways shown in M-5. More detailed coverage of the geology and hydrogeology of the study area is contained in the selected readings and the references cited therein.

During the peaks of the irrigation seasons between July 1974 and July 1981, water samples were collected from a cumulative total of 1,232 different pumping irrigation wells in western and south-central Kansas. These samples were analyzed at the Kansas Geological Survey laboratories, and the data from these analyses are the basis for this ground-water-quality atlas. Concentration data for bicarbonate (HCO_3^-) and silica (SiO_2) approximate normally distributed sets, whereas data sets for other chemical constituents approach log-normal distributions. Concentration intervals for maps of chemical constituents generally were chosen to set apart the lower 20% and upper 15% fractions of the sample population.

The maps of this atlas present chemical-quality data in a two-dimensional fashion for ground waters as produced and used. Thus, no attempt is made to address variability in water quality that results from different wells sampling unequal portions of the aquifer. Therefore, maps of this atlas merely serve as guides for the general interpretation of chemical quality in the aquifer system as it is being used presently, rather than as definitive or absolute statements of its total status.

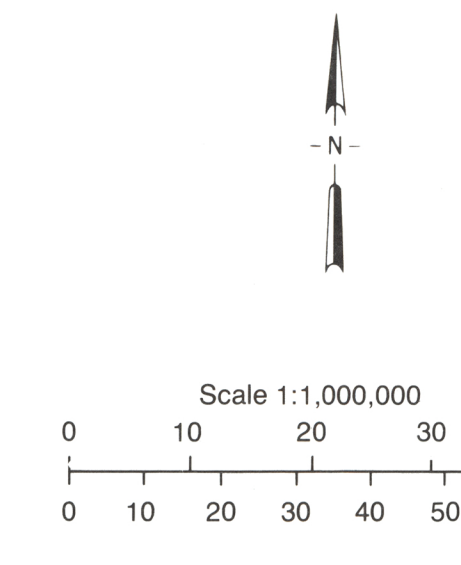
The total residue map (Map 2) makes it possible to visualize those areas in which the dissolved-solids loads of the ground water increase with resultant decrease in general water quality. The low total residue zone south of the Arkansas River and comparable features on other maps which trend in a southeastward direction from eastern Kearny County may be related to Early Pleistocene drainage patterns, reflecting an area where unconsolidated sediments have been reworked. The area south of the Arkansas River in the eastern half of the study area also has received extensive alluviation during Pleistocene times. The low total residue areas of the northwestern portion of the study area are more problematic but may represent regions of local recharge through fracture systems.

Total residue levels in excess of 500 mg/L typically are associated with alluvial deposits of drainageways. Ground waters in areas of restricted surface drainage and relatively shallow water-table conditions, such as central Scott and Finney counties, may be prone to elevated levels of dissolved salts. In central Finney County this situation has been exacerbated by past use of surface water from the Arkansas River for irrigation. Salt-bearing Permian-age bedrock units can have an adverse effect upon water quality in the overlying unconsolidated aquifer. This is reflected in saltwater seeps into drainageways in Seward and Meade counties and in the practice of water withdrawal only from upper portions of the aquifer in parts of south-central Kansas. Limited well depths and shallower water-table conditions coupled with the extensive oil-gas activity in south-central Kansas have created situations where ground-water contamination is evident locally.

The cation (Map 3) and anion (Map 4) water-type classification maps convey general information concerning chemical compositions of the solids dissolved in the ground waters. These classifications are based upon percent milliequivalent contributions of the various chemical species to the total number of milliequivalents per liter of cations or anions. Ca-HCO_3 and mixed Ca-Mg-HCO_3 -type waters provide the underlying fabric for water classification in the unconsolidated aquifer system. Ca-HCO_3 -type waters prevail in sandy soil regions south of the Arkansas River and in the eastern half of the study area where shallower water-table conditions generally are encountered. Superimposed more broadly upon this basic ground-water chemistry are the Ca-SO_4 and $\text{Ca-mixed(HCO}_3\text{-SO}_4\text{)}$ -type waters of the alluvial deposits of drainageways and of areas with restricted external surface drainage such as central Scott and Finney counties. The major influence of Na-Cl-type waters in the unconsolidated aquifer is noted in areas overlying Permian age bedrock containing halite (NaCl) or Na-Cl-type waters, or in areas in which oil-gas brines have escaped and sandy soil and/or shallow water-table conditions exist.

Selected readings

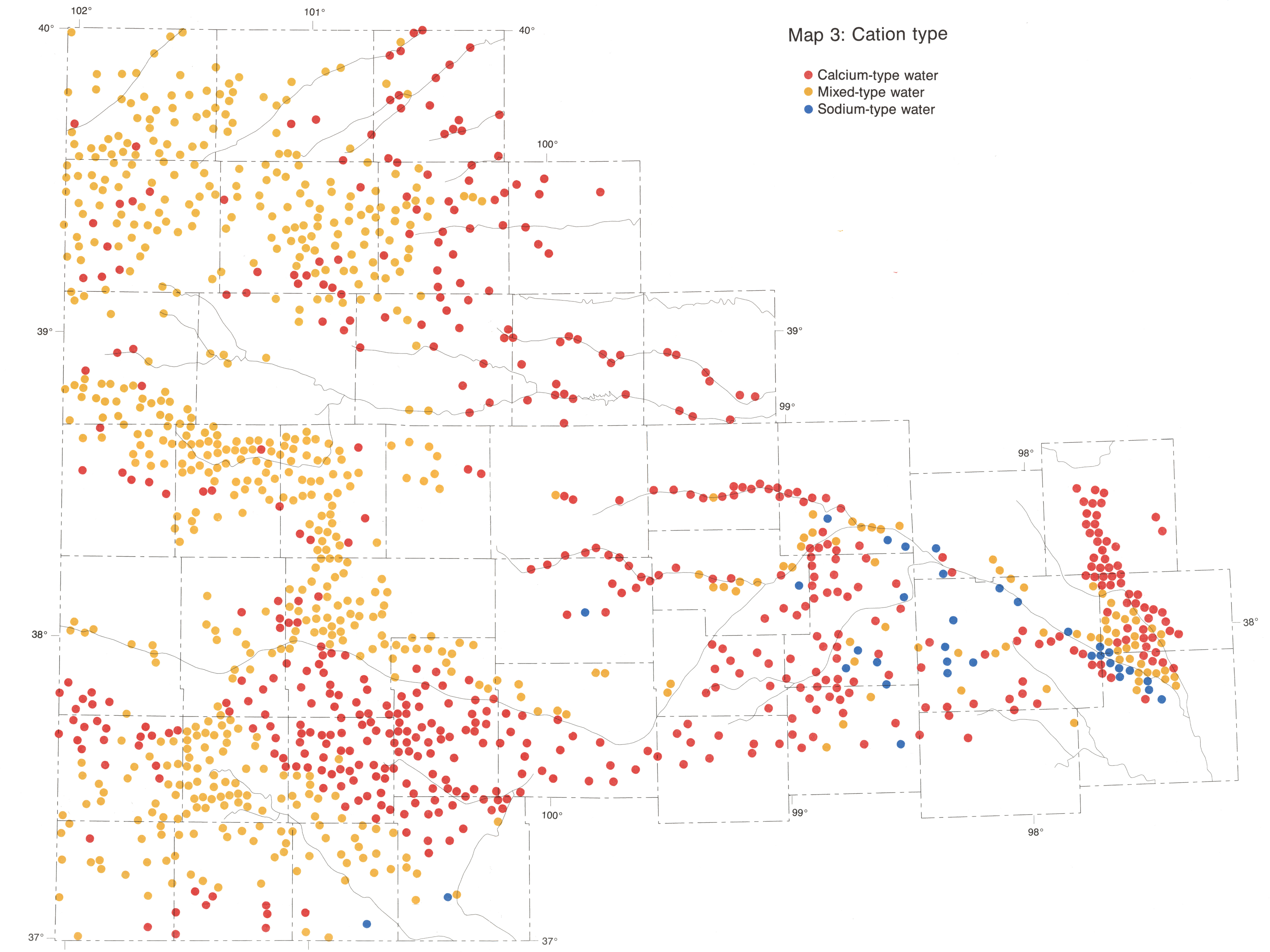
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- Hathaway, L. R., and Dickey, H. P., 1978. Soil associations of southwestern Kansas: Kansas Geological Survey, Map M-6A.
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- Hathaway, L. R., Galle, O. K., Waugh, T. C., and Dickey, H. P., 1978. Chemical quality of irrigation waters in Ford County and the Great Bend Prairie of Kansas: Kansas Geological Survey, Chemical Quality Series 7, 41 p.
- Hathaway, L. R., Magnuson, L. M., Carr, B. L., Galle, O. K., and Waugh, T. C., 1975. Chemical quality of irrigation waters in west-central Kansas: Kansas Geological Survey, Chemical Quality Series 2, 45 p.
- Hathaway, L. R., Waugh, T. C., Galle, O. K., and Dickey, H. P., 1979. Chemical quality of irrigation waters in northwestern Kansas: Kansas Geological Survey, Chemical Quality Series 8, 45 p.
- , 1981. Chemical quality of irrigation waters in the Equus Beds area, south-central Kansas: Kansas Geological Survey, Chemical Quality Series 10, 45 p.
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The county boundaries, streams, contours of saturated thickness shown on Plate 1, and color-separated dot symbols on all five plates were produced by computer in the Automated Cartography Laboratory of the Kansas Geological Survey. Dot symbols were generated from supplied locations. Software used to perform these tasks is a part of GIMMAP (GeoData Interactive Management Map Analysis and Production), a computer-assisted cartography system developed at the Kansas Geological Survey. All other preparation and layout by Renate Hensiek.

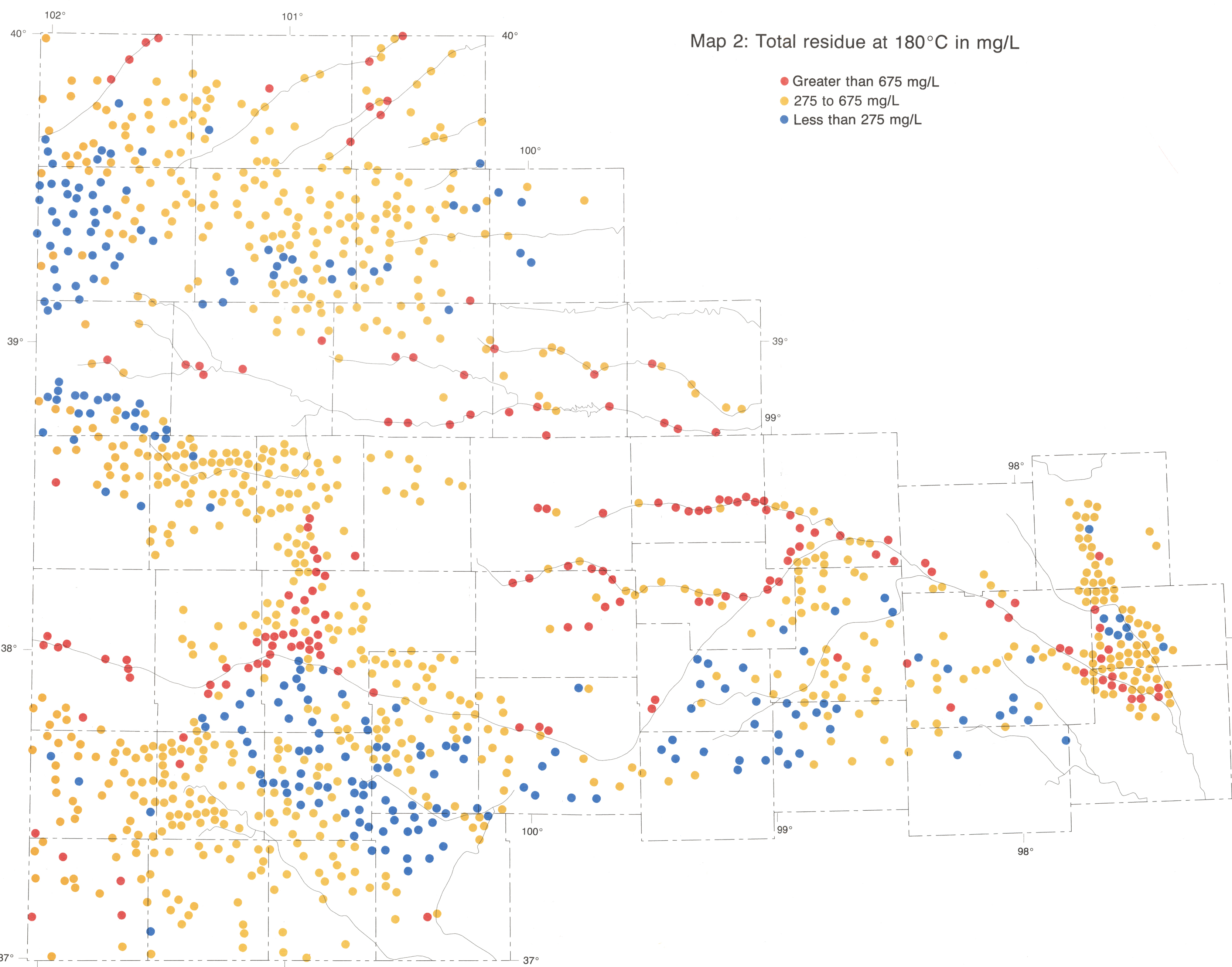
Map 3: Cation type

● Calcium-type water
● Mixed-type water
● Sodium-type water



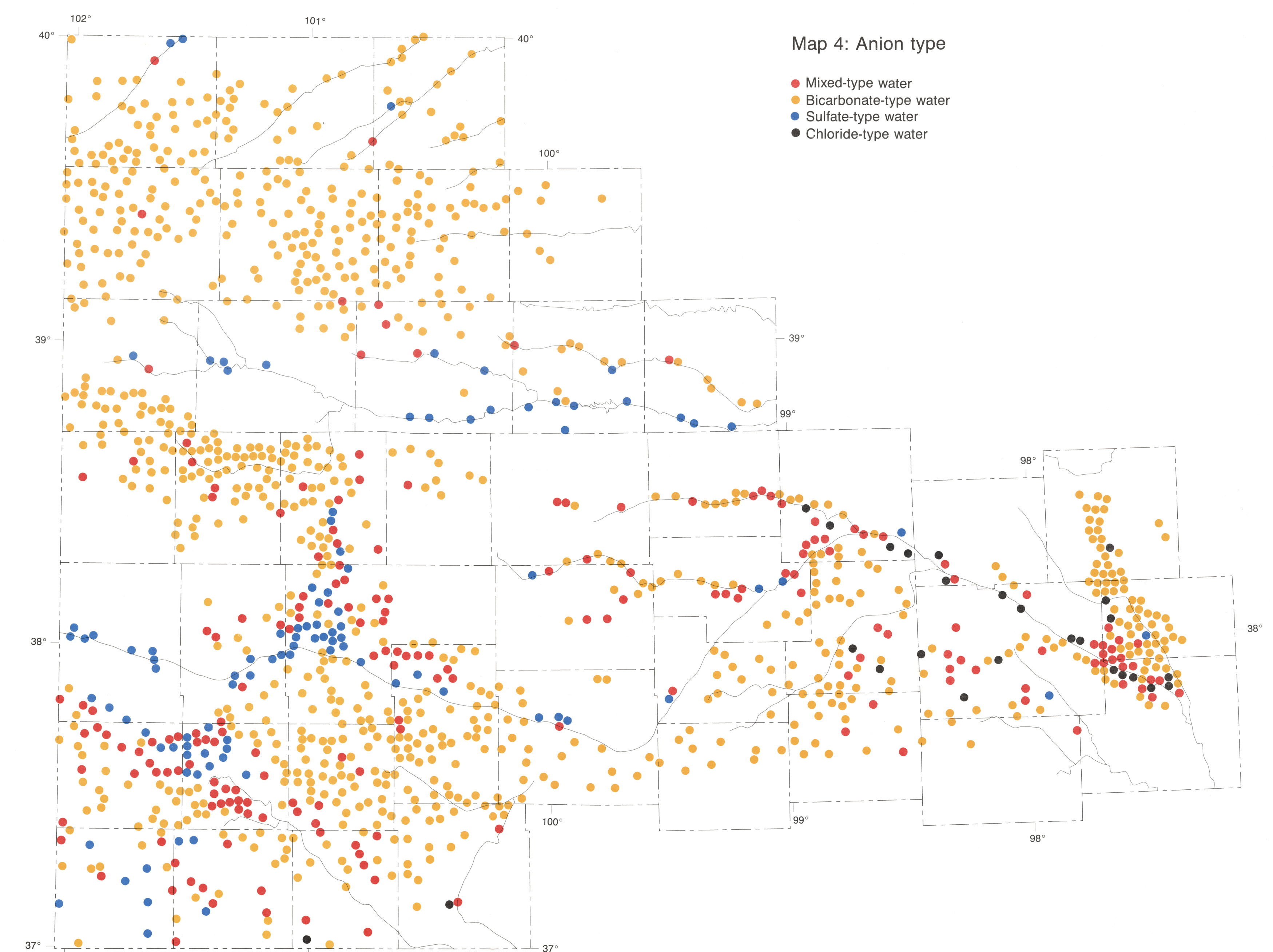
Map 2: Total residue at 180°C in mg/L

● Greater than 675 mg/L
● 275 to 675 mg/L
● Less than 275 mg/L



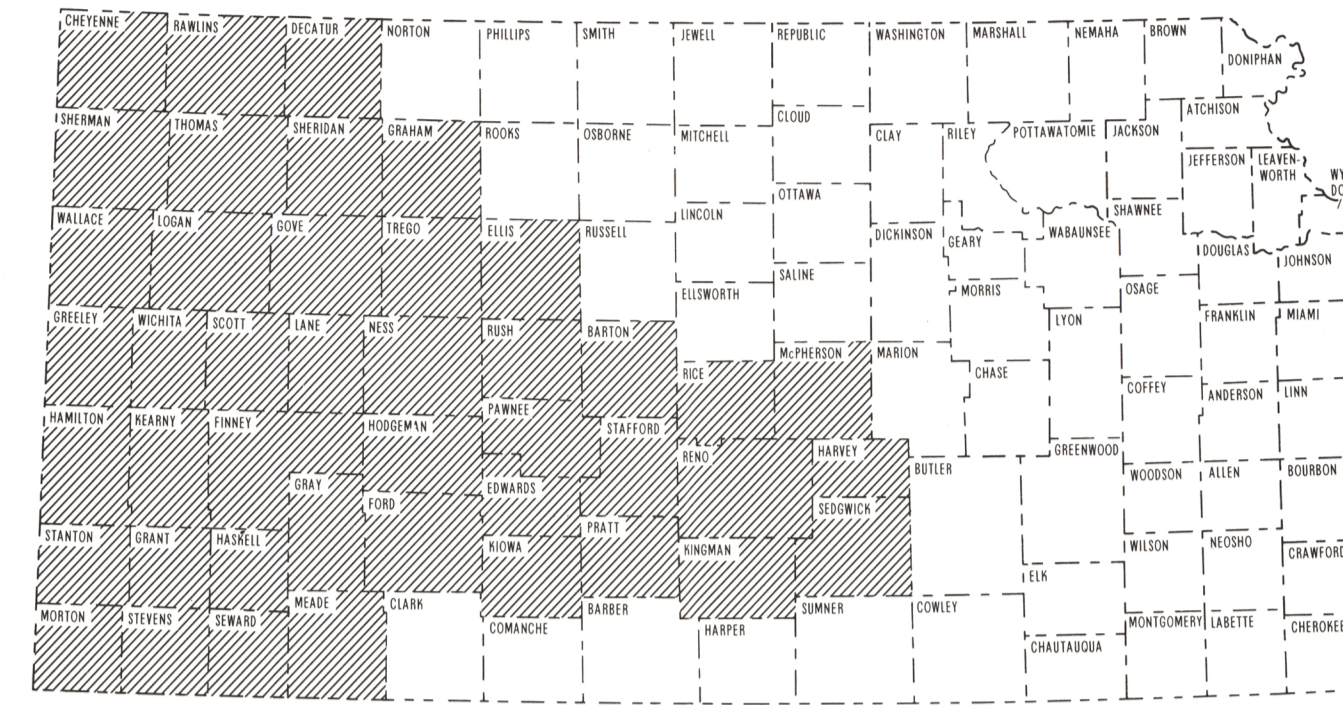
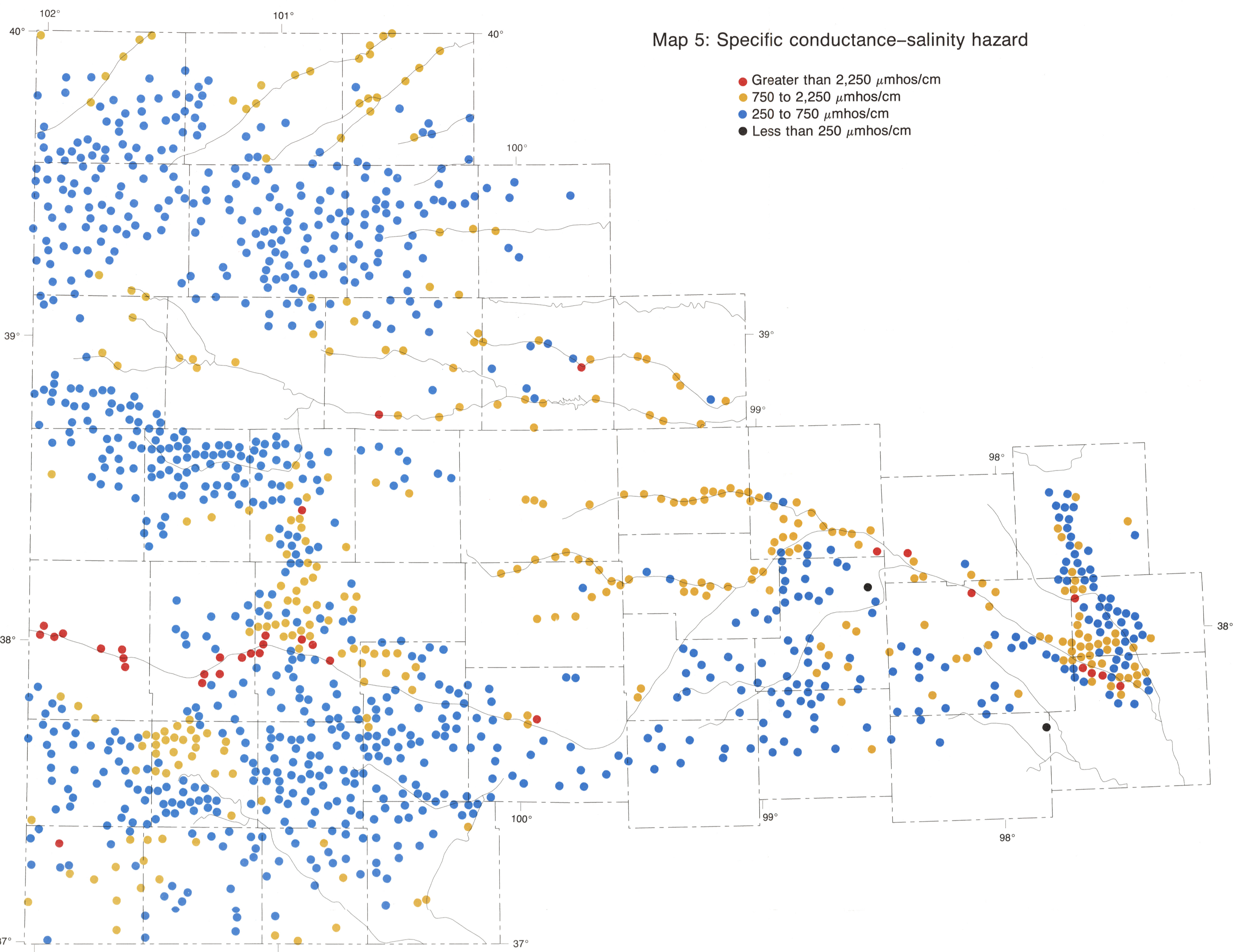
Map 4: Anion type

● Mixed-type water
● Bicarbonate-type water
● Sulfate-type water
● Chloride-type water



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The specific conductance of a water sample is a measure of the sample's ability to conduct an electrical current and is related to the nature and concentration of ionic species present in the sample. Thus, maps of specific conductance (Map 5) and total residue (Map 2) will tend to mirror one another. The plotting intervals used in Map 5 correspond to those employed in the salinity-hazard classification of water for irrigation usage. Specific-conductance values in the range of 250-750 μmhos are dominant for ground waters of the study area. Values above 750 μmhos typically are found in areas associated with shallow water-table conditions, drainageways, Permian-age bedrock directly below the aquifer, or contamination from oil-gas activity. The very high salinity-hazard classification associated with ground water from the western portion of the Arkansas River valley in the study area reflects accumulation of salts in the alluvium which are derived from weathering processes active in the Colorado reaches of the river system. The decrease of specific-conductance values below 2250 μmhos in the Arkansas River valley in western Gray County may be related to an influx of better-quality ground water from the sandy area south of the river. Eastward of Gray County, poorer-quality waters delivered by tributaries to the Arkansas River tend to increase specific-conductance levels in the main river-valley system.

The sodium-adsorption ratio (SAR) is a parameter that is calculated from general water-quality data. SAR is used to estimate the extent to which the irrigation water will undergo cation-exchange reactions with the clay minerals of the soil. As sodium from the water displaces calcium and magnesium from the clay minerals, the structure of the soil is broken down, resulting in reduced movement of water through the soil. Higher SAR values in irrigation waters are more tolerable if the total-residue level of the water is low and the soil is well drained and/or fairly sandy. Map 6 shows that most ground water in the study area has a SAR value that is less than 1.5, reflecting a dominance of calcium and magnesium over sodium in the dissolved load of the ground water. The effects of alluviation during Pleistocene times may be reflected in the zone of <0.7 SAR values south of the Arkansas River. The low SAR values in the northeastern third of the study area probably reflect an eastward thinning of the unconsolidated aquifer and the presence of a carbonate bedrock unit. Locations with SAR values above 1.5 reflect areas of near-surface accumulations of sodium-rich salts or areas where sodium-rich fluids reach the unconsolidated aquifer from sources below. Areas of shallow water-table conditions and drainage ways represent the near-surface condition; whereas, areas overlying halite or Na-Cl water-bearing Permian-age bedrock and sites contaminated by oil brine may reflect the effects of the deeper sources. However, cation-exchange reactions with clay minerals may serve to temper the SAR value of ground water contaminated by brine.

Salinity-sodium (alkali)-hazard classifications are used to assess the compatibility of an irrigation water's chemistry with local soil conditions and crop tolerance. Salinity-hazard classes are defined by specific-conductance intervals (Map 5). Sodium (alkali)-hazard classes are defined by intervals in a relationship that is linear in specific conductance and logarithmic in SAR. Map 7 depicts the distribution of ground-water sodium (alkali)-hazard classes within the study area and, together with Map 5, provides a means for visualizing regional changes in the salinity-sodium (alkali)-hazard classifications.

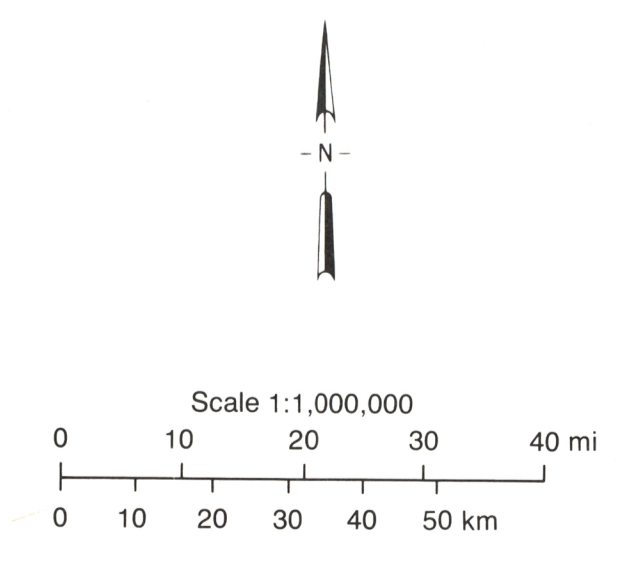
Most ground water of the study area, except that in the western one-third and eastern one-third of the Arkansas River valley, falls into the low sodium (alkali)-hazard class. The accumulation of soluble salts, which are enriched in sodium, in the alluvium of the river valley accounts for the medium- to high-hazard classes noted in the valley system. The potential for increased sodium (alkali)-hazard classification of irrigation waters exists in regions where oil-brine contamination of the aquifer exists or in areas where bedrock units may contribute halite brine to the unconsolidated aquifer. Fields that have been irrigated with waters having a medium sodium (alkali)-hazard classification or greater may require periodic soil-amendment procedures such as addition of gypsum in order to maintain productivity.

Map 8 depicts sodium-chloride (Na/Cl) mass ratios for ground waters of the study area. The Na/Cl ratio of halite is 0.65, whereas that for Kansas oil brine is of the order of 0.50 \pm 0.1. In theory, this ratio should serve to distinguish the type of brine pollution involved at a given well site. However, cation-exchange reactions may reduce the Na/Cl ratio of the polluted ground water making source identification difficult. Detailed studies of the variations in concentration of trace constituents such as iodide and bromide are more useful in brine-source identification.

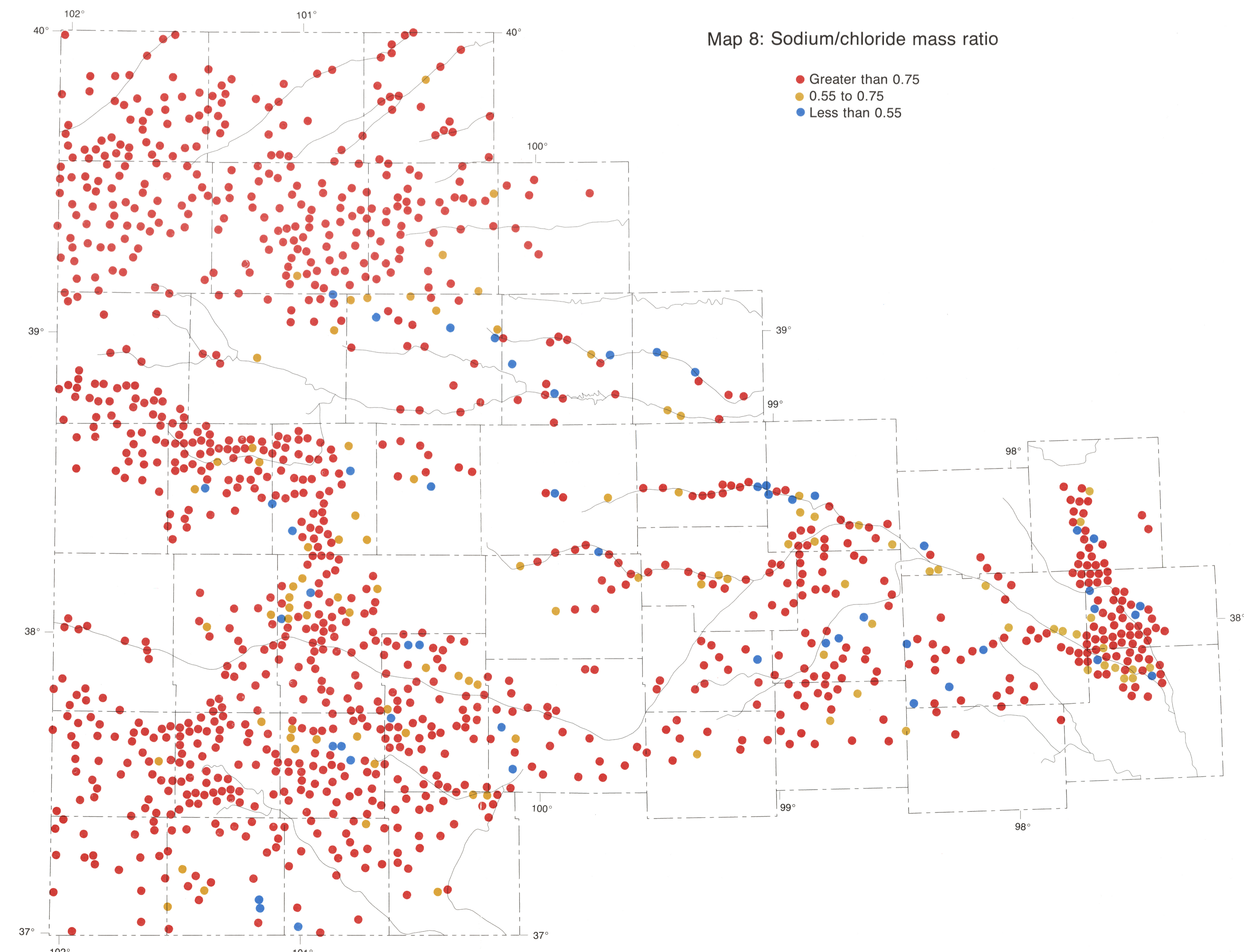
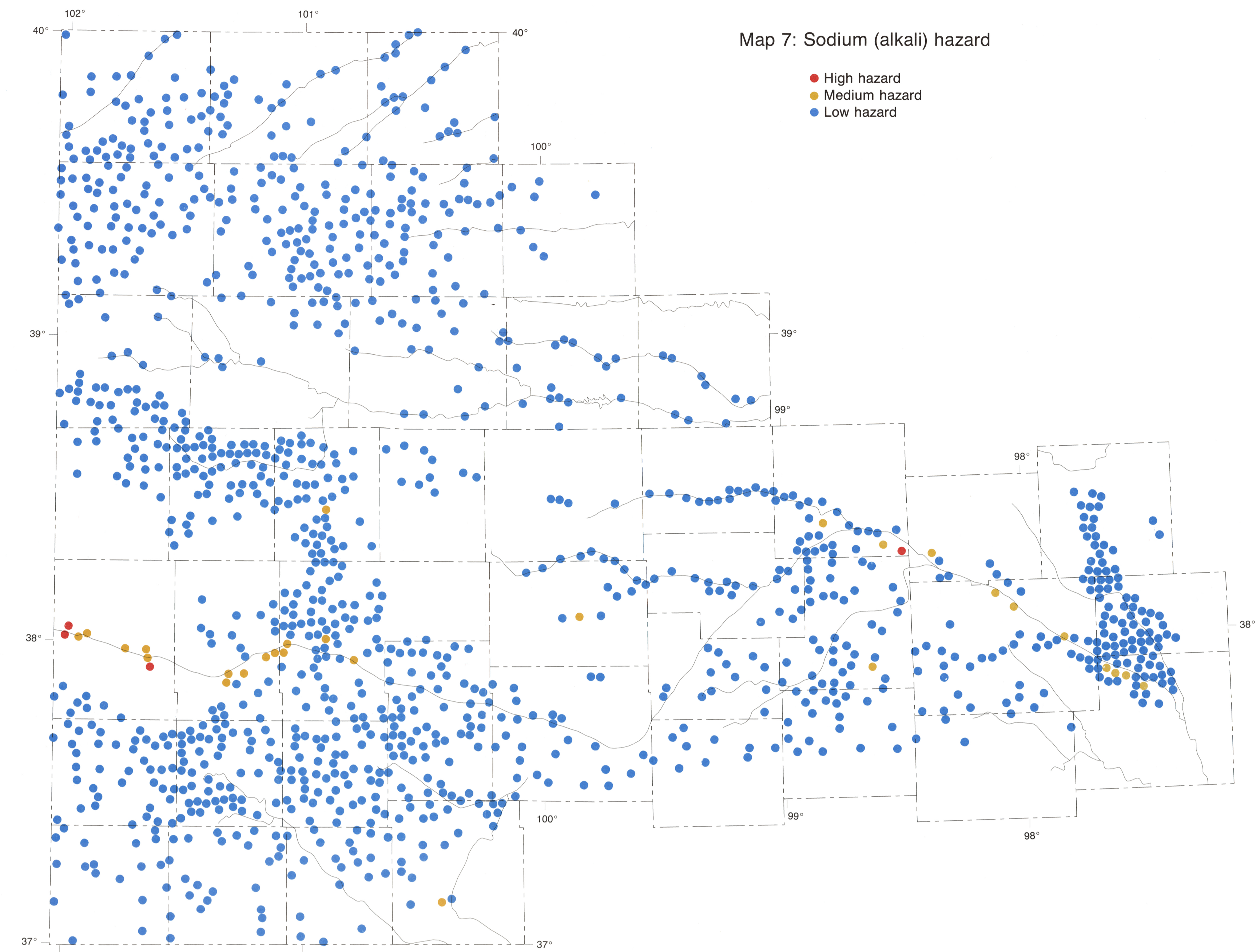
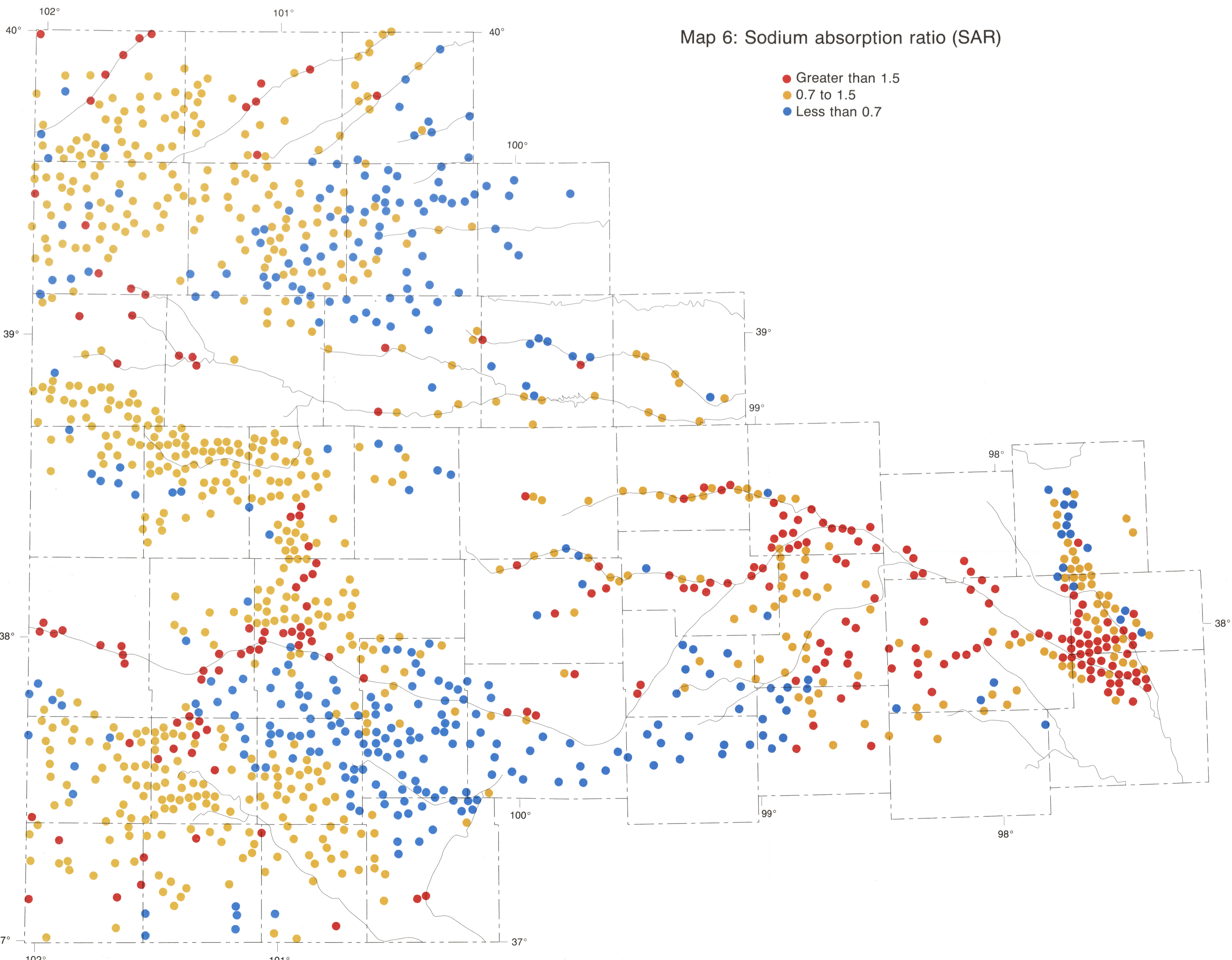
The intervals selected for Map 8 correspond approximately to an oil-brine interval (Na/Cl <0.55), a halite-brine interval (Na/Cl 0.55-0.75), and an interval in which the sodium content of the ground water is tied to anions other than just chloride. Most ground waters of the study area fall into this latter class. General brine contamination of the freshwater aquifer may be indicated if low Na/Cl ratios are accompanied by chloride concentrations substantially elevated above background levels.

Selected readings

1. Berendsen, P., and Hathaway, L. R., 1981, Uranium in unconsolidated aquifers of western Kansas: Kansas Geological Survey, Mineral Resources Series 9, 43 p.
2. Hathaway, L. R., Carr, B. L., Flanagan, M. A., Galle, O. K., Waugh, T. C., and Dickey, H. P., 1978, Chemical quality of irrigation waters in southwestern Kansas: Kansas Geological Survey, Chemical Quality Series 6, 33 p.
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5. ———, 1980, Soil associations of northwestern Kansas: Kansas Geological Survey, Map M-8B.
6. ———, 1982, Soil associations of south-central Kansas: Kansas Geological Survey, Map M-8C.
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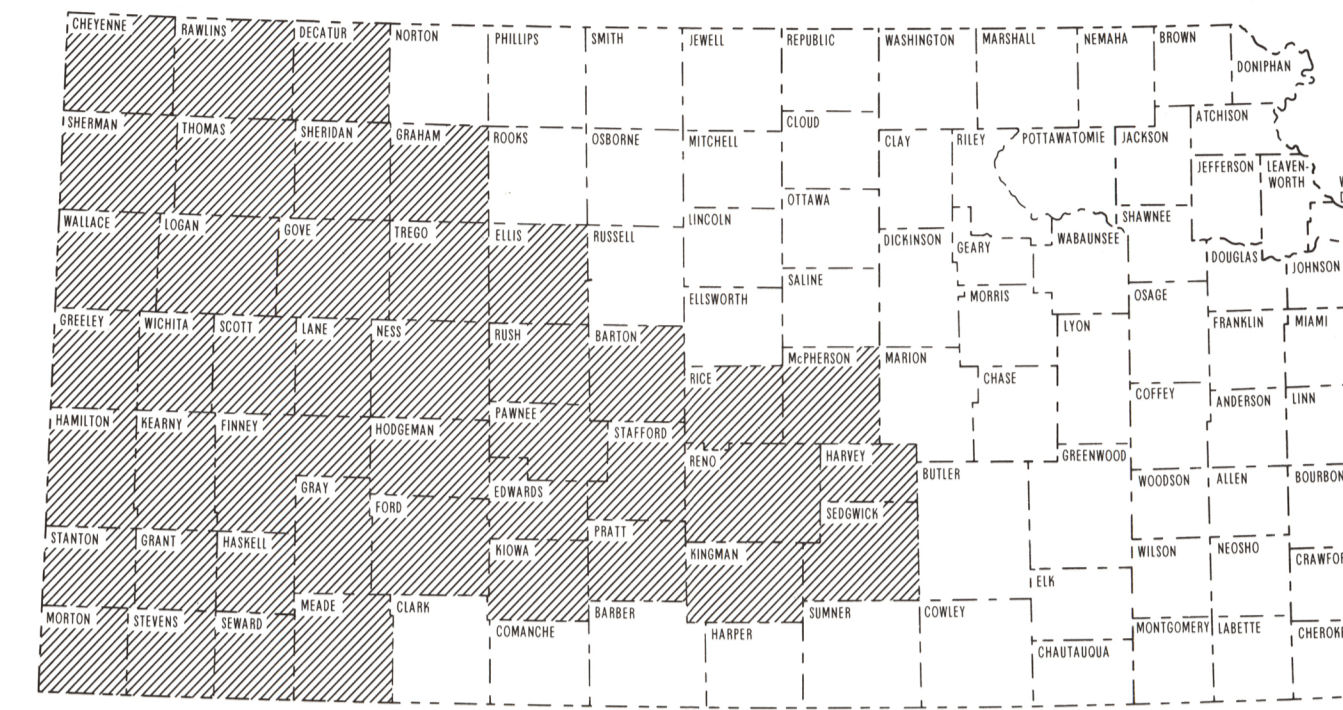
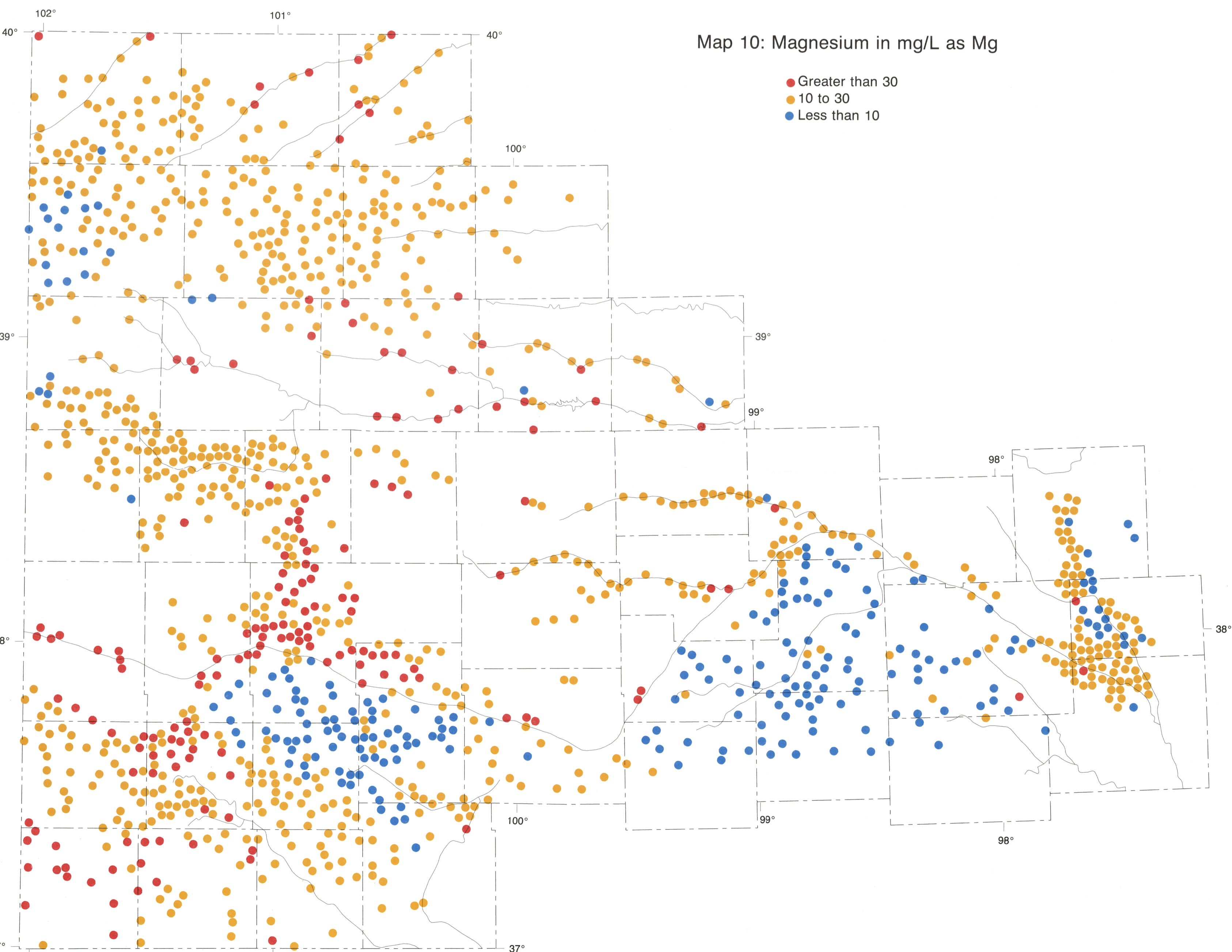
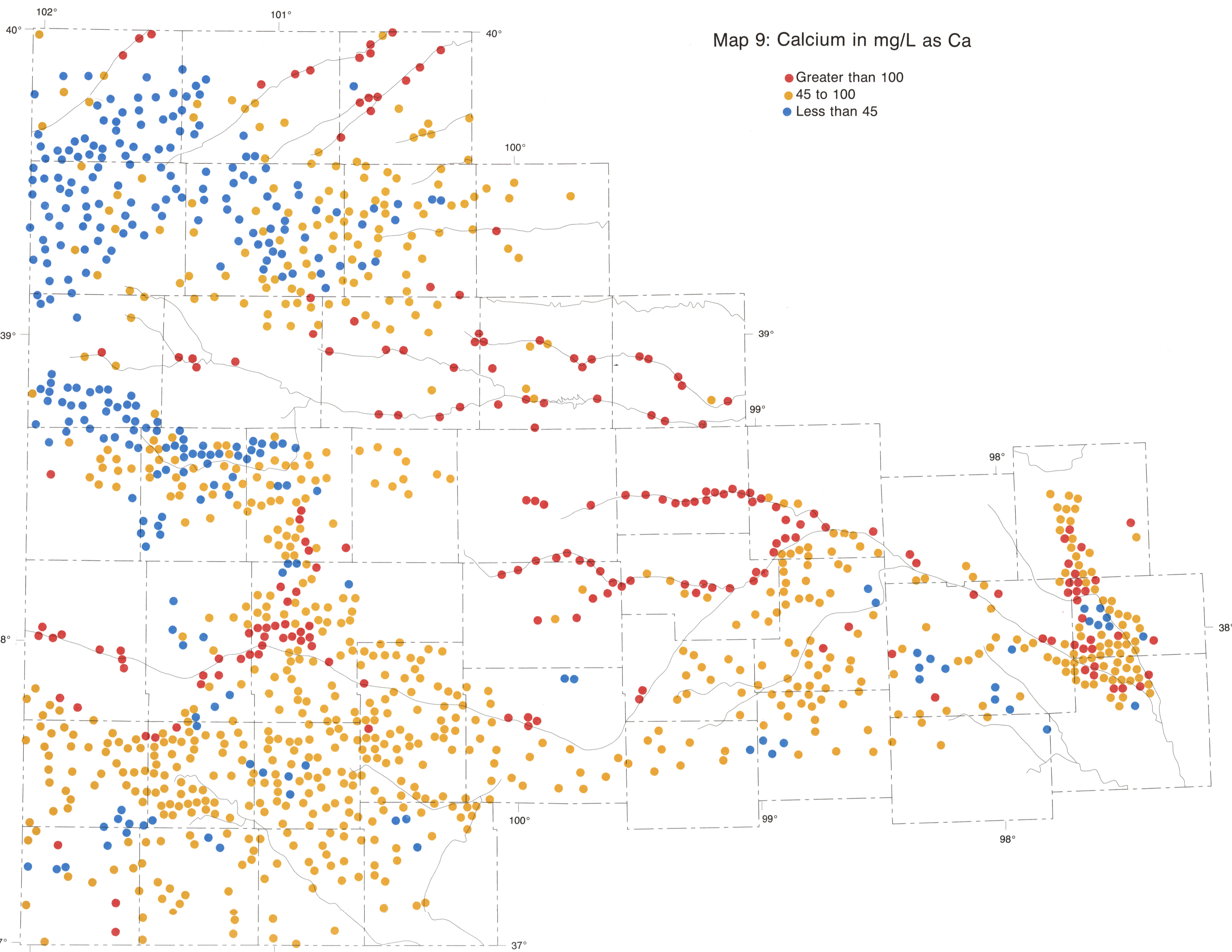


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Index map of study area.

Calcium (Ca), magnesium (Mg), and strontium (Sr) are all members of the same chemical family of elements, the alkaline earths. The relative abundance of these elements in sediments which make up the aquifer systems of the study area is $Ca > Mg > Sr$. The relative mass and molar concentrations in ground water normally are in the same order. Cations of these three alkaline-earth elements usually are associated with bicarbonate (HCO_3^-) or sulfate (SO_4^{2-}) anions in ground water, contributing to the water's carbonate and noncarbonate hardness, respectively. The three alkaline-earth sulfates are more soluble than the corresponding carbonates, with the general solubility order for both being $Mg > Ca > Sr$. Thus abundance in the sediment seems to be the primary factor in determining relative amounts of the ions in ground water.

Map 9 presents calcium concentrations in ground water from the study area. Two features stand out in this map and are reflected also in Map 2 (total residue). First is the concentration of <45 ppm values in the northwestern part of the study area where the ground water exhibits little if any noncarbonate hardness. Second is the concentration of >100 ppm values in ground water from areas associated with shallow water-table conditions, drainageways, and sites subjected to oil-brine contamination where considerable noncarbonate hardness exists. Map 9 differs from the total residue map (Map 2) in that it does not display a well-developed low-concentration zone south of the Arkansas River.

The distribution of magnesium concentrations in ground water (Map 10) shares some features of the total residue map (Map 2) but also exhibits some differences. Comparison of Map 10 and Map 9 indicates that magnesium and calcium may show similar behavior of build-up in areas associated with drainageways or restricted surface drainage and shallow water-table conditions as in central Scott and Finney counties. An increase in sulfate concentration (Map 17) also is typical of such areas. However, these two alkaline earths differ in the concentration patterns noted in portions of the upland area.

The low-magnesium zone in the northwestern part of the study area is less pronounced than comparable zones on Map 2 (total residue) or Map 9 (calcium). This may indicate a leachable source of magnesium in the sediments of this part of the study area. South of the Arkansas River the low-magnesium zone is well established, especially in the eastern half of the study area where magnesium levels of 5 ppm or less are noted for a number of well sites. This points to an effective removal of source materials from sediments of the aquifer in this region.

In the southwest corner of the study area, magnesium levels may exceed 30 ppm. Some wells in this area produce ground water which has a Mg/Ca mole ratio that is greater than 1.0. Enrichment of magnesium in these waters may be the result of calcium removal through calcite ($CaCO_3$) precipitation. Water from a number of these wells also exhibits fluoride (F) concentrations (Map 16) in excess of 2 ppm.

Strontium is a minor constituent in most ordinary rocks, sediment, and natural waters. Its behavior in the surface and near-surface hydrogeochemical environment is expected to be much like that of calcium. However, a comparison of the distribution of strontium-concentration values in Map 11 with the patterns for calcium (Map 9) and magnesium (Map 10) indicates that strontium is more closely aligned with magnesium in ground water of the study area.

Statistical analysis of water-quality data for ground water from wells in Greeley, Wichita, Scott, Lane, Hamilton, Kearny, Finney, southern Wallace, and northern Gray counties showed, after correction for common correlation with total residue, that strong correlations exist among uranium, silica (SiO_2), fluoride, magnesium, potassium (K), and strontium. Thus, several lines of evidence point to a source of the constituents such as the volcanic ash which is distributed within the body of aquifer sediment in the western half of the study area. Alluviation of these sediments during Pleistocene times may have produced a distribution of the source material which now operates in concert with geologic factors such as bedrock geology and present drainage features to produce the distribution patterns noted in some maps of this atlas.

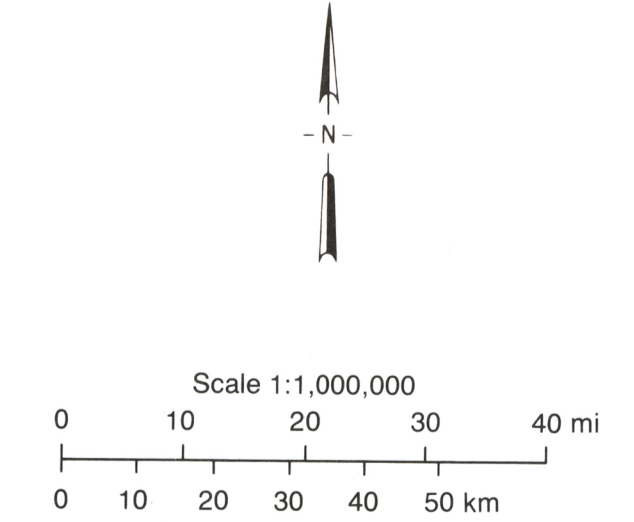
The discharging of carbon dioxide (CO_2) or dissolution of carbonate minerals introduces inorganic carbon into natural waters in the form of carbonic acid ($H_2CO_3^*$), bicarbonate ion (HCO_3^-), or carbonate ion (CO_3^{2-}). The distribution of carbon among the three forms is controlled by the pH of the water, which ranges from 7.0 to 8.0 for most ground water in the study area. In this pH range, bicarbonate is the prevalent form of inorganic carbon and the dominant factor in the alkalinity of the ground water. Carbonate-mineral solubility relationships, especially those for calcite, are expected to exert a limiting effect upon the bicarbonate concentration of ground water in the study area.

The bicarbonate map (Map 12) displays some characteristics of both the calcium map (Map 9) and the magnesium map (Map 10). Like calcium, a low-concentration region exists in the northwestern part of the bicarbonate map. The occurrence of high-bicarbonate concentrations in areas associated with drainageways, restricted surface drainage, and shallow water-table conditions resembles more the distribution of high levels of calcium than the pattern of high-magnesium values. The low-bicarbonate concentration areas south of the Arkansas River extend westward of the general location of the corresponding low-magnesium zone.

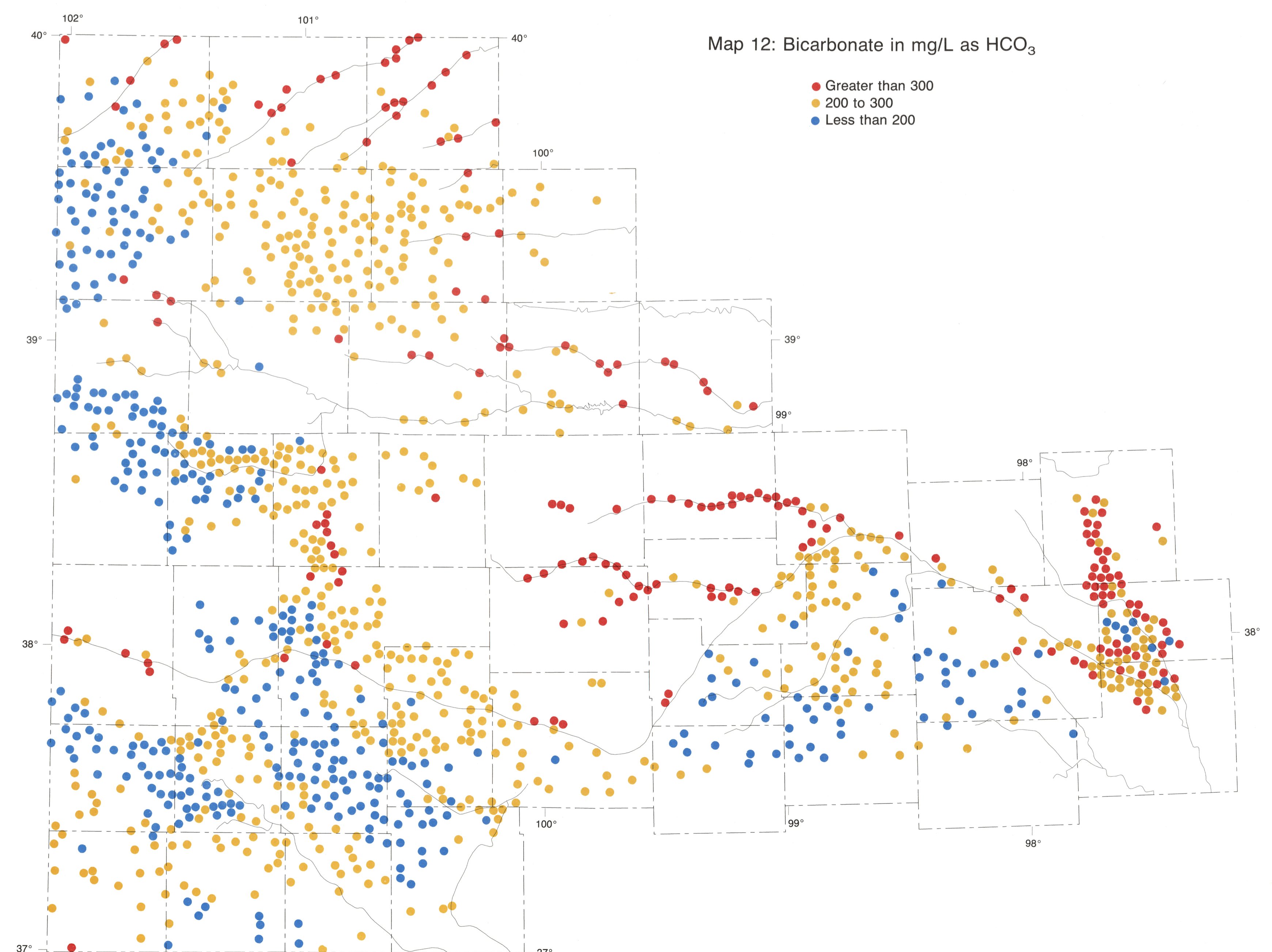
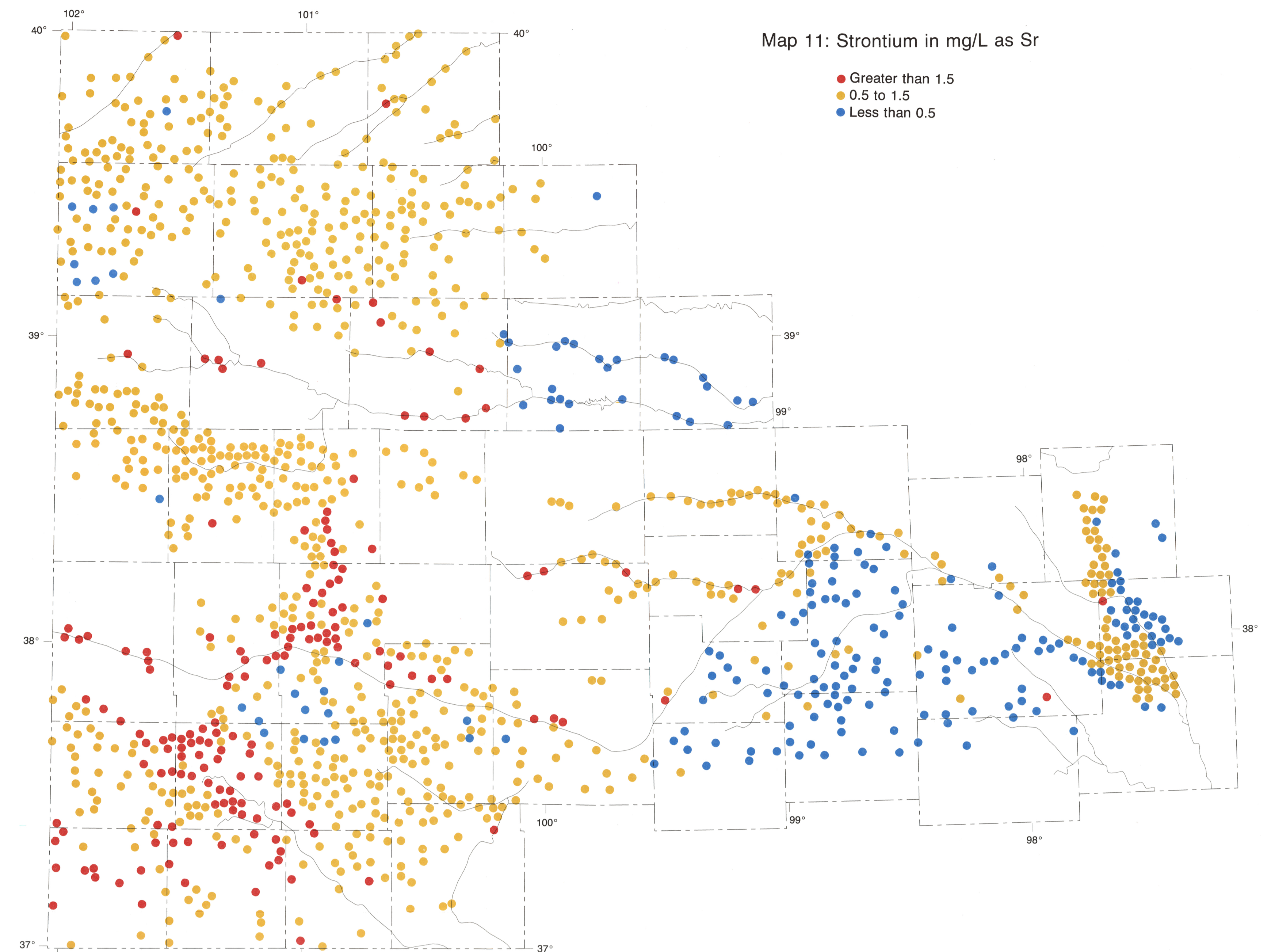
Preliminary analysis of the chemical-quality data for Kearny and Finney counties suggests that ground water north of the Arkansas River in areas that have been irrigated with river water are at saturation with respect to calcite solubility. Ground water from sandy areas south of the river seems to be unsaturated. Thus, low values in this region seem to arise from two different causes. Higher bicarbonate levels in alluvial deposits may result from processes such as greater solubility of carbonate minerals in waters with higher dissolved-solids loads, increased carbon-dioxide levels from respiration and decay, and oxidation of pyrite (FeS_2) in the presence of carbonate-containing sediments or bedrock. The high bicarbonate levels noted in McPherson and Harvey counties near the eastern edge of the study area may reflect the action of anaerobic bacteria and reducing conditions in the aquifer. Ammonium ion and elevated levels of iron (Fe), manganese (Mn), and phosphate (PO_4) are present in ground water of this area.

Selected readings

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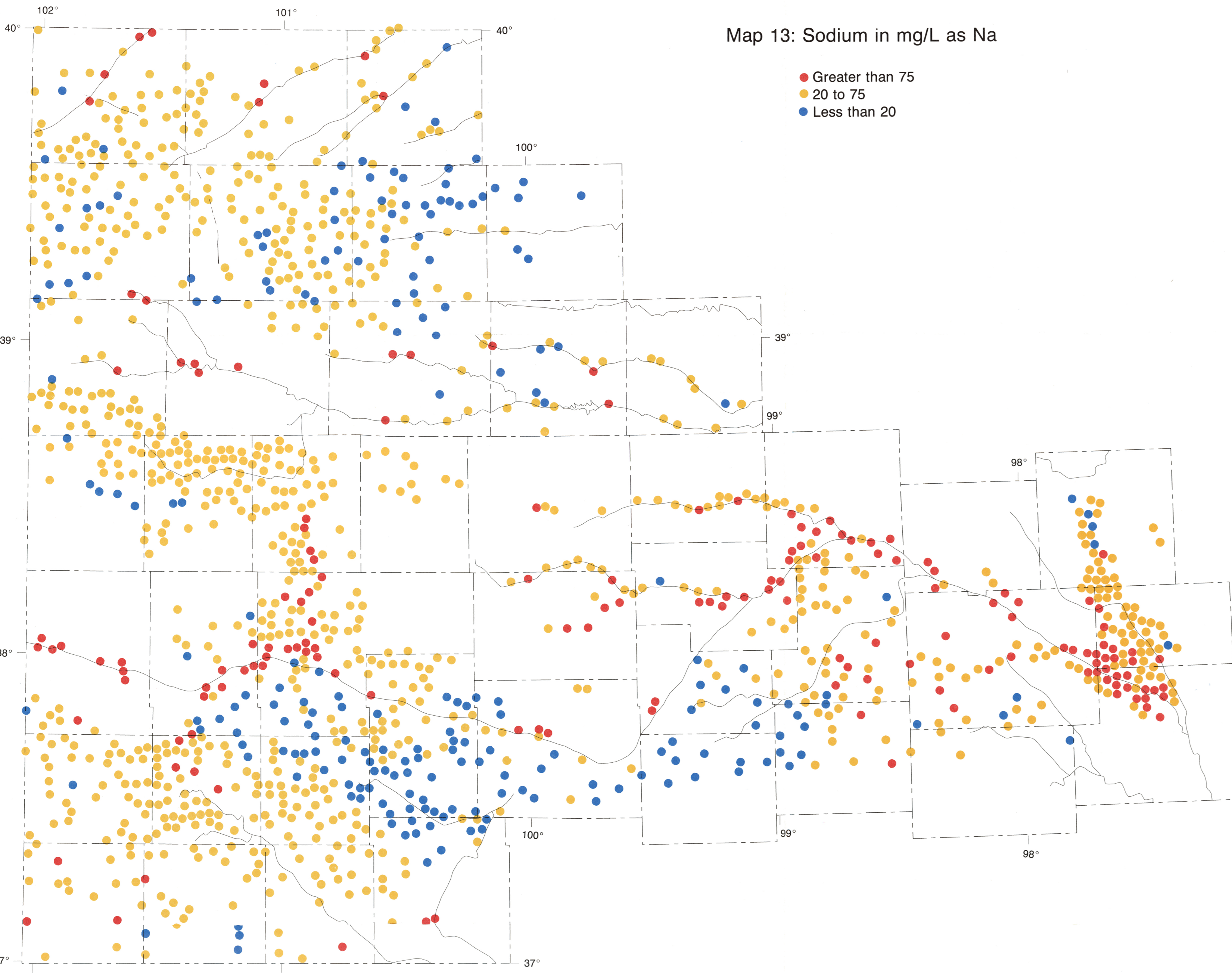
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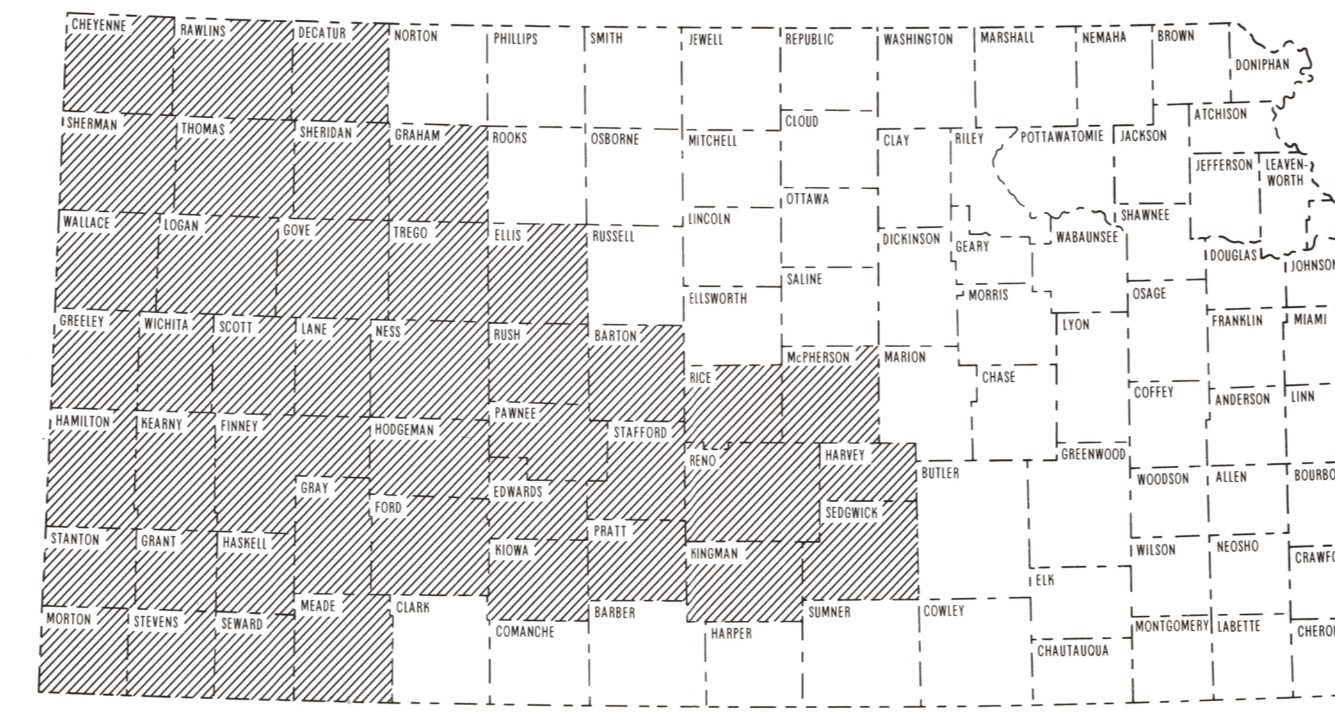
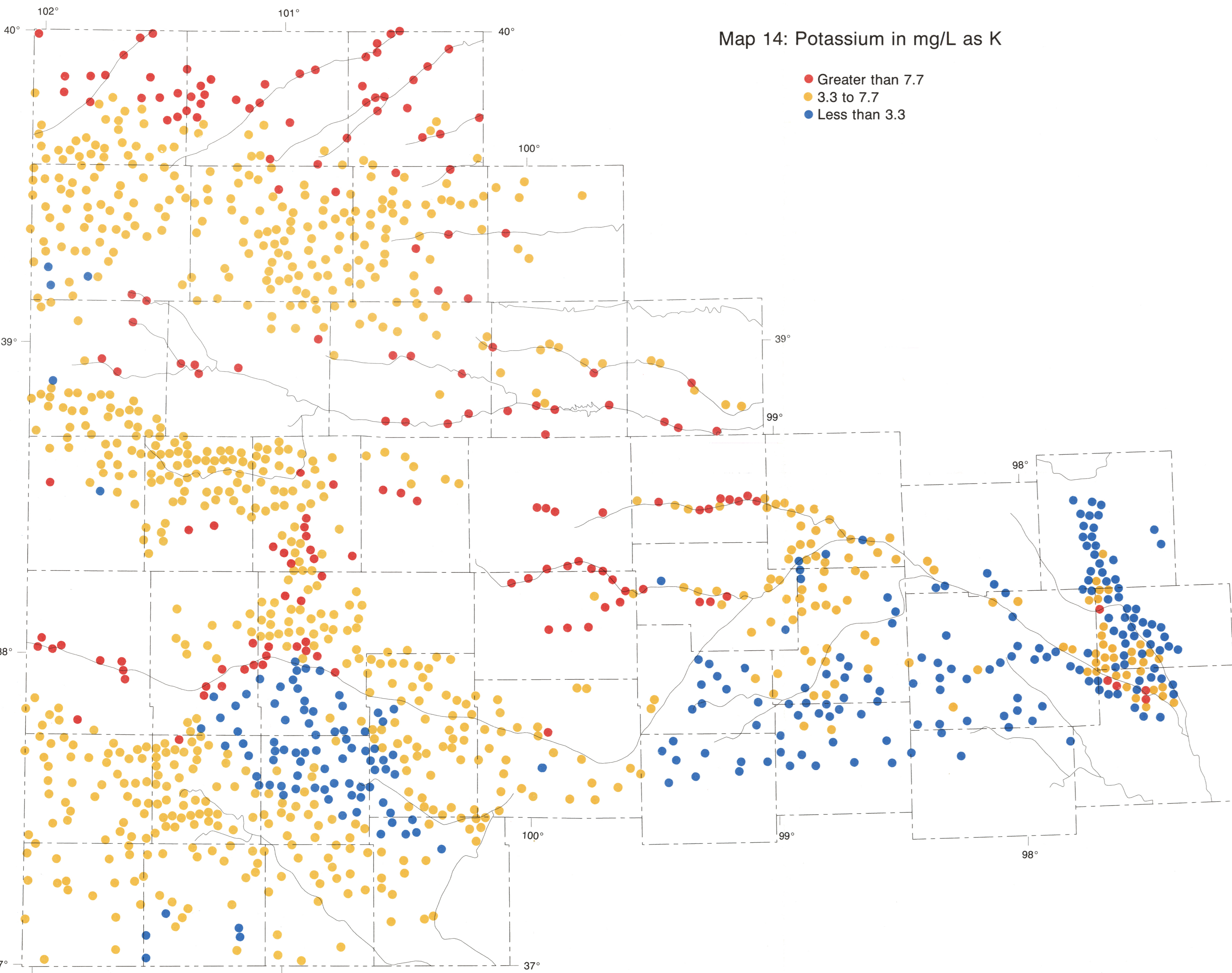
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Map 13: Sodium in mg/L as Na



Map 14: Potassium in mg/L as K



Index map of study area.

The two most prominent members of the alkali-metal family of elements are sodium and potassium. Characteristic of these elements is the marked solubility of their common salts. Both sodium and potassium are common constituents of igneous rocks, with sodium being slightly more abundant. Weathering of igneous rocks leads to a fractionation of these two elements. In part this separation is due to the greater resistance of potassium feldspars to chemical attack. Once liberated, potassium tends to recombine with by-products of weathering such as the clay minerals.

Thus, sodium tends to collect in the aqueous phase with the result that natural waters generally contain a greater amount of sodium than potassium. Ion-exchange reactions with clay minerals can serve to alter the sodium concentration of natural waters. Soluble salts of sodium and potassium ultimately are concentrated in nature in the oceans and in evaporite deposits. Some of these deposits serve as important sources of potassium, an essential plant nutrient.

Sodium concentrations for ground water of the study area are displayed in Map 13. As expected, this map shows a great similarity to the distribution of SAR values in Map 6. Low sodium concentrations in ground water in the vicinity of Sheridan County in northwestern Kansas coincide with presence of a carbonate bedrock and an eastward thinning of the unconsolidated aquifer. The low-sodium zone south of the Arkansas River follows a pattern noted for other constituents but gives way to concentrations above 20 ppm in western Pratt and Stafford counties and eastward. This transition in quality reflects a change in nature of the bedrock from Cretaceous- to Permian-age units which contain Na-Cl-type waters. Sodium concentrations may exceed 75 ppm in ground waters associated with drainageways, areas contaminated by oil brines, and regions of restricted surface drainage and shallow water-table conditions. Ion-exchange reactions with clay minerals of the soil and aquifer can make high-sodium levels a persistent problem.

Potassium (Map 14), like sodium, shows a build-up in ground water associated with portions of different drainageways. Potassium concentrations of 10-24 ppm are common near drainageways in the western half of the study area, with the 24 ppm levels being found in the northwest area. Map 14 also shows zones of low concentration south of the Arkansas River; unlike the low-sodium zone, the low-potassium zone extends eastward across the region overlying Permian-age bedrock. This divergence in distribution patterns noted between sodium (Map 13) and potassium (Map 14) in areas overlying Permian-age bedrock in the eastern third of the study area may be the result of two different factors. First, the K/Na mass ratio tends to be lower in Na-Cl-type waters derived from the Permian-age bedrock than in the alkaline-earth HCO₃-type waters from areas overlying younger-age bedrock. Second, an increased amount of clay mineral content seems to be in the aquifer sediments of the eastern half of the study area for the region south of the Arkansas River and the McPherson-Harvey counties area. A low K/Na mass ratio in oil-field brines and reactivity with clay minerals also serve to limit the areal extent of ground water with high potassium concentrations in contaminated regions. Failure of potassium to exhibit low-concentration areas such as sodium does in the northwestern part of the state seems to reflect a source in the sediments of the area.

Fluorine and chlorine are members of the halogen family of chemical elements. In the hydrogeochemical environment they normally exist as halide anions, F⁻ and Cl⁻. Fluorine is more abundant than chlorine in igneous rocks and in many sediments. However, in natural waters chloride ions are spread more widely and are of greater importance to the overall water chemistry. This fractionation of the elements probably arises largely from solubility differences.

Chloride is a conservative anion in the aqueous environment. Chloride compounds of the major cations found in natural waters are noted for their solubility. Chloride ions do not exhibit significant tendency to participate in adsorption, complex formation, or oxidation-reduction processes. Hence, chloride, like sodium, tends to become concentrated in the oceans and in some types of evaporite deposits. By contrast, fluoride ions form strong complexes with trivalent aluminum and iron; fluorine-containing common minerals such as fluore (CaF₂) and fluorapatite (Ca₅(PO₄)₃F) are fairly insoluble.

Chloride (Map 15), like other major constituents of the dissolved-solids load, exhibits a build-up in concentration in ground water associated with drainageways of the study area and in the area of restricted surface drainage in central Scott and Finney counties. It also displays a low-concentration zone south of the Arkansas River. The low-chloride zone, like the low-sodium zone (Map 13), seems to terminate with the on-set of Permian-age bedrock in the eastern third of the study area. However, chloride concentrations of about 8 ppm in ground water from two flowing artesian wells in eastern Stafford County attest to the complexity of the aquifer in the region south of the Arkansas River. High chloride concentrations also coincide with high sodium levels in areas contaminated by oil-field brine.

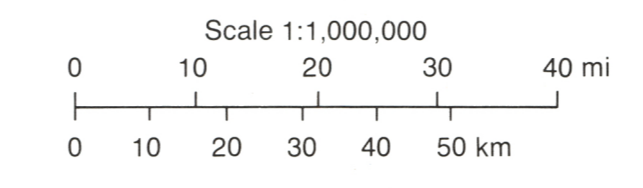
Low chloride values occur in greater frequency than low sodium levels throughout the northwestern part of the study area. This observation together with the predominance of Na/Cl mass ratios (Map 8) above 0.75 in the upland areas in the western half of the study area indicates that here sodium and chloride in the ground water probably are not derived from a single, simple source such as halite (NaCl).

Fluoride (Map 16) concentrations above 1.7 ppm are evident in ground water from upland areas of the western half of the study area, and levels below 0.5 ppm are abundant in the eastern half of the study area and in the area south of the Arkansas River where other constituents have shown a low-concentration zone trending southeastward from Kearny County. Unlike other major constituents, fluoride does not accumulate to a great extent in ground water associated with drainageways. The distribution noted for this component of the ground-water-dissolved load probably reflects combined effects of a source such as volcanic ash in the western areas and mineral solubility controls in ground water from the eastern area and regions near drainageways where increased levels of calcium (Map 9) and/or phosphate (Map 19) may occur.

Fluoride concentrations of about 1 ppm are considered to have beneficial effects in reducing dental caries. High levels of fluoride intake can cause mottling of teeth and fluorosis in humans and animals.

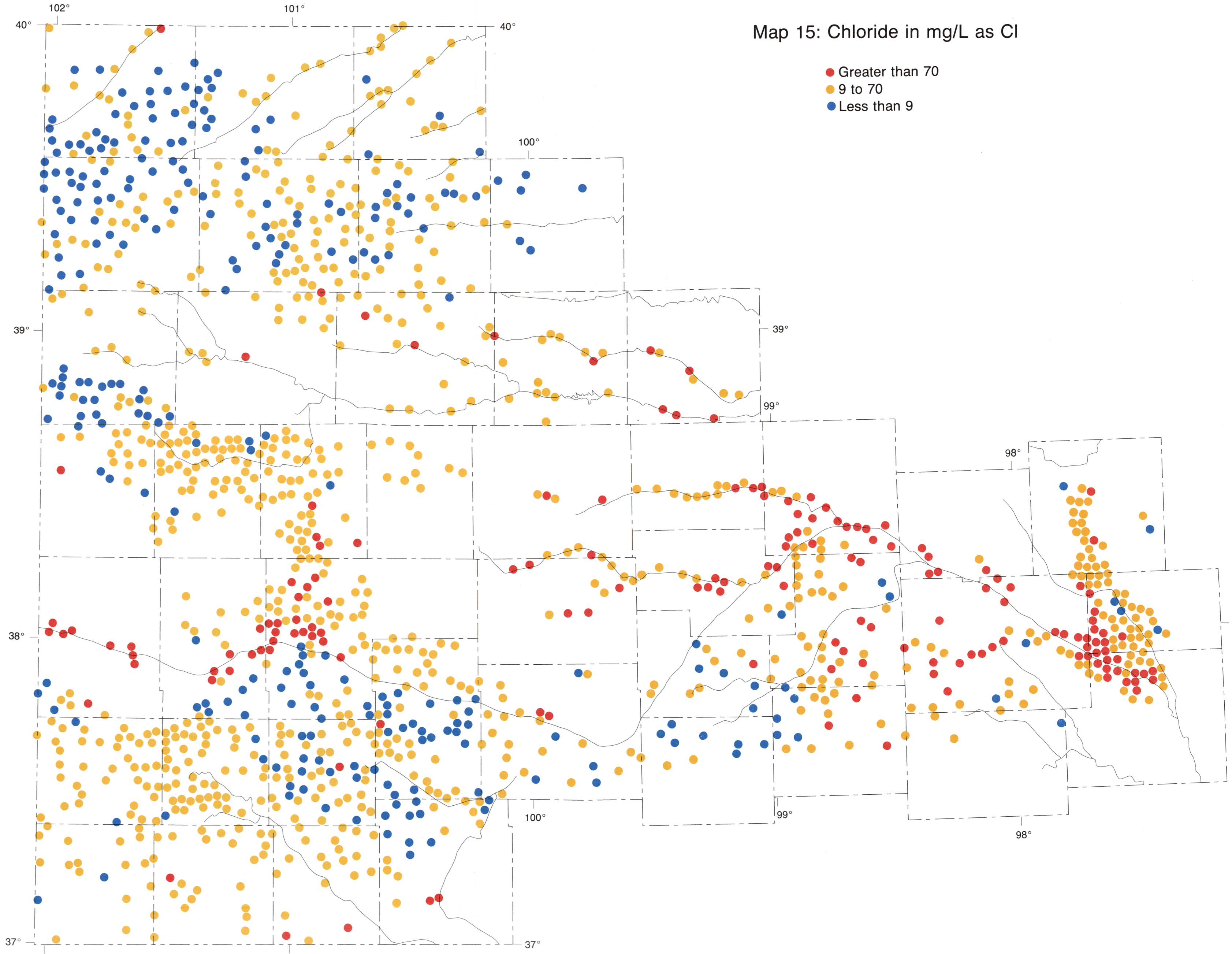
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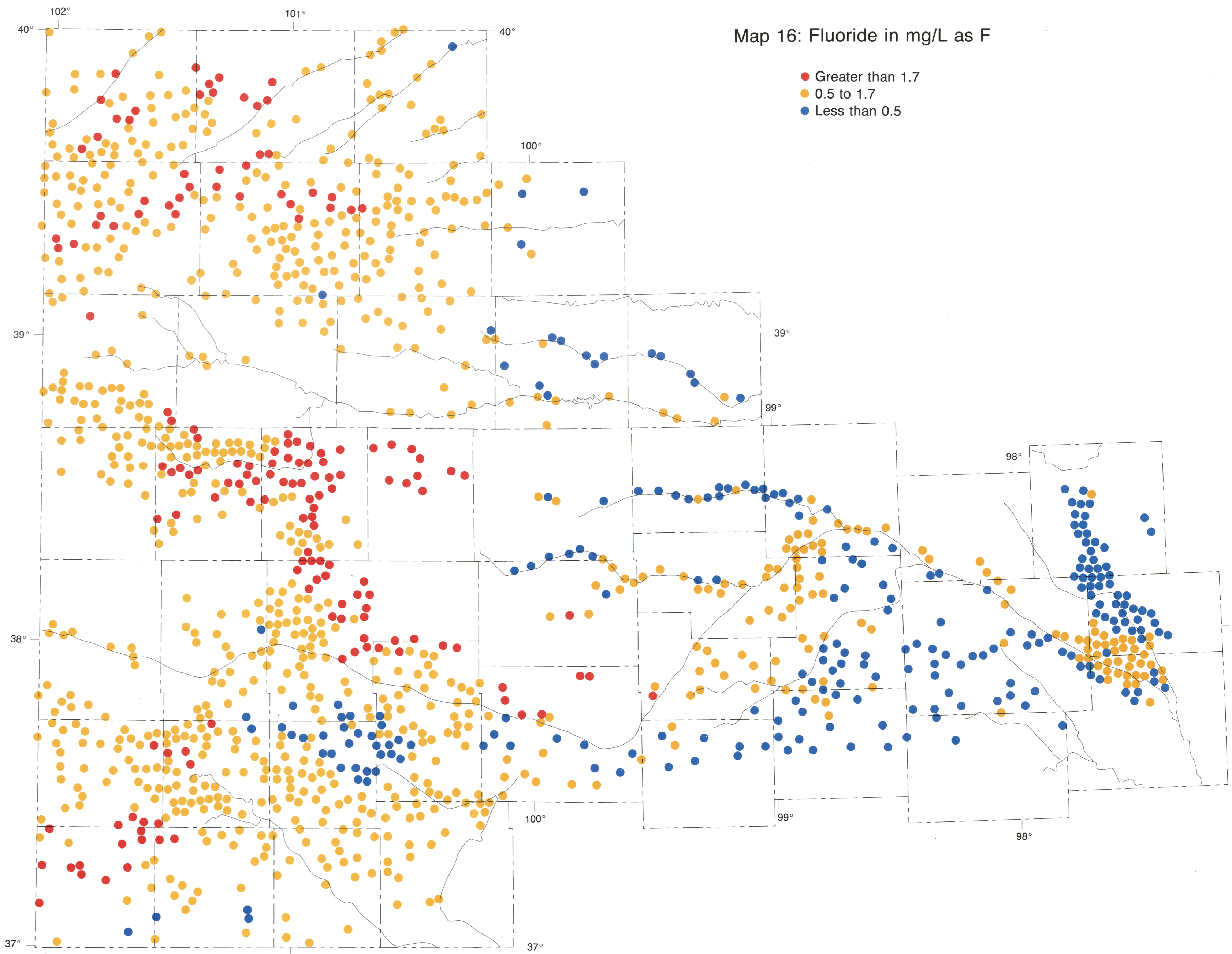


The county boundaries, streams, contours of saturated thickness shown on Plate 1, and color-separated dot symbols on all five plates were produced by computer in the Automated Cartography Laboratory of the Kansas Geological Survey. Dot symbols were generated from supplied locations. Software used to perform these tasks is a part of GIMAP (Geospatial Interactive Management, Analysis and Production), a computerized cartography system developed at the Kansas Geological Survey. All other preparation and layout by Renate Hensiek.

Map 15: Chloride in mg/L as Cl

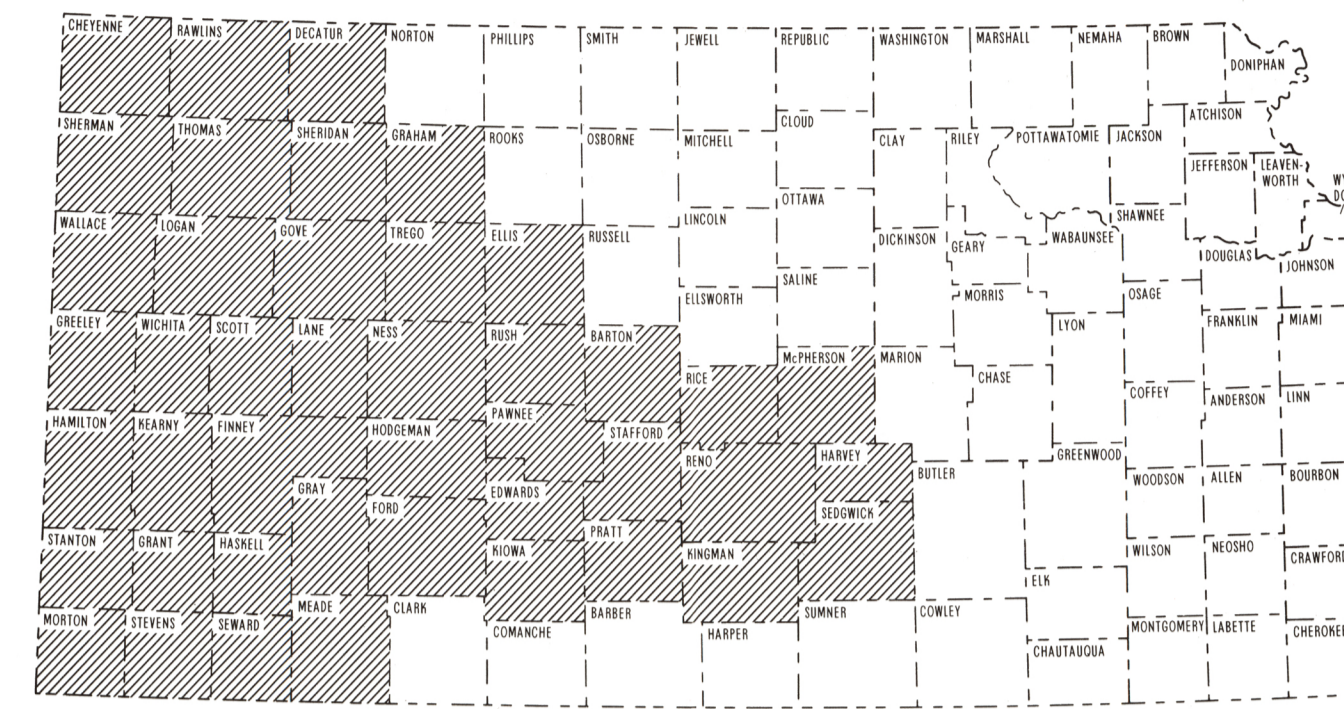
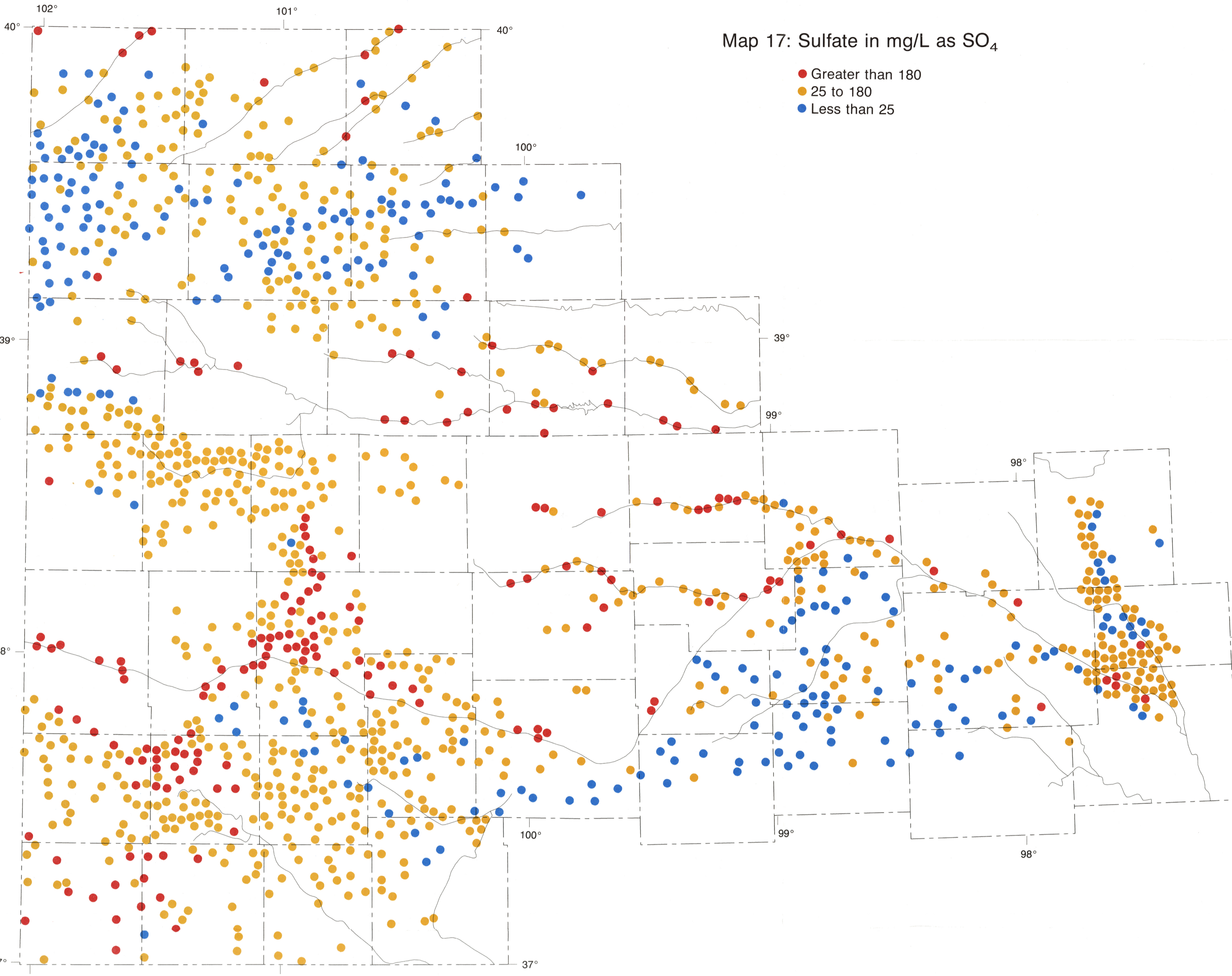


Map 16: Fluoride in mg/L as F



Atlas of chemical-quality data for irrigation waters of western Kansas

by
L. R. Hathaway and L. M. Magnuson
Kansas Geological Survey
1985



Sulfur is widely distributed in the geochemical environment. It is present in reduced form in metallic sulfide minerals which are found in both igneous and sedimentary rocks. Sulfur is present also in some sedimentary units in an oxidized form as sulfate minerals such as gypsum (CaSO₄·2H₂O) and anhydrite (CaSO₄). Sulfate anion (SO₄²⁻) is the dominant sulfur species in the hydrogeochemical environment where it tends to form ion-pair complexes with cations present. Metal sulfides in contact with aerated water are oxidized, yielding acidic sulfate-rich solutions. However, certain types of bacteria in a reducing environment containing a suitable food supply can reduce sulfate, producing in solution H₂S below pH7 or HS⁻ above pH7. No evidence of soluble-reduced sulfur species was found for ground water from the unconsolidated aquifer of the study area.

Map 17 displays sulfate concentrations in ground water of the study area. Concentrations in excess of 180 ppm are associated with ground water near drainageways and in areas of restricted surface drainage and shallow water tables. In these areas sulfate often becomes the dominant anion of the dissolved-solids load of the ground water. Saline soils in these environs often reflect regions where the concentrations of calcium and sulfate locally may have exceeded the solubility conditions for gypsum. Scattered low-sulfate concentrations, like low-chloride levels (Map 15), are present in ground water from upland areas in the northwestern part of the study area. The low-concentration zone south of the Arkansas River which trends south and eastward from Kearny County is a feature of the sulfate map which has counterparts in other maps of this atlas. Sulfate concentrations in excess of 180 ppm in ground water of Morton and western Stevens counties are problematic, but may be related to factors responsible for Mg/Ca mole ratios > 1.0 and fluoride concentrations > 2 ppm (Map 16) in ground water of the southwestern portion of the study area.

Both nitrogen and phosphorus belong to the same chemical family of elements and exhibit a multiplicity of oxidation states from -3 to +5 in their compounds. A major difference exists in the occurrence of these two elements at the earth's surface. Nitrogen in the free gaseous state makes up about 80% of the volume of the earth's atmosphere and is the principal source of the element. Phosphorus, as phosphate (PO₄), is widely distributed in igneous rocks as a component of the mineral apatite and is concentrated in phosphorite deposits in sedimentary units. Both elements are essential to biological activity and are present in the waste of such activity.

In the hydrogeochemical environment, chemical species of nitrogen and phosphorus in the +5 oxidation state are of greatest importance. Nitrogen exists as nitrate anions (NO₃⁻); in the 7 to 8 pH range of most ground water of the study area, phosphorus is distributed between the phosphate anions HPO₄²⁻ and H₂PO₄⁻. Differences in chemical behavior lead to a separation of nitrate and phosphate in natural waters. Nitrate has little tendency to form complexes with cations common to natural waters and nitrate salts are noted for their solubility. In contrast, phosphate tends to form polymeric and ionic complexes and many of its compounds exhibit low solubility. Accordingly, in most ground water of the study area, nitrate concentrations exceed phosphate concentrations by a large margin. Certain types of bacteria in soil can fix atmospheric nitrogen as nitrate. Other bacteria in suitable environments are capable of reducing nitrate, with ammonium ion (NH₄⁺) being one possible end product. Nitrogen present in natural water as ammonium ion may be retained on clay minerals through ion-exchange reactions.

Nitrate-concentration data for ground water of the study area are presented in Map 18. Nitrate levels in excess of 45 ppm are mostly found in ground water associated with drainageways of the study area. 45 ppm NO₃ corresponds approximately to the 10 ppm nitrate as nitrogen primary-pollutant limit set for drinking water by the U.S. Environmental Protection Agency. Ingestion of high-nitrate water may lead to methemoglobinemia in infants and produce adverse effects in farm animals. Only about 3.5% of the collection sites used in this study produced water which exceeded this limit and 75% have NO₃ levels below 20 ppm. The practice of injecting liquid fertilizer into the flow stream of an irrigation well provides the potential for local pollution of the aquifer as well as possible contamination of water samples collected at the well. Nitrate-containing leachate from animal lots also poses a threat to shallow ground-water regimes. At the other end of the spectrum, ground water from a number of wells in McPherson and Harvey counties is conspicuous for its low nitrate content of less than 1 ppm. An ammonium-ion concentration of 0.8 ppm and the presence of 5.5 ppm iron, 1.1 ppm manganese, and 2.0 ppm phosphate in water from one of these wells indicate a reducing environment in this part of the aquifer system.

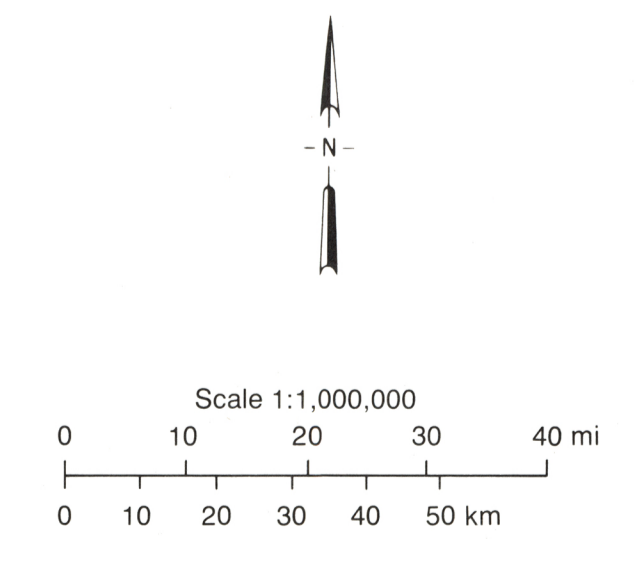
The total concentration of all soluble phosphate species in ground water of the study area is reported in terms of ppm PO₄ in Map 19. Phosphate levels in ground water from upland areas in the western half of the study area are typically below 0.1 ppm. In this same region phosphate concentrations above 0.3 ppm are found in near proximity to drainageways which are located north of the Arkansas River; the area south of the Arkansas River being devoid of high-phosphate levels. The general phosphate concentration of the ground water increases upon moving into the eastern half of the study area and reaches an average concentration of about 0.5 ppm in ground water from McPherson, Harvey, and Sedgwick counties along the eastern boundary of the study area. Reasons for these north-south and west-east variations in phosphate concentration are not readily apparent.

Silicon and carbon are members of the same chemical family of elements. The importance of carbon as a fundamental building unit in the biochemical realm is matched by the importance of silicon in tetrahedral SiO₄⁴⁻ to the structure of many minerals making up rocks and soils in the geochemical environment. Concentrations of silicon in natural waters are usually reported in terms of ppm silica (SiO₂), but the element probably is present in solution as a hydrated species such as H₄SiO₄. Concentrations of silica in natural waters typically lie between the solubility values of quartz (6 ppm at 25°C) and amorphous silica (115 ppm at 25°C).

Map 20 indicates that silica concentrations above 50 ppm in ground water of the study area are only to be found north of the Arkansas River. A small cluster of high-silica values is found in the west-central part of the study area, but the principal region of high ground-water silica concentration is north of the Smoky Hill River valley in the northwestern corner of the state. Silica concentrations in ground water south of the Arkansas River, where areas of dunes and sandy soils exist, average about 25 ppm. Uncertainty exists regarding sources responsible for the high silica content of ground water from the northwestern part of the study area, but volcanic ash disseminated in aquifer sediments of the area is one possibility. Previous mention of silica-rich fluids in this area is inferred today from local exposures of silicified sediments along drainageways.

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