# VERTICAL DISTRIBUTION OF CHLORIDE IN THE SUBSURFACE OF SELECTED OIL-PRODUCING STATES

By

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Bachelor of Science

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1987

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial Fulfillment of
the requirements for
the degree of
MASTER OF SCIENCE
May, 1994

OKLAHOMA STATE UNIVERSITY

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IN THE SUBSURFACE OF SELECTED
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# PREFACE

I wish to offer my sincere gratitude to the people whom I have had the pleasure to work and play with during my studies at O.S.U.. First, I would like to thank Dr. Wayne Pettyjohn for serving as my advisor, for the generous use of his office, and for the guidance and assistance he has given me. I would also like to thank Dr. Pettyjohn for reminding me to pause, remember history, and look at the bigger picture from time to time. I would offer sincere thanks to Dr. Arthur Hounslow for the introduction to water chemistry and for his superb wit. Thanks also goes to Dr. Brian Carter for helping me learn the difference between "dirt" and "soil", and for his exuberance. Kelly Geoff was invaluable with his technical assistance with the hardware and helping me work out the software "bugs". Thanks Len for talking me into attending graduate school, and for being such a good friend through the years. Thank you Cathy for the summer job and for being a friend when I really needed one. One could not ask for better friends than Augie and Suzanne, they have freely shared their home and friendship with me, I kindly thank you. Above all others I would like to express by deepest appreciation and love to my spouse, Melissa Knighten, without her understanding and support none of this would have been possible.

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# CHAPTER I

# INTRODUCTION

## General Overview

More than three-quarters of the total amount of chloride in the Earth's outer crust and hydrosphere is contained in solution as $Cl^-$ ions in the oceans (Hem, 1985). This reflects the chemically conservative nature of chloride, that is, once in solution, it is not easily removed by processes other than precipitation by evaporation.

The concentration of chloride in rain varies from 1 to about 20 mg/L in coastal areas to less than 1 mg/L inland. Ocean spray and wind transport also are largely responsible for the higher chloride concentrations in coastal streams and ground water. Most fresh-water sources contain chloride concentrations that range from about 1 to 10 mg/L, which is far less that the 250 mg/L recommended for drinking water (U.S. Environmental Protection Agency, 1977).

Concentrations of chloride in ground water commonly increase with both depth and distance from the recharge area, eventually approaching the concentration of sea water, which is approximately 19,000 mg/L (Hem, 1989). Deep formation waters and especially waters associated with the accumulation of oil and gas resources commonly contain chloride concentrations in excess of 100,000 mg/L (Richter, 1991).

Major natural sources of chloride in ground water are dissolution of evaporites, flushing of saline waters from fine-grained sediments, and sea-water intrusion. Anthropogenic sources include highway deicing salts, industrial, domestic and agricultural wastes, oil-field brines, and pumping induced salt-water intrusion in both coastal and inland regions.

Evaporation of water increases chloride concentrations in both surface and very shallow ground water. As a direct result of its conservative nature, chloride is commonly used as a tracer as well as a parameter in the identification of the deterioration of water quality.

## Purpose and Scope

The purpose of this study is to provide, in a generalized, graphical format, a report that characterizes the vertical and areal distribution of chloride in the ground water. The generalized assessment may be used to identify geographical areas where elevated chloride levels may be an indicator of ground-water contamination or quality concerns.

The study should provide a source of information, on a state by state basis, about background chloride levels. This information might serve as a basis for the establishment of remediation levels for contamination problems, and as a basis for the study of long term changes in chemical quality of the ground water in the United States. Another use of the maps is the determination of the thickness of the zone containing fresh water. In several instances the generalized boundary between fresh and saline water is evident. These data might be useful by selected regulatory agencies to establish the length of surface casing of oil, gas, or disposal wells.

The study includes 11 mid-western and Gulf Coast states that are involved in the production of petroleum and gas. The states included in the study are illustrated in Figure 1. These states have the largest potential for ground-water contamination brought about by the production and disposal of brines. Generalized areas of oil and gas production in the United States are illustrated in Figure 2. Figure 3 shows the approximate extent of halite deposits in the United States.

Oil production is usually accompanied by the production of saline water in amounts that vary with the production procedures and the field. Table 1 shows data for crude oil production for the period 1971 through 1991 for the states considered in this study.

It is estimated that for every barrel of oil recovered 10 barrels of brine are produced (Keeley, 1977). Brine was formally disposed of by extensive use of unlined evaporation pits. Leakage from such pits has caused ground-water contamination in the oil producing regions (Scalf, 1973).

Present practices for brine disposal include injection of the brine into subsurface formations that are unusable for other purposes and reinjection of brine into oil producing formations to enhance oil recovery. These injection practices, if not properly controlled, can contribute to contamination problems. Powell(1992) examined a site of such contamination near Cyril, Oklahoma and suggested that disposal pits and injection wells caused an increase in chloride levels in the town of Cyril's municipal wells to such an extent that the municipal well field had to be abandoned.

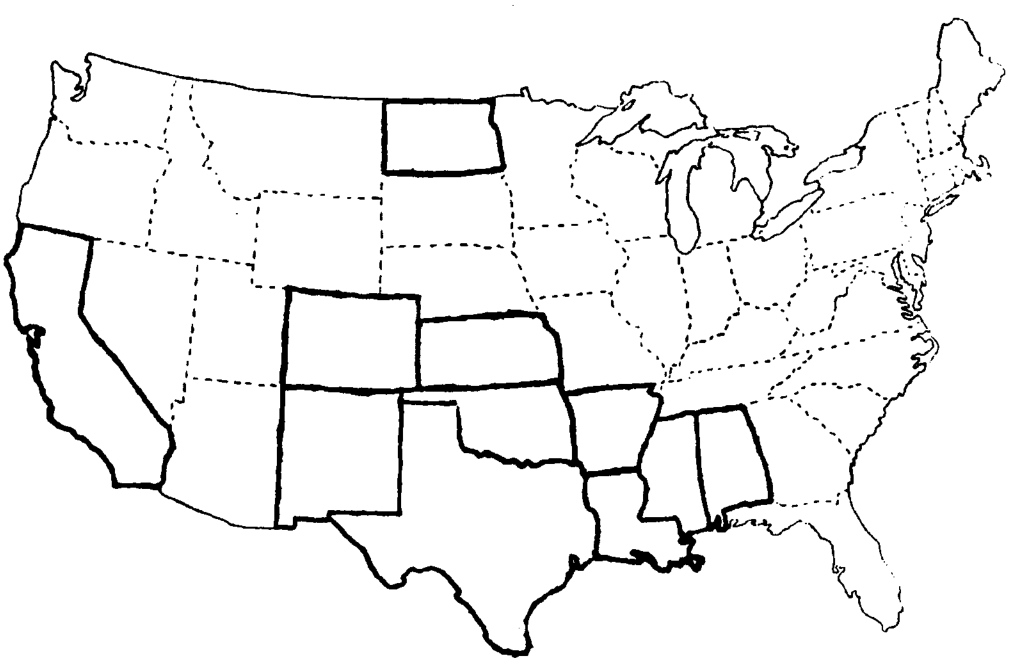


Figure 1. Regional Locator Map

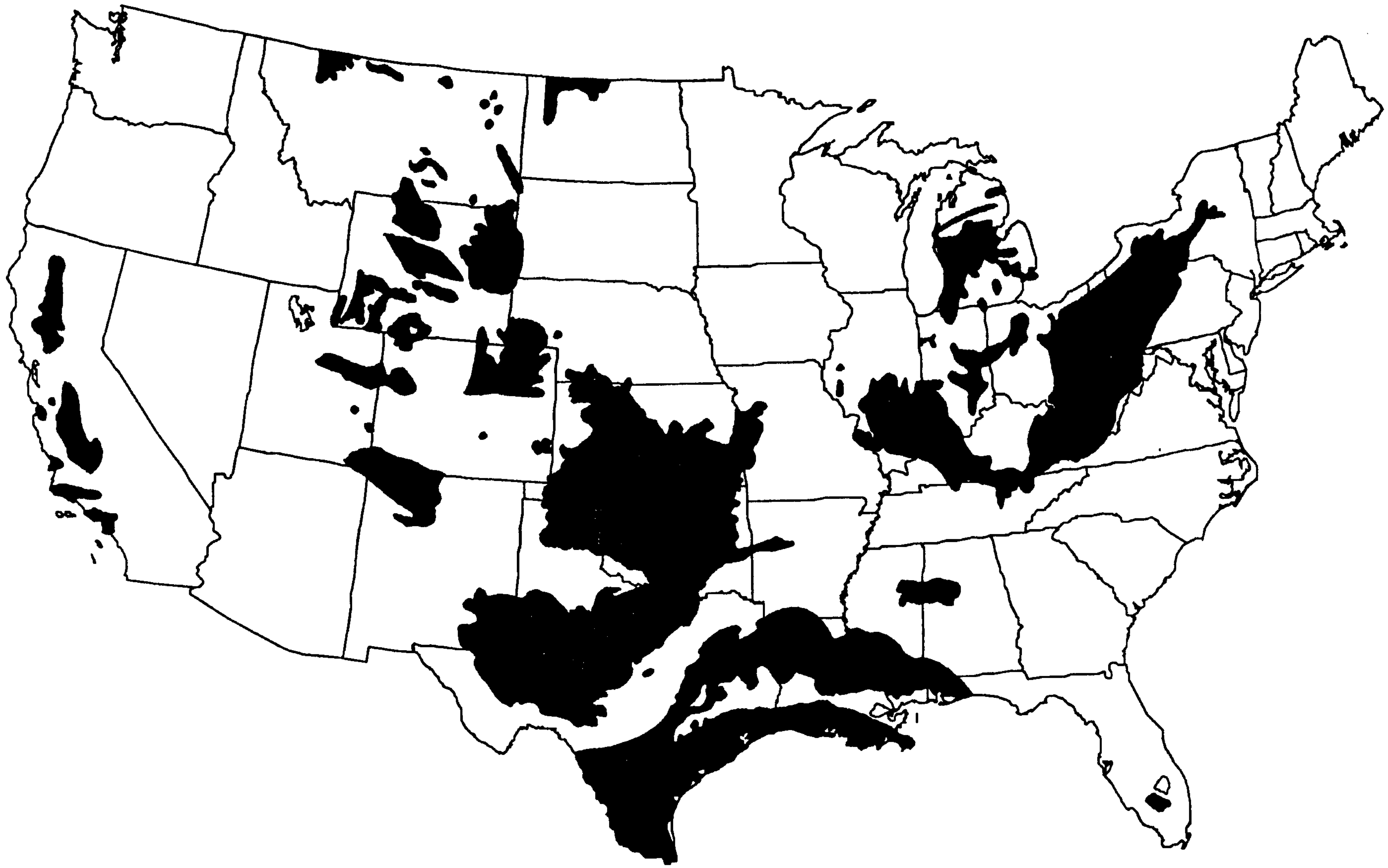


Figure 2. Map of the United States Showing General Areas of Oil and Gas Production
(Modified From PennWell Publishing Co., 1982)

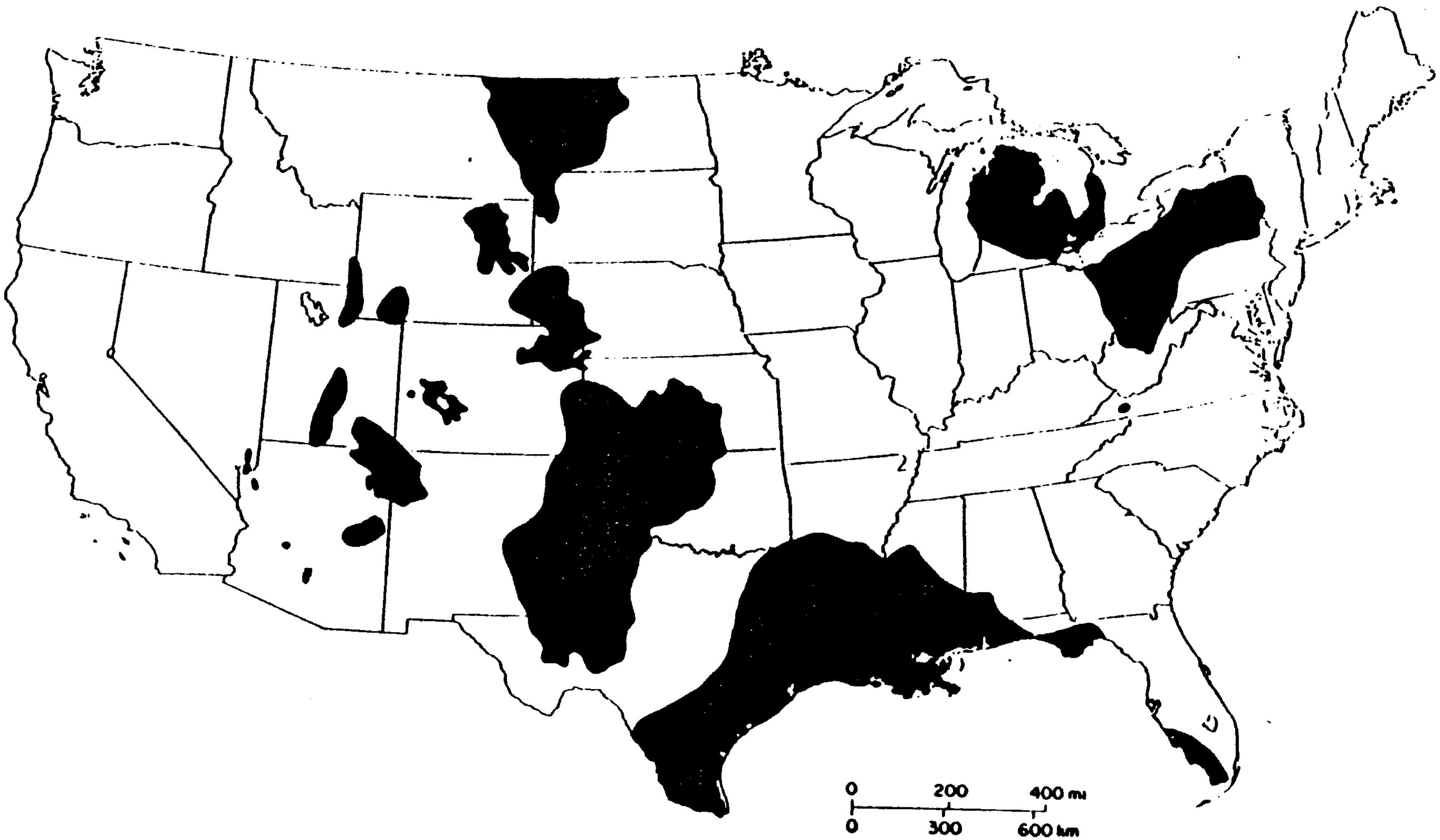



Figure 3. Map of the United States Showing Approximate Extent of Halite Deposits
(Modified From E.P.A., 1991)

| | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 |
|---|---|---|---|---|---|---|---|
| Alabama | 7832000 | 9934000 | 11677000 | 13323000 | 13477000 | 14706000 | 18252000 |
| Arkansas | 18263000 | 18519000 | 18016000 | 16527000 | 16133000 | 18097000 | 20204000 |
| California | 358484000 | 347022000 | 336075000 | 323003000 | 322199000 | 326021000 | 349609000 |
| Colorado | 27391000 | 32015000 | 36590000 | 37508000 | 38089000 | 38992000 | 39460000 |
| Kansas | 78532000 | 73744000 | 66227000 | 61691000 | 59106000 | 58714000 | 57496000 |
| Louisiana | 935243000 | 891827000 | 831524000 | 737324000 | 650840000 | 606501000 | 562905000 |
| Mississippi | 64066000 | 61100000 | 56102000 | 50779000 | 46614000 | 46072000 | 43022000 |
| New Mexico | 118412000 | 110525000 | 100986000 | 98695000 | 95063000 | 92130000 | 87223000 |
| North Dakota | 21653000 | 20624000 | 20235000 | 19697000 | 20452000 | 21725000 | 23273000 |
| Oklahoma | 213313000 | 207633000 | 191204000 | 177785000 | 163123000 | 161426000 | 156382000 |
| Texas | 1222926000 | 1301686000 | 1294671000 | 1262126000 | 1221929000 | 1189523000 | 1137880000 |

| | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 |
|---|---|---|---|---|---|---|---|
| Alabama | 19829000 | 19161000 | 22153000 | 20680000 | 20014000 | 18746000 | 19804000 |
| Arkansas | 20329000 | 18869000 | 18210000 | 18352000 | 18849000 | 18849000 | 18730000 |
| California | 347181000 | 352268000 | 356923000 | 384958000 | 401572000 | 404688000 | 412020000 |
| Colorado | 36797000 | 32324000 | 29802000 | 30303000 | 30545000 | 29050000 | 28845000 |
| Kansas | 56586000 | 56995000 | 60151000 | 65810208 | 70525451 | 71594250 | 75722677 |
| Louisiana | 532740000 | 489687000 | 469141000 | 449315000 | 458395000 | 479569000 | 515268000 |
| Mississippi | 42024000 | 37327000 | 35945000 | 34204000 | 33047025 | 31450695 | 32776000 |
| New Mexico | 83365000 | 79649000 | 75324000 | 71568000 | 71024000 | 75169000 | 79336000 |
| North Dakota | 24812000 | 30914000 | 40337000 | 45424000 | 47271000 | 50690000 | 52652000 |
| Oklahoma | 150456000 | 143642000 | 150140000 | 154056000 | 158621000 | 158604000 | 168385000 |
| Texas | 1074050000 | 1018094000 | 977436000 | 945132000 | 925296000 | 902676000 | 904774000 |

| | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 |
|---|---|---|---|---|---|---|---|
| Alabama | 21581000 | 21122000 | 20607000 | 29797000 | 19813000 | 18538000 | 18637000 |
| Arkansas | 19044000 | 15778000 | 14230000 | 13606000 | 11261000 | 10387000 | 10300000 |
| California | 423877000 | 406665000 | 395698000 | 386014000 | 364249000 | 350900000 | 351016000 |
| Colorado | 30246000 | 29309000 | 28802000 | 32352000 | 30665000 | 30454000 | 31380000 |
| Kansas | 75406909 | 67034000 | 59884000 | 58824000 | 55484000 | 55427000 | 56929000 |
| Louisiana | 508239000 | 512108000 | 473989000 | 435166000 | 402569000 | 392781000 | 414469000 |
| Mississippi | 30641000 | 29997000 | 28103000 | 27553000 | 27403000 | 27033000 | 27055000 |
| New Mexico | 78530000 | 75712000 | 72328000 | 71235000 | 68713000 | 67247000 | 70416000 |
| North Dakota | 50857000 | 45628000 | 41351000 | 39343000 | 36744000 | 36716000 | 35891000 |
| Oklahoma | 162739000 | 149105000 | 134378000 | 128874000 | 117493000 | 112274000 | 108095000 |
| Texas | 888831000 | 839606000 | 787516000 | 764793000 | 717821000 | 703086000 | 706961000 |

**Production Figures In Barrels**

**TABLE 1. CRUDE OIL PRODUCTION IN SELECTED STATES 1971-1991**

# CHAPTER II

# METHODOLOGY

## Data Retrieval

This report is based entirely on published information that represent the U.S. Geological Surveys (USGS) WATSTORE Quality of Water File data base. The WATSTORE data base was accessed from compact disks that are commercially available from EarthInfo Incorporated. These compact disks, titled HYDRODATA QW are distributed with the necessary software to access the "read only" compact disks.

### Computer Hardware

The computer hardware utilized for this investigation consists of an IBM compatible 386 personal computer equipped with an internal 40 megabyte hardrive and an optical disk (CD-ROM) drive. A Macintosch IIfx desktop computer with an internal hard drive, external hard drive, and a removable hardrive also was utilized. A Laser Writer II printer, also produced by Apple, was used to print the maps.

### Computer Software

Maps for this report were prepared by the use of the Macintosh computer software package ATLAS PRO. The PC ASCII data files were processed with APPLE FILE EXCHANGE to convert them to Macintosh files. State and county boundary files, geographic files, and the parameter file were input into the ATLAS PRO program along with parameter division criteria to produce the chloride maps.

## Map Production

A series of maps was generated for each state to represent chloride distribution. Data for each map were filtered by depth using a 100-foot interval. The legend of each map was edited to filter data by chloride concentration interval. The intervals 0-25, 25-100, 100-250, 250-500 and >500 mg/L were utilized.

Files were built for each state by initially choosing station criteria, the parameter (chloride expressed in milligrams per liter (mg/L)), and range of well depth. After the query criteria were entered, the data base was searched.

In states where the data were extensive the computer time required for the data search ranged from 72 to 120 hours. The time required is related to the speed of the CD Rom drive. States with less extensive data files required less time for each search, however, the initial 0-100 ft depth search for every state was very time intensive. Data were exported from the HYDRODATA QW program search in the form of an ASCII file. The ASCII data files were further processed to separate parameter and geographic locator files, convert the latitude and longitude of well locations to decimal format, and eliminate extraneous blank spaces.

Key strokes required to produce map files, correct and format input data, and to produce the completed maps is outlined as follows:

HYDRODATA QW

C:\cd\cd\quality <CR>
C:\quality>QW <CR>
Select state and mark <F5>
<ESC>
STATION <CR>
specify well depth interval<CR>
<ESC>
PARAMETER <CR>
select 940 (chloride mg/L)
mark<F5>
<ESC>
SEARCH
begin search <CR>
when the search is finished
EXPORT <CR>
mark all <F5>
Filename:AL0-100 (enter a filename)
choose short report
<CR>

SEPCL

C:\>SEPCL
FILENANE:AL0-100 (filename from HYDRODATA QW)
creates 2 files AL0-100.dat and AL0-100.11

WS4 (Wordstar)
C:WS4 <WS>
open nondocument <N>
Nondoc file to open? AL0-100.DAT
(filename from SEPCL with .DAT and .LL extension)
<CTRL> QA
find "space" (use spacebar)
replace with <CR>
options GN <CR>
<ESC>
<CTRL> KD
repeat for both files (.dat and .11)
X to exit Wordstar
C:>copy C:\cd\cd\quality\AL0-100.dat B:
repeat for AL0-100.11 file

APPLE FILE EXCHANGE

start Apple File Exchange
select NEW Folder (name folder)
insert IBM data disk in drive
Select files to translate (both .dat and .11)
translate

ATLAS PRO

File: New
Files Geographic Utilities; Conversions
change text file to Atlas Pro geographic file: OK
project: use lat/long: OK
select file AL0-100.11: OPEN
rename file AL0-100 locations: SAVE
File import: Geography
Select: combine several complete files: OK
AtlasPro Data: United States: OPEN
Counties: OPEN
Detailed county geography: OPEN
Select state: OPEN
Add geography to base map: OK
Select Al0-100 locations file
specify map size: OK
File import attribute:
select AL0-100.dat file (matching file for location file)
Edit legend
SAVE: or SAVE AS:(name map)

# CHAPTER III

# STATE EVALUATIONS

## ALABAMA

### General Setting

Alabama consists of approximately 51,700 square miles. The southwestern part includes the low lying coast and uplands of the Coastal Plain physiographic province, while in the northeastern lies the mountains and hills of the Piedmont, Valley and Ridge, Appalachian Plateaus, and the Interior Low Plateaus provinces. Alabama's coastal plain is underlain by a south to southwest dipping sequence of Cretaceous to Quaternary age, unconsolidated to semiconsolidated sand, clay, gravel, lignite coal, marl and limestone. These sediments are locally overlain by alluvial and coastal deposits. Folded and faulted sedimentary rocks underlie the remainder of the state.

Surface drainage in north Alabama is accomplished by the Tennessee River. The southern part of the state is drained by the Tombigbee, Chattahoochee, and Alabama rivers.

## Principal Aquifers

The coastal plane of Alabama is the state's largest and most productive ground-water resource area. Pleistocene and Holocene alluvial and terrace deposits form important aquifers in some locals, while the Pliocene (Miocene?) Citronelle Formation and younger deposits serve as an important local aquifers. Miocene deposits, which constitute major Coastal Plain aquifers, include the Catahoula Sandstone, and Payes Hammock Sand.

The Floridian Aquifer consists of the Oligocene Chickasaway Limestone, along with the Vicksburg Group. Eocene age aquifers include the Gosport Sand, Lisbon and Tallahatta Formations of the Claiborn Group, and the Hatchetigbee, Tuscahoma Sand, and the Nanafalia of the Wilcox Group. Paleocene deposits that are considered to be aquifers consist of the Naheola and Clayton of the Midway Group. Cretaceous deposits in the Coastal Plain that serve as major aquifers include the Eutaw-McShan Sands, and the Gordo and Coker formations of the Tuscaloosa Group.

The igneous and metamorphic rocks in the Piedmont and consolidated sedimentary rocks in the Interior Low Plateau, the Appalachian Plateau, and the Valley and Ridge also serve as aquifers in varying capacities (Miller, 1977). The generalized aquifer systems of Alabama are illustrated in Figure 4.

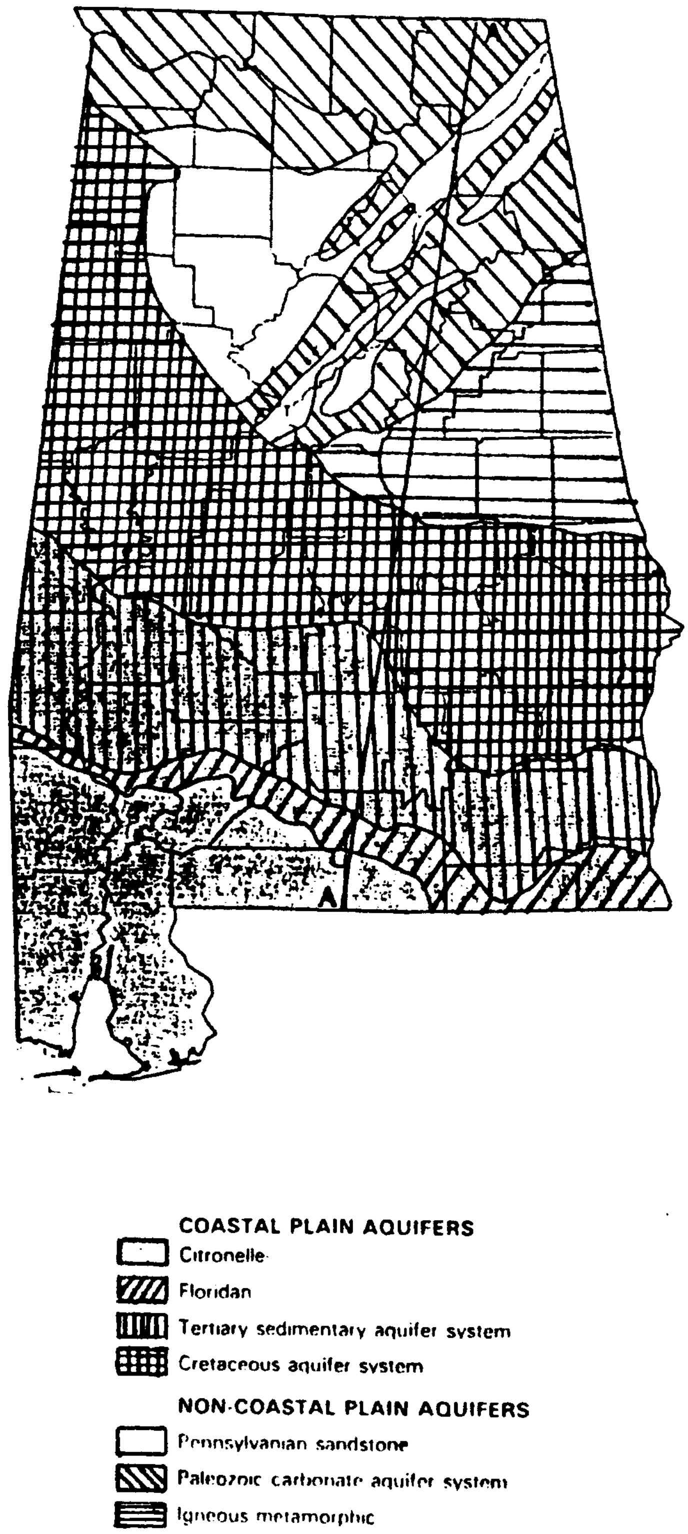



Figure 4. Alabama Principal Aquifers Map
(Modified From U.S.G.S.,1985)

## Chloride Distribution

The series of chloride maps produced for Alabama represent a total of 4958 stations mapped over 12 depth intervals (table 3). Tabulation of the number of stations per depth, concentration interval, total number of stations, and number of wells per depth interval that exceed the EPA standard is presented in table 2. Although the total percentage of wells in the state that exceed the EPA standard of 250 mg/L is a modest eight percent(Table 2), percentages for individual mapping intervals are substantially higher(Table 3), particularly below the 600-700 foot interval. Percentages for individual depth intervals are tabulated in Table 3 and presented graphically in Figure 5.

Alabama chloride maps suggest that some of the shallow wells contain elevated chloride levels. Areal distribution of wells that exceed 250 mg/L are, for the most part, restricted to the western half of the state (Figures. 7-18). Charting of concentration interval and well depth interval(fig. 5) graphically suggests the percentage of wells that have chloride levels less that 25 mg/L steadily decreases with depth. Figure 6 shows the percentage of wells that exceed 250 mg/L chloride vs well depth. The graph demonstrates a steady increase in the percentage of wells that exceed the 250 mg/L standard with depth. There appears to be a substantial increase in the percentage of wells that exceed 250 mg/L at the 600-700 foot interval. The depth to the top of the fresh-brine interface probably is in the range of 800-1000 feet in the western half of the Alabama and greater than 1500 feet in the eastern part of the state.

Contamination of natural waters due to oil field activities in alabama have been reported in the Pollard, Gilbert-town Citronelle, and South Carlton oil fields in Southwestern Alabama. Principal sources of contamination are unlined pits, leaks from pipelines and spills(Miller and others, 1977). Chloride maps(Figures. 7-18) do show stations with chloride levels in excess of 250 mg/L in Washington, Mobile, Baldwin, Clark, Wilcox, Lowndes, and Montgomery counties that may be related to oil field activities.

Occurrences of halite deposits are found throughout Southern and Southeastern Alabama(fig 3). Slack and Planert (1988), suggest natural salinization in Marengo, Sumpter and green counties is due to brine migration along faults, affecting all major aquifers in this area.

| | Concentration Interval (mg/L) | | | | | total | wells |
|---|---|---|---|---|---|---|---|
| | 0-25 | 25-100 | 100-250 | 250-500 | >500 | wells | > 250 |
| Depth Interval (feet) | | | | | | | |
| 0-100 | 1101 | 104 | 16 | 11 | 31 | 1263 | 42 |
| 100-200 | 990 | 45 | 8 | 10 | 10 | 1063 | 20 |
| 200-300 | 710 | 41 | 18 | 9 | 17 | 795 | 26 |
| 300-400 | 436 | 38 | 16 | 15 | 16 | 521 | 31 |
| 400-500 | 278 | 49 | 25 | 22 | 21 | 395 | 43 |
| 500-600 | 168 | 40 | 17 | 15 | 20 | 260 | 35 |
| 600-700 | 99 | 22 | 2 | 17 | 22 | 162 | 39 |
| 700-800 | 93 | 23 | 9 | 16 | 21 | 162 | 37 |
| 800-900 | 37 | 16 | 10 | 19 | 22 | 104 | 41 |
| 900-1000 | 37 | 15 | 7 | 13 | 24 | 96 | 37 |
| 1000-1100 | 19 | 10 | 5 | 13 | 10 | 57 | 23 |
| 1100-1500 | 18 | 14 | 10 | 13 | 25 | 80 | 38 |
| State Total | 3986 | 417 | 143 | 173 | 239 | 4958 | 412 |
| Percent Of Wells With Concentrations Greater Than 250 mg/L | | | | | | | 8 |

TABLE 2. NUMBER OF STATIONS PER DEPTH AND CONCENTRATION INTERVAL IN ALABAMA

| | Concentration Interval (mg/L) | | | | | |
|---|---|---|---|---|---|---|
| | 0-25 | 25-100 | 100-250 | 250-500 | >500 | >250 |
| Depth Interval (feet) | | | | | | |
| 0-100 | 87 | 8 | 1 | 1 | 2 | 3 |
| 100-200 | 93 | 4 | 1 | 1 | 1 | 2 |
| 200-300 | 89 | 5 | 2 | 1 | 2 | 3 |
| 300-400 | 84 | 7 | 3 | 3 | 3 | 6 |
| 400-500 | 70 | 12 | 6 | 6 | 5 | 11 |
| 500-600 | 65 | 15 | 7 | 6 | 8 | 13 |
| 600-700 | 61 | 14 | 1 | 10 | 14 | 24 |
| 700-800 | 57 | 14 | 6 | 10 | 13 | 23 |
| 800-900 | 36 | 15 | 10 | 18 | 21 | 39 |
| 900-1000 | 39 | 16 | 7 | 14 | 25 | 39 |
| 1000-1100 | 33 | 18 | 9 | 23 | 18 | 40 |
| 1100-1500 | 23 | 18 | 13 | 16 | 31 | 48 |

TABLE 3. PERCENT OF STATIONS PER DEPTH AND CONCENTRATION INTERVAL IN ALABAMA

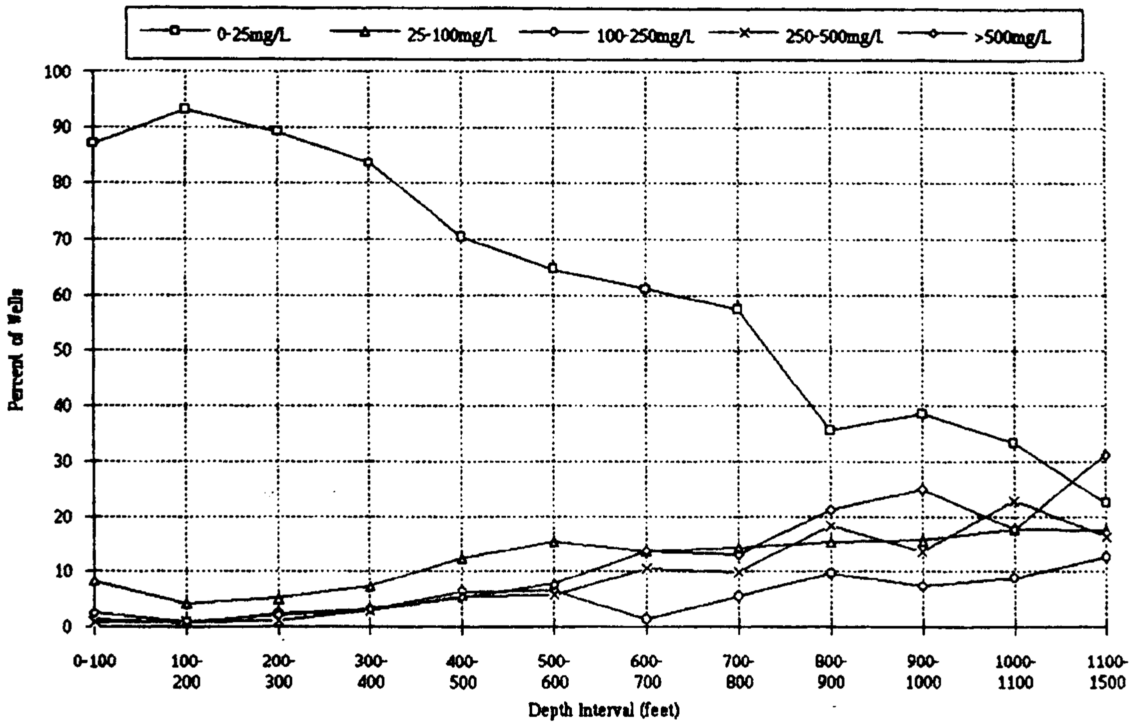



**Figure 5. Alabama Percent of Wells Per Concentration Interval vs Well Depth**

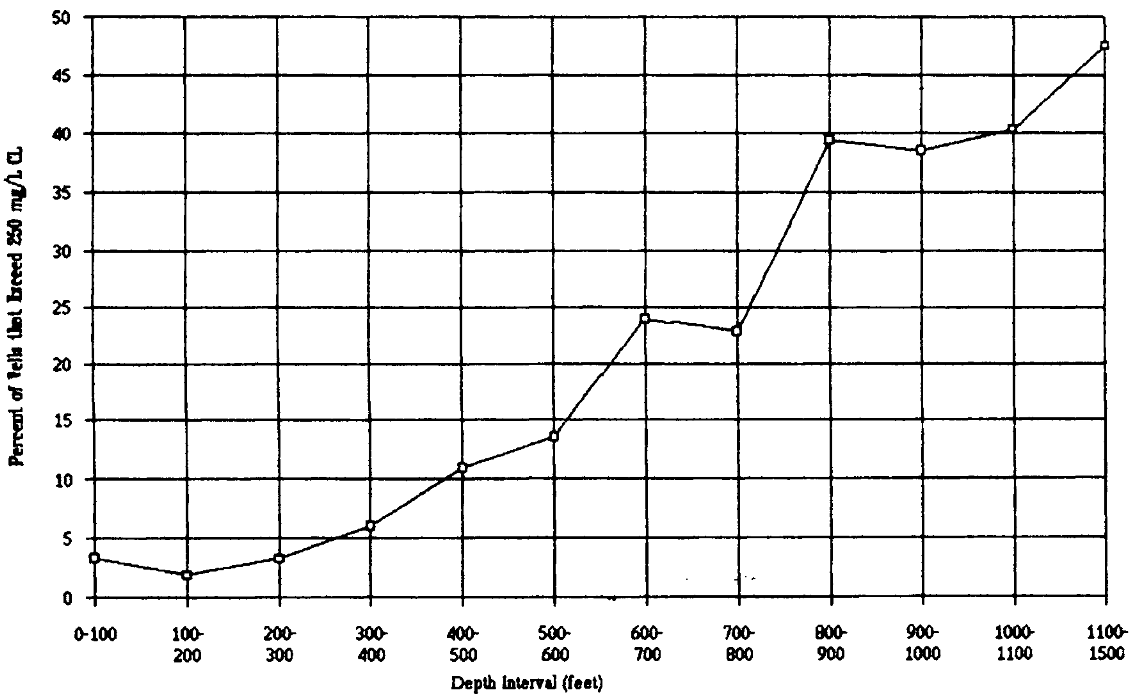



**Figure 6. Alabama Percent of Wells That Exceed 250mg/L Chloride**

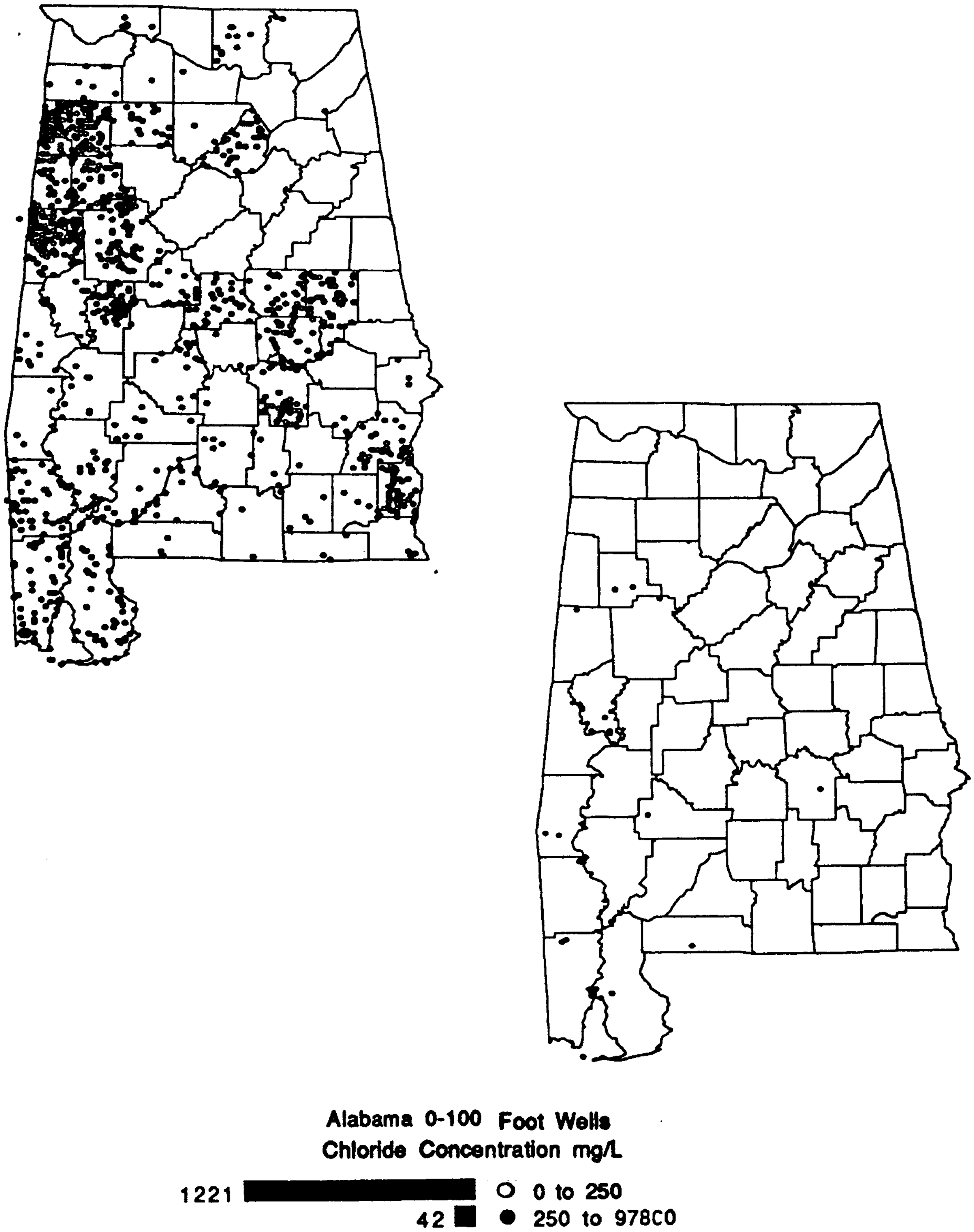



Figure 7. Alabama 0-100 Foot Interval Chloride Map

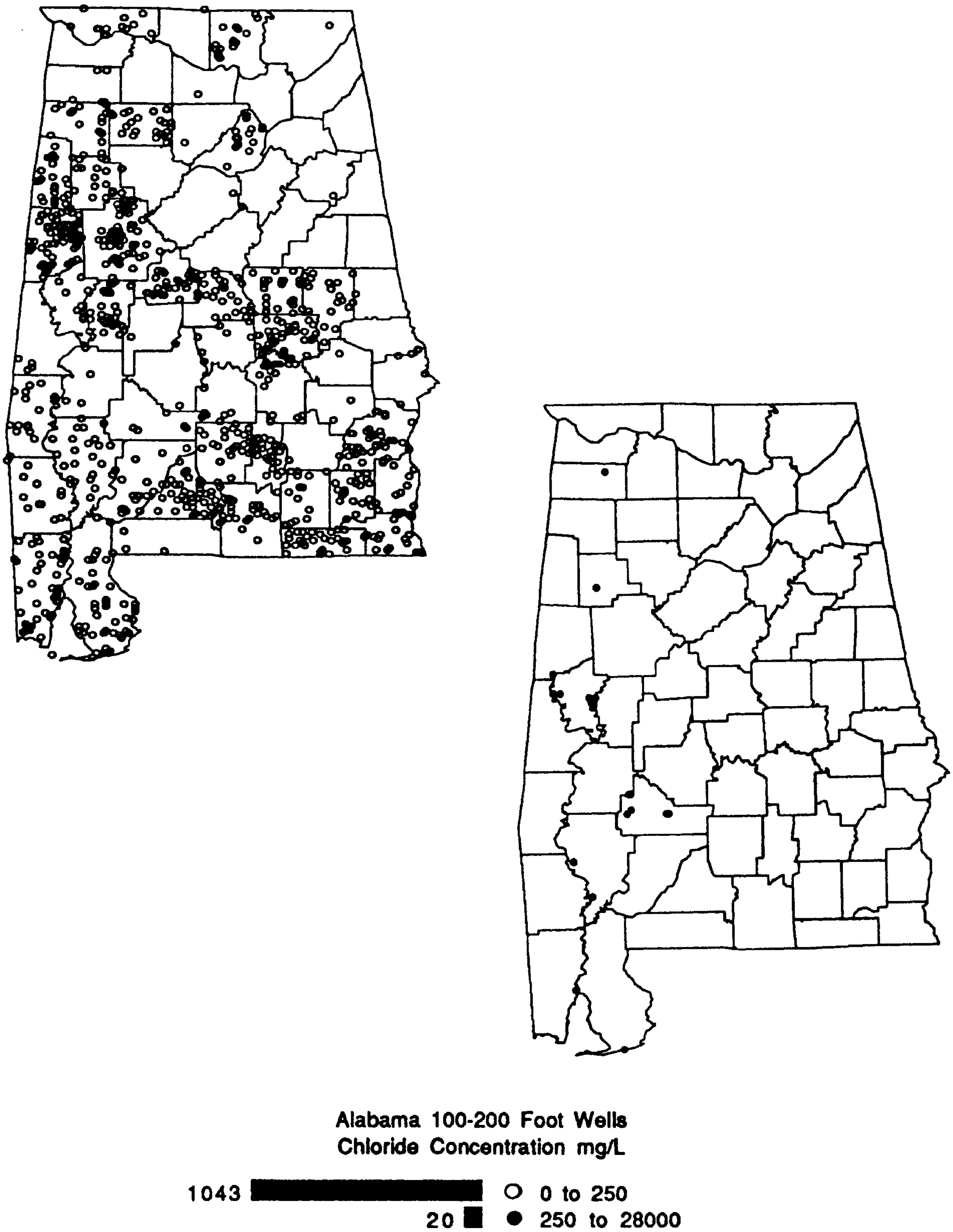



Figure 8. Alabama 100-200 Foot Interval Chloride Map

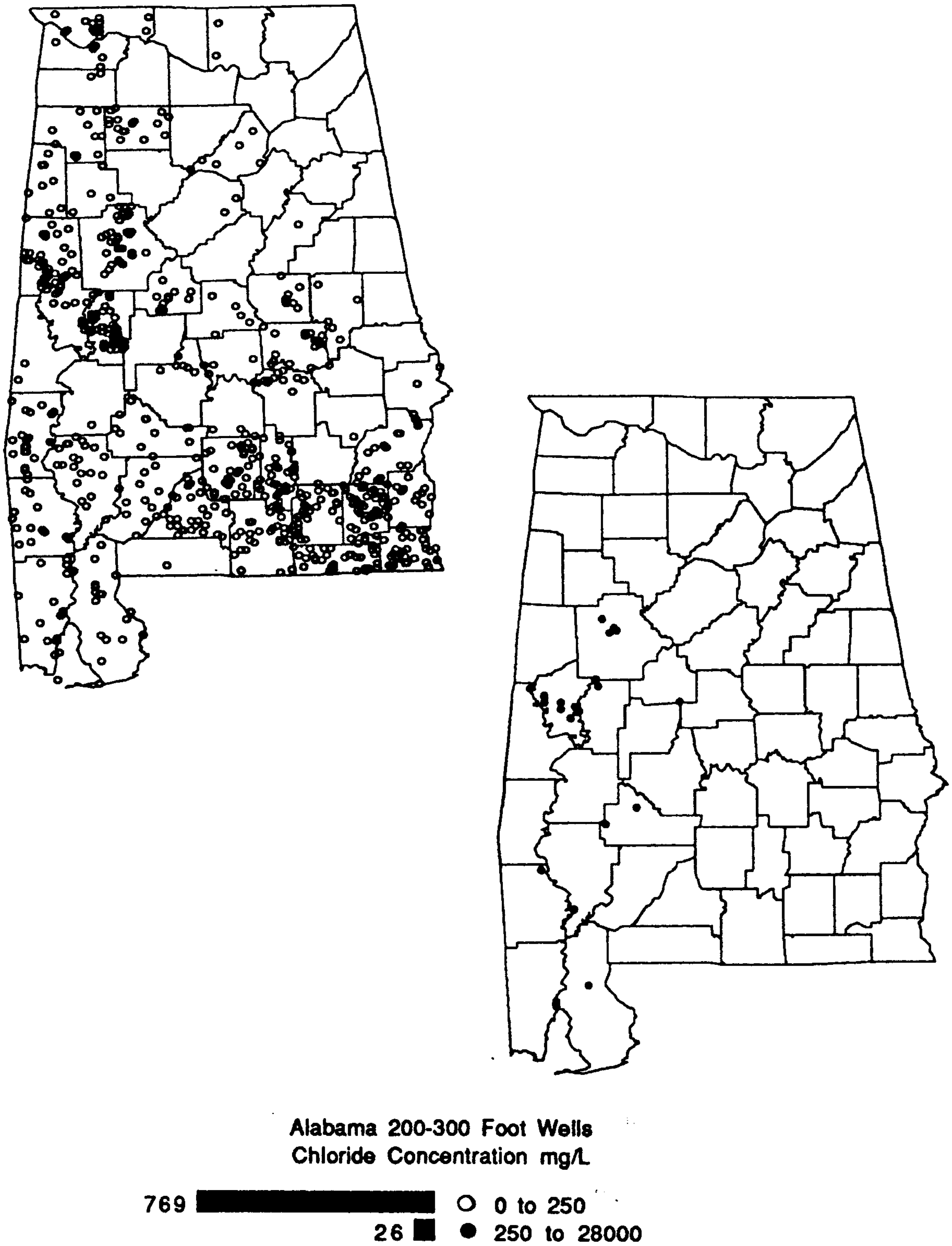



Figure 9. Alabama 200-300 Foot Interval Chloride Map

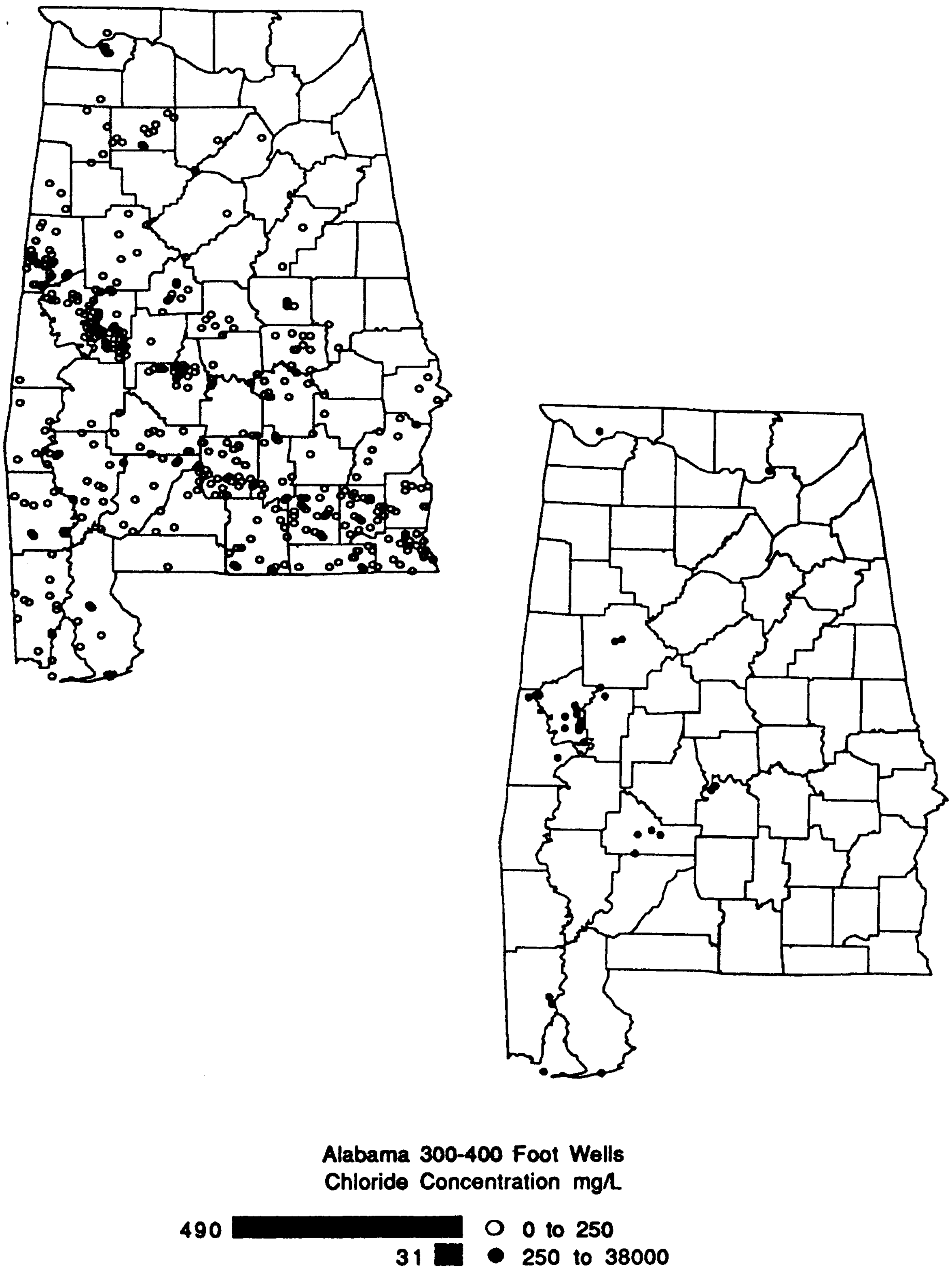



Figure 10. Alabama 300-400 Foot Interval Chloride Map

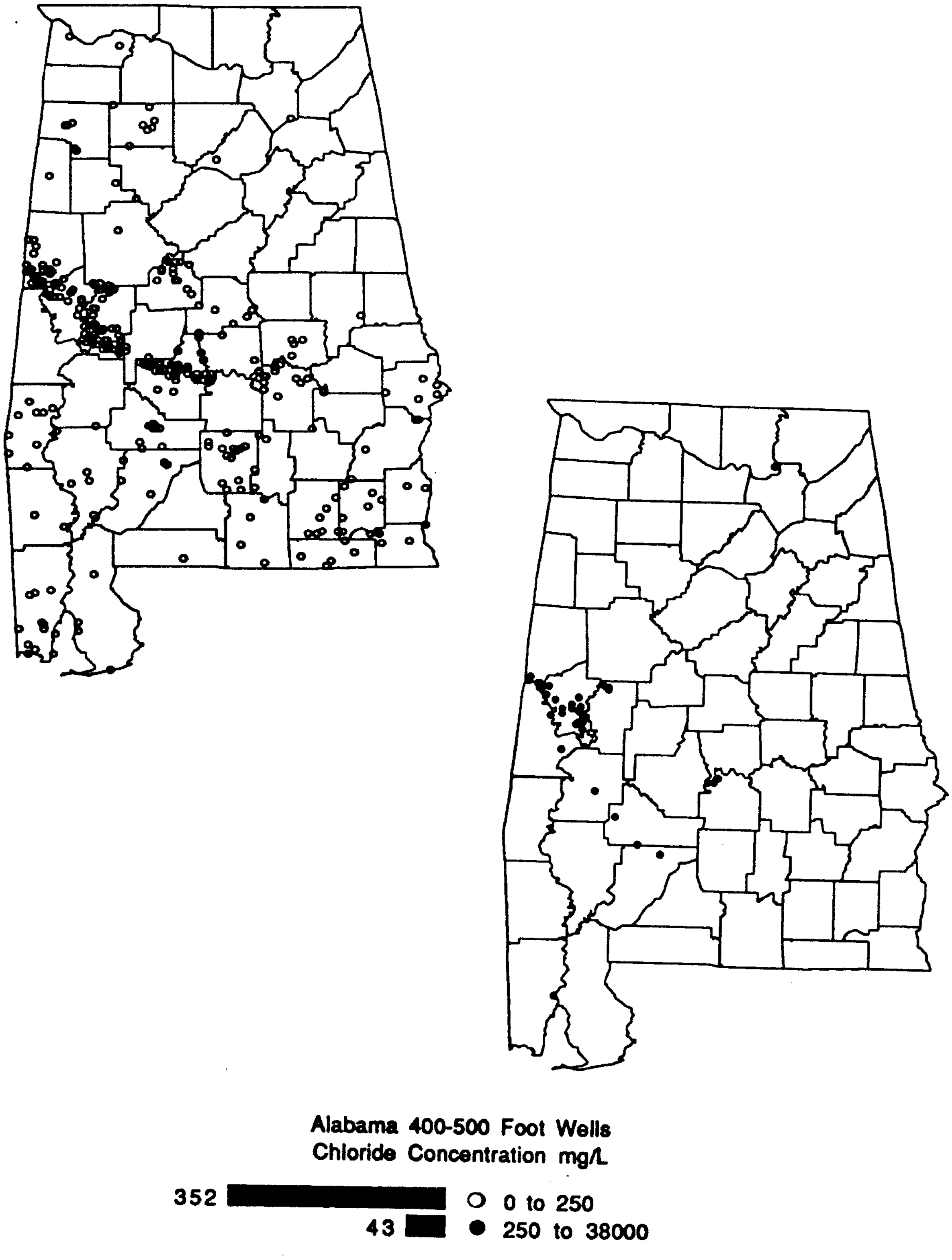



Figure 11. Alabama 400-500 Foot Interval Chloride Map

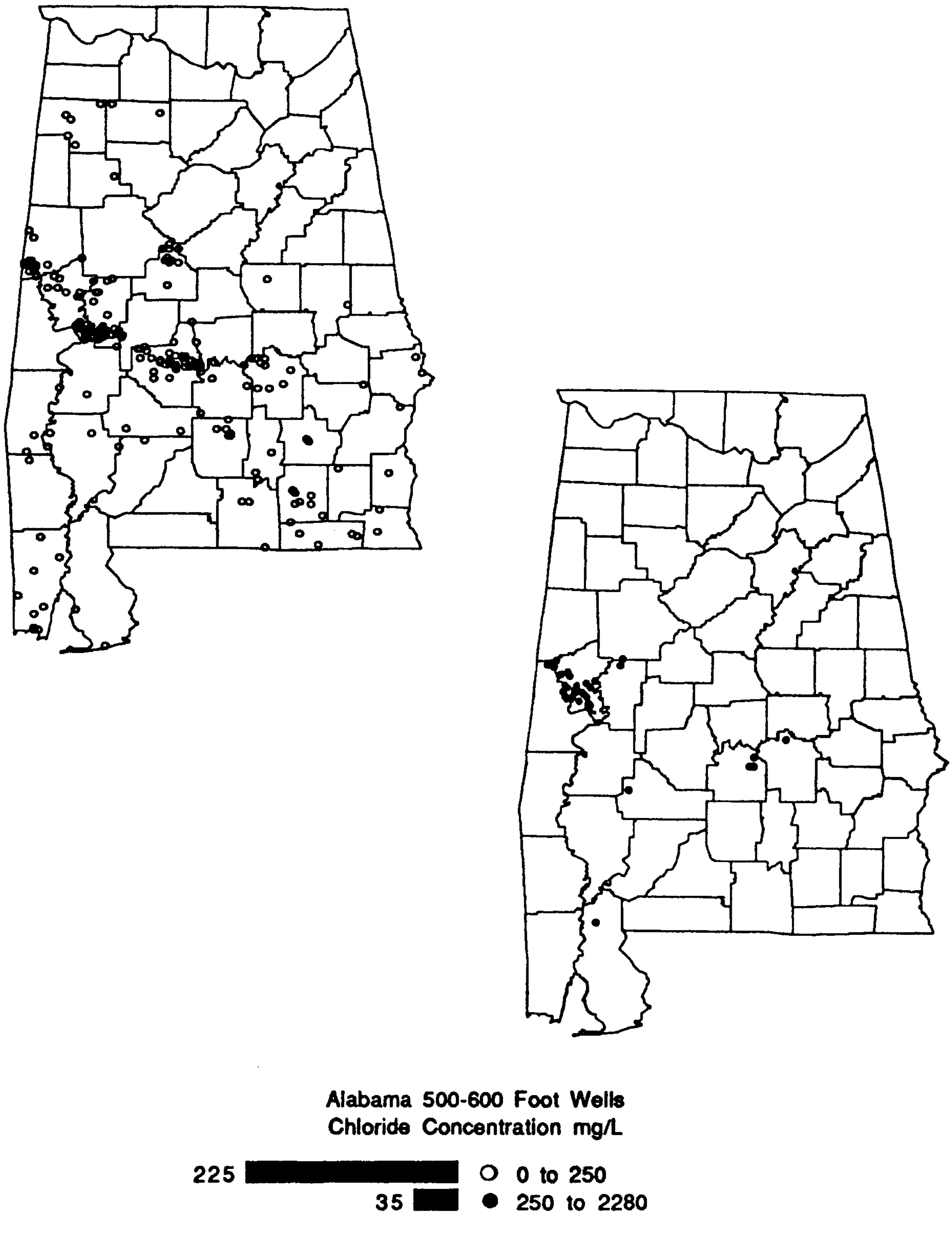



Figure 12. Alabama 500-600 Foot Interval Chloride Map

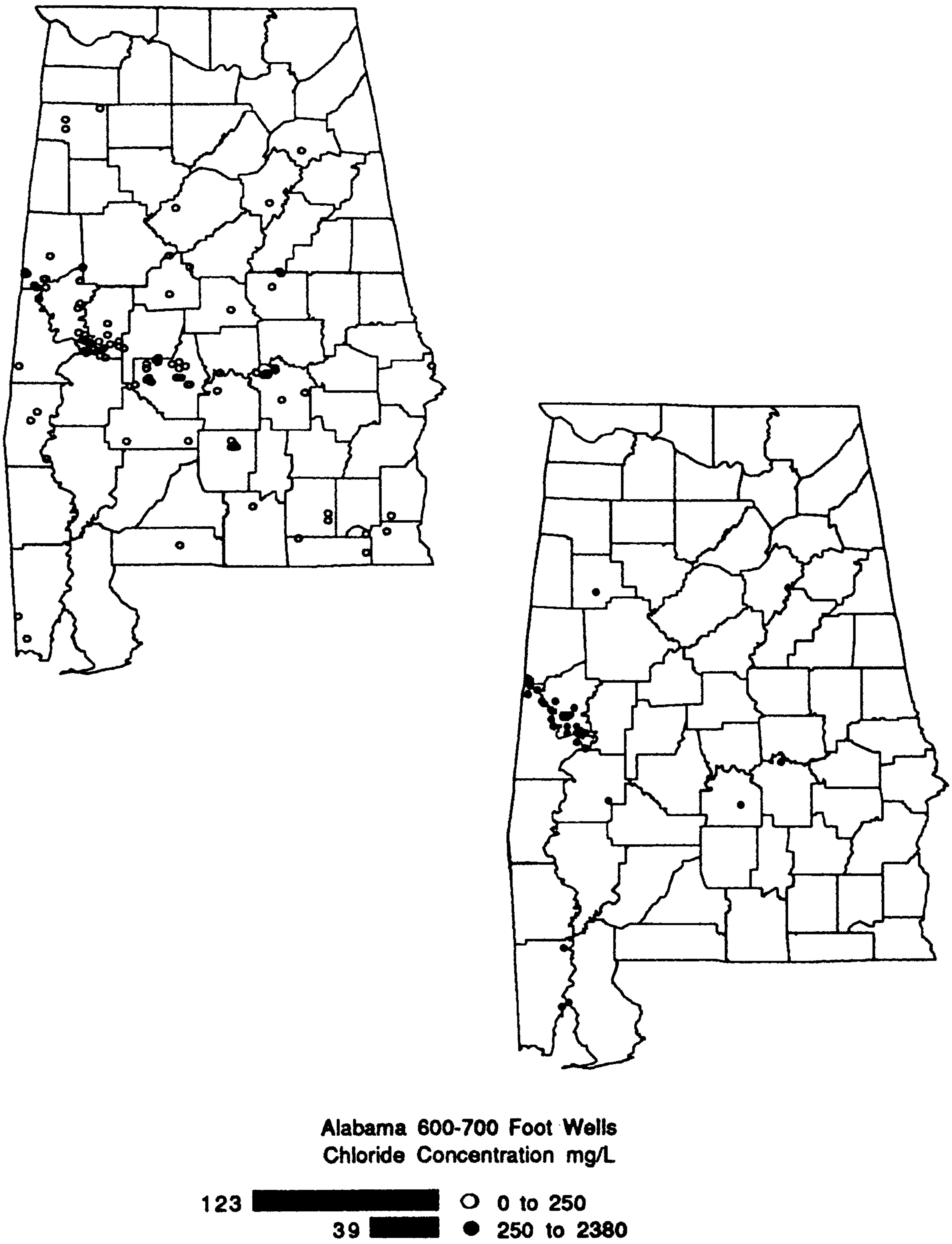



Figure 13. Alabama 600-700 Foot Interval Chloride Map

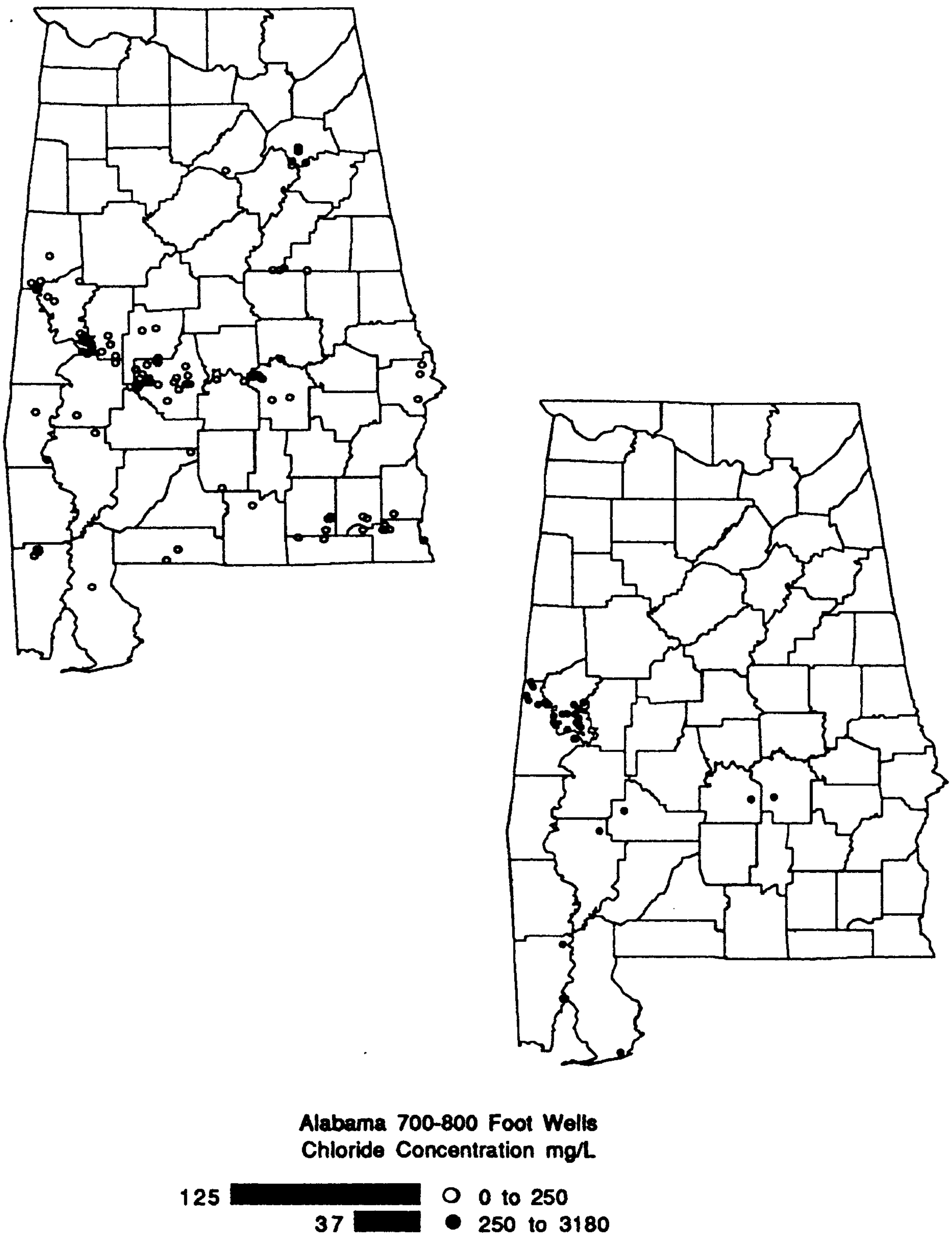



Figure 14. Alabama 700-800 Foot Interval Chloride Map

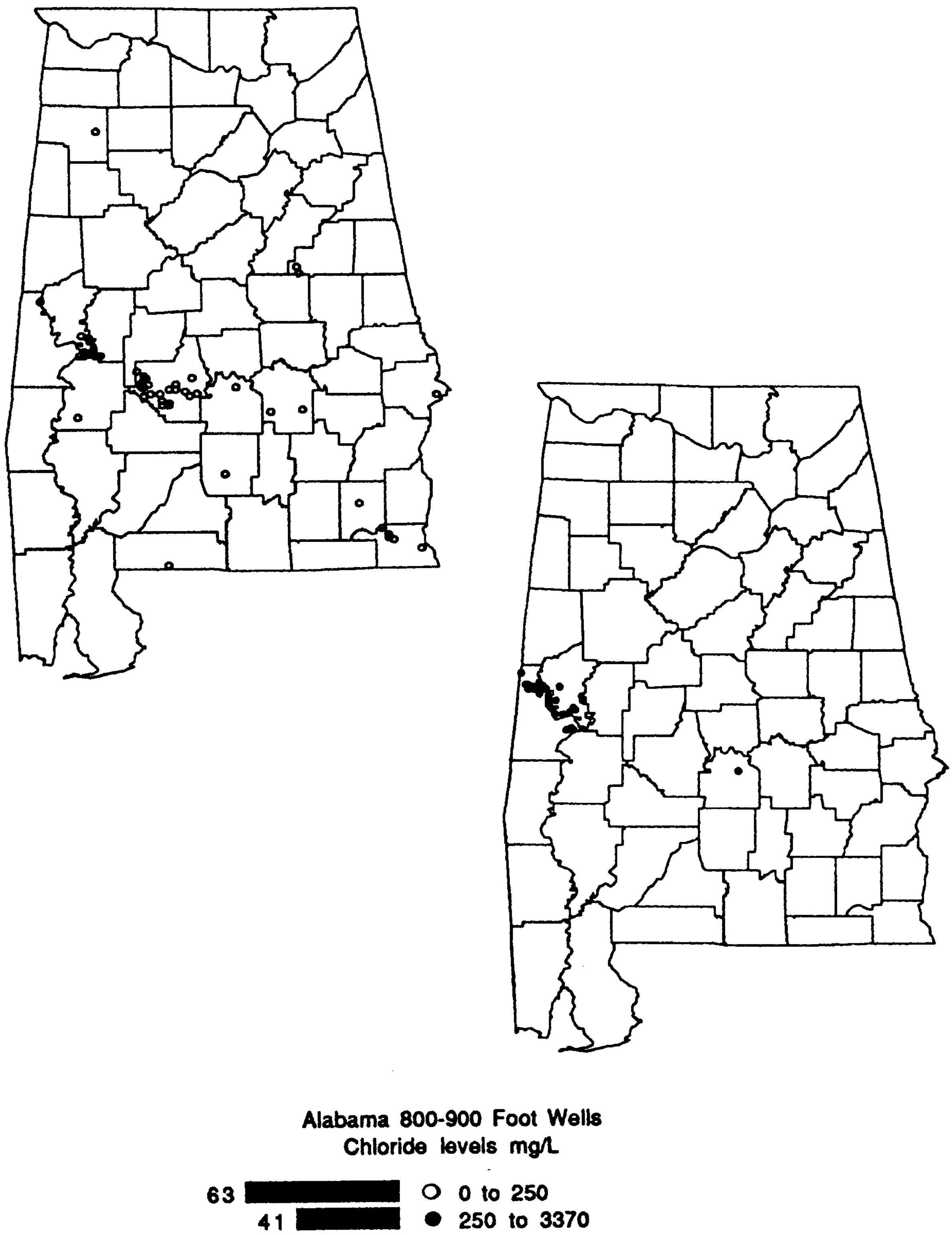



Figure 15. Alabama 800-900 Foot Interval Chloride Map

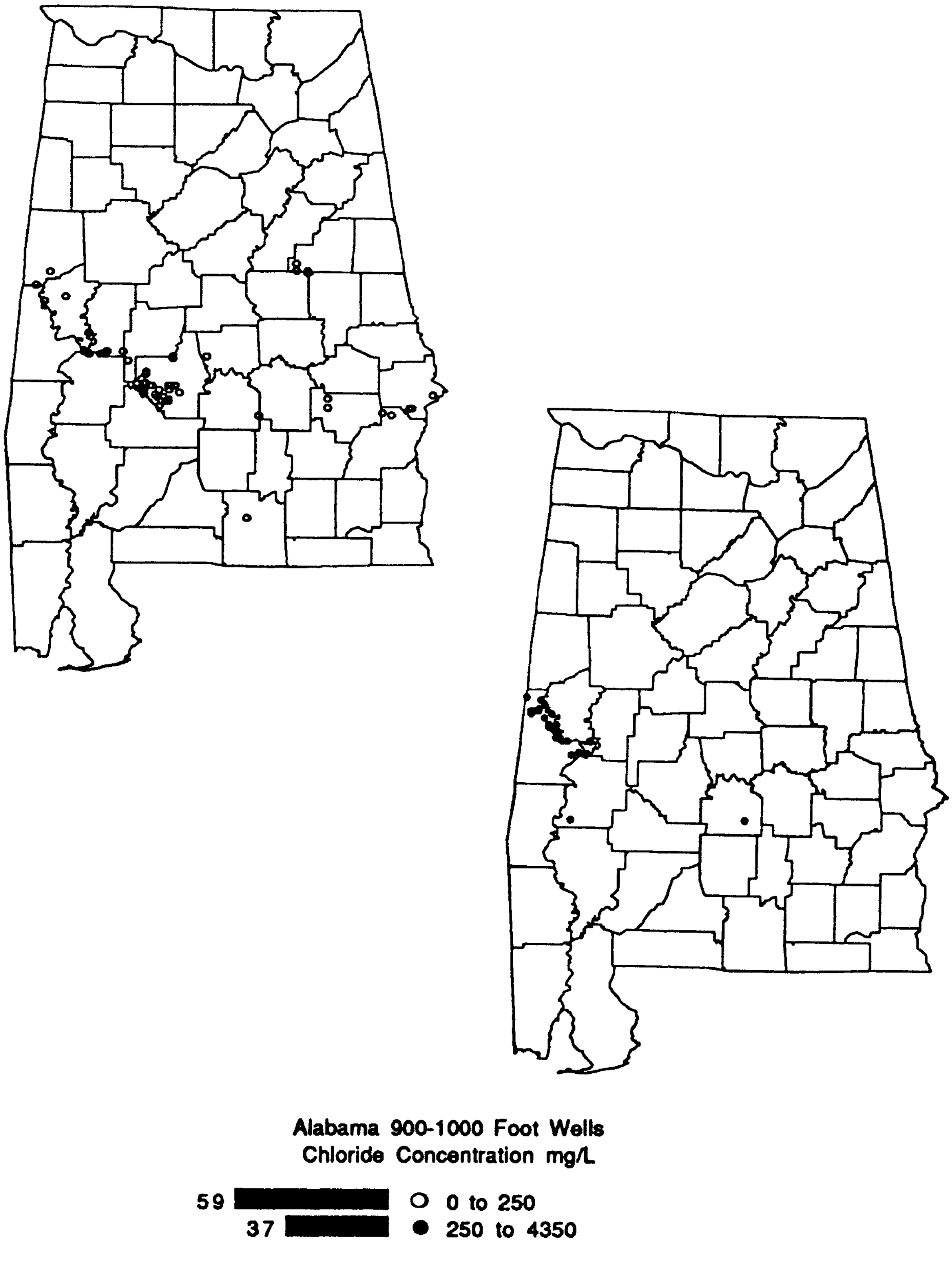



Figure 16. Alabama 900-1000 Foot Interval Chloride Map

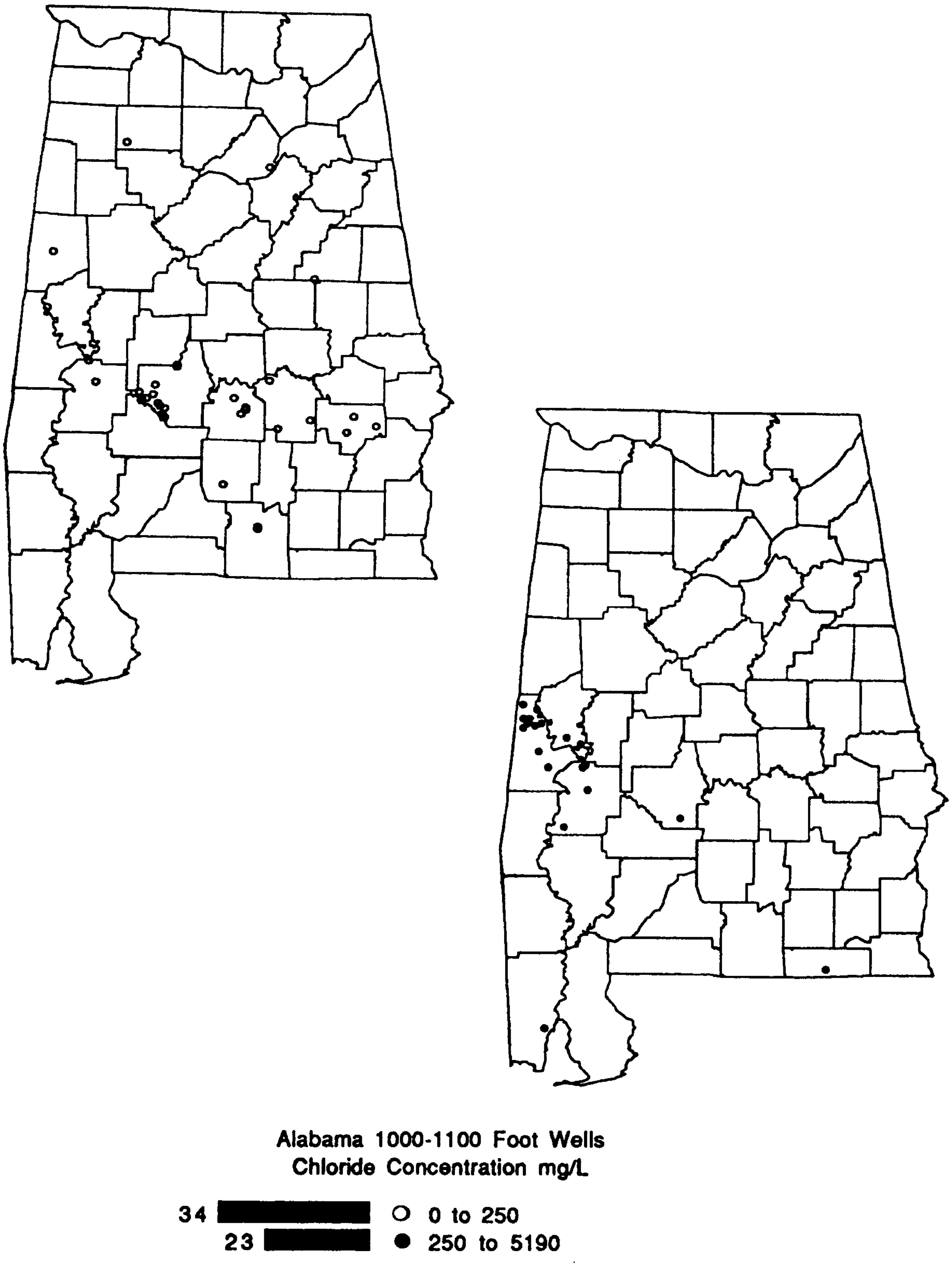



Figure 17. Alabama 1000-1100 Foot Interval Chloride Map

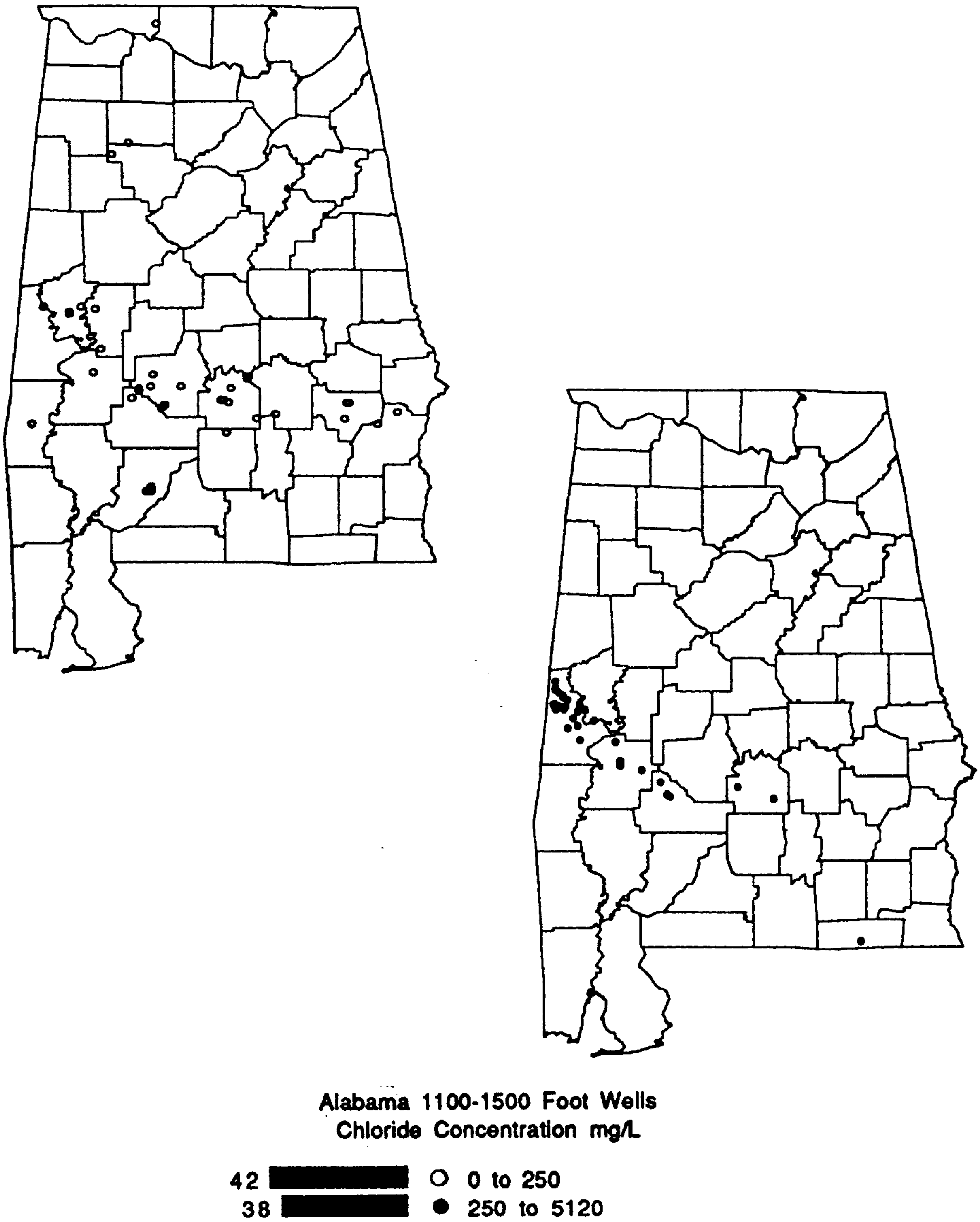



Figure 18. Alabama 1100-1500 Foot Interval Chloride Map

# ARKANSAS

## General Setting

Arkansas contains approximately 52,100 square miles and is roughly divided into two physiographic divisions along the northwest-southeast trending Fall Line. The northwest half of the state is characterized by rolling to rugged terrain of the Interior Highlands, including the Ozark Plateau and Ouachita Province. This area is underlain by Ordovician to Pennsylvanian age folded and faulted sedimentary rocks. The southeastern part of the state is in the generally flat lying Coastal Plain Province, which is underlain by southeastern dipping unconsolidated strata of Cretaceous to Quaternary age. Arkansas is principally drained by the southwest flowing Arkansas, White, and Ouachita river system.

## Principal Aquifers

The major aquifers in the Interior Highlands of the northeast include unconsolidated alluvial deposits along the Arkansas river system, as well as the underlying Atoka Formation of Pennsylvanian age. The Atoka consists principally of sandstone and fractured shale. Principal aquifers of the Ozark Plateaus include Ordovician limestone formations in the Salem Plateau, and the Batesville Sandstone and Boone Formation in the Springfield Plateau.

Major aquifers in the Coastal Plain Province include the Tertiary age Sparta Sand of South Central Arkansas, which consists of fine to medium grained sand with interbedded lenses of silty to sandy clay, and the Tertiary age "1400" foot fine to medium-grained sand of the Wilcox Group. Quaternary alluvium is the most important and highest yielding source of ground water in the Coastal Plain. Deposits of Quaternary age occur in a large part of the Gulf Coast in eastern Arkansas as well as in the valleys of the Sabine, Ouachita, Red, and Arkansas rivers (Scalf, 1977). Figure 19 outlines the geographical extent of the state's major aquifers.

Chloride Distribution

Chloride maps of Arkansas are based on 3153 stations distributed over 11 depth intervals (table 4). In the Interior Highlands Chloride levels that exceed 250 mg/L are restricted, for the most part, to the shallow alluvial aquifers in the Arkansas and the White River valleys. Scalf (1977) suggested that the source of chloride in ground water in the Arkansas River Valley is due to brine disposal from oil-field activities. Northwest of the Fall Line chloride maps (Figures. 22-31) below the 300 foot level do not show any wells that exceed 250 mg/L. An appreciable number of wells in the coastal sediments do show elevated chloride levels, although, the percentage is rather small as suggested by Table 5, and Figure 21. The percentage of wells that exceed 250 mg/L remains below six percent at depths less than 300 feet. The percentage rises to 14 percent at the 500-600 foot interval and then declines to only three percent in the 600-700 foot interval. The maximum percentage of wells exceeding 250 mg/L is encountered at the 900-1000 foot depth interval(fig.21). In general it appears that the southwestern part of the state, including Sevier, Littleriver, Hempstead, Miller, Clark, and Ouachita counties, exhibit the greatest number of wells that exceed 250 mg/L. The depth to the fresh-brine interface is shallowest in the southwest part of the state where it occurs at a depth of about 500 feet. Elsewhere the interface appears to be at depths in excess of 1000 feet. state.

Contamination as a result of oil field activities have been reported in Independence, White, Woodruff, Chilcot, Ashley, Miller and Union Counties (Richter, and others, 1991). Chloride maps of Arkansas produced for this study demonstrate stations with chloride levels in excess of 250 mg/L for all of the above mentioned counties plus Prairie, Monroe, Clark, Cleveland, Desha, Calhoun, and Drew Counties. As there are halite deposits in southern Arkansas (fig 3), it is probable that some of the stations mapped with higher chloride levels are due to the result of dissolution of these evaporites.

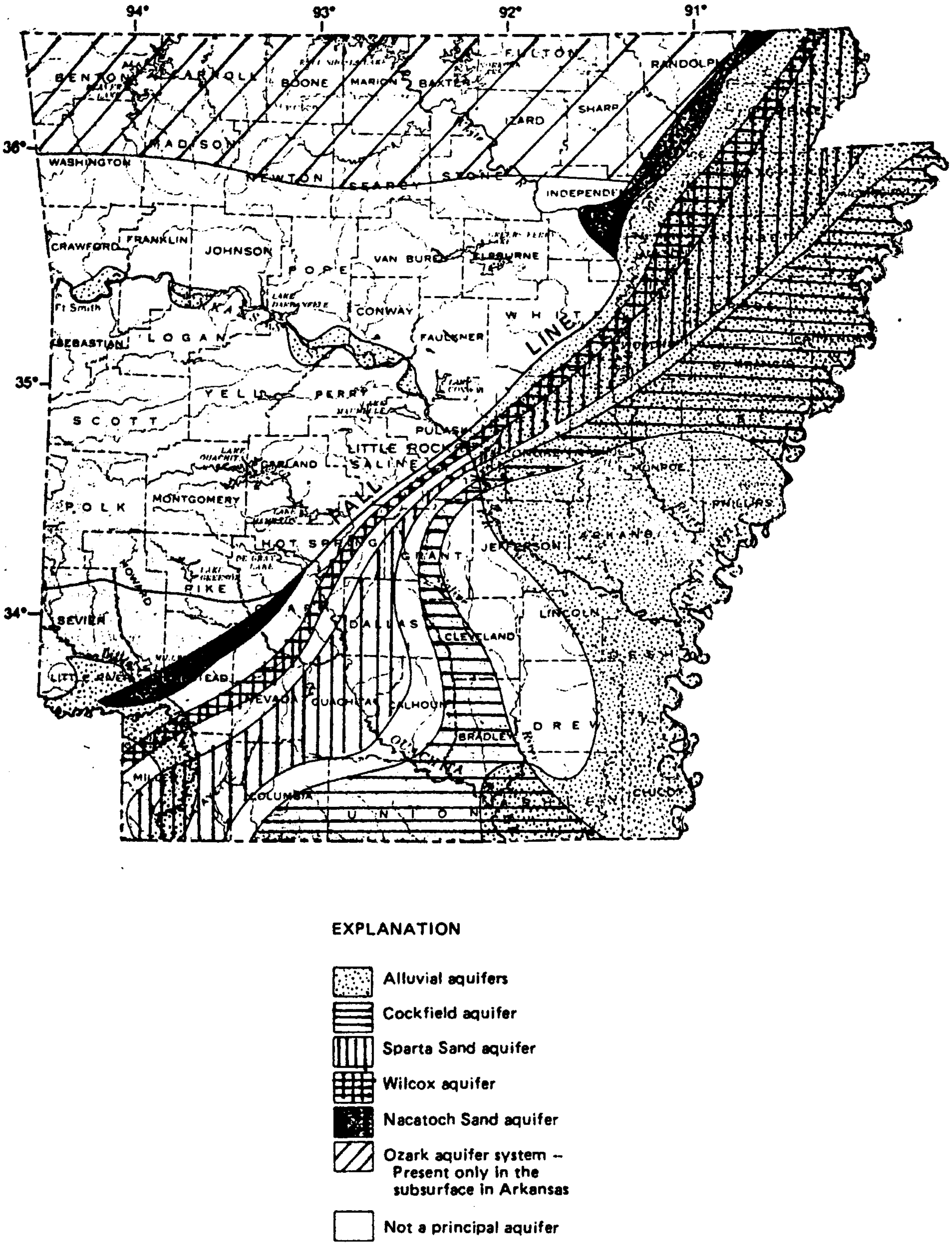



Figure 19. Arkansas Principal Aquifers Map
(Modified From U.S.G.S., 1985)

| | Concentration Interval (mg/L) | | | | | total | wells |
|---|---|---|---|---|---|---|---|
| | 0-25 | 25-100 | 100-250 | 250-500 | >500 | wells | >250 |
| Depth Interval (feet) | | | | | | | |
| 0-100 | 911 | 367 | 109 | 48 | 32 | 1467 | 80 |
| 100-200 | 471 | 192 | 58 | 16 | 13 | 750 | 29 |
| 200-300 | 147 | 28 | 9 | 5 | 3 | 192 | 8 |
| 300-400 | 117 | 34 | 15 | 10 | 10 | 186 | 20 |
| 400-500 | 108 | 20 | 12 | 3 | 18 | 161 | 21 |
| 500-600 | 89 | 20 | 9 | 4 | 15 | 137 | 19 |
| 600-700 | 56 | 34 | 5 | 1 | 2 | 98 | 3 |
| 700-800 | 42 | 16 | 4 | 1 | 2 | 65 | 3 |
| 800-900 | 43 | 5 | 3 | 5 | 1 | 57 | 6 |
| 900-1000 | 12 | 2 | 2 | 1 | 2 | 19 | 3 |
| 1000-1100 | 16 | 3 | 0 | 3 | 0 | 22 | 3 |
| State Total | 2012 | 721 | 226 | 97 | 98 | 3154 | 195 |
| Percent Of Wells With Concentrations Greater Than 250mg/L | | | | | | | 6 |

TABLE 4. NUMBER OF STATIONS PER DEPTH AND CONCENTRATION INTERVAL IN ARKANSAS

| | Concentration Interval (mg/L) | | | | | |
|---|---|---|---|---|---|---|
| | 0-25 | 25-100 | 100-250 | 250-500 | 500 > | >250 |
| Depth Interval (feet) | | | | | | |
| 0-100 | 62 | 25 | 7 | 3 | 2 | 5 |
| 100-200 | 63 | 26 | 8 | 2 | 2 | 4 |
| 200-300 | 77 | 15 | 5 | 3 | 2 | 4 |
| 300-400 | 63 | 18 | 8 | 5 | 5 | 11 |
| 400-500 | 67 | 12 | 7 | 2 | 11 | 13 |
| 500-600 | 65 | 15 | 7 | 3 | 11 | 14 |
| 600-700 | 57 | 35 | 5 | 1 | 2 | 3 |
| 700-800 | 65 | 25 | 6 | 2 | 3 | 5 |
| 800-900 | 75 | 9 | 5 | 9 | 2 | 11 |
| 900-1000 | 63 | 11 | 11 | 5 | 11 | 16 |
| 1000-1100 | 73 | 14 | 0 | 14 | 0 | 14 |

TABLE 5. PERCENT OF STATIONS PER DEPTH AND CONCENTRATION INTERVAL IN ARKANSAS

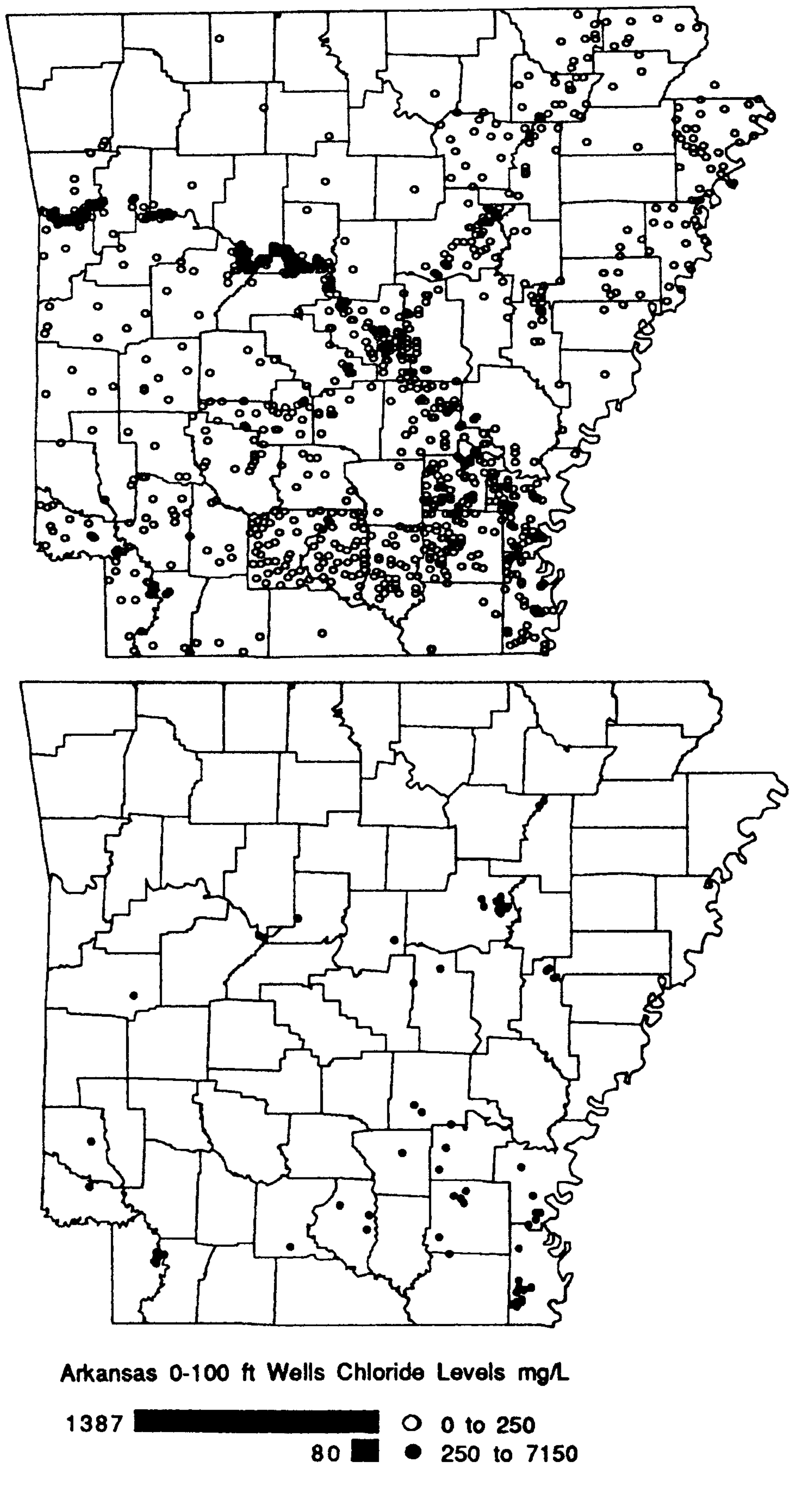



Figure 22. Arkansas 0-100 Foot Interval Chloride Map

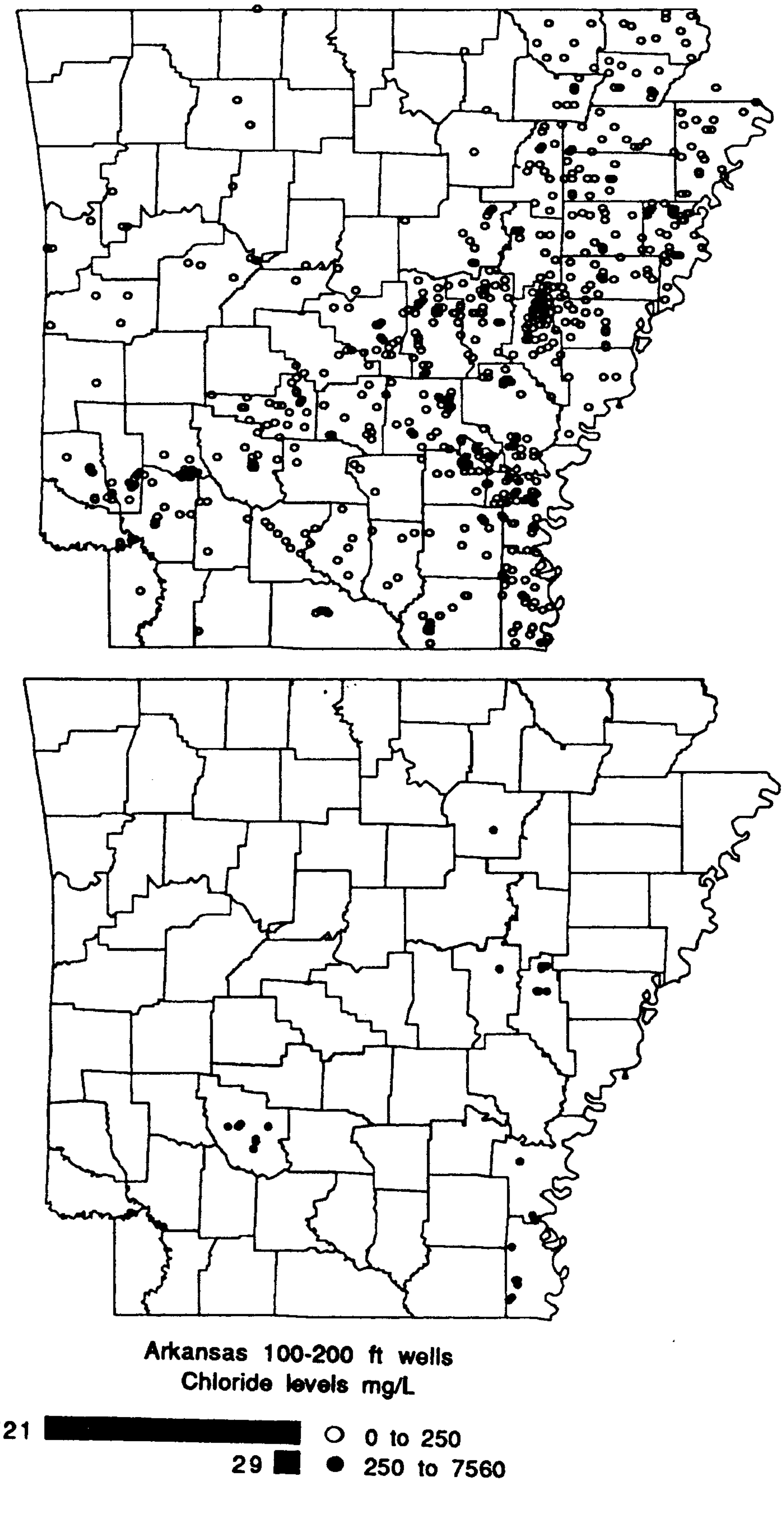



Figure 23. Arkansas 100-200 Foot Interval Chloride Map

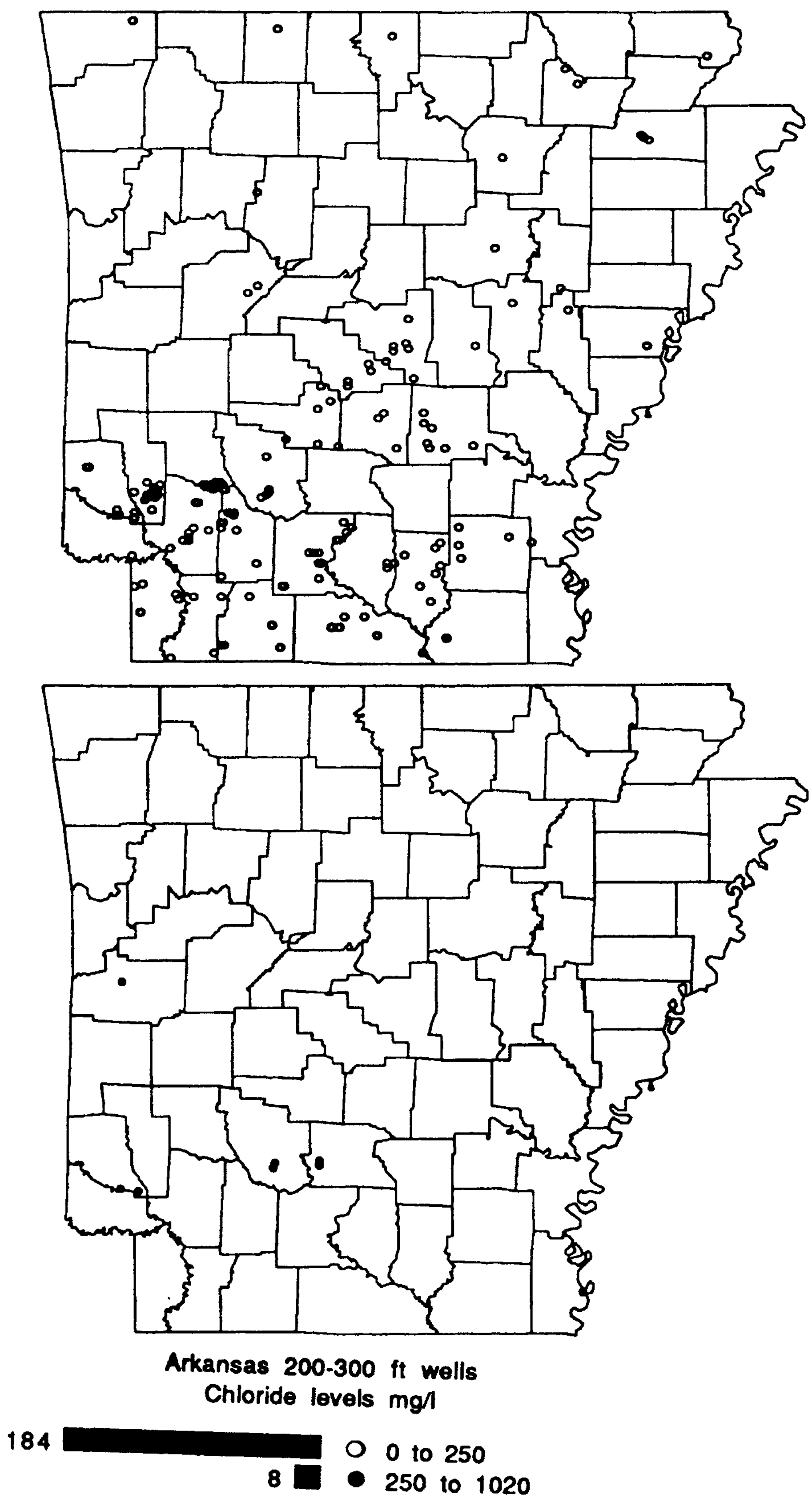



Figure 24. Arkansas 200-300 Foot Interval Chloride Map

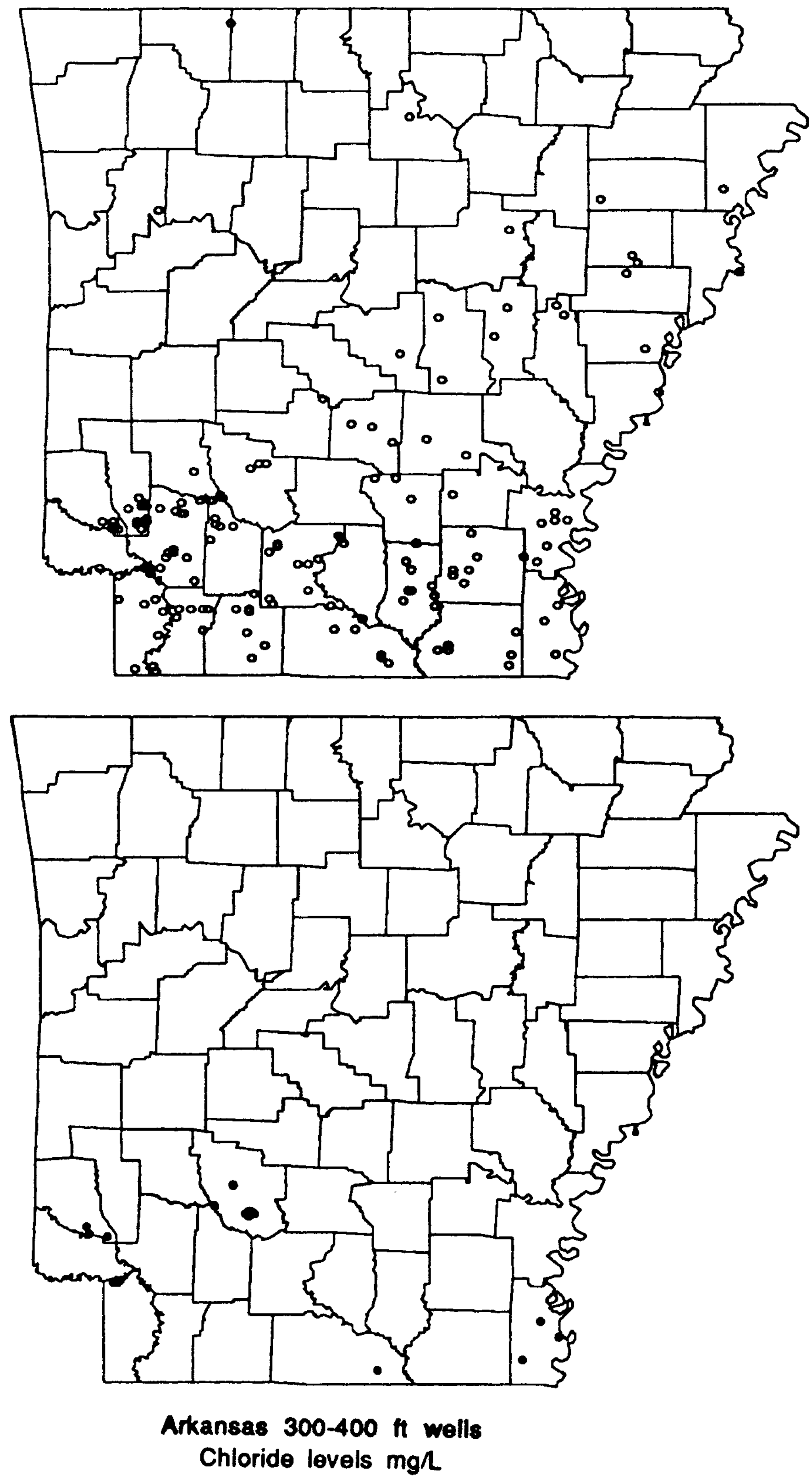



Figure 25. Arkansas 300-400 Foot Interval Chloride Map

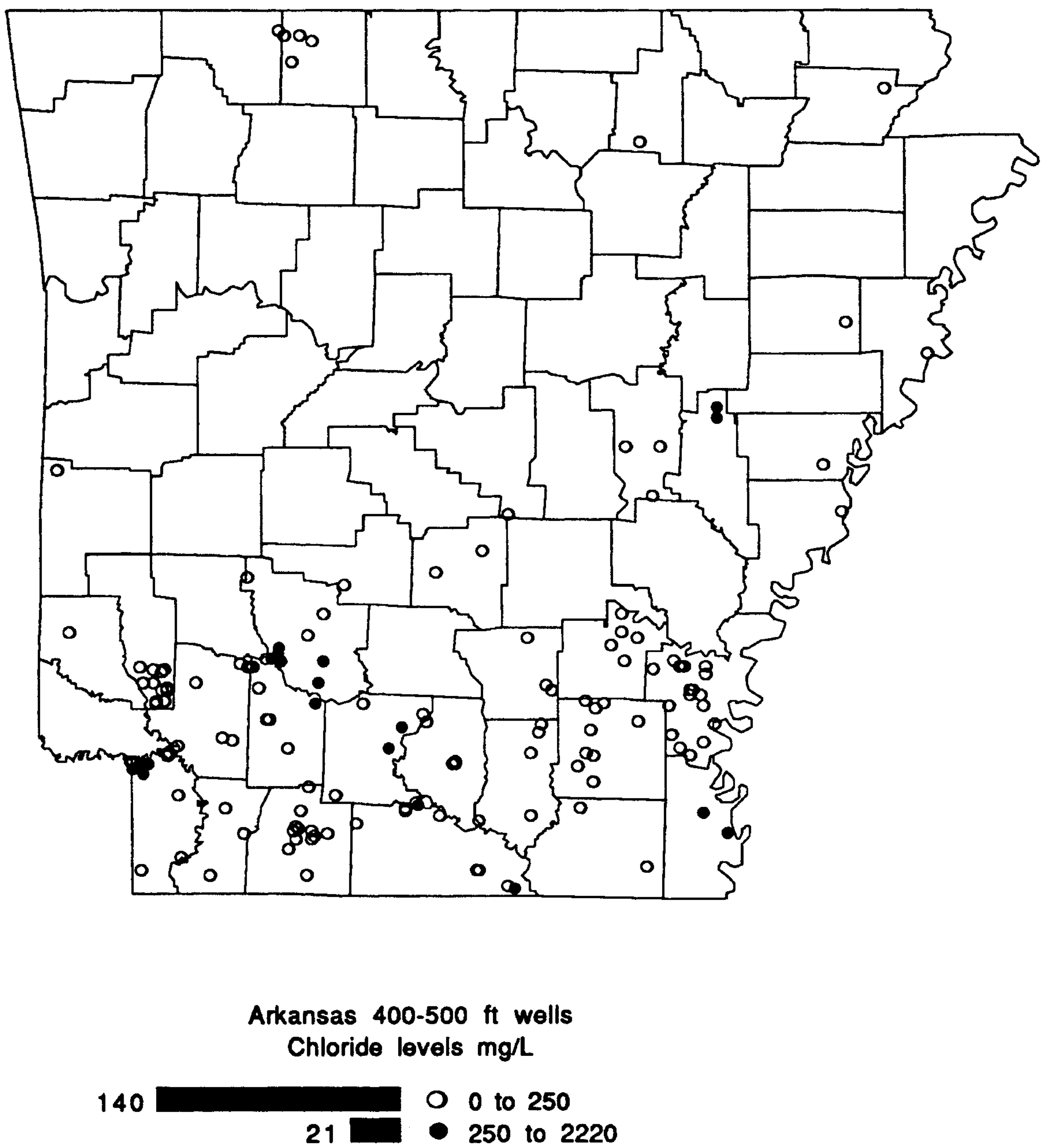



Figure 26. Arkansas 400-500 Foot Interval Chloride Map

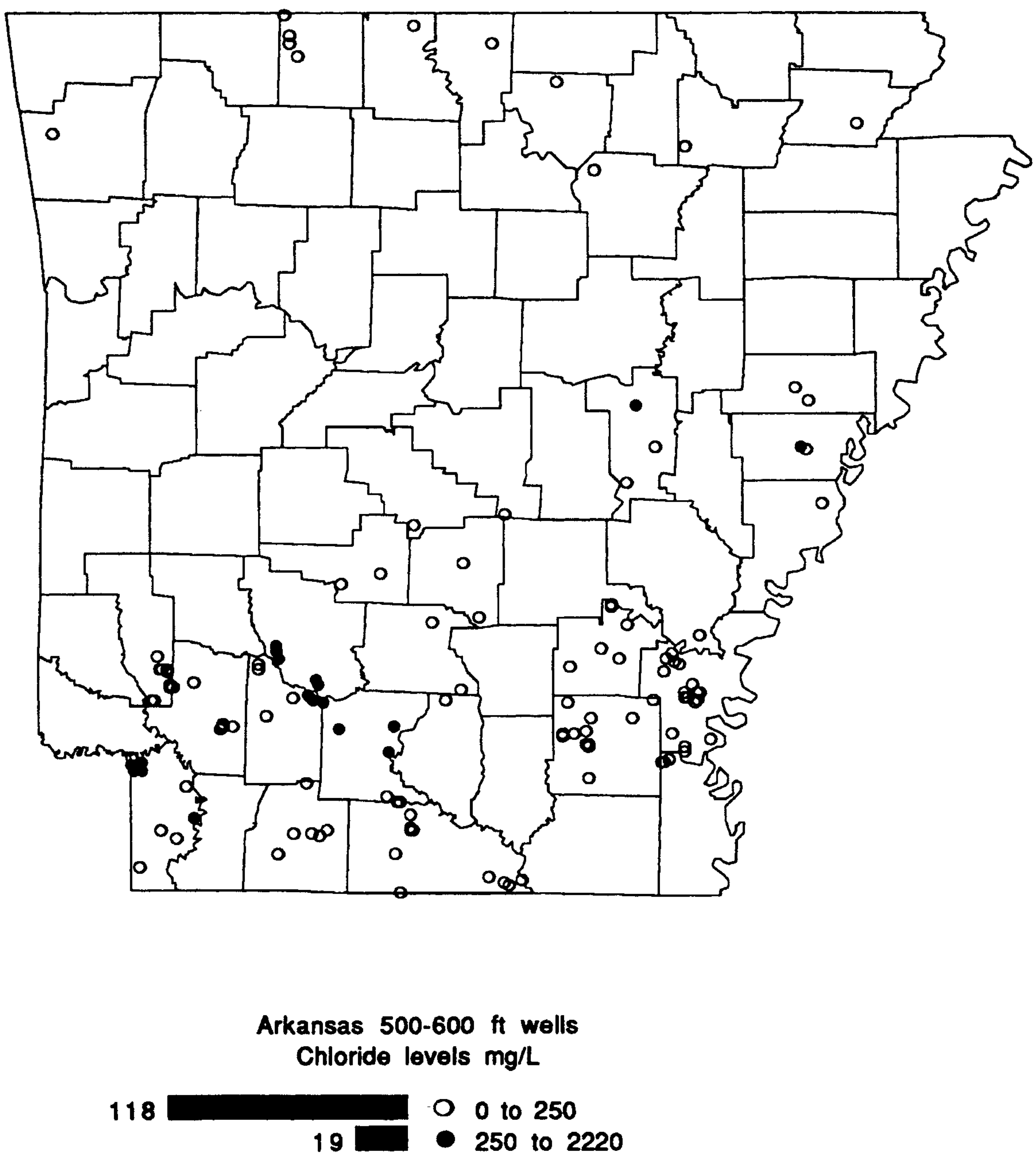



Figure 27. Arkansas 500-600 Foot Interval Chloride Map

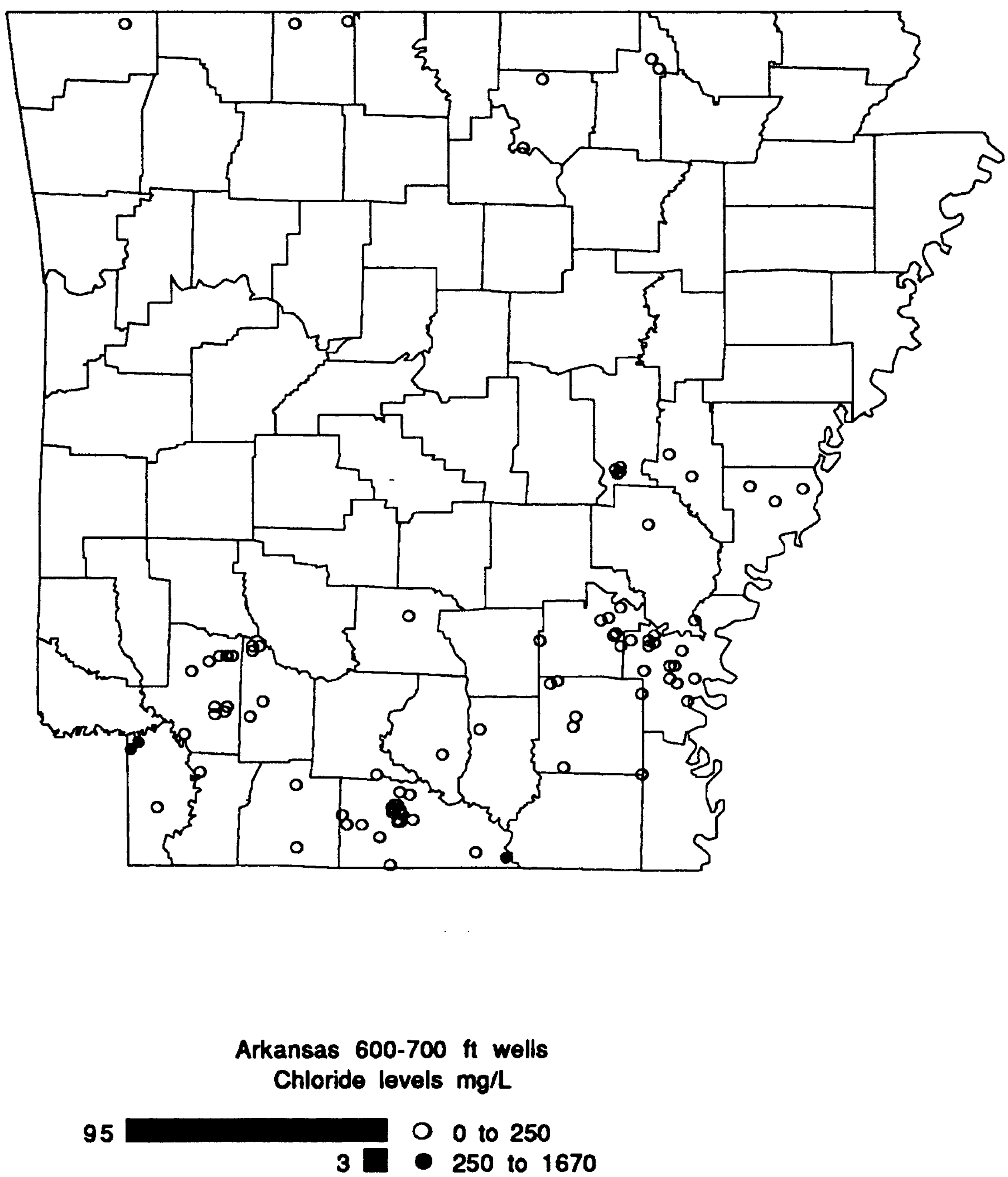



Figure 28. Arkansas 600-700 Foot Interval Chloride Map

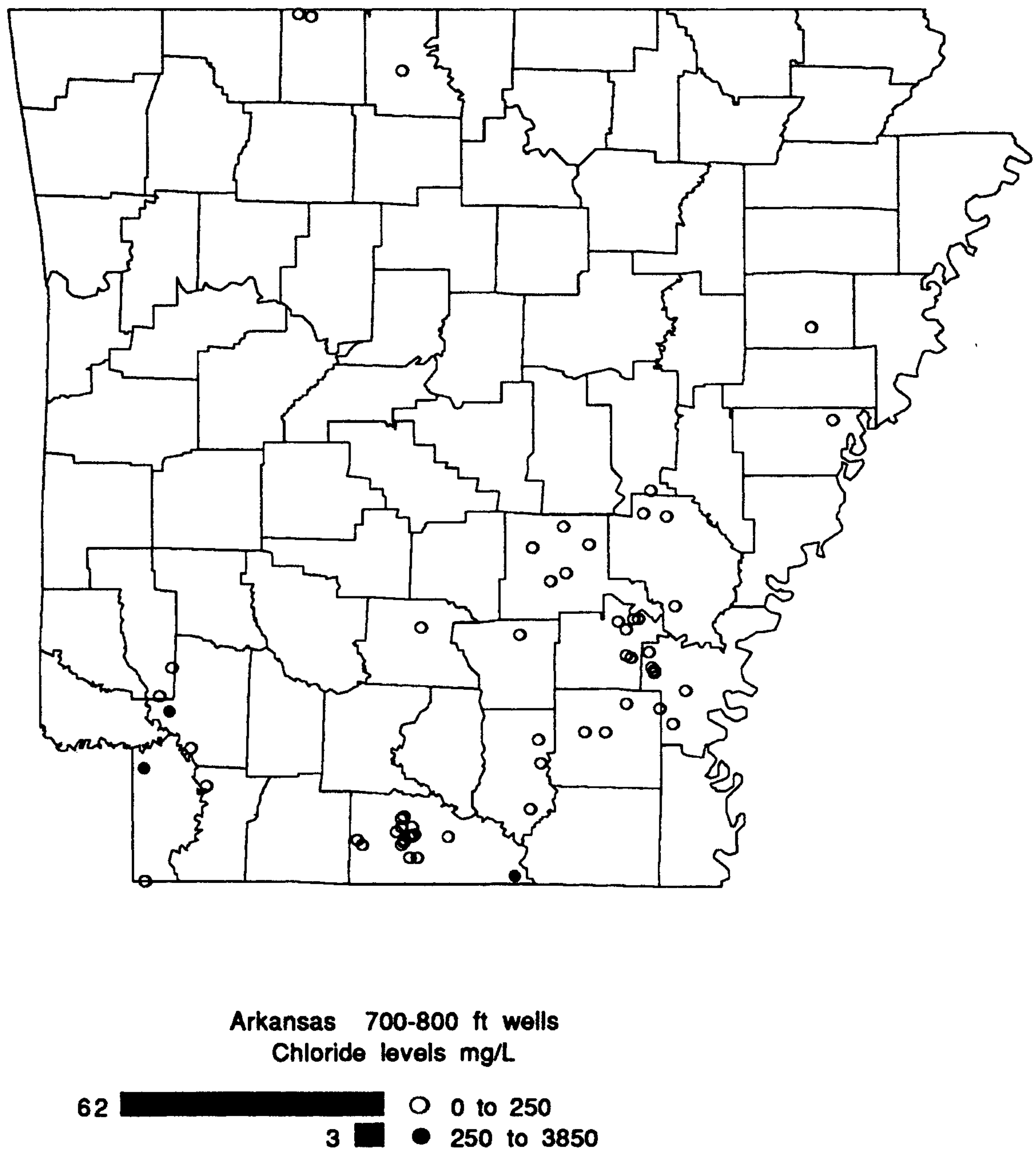



Figure 29. Arkansas 700-800 Foot Interval Chloride Map

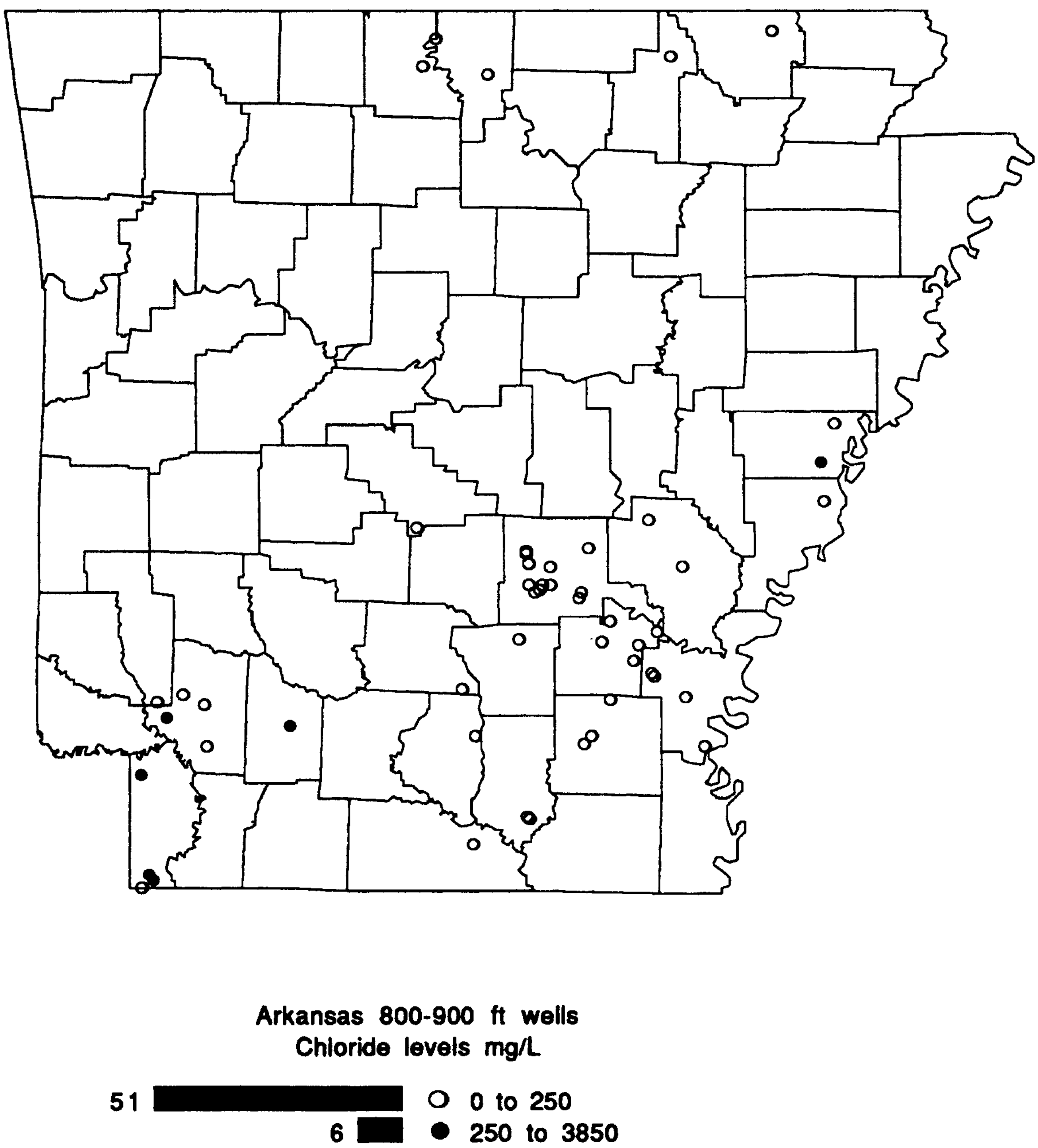



Figure 30. Arkansas 800-900 Foot Interval Chloride Map

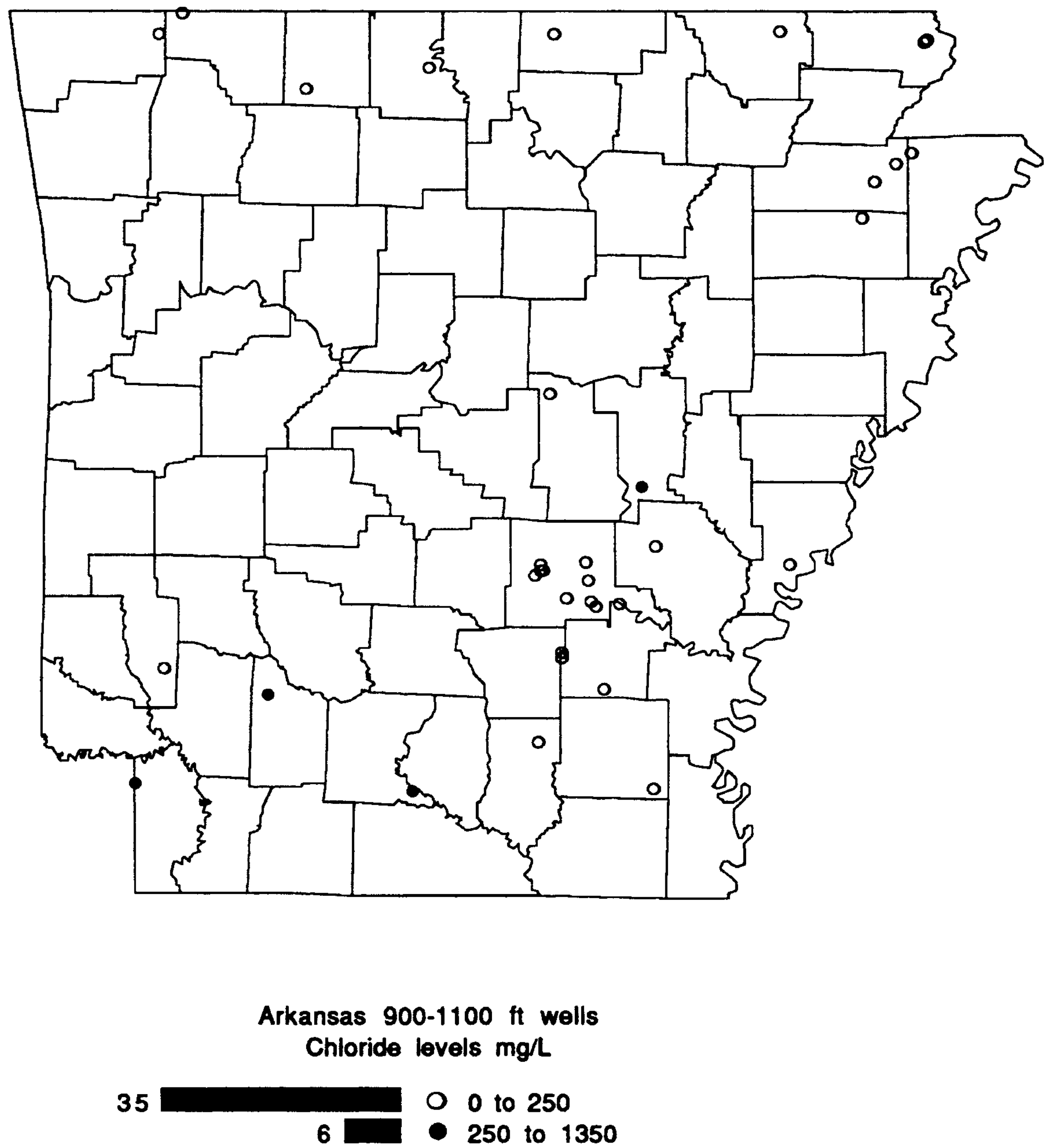



Figure 31. Arkansas 900-1100 Foot Interval Chloride Map

# CALIFORNIA

## General Setting

California, which contains approximately 156,300 square miles, lies in a physiographically diverse region. The broad and flat, northwestern trending, Central Valley is bounded by the rugged mountains and valleys of the Coast Ranges, Kalamath Mountains, Southern Cascade Range, Sierra Nevada, and Transverse, and Peninsular Ranges sub-provinces. Northeastern and southeastern California lie in the arid block faulted mountains, valleys, and plateaus of the Basin and Range and the Southern California Desert.

California's mountains are composed of a variety of folded and faulted, Precambrian to Cenozoic age sedimentary, igneous and metamorphic rocks. Sedimentary and metasedimentary units present include Precambrian to Mesozoic marine age shale, sandstone, conglomerate, limestone and dolomite, and their metamorphic equivalents. Cenozoic rocks include semiconsolidated marine and nonmarine sandstone, shale, conglomerate, siltstone, as wells as igneous intrusive and extrusive rocks. Valley and basin fill deposits generally consist of considerable thicknesses of interbedded unconsolidated, marine and nonmarine, sand, gravel, silt, and clay of Cenozoic age.

Most of California is drained by rivers that originate in the mountainous parts of the state and flow westward to the Pacific Ocean. Rivers in northeast and southeast California commonly terminate in closed basins.

Principal Aquifers

The significant aquifers of California are those in the valley fill, but there are some productive lava rocks in the northern most part of the state (McGunniss, 1963). There are five general areas described by Smith (1988) that serve California as productive aquifer systems. These Include the alluvium and sediments in the Coastal Basin, the alluvium and older sediments in Southern California, the alluvium and older sediments in the Central Valley, the basin fill deposits in desert areas, and the volcanic (lava) rocks in the northwest.

Aquifers in the Coastal Basin consist mainly of alluvium and older sediments that underlie the valleys that drain into the Pacific Ocean from the border of Oregon to Santa Barbara County. The largest valleys are the Santa Clara, Salinas, and the Santa Maria Valleys.

The Central Valley of California, approximately 500 miles long and 20 to 50 miles wide, is one of the most intensively developed irrigated agricultural areas of the state. The valley is divided into two regions, the northern Sacramento Valley and the southern San Joaquin Valley. The alluvium and older sediments that underlie the Central Valley constitute one of the world's most extensive aquifer systems (Spieker, 1986).

The principal aquifers of Southern California are in the coastal plains of Ventura, Los Angeles, and Orange

Counties and in adjacent valleys. The aquifer consists of alluvium and other continental sediments along with deltaic and marine sediments in the coastal areas. The aquifers in the desert areas of southeastern California are composed of alluvium with interbedded lacusterine deposits. Volcanic rock aquifers are located mainly in northern California, on the flanks of the mountain ranges, and along the eastern side of Sacramento Valley. The most often encountered rocks are andesite, rhyolite, and basalt. Most aquifers are situated in fractures, rubble zones, and sand and gravel layers interbedded between lava flows. Principal aquifers of California are outlined in Figure 32.

Chloride Distribution

Chloride maps of California are based upon 8244 stations that are distributed over 23 depth intervals (Table 6). The percentage of wells that exceed 250 mg/L varies from a low of five percent at the 800-900 foot interval to a high of 25 percent at the 1400-1500 foot interval (Table 7). Significant peaks in chloride levels occur at the 0-100, 500-600, 1400-1500, and 1900-2200 foot intervals (fig. 34). Regionally 13 percent (1099) of the wells in California have chloride concentrations greater than the drinking water standard. Areal mapping of each depth interval (Figures. 35-44) suggest the majority of wells in which the chloride concentration exceeds 250 mg/L occur predominantly in the Central Valley. Although less numerous, wells exceeding 250 mg/L also occur in the alluvium of Southern California and in the basin fill deposits of the desert areas. The percentage of wells for each concentration interval plotted against well depth (fig. 33), suggests an over all decrease in the percentage of wells with chloride concentrations in the 0-25 mg/L range with depth, and a general increase with depth in the percentage of wells that have concentrations of chloride greater than 25 mg/L. Tabulated data for California are presented in Tables 6 & 7.

Contamination due to oil field activities in California has not been well documented. General areas of oil and gas production in California (fig. 2) do coincide with areas mapped as having chloride levels in excess of 250 mg/L.

Areas of shallow saline ground water at depths less than 500 feet occur in many parts of the state including large areas such as the San Joaquin Valley and the Colorado River Basin(Feth and others, 1965). Intrusion of sea water in coastal areas due to overdraft of ground water has also been reported. Salinization has occurred by evaporation of ground water at times when the water Table was close to the land surface. Subsequent dissolution of these salts by extensive irrigation has also contributed to the decline in ground water quality in agricultural areas of California.

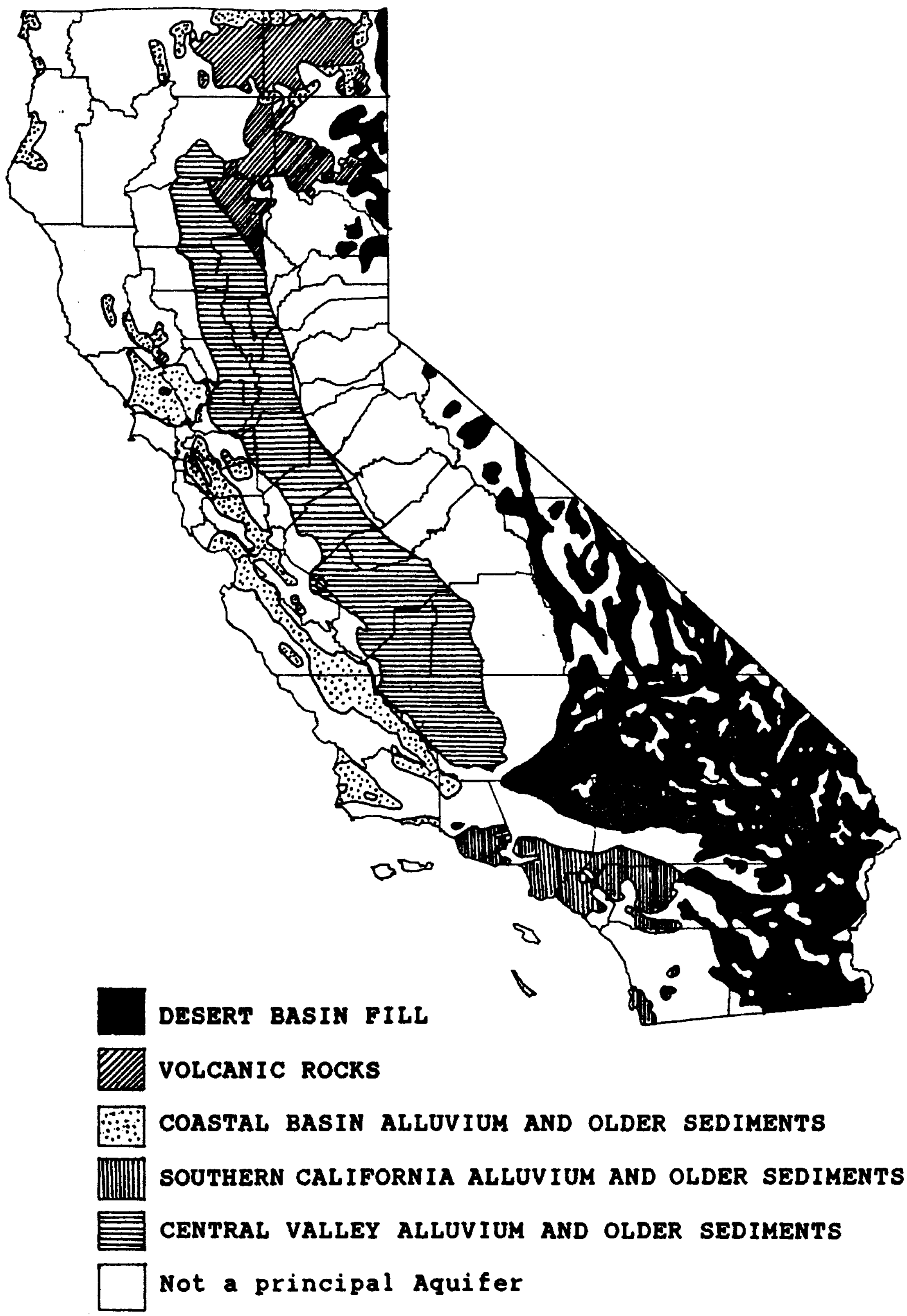



Figure 32. California Principal Aquifers Map
(Modified From U.S.G.S., 1988)

| | Concentration Interval (mg/L) | | | | | total | wells |
|---|---|---|---|---|---|---|---|
| | 0-25 | 25-100 | 100-250 | 250-500 | >500 | wells | >250 |
| Depth Interval (feet) | | | | | | | |
| 0-100 | 532 | 440 | 382 | 177 | 177 | 1708 | 354 |
| 100-200 | 603 | 623 | 399 | 132 | 78 | 1835 | 210 |
| 200-300 | 374 | 445 | 189 | 59 | 44 | 1111 | 103 |
| 300-400 | 240 | 265 | 89 | 41 | 34 | 669 | 75 |
| 400-500 | 186 | 203 | 72 | 40 | 20 | 521 | 60 |
| 500-600 | 280 | 30 | 25 | 22 | 73 | 430 | 95 |
| 600-700 | 144 | 127 | 37 | 16 | 12 | 336 | 28 |
| 700-800 | 113 | 97 | 25 | 10 | 14 | 259 | 24 |
| 800-900 | 107 | 66 | 32 | 3 | 8 | 216 | 11 |
| 900-1000 | 69 | 52 | 18 | 5 | 6 | 150 | 11 |
| 1000-1100 | 51 | 70 | 17 | 8 | 6 | 152 | 14 |
| 1100-1200 | 24 | 34 | 16 | 3 | 6 | 83 | 9 |
| 1200-1300 | 22 | 45 | 18 | 3 | 8 | 96 | 11 |
| 1300-1400 | 10 | 41 | 7 | 2 | 7 | 67 | 9 |
| 1400-1500 | 12 | 41 | 7 | 10 | 10 | 80 | 20 |
| 1500-1600 | 5 | 34 | 8 | 1 | 3 | 51 | 4 |
| 1600-1700 | 1 | 40 | 17 | 4 | 2 | 64 | 6 |
| 1700-1800 | 1 | 51 | 15 | 5 | 1 | 73 | 6 |
| 1800-1900 | 1 | 45 | 21 | 4 | 0 | 71 | 4 |
| 1900-2000 | 1 | 33 | 12 | 6 | 5 | 57 | 11 |
| 2000-2100 | 1 | 49 | 41 | 12 | 4 | 107 | 16 |
| 2100-2200 | 1 | 44 | 24 | 12 | 3 | 84 | 15 |
| 2200-2400 | 1 | 15 | 5 | 1 | 2 | 24 | 3 |
| State Total | 2779 | 2890 | 1476 | 576 | 523 | 8244 | 1099 |
| Percent Of Wells With Concentrations Greater Than 250mg/L | | | | | | | 13 |

TABLE 6. NUMBER OF STATIONS PER DEPTH AND CONCENTRATION INTERVAL IN CALIFORNIA

| | Concentration Interval (mg/L) | | | | | |
|---|---|---|---|---|---|---|
| | 0-25 | 25-100 | 100-250 | 250-500 | >500 | >250 |
| Depth Interval (feet) | | | | | | |
| 0-100 | 31 | 26 | 22 | 10 | 10 | 21 |
| 100-200 | 33 | 34 | 22 | 7 | 4 | 11 |
| 200-300 | 34 | 40 | 17 | 5 | 4 | 9 |
| 300-400 | 36 | 40 | 13 | 6 | 5 | 11 |
| 400-500 | 36 | 39 | 14 | 8 | 4 | 12 |
| 500-600 | 65 | 7 | 6 | 5 | 17 | 22 |
| 600-700 | 43 | 38 | 11 | 5 | 4 | 8 |
| 700-800 | 44 | 37 | 10 | 4 | 5 | 9 |
| 800-900 | 50 | 31 | 15 | 1 | 4 | 5 |
| 900-1000 | 46 | 35 | 12 | 3 | 4 | 7 |
| 1000-1100 | 34 | 46 | 11 | 5 | 4 | 9 |
| 1100-1200 | 29 | 41 | 19 | 4 | 7 | 11 |
| 1200-1300 | 23 | 47 | 19 | 3 | 8 | 11 |
| 1300-1400 | 15 | 61 | 10 | 3 | 10 | 13 |
| 1400-1500 | 15 | 51 | 9 | 13 | 13 | 25 |
| 1500-1600 | 10 | 67 | 16 | 2 | 6 | 8 |
| 1600-1700 | 2 | 63 | 27 | 6 | 3 | 9 |
| 1700-1800 | 1 | 70 | 21 | 7 | 1 | 8 |
| 1800-1900 | 1 | 63 | 30 | 6 | 0 | 6 |
| 1900-2000 | 2 | 58 | 21 | 11 | 9 | 19 |
| 2000-2100 | 1 | 46 | 38 | 11 | 4 | 15 |
| 2100-2200 | 1 | 52 | 29 | 14 | 4 | 18 |
| 2200-2400 | 4 | 63 | 21 | 4 | 8 | 13 |

TABLE 7. PERCENT OF STATIONS PER DEPTH AND CONCENTRATION INTERVAL IN CALIFORNIA

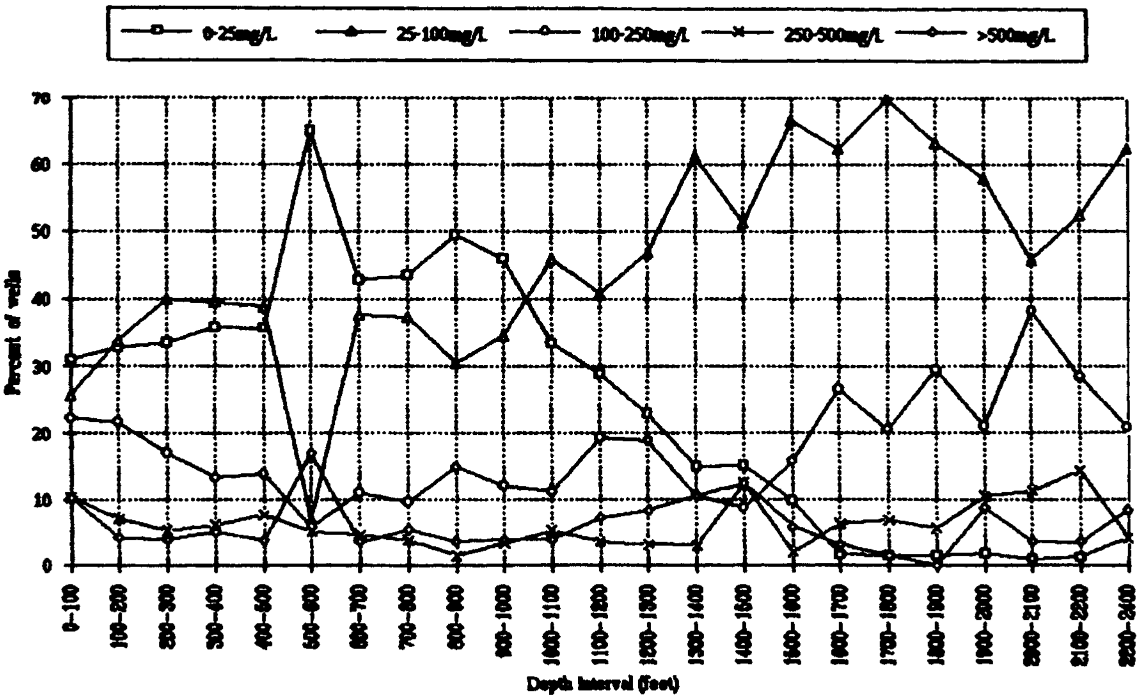



**Figure 33. California Percent Of Wells Per Concentration Interval vs Well Depth**

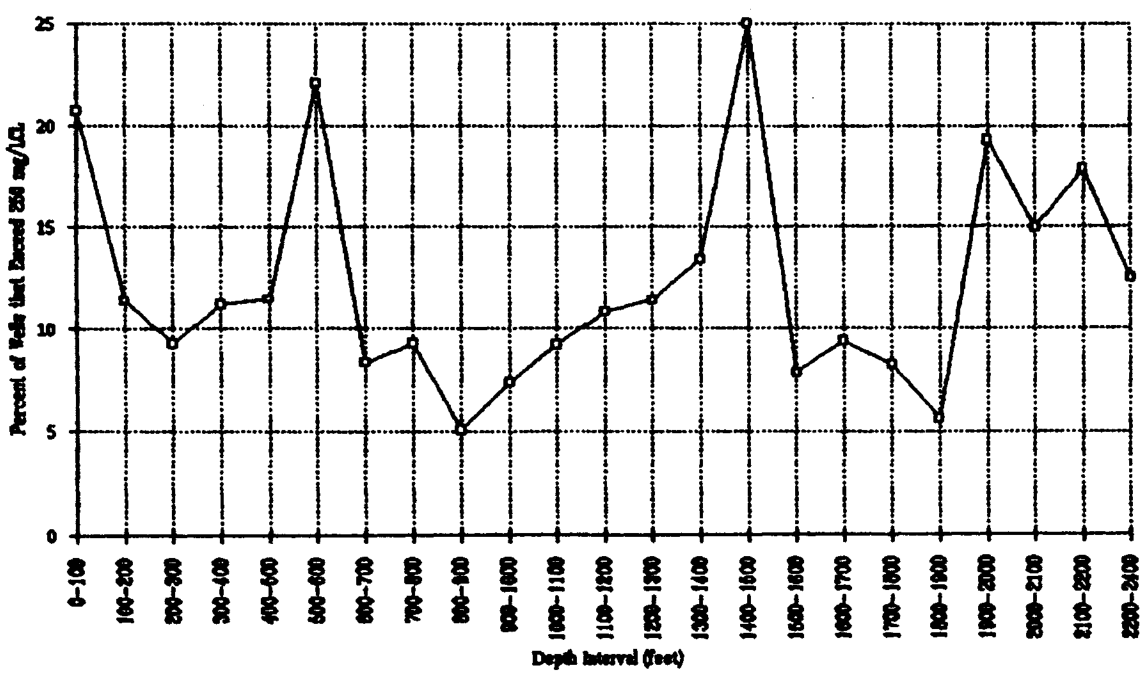



**Figure 34. California Percent Of Wells That Exceed 250 mg/L Chloride**

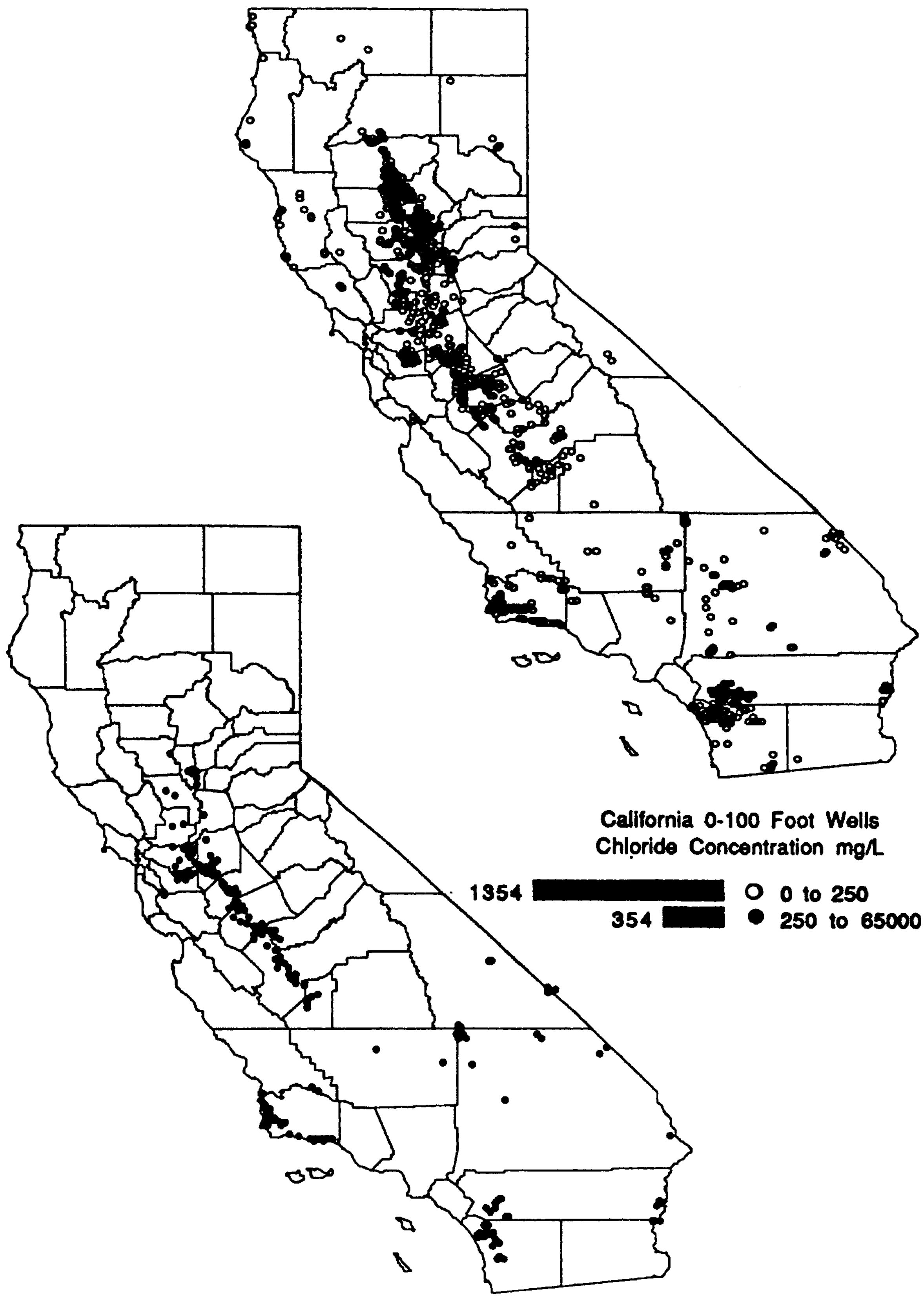



Figure 35. California 0-100 Foot Interval Chloride Map

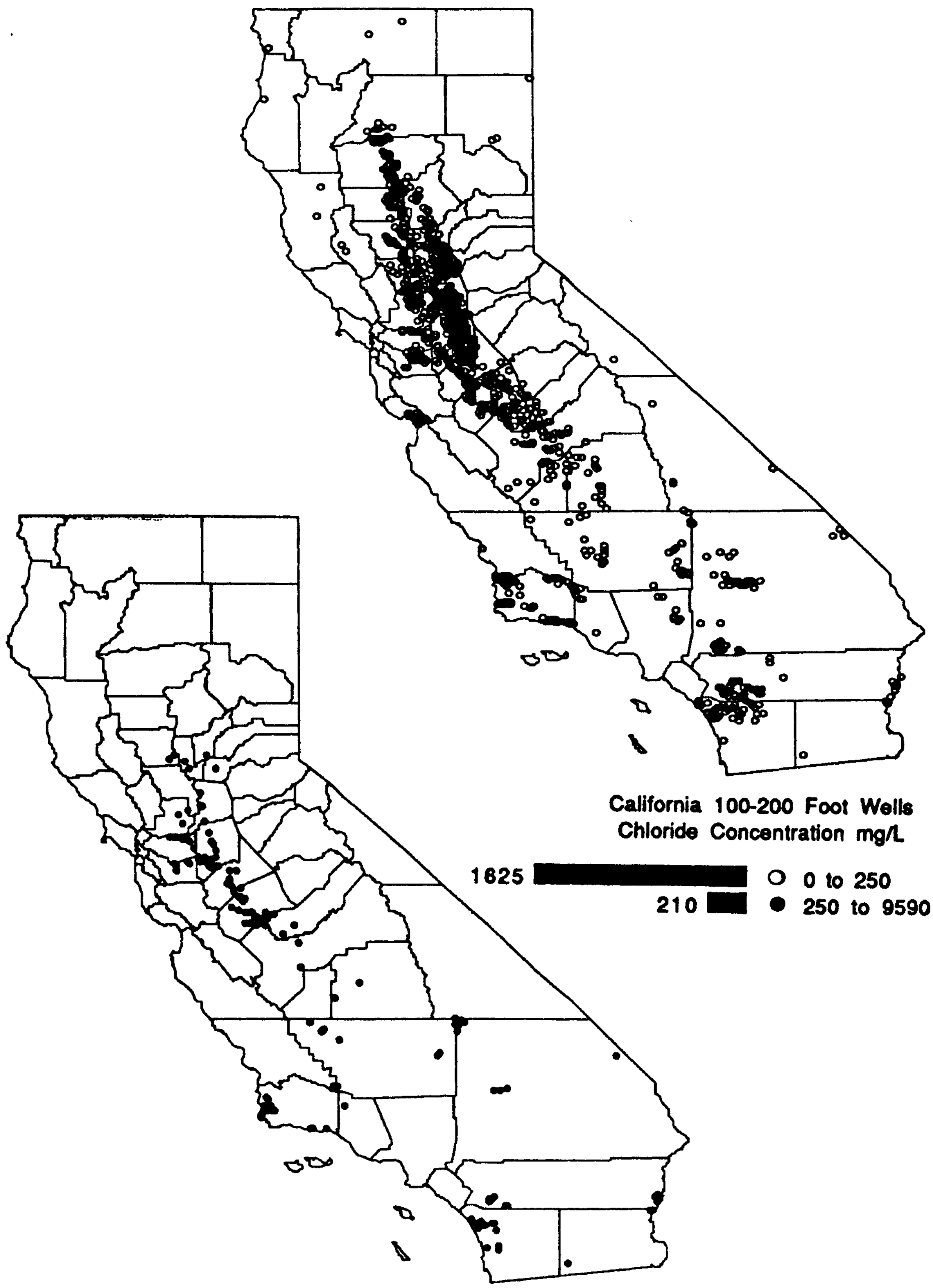



Figure 36. California 100-200 Foot Interval Chloride Map

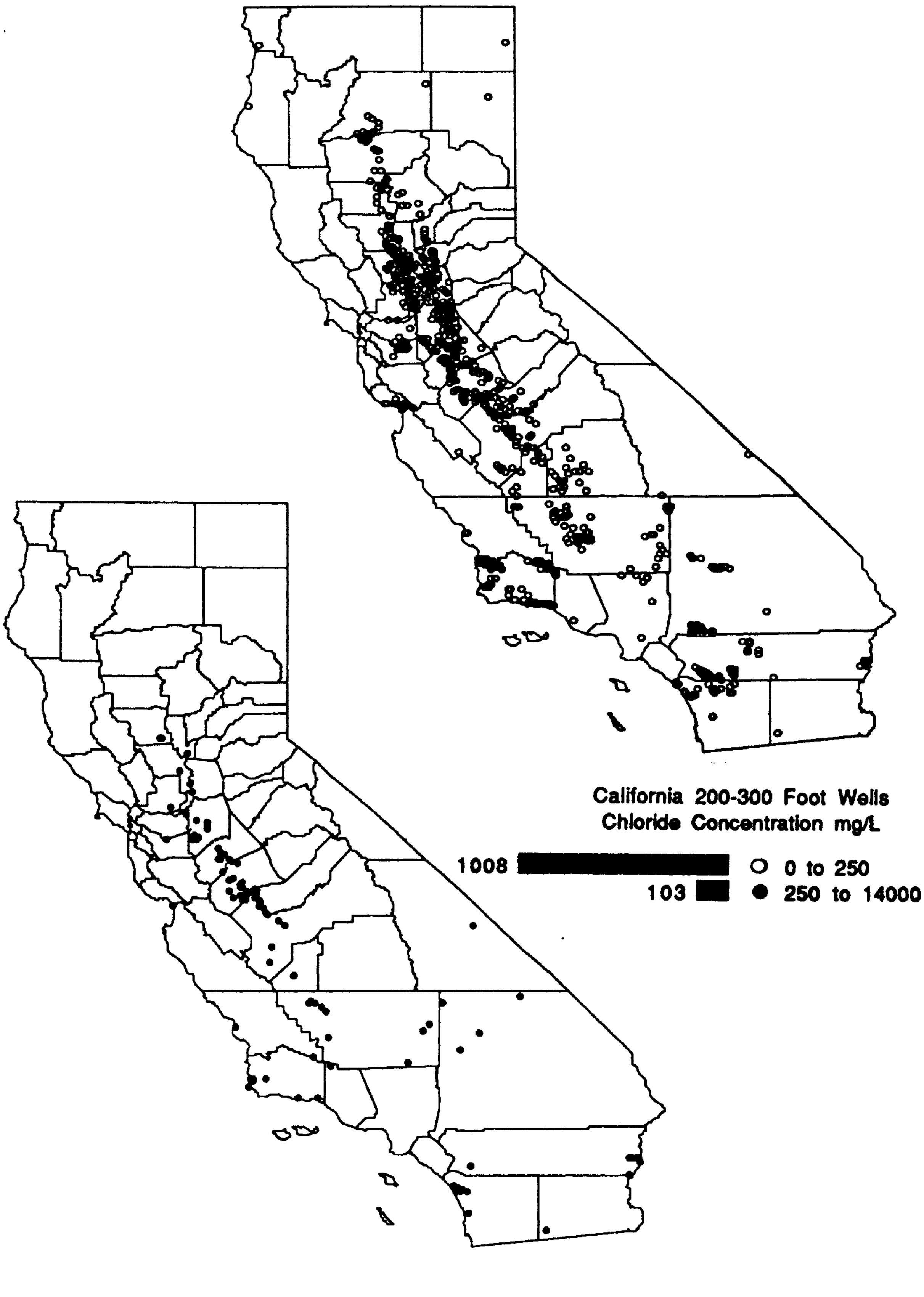



Figure 37. California 200-300 Foot Interval Chloride Map

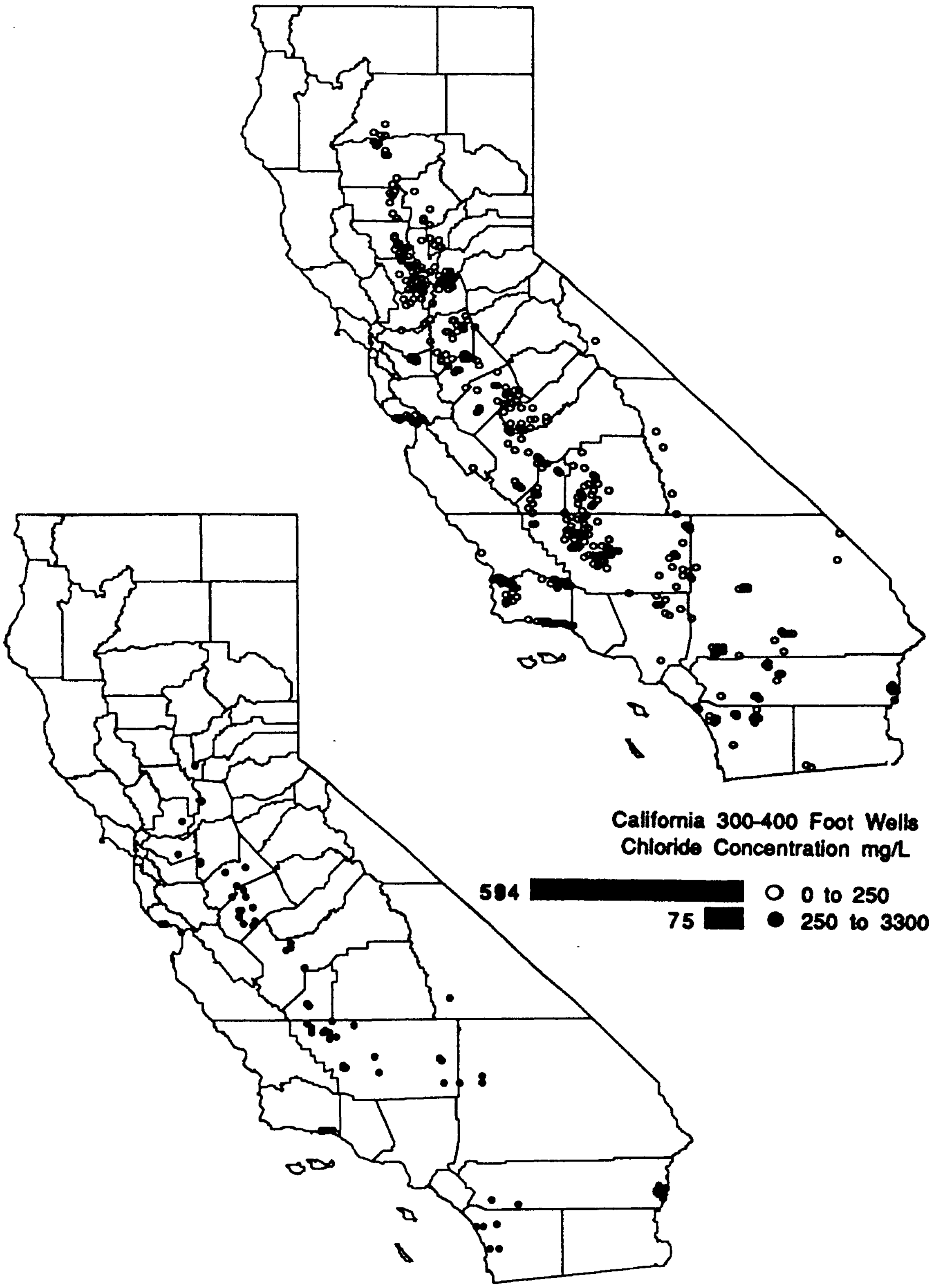



Figure 38. California 300-400 Foot Interval Chloride Map

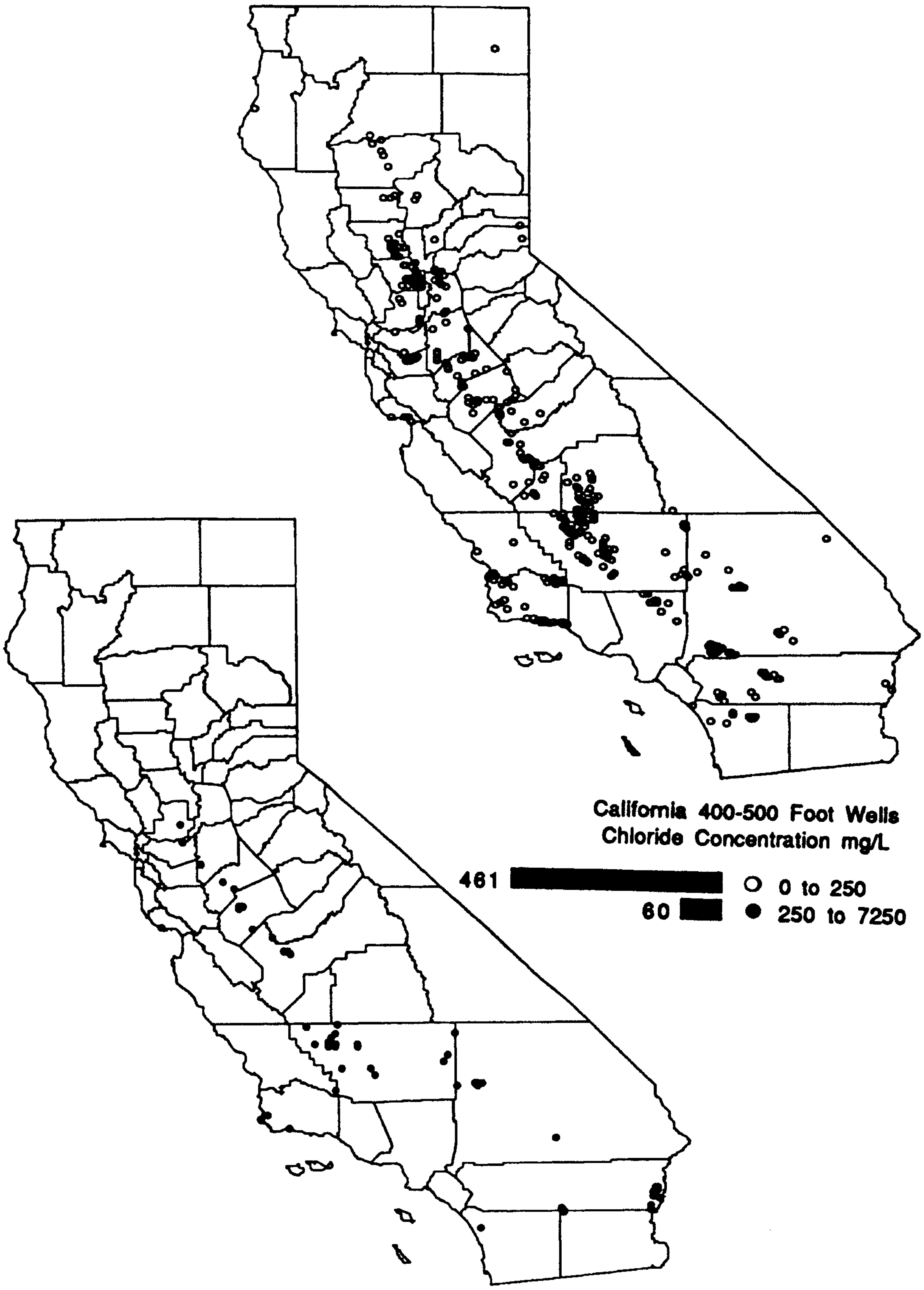



Figure 39. California 400-500 Foot Interval Chloride Map

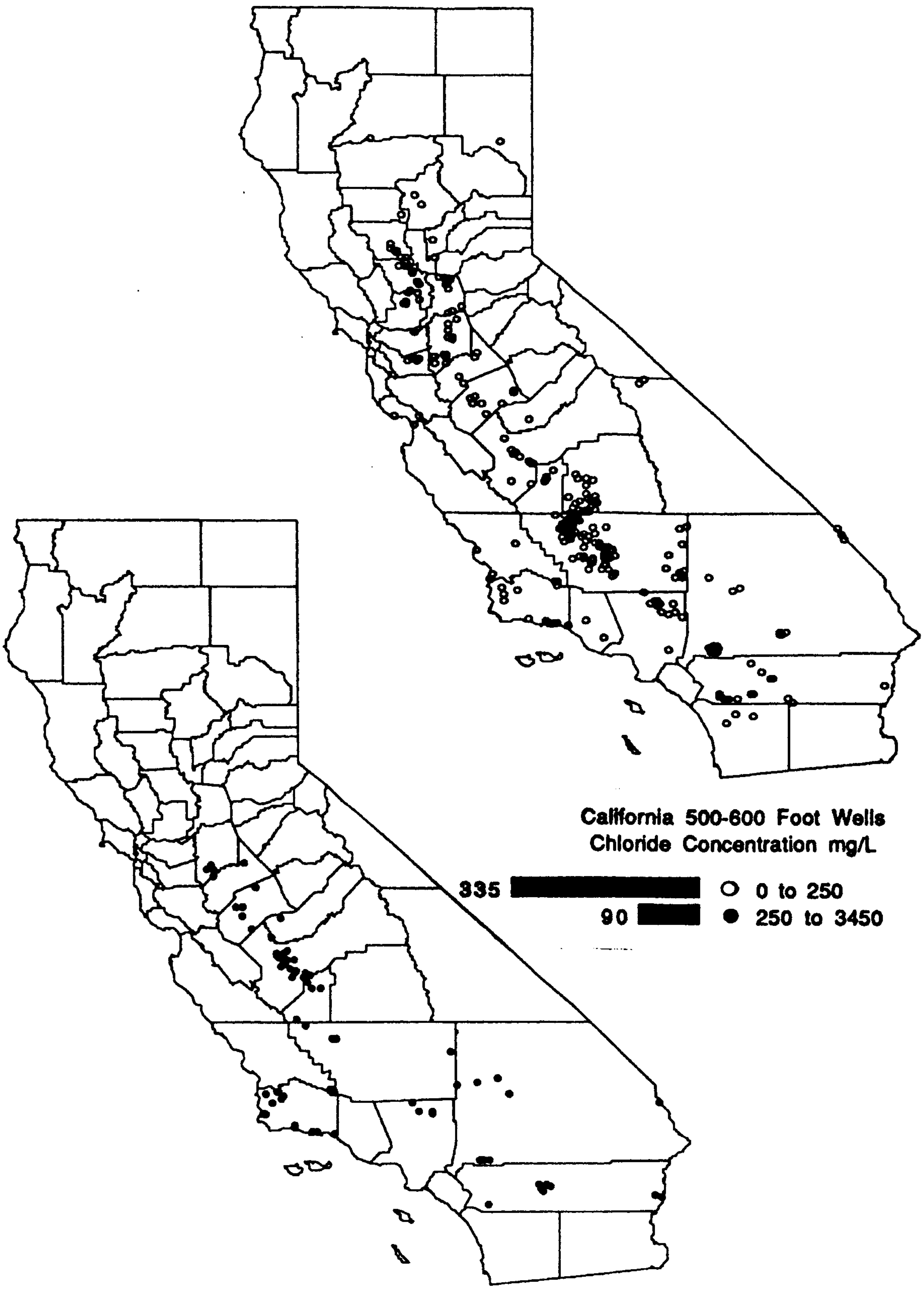



Figure 40. California 500-600 Foot Interval Chloride Map

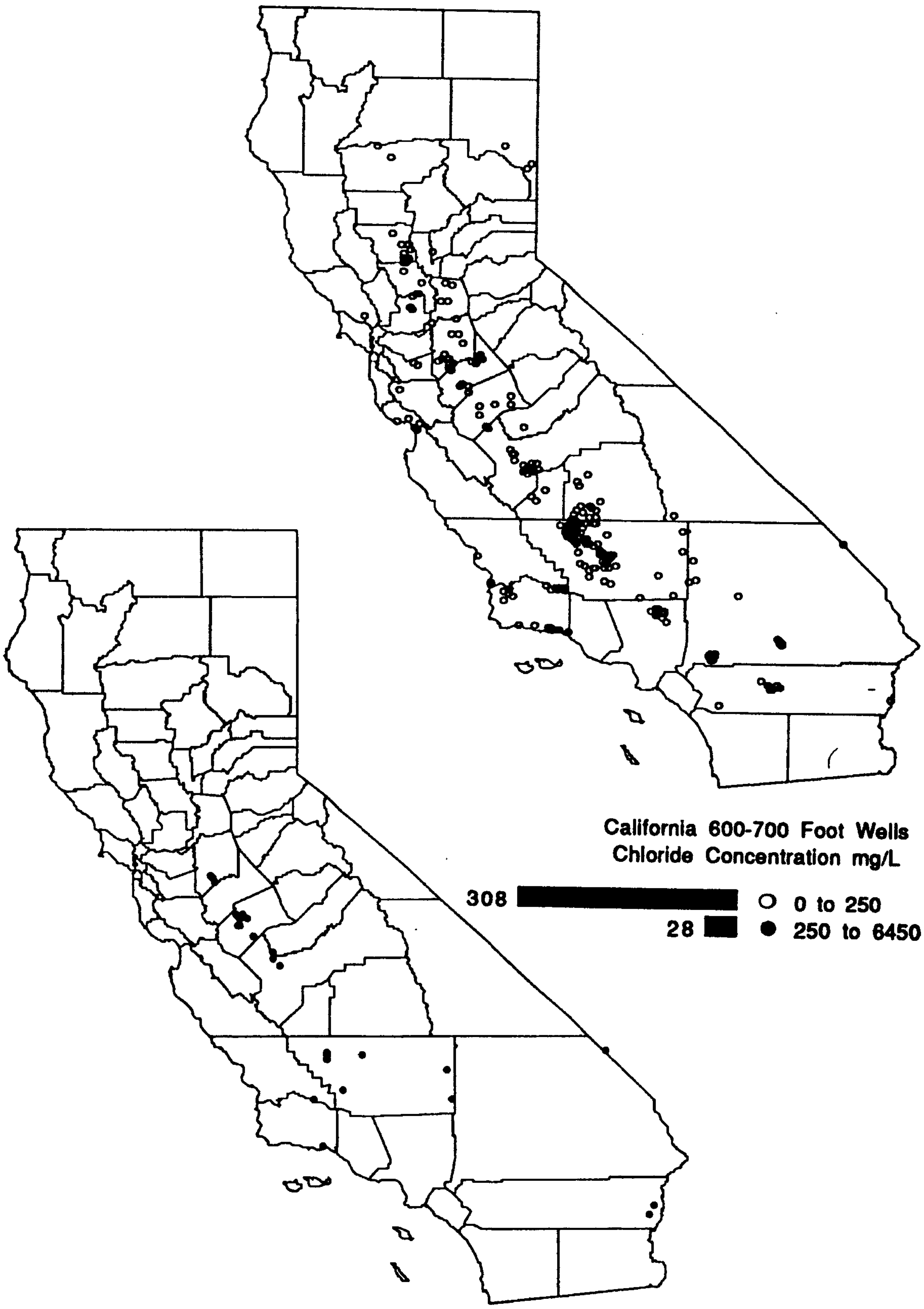



Figure 41. California 600-700 Foot Interval Chloride Map

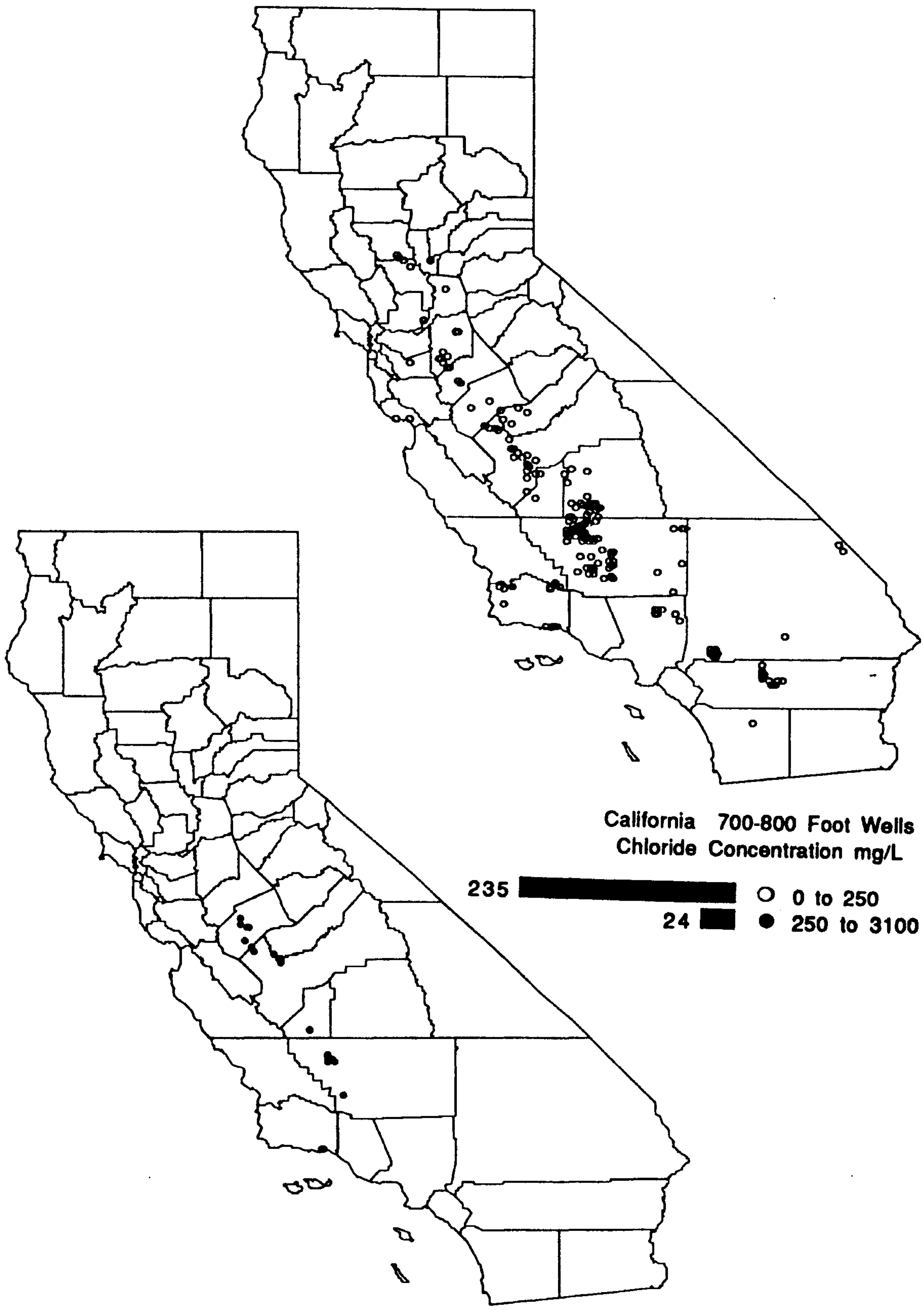



Figure 42. California 700-800 Foot Interval Chloride Map

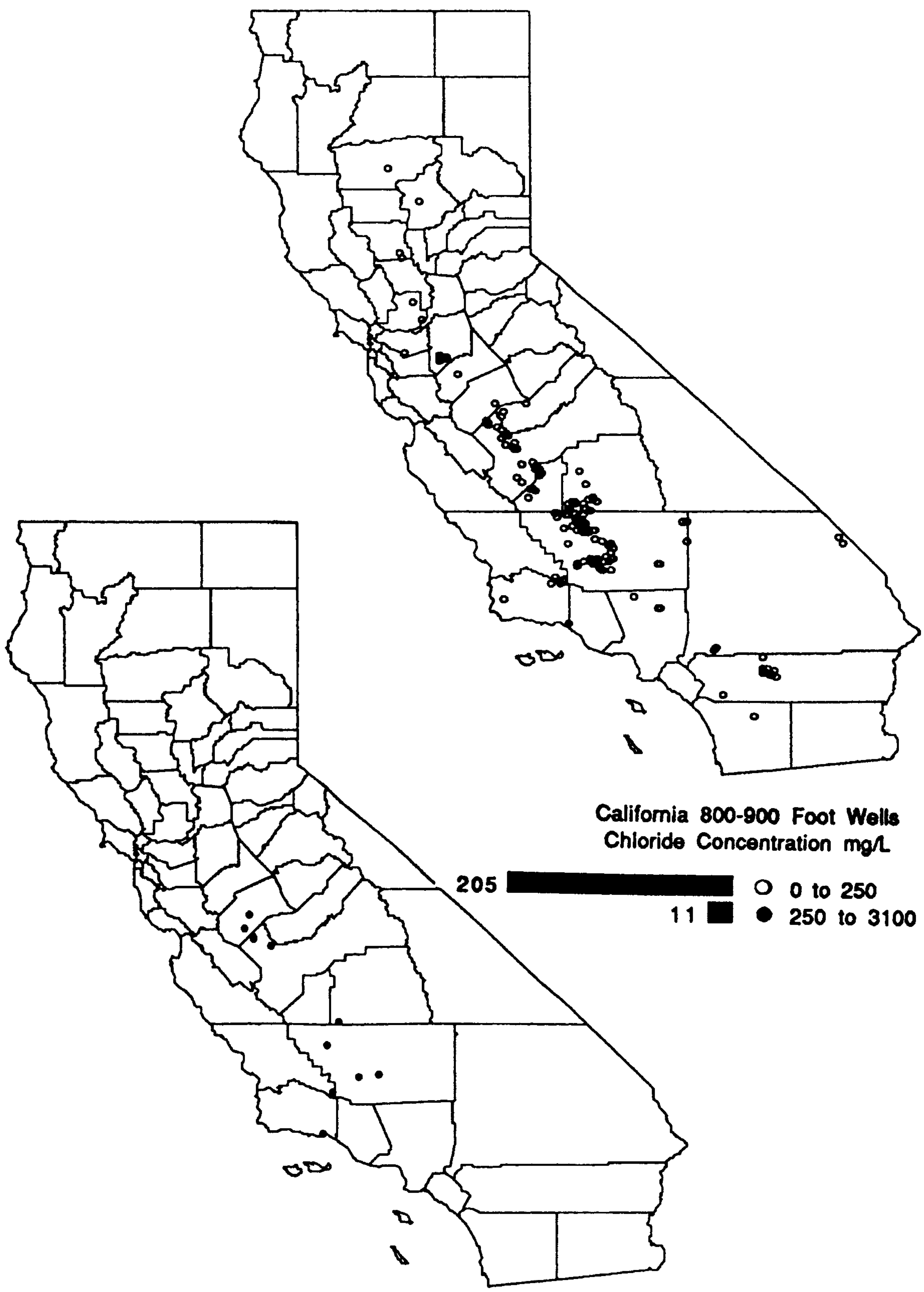



Figure 43. California 800-900 Foot Interval Chloride Map

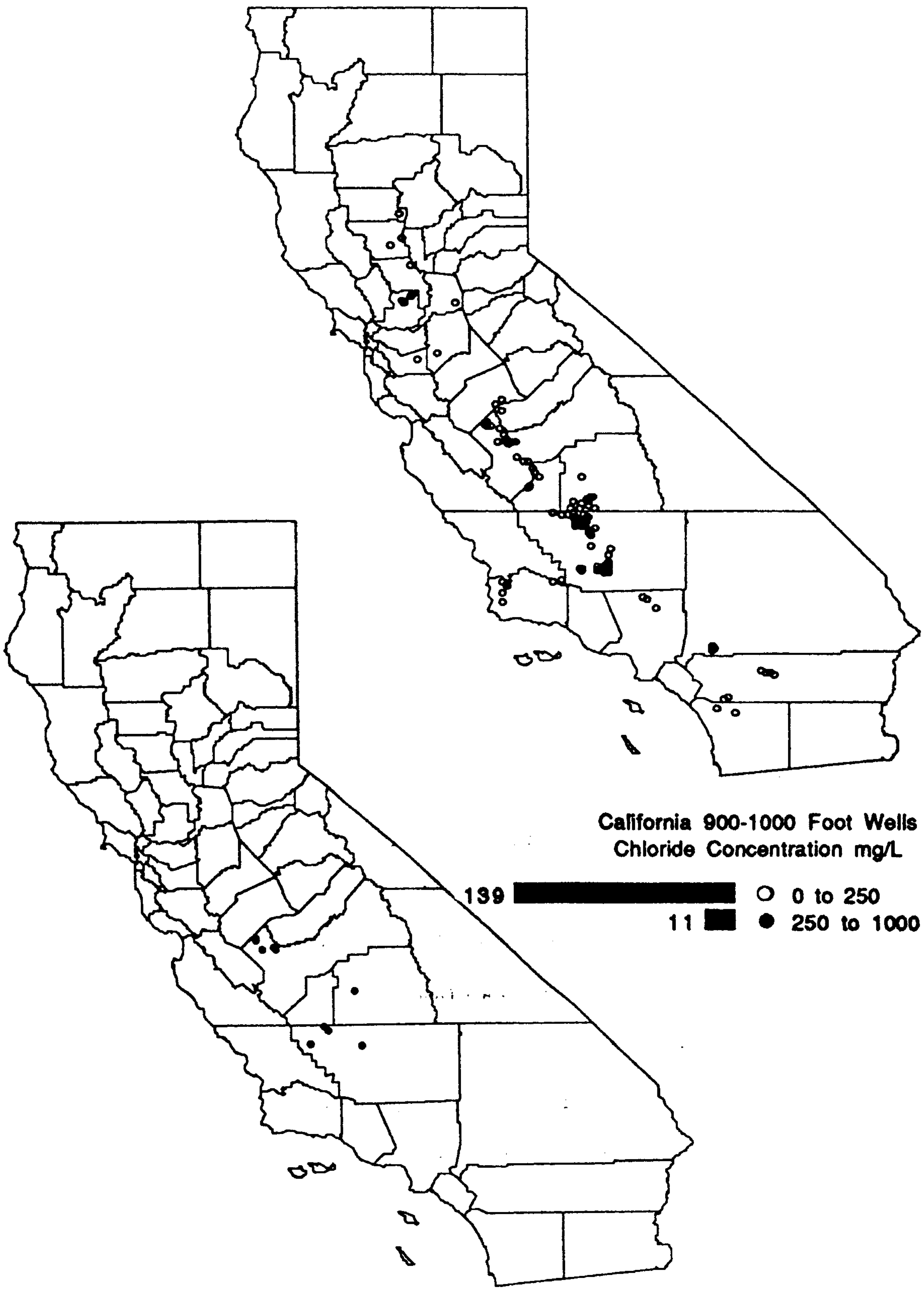



Figure 44. California 900-1000 Foot Interval Chloride Map

# COLORADO

## General Setting

Colorado which contains 103,600 square miles, lies in the high plains, mountains, valleys, and dissected plateaus of the Great Plains, Southern and Middle Rocky Mountains, Wyoming Basin, and Colorado Plateau provinces. The mountains of central and northern Colorado consist largely of faulted Precambrian age metamorphic and igneous rocks, flanked by steeply dipping Paleozoic and Mesozoic age clastic and carbonate sedimentary units. The mountains of southern and west central Colorado are composed of Tertiary age volcanic and granitic rocks, as well as Paleozoic clastic and carbonate sediments.

The plateaus and plains of western and eastern Colorado are underlain by relatively flat lying, consolidated to semiconsolidated Mesozoic and Cenozoic age clastic rocks. Unconsolidated, alluvial, eolian, and glacial deposits occur throughout the state. Surface drainage in Colorado is controlled by the continental divide. The eastern half of the state is drained by the east-flowing South Platte River, Arkansas River, and their tributaries. The western half of Colorado is drained by the Colorado, Gunnison, Green, and San Juan rivers.

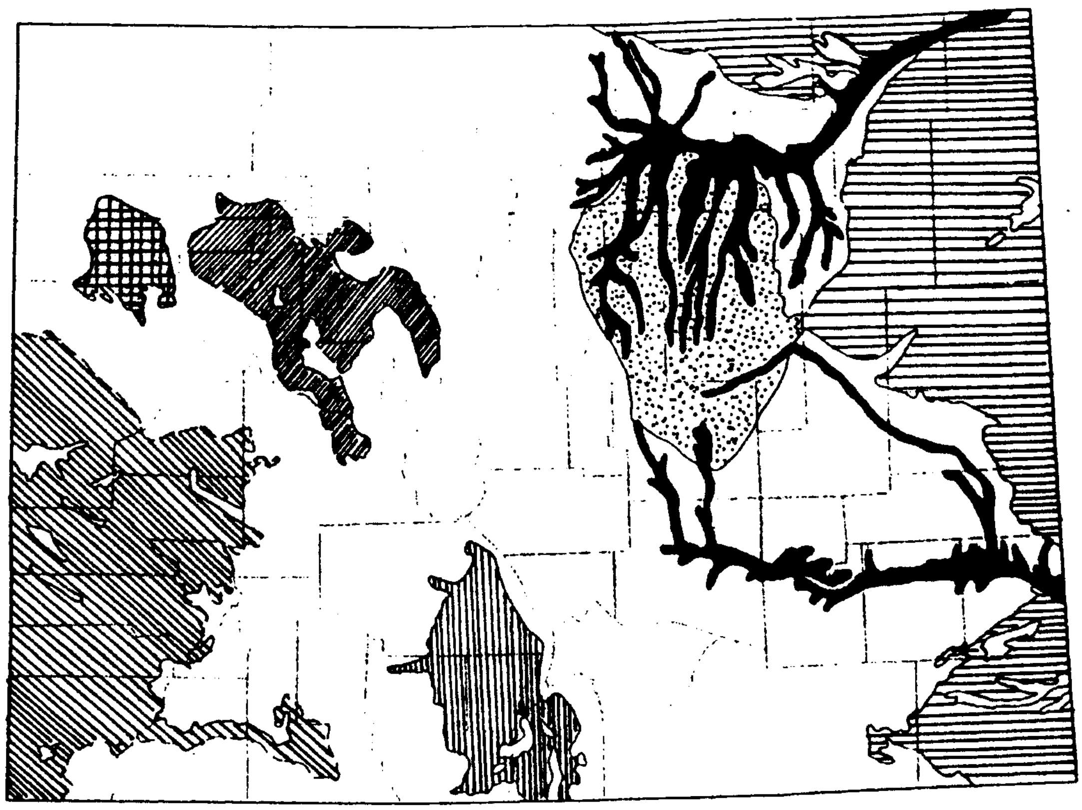
## Principal Aquifers

Colorado is primarily dependant upon surface water for supplies west of the Rocky Mountains. Figure 45 illustrates the principal ground-water resources in the state. In the southwestern part of Colorado principal aquifers consist of the Cretaceous age Dakota Sandstone, and the Morrison Formation and the Entrada Sandstone both of which are Jurassic in age. The northwestern part of the state also derives ground-water supplies from the Leadville Limestone and the Piceance Basin aquifer system. The eastern half of Colorado derives ground water supplies from the South Platt and Arkansas alluvial aquifer systems, the Ogallala High Plains aquifer and the Denver Basin system. In the south central part of the state the San Luis Valley aquifer system provides ground water supplies.

## Chloride Distribution

Chloride maps of Colorado are based on 1681 stations distributed over 11 depth intervals (Table 8). Regionally four percent (67) of the states well exceed 250 mg/L chloride. Areal Distribution maps of Colorado (Figures. 48-58) suggest several areas where chloride levels in excess of 250 mg/L can be found. The 0-100 foot depth interval map (fig. 48) reveals chloride levels in excess of 250 mg/L are located in the south central San Luis Valley aquifer system. Significant numbers of wells along the South Platt Alluvial aquifer system in northeastern Colorado also have elevated chloride. Graphing depth vs percent of wells per concentration interval(fig. 46) shows a gradual increase in the percentage of wells with chloride levels in the 0-25 mg/L range, until the 500-600 foot well interval. At the 700-800 foot interval the percentage of wells with chloride levels less than 25 mg/L falls dramatically from over 70 percent to 30 percent. The number of wells with Chloride levels in excess of 100-250 mg/L and greater than 500 mg/L dramatically increase, this trend is reversed in the 800-900 foot well interval(fig 46). The percentage of Colorado wells that exceed 250 mg/L chloride is less than five percent for all mapped well intervals with the exception of seven percent for the 500-600 foot interval and 42 percent in the 700-800 foot interval.(fig. 47) Interestingly the areal distribution of the wells in the 700-800 foot interval(fig. 55) with elevated chloride levels are distributed state wide and do not appear to limit themselves to any one aquifer.

Disposal of brine and abandonment of wells has led to numerous occurrences of ground water pollution in Colorado (Richter, 1991). The South Platt River Basin is probably affected by oil field activities. Chloride maps show levels that exceed 250 mg/L are found in Weld, Adams, Denver, and Morgon counties.



ALLUVIAL AQUIFERS

DENVER BASIN AQUIFER SYSTEM

HIGH PLAINS AQUIFER

SAN LUIS VALLEY AQUIFER SYSTEM

PICEANCE BASIN AQUIFER SYSTEM

LEADVILLE LIMESTONE

DAKOTA-MORRISON-ENTRADA

Not a principal aquifer

Figure 45. Colorado Principal Aquifers Map
(Modified From U.S.G.S., 1986)

| | Concentration Interval (mg/L) | | | | | total | wells |
|---|---|---|---|---|---|---|---|
| | 0-25 | 25-100 | 100-250 | 250-500 | >500 | wells | >250 |
| Depth Interval (feet) | | | | | | | |
| 0-100 | 367 | 264 | 125 | 18 | 19 | 793 | 37 |
| 100-200 | 199 | 58 | 12 | 1 | 6 | 276 | 7 |
| 200-300 | 148 | 37 | 10 | 0 | 1 | 196 | 1 |
| 300-400 | 106 | 14 | 6 | 0 | 0 | 126 | 0 |
| 400-500 | 46 | 8 | 1 | 0 | 0 | 55 | 0 |
| 500-600 | 27 | 8 | 1 | 3 | 0 | 39 | 3 |
| 600-700 | 30 | 8 | 1 | 0 | 0 | 39 | 0 |
| 700-800 | 11 | 1 | 9 | 3 | 12 | 36 | 15 |
| 800-900 | 15 | 1 | 0 | 0 | 0 | 16 | 0 |
| 900-1000 | 12 | 2 | 0 | 0 | 0 | 14 | 0 |
| 1000-5000 | 69 | 11 | 7 | 1 | 3 | 91 | 4 |
| State Total | 1030 | 412 | 172 | 26 | 41 | 1681 | 67 |
| Percent of Wells With Concentrations Greater Than 250mg/L | | | | | | | 4 |

TABLE 8. NUMBER OF STATIONS PER DEPTH AND CONCENTRATION INTERVAL IN COLORADO

| | Concentration Interval (mg/L) | | | | | |
|---|---|---|---|---|---|---|
| | 0-25 | 25-100 | 100-250 | 250-500 | >500 | >250 |
| Depth Interval (feet) | | | | | | |
| 0-100 | 46 | 33 | 16 | 2 | 2 | 5 |
| 100-200 | 72 | 21 | 4 | 0 | 2 | 3 |
| 200-300 | 76 | 19 | 5 | 0 | 1 | 1 |
| 300-400 | 84 | 11 | 5 | 0 | 0 | 0 |
| 400-500 | 84 | 15 | 2 | 0 | 0 | 0 |
| 500-600 | 69 | 21 | 3 | 8 | 0 | 8 |
| 600-700 | 77 | 21 | 3 | 0 | 0 | 0 |
| 700-800 | 31 | 3 | 25 | 8 | 33 | 42 |
| 800-900 | 94 | 6 | 0 | 0 | 0 | 0 |
| 900-1000 | 86 | 14 | 0 | 0 | 0 | 0 |
| 1000-5000 | 76 | 12 | 8 | 1 | 3 | 4 |

TABLE 9. PERCENT OF STATIONS PER DEPTH AND CONCENTRATION INTERVAL IN COLORADO

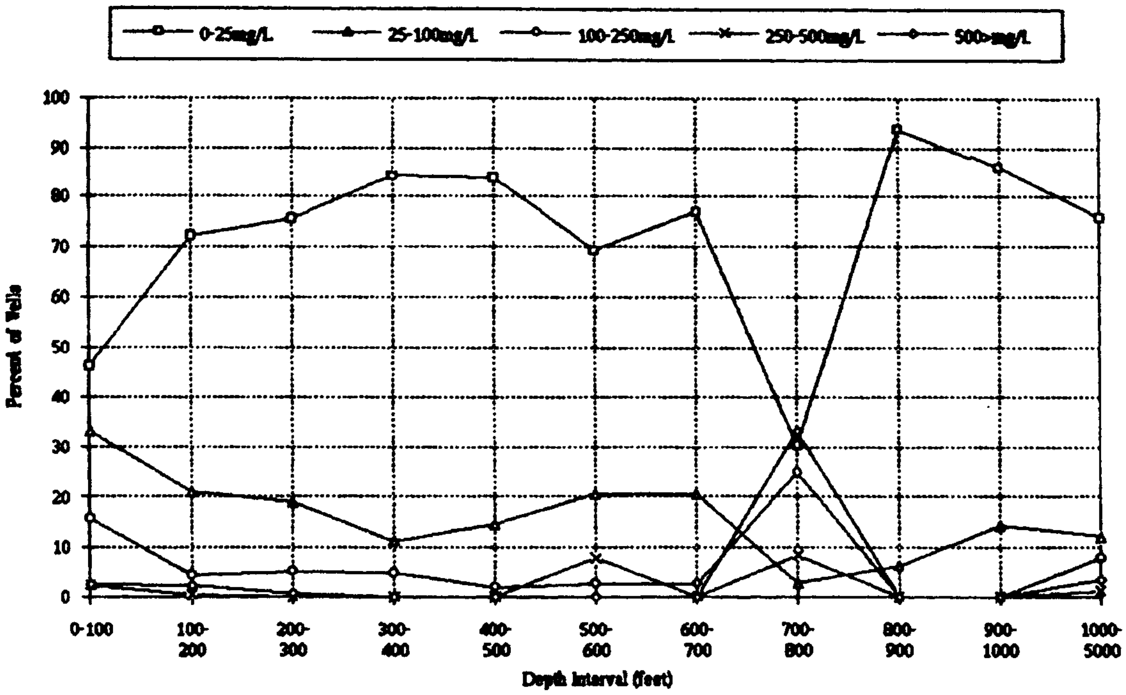



**Figure 46. Colorado Percent Of Wells Per Concentration Interval vs Well Depth**

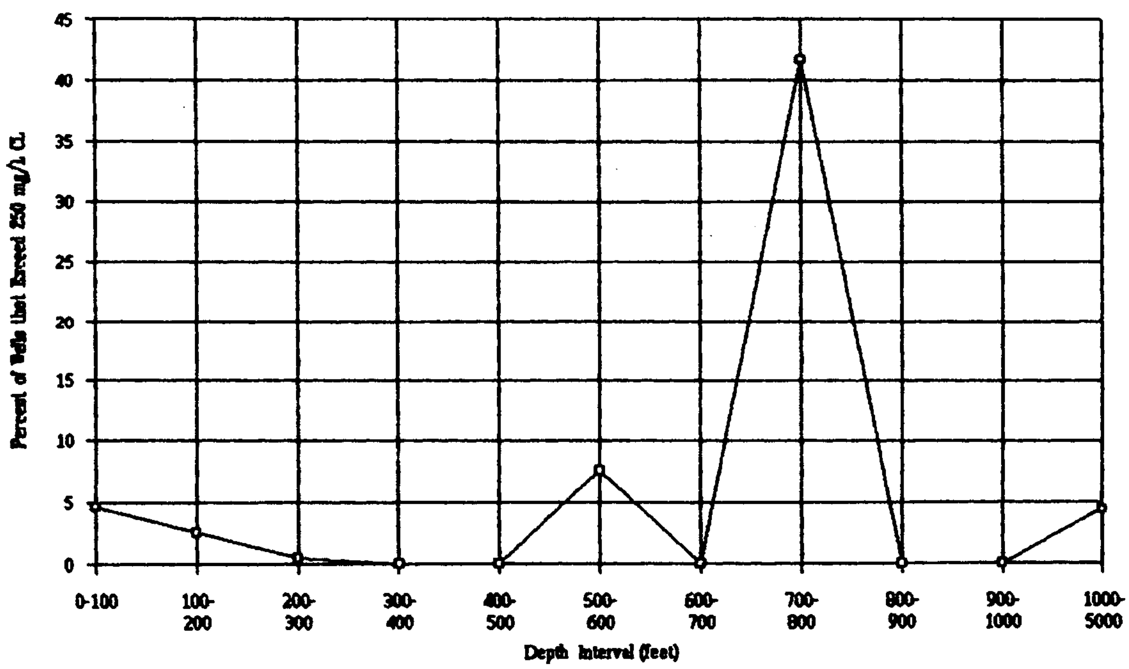



**Figure 47. Colorado Percent Of Wells That Exceed 250 mg/l Chloride**

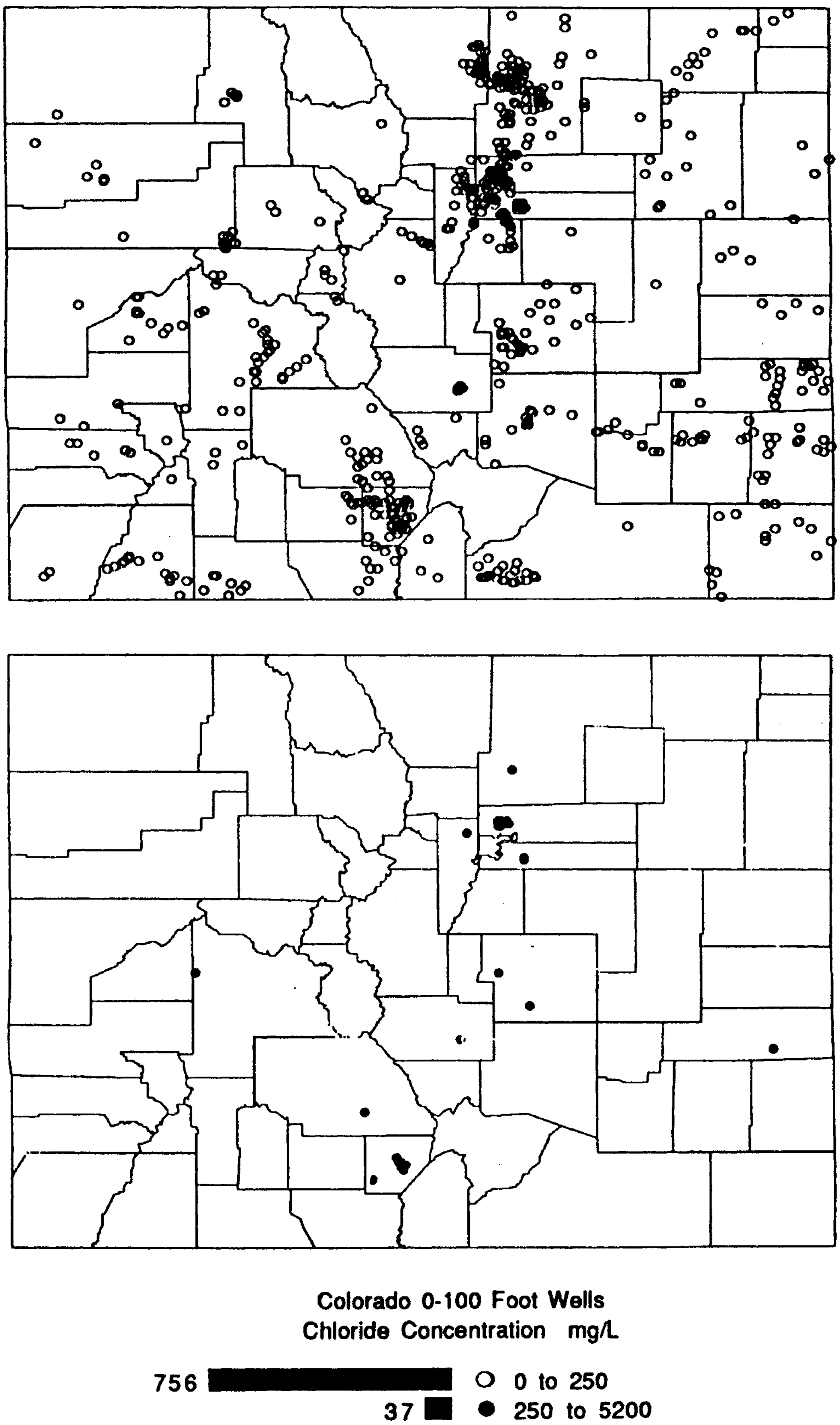



Figure 48. Colorado 0-100 Foot Interval Chloride Map

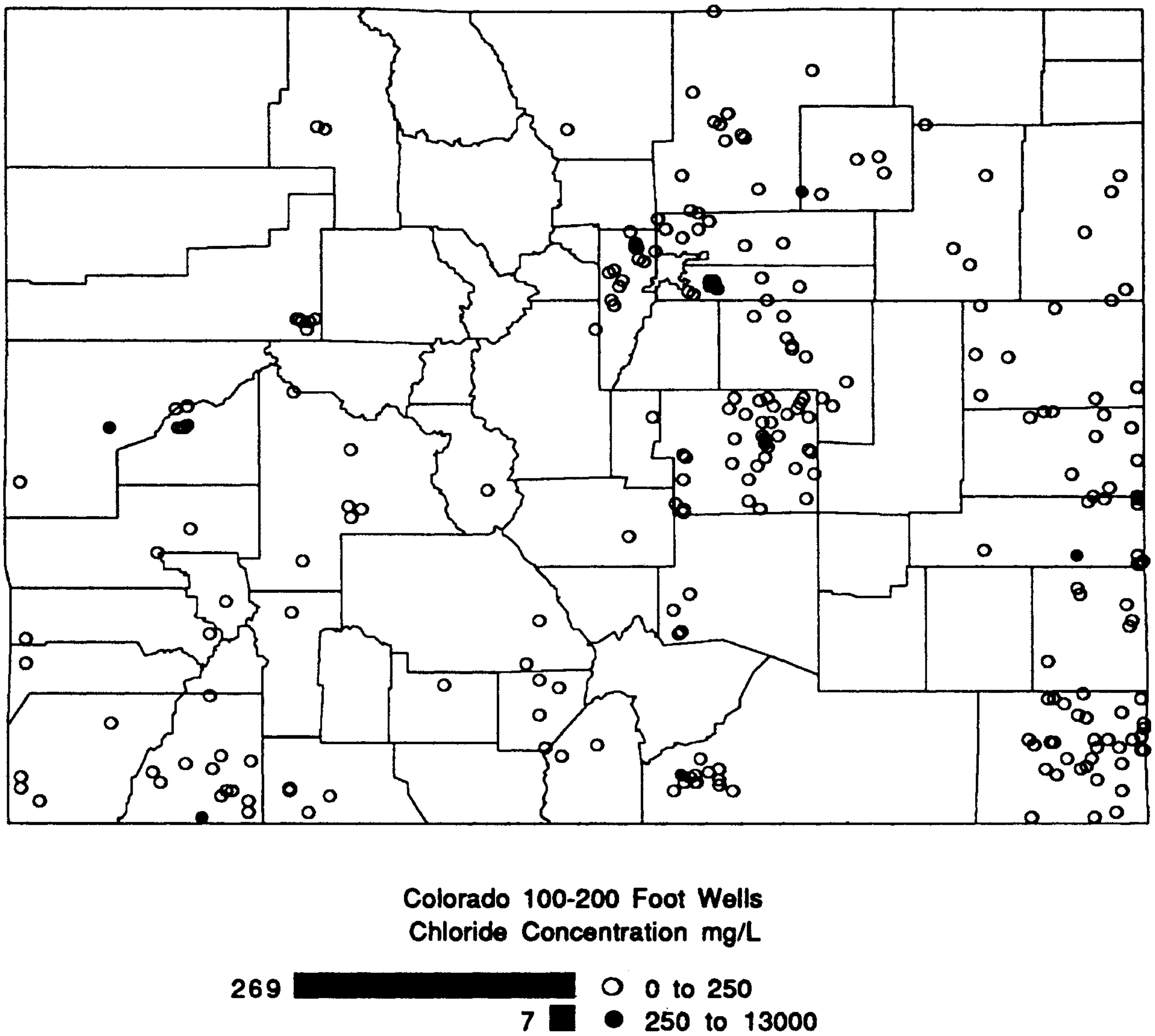



Figure 49. Colorado 100-200 Foot Interval Chloride Map

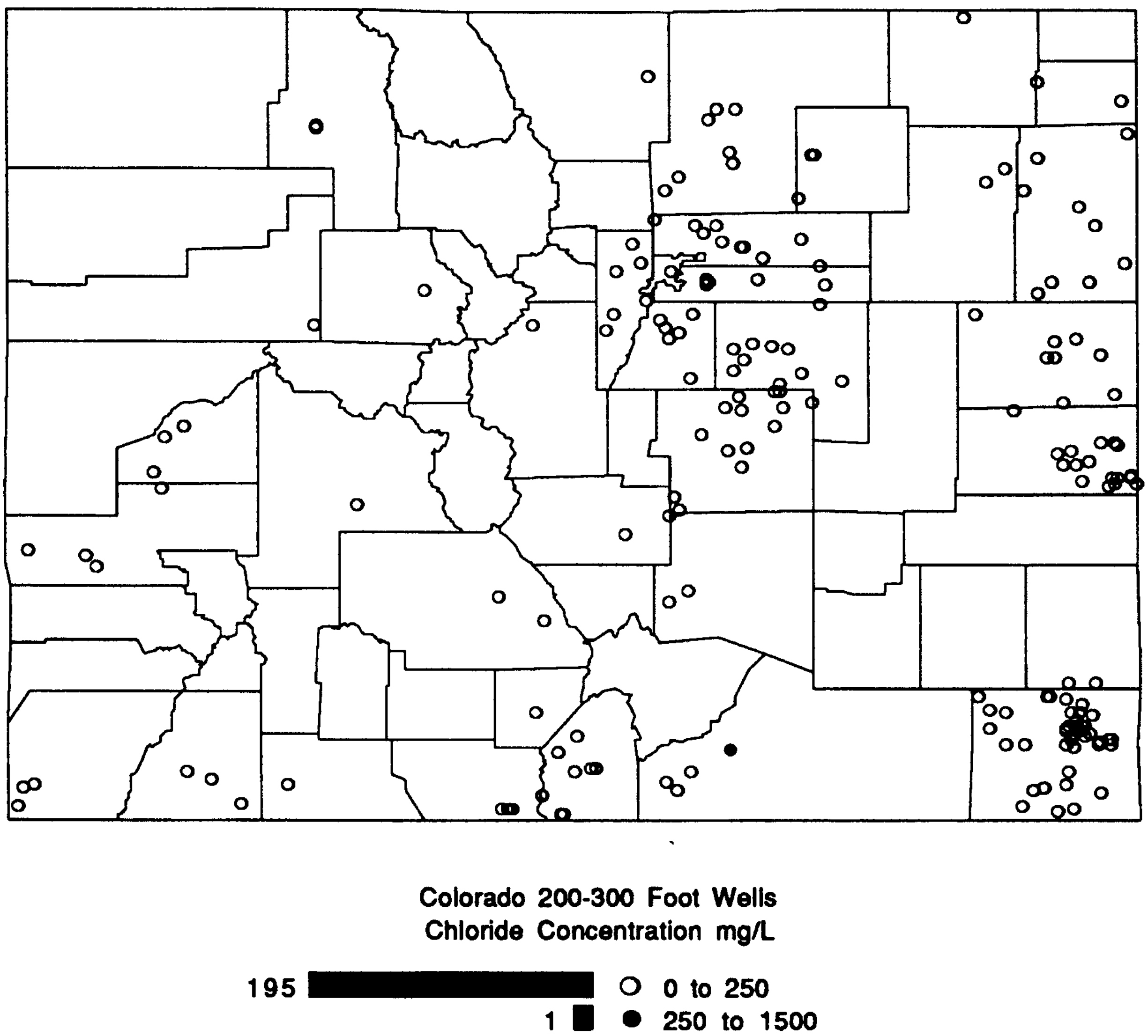



Figure 50. Colorado 200-300 Foot Interval Chloride Map

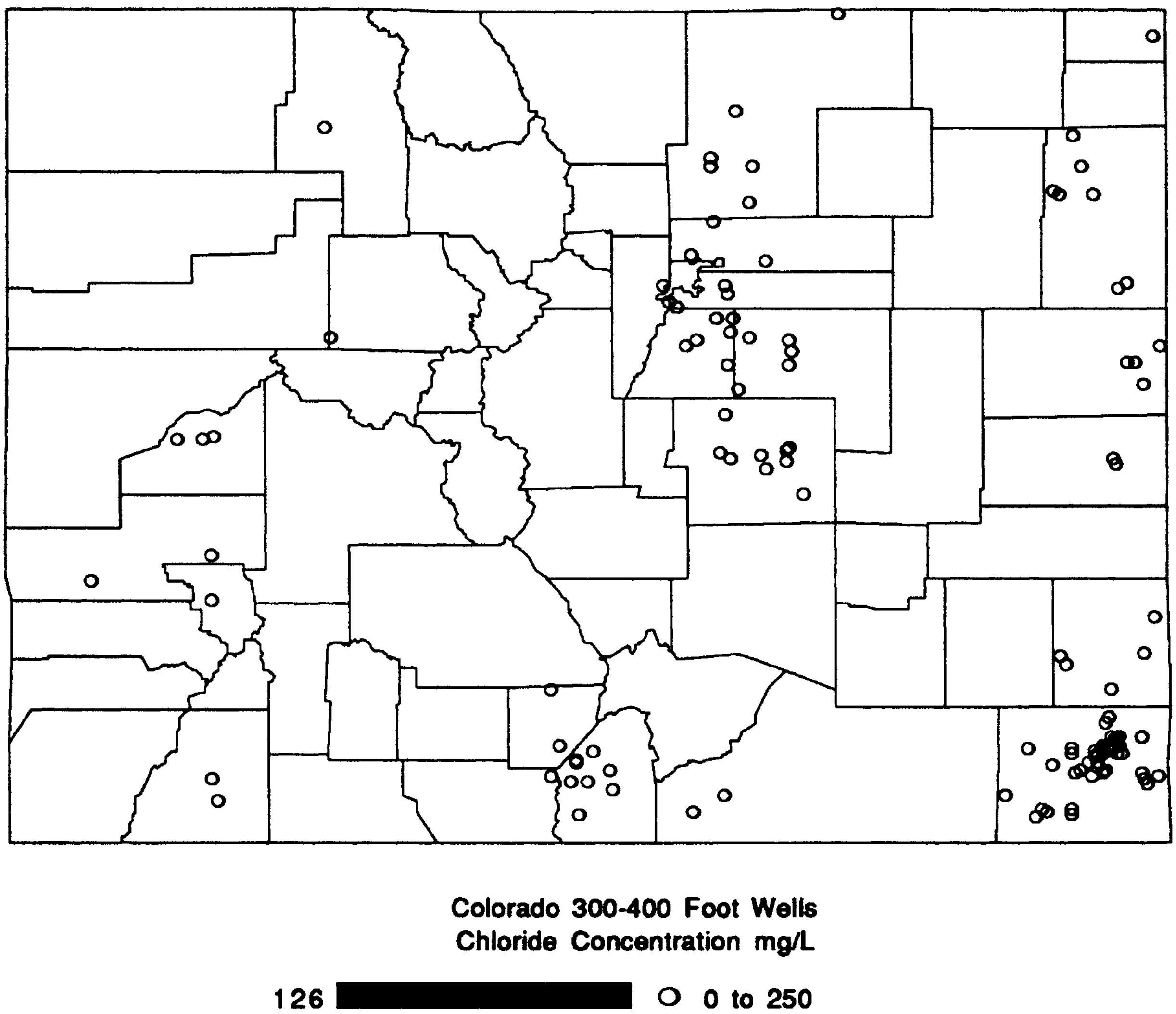



Figure 51. Colorado 300-400 Foot Interval Chloride Map

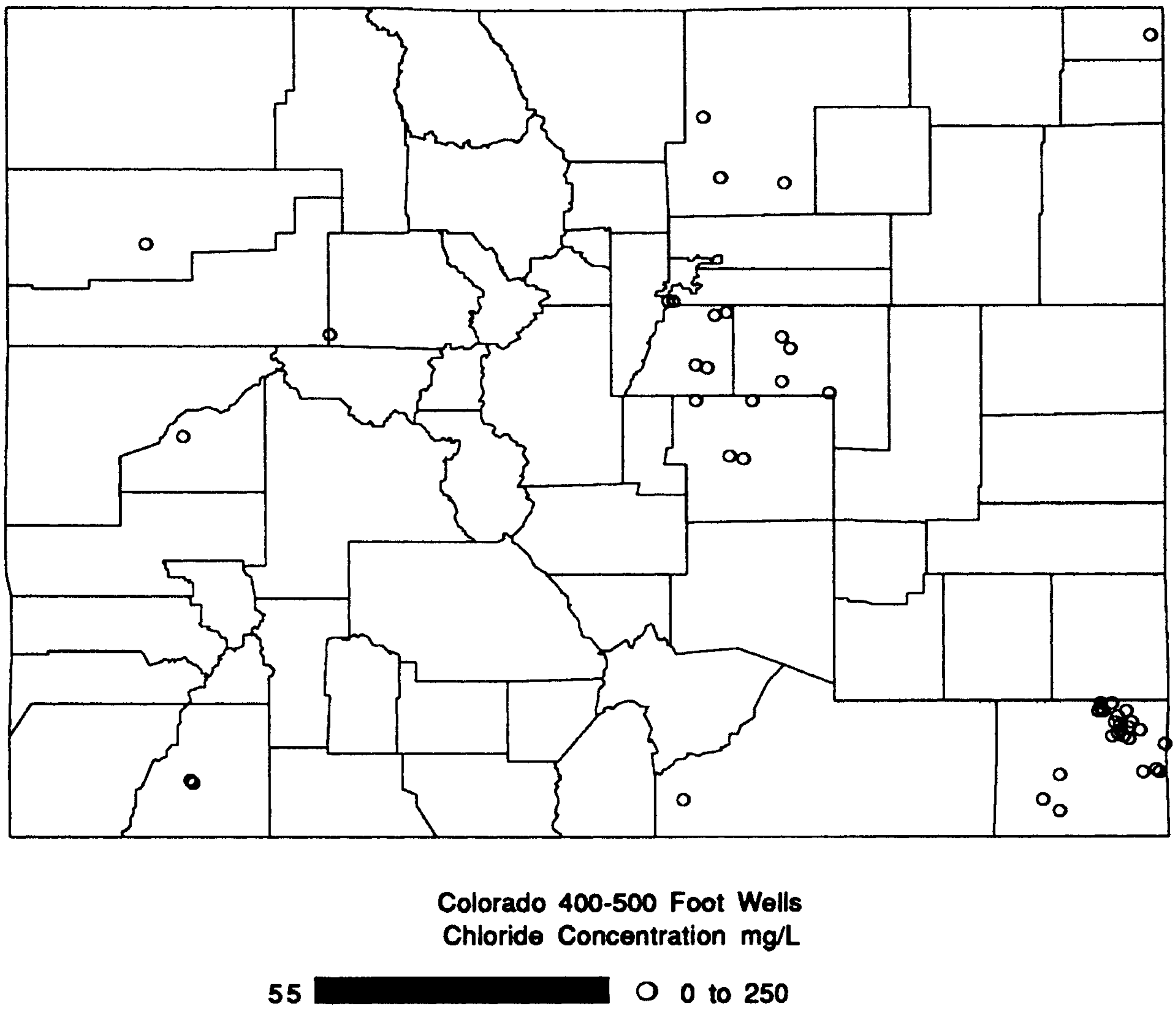



Figure 52. Colorado 400-500 Foot Interval Chloride Map

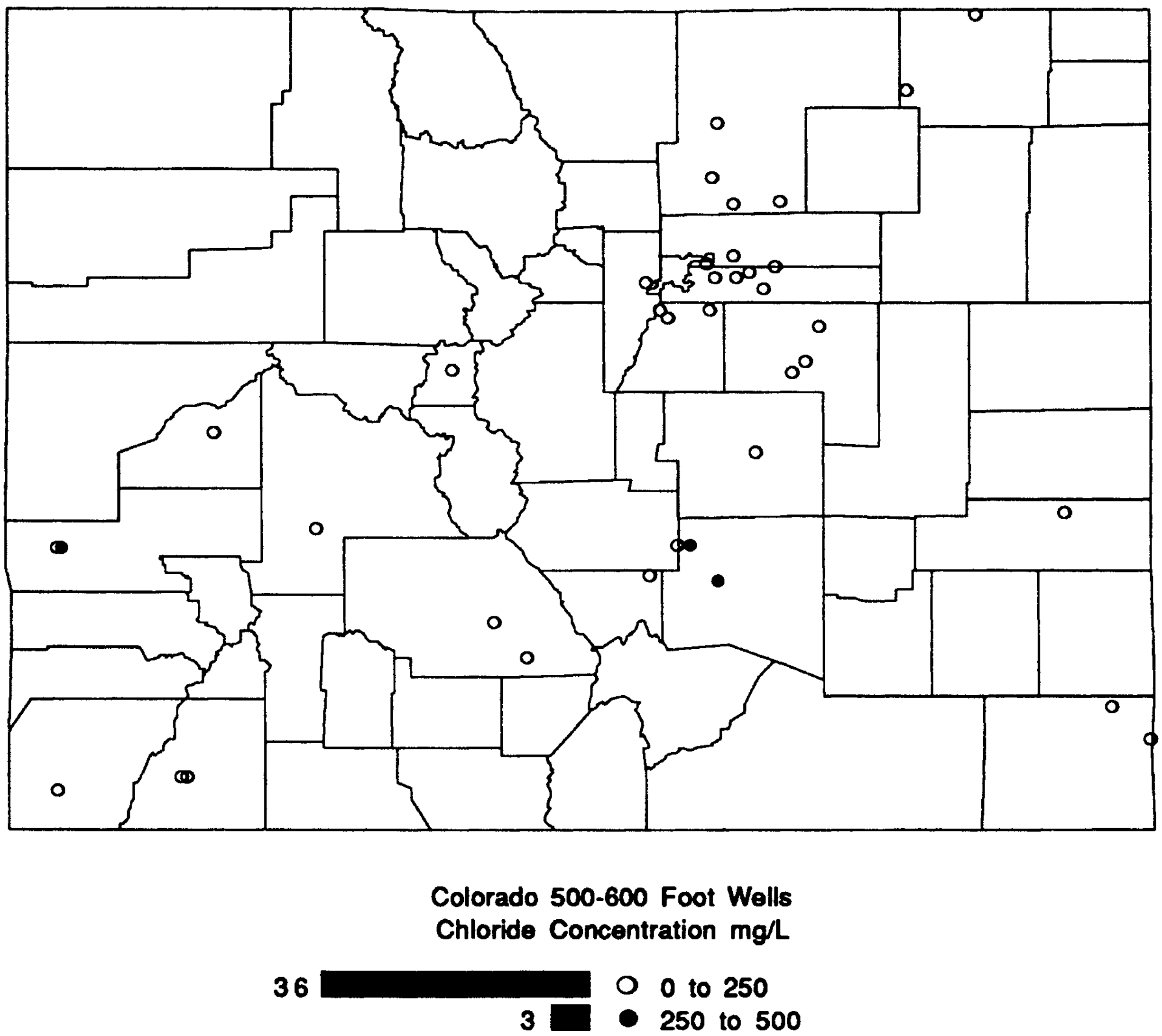



Figure 53. Colorado 500-600 Foot Interval Chloride Map

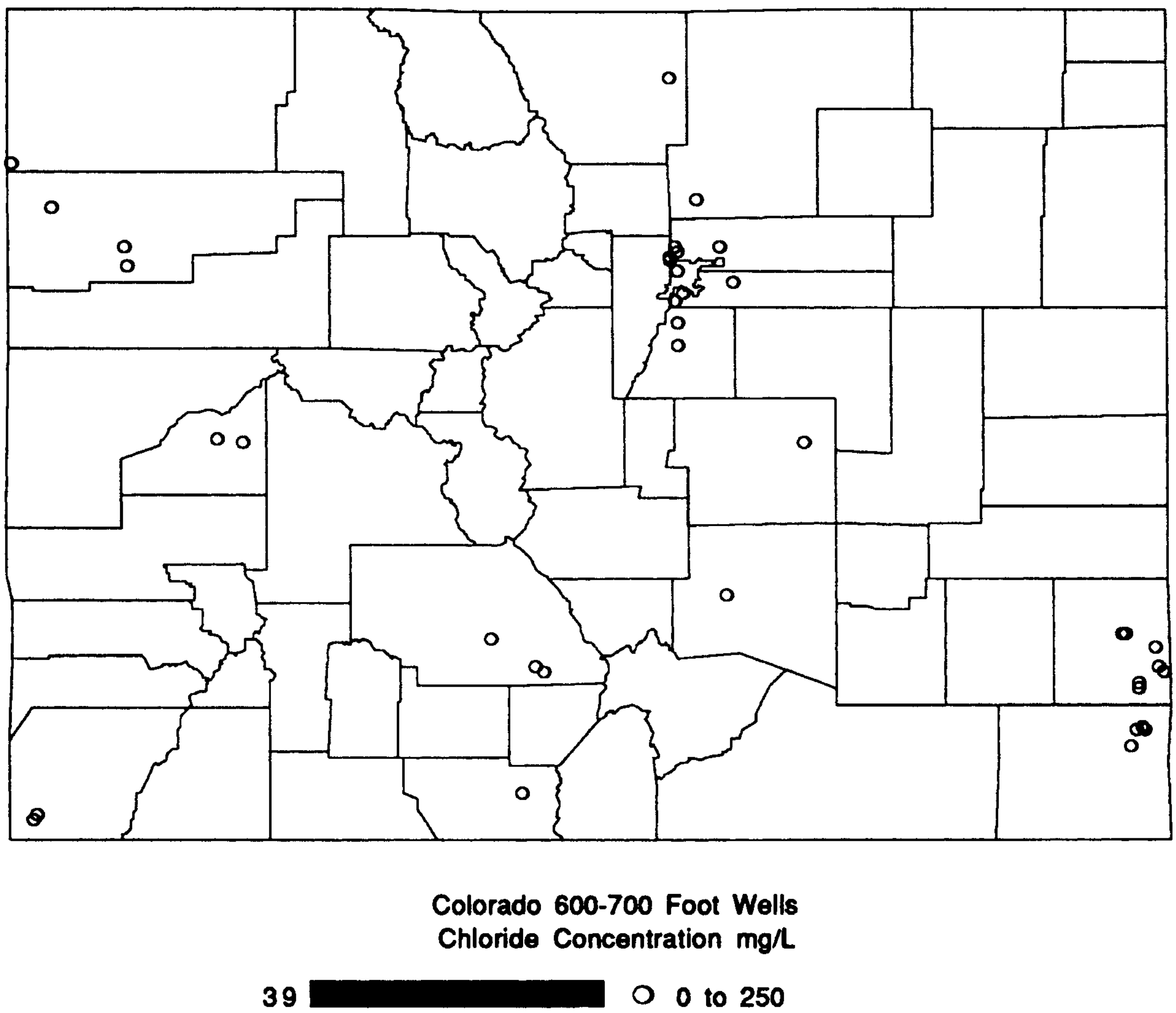



Figure 54. Colorado 600-700 Foot Interval Chloride Map

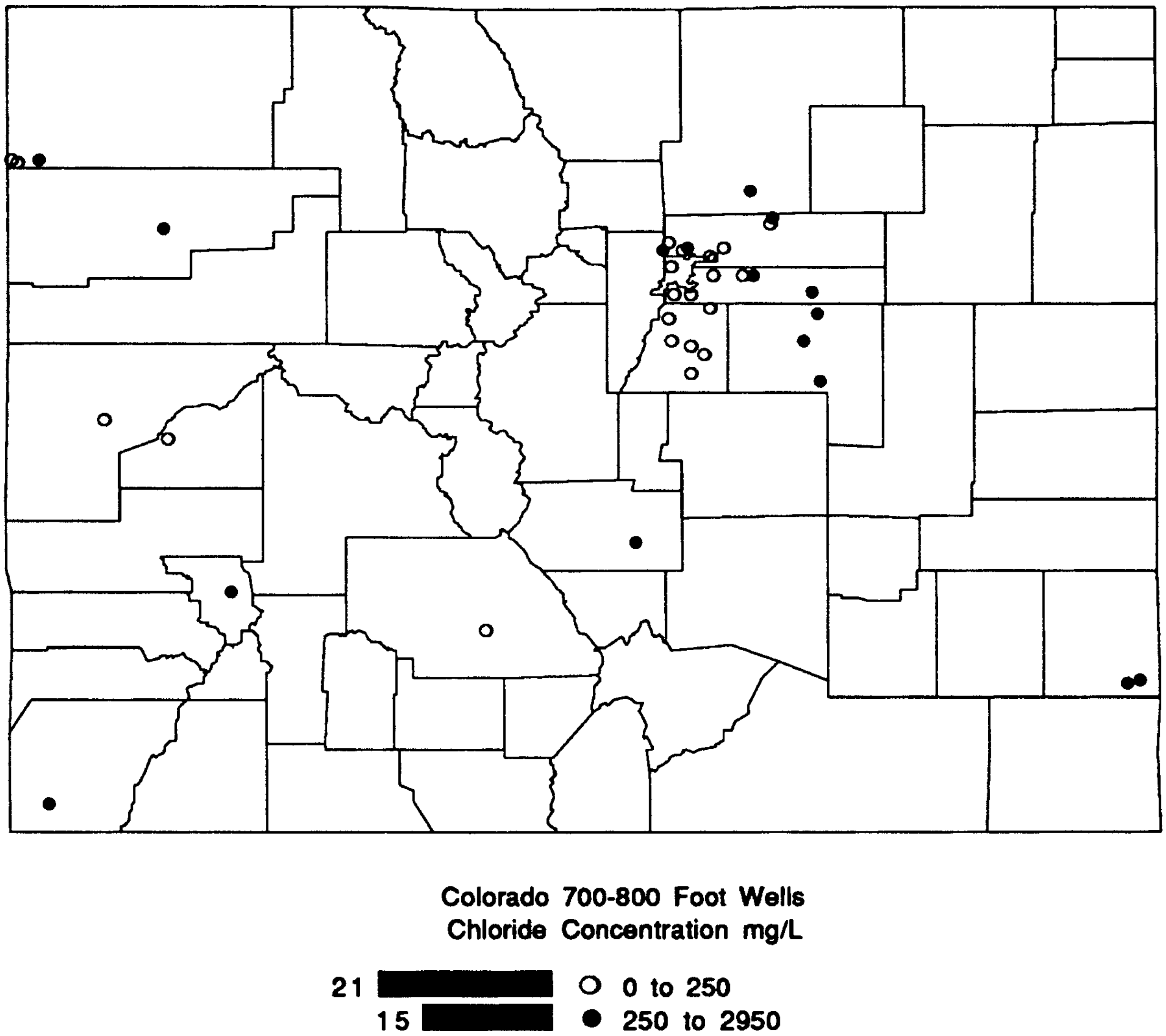



Figure 55. Colorado 700-800 Foot Interval Chloride Map

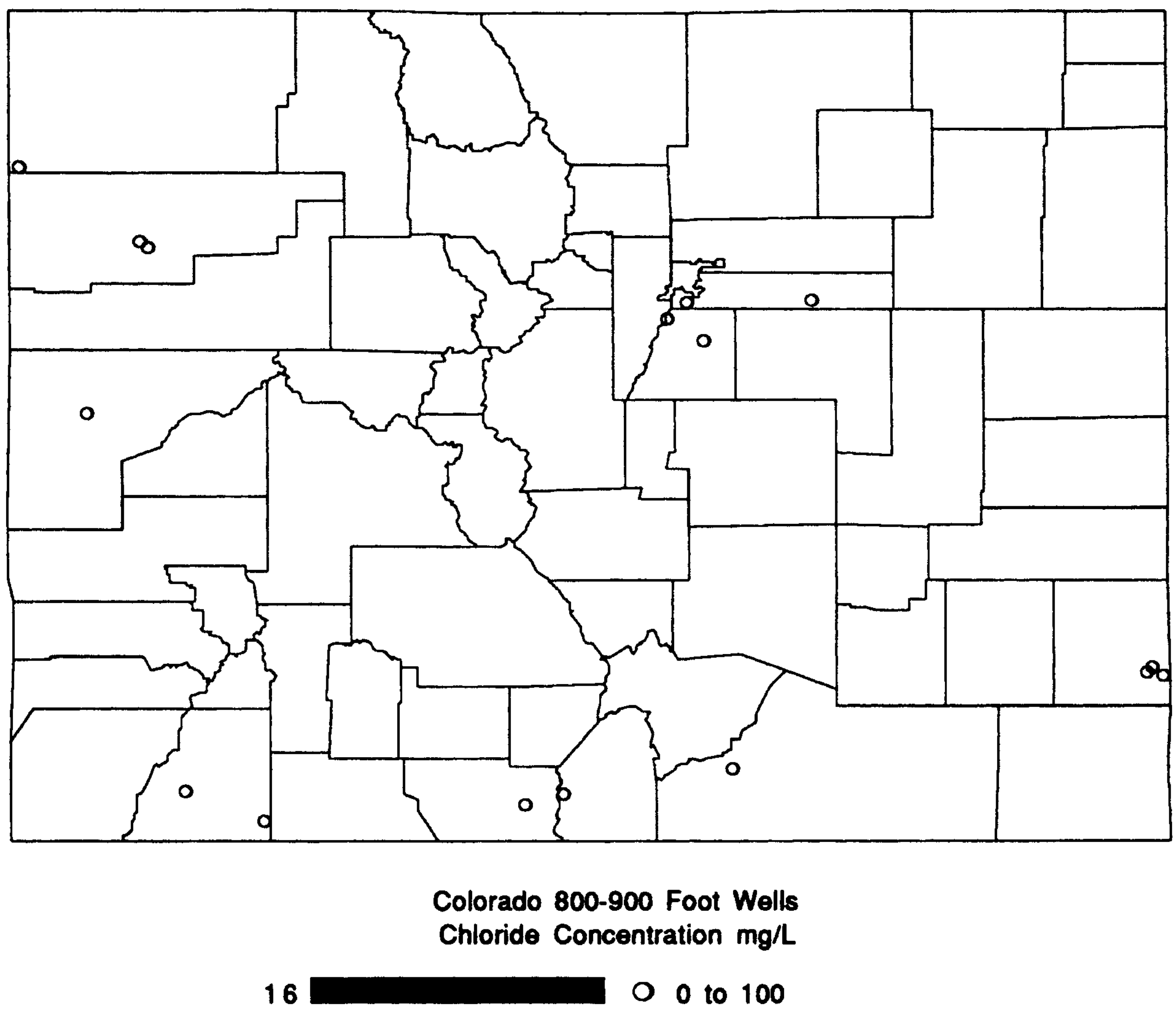



Figure 56. Colorado 800-900 Foot Interval Chloride Map

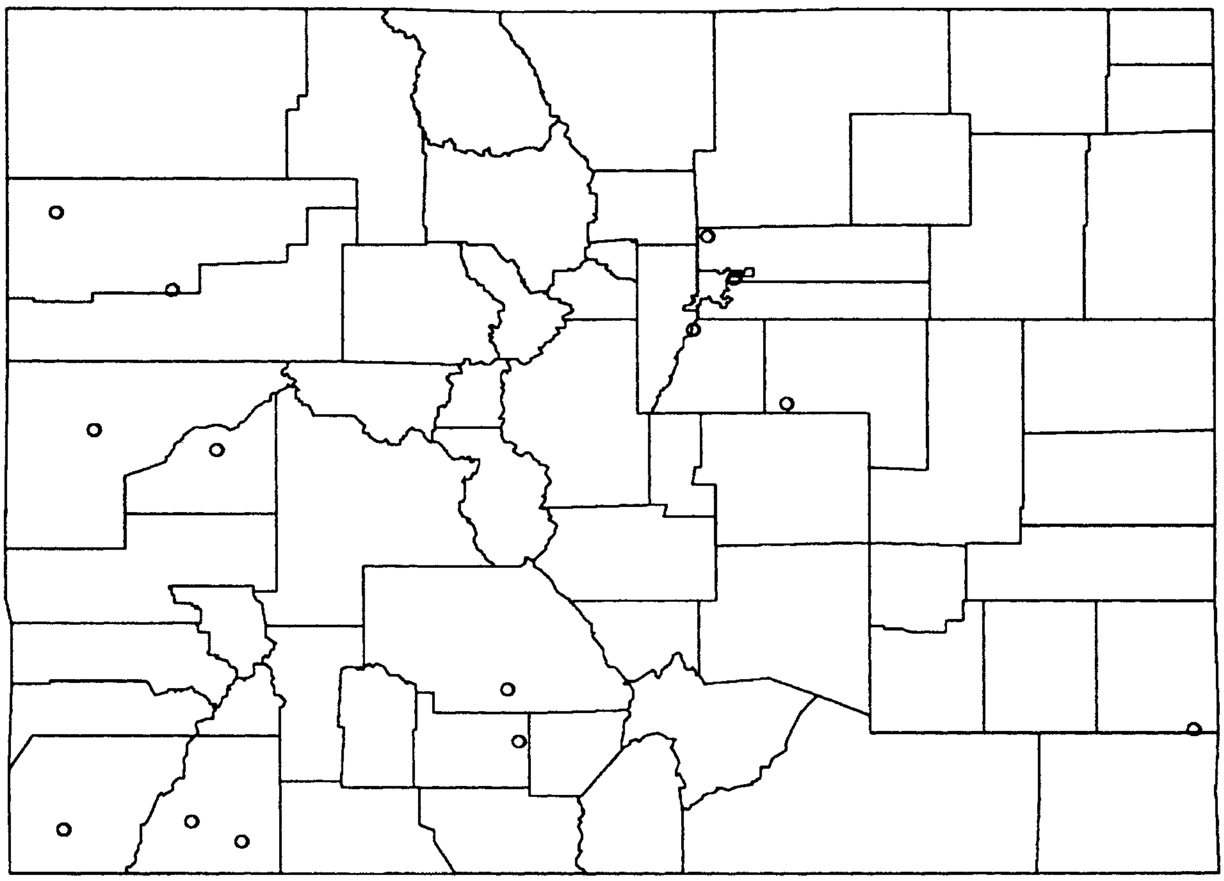



Figure 57. Colorado 900-1000 Foot Interval Chloride Map

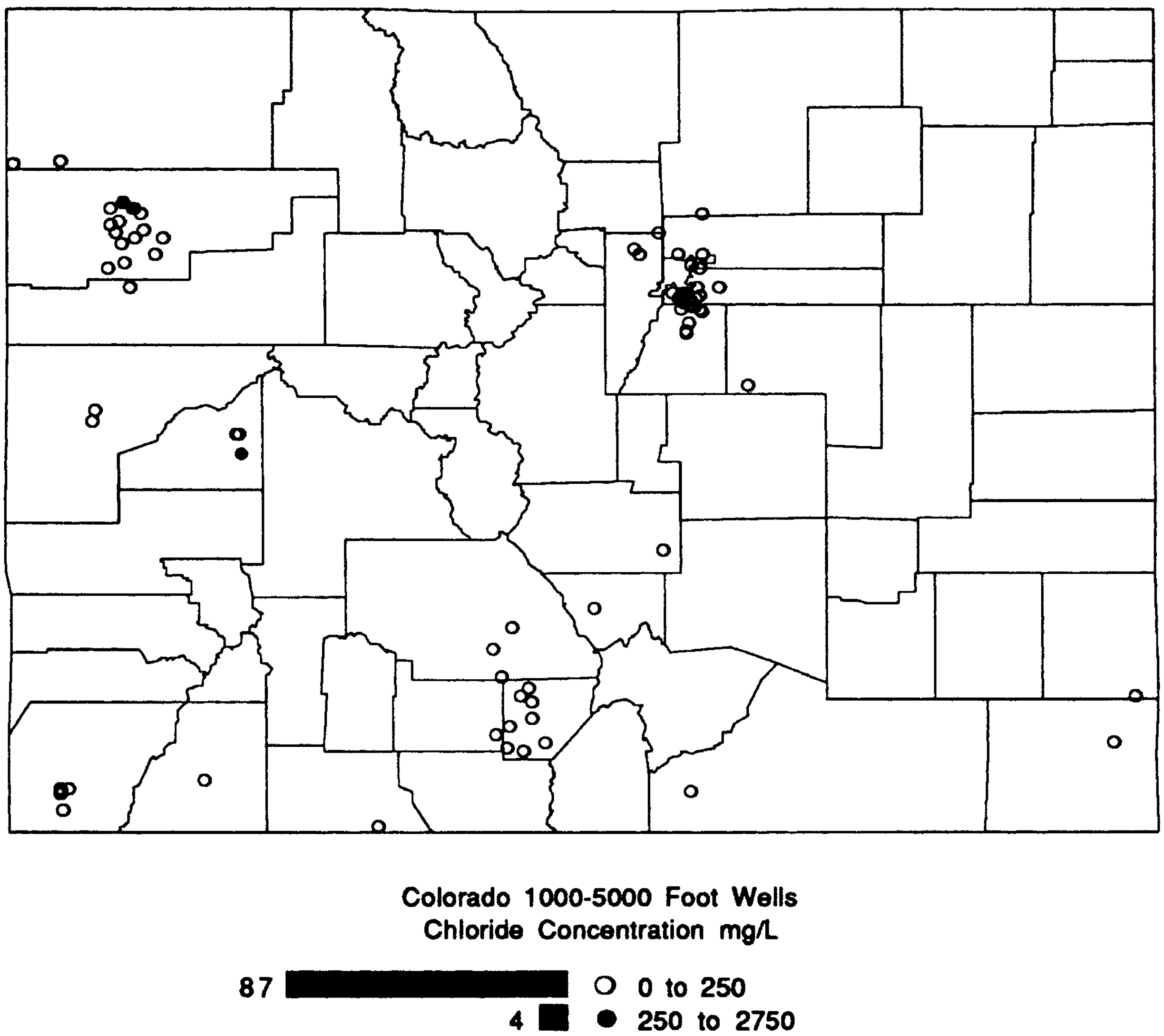



Figure 58. Colorado 1000-5000 Foot Interval Chloride Map

# KANSAS

## General Setting

Kansas contains approximately 82,000 square miles, and lies primarily in the high plains, mesas, rolling plains, and low hills of the Great Plains and Central Lowlands physiographic provinces. The Ozark Plateau province occupies the southeastern corner of the state. Kansas is underlain by Paleozoic age rocks that dip gently westward from the structurally higher Ozark Plateaus in Missouri, into the north trending shallow structural basin beneath the Great Plains. Pennsylvanian and Permian age shale, limestone, and sandstone crop out in the southeastern part of the state and dip to the northwest. Pleistocene age glacial deposits cover large areas of Pennsylvanian and Permian rocks in the northeast. Paleozoic rocks lie beneath Cretaceous age shale, sandstone, limestone, and chalk in Central Kansas. Cretaceous strata are overlain, especially to the west, by the Tertiary age Ogallala Formation, and by younger fluvial and eolian sediments. Quaternary age alluvial deposits are present along major river valleys throughout the state.

Several east flowing tributaries of the Missouri River drain the northern half of Kansas. A network of east to southeast flowing rivers drain the southern half of the state.

## Principal Aquifers

Kansas has seven principal aquifers that can be divided into two groups. The first group consists of Cenozoic age unconsolidated materials including alluvial deposits, glacial drift, and the High Plains (Ogallala) aquifer. The second group consists of Mesozoic and Paleozoic age consolidated deposits including the Great Plains, Chase and Council Grove, Douglas, and Ozark aquifers. The areal distribution of each of the seven principal aquifers of Kansas are outlined in Figure 59.

The Alluvial aquifers of Kansas are distributed along the drainage of the states major streams including the Arkansas, Kansas, and Smoky Hill Rivers. They are composed of Quaternary age fluvial deposits of clay, silt, sand, and gravel.

Glacial drift aquifers are limited to the extreme northeast of Kansas. The Pleistocene glacial deposits of clay, silt, sand and gravel are locally important ground water sources.

The High Plains aquifer (Ogallala) accounts for approximately 90 percent of the groundwater use in Kansas (U.S.-G.S.,1988). The Ogallala cover an extensive portion of Central and Western Kansas and ranges in thickness from 300 feet in the northwestern part of the state to 600 feet in the southwest. The Ogallala in Kansas is divided into three members, the Valentine, composed of silica cemented sand and gravel, the Ash Hollow, composed of loosely carbonate cemented silt, sand, and gravel, beds of fresh water limestone and volcanic ash, and the Kimbal composed of calcareous sand, gravel and silt

The Chase and Council Grove aquifer in East Central Kansas is composed of Permian age limestone deposits. Pennsylvanian deposits of the Douglas aquifer in Eastern Kansas are composed of channel sandstones and are equivalent to the Vamoosa-Ada in Oklahoma. The Ozark aquifer in extreme Southeastern Kansas is composed of weathered sandy dolomites of the Arbuckle Group and is of Ordovician to Cambrian age.

The water bearing members of the Great Plains aquifer of Central and North Central Kansas consist of deposits of the Upper Cretaceous Dakota Sandstone and the Lower Cretaceous Cheyenne Sandstone.

## Chloride Distribution

The maps produced for Kansas represent a total of 863 stations distributed over five depth intervals (Table 10). State wide only six percent (50) of the stations reveal chloride levels in excess of 250 mg/L. The record for Kansas is the smallest of the eleven states addressed in this study. Although the number of stations decreases rapidly with depth in Kansas, the percentage of wells at each mapped interval that exceed 250 mg/L remains remarkably consistent and never exceed eight percent(Table 11). This trend is demonstrated graphically by Figure 61. There is a trend in the state for the percentage of wells with concentrations in the 0-25 mg/L range to increase with depth. Also, remarkably, the percent of wells with concentrations greater than 100 mg/L never rises higher than 11 percent (fig. 60). Areal distribution of stations with elevated chloride levels appear for the most part to be limited to the eastern and southern parts of the state. Elevated chloride levels appear to be primarily restricted to alluvial and glacial aquifers(Figures. 62-66).

Several areas in Kansas have been affected by oil and gas activities. The Walnut River Basin, Little Arkansas River Basin, and areas of Barber County have been affected by brine disposal(Richter, 1991). These areas are identified by chloride maps as having stations with levels in excess of 250 mg/L.

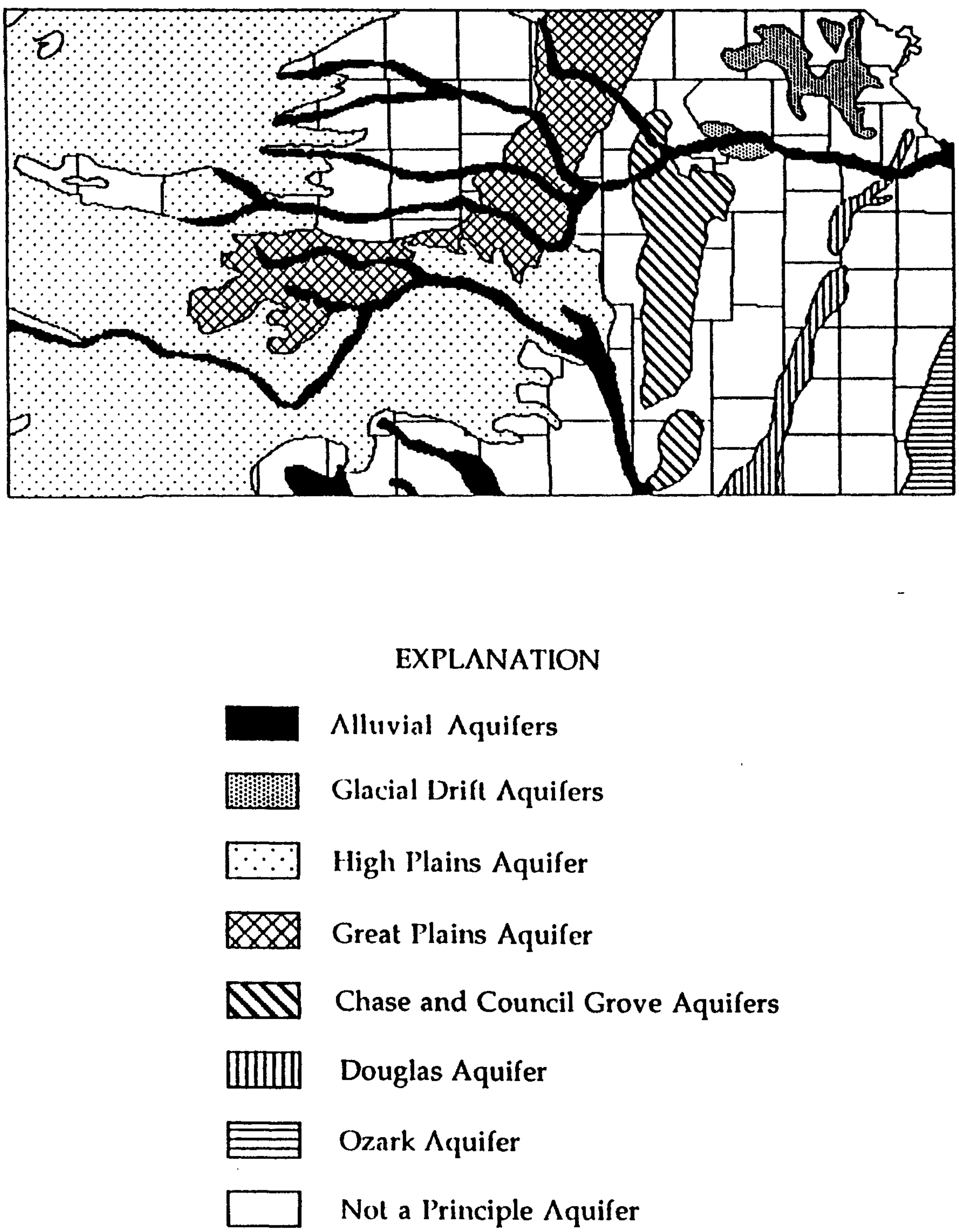



Figure 59. Kansas Principal Aquifers Map
(Modified From U.S.G.S., 1985)

| | Concentration Interval (mg/L) | | | | | total | wells |
|---|---|---|---|---|---|---|---|
| | 0-25 | 25-100 | 100-250 | 250-500 | >500 | wells | >250 |
| Depth Interval (feet) | | | | | | | |
| 0-100 | 243 | 185 | 54 | 21 | 10 | 513 | 31 |
| 100-200 | 128 | 63 | 9 | 5 | 4 | 209 | 9 |
| 200-300 | 58 | 16 | 3 | 2 | 4 | 83 | 6 |
| 300-400 | 20 | 10 | 4 | 3 | 0 | 37 | 3 |
| 400-500 | 16 | 3 | 1 | 1 | 0 | 21 | 1 |
| State Total | 465 | 277 | 71 | 32 | 18 | 863 | 50 |
| Percent Of Wells With Concentrations Greater Than 250mg/L | | | | | | | 6 |

**TABLE 10. NUMBER OF STATIONS PER DEPTH AND CONCENTRATION INTERVAL IN KANSAS**

| | Concentration Interval (mg/L) | | | | | |
|---|---|---|---|---|---|---|
| | 0-25 | 25-100 | 100-250 | 250-500I | >500 | >250 |
| Depth Interval (feet) | | | | | | |
| 0-100 | 47 | 36 | 11 | 4 | 2 | 6 |
| 100-200 | 61 | 30 | 4 | 2 | 2 | 4 |
| 200-300 | 70 | 19 | 4 | 2 | 5 | 7 |
| 300-400 | 54 | 27 | 11 | 8 | 0 | 8 |
| 400-500 | 76 | 14 | 5 | 5 | 0 | 5 |

**TABLE 11. PERCENT OF STATIONS PER DEPTH AND CONCENTRATION INTERVAL IN KANSAS**

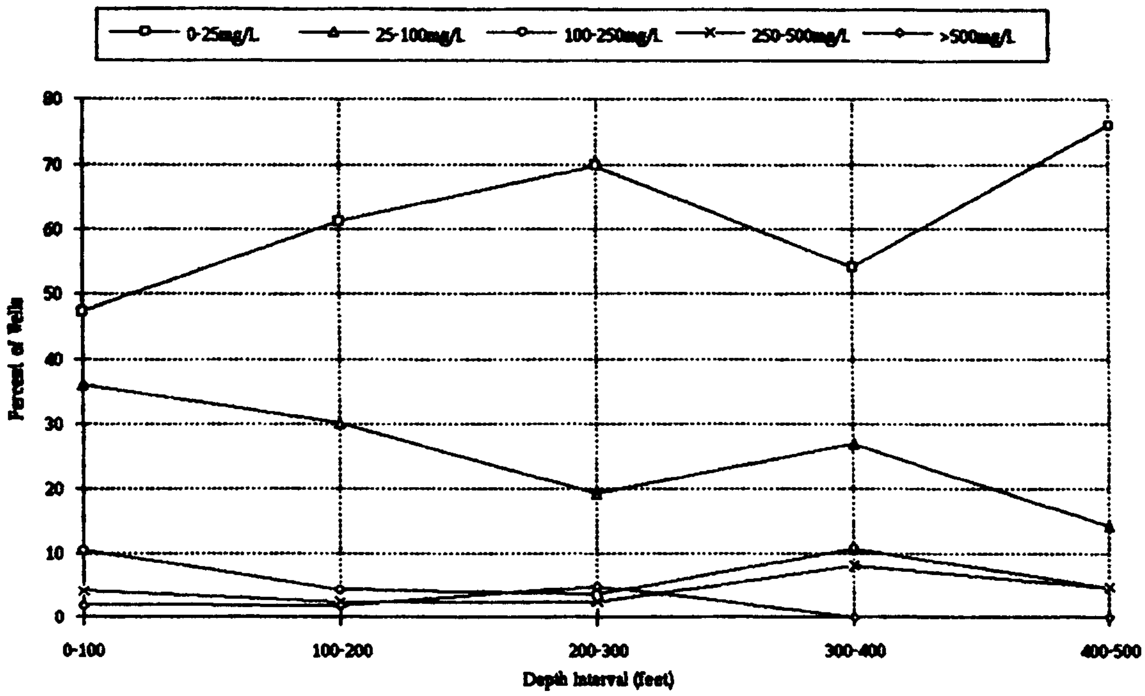



**Figure 60. Kansas Percent Of Wells Per Concentration Interval vs Well Depth**

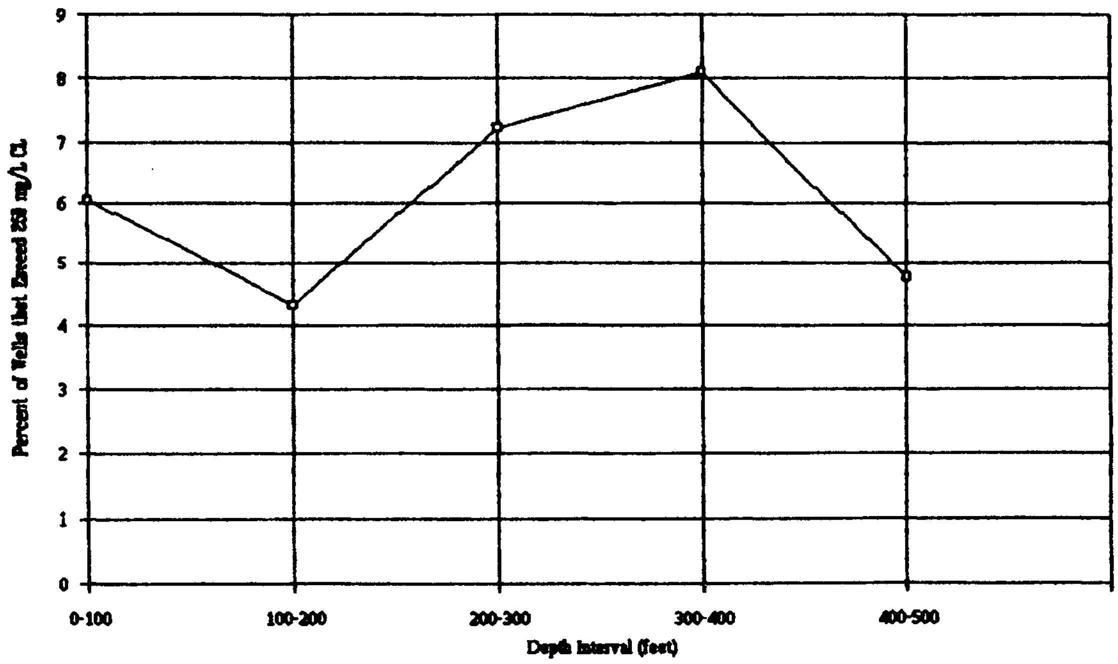



**Figure 61. Kansas Percent Of Wells That Exceed 250 mg/L Chloride**

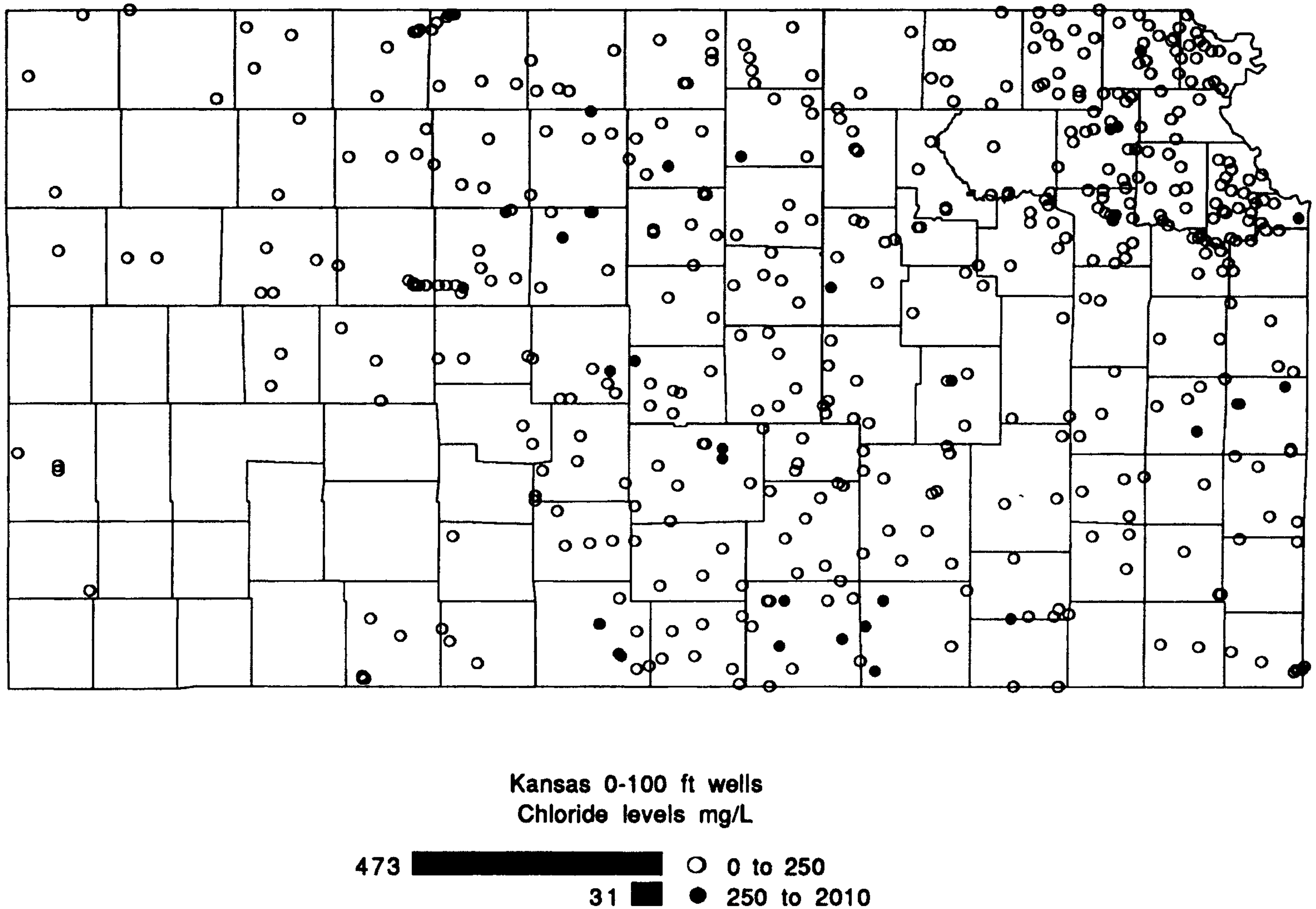



Figure 62. Kansas 0-100 Foot Interval Chloride Map

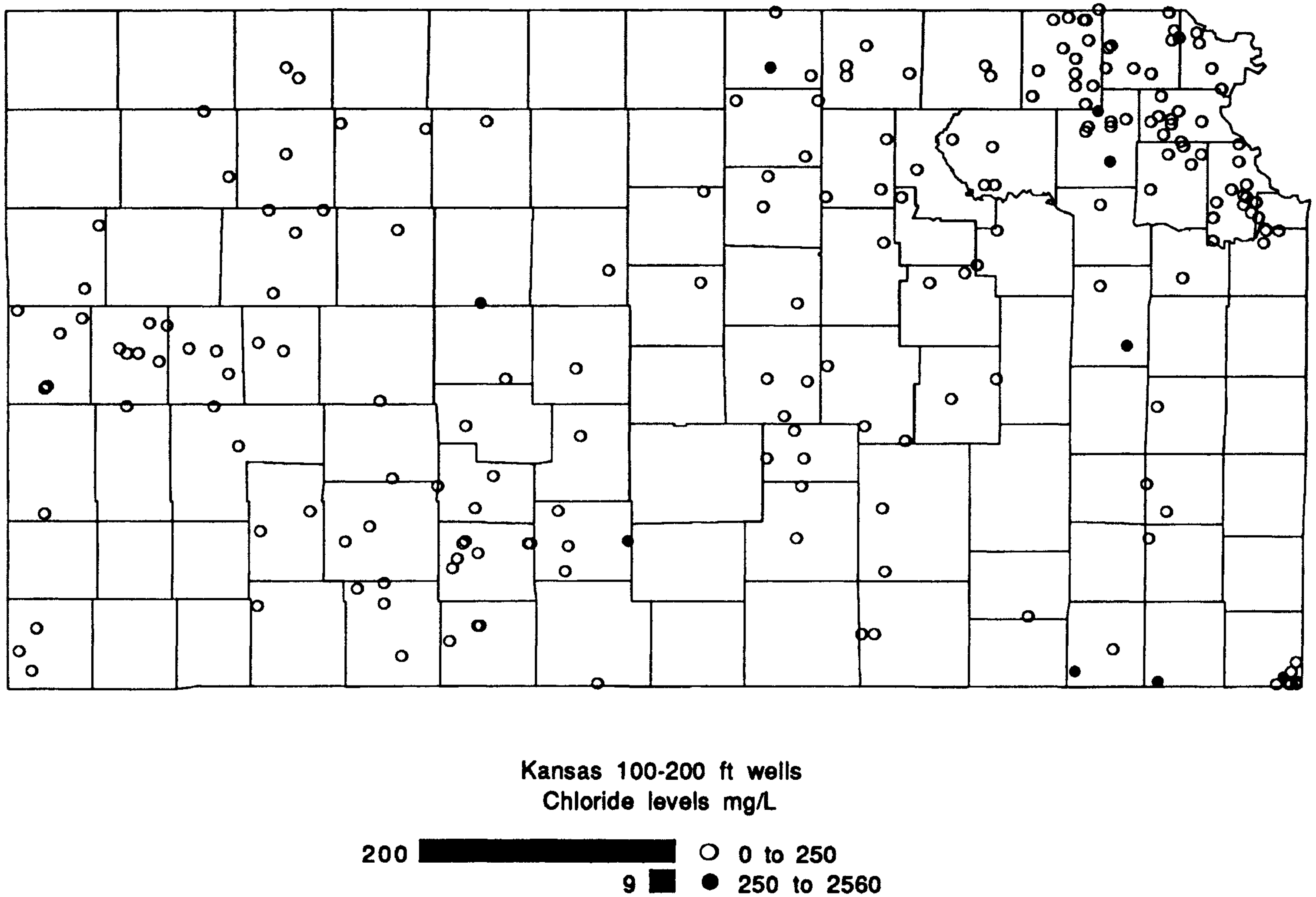



Figure 63. Kansas 100-200 Foot Interval Chloride Map

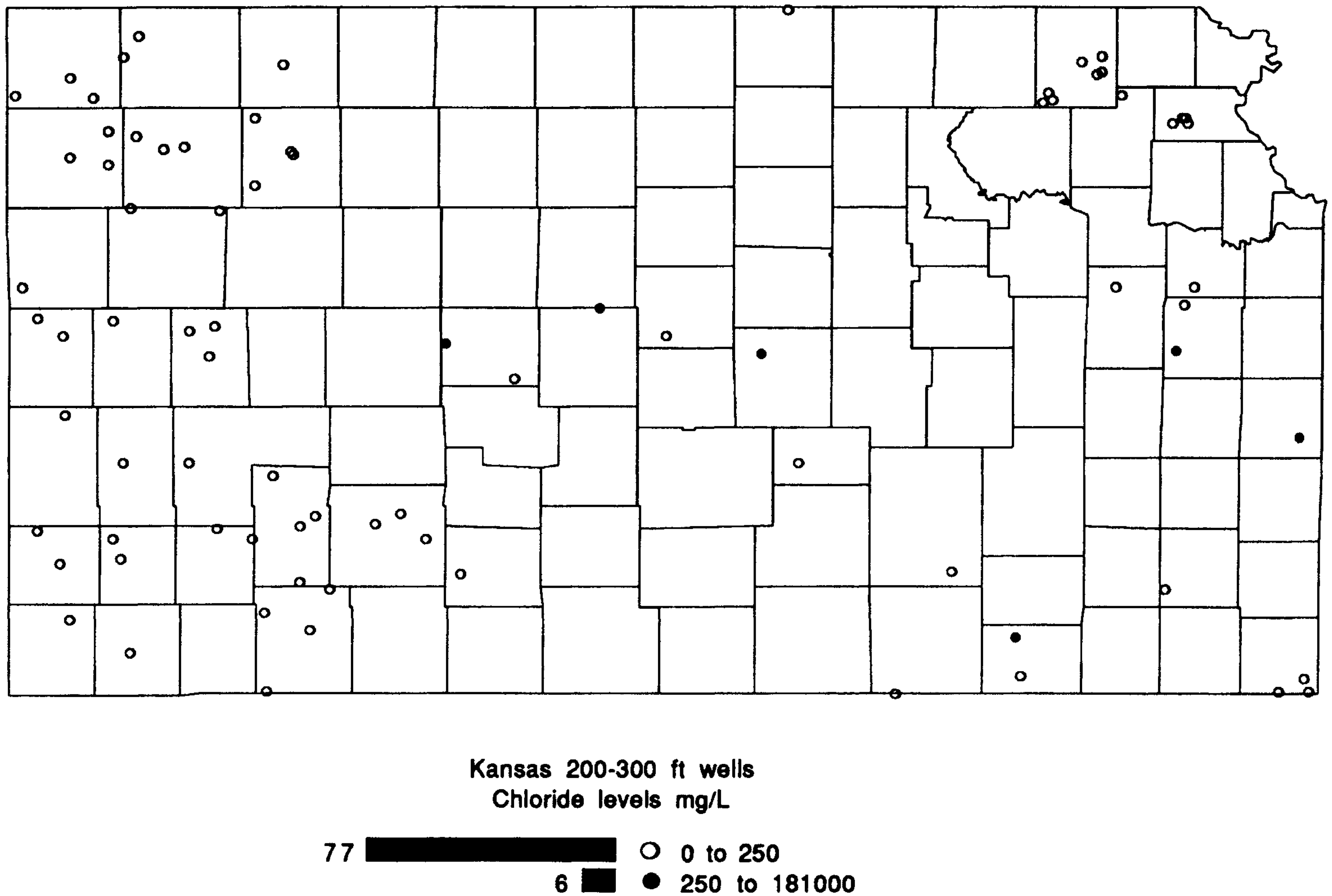



Figure 64. Kansas 200-300 Foot Interval Chloride Map

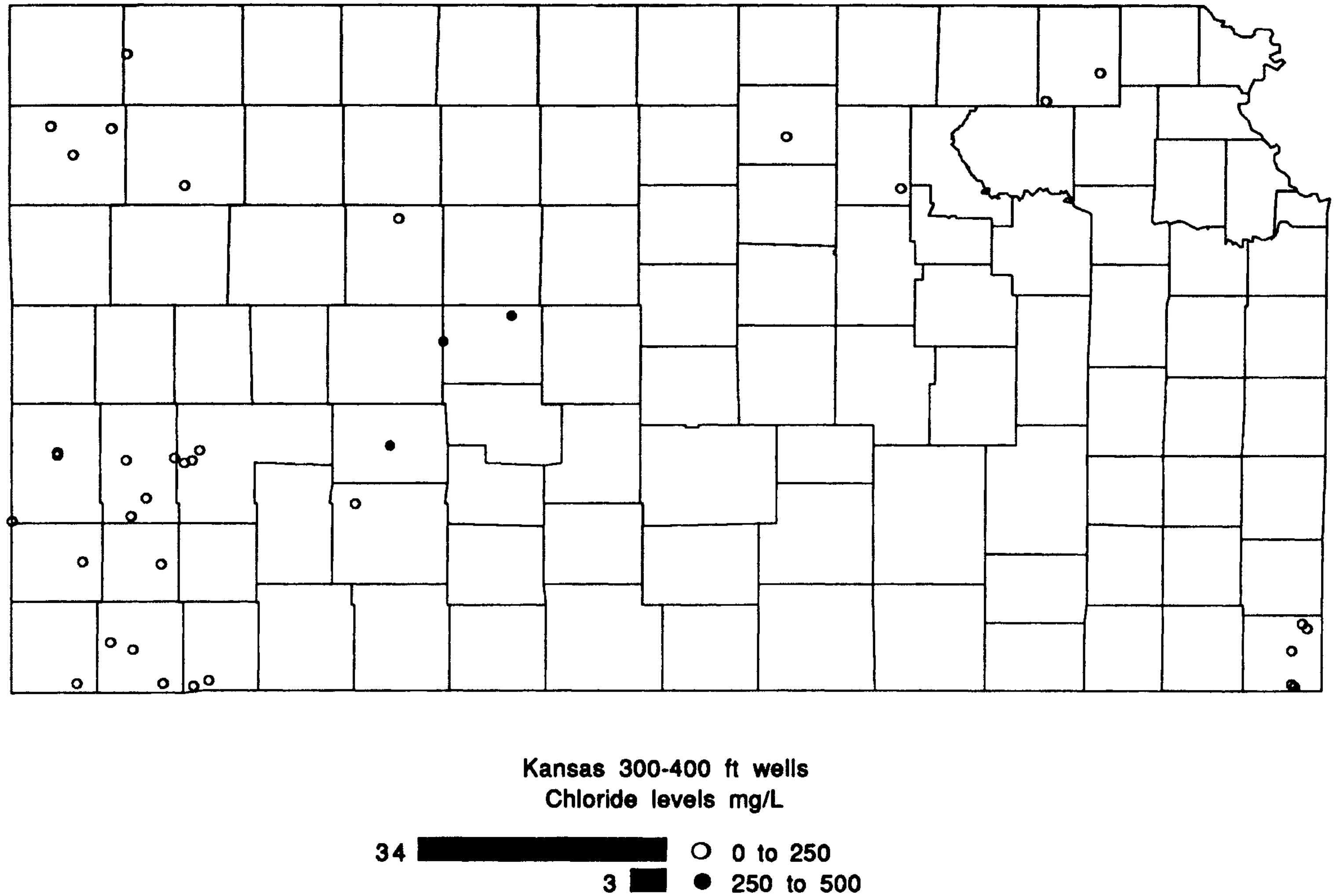



Figure 65. Kansas 300-400 Foot Interval Chloride Map

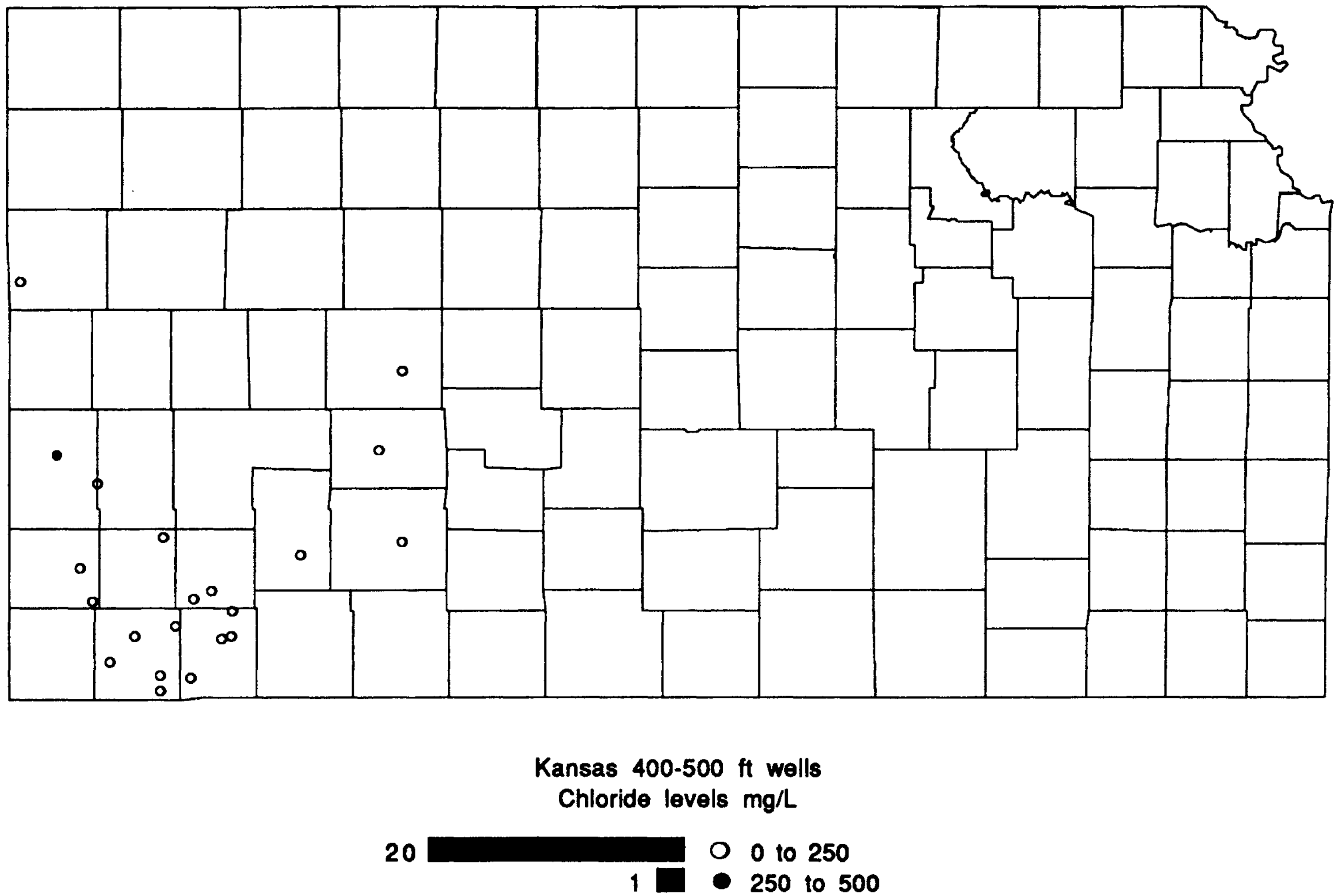



Figure 66. Kansas 400-500 Foot Interval Chloride Map

# LOUISIANA

## General Setting

Louisiana covers an area of approximately 48,000 square miles, and is situated in the relatively flat lying Gulf Coastal Plain physiographic province. The state is underlain by southward dipping semiconsolidated to unconsolidated, interbedded silt, clay, sand, gravel, shale, limestone, and tufaceous and lignitic beds that range in age from Cretaceous to Holocene.

Surface water drainage in Louisiana is to the south-southeast via the southeast flowing Sabine, Red, and Mississippi rivers.

## Principal Aquifers

The principal aquifers in Louisiana can be placed into five groups based upon age of the aquifer. Areal distribution of the principal aquifers in Louisiana are illustrated in Figure 67. The youngest deposits are the Quaternary alluvial deposits in the Mississippi, Red, and Ouachita River Valleys. These alluvial deposits typically consist of sand and gravel deposits overlain by a confining layer of clay and silt.

The Pleistocene aquifers of Central, Southwestern and, Southeastern Louisiana include; terrace alluvial deposits, The thick sands of the Chicot, including the 200, 500, and 700 foot Lake Charles Sands; the 400 and 600 foot sands of

Baton Rouge, and the fine to course sands of the Gonalez-New Orleans aquifers.

Pliocene-Miocene age aquifers in Louisiana consist of several formations including the Evangeline, Jasper, and Catahoula which are characterized by fine to course sand interbedded with silt and clays. Deeper sands found in the Baton Rouge are also of Pliocene-Miocene age.

Eocene age formations that are important aquifers in Louisiana consist of the Cockfield and Sparta sand aquifers of the north central, and the Wilcox and Carrizo sands of the northwest.

Chloride Distribution

Chloride maps of Louisiana are based upon 9751 stations distributed over 12 depth intervals (Table 12). The percentage of wells that exceed the 250 mg/L standard varies from a low of eight percent at the 1100-1200 foot interval, to a high of 33 percent at the 800-900 foot interval(Table 13). Significant peaks in chloride levels occur at the 700-800, and 800-900 foot intervals (fig. 69). Regionally 15 percent (1426) of the states wells have chloride concentrations greater than 250 mg/L.

Areal mapping of shallower depth intervals suggest the majority of wells that exceed the 250 mg/L level occur predominantly in the alluvial aquifers associated with the states major streams and in an isolated area of Franklin Parish(fig. 70). Other areas in the state that exceed 250 mg/L include many coastal areas and the industrial corridor from Baton Rouge to New Orleans(Figures. 71-74).

Oil and gas activities in conjunction with salt domes in the southern and northern parts of Louisiana are potential sources of large amounts of brine. Louisiana state regulations allow for disposal of brine into naturally saline or otherwise unusable water.(Richter, 1991) Disposal of drilling and production wastes has contaminated shallow ground water in Vermilion Parish, where the wastes have been disposed of by injection, unlined surface impoundments, land application, and land Burial(Subra, 1990). Evidence of this waste disposal is evident in the chloride maps produced in this study. Calcasieu, Jefferson Davis, Acidia, and Vermillion Parishes are well represented with stations with chloride levels in excess of 250 mg/l at shallow depths. Caddo, Bossier, Red River, Natchitoches, and Grant Parishes in the northwest, as well as Morehouse, East Carrol, Richland, Franklin, Catahoula, Concordia, Lasalle, Avoyelles and Rapides parishes in the northeast are probably affected by both disposal of oil field brine and dissolution of material from salt domes and halite deposits.

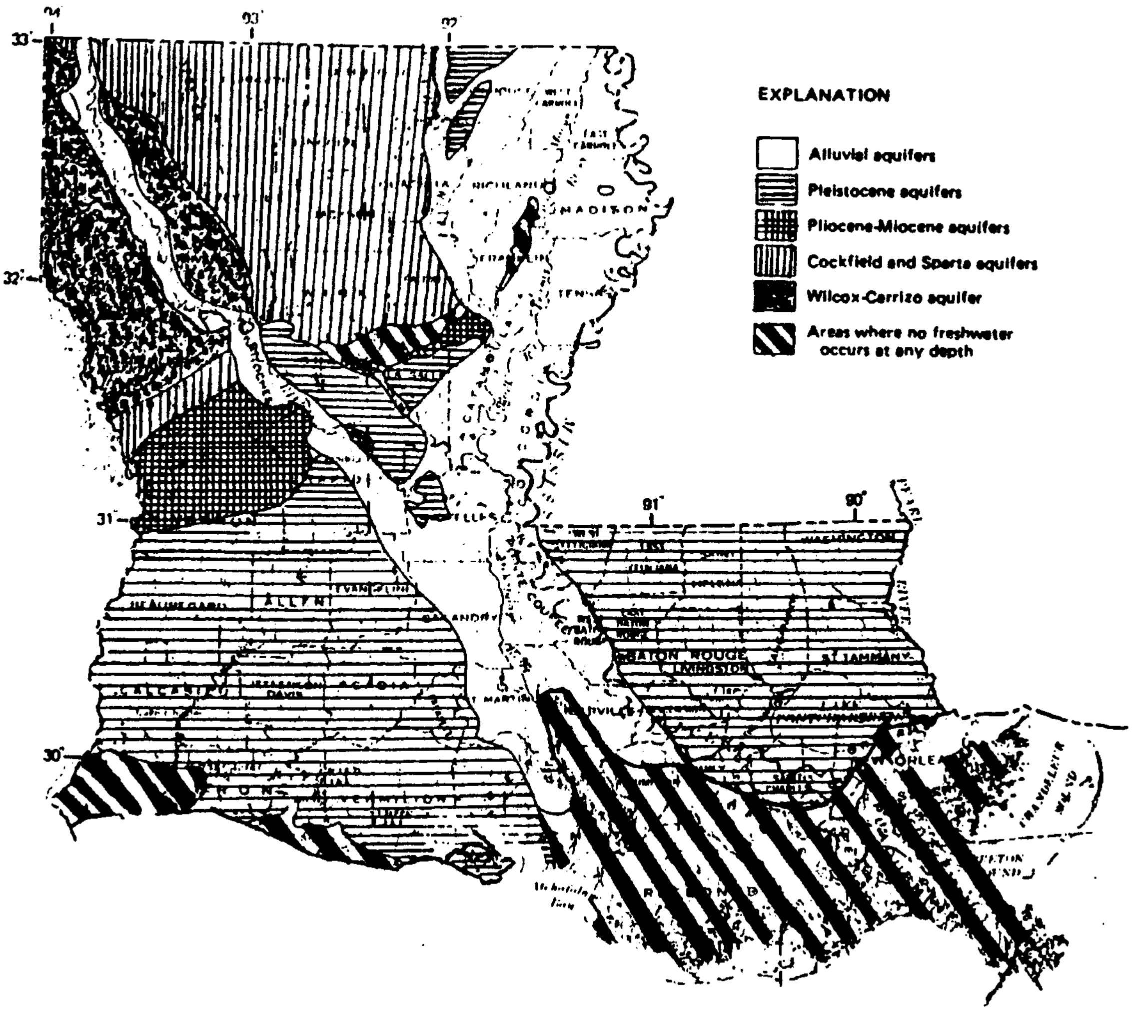



Figure 67. Louisiana Principal Aquifers Map
(Modified From U.S.G.S., 1985)

| | Concentration Interval (mg/L) | | | | | total | wells |
|---|---|---|---|---|---|---|---|
| | 0-25 | 25-100 | 100-250 | 250-500 | >500 | wells | >250 |
| Depth Interval (feet) | | | | | | | |
| 0-100 | 767 | 655 | 237 | 115 | 148 | 1922 | 263 |
| 100-200 | 899 | 459 | 152 | 56 | 111 | 1677 | 167 |
| 200-300 | 622 | 651 | 205 | 125 | 139 | 1742 | 264 |
| 300-400 | 470 | 461 | 207 | 110 | 90 | 1338 | 200 |
| 400-500 | 404 | 248 | 129 | 76 | 62 | 919 | 138 |
| 500-600 | 291 | 235 | 121 | 70 | 38 | 755 | 108 |
| 600-700 | 217 | 147 | 107 | 46 | 30 | 547 | 76 |
| 700-800 | 97 | 106 | 87 | 72 | 45 | 407 | 117 |
| 800-900 | 68 | 28 | 32 | 32 | 30 | 190 | 62 |
| 900-1000 | 65 | 16 | 8 | 4 | 10 | 103 | 14 |
| 1000-1100 | 59 | 10 | 4 | 3 | 9 | 85 | 12 |
| 1100-1200 | 55 | 4 | 2 | 2 | 3 | 66 | 5 |
| State Total | 4014 | 3020 | 1291 | 711 | 715 | 9751 | 1426 |
| Percent Of Wells With Concentrations Greater Than 250mg/L | | | | | | | 15 |

TABLE 12. NUMBER OF STATIONS PER DEPTH AND CONCENTRATION INTERVAL IN LOUISIANA

| | Concentration Interval (mg/L) | | | | | |
|---|---|---|---|---|---|---|
| | 0-25 | 25-100 | 100-250 | 250-500 | >500 | >250 |
| Depth Interval (feet) | | | | | | |
| 0-100 | 40 | 34 | 12 | 6 | 8 | 14 |
| 100-200 | 54 | 27 | 9 | 3 | 7 | 10 |
| 200-300 | 36 | 37 | 12 | 7 | 8 | 15 |
| 300-400 | 35 | 34 | 15 | 8 | 7 | 15 |
| 400-500 | 44 | 27 | 14 | 8 | 7 | 15 |
| 500-600 | 39 | 31 | 16 | 9 | 5 | 14 |
| 600-700 | 40 | 27 | 20 | 8 | 5 | 14 |
| 700-800 | 24 | 26 | 21 | 18 | 11 | 29 |
| 800-900 | 36 | 15 | 17 | 17 | 16 | 33 |
| 900-1000 | 63 | 16 | 8 | 4 | 10 | 14 |
| 1000-1100 | 69 | 12 | 5 | 4 | 11 | 14 |
| 1100-1200 | 83 | 6 | 3 | 3 | 5 | 8 |

TABLE 13. PERCENT OF STATIONS PER DEPTH AND CONCENTRATION INTERVAL IN LOUISIANA

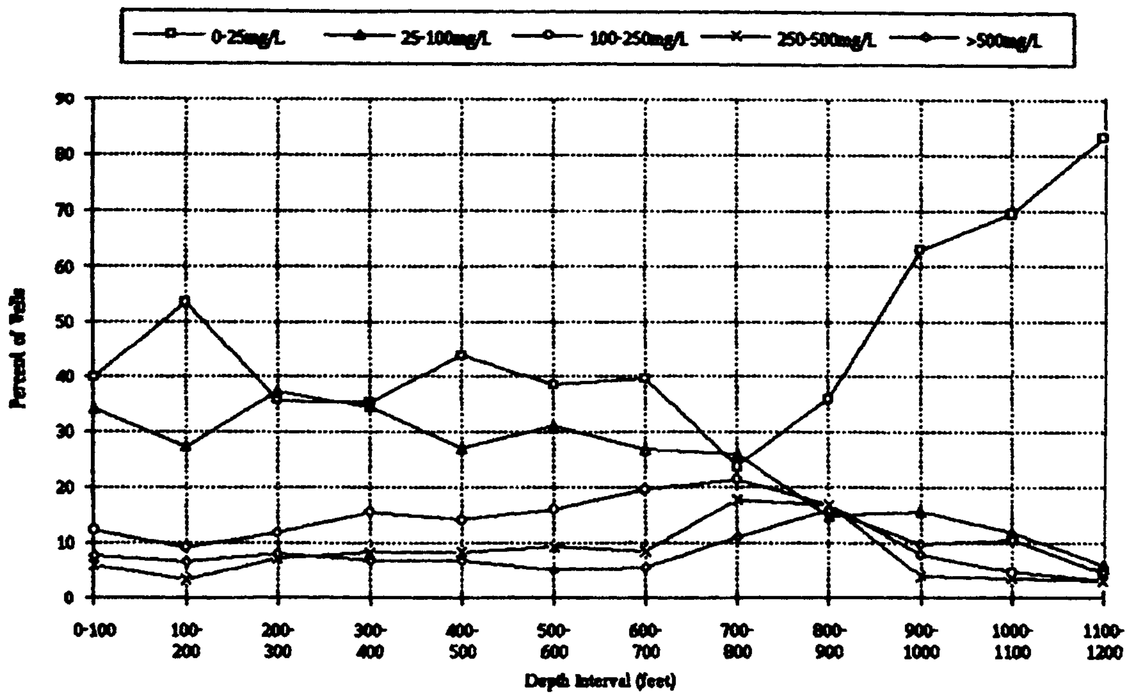



**Figure 68. Louisiana Percent Of Wells Per Concentration Interval vs Well Depth**

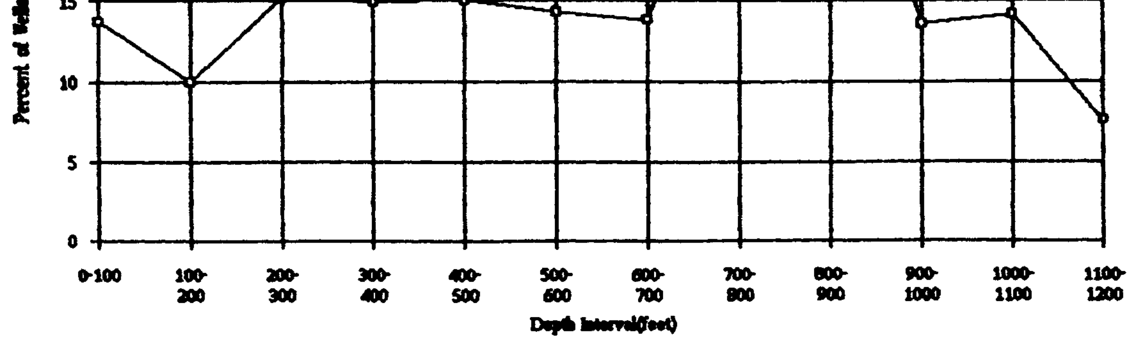



**Figure 69. Louisiana Percent Of Wells That Exceed 250mg/L Chloride**

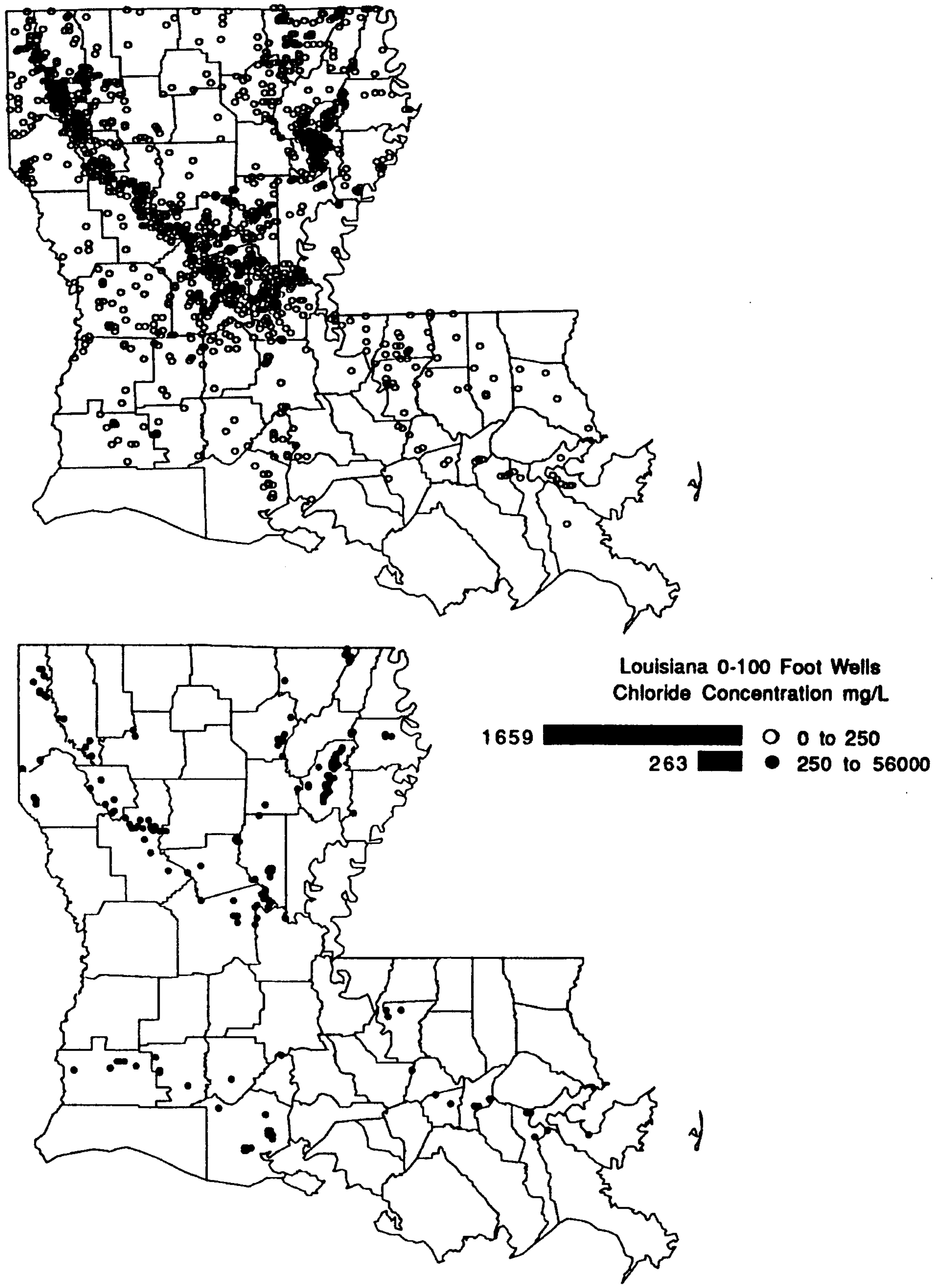



Figure 70. Louisiana 0-100 Foot Interval Chloride Map

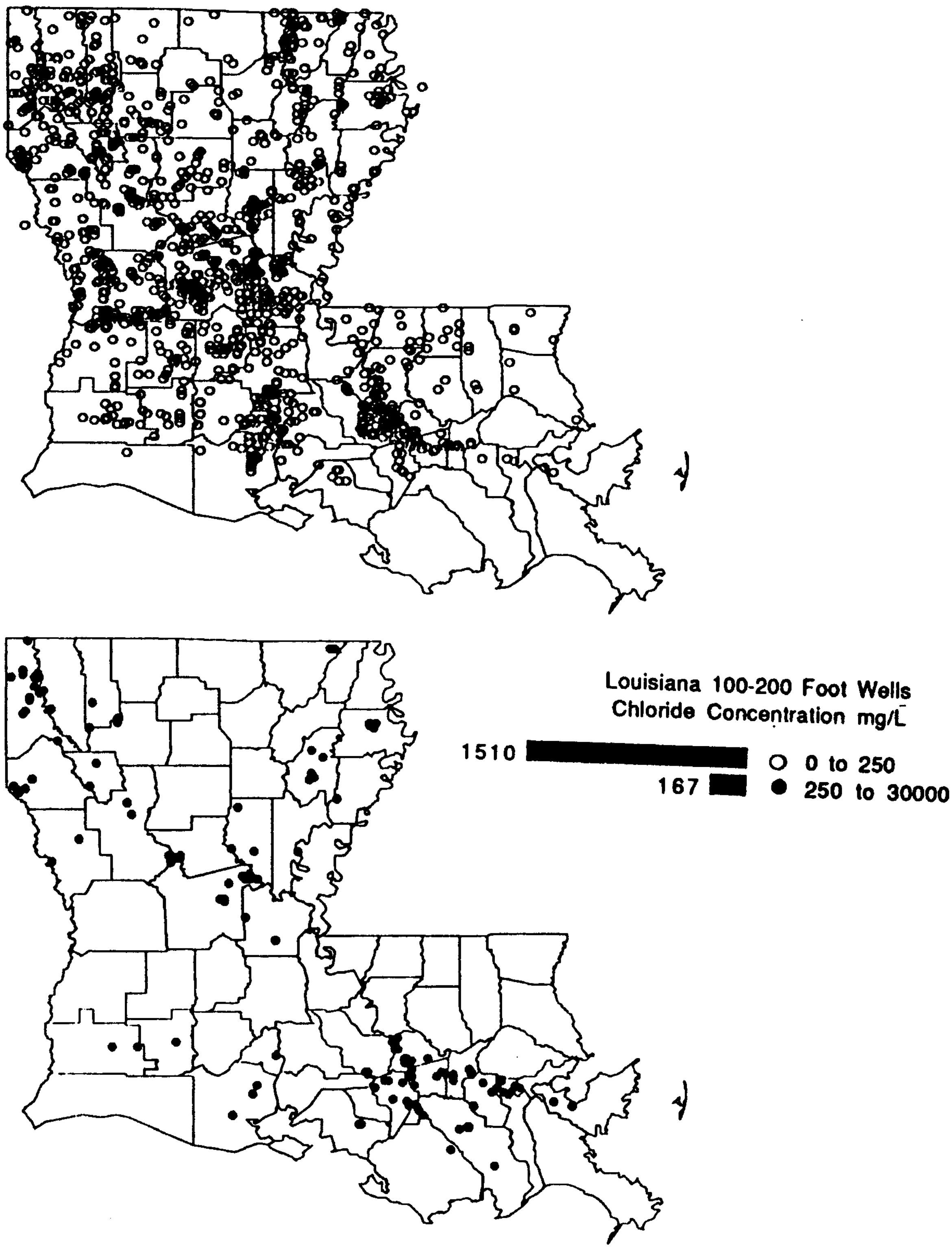



Figure 71. Louisiana 100-200 Foot Interval Chloride Map

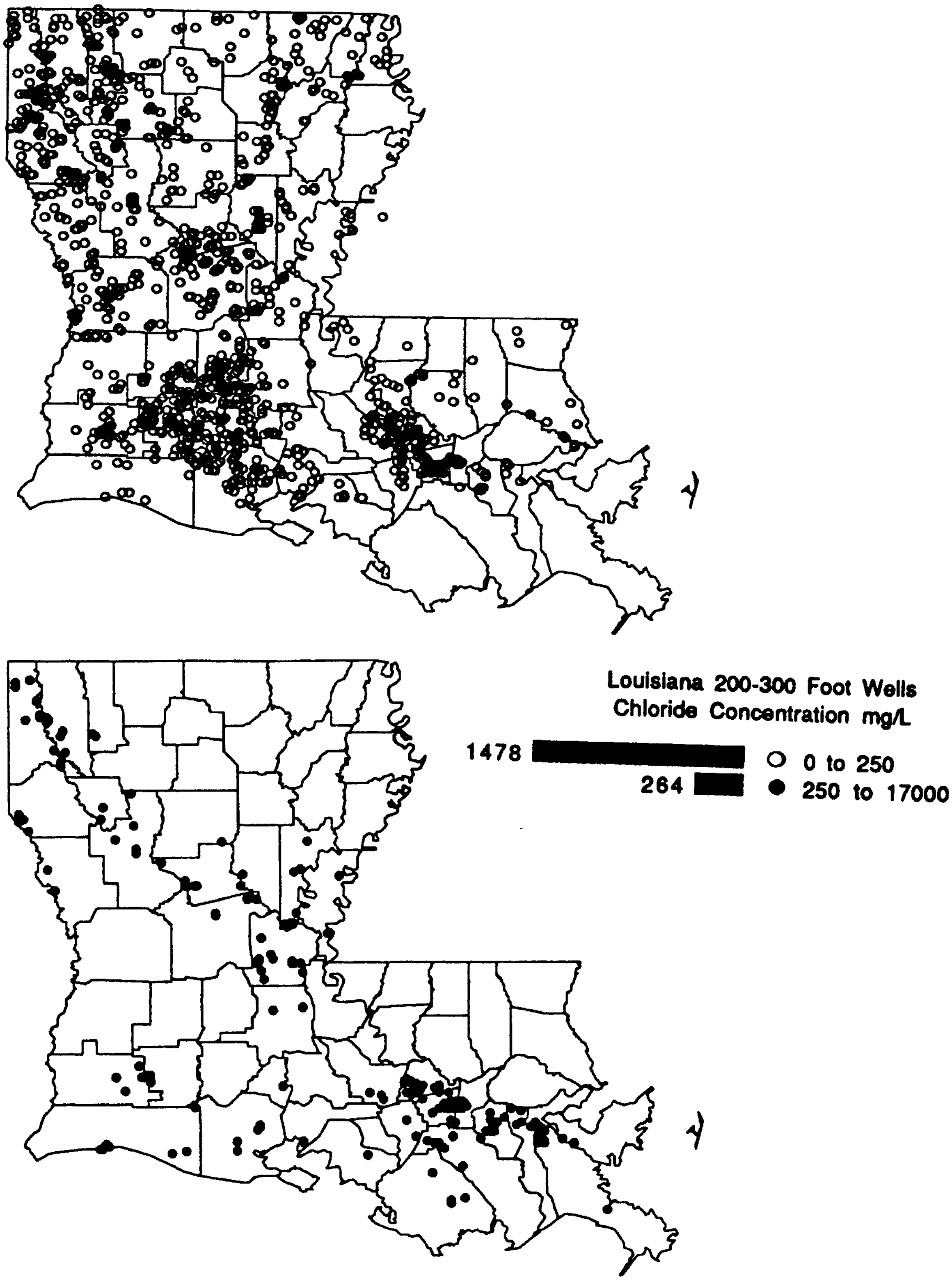



Figure 72. Louisiana 200-300 Foot Interval Chloride Map

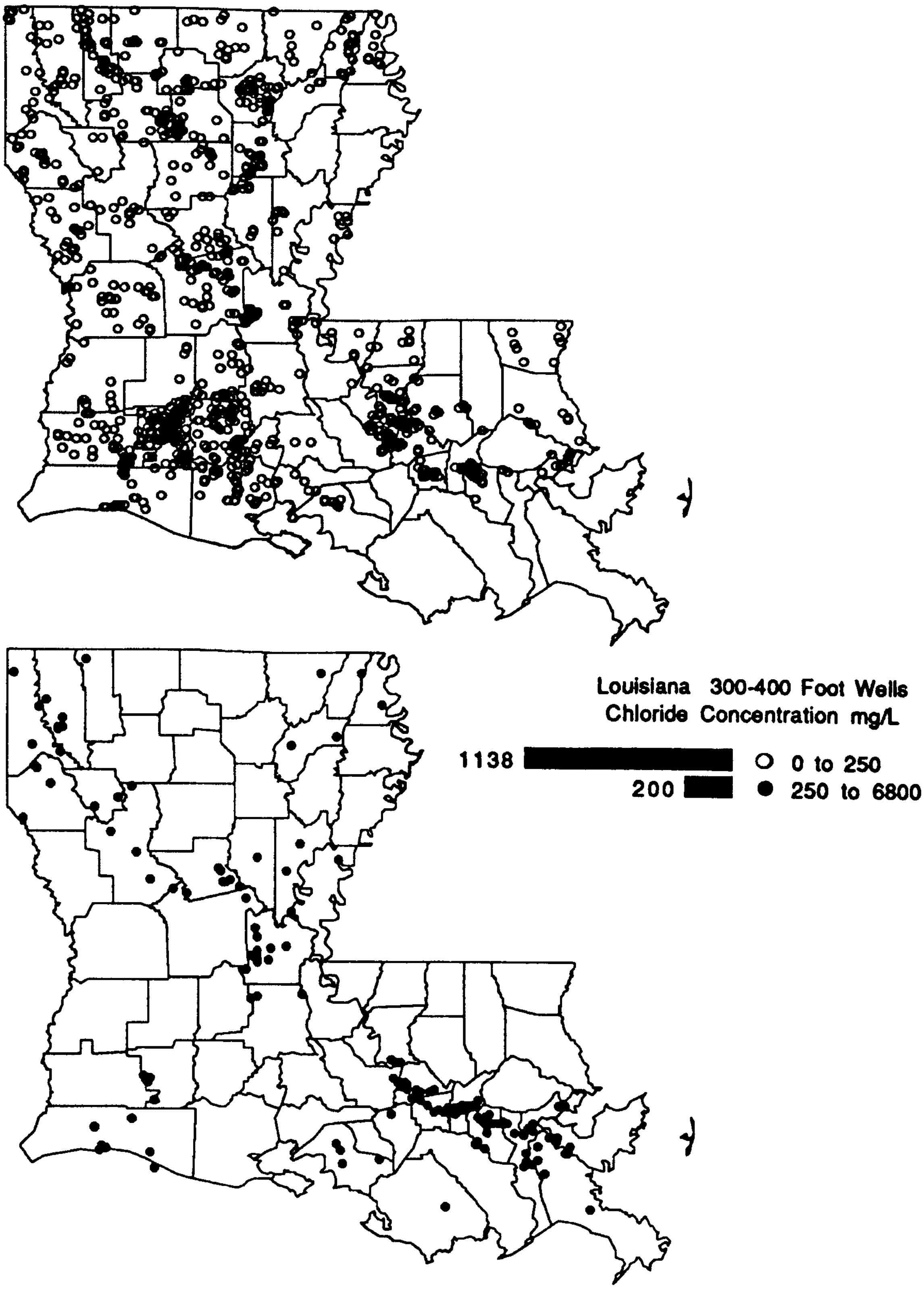



Figure 73. Louisiana 300-400 Foot Interval Chloride Map

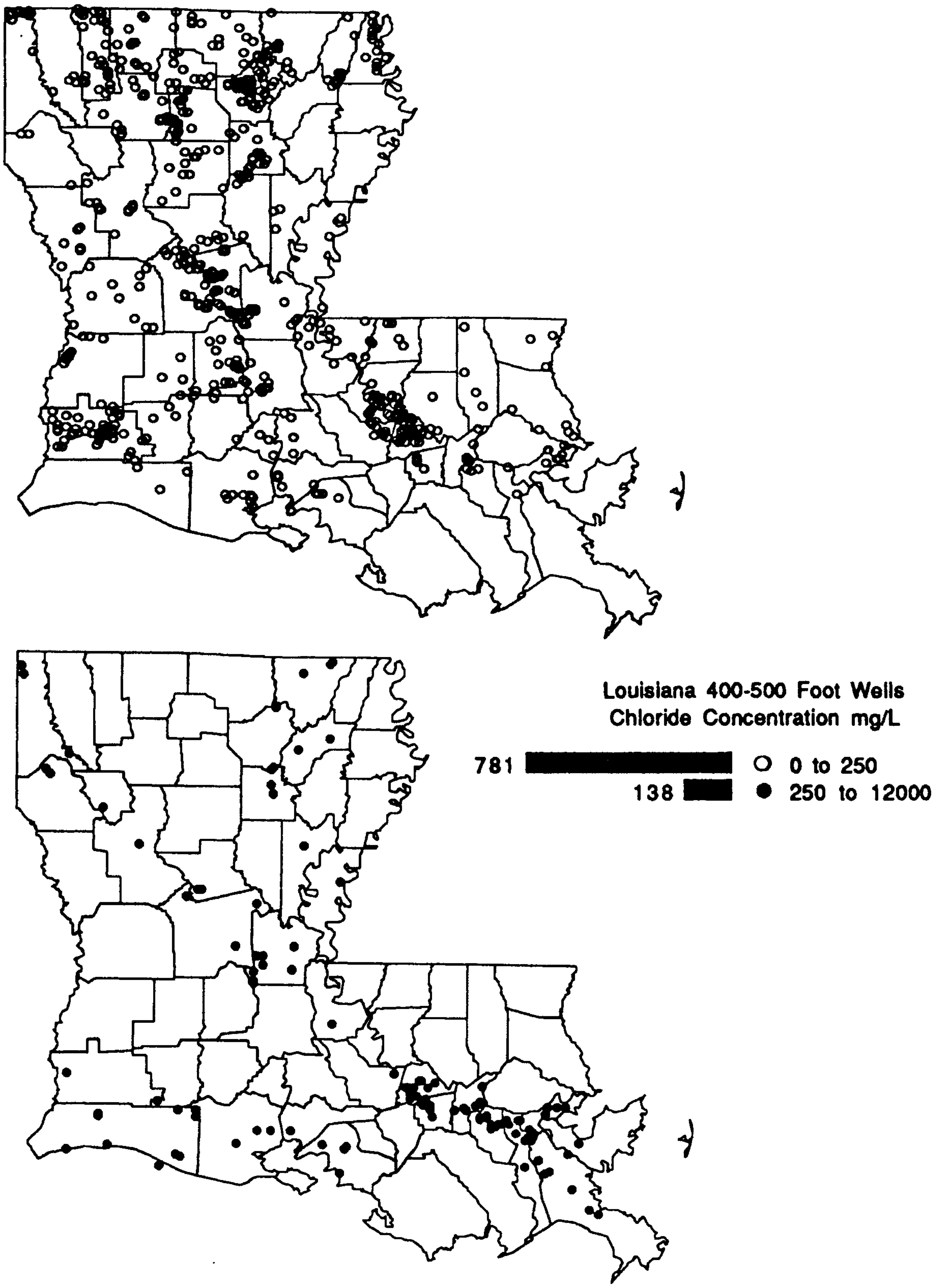



Figure 74. Louisiana 400-500 Foot Interval Chloride Map

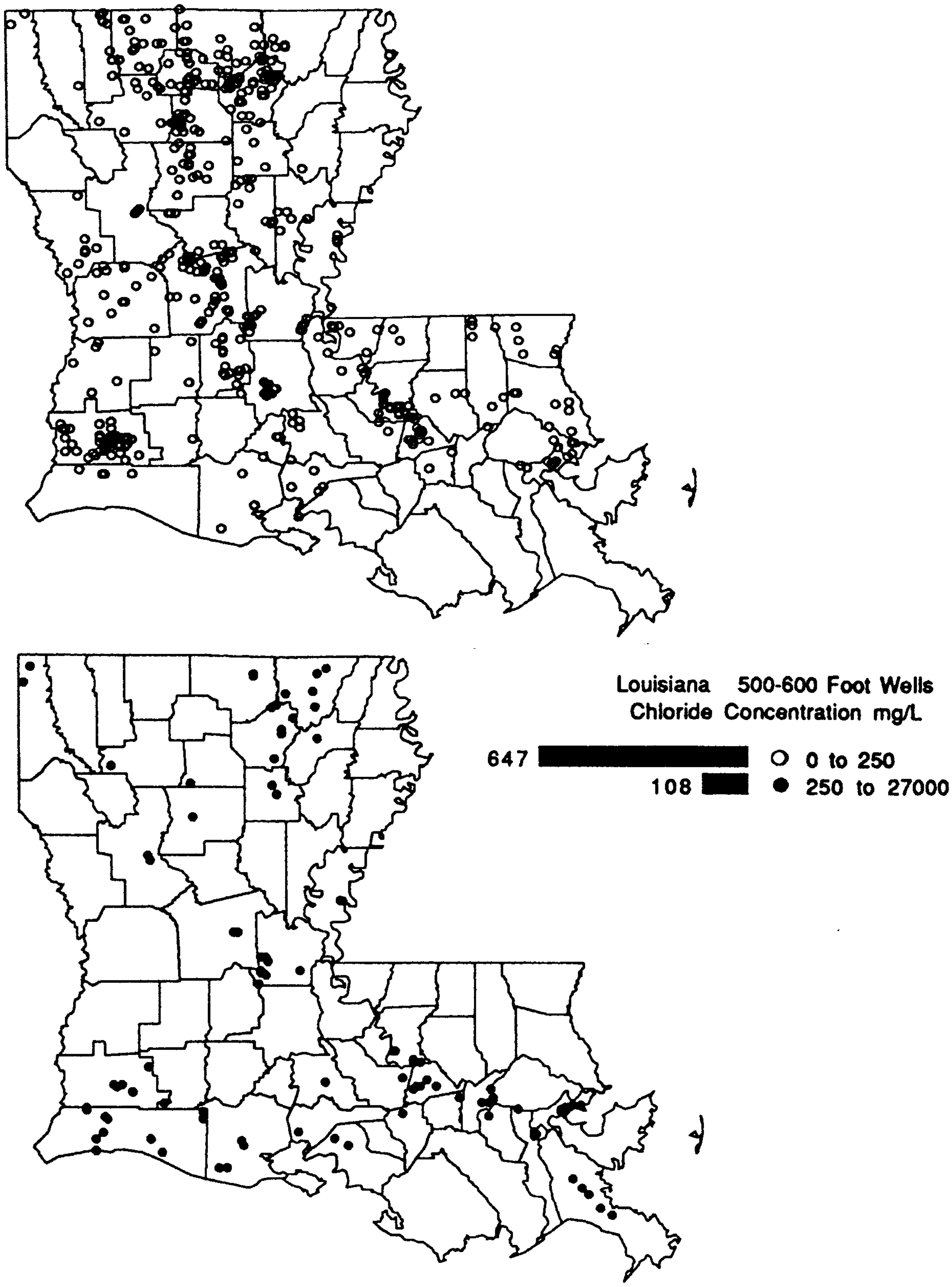



Figure 75. Louisiana 500-600 Foot Interval Chloride Map

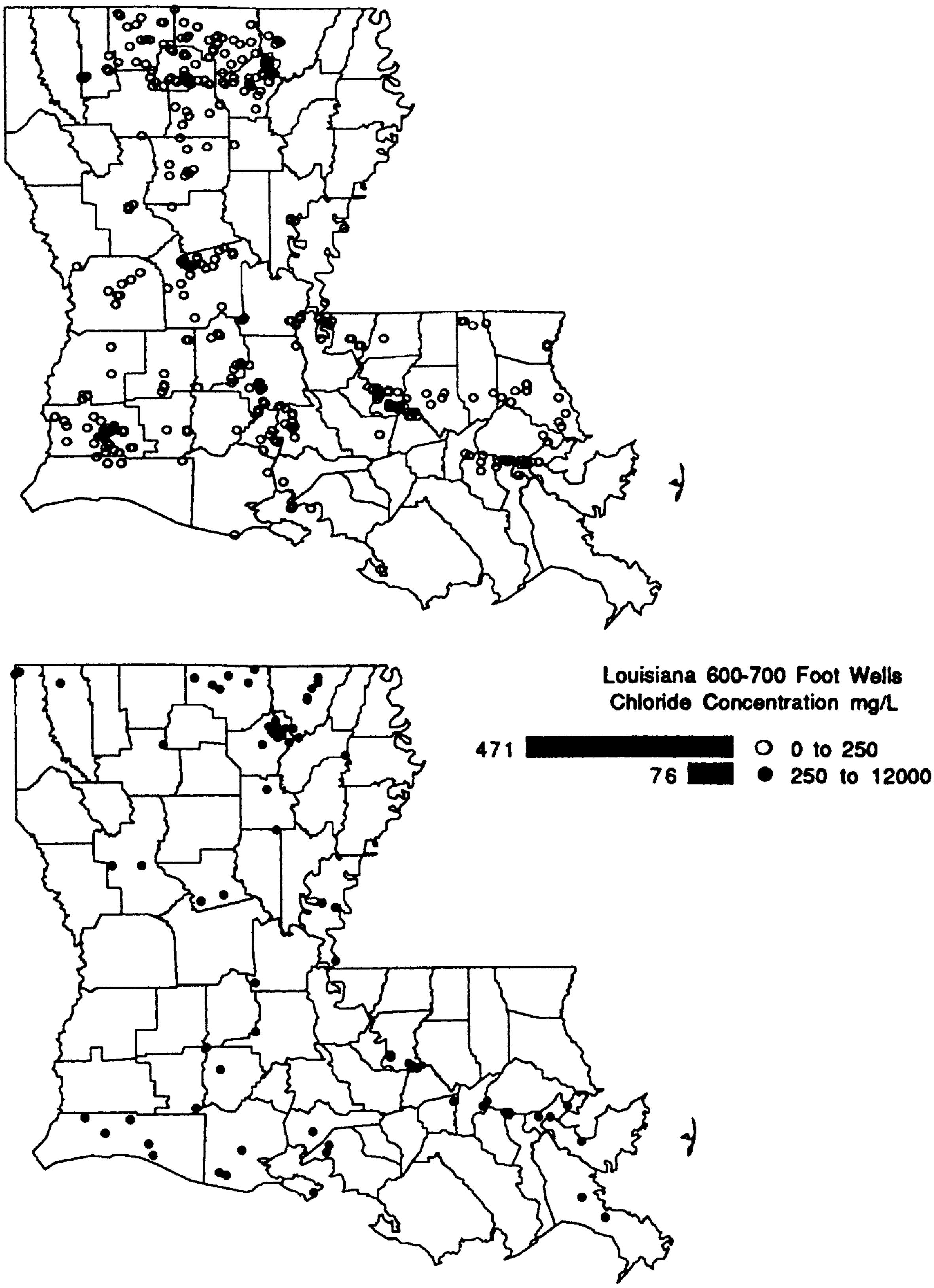



Figure 76. Louisiana 600-700 Foot Interval Chloride Map

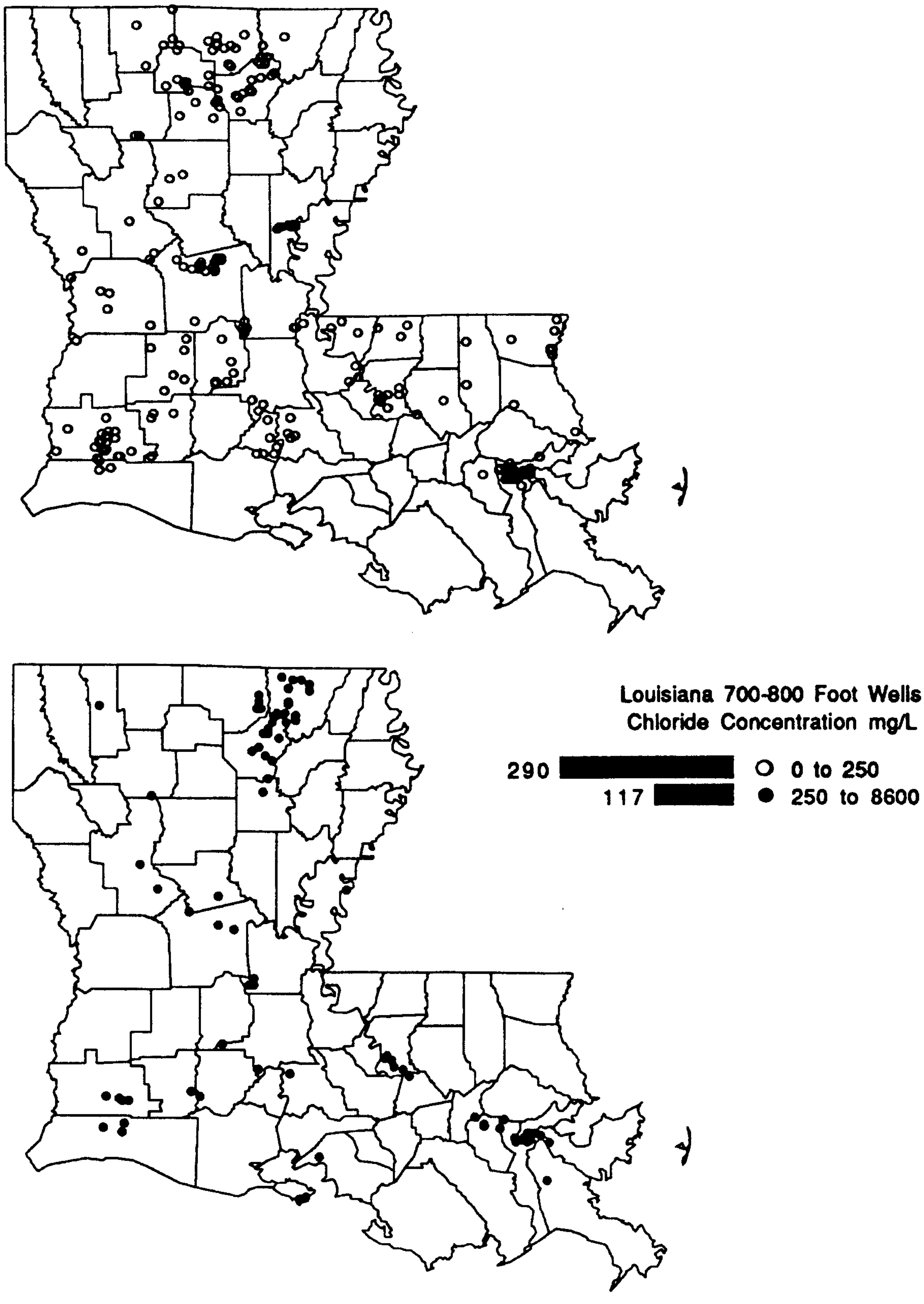



Figure 77. Louisiana 700-800 Foot Interval Chloride Map

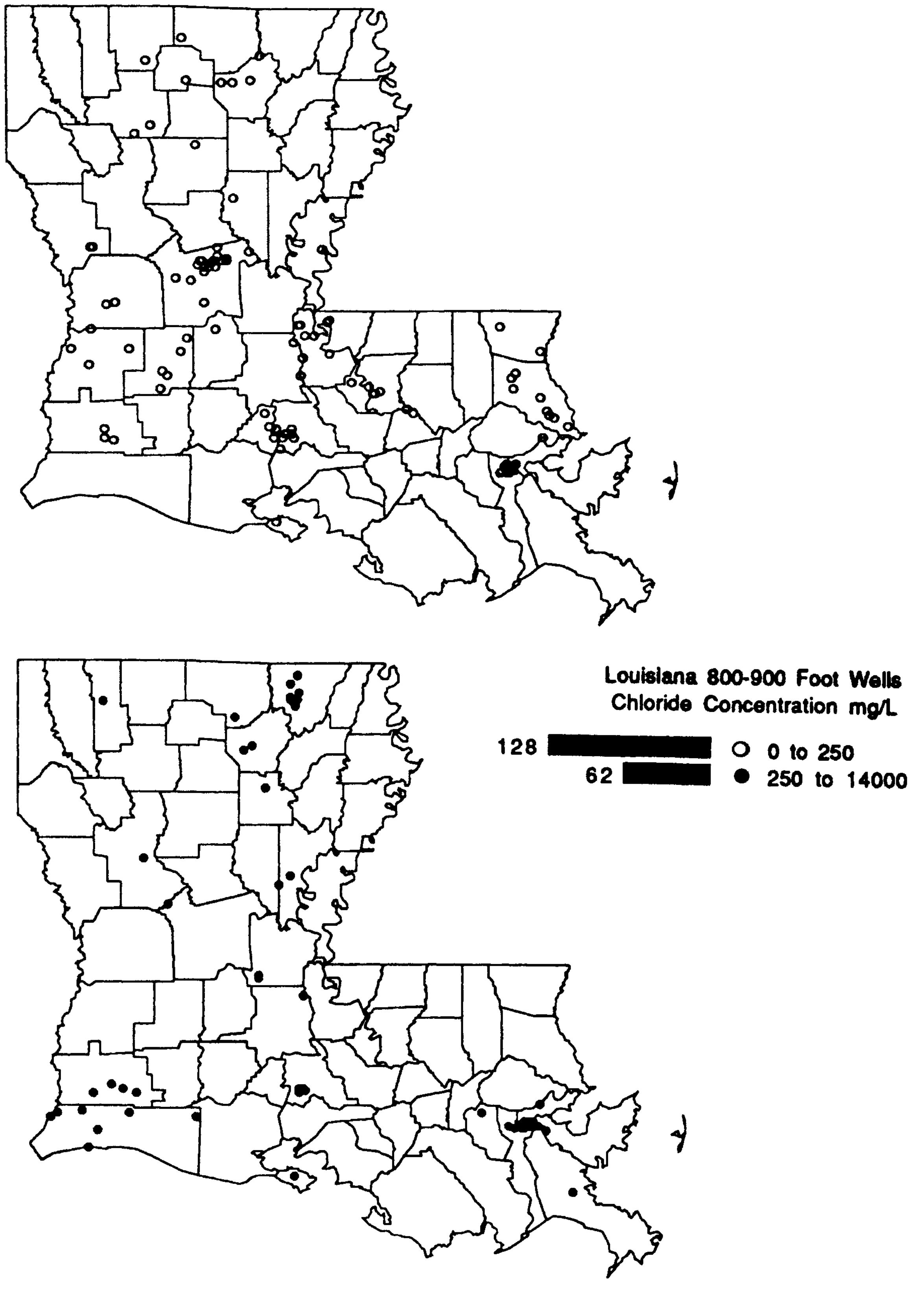



Figure 78. Louisiana 800-900 Foot Interval Chloride Map

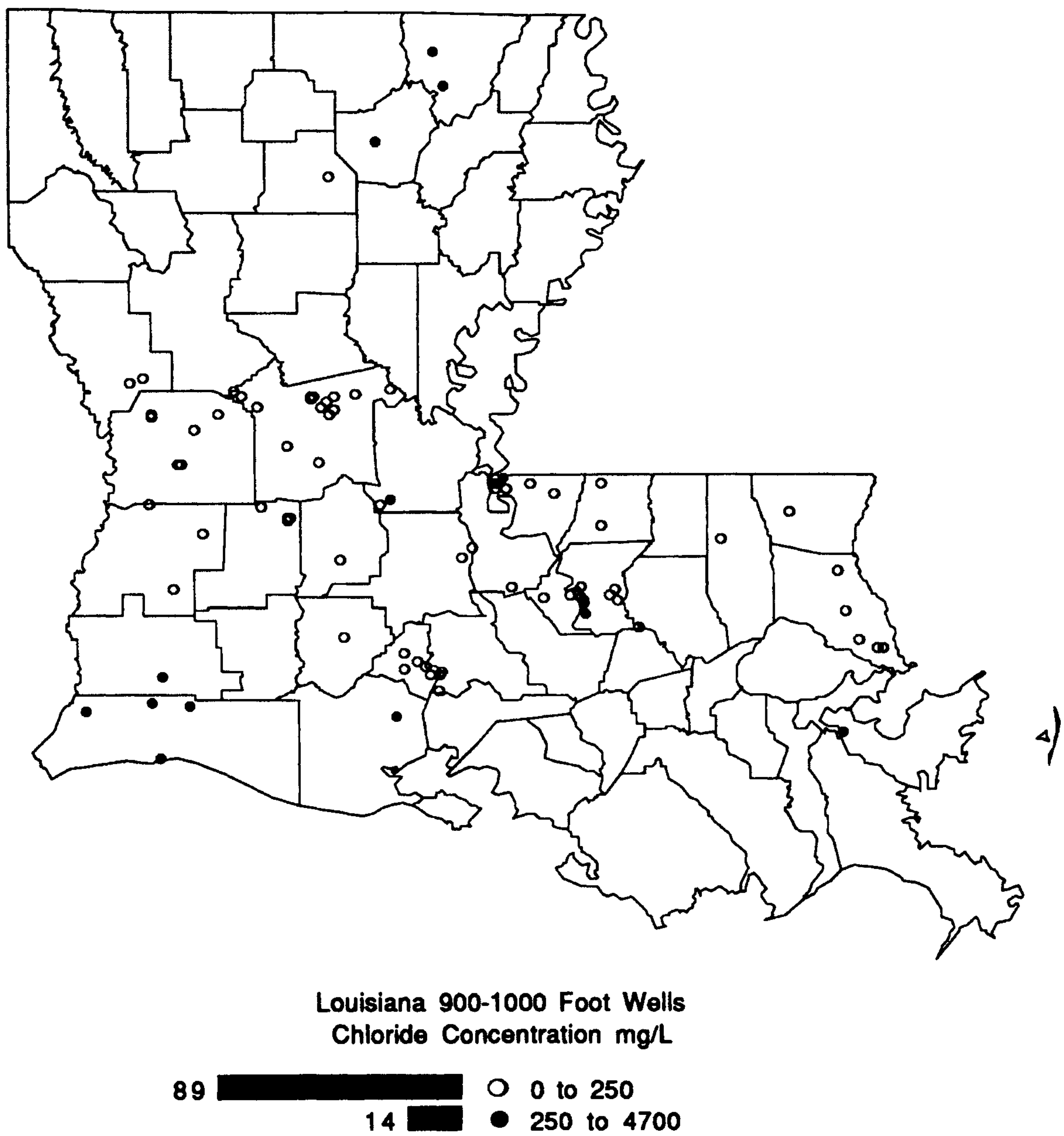



Figure 79. Louisiana 900-1000 Foot Interval Chloride Map

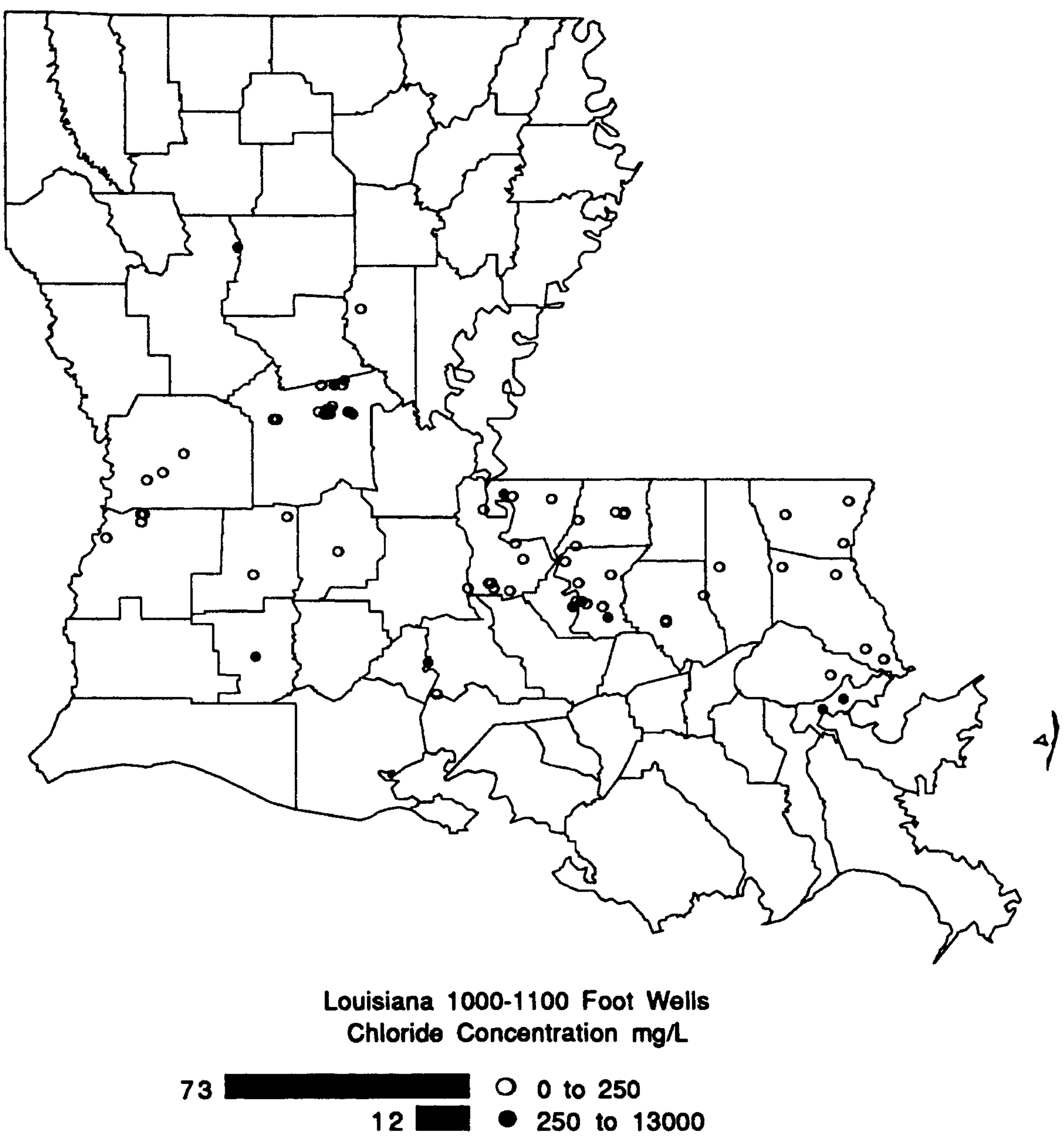



Figure 80. Louisiana 1000-1100 Foot Interval Chloride Map

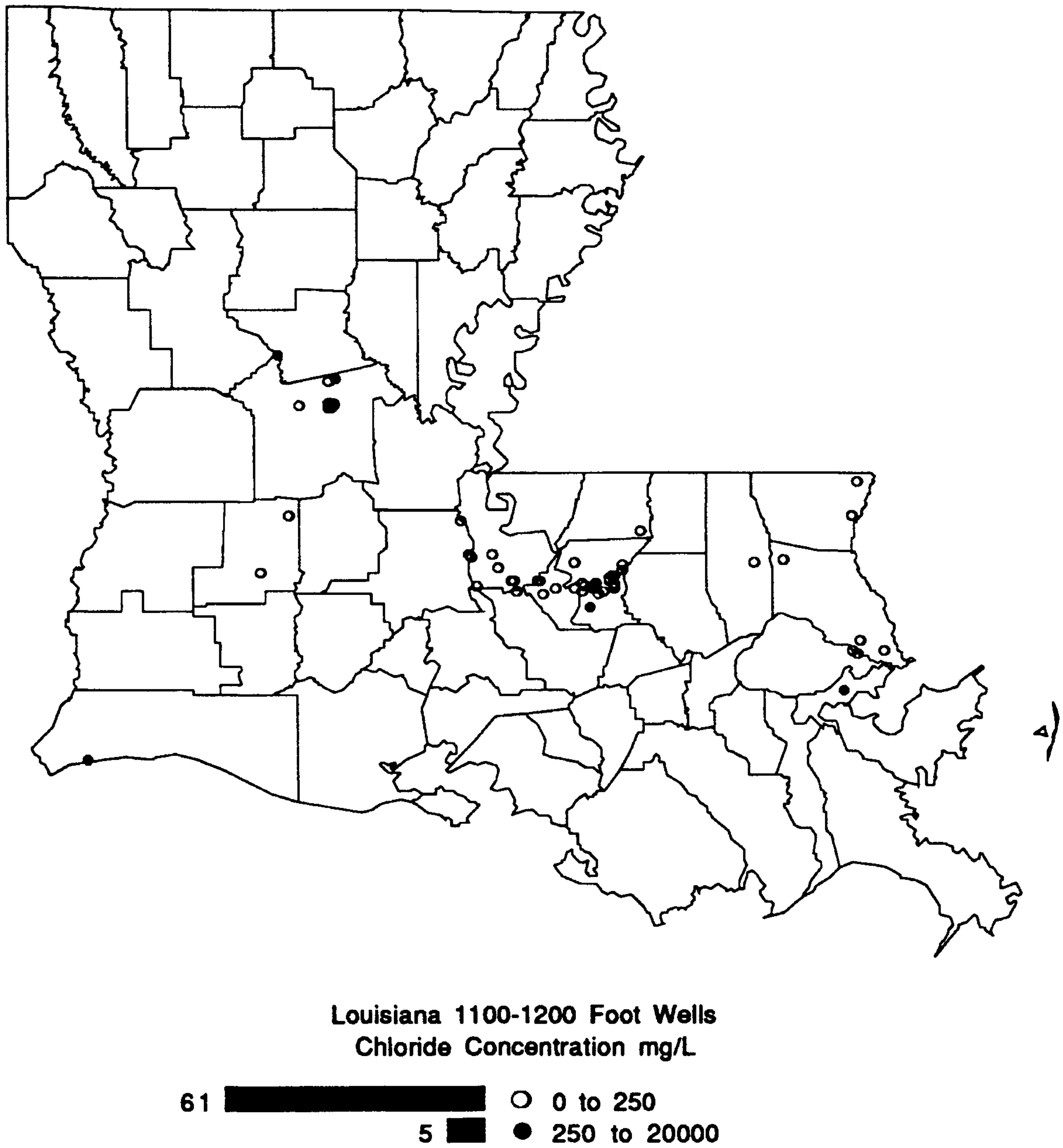



Figure 81. Louisiana 1100-1200 Foot Interval Chloride Map

# MISSISSIPPI

## General Setting

Mississippi contains approximately 48,000 square miles, and lies largely in the relatively flat lying Coastal Plain physiographic province. The extreme northeastern corner of the state is in the Central Lowland province. The Coastal Plain is underlain by a south to southwest dipping sequence of Cretaceous to Tertiary age semiconsolidated to unconsolidated sand, silt, clay, gravel, marl, and limestone. These sediments are covered by unconsolidated Mississippi River alluvium and loess deposits in the west and, locally, by river alluvium and coastal deposits. Devonian and Mississippian age carbonate and clastic rocks are found in the extreme northeast corner of the state.

The Mississippi River and its southwest flowing tributaries drain western Mississippi. The remainder of the state is drained by a south flowing series of streams including the Mississippi, Pearl, and Pascagoula Rivers.

## Principal Aquifers

Most principal aquifers in Mississippi consist of unconsolidated sand and gravel of varying thickness and physical character. The areal distribution of Mississippi's principal aquifers is shown in Figure 82.

The Mississippi River alluvial deposits of Northwestern Mississippi are an important source of groundwater for this region of the state. The alluvium in this area consists of 30 to 40 feet of fine grained materials underlain by sand and gravel beds.

The Citronelle aquifers overlie older aquifers in Southern Mississippi and consists of fluvial deposits of sand, gravel, silt and clay. The formations of the Citronelle were formally much more extensive but have since been dissected by subsequent drainage.

The aquifers in Southern Mississippi overlie the Citronelle and consist of a number of Miocene and Oligocene formations. These formations include; the sands and gravels of the Graham Ferry Formation, the sands and gravels of the Pascagoula and Hattiesburg Formations, the Catahoula Sandstone, the sand, marl, and limestone of the Vicksburg Group, and the Forest Hill Sand.

Eocene age aquifer formations crop out in the central, north central and northwestern part of the state. Included in this Eocene aquifer system are the formations of the Claiborne Group including; The course sands and interbedded clays and lignite of the Cockfield Formation, the Sparta Formations sand and clays, The fine to course sand of the Winona Formation, the fine to course sands, shale, claystone and sandstone of the Tallahatta Formation, and the sand shale, silt, and clays of the Upper Wilcox (Meridian) Formation. The basal Eocene Lower Wilcox Formations completes the Eocene aquifer system of Mississippi.

Cretaceous formations in Northeastern Mississippi are also productive ground water sources. The formations of Cretaceous age which are important water sources include; the sand, clay, limestone, and chalk of the Ripley Formation, the sand, sandy clay, and calcareous sandstone of the Coffee Sands Formation, fine, glauconitic, silty, sands of the Eutaw Formation, and the course sand and gravels of the Tuscaloosa Formation. The extreme northeastern corner of Mississippi has some locally important undifferentiated Pennsylvanian, Mississippian, and Devonian carbonates and sandstones which serve as aquifers.

### Chloride Distribution

Chloride maps of Mississippi are based upon 4184 stations distributed over 18 depth intervals(Table 14). The percentage of wells that exceed the 250 mg/L standard varies from a low of one percent at the 300-400 and 500-600 foot intervals, to a high of 56 percent at the 1800-2000 foot interval(Table 15). Significant peaks in chloride levels occur at the 1200-1300, 1600-1800, and 1800-2000 foot intervals(fig. 84). Regionally five percent (207) of the states wells have chloride concentrations greater than 250 mg/L. Areas of concern with higher chloride levels include the extreme southern part of the state at shallow intervals to 300 feet, and alluvial material along the Mississippi. Wells deeper than 1800 feet are predominantly (57 percent) affected by high chloride levels and may reflect the fresh water-brine interface. Tabulated data for Mississippi are presented in Tables 14 & 15.

According to an inventory by Miller and others (1977), 13 of 25 counties in which brine disposal wells are located, contamination of ground water due to oil field brines has occurred. Saline springs and seeps resulting from the disposal of brine into unlined pits have occurred in Wayne, Wilkinson and Yazoo Counties(Richter, 1991). Contamination of surface and shallow ground water as a result of oil field activities has occurred at numerous oil fields in Adams County(Richter, 1991). Kemper and Noxubee counties in East Central Mississippi also are also identified as having stations with chloride levels in excess of 250 mg/l. These stations could represent an area with oil field brine contamination problems.

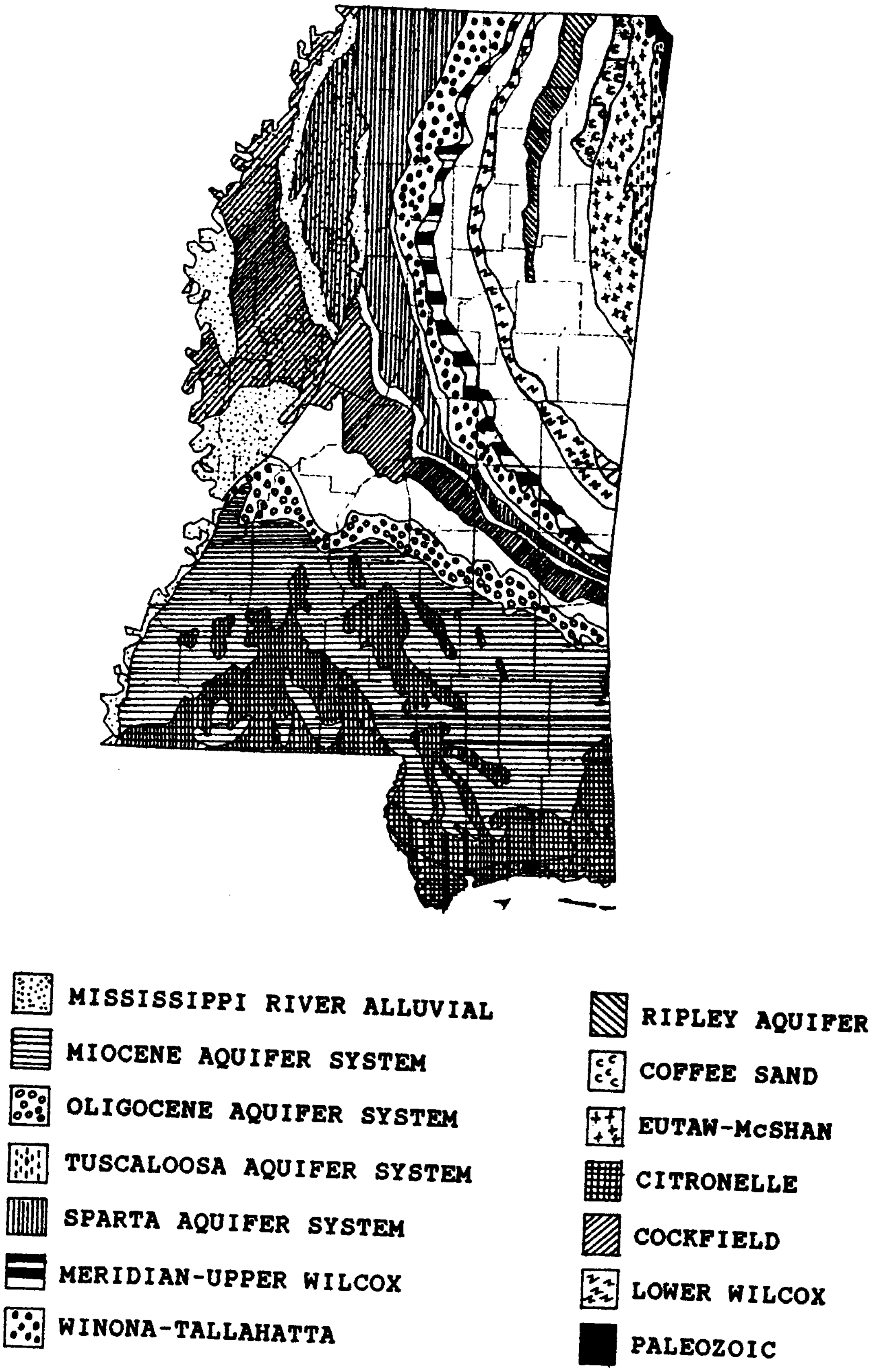



Figure 82. Mississippi Principal Aquifers Map
(Modified From U.S.G.S., 1986)

| | Concentration Interval (mg/L) | | | | | total | wells |
|---|---|---|---|---|---|---|---|
| | 0-25 | 25-100 | 100-250 | 250-500 | >500 | wells | >250 |
| Depth Interval (feet) | | | | | | | |
| 0-100 | 492 | 87 | 28 | 10 | 6 | 623 | 16 |
| 100-200 | 532 | 69 | 19 | 6 | 7 | 633 | 13 |
| 200-300 | 365 | 40 | 27 | 4 | 3 | 439 | 7 |
| 300-400 | 290 | 63 | 31 | 3 | 0 | 387 | 3 |
| 400-500 | 266 | 82 | 10 | 6 | 3 | 367 | 9 |
| 500-600 | 189 | 74 | 23 | 2 | 0 | 288 | 2 |
| 600-700 | 178 | 37 | 16 | 7 | 5 | 243 | 12 |
| 700-800 | 155 | 27 | 15 | 9 | 1 | 207 | 10 |
| 800-900 | 160 | 38 | 30 | 9 | 4 | 241 | 13 |
| 900-1000 | 121 | 31 | 7 | 6 | 3 | 168 | 9 |
| 1000-1100 | 52 | 22 | 7 | 3 | 2 | 86 | 5 |
| 1100-1200 | 62 | 30 | 5 | 3 | 3 | 103 | 6 |
| 1200-1300 | 47 | 15 | 9 | 18 | 5 | 94 | 23 |
| 1300-1400 | 35 | 11 | 12 | 6 | 7 | 71 | 13 |
| 1400-1500 | 30 | 5 | 11 | 3 | 3 | 52 | 6 |
| 1500-1600 | 18 | 4 | 8 | 2 | 1 | 33 | 3 |
| 1600-1800 | 33 | 13 | 15 | 7 | 11 | 79 | 18 |
| 1800-2000 | 26 | 4 | 1 | 0 | 39 | 70 | 39 |
| State Total | 3051 | 652 | 274 | 104 | 103 | 4184 | 207 |
| Percent Of Wells With Concentrations Greater Than 250mg/L | | | | | | | 5 |

TABLE 14. NUMBER OF STATIONS PER DEPTH AND CONCENTRATION INTERVAL IN MISSISSIPPI

| | Concentration Interval (mg/L) | | | | | |
|---|---|---|---|---|---|---|
| | 0-25 | 25-100 | 100-250 | 250-500 | >500 | >250 |
| Depth Interval (feet) | | | | | | |
| 0-100 | 79 | 14 | 4 | 2 | 1 | 3 |
| 100-200 | 84 | 11 | 3 | 1 | 1 | 2 |
| 200-300 | 83 | 9 | 6 | 1 | 1 | 2 |
| 300-400 | 75 | 16 | 8 | 1 | 0 | 1 |
| 400-500 | 72 | 22 | 3 | 2 | 1 | 2 |
| 500-600 | 66 | 26 | 8 | 1 | 0 | 1 |
| 600-700 | 73 | 15 | 7 | 3 | 2 | 5 |
| 700-800 | 75 | 13 | 7 | 4 | 0 | 5 |
| 800-900 | 66 | 16 | 12 | 4 | 2 | 5 |
| 900-1000 | 72 | 18 | 4 | 4 | 2 | 5 |
| 1000-1100 | 60 | 26 | 8 | 3 | 2 | 6 |
| 1100-1200 | 60 | 29 | 5 | 3 | 3 | 6 |
| 1200-1300 | 50 | 16 | 10 | 19 | 5 | 24 |
| 1300-1400 | 49 | 15 | 17 | 8 | 10 | 18 |
| 1400-1500 | 58 | 10 | 21 | 6 | 6 | 12 |
| 1500-1600 | 55 | 12 | 24 | 6 | 3 | 9 |
| 1600-1800 | 42 | 16 | 19 | 9 | 14 | 23 |
| 1800-2000 | 37 | 6 | 1 | 0 | 56 | 56 |

TABLE 15. PERCENT OF STATIONS PER DEPTH AND CONCENTRATION INTERVAL IN MISSISSIPPI

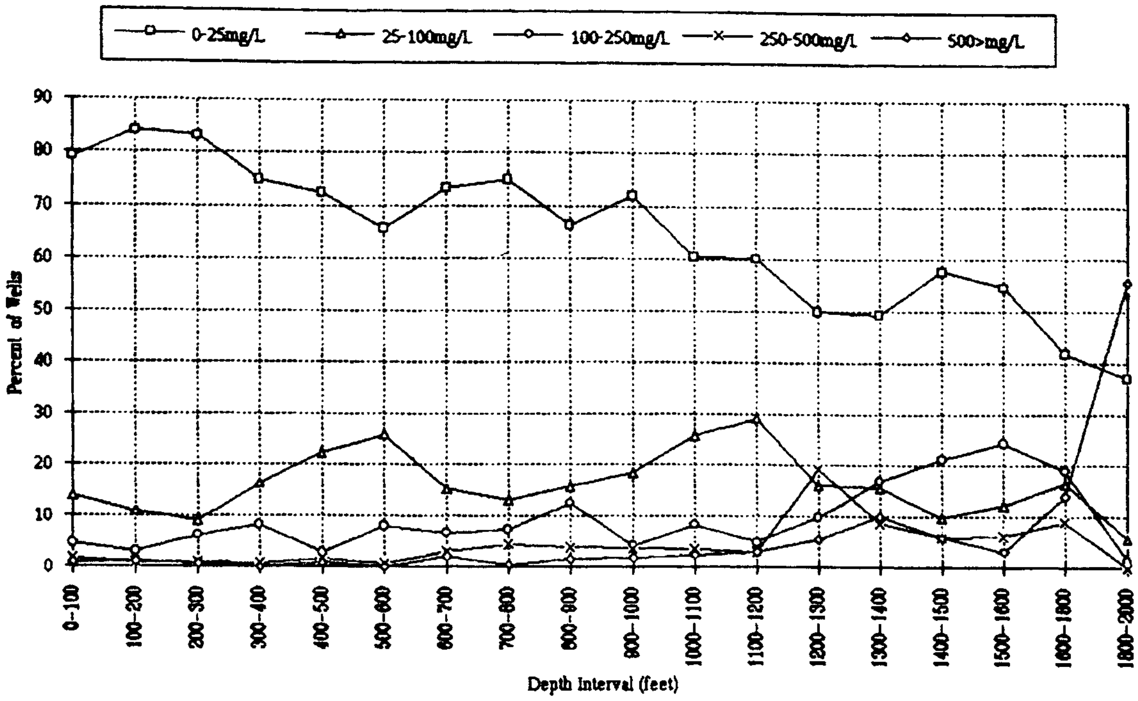



**Figure 83. Mississippi Percent Of Wells Per Concentration Interval vs Well Depth**

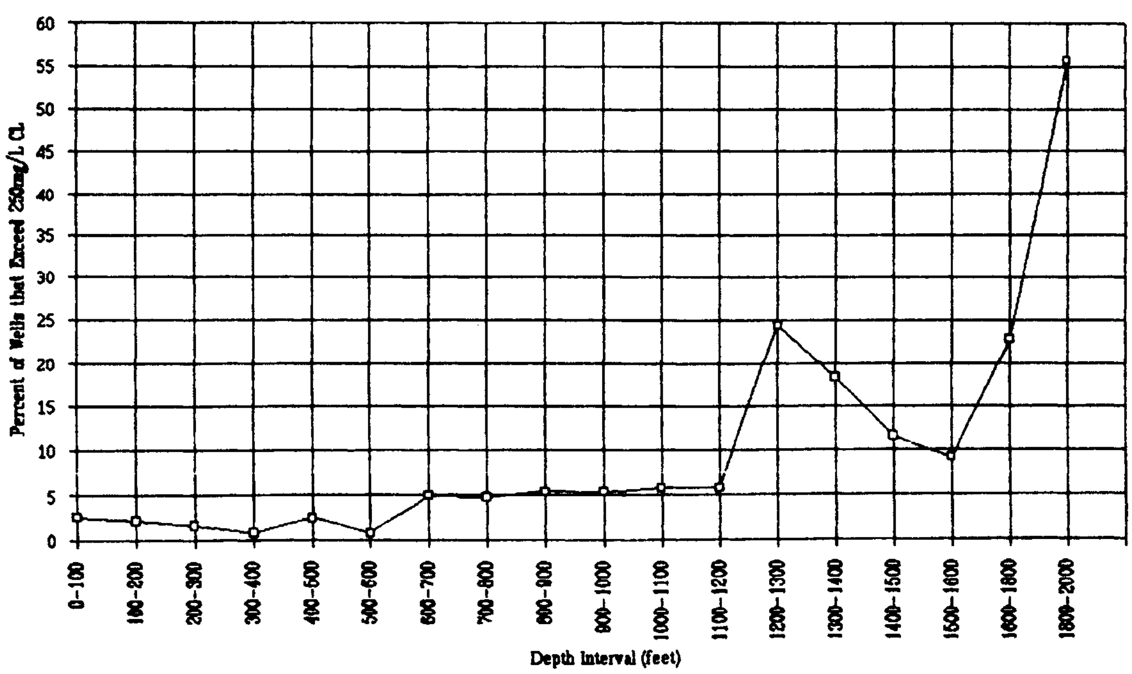



**Figure 84. Mississippi Percent Of Wells That Exceed 250 mg/L Chloride**

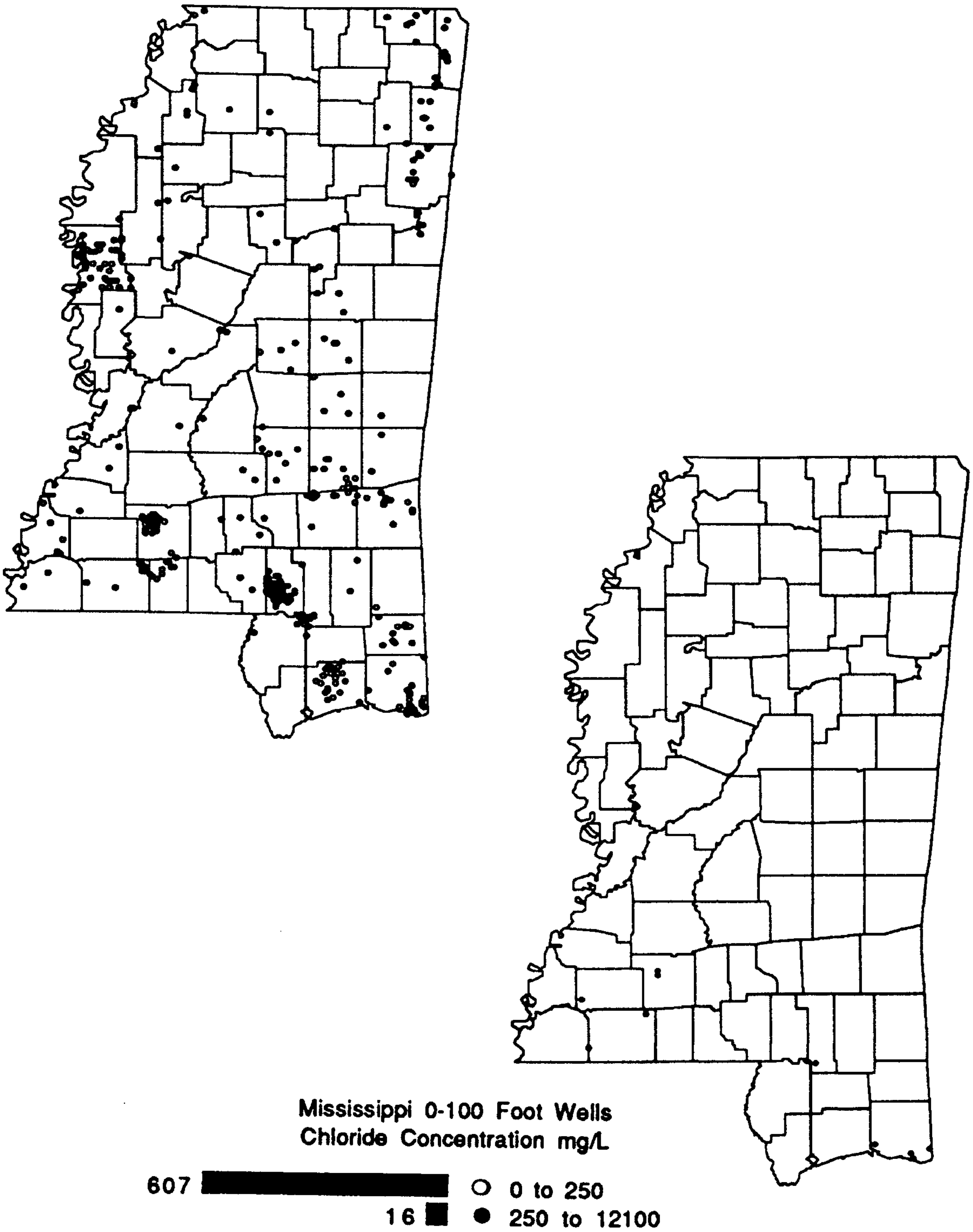



Figure 85. Mississippi 0-100 Foot Interval Chloride Map

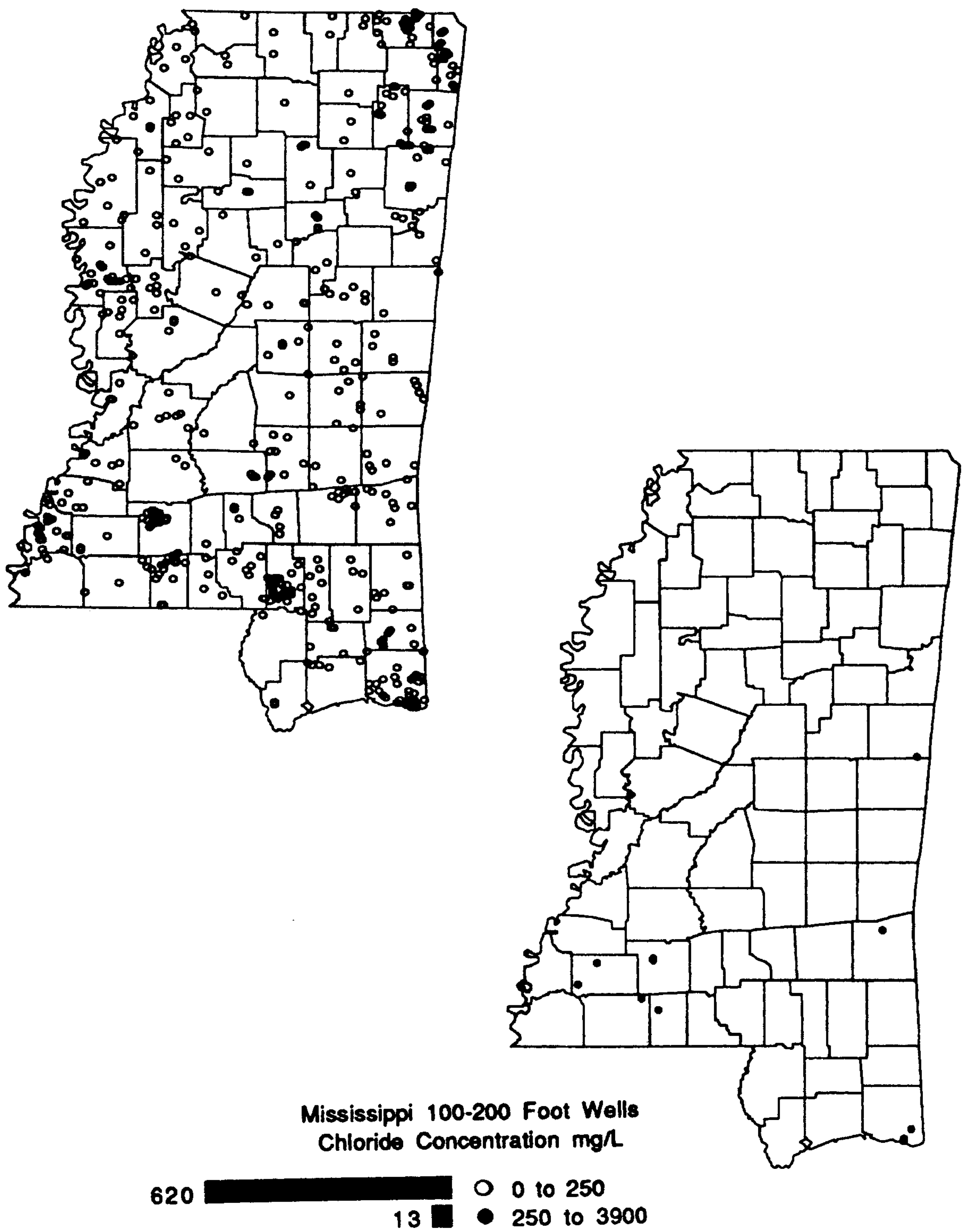



Figure 86. Mississippi 100-200 Foot Interval Chloride Map

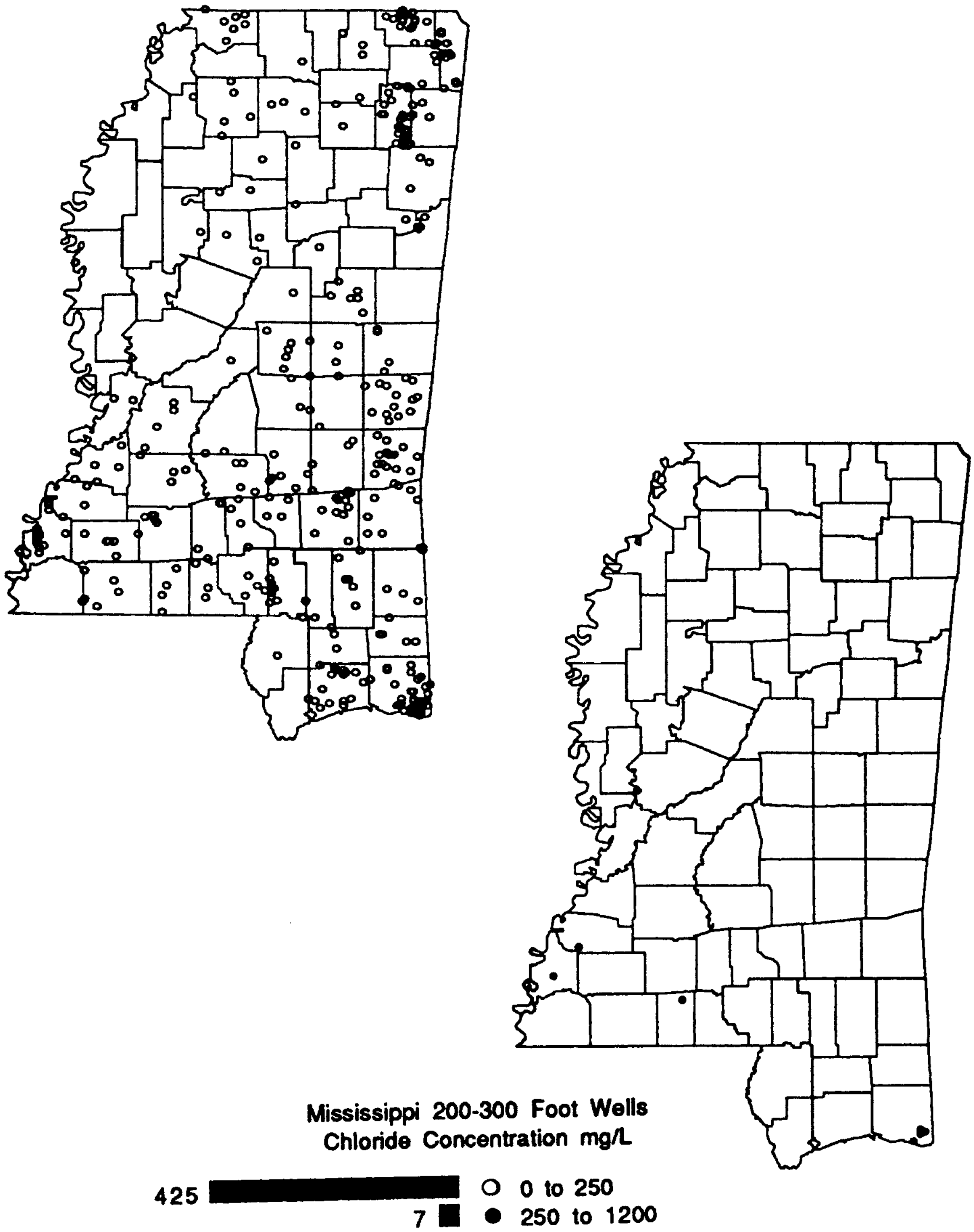



Figure 87. Mississippi 200-300 Foot Interval Chloride Map

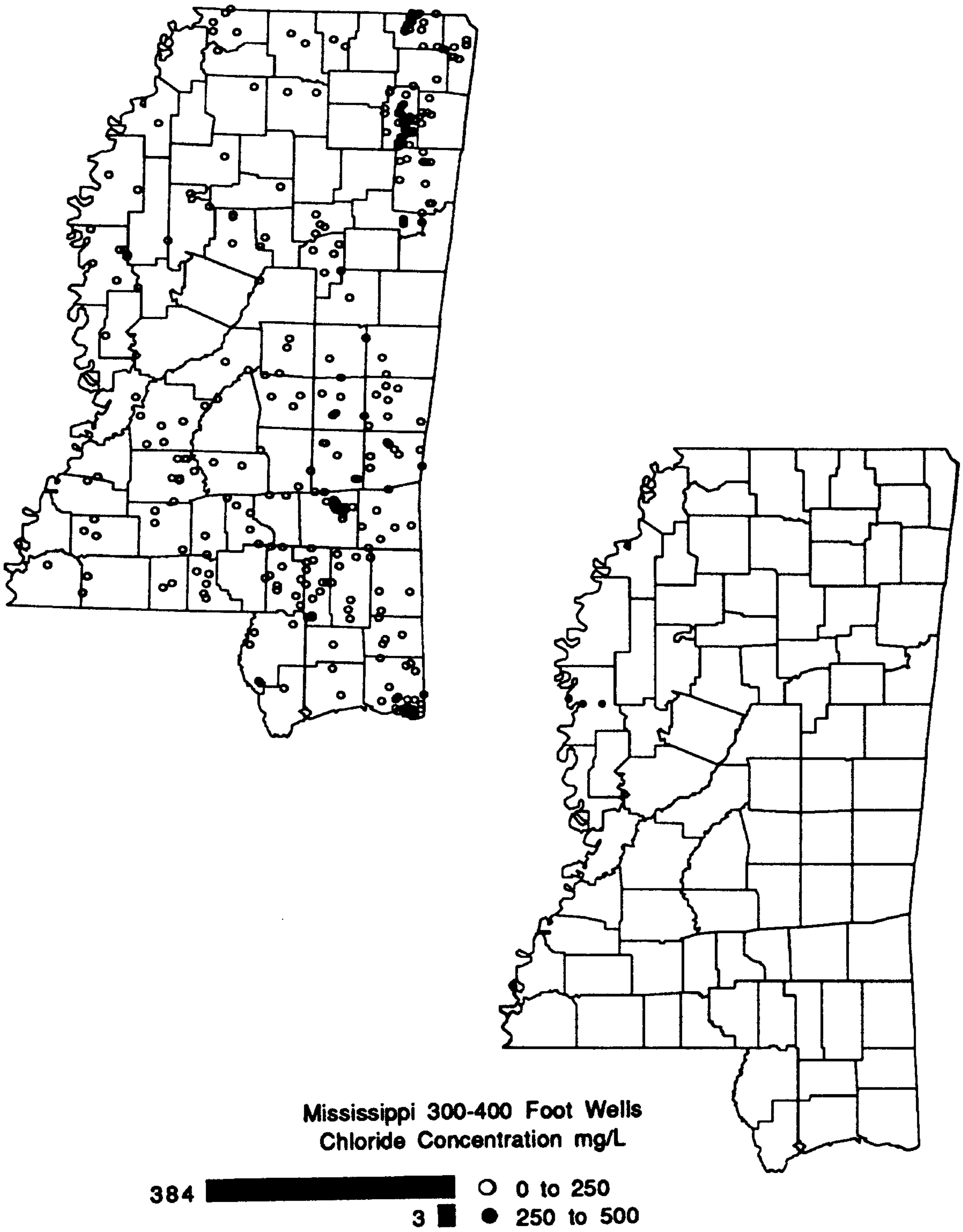



Figure 88. Mississippi 300-400 Foot Interval Chloride Map

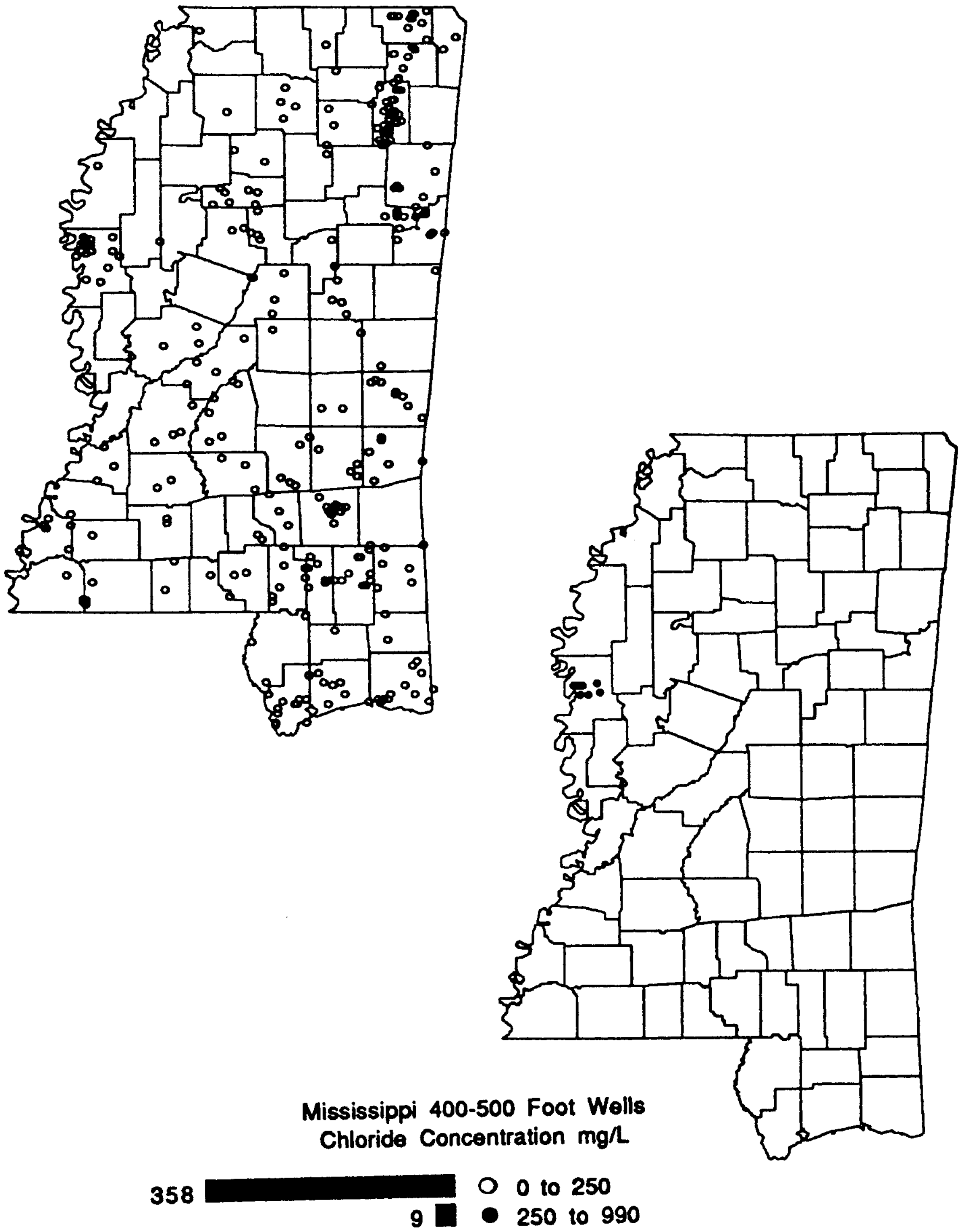



Figure 89. Mississippi 400-500 Foot Interval Chloride Map

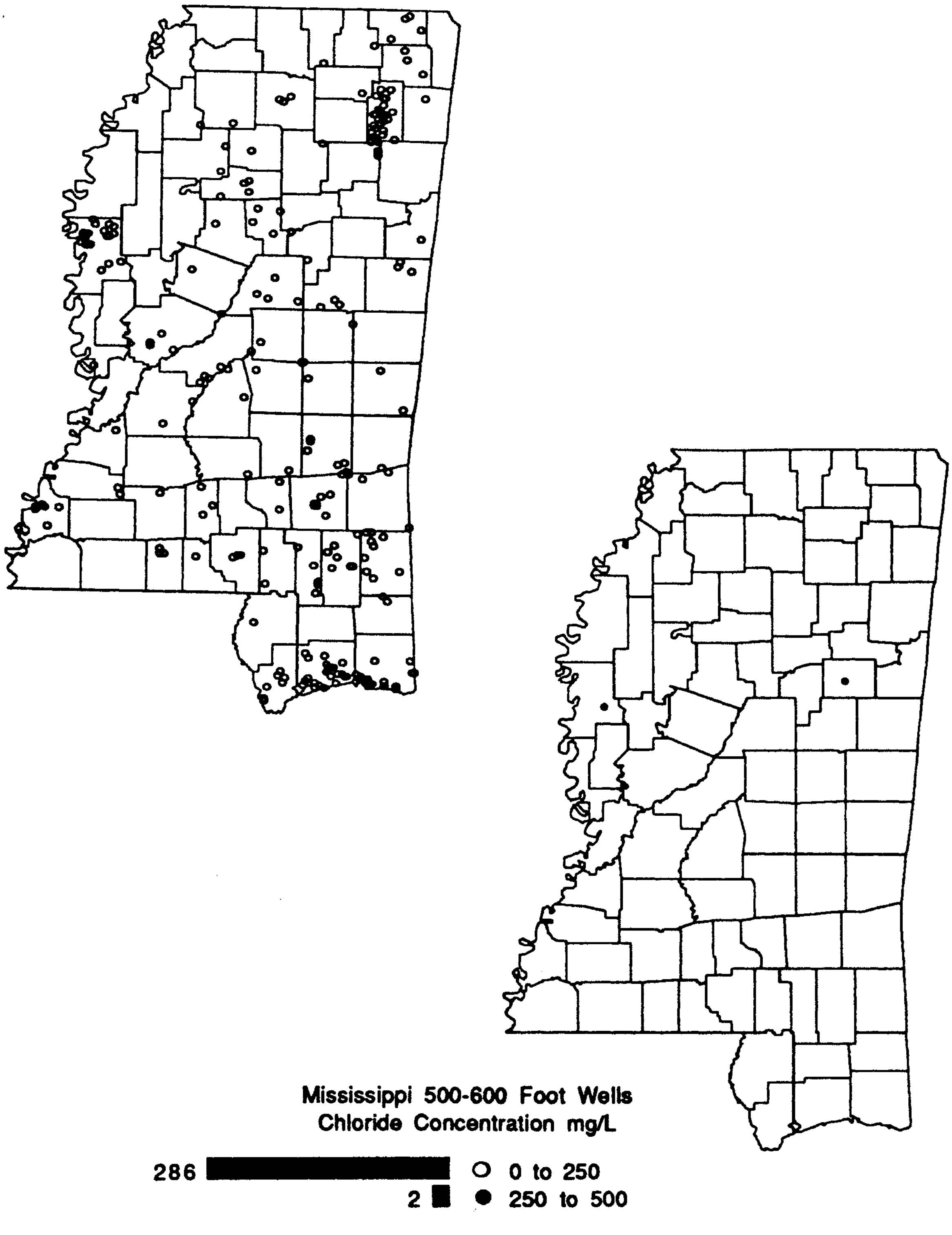



Figure 90. Mississippi 500-600 Foot Interval Chloride Map

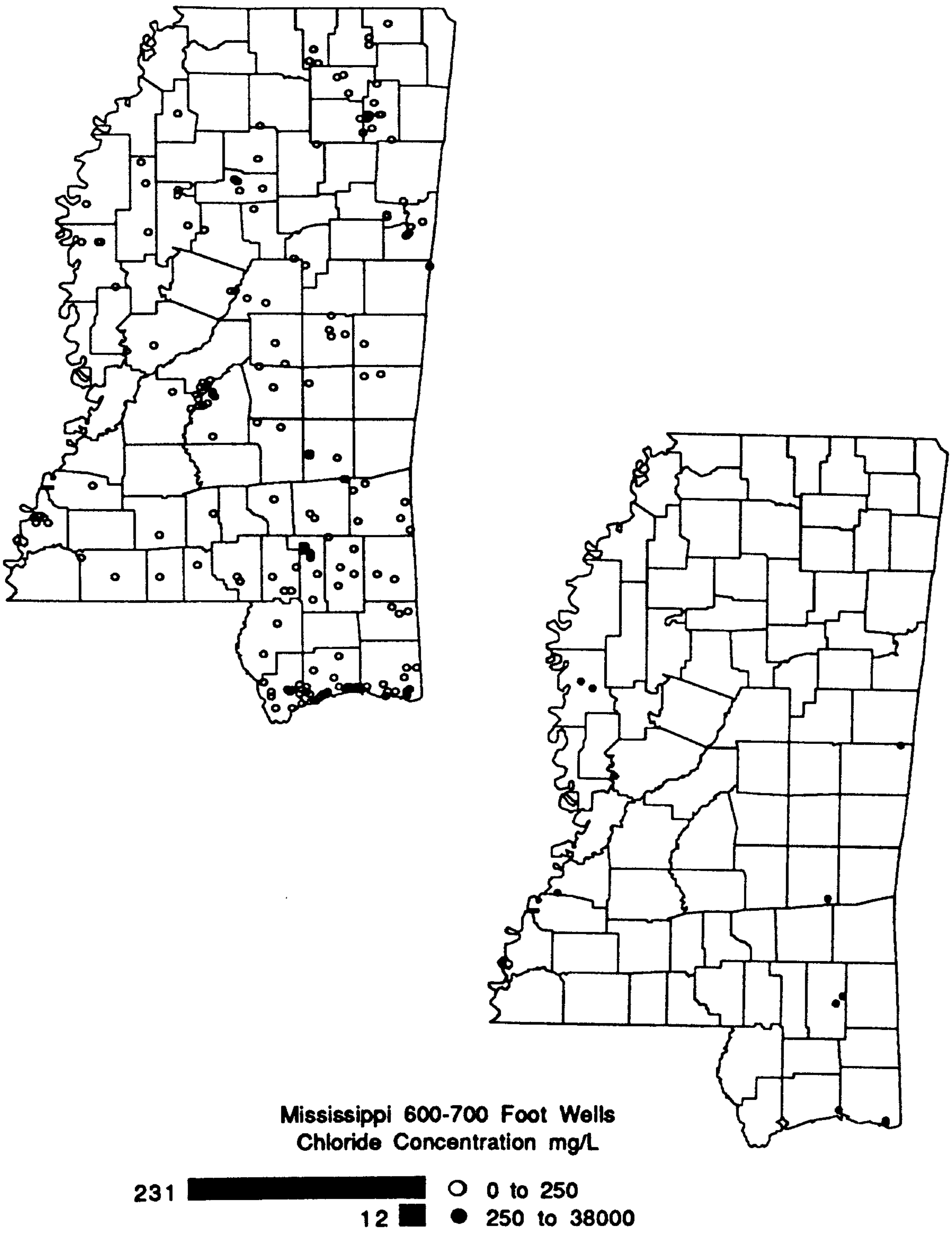



Figure 91. Mississippi 600-700 Foot Interval Chloride Map

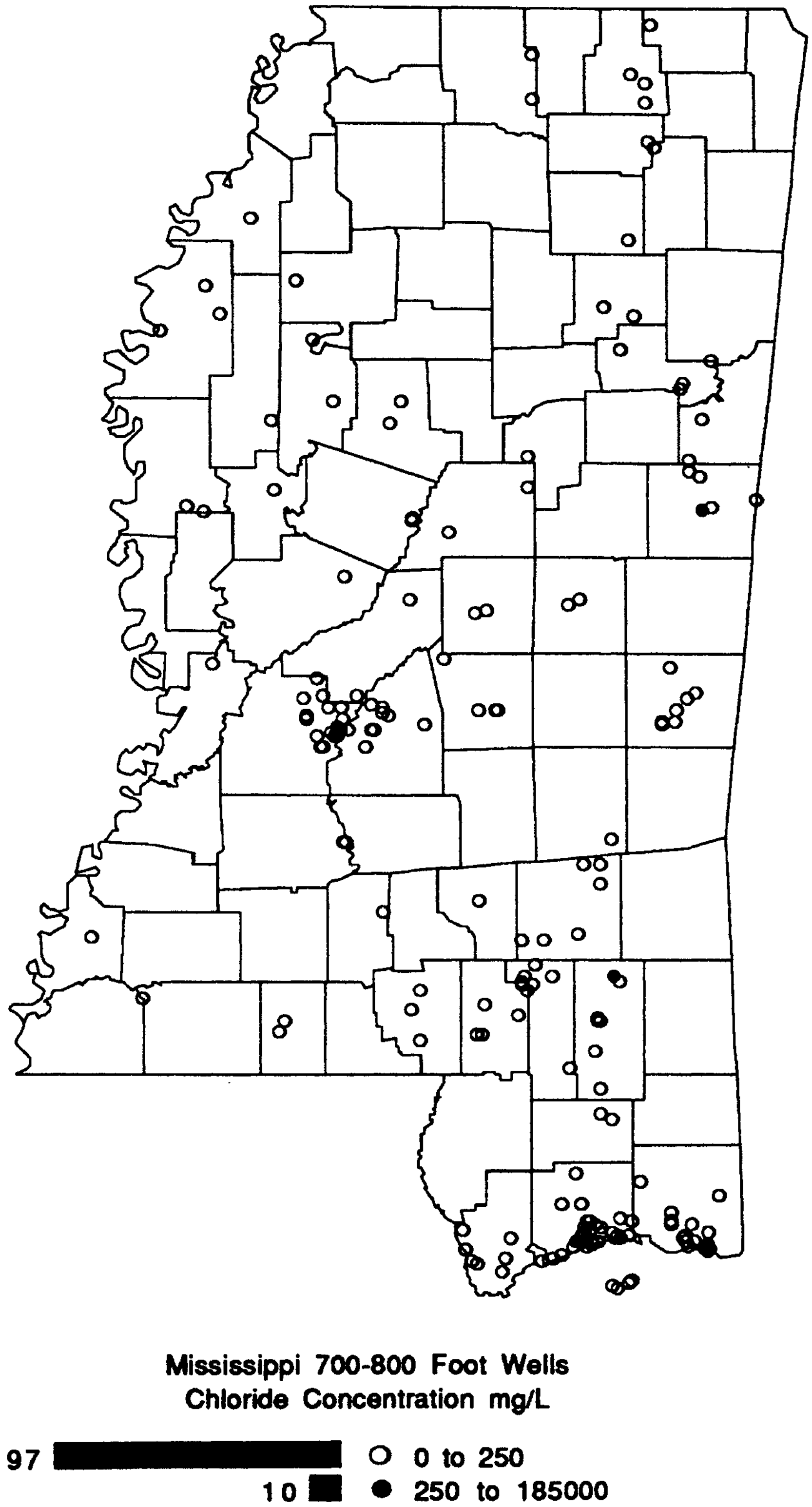



Figure 92. Mississippi 700-800 Foot Interval Chloride Map

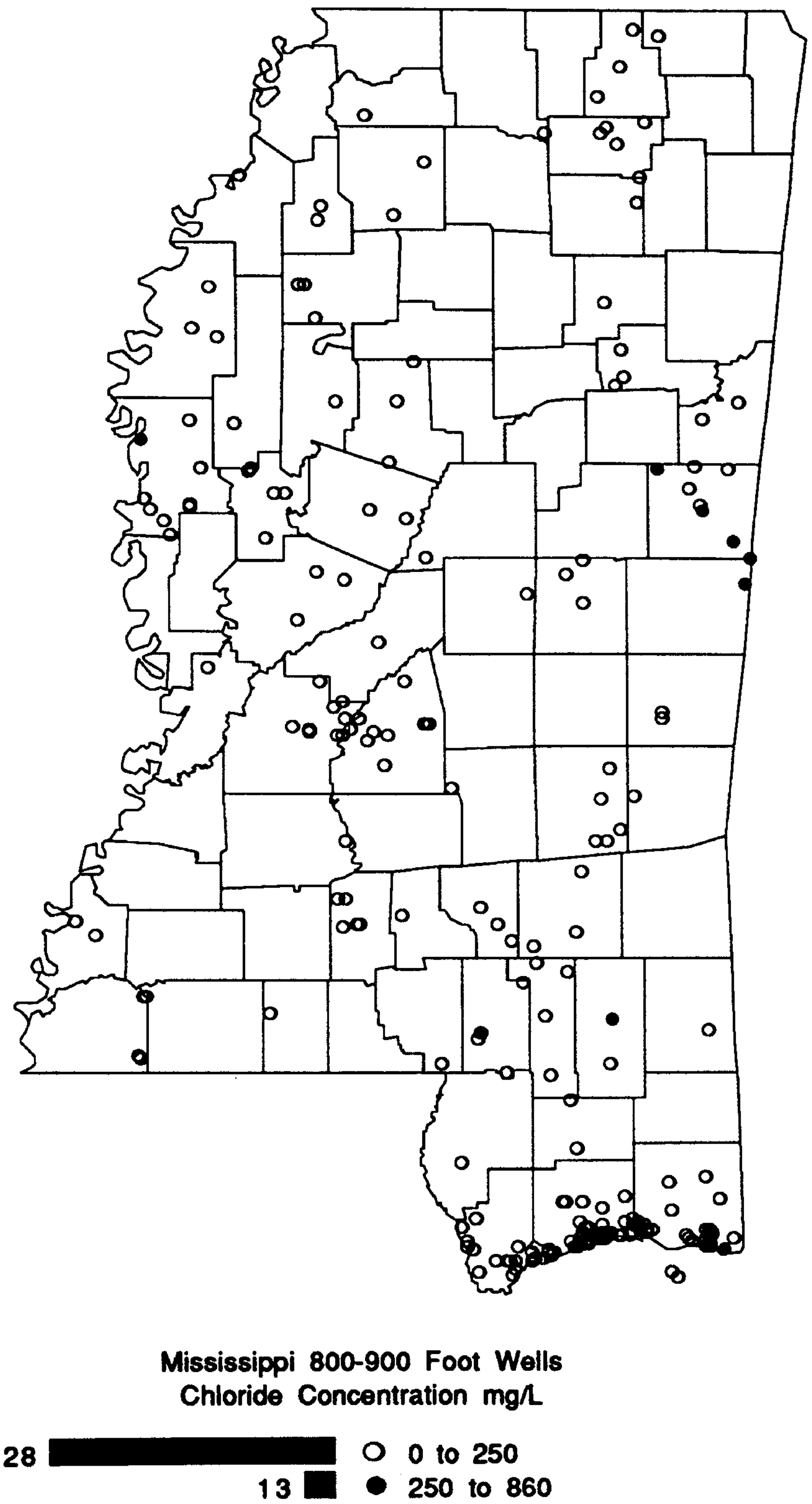



Figure 93. Mississippi 800-900 Foot Interval Chloride Map

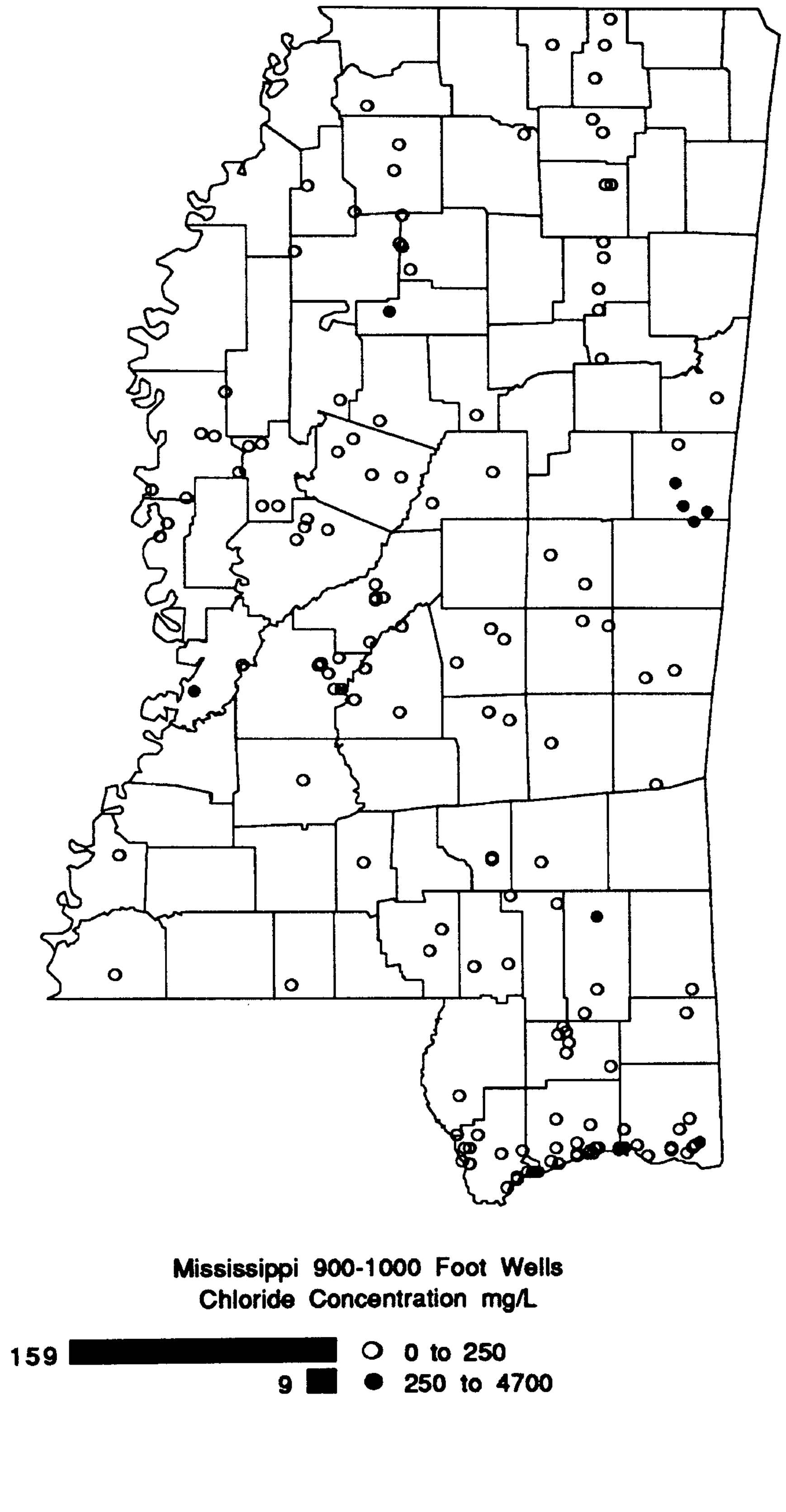



Figure 94. Mississippi 900-1000 Foot Interval Chloride Map

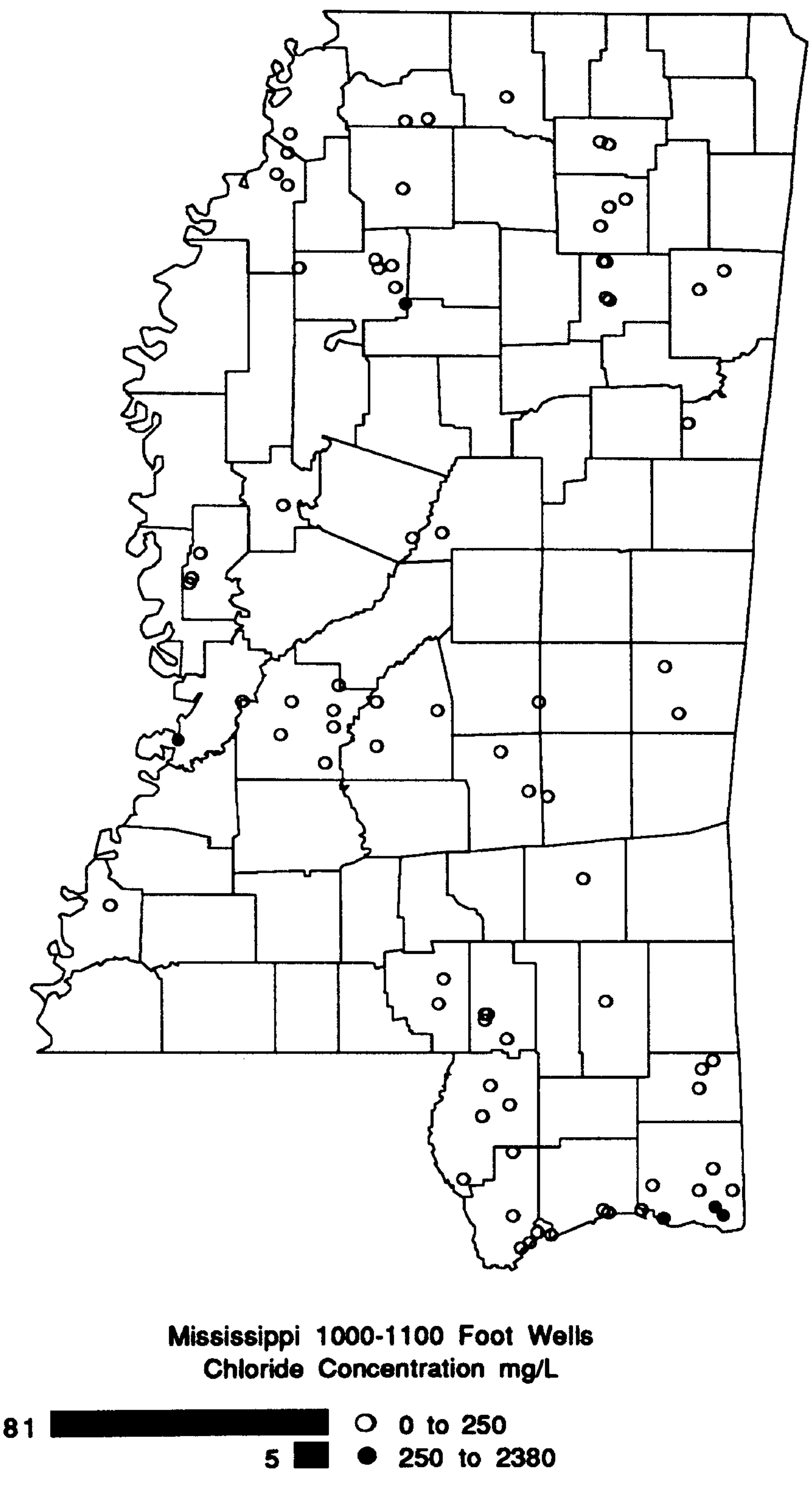



Figure 95. Mississippi 1000-1100 Foot Interval Chloride Map

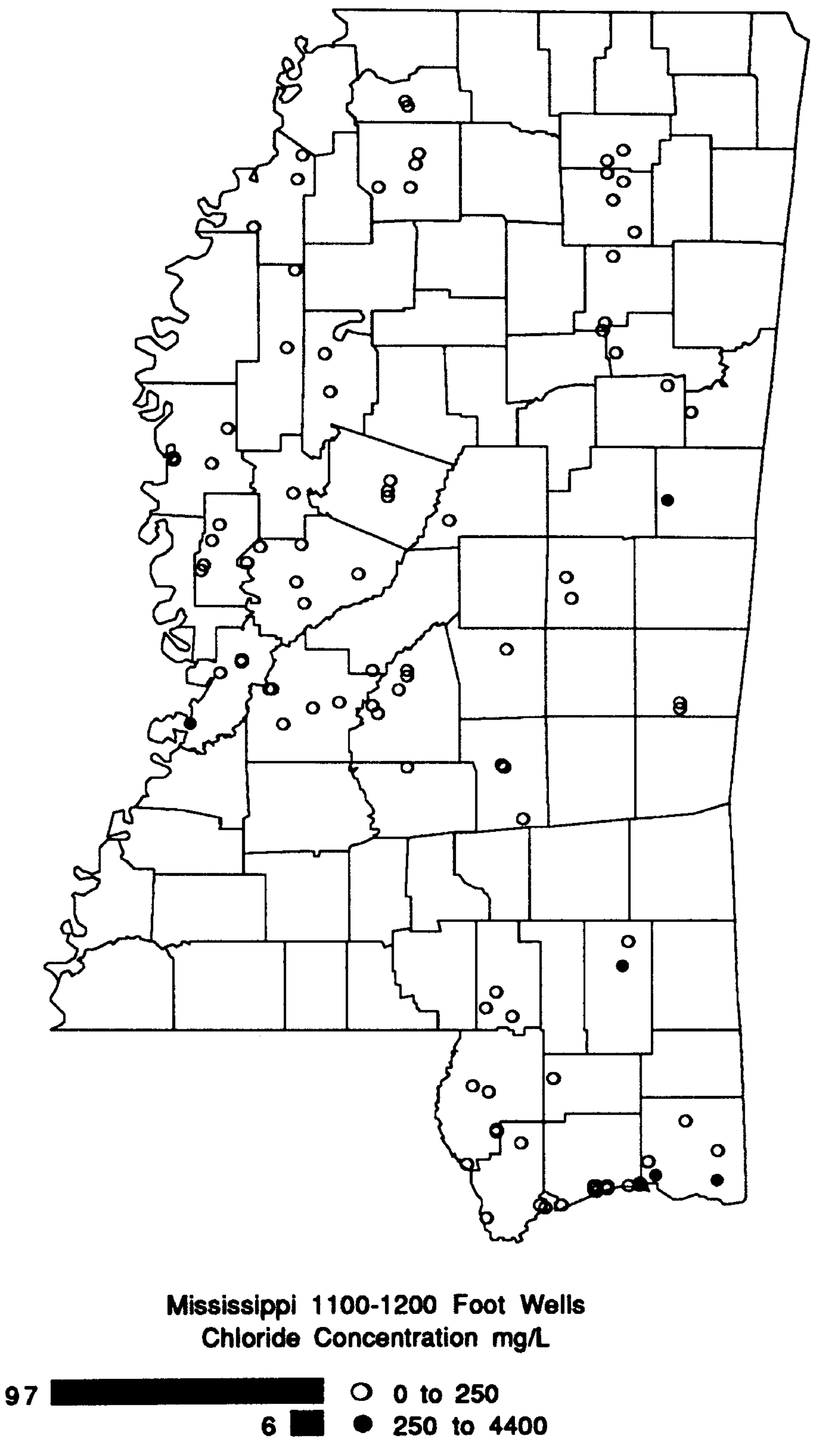



Figure 96. Mississippi 1100-1200 Foot Interval Chloride Map

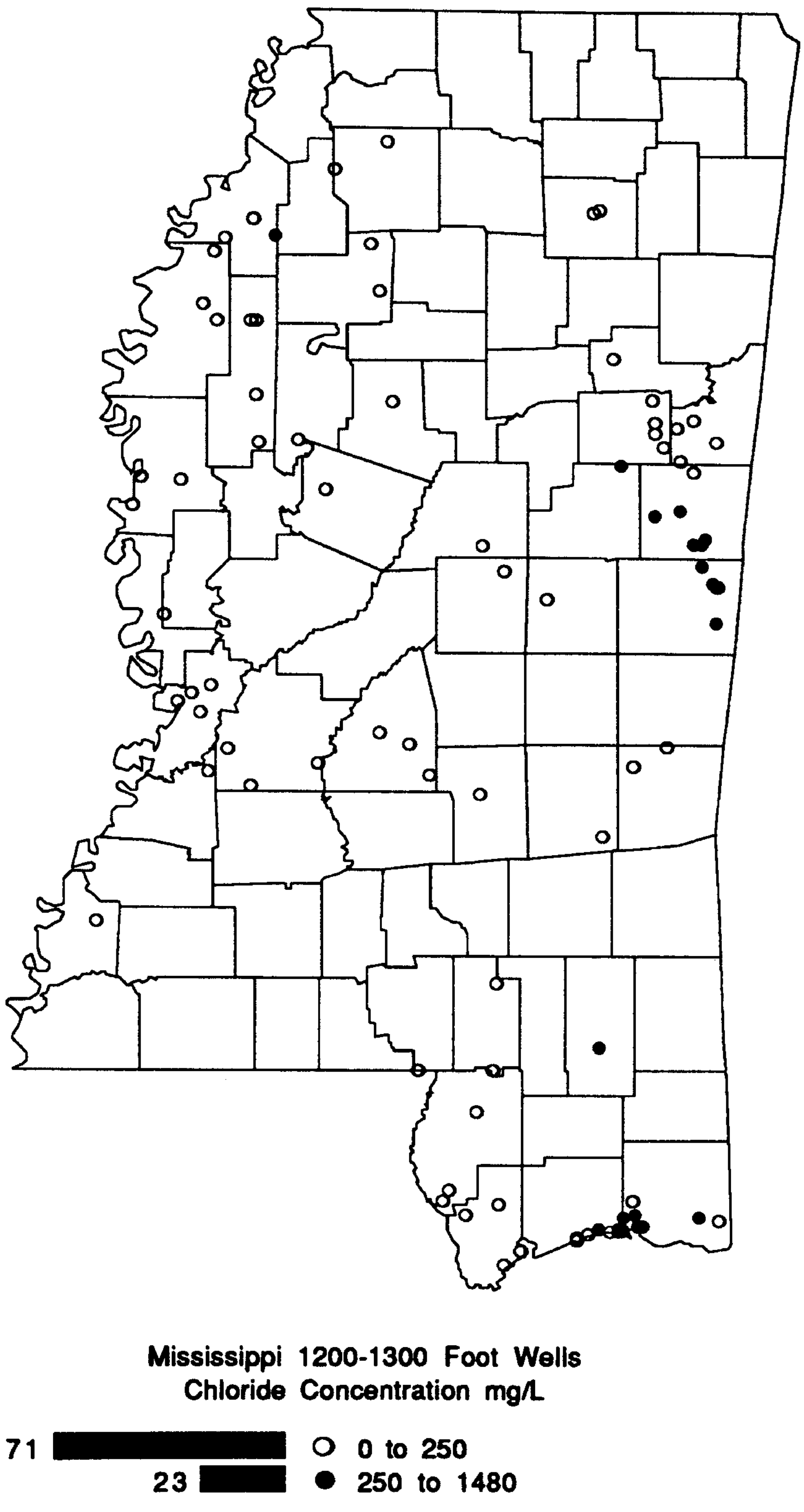



Figure 97. Mississippi 1200-1300 Foot Interval Chloride Map

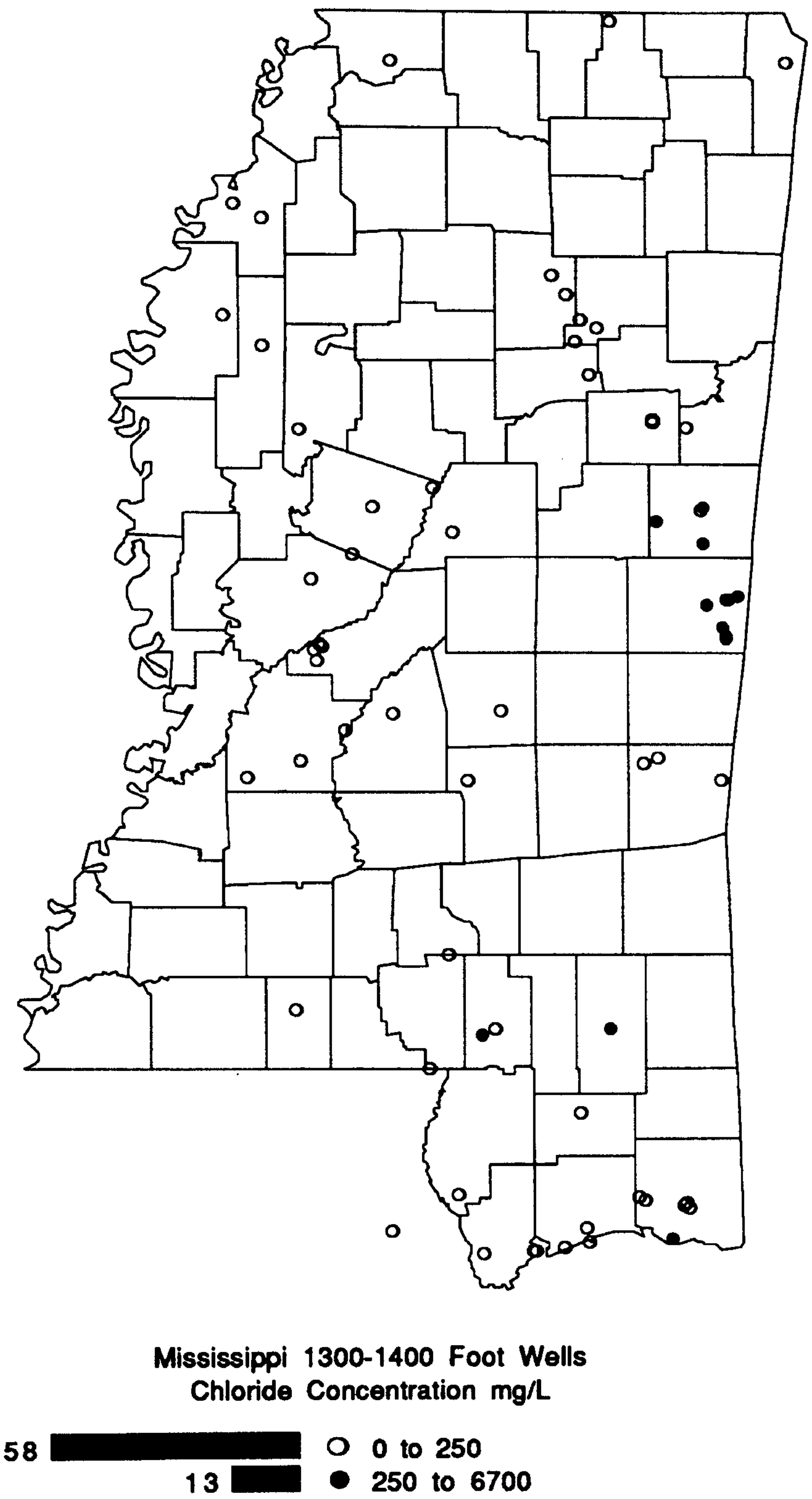



Figure 98. Mississippi 1300-1400 Foot Interval Chloride Map

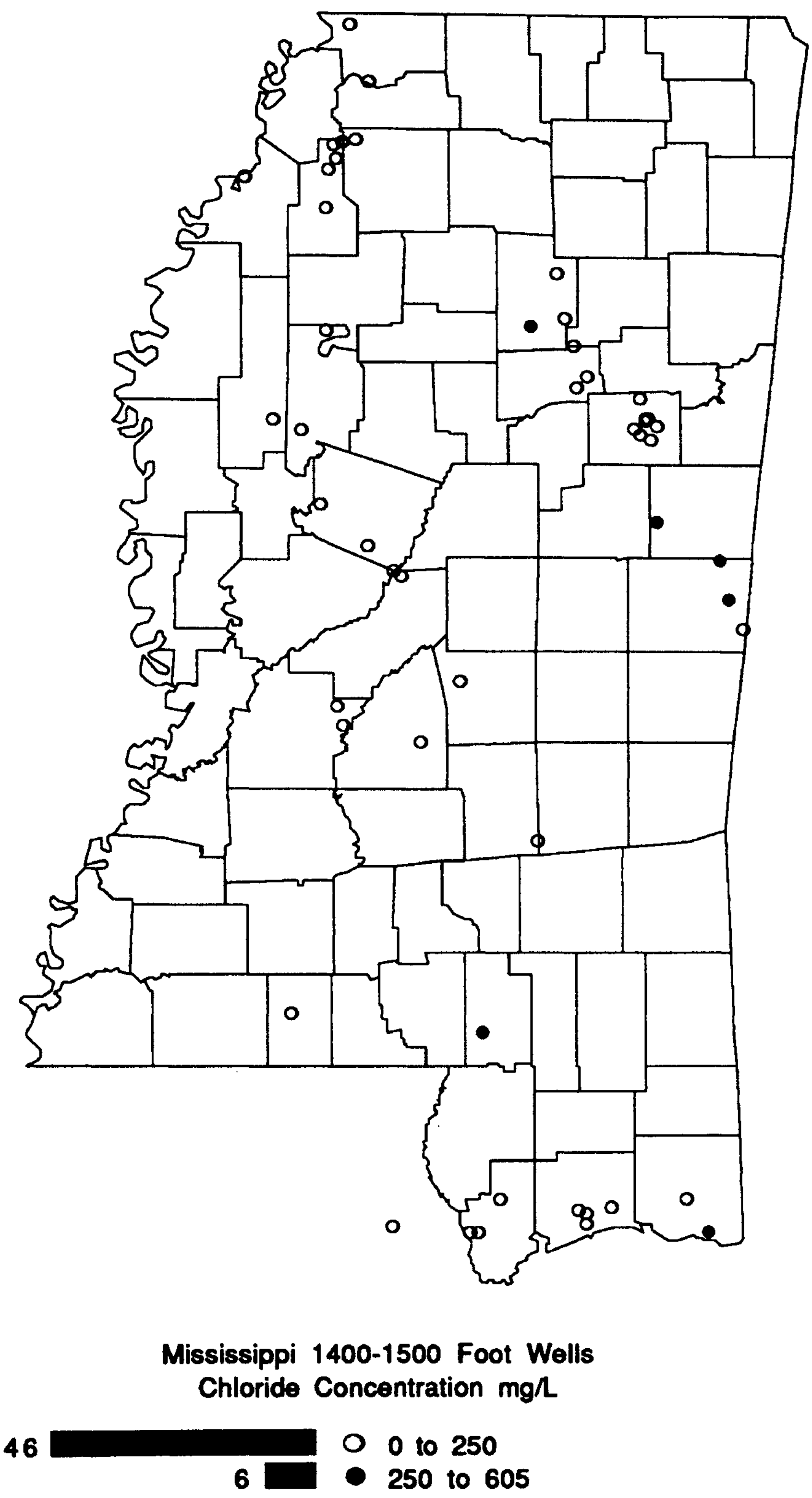



Figure 99. Mississippi 1400-1500 Foot Interval Chloride Map

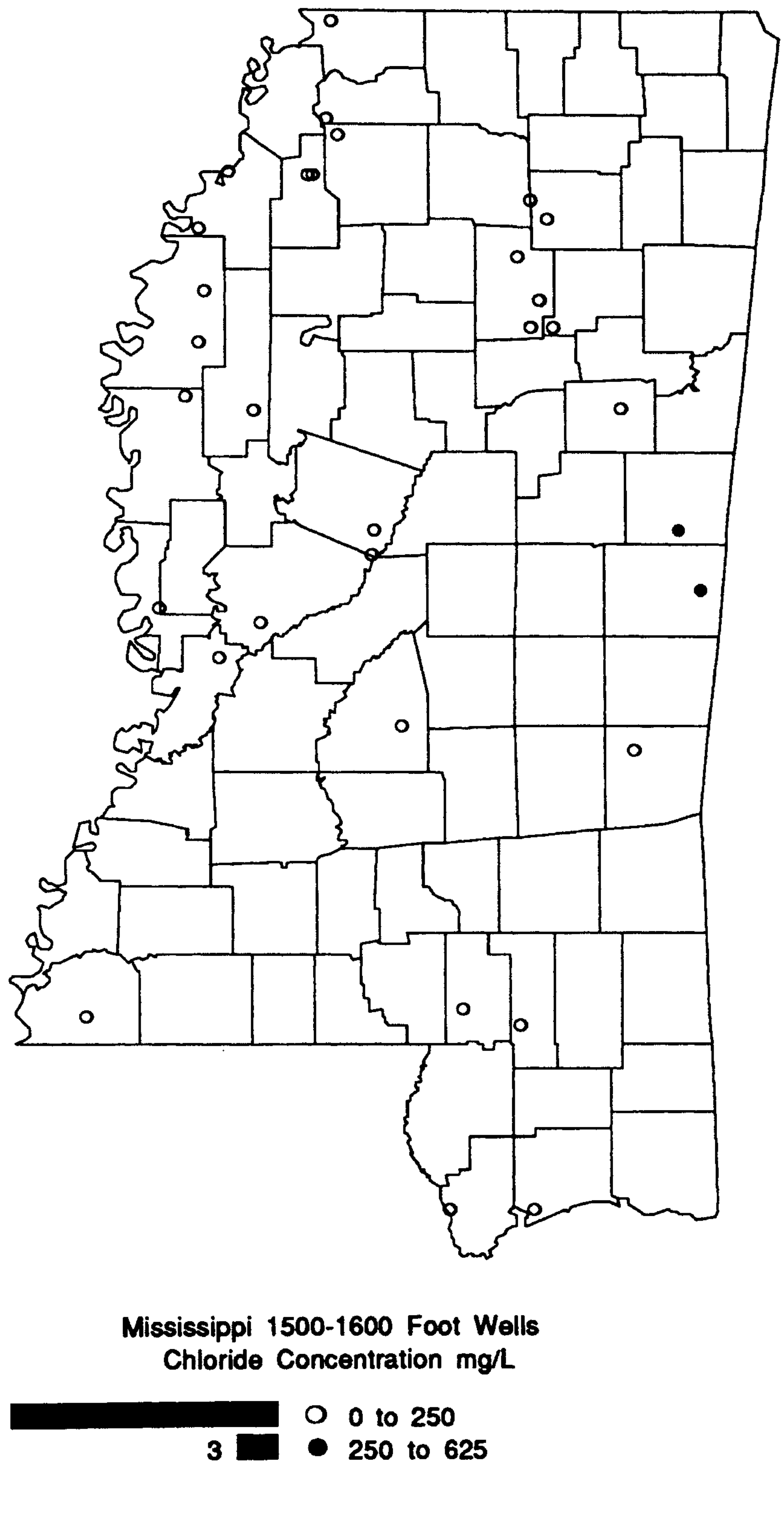



Figure 100. Mississippi 1500-1600 Foot Interval Chloride Map

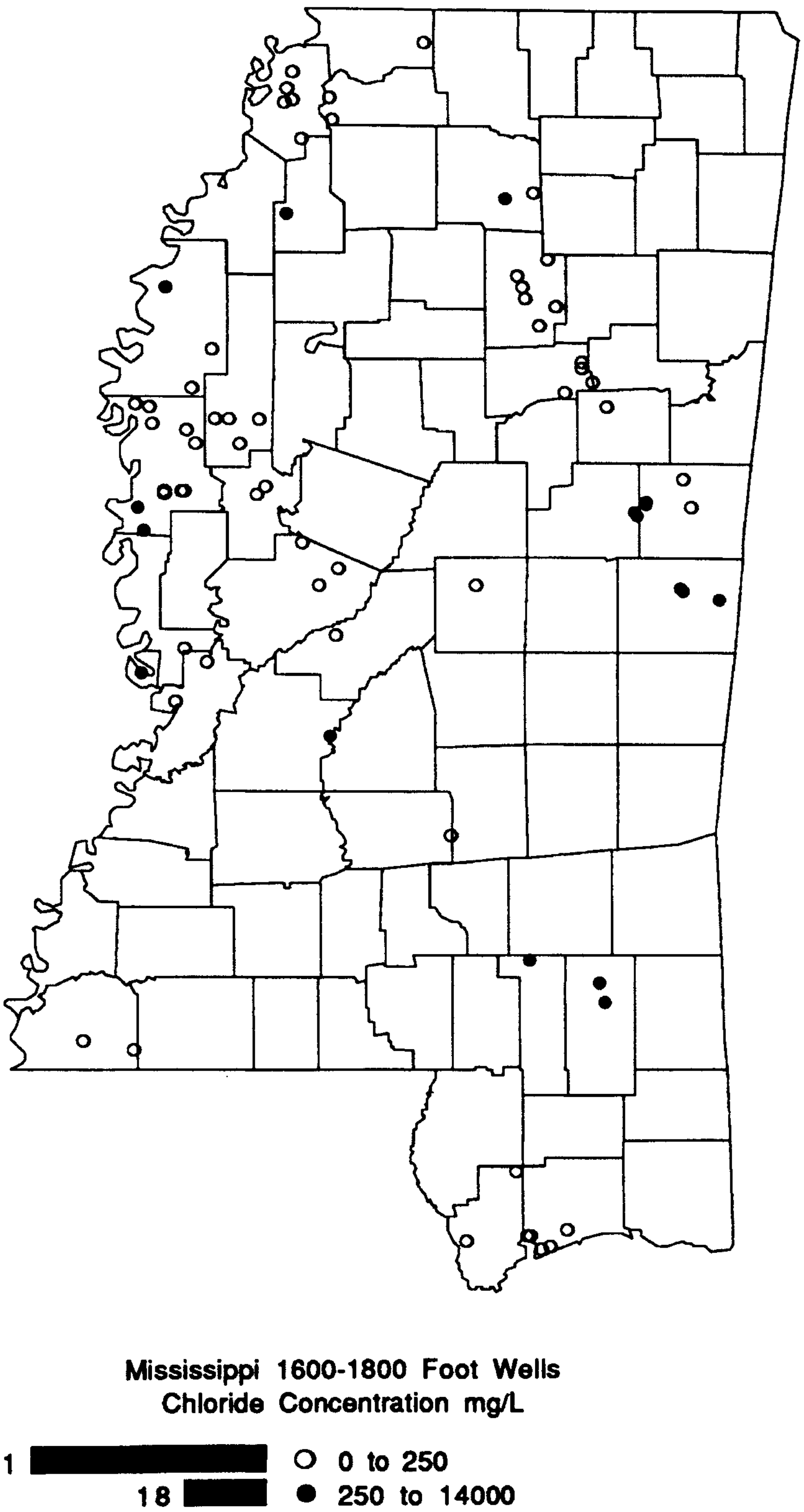



Figure 101. Mississippi 1600-1800 Foot Interval Chloride Map

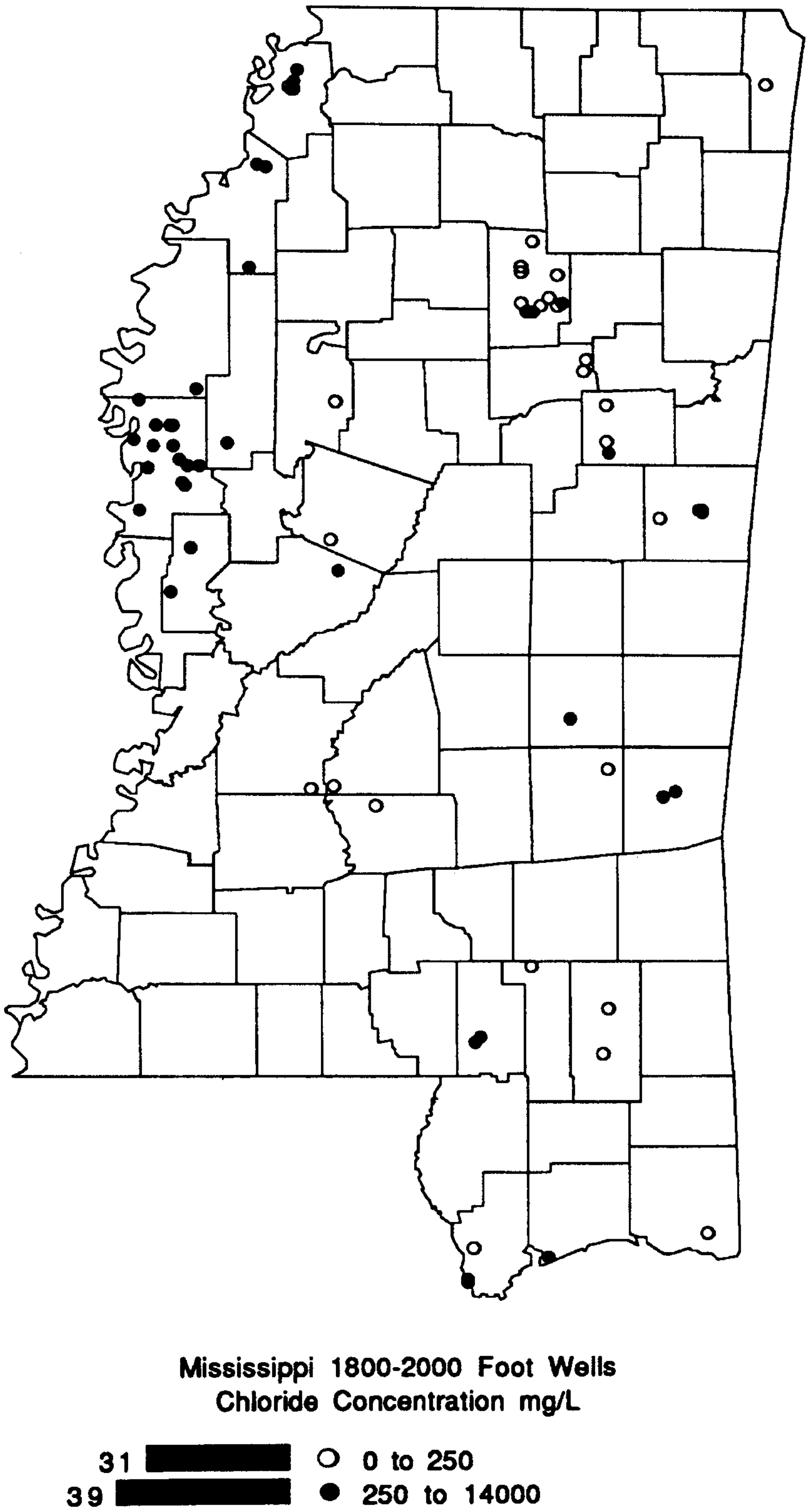



Figure 102. Mississippi 1800-2000 Foot Interval Chloride Map

# NEW MEXICO

## General Setting

The area of New Mexico is approximately 121,600 square miles. The state lies in the mountains, intermountain basins, dissected plateaus and high plains of the Basin and Range, Southern Rocky Mountains, Colorado Plateau, and Great Plains physiographic provinces.

The mountains of Northern, Central, and Southwestern New Mexico consist largely of Tertiary and Quaternary age basalt, andesite, and rhyolite flows, pyroclastic deposits, and associated sediments. Scattered throughout the state are isolated exposures of Precambrian metamorphic rocks, Paleozoic and Mesozoic sedimentary units, and Cretaceous and Tertiary age intrusives.

Intermountain basins contain thick accumulations of Cenozoic age alluvial, eolian, lacustrine, and volcanic deposits. The plateaus and plains of Northwestern and Eastern New Mexico are underlain by relatively flat lying Paleozoic, Mesozoic, and Tertiary age sandstone, shale, limestone, and gypsum deposits. New Mexico is drained by a network of south flowing rivers.

## Principal Aquifers

The principal groundwater aquifers in New Mexico may be grouped into four distinct types including; Quaternary age valley fill deposits of the Rio Grande, Pecos and San Juan rivers, Cenozoic basin fill aquifers in Eastern, Central, and Southwestern New Mexico, including the Ogallala Formation, sandstone aquifers of the northwestern part of the state consisting of the Cretaceous Dakota Sandstone, Jurassic Morrison Formation and the Jurassic Entrada Sandstone, and limestone aquifers of the Pecos River and Rio San Jose basins. The areal extent of these principal aquifers are outlined in Figure 103.

Chloride Distribution

Chloride maps of New Mexico are based upon 1471 stations distributed over ten depth intervals(Table 16). The percentage of wells that exceed the 250 mg/L standard varies from a low of five percent at the 1000-1200 foot interval, to a high of 13 percent at the 700-800 foot interval(Table 17). Regionally ten percent (147) of the states wells have chloride concentrations greater than 250 mg/L.

Areal mapping of the stations for each depth interval (Figures. 106-115) suggest the distribution of stations with elevated chloride levels are not restricted to any one aquifer or geographical area but are distributed through out the state. The percentage of wells for each concentration interval plotted against depth (fig. 104), illustrates an increase with depth in the percentage of wells in the 0-25 mg/L range and fairly consistent percentages for the other concentration intervals. Charting of the percentage of wells that exceed 250 mg/l with depth (fig. 105) displays consistent percentages throughout the range of depth intervals, but declines after the 700-800 foot interval

Oil field activities in New Mexico which have influenced aquifers are probably limited to the northwest and southeast part of New Mexico(Fig. 2). Counties in these areas with stations having chloride levels in excess of 250 mg/L include Lea and Eddy Counties in the southeast and San Juan, Sandoval, and Bernalillo counties in the northwest. Increased salinity in the San Juan River valley fill aquifer is also attributed to brine disposal(Ong, 1988)

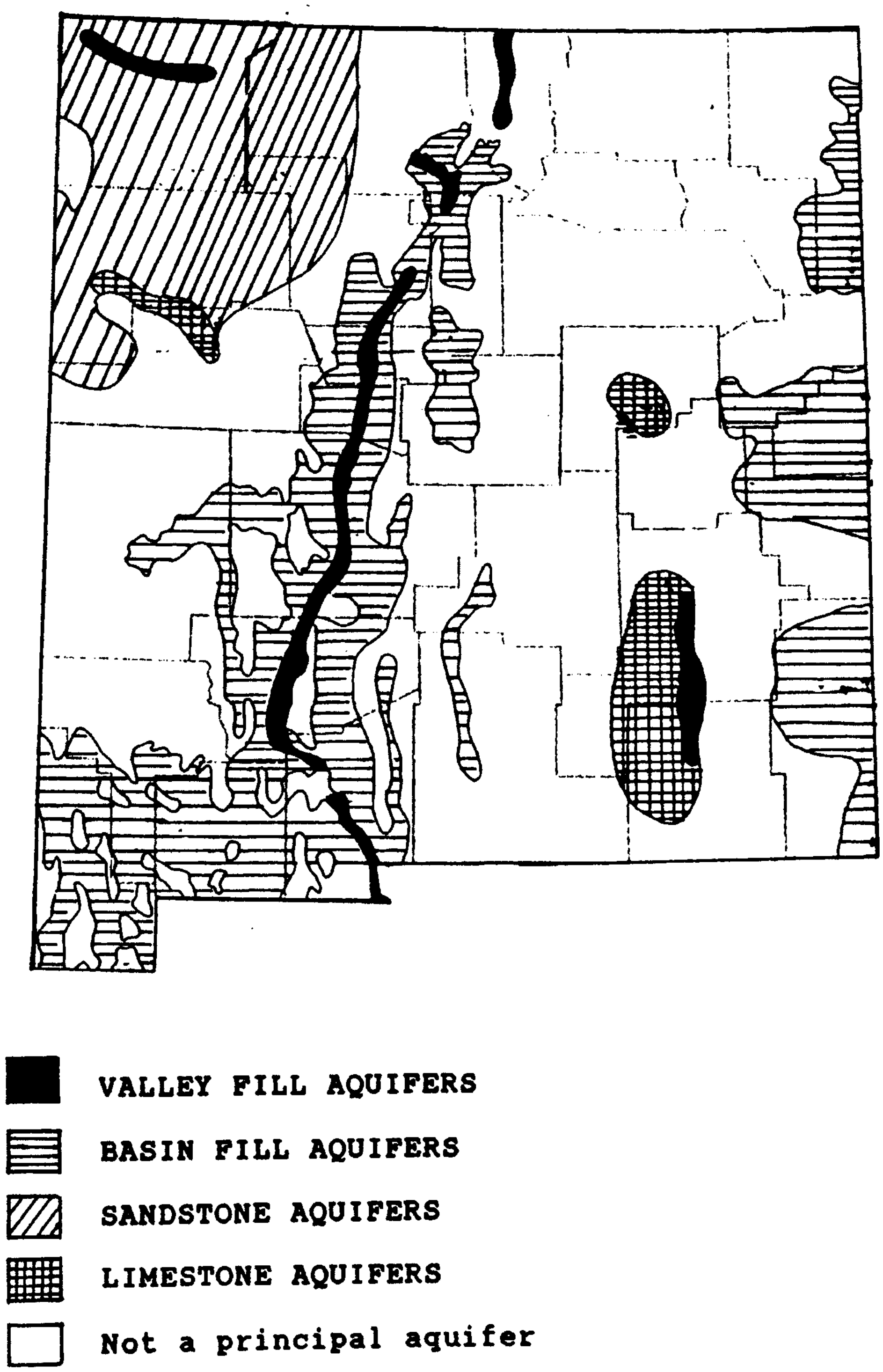



Figure 103. New Mexico Principal Aquifers Map
(Modified From U.S.G.S., 1985)

| | Concentration Interval (mg/L) | | | | | total | wells |
|---|---|---|---|---|---|---|---|
| | 0-25 | 25-100 | 100-250 | 250-500 | >500 | wells | >250 |
| Depth Interval (feet) | | | | | | | |
| 0-100 | 131 | 136 | 42 | 18 | 22 | 349 | 40 |
| 100-200 | 162 | 126 | 41 | 17 | 12 | 358 | 29 |
| 200-300 | 110 | 79 | 19 | 13 | 11 | 232 | 24 |
| 300-400 | 82 | 40 | 11 | 5 | 8 | 146 | 13 |
| 400-500 | 64 | 17 | 9 | 6 | 7 | 103 | 13 |
| 500-600 | 38 | 29 | 9 | 3 | 7 | 86 | 10 |
| 600-700 | 28 | 18 | 11 | 1 | 4 | 62 | 5 |
| 700-800 | 22 | 13 | 5 | 0 | 6 | 46 | 6 |
| 800-1000 | 31 | 13 | 4 | 1 | 4 | 53 | 5 |
| 1000-1200 | 21 | 12 | 1 | 0 | 2 | 36 | 2 |
| State Total | 689 | 483 | 152 | 64 | 83 | 1471 | 147 |
| Percent Of Wells With Concentrations Greater Than 250mg/L | | | | | | | 10 |

TABLE 16. NUMBER OF STATIONS PER DEPTH AND CONCENTRATION INTERVAL IN NEW MEXICO

| | Concentration Interval (mg/L) | | | | | |
|---|---|---|---|---|---|---|
| | 0-25 | 25-100 | 100-250 | 250-500 | >500 | >250 |
| Depth Interval (feet) | | | | | | |
| 0-100 | 38 | 39 | 12 | 5 | 6 | 11 |
| 100-200 | 45 | 35 | 11 | 5 | 3 | 8 |
| 200-300 | 47 | 34 | 8 | 6 | 5 | 10 |
| 300-400 | 56 | 27 | 8 | 3 | 5 | 9 |
| 400-500 | 62 | 17 | 9 | 6 | 7 | 13 |
| 500-600 | 44 | 34 | 10 | 3 | 8 | 12 |
| 600-700 | 45 | 29 | 18 | 2 | 6 | 8 |
| 700-800 | 48 | 28 | 11 | 0 | 13 | 13 |
| 800-1000 | 58 | 25 | 8 | 2 | 8 | 9 |
| 1000-1200 | 58 | 33 | 3 | 0 | 6 | 6 |

TABLE 17. PERCENT OF STATIONS PER DEPTH AND CONCENTRATION INTERVAL IN NEW MEXICO

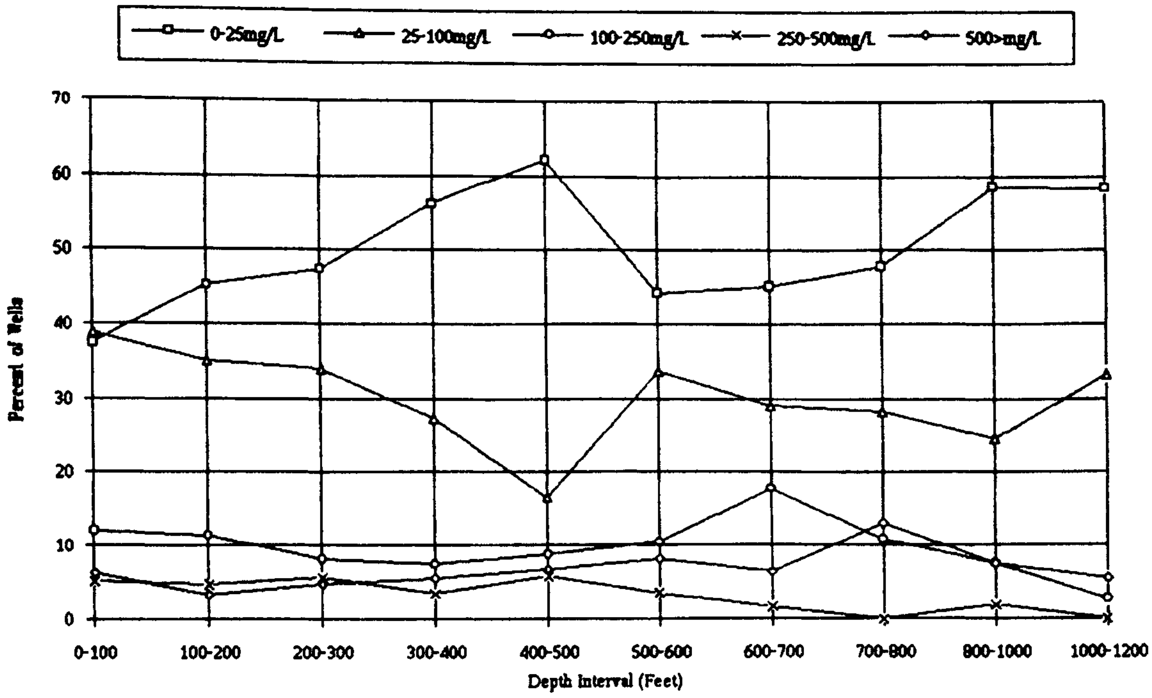



**Figure 104. New Mexico Percent Of Wells Per Concentration Interval vs Well Depth**

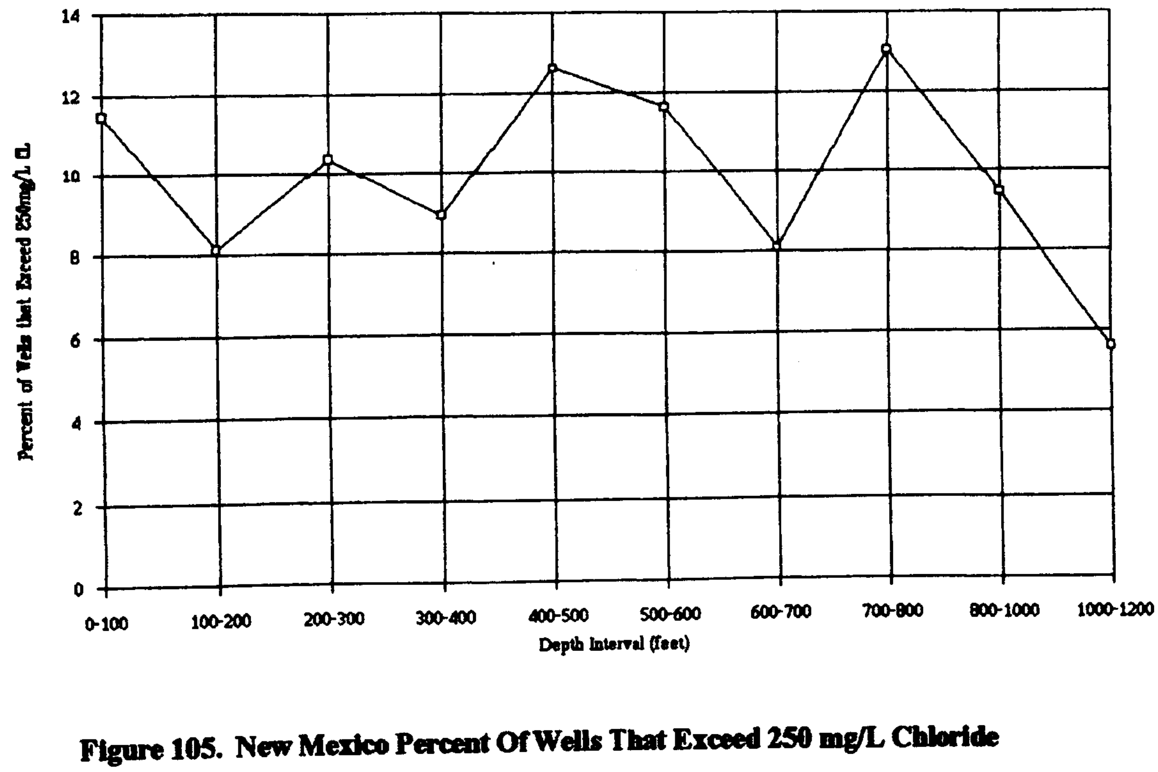



**Figure 105. New Mexico Percent Of Wells That Exceed 250 mg/L Chloride**

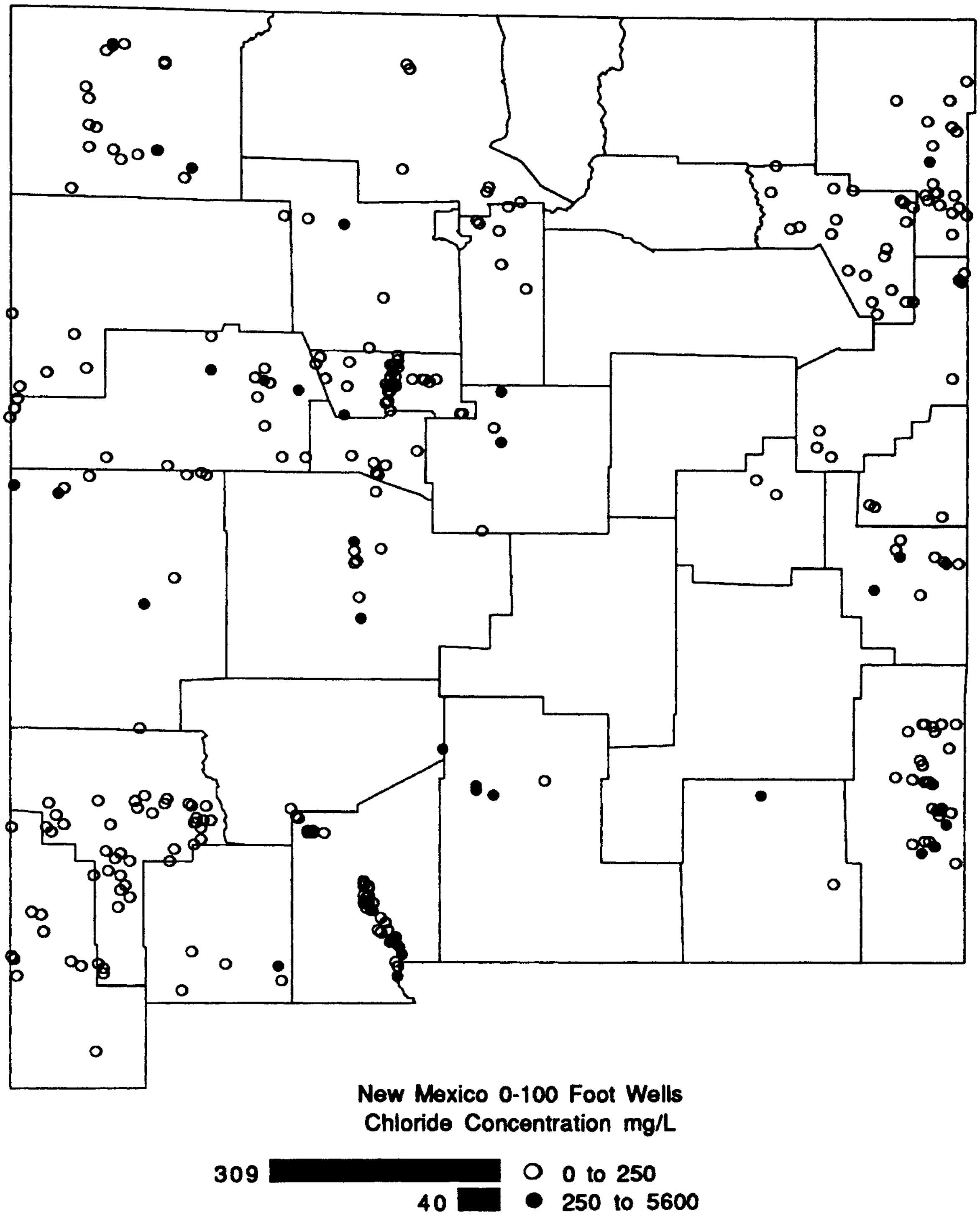



Figure 106. New Mexico 0-100 Foot Interval Chloride Map

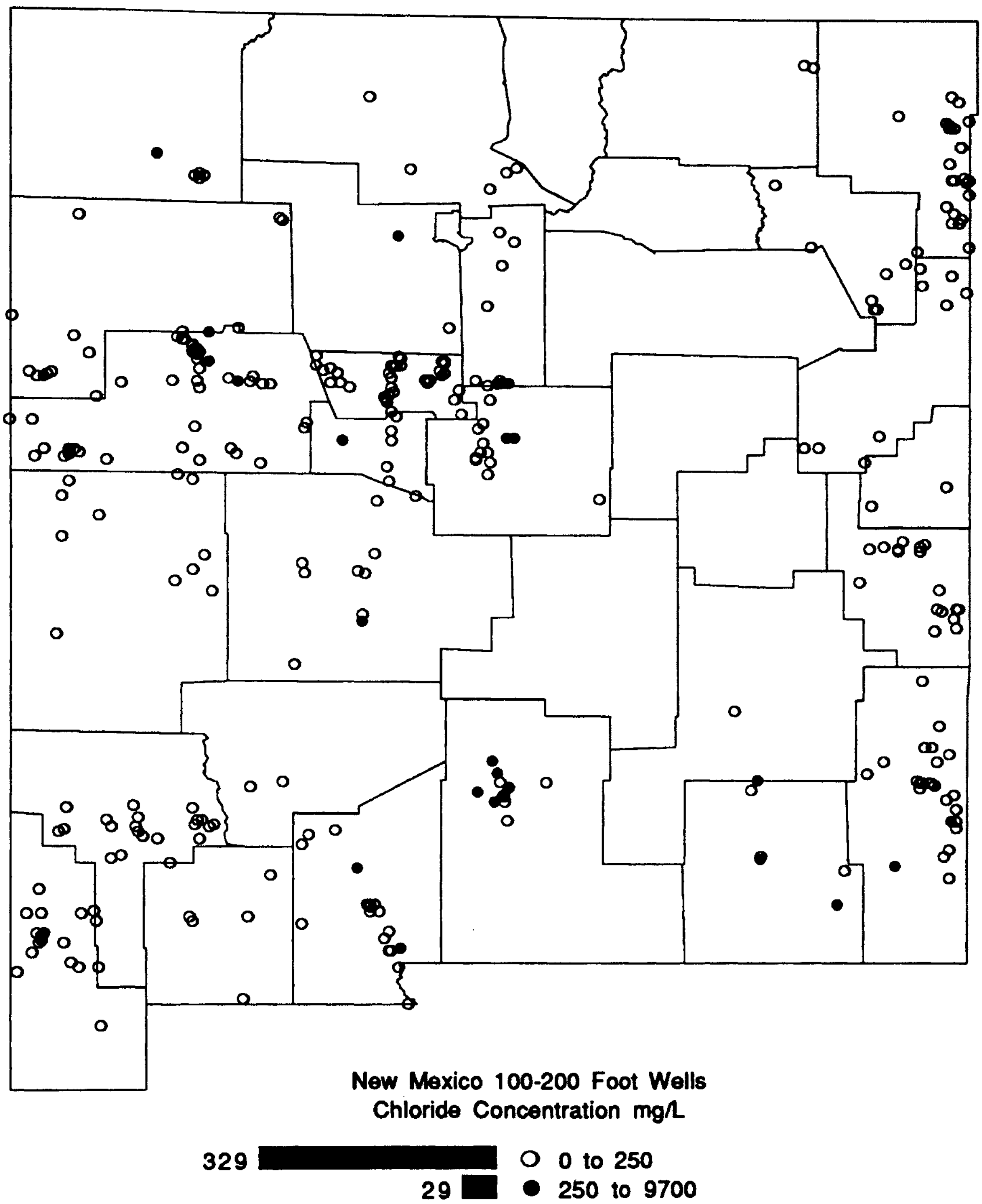



Figure 107. New Mexico 100-200 Foot Interval Chloride Map

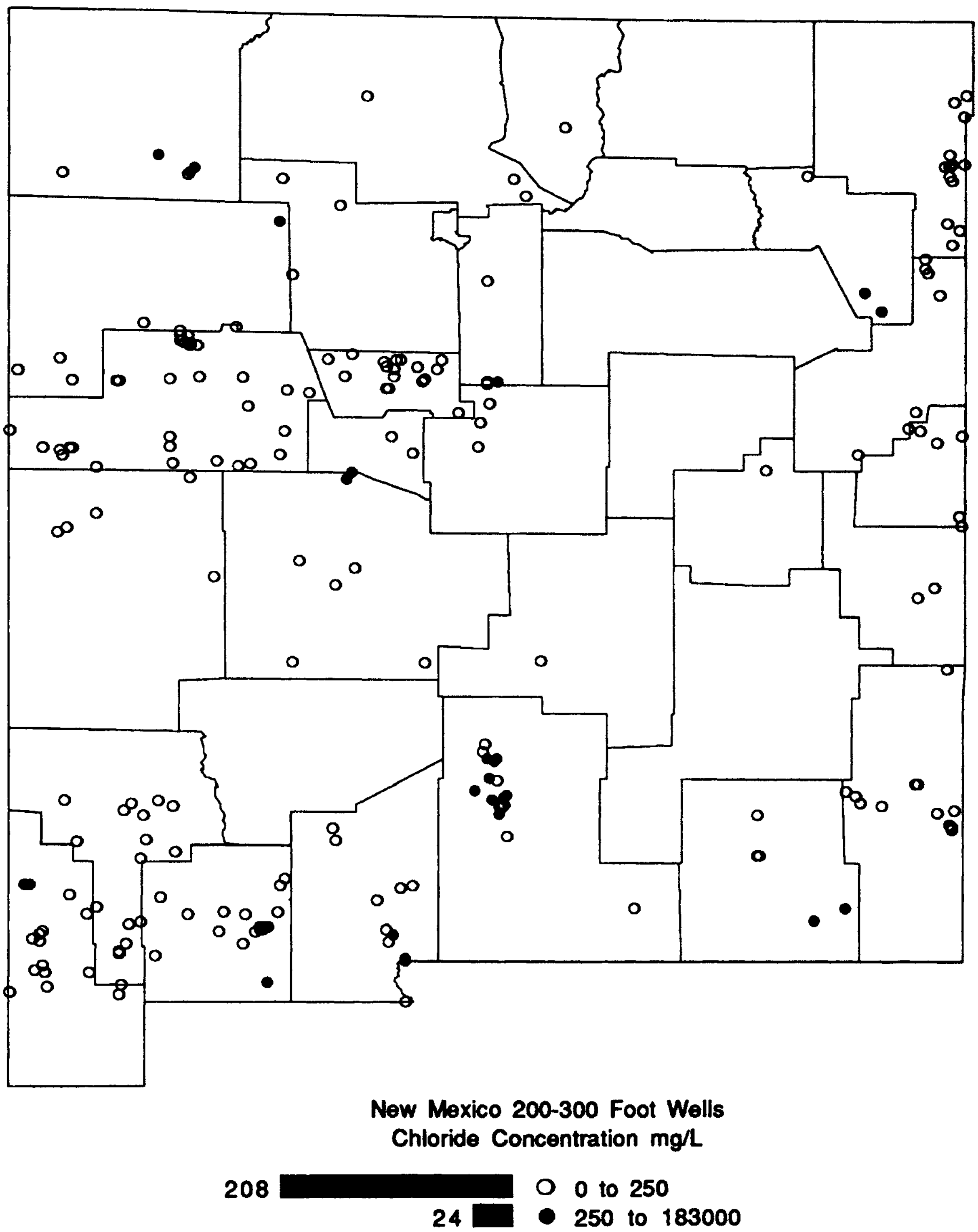



Figure 108. New Mexico 200-300 Foot Interval Chloride Map

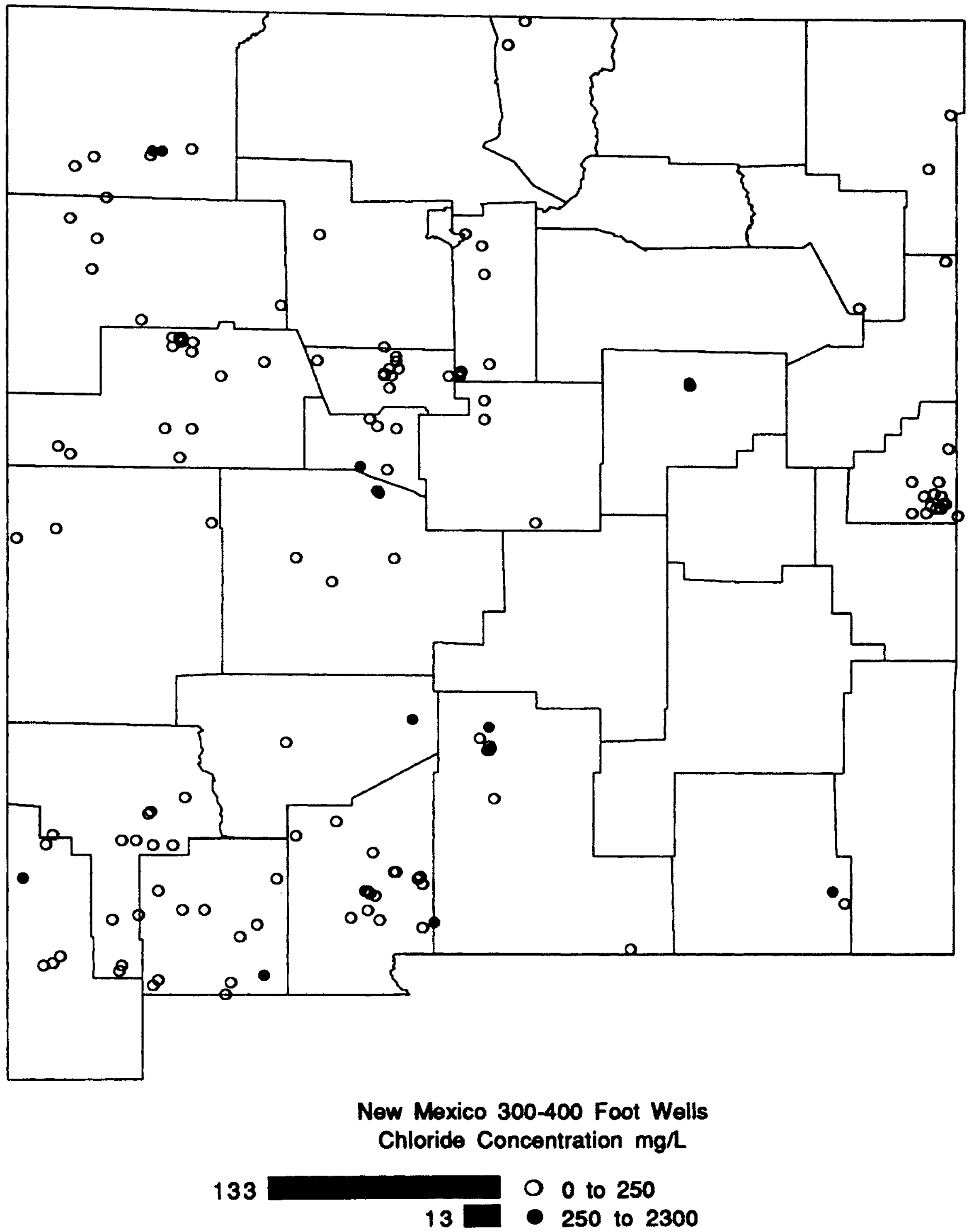



Figure 109. New Mexico 300-400 Foot Interval Chloride Map

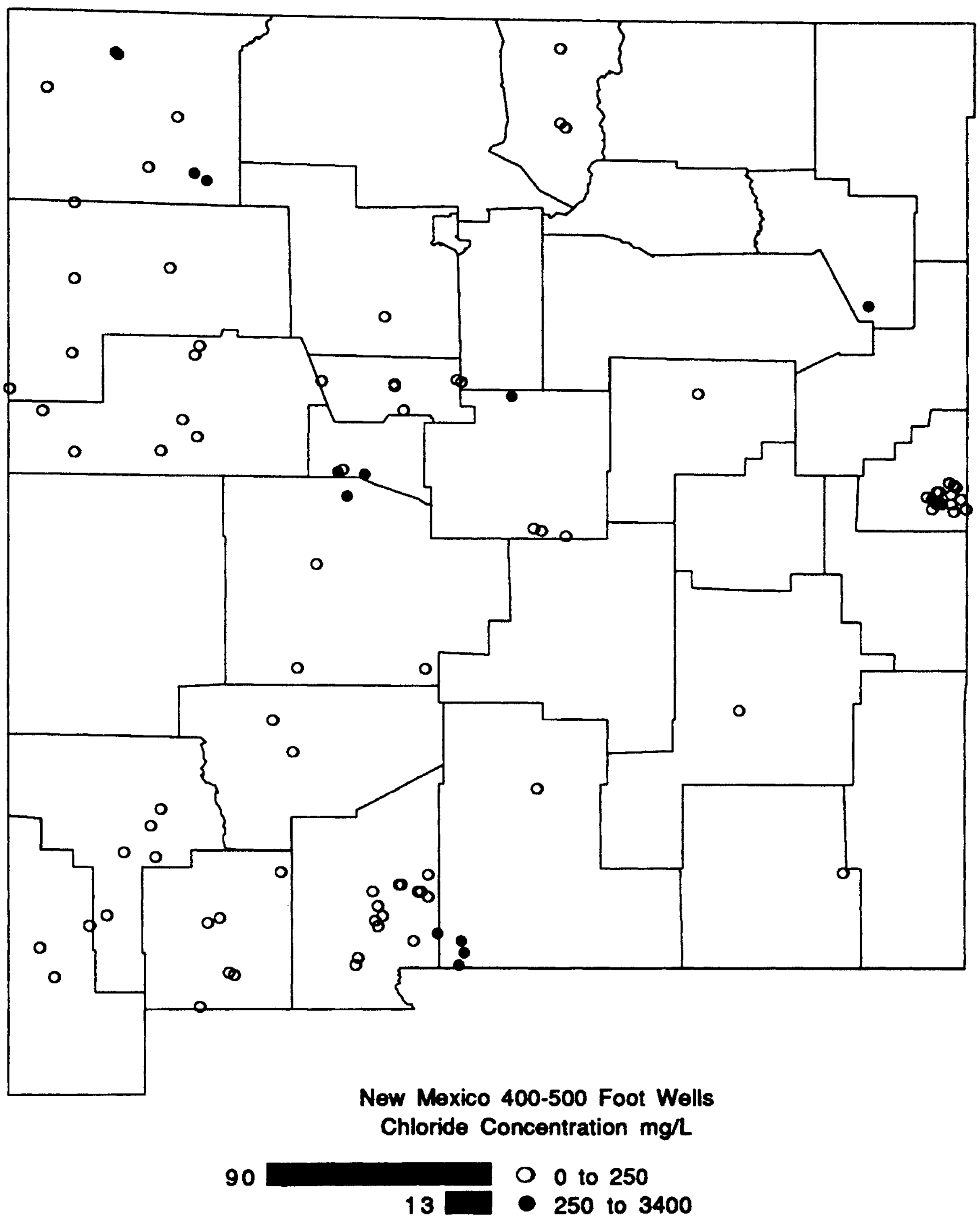



Figure 110. New Mexico 400-500 Foot Interval Chloride Map

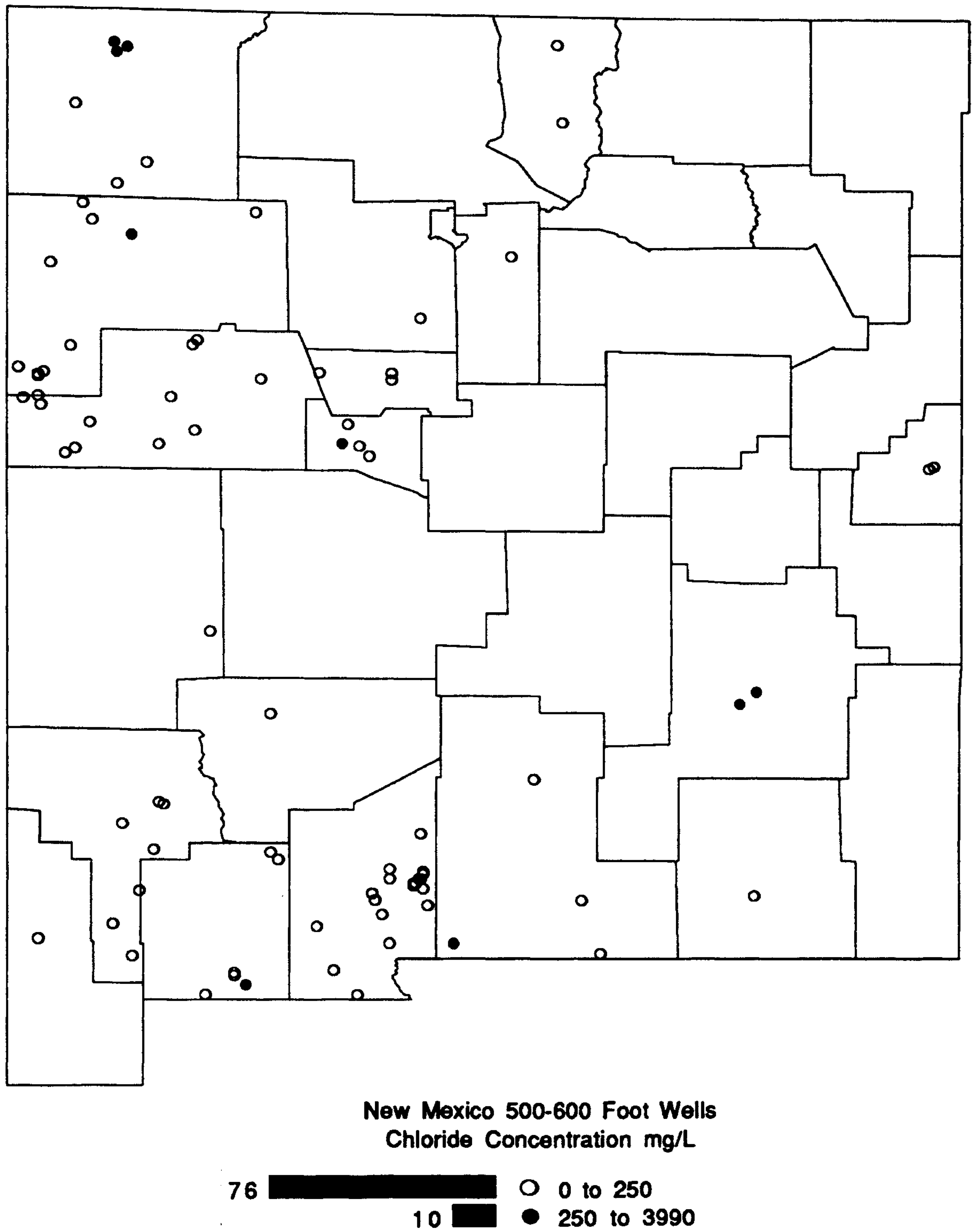



Figure 111. New Mexico 500-600 Foot Interval Chloride Map

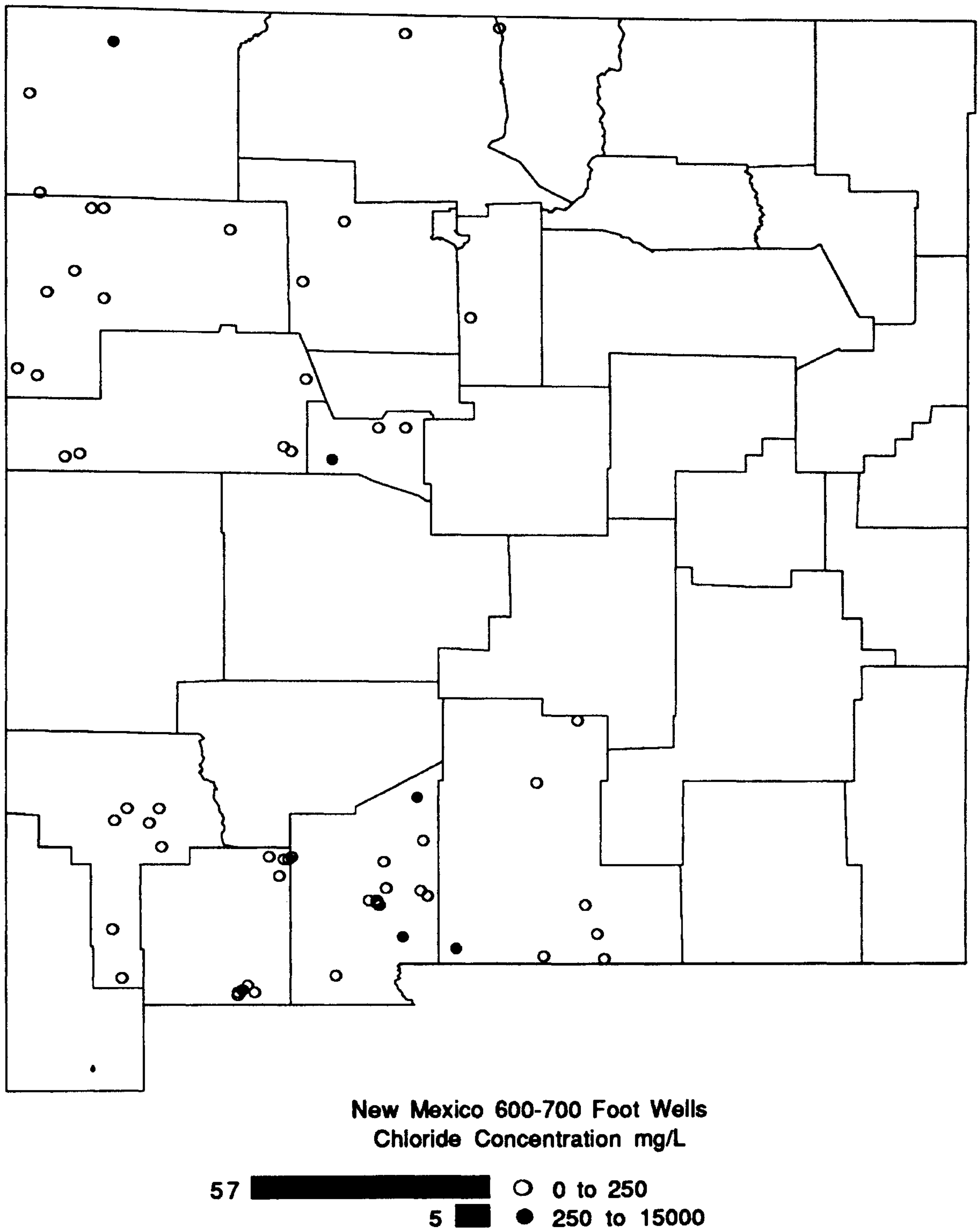



Figure 112. New Mexico 600-700 Foot Interval Chloride Map

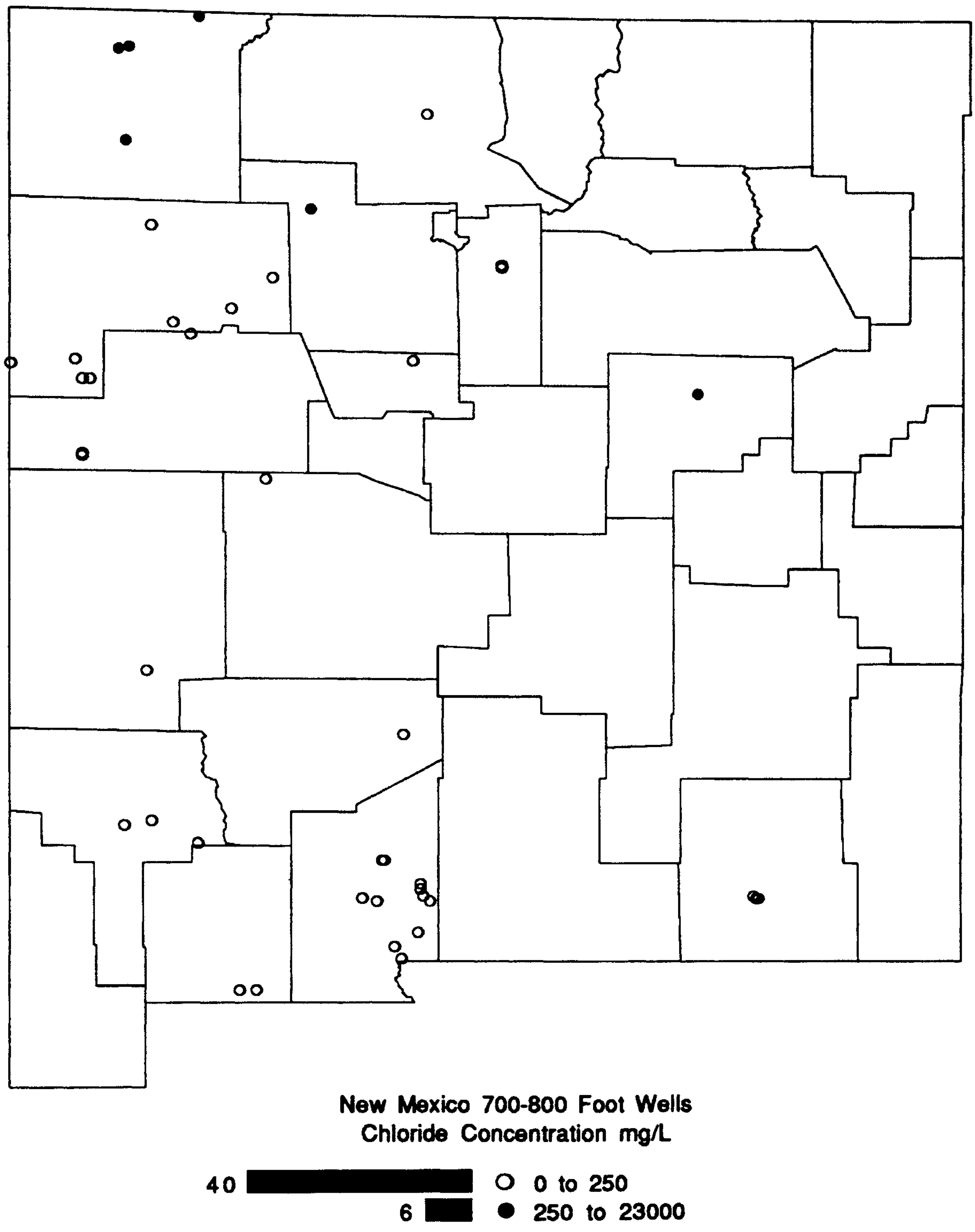



Figure 113. New Mexico 700-800 Foot Interval Chloride Map

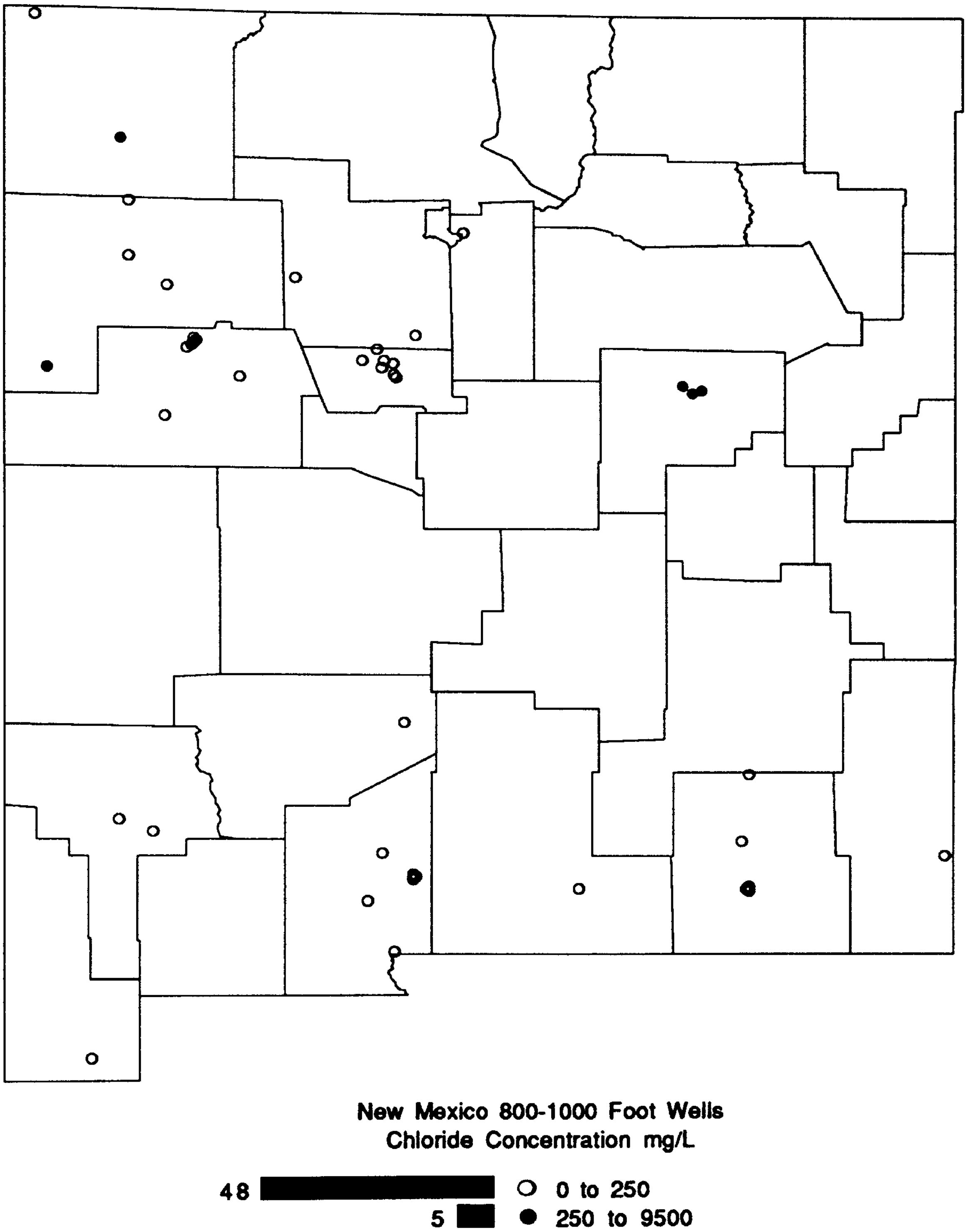



Figure 114. New Mexico 800-1000 Foot Interval Chloride Map

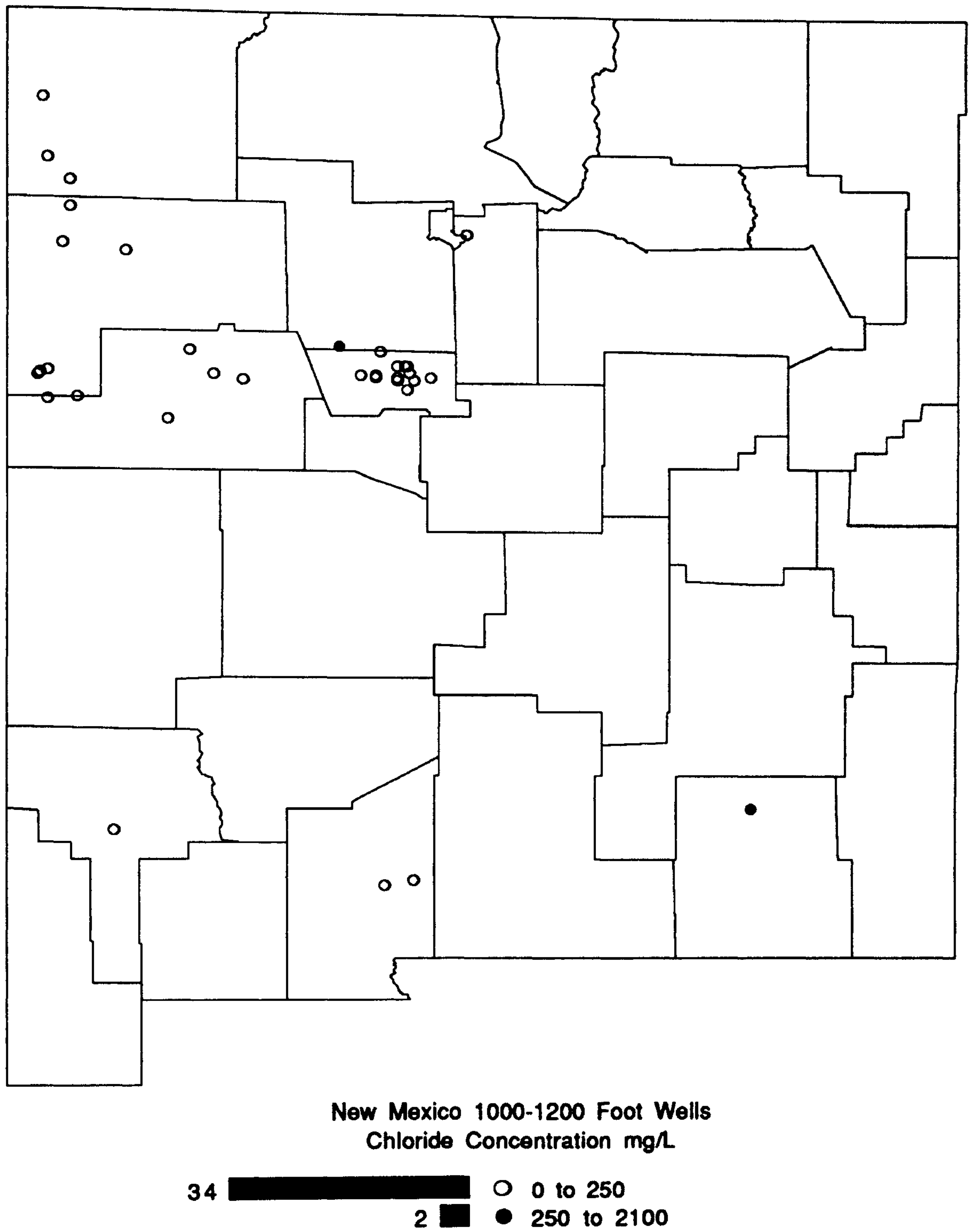



Figure 115. New Mexico 1000-1200 Foot Interval Chloride Map

# NORTH DAKOTA

## General Setting

North Dakota contains approximately 70,700 square miles and lies in the rolling to hilly, largely glaciated prairies of the Great Plains and Central Lowland provinces. The Badlands of Southwestern North Dakota contain rugged hills along the Little Missouri River. All but the southwestern quarter of North Dakota is covered with unconsolidated Quaternary age glacial deposits. These sediments range from less than 10 to more than 600 feet in thickness (Bluemle, 1986). The glacial boundary roughly parallels the present course of the Missouri River.

The Williston structural basin in western North Dakota contains thick accumulations of Paleozoic to Tertiary age limestone, sandstone, siltstone, and shale. These deposits gradually thin toward the margins of the basin, and Precambrian age granitic rocks locally underlie glacial deposits in the eastern part of the state(Pettyjohn, 1991).

The Great Plains province is drained by the Missouri River it's tributaries, and the Little Missouri River. The north flowing Red and Souris rivers drain most of the Central Lowlands province.

## Principal Aquifers

Principal aquifers in North Dakota consist of unconsolidated glaciofluvial and glaciolacustrine deposits, and sedimentary bedrock. Unconsolidated glacial sand and gravel deposits are the states most productive aquifers.

The western half of North Dakota is dominated by the sandstone, siltstone, and lignite deposits of the Fort Union aquifer system. The Hell Creek-Fox Hills aquifer system underlies the Fort Union. Lithology of the Hell Creek is sandstone, while the Fox Hills is less continuous sandstone interbedded with siltstone and shale.

The Great Plains Aquifer System, also called the Dakota Sandstone Aquifer, underlies much of the state. The Great Plains Aquifer system is composed of several sandstone layers. The water of the Dakota is of limited use in many locals due to high salinity.

The Madison Group is separated from the overlying Dakota by thick deposits of Jurassic and Triassic age shale and other fine-grained sedimentary rock. The material is for the most part limestone, however, it also contains some sandstone and shale layers. The Madison is not exposed at the surface but is found at relatively shallow depths of only a few hundred feet in the eastern part of the state. Figure 116 outlines the major aquifers of the state.

Chloride Distribution

Chloride maps of North Dakota are based upon 8312 stations distributed over 15 depth intervals(Table 18). The percentage of wells that exceed the 250 mg/L standard varies from a low of five percent at the 0-100 foot interval, to a high of 56 percent at the 400-500 foot interval(Table 19).

Significant peaks in chloride levels occur at the 400-500, and 700-1100 foot intervals(fig. 117). Regionally 14 percent (1166) of the states wells have chloride concentrations greater than 250 mg/L. Areal mapping of each depth interval(Figures. 119-133) suggest the majority of wells that exceed 250 mg/L occur in the eastern third of the state . This part of the state is dominated by the Dakota Aquifer system and Paleozoic and PreCambrian bedrock aquifers. Significant numbers of elevated stations also originate in the Hell Creek-Fox Hills System in the north central part of the state.

Areas of North Dakota affected by oil field activities are probably limited to the Williston Basin in the northwest part of the state including Burke, Renville, Montrail, and Ward Counties.

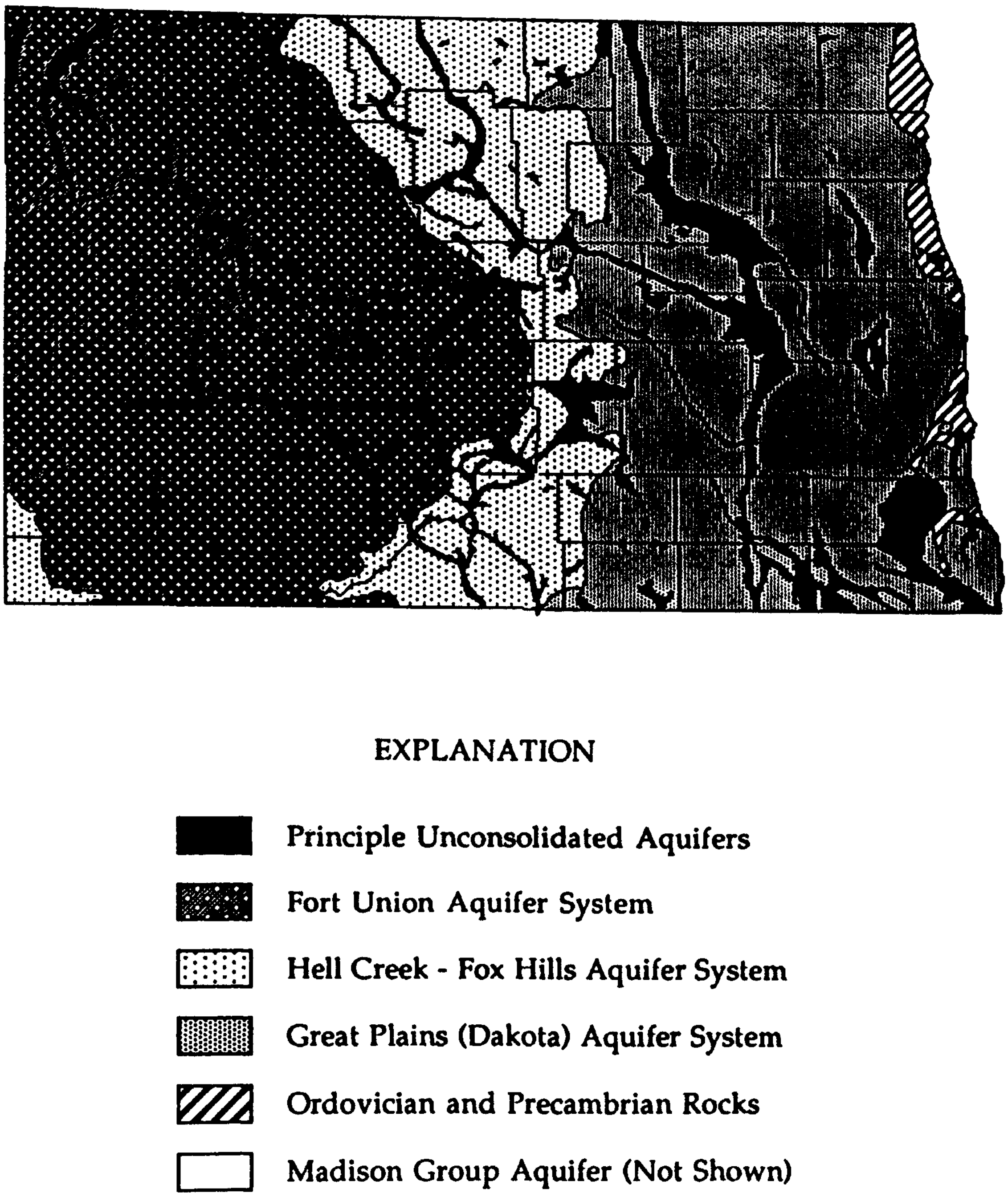



Figure 116. North Dakota Principal Aquifers Map
(Modified From U.S.G.S., 1985)

| Depth Interval (feet) | Concentration Interval (mg/L) 0-25 | 25-100 | 100-250 | 250-500 | >500 | total wells | wells >250 |
|---|---|---|---|---|---|---|---|
| 0-100 | 2457 | 793 | 258 | 107 | 93 | 3708 | 200 |
| 100-200 | 1270 | 561 | 197 | 110 | 175 | 2313 | 285 |
| 200-300 | 523 | 254 | 89 | 56 | 123 | 1045 | 179 |
| 300-400 | 192 | 73 | 36 | 19 | 102 | 422 | 121 |
| 400-500 | 97 | 2 | 0 | 97 | 27 | 223 | 124 |
| 500-600 | 46 | 18 | 14 | 23 | 32 | 133 | 55 |
| 600-700 | 28 | 11 | 9 | 20 | 12 | 80 | 32 |
| 700-800 | 17 | 6 | 4 | 16 | 16 | 59 | 32 |
| 800-900 | 18 | 10 | 3 | 16 | 14 | 61 | 30 |
| 900-1000 | 13 | 7 | 4 | 14 | 11 | 49 | 25 |
| 1000-1100 | 6 | 10 | 4 | 13 | 11 | 44 | 24 |
| 1100-1200 | 7 | 15 | 2 | 7 | 9 | 40 | 16 |
| 1200-1300 | 2 | 26 | 15 | 4 | 14 | 61 | 18 |
| 1300-1400 | 3 | 12 | 12 | 5 | 6 | 38 | 11 |
| 1400-1500 | 0 | 7 | 15 | 9 | 5 | 36 | 14 |
| State Total | 4679 | 1805 | 662 | 516 | 650 | 8312 | 1166 |
| Percent Of Wells With Concentrations Greater That 250mg/L | | | | | | | 14 |

TABLE 18. NUMBER OF STATIONS PER DEPTH AND CONCENTRATION INTERVAL IN NORTH DAKOTA

| Depth Interval (feet) | Concentration Interval (mg/L) 0-25 | 25-100 | 100-250 | 250-500 | >500 | >250 |
|---|---|---|---|---|---|---|
| 0-100 | 66 | 21 | 7 | 3 | 3 | 5 |
| 100-200 | 55 | 24 | 9 | 5 | 8 | 12 |
| 200-300 | 50 | 24 | 9 | 5 | 12 | 17 |
| 300-400 | 45 | 17 | 9 | 5 | 24 | 29 |
| 400-500 | 43 | 1 | 0 | 43 | 12 | 56 |
| 500-600 | 35 | 14 | 11 | 17 | 24 | 23 |
| 600-700 | 35 | 14 | 11 | 25 | 15 | 40 |
| 700-800 | 29 | 10 | 7 | 27 | 27 | 54 |
| 800-900 | 30 | 16 | 5 | 26 | 23 | 49 |
| 900-1000 | 27 | 14 | 8 | 29 | 22 | 51 |
| 1000-1100 | 14 | 23 | 9 | 30 | 25 | 55 |
| 1100-1200 | 18 | 38 | 5 | 18 | 23 | 40 |
| 1200-1300 | 3 | 43 | 25 | 7 | 23 | 30 |
| 1300-1400 | 8 | 32 | 32 | 13 | 16 | 29 |
| 1400-1500 | 0 | 19 | 42 | 25 | 14 | 39 |

TABLE 19. PERCENT OF STATIONS PER DEPTH AND CONCENTRATION INTERVAL IN NORTH DAKOTA

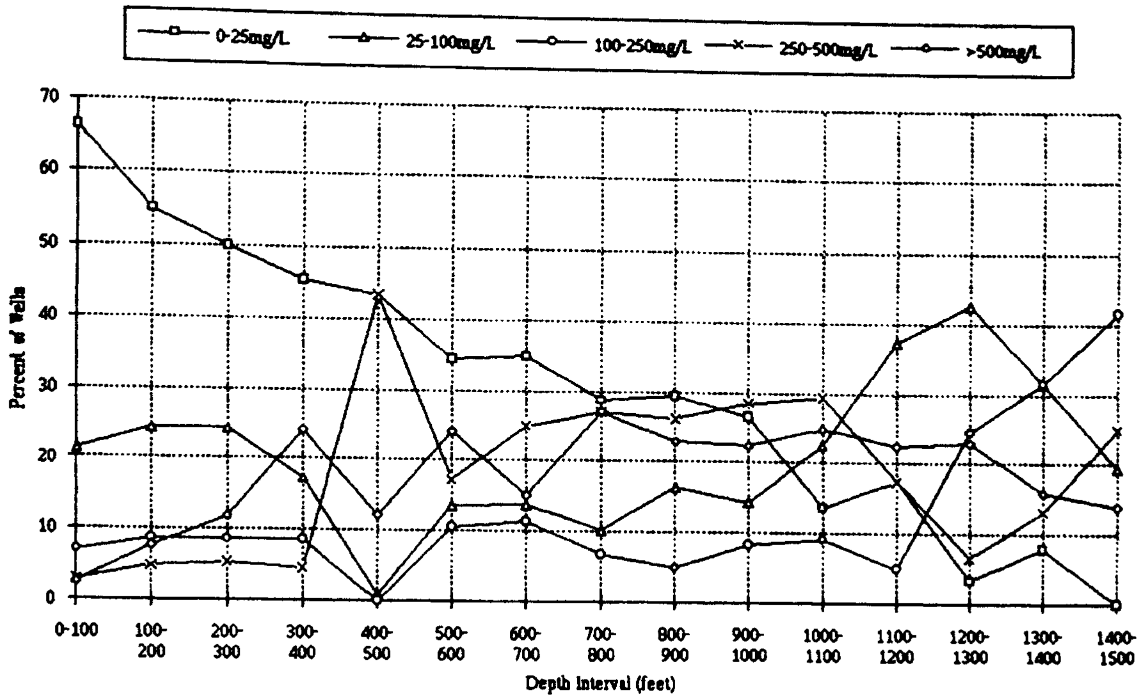



**Figure 117. North Dakota Percent Of Wells Per Concentration Interval vs Well Depth**

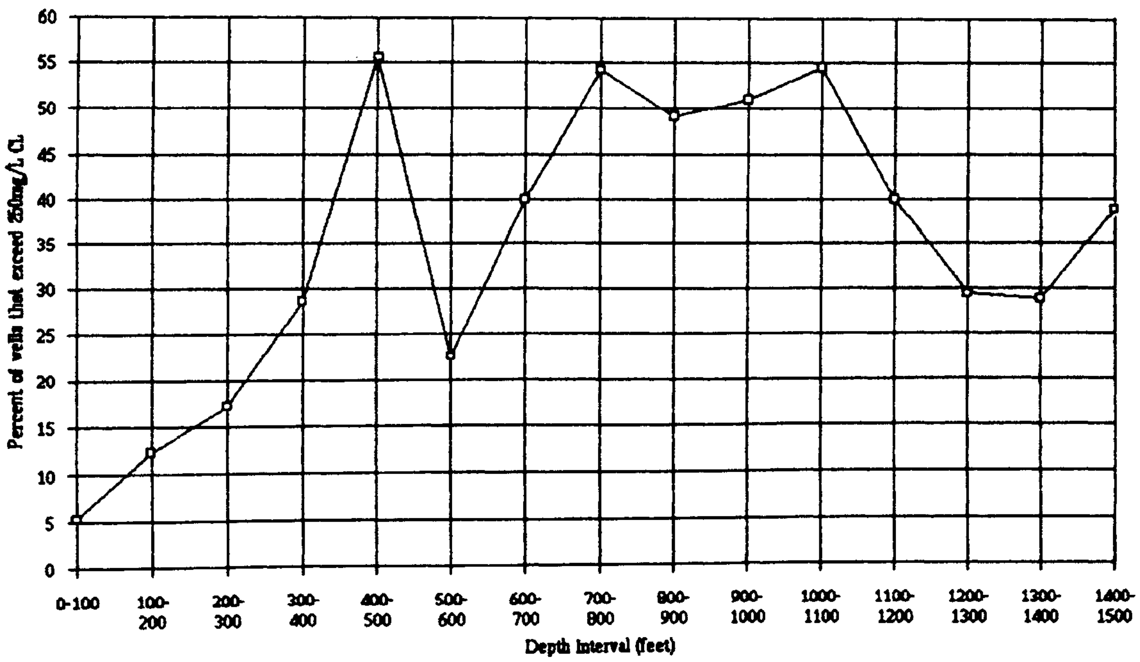



**Figure 118. North Dakota Percent Of Wells That Exceed 250 mg/L Chloride**

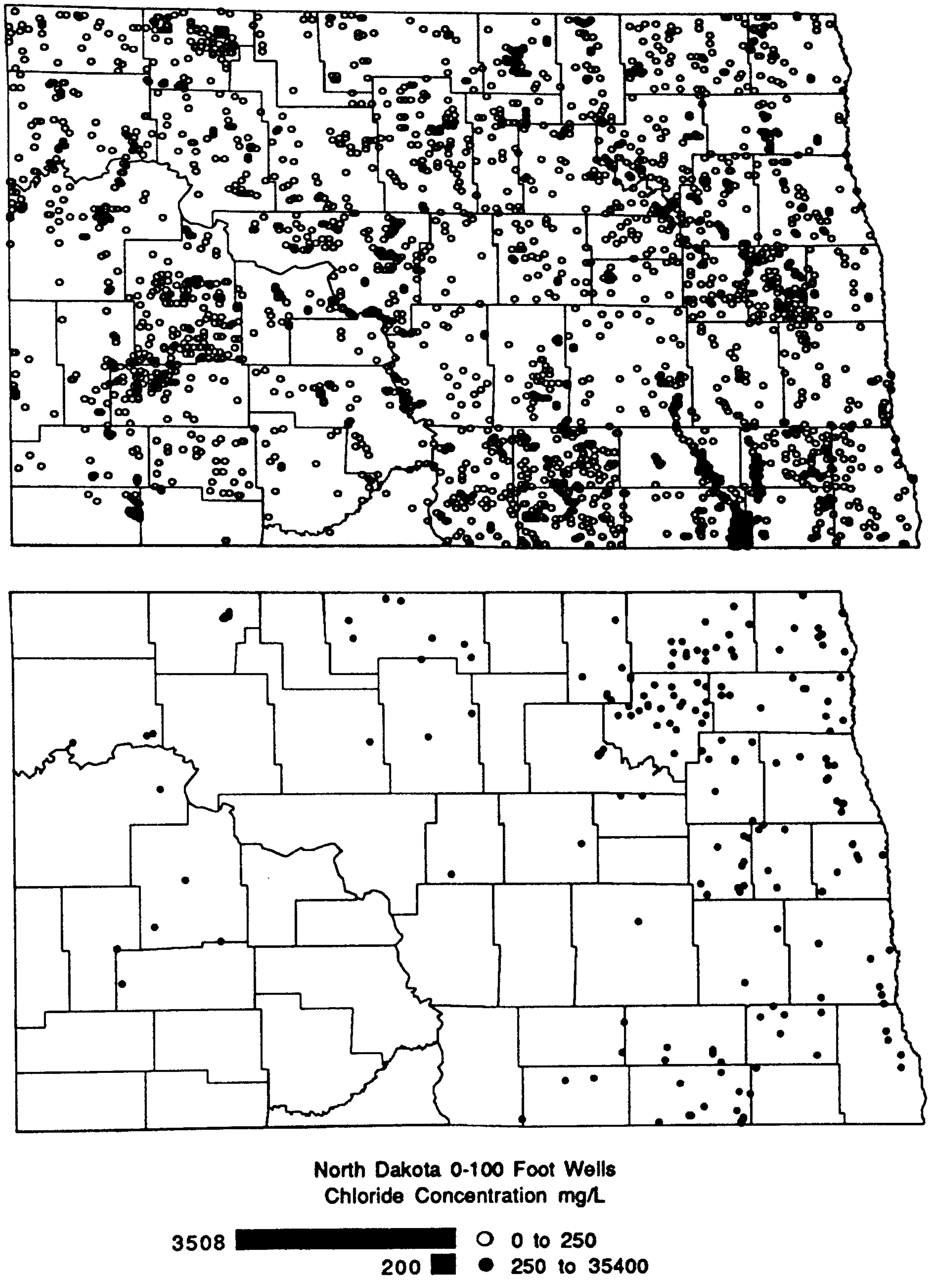



Figure 119. North Dakota 0-100 Foot Interval Chloride Map

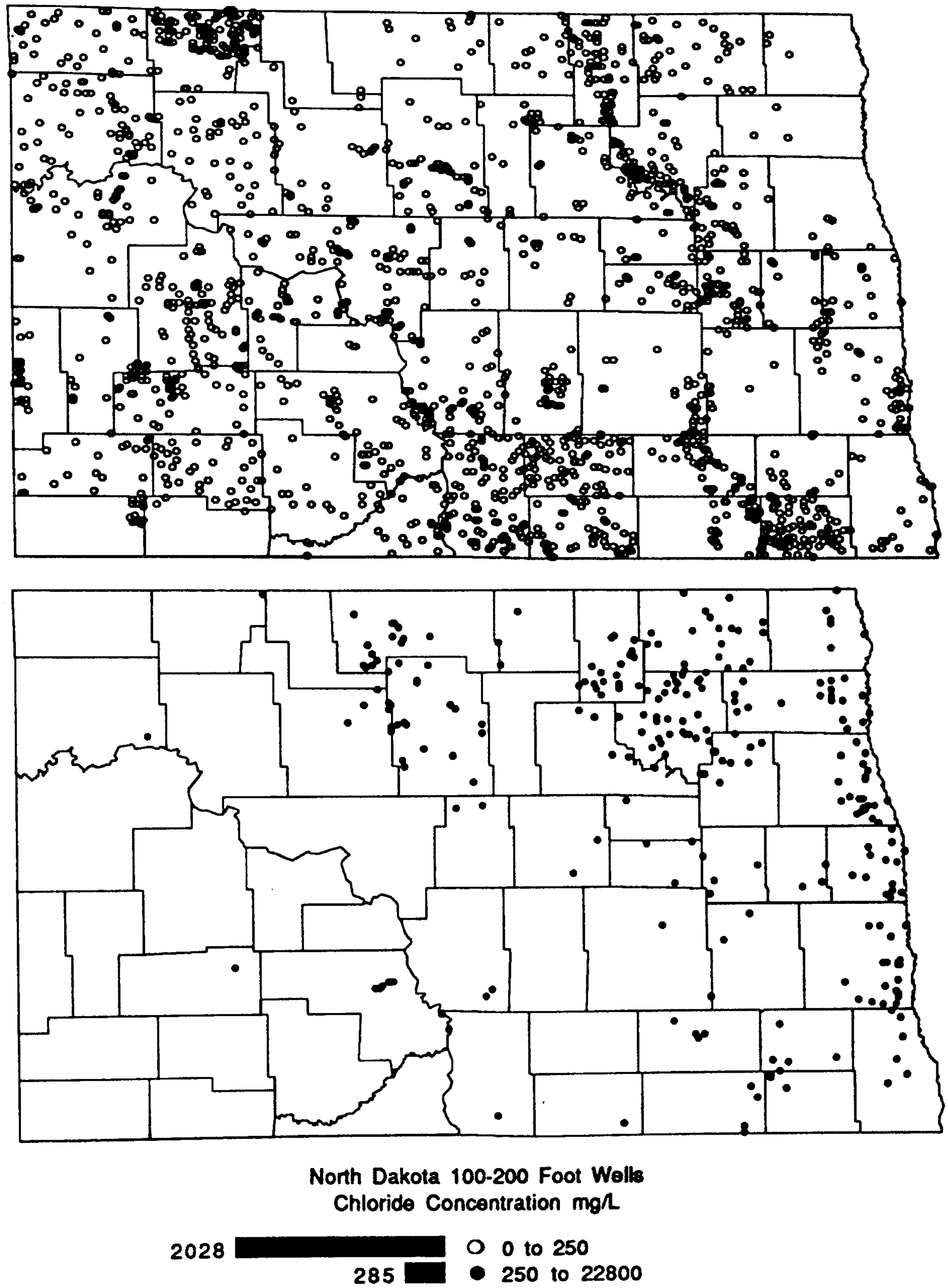



Figure 120. North Dakota 100-200 Foot Interval Chloride Map

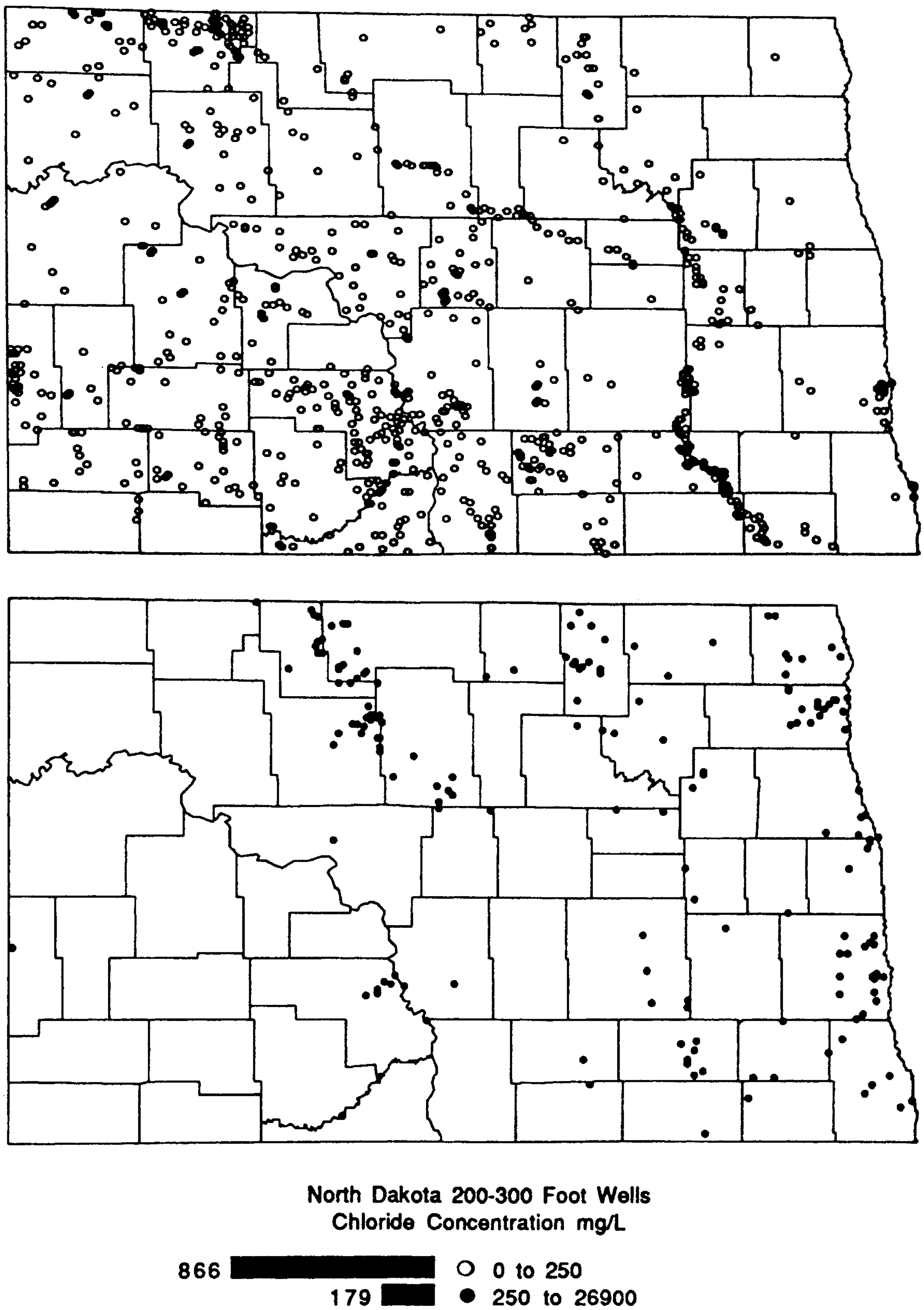



Figure 121. North Dakota 200-300 Foot Interval Chloride Map

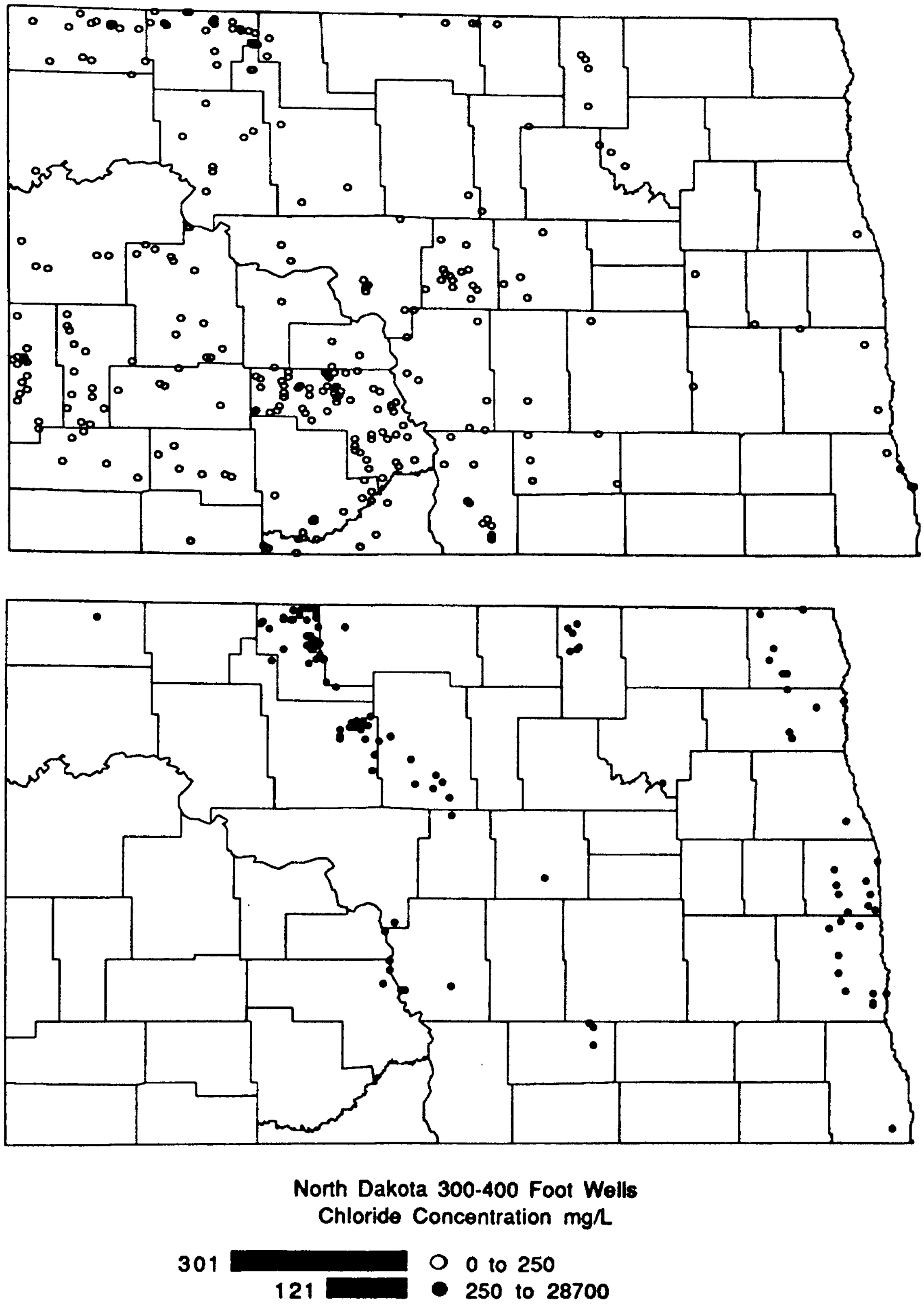



Figure 122. North Dakota 300-400 Foot Interval Chloride Map

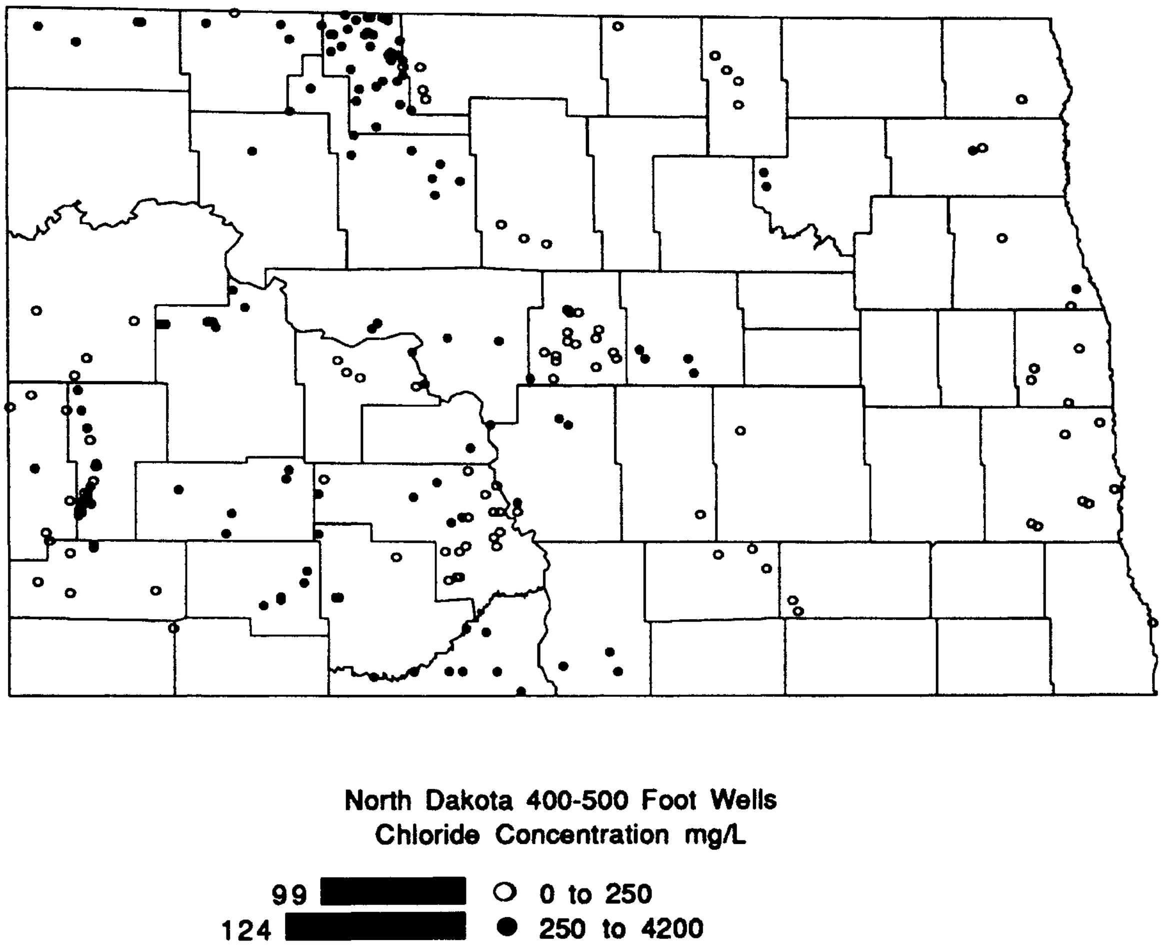



Figure 123. North Dakota 400-500 Foot Interval Chloride Map

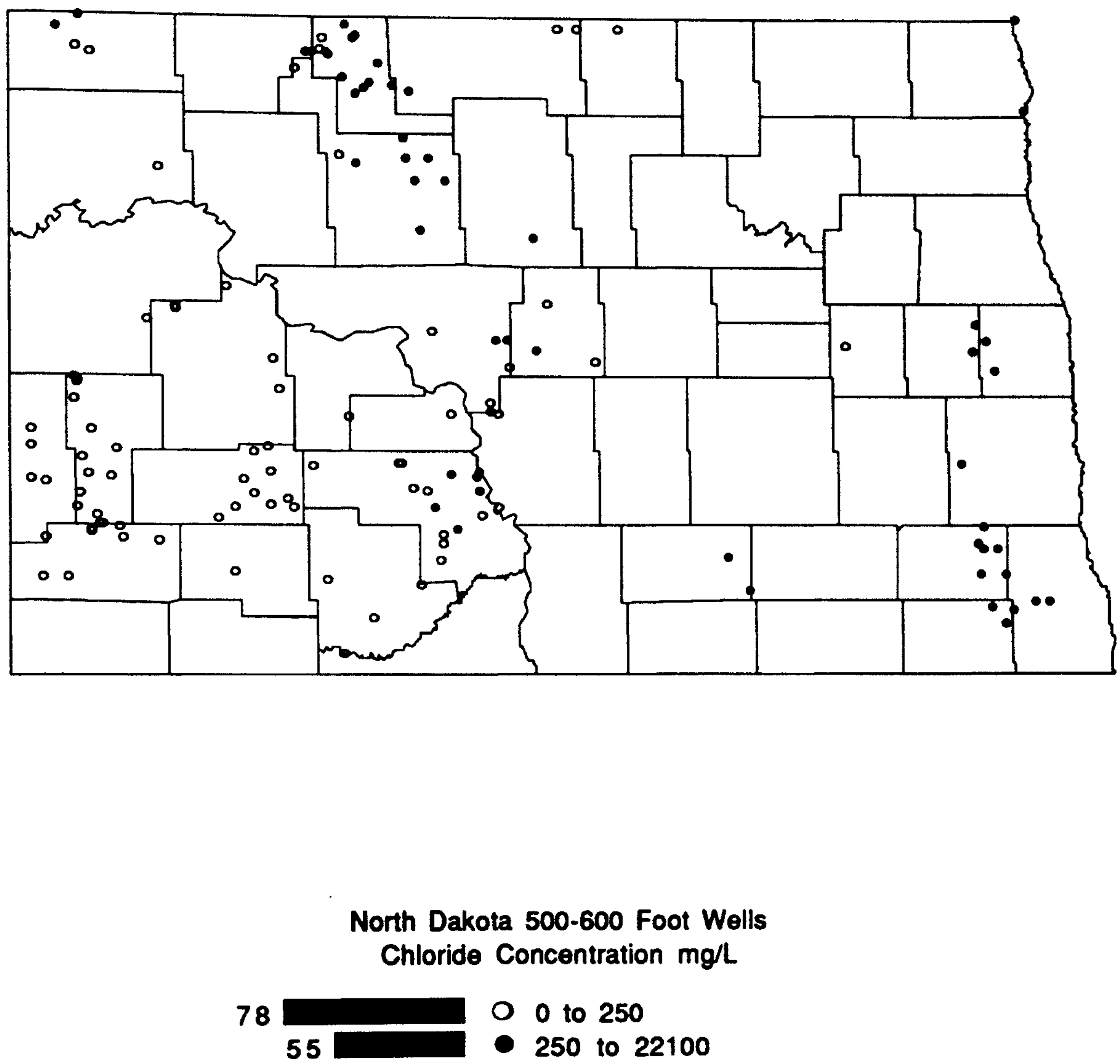



Figure 124. North Dakota 500-600 Foot Interval Chloride Map

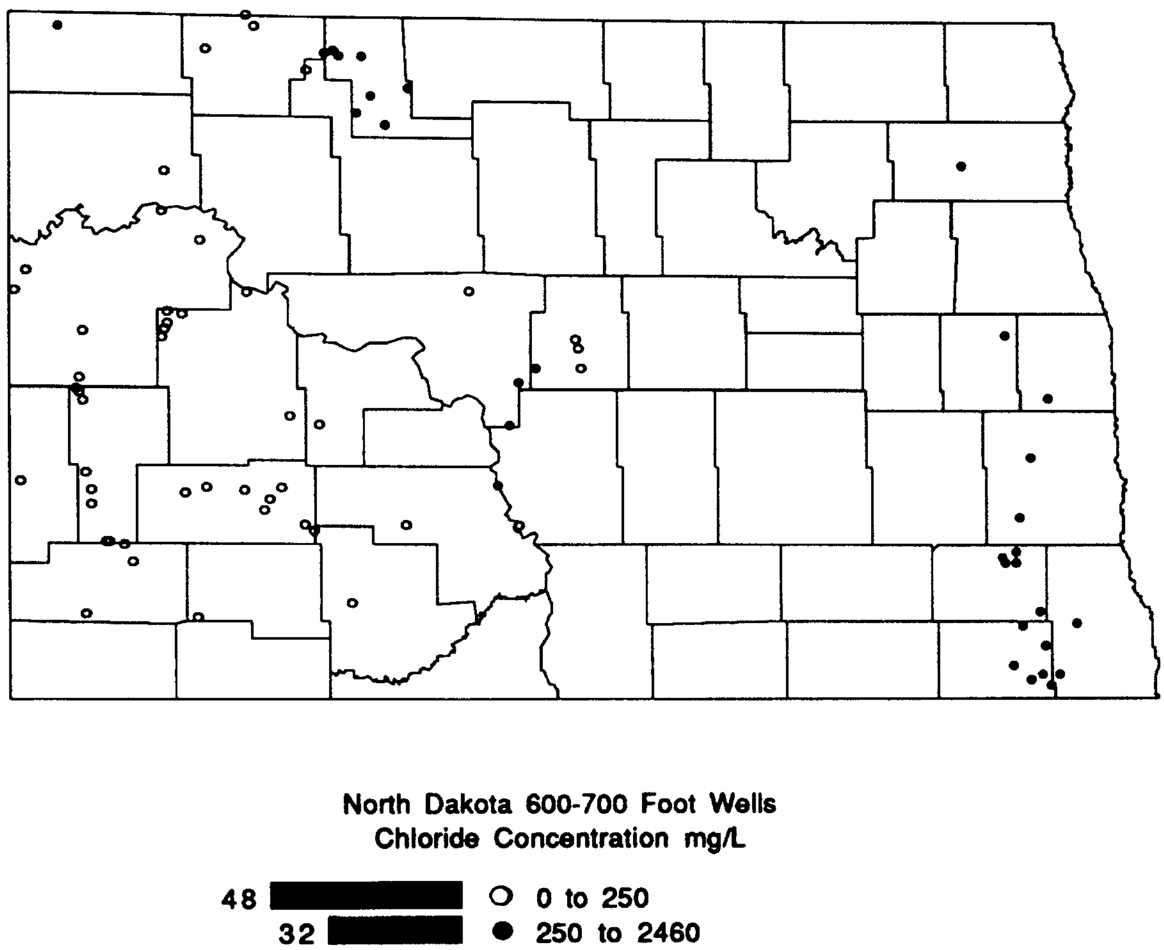



Figure 125. North Dakota 600-700 Foot Interval Chloride Map

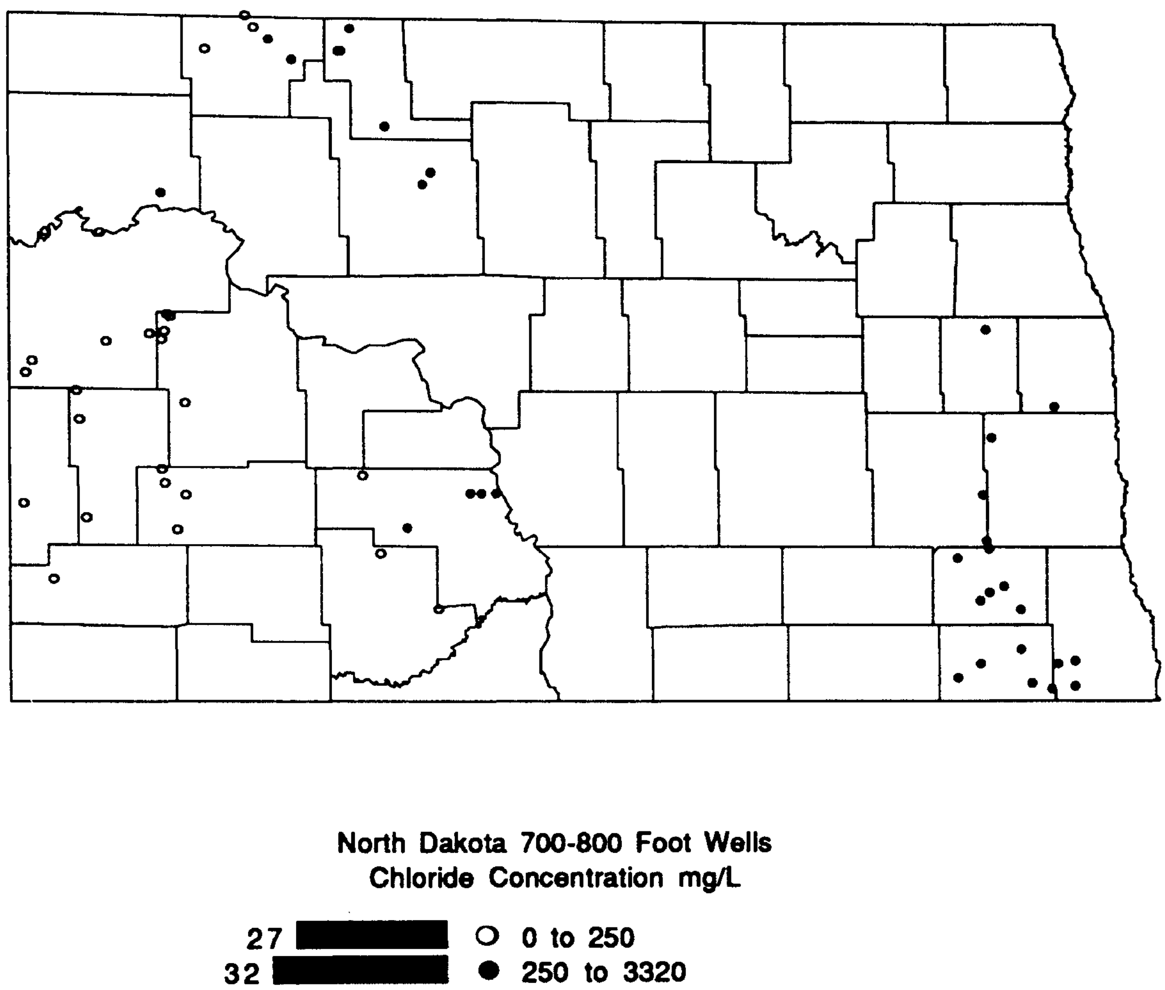



Figure 126. North Dakota 700-800 Foot Interval Chloride Map

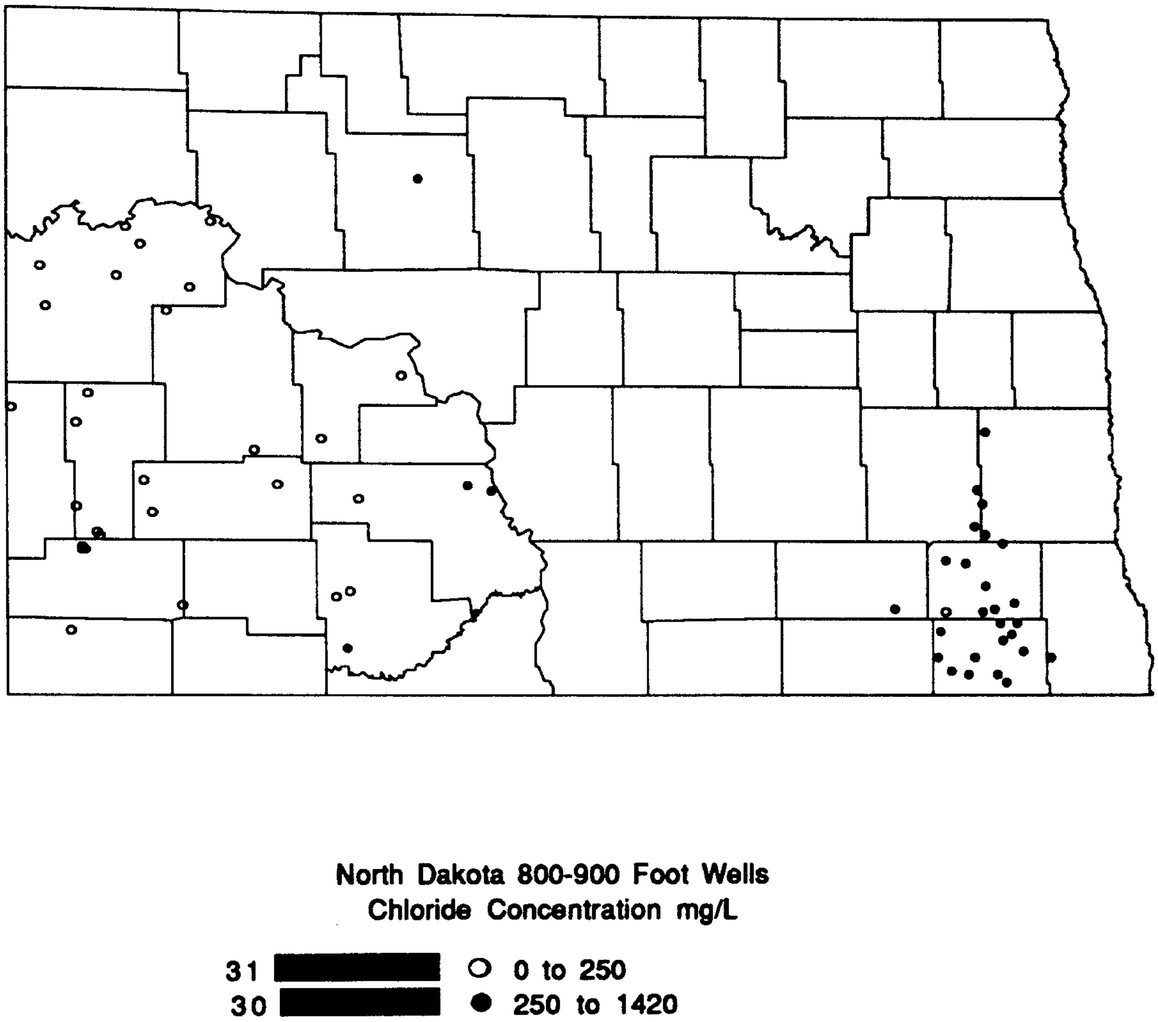



Figure 127. North Dakota 800-900 Foot Interval Chloride Map

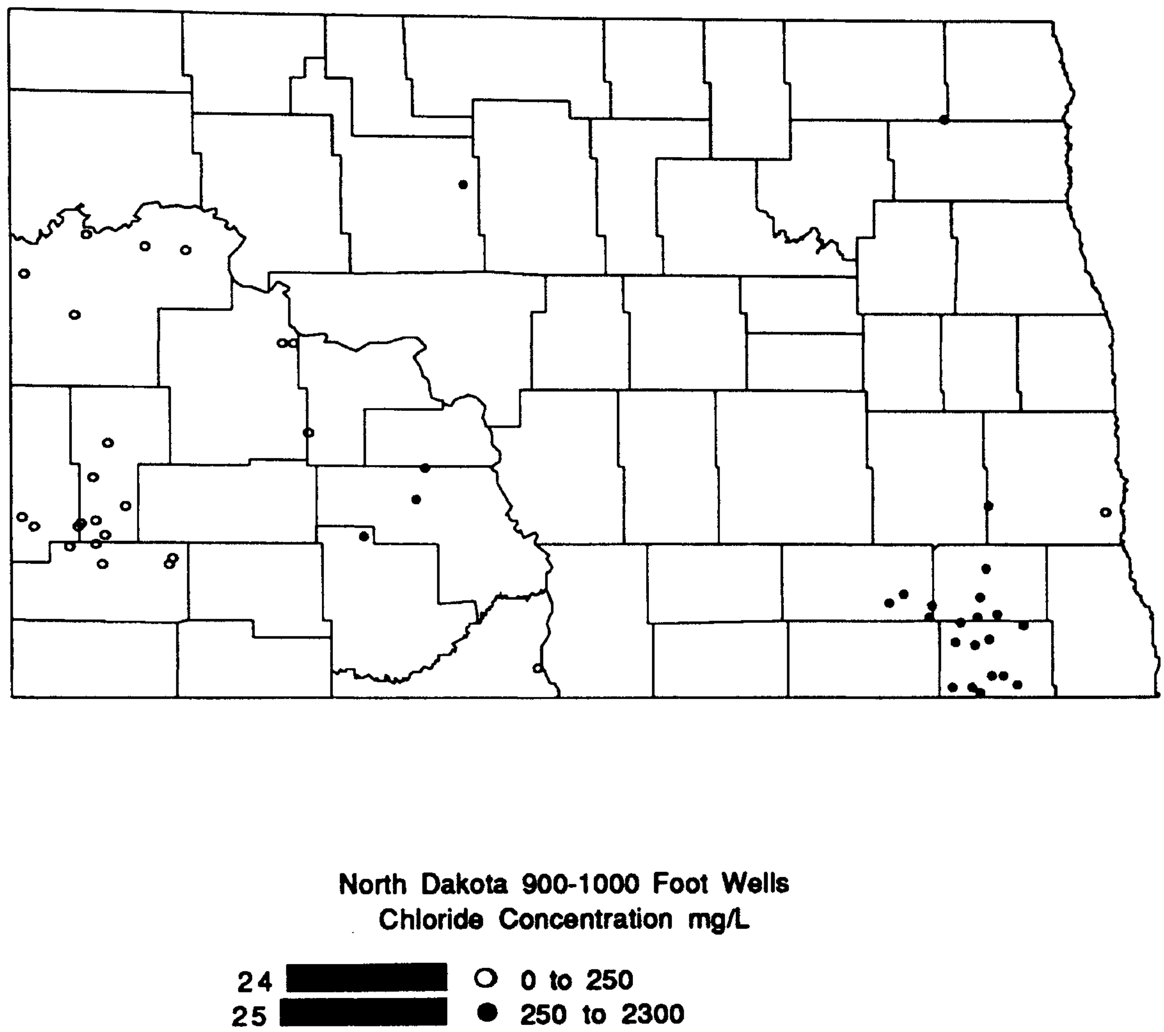



Figure 128. North Dakota 900-1000 Foot Interval Chloride Map

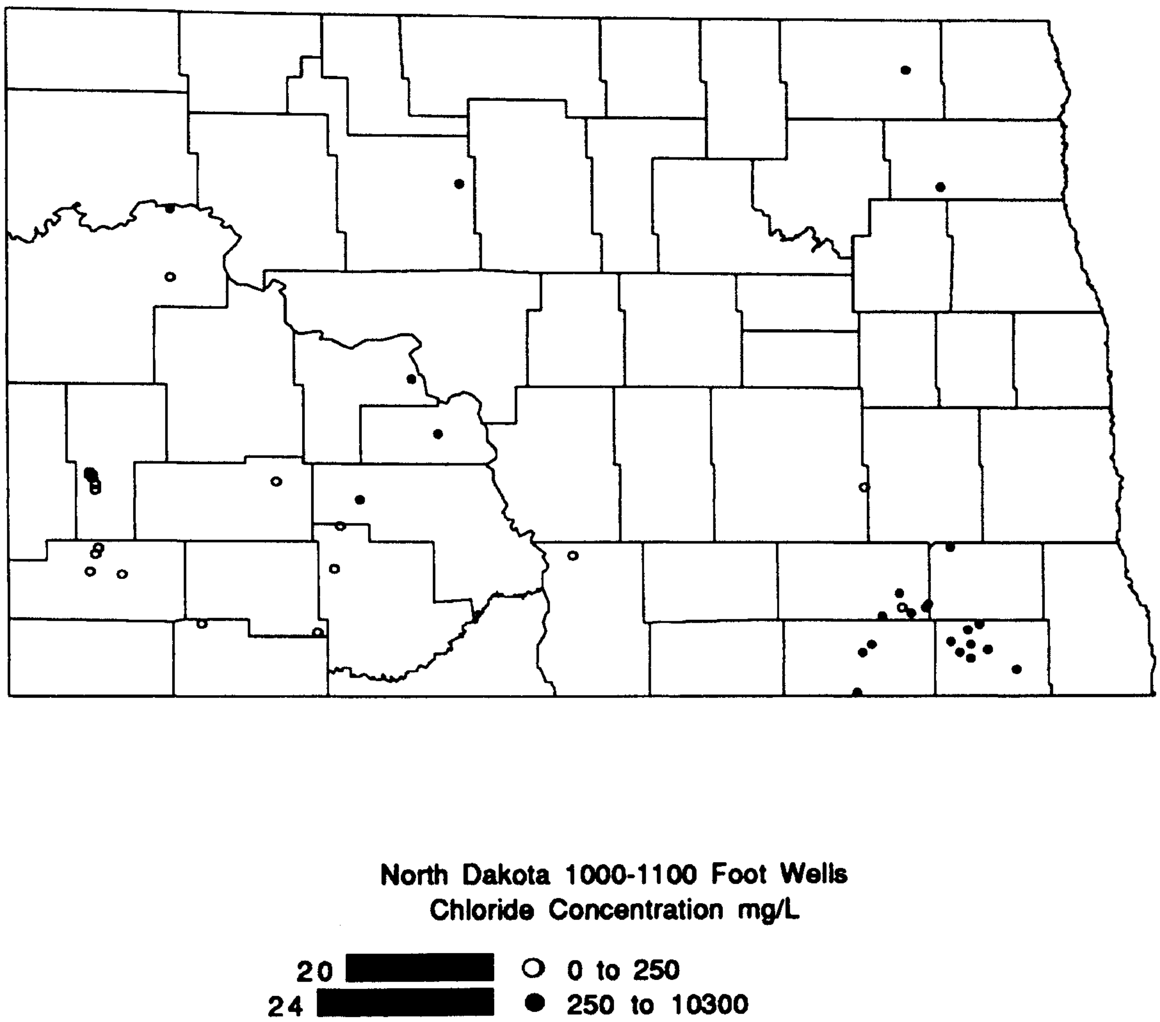



Figure 129. North Dakota 1000-1100 Foot Interval Chloride Map

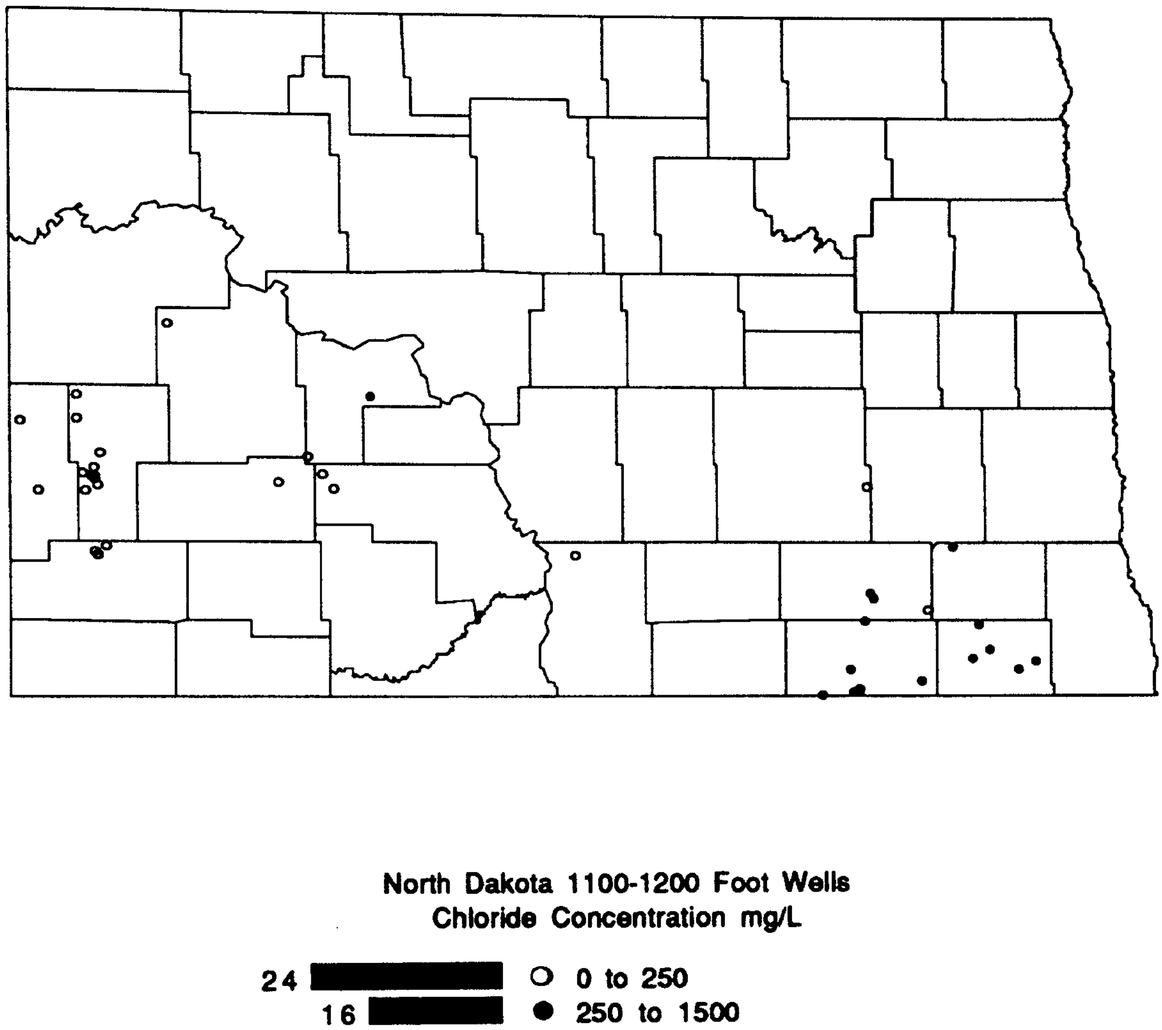



Figure 130. North Dakota 1100-1200 Foot Interval Chloride Map

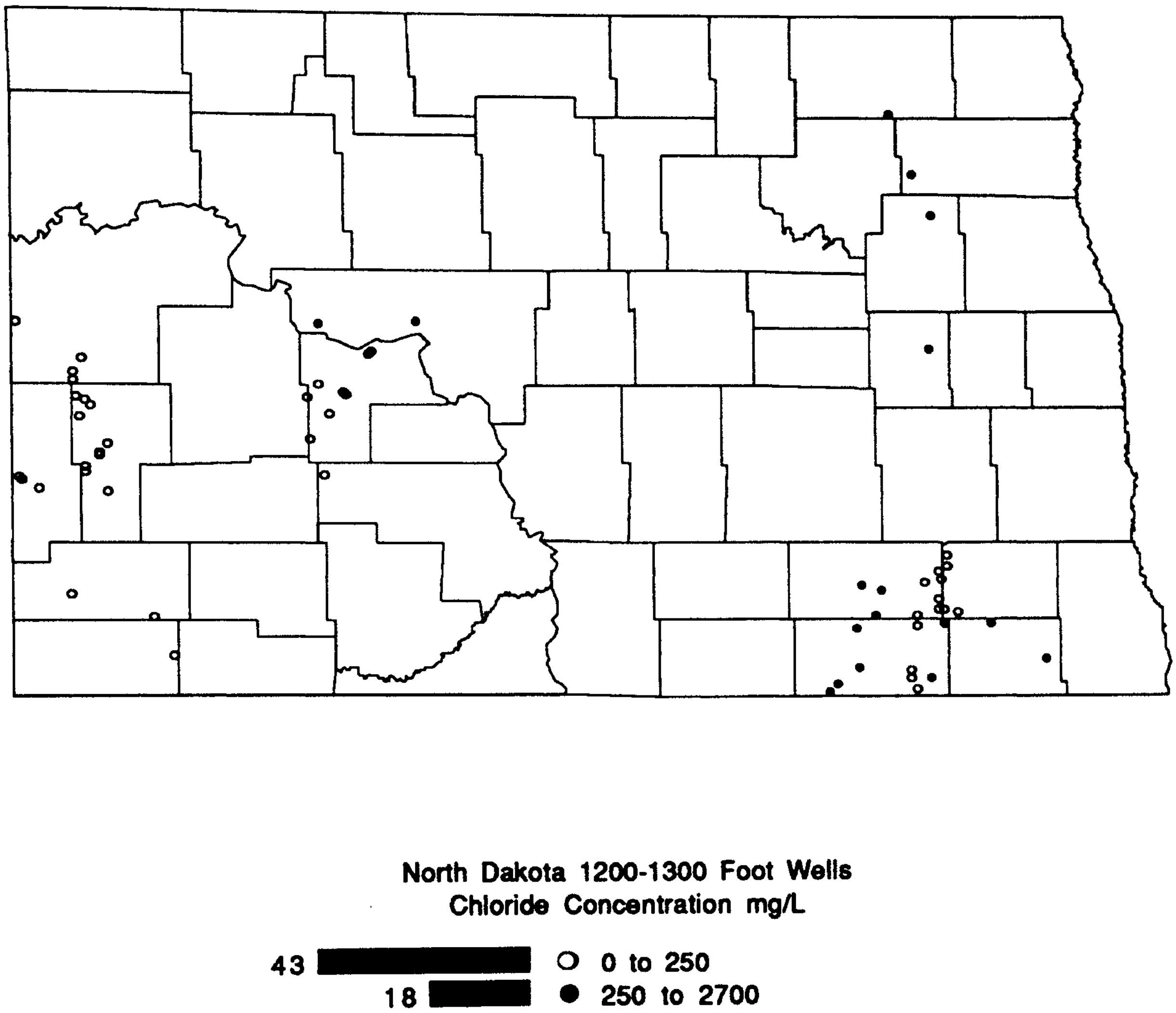



Figure 131. North Dakota 1200-1300 Foot Interval Chloride Map

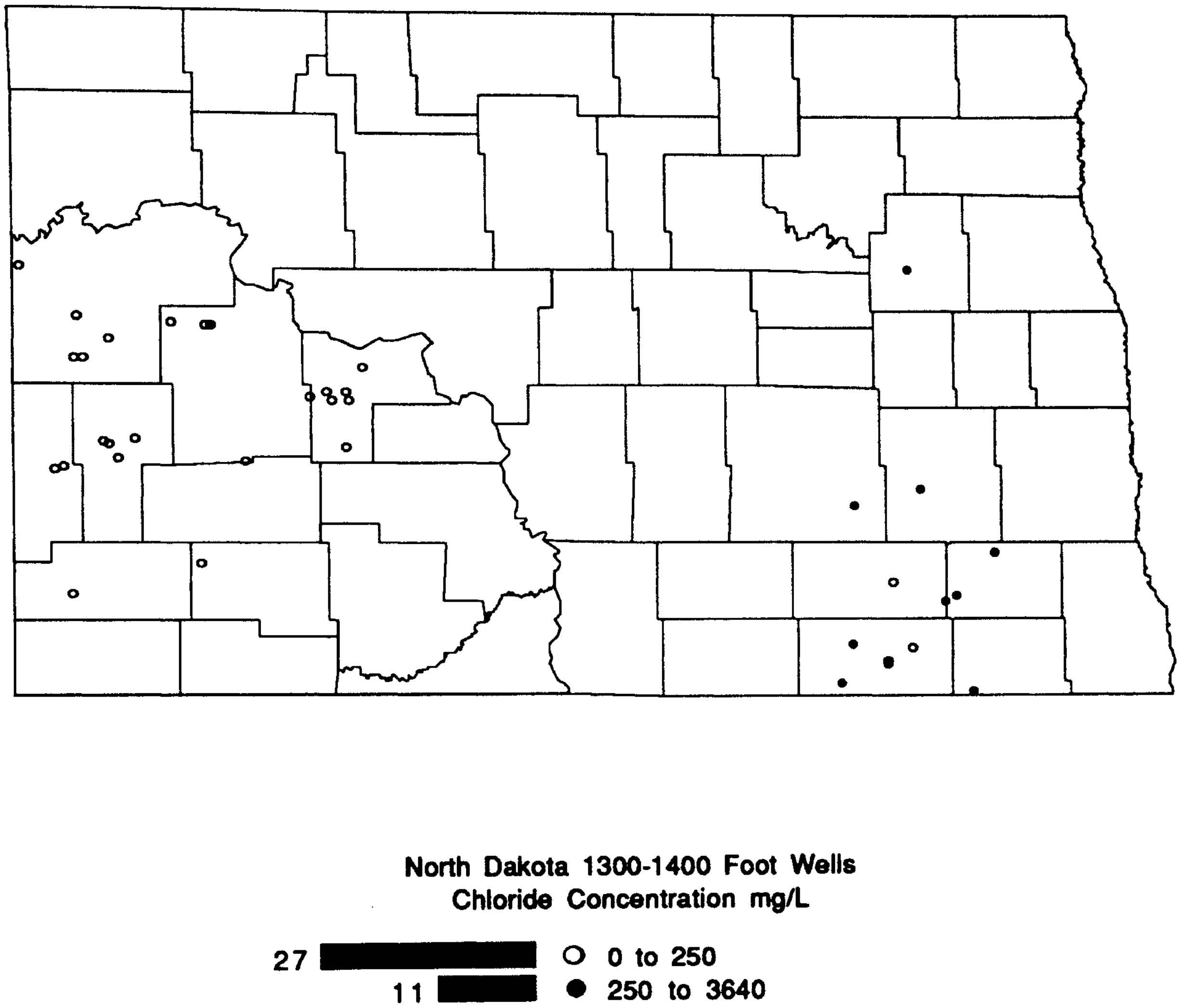



Figure 132. North Dakota 1300-1400 Foot Interval Chloride Map

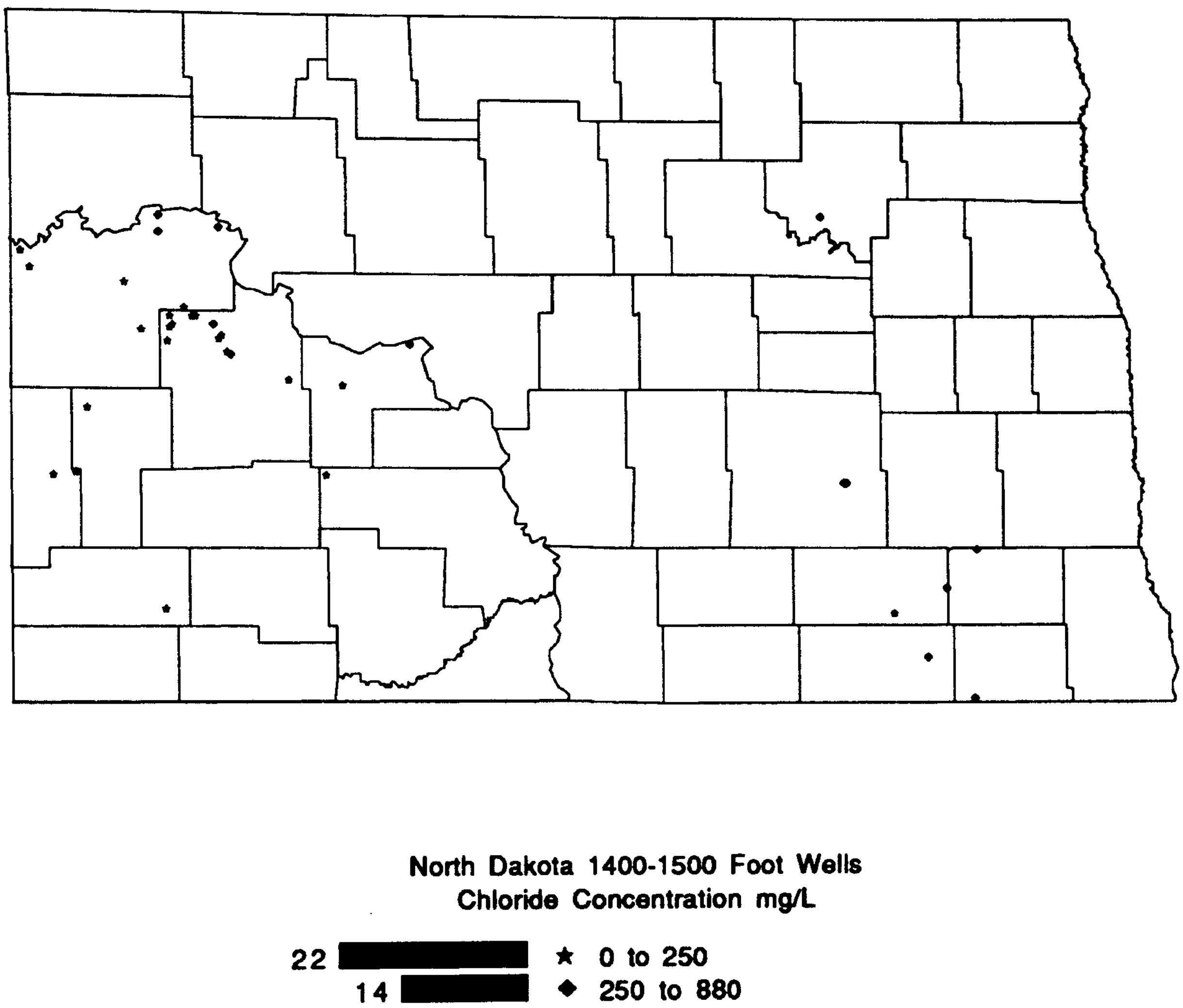



Figure 133. North Dakota 1400-1500 Foot Interval Chloride Map

# OKLAHOMA

## General Setting

Oklahoma which encompasses about 70,000 square miles, lies primarily in the rolling plains and low hills of the Central Lowlands, the Great Plains, and the Costal Plains physiographic provinces. The states eastern mountainous region also includes portions of the Ozark Plateau and Ouachita provence. The Arbuckle Mountains occur in the south central part of the state and the Wichita Mountains occur in the southwestern part of the state, both which expose precambrian crystalline rock, as well as sequences of folded and faulted paleozoic age rocks. Most of Oklahoma is underlain by thick sequences of westward dipping Paleozoic age carbonate and shale rock. Mesozoic age clastic and carbonate units are exposed in the northwestern part of the panhandle, and southwestern dipping clastic and carbonate strata of Cretaceous age occurs in the southeastern section of the state(Pettyjohn, 1991).

## Principal Aquifers

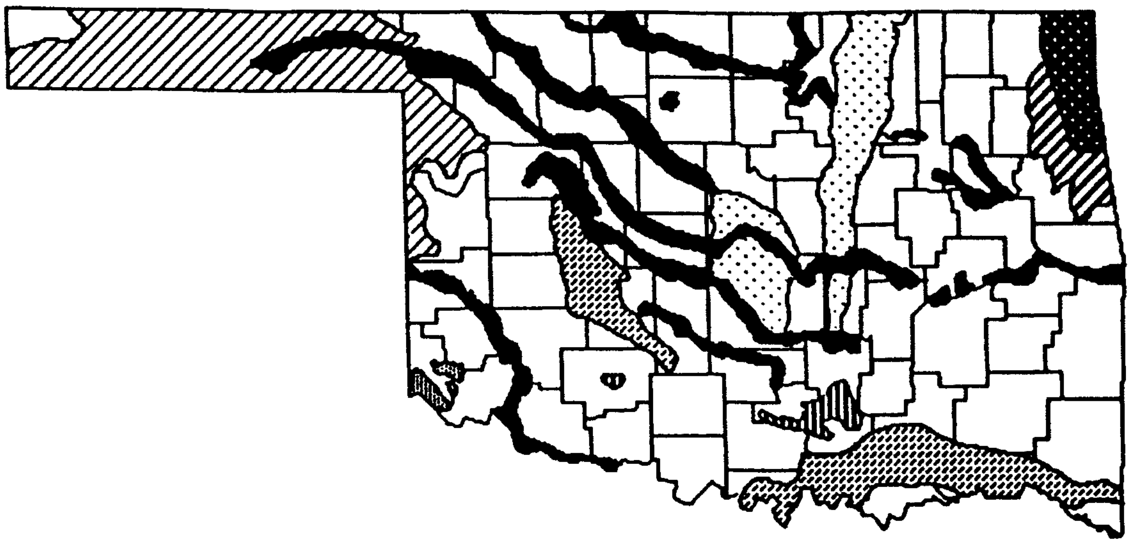
Principal groundwater resources in Oklahoma occur with the tertiary age Ogallala formation in the high plains of the Panhandle and adjacent areas. Groundwater resources are also found in the alluvium and terrace deposits along major streams. Moderate supplies of water are found in sandstone aquifers of Ordovician to Cretaceous age occur in central, northeastern, and southeastern parts of the state.

Moderate to large water supplies are found in the Cambrian and Ordovician age carbonate rocks of the Arbuckle and Simpson Groups in South Central Oklahoma and in the Mississippian age limestones of the Boone Formation of the northeast. Moderate supplies of water can also be found in the Blaine Formation and Permian Dog Creek Shale in the southwest(McGuinness, 1963). Oklahoma's principal aquifers are outlined in Figure 134.

Chloride Distribution

Chloride maps of Oklahoma are based upon 1686 stations distributed over seven depth intervals(Table 20). The percentage of wells that exceed 250 mg/L varies from a low of eight percent at the 300-400 foot interval, to a high of 25 percent at the 500-600 foot interval(Table 21). Regionally 17 percent (289) of the states wells have chloride concentrations greater than 250 mg/L(Table 20). Many counties in the state of Oklahoma are affected by shallow groundwater with elevated chloride levels. A disproportionate number of wells with elevated chloride levels are in the southwest of the state,(Figures. 137-143) including Harmon, Greer, Kiowa, Jackson and Tillman counties. These wells probably are completed in the Dog Creek-Blane which has historically demonstrated chloride levels in the range of 425-1950 mg/L (Pettyjohn, 1983). Other areas of concern include shallow alluvial terrace aquifers in Canadian, Blane, Kingfisher, Grant, and Harper counties. Terrace alluvium deposits in the north central of the state have demonstrated chloride levels from 30 to 1520 mg/L(Pettyjohn, 1983).

Chloride concentrations in Oklahoma may well represent influences from evaporites and contamination brought about by the states long history of oil field activities(Pettyjohn, 1993). Counties in Oklahoma identified as having oil field brine contamination problems include; Woods, Logan, Creek, Lincoln, Okfuskee, Oklahoma, Pottawatomie, Seminole, Garvin, and Pontotoc Counties(Richter, 1991).



Alluvium and Terrace Deposit Along Major Streams

High Plains Aquifer

Antlers and Rush Springs Aquifers

Dog Creek - Blaine Aquifers

Garber-Wellington and Vamoosa - Ada Aquifers

Keokuk-Reeds Spring Aquifers (Boone)

Roubidoux Aquifer

Arbuckle - Simpson and Arbuckle-Timbered Hills Aquifer

Not a Principal Aquifer

Figure 134. Oklahoma Principal Aquifers Map
(Modified From U.S.G.S., 1985)

| | Concentration Interval (mg/L) | | | | | total | wells |
|---|---|---|---|---|---|---|---|
| | 0-25 | 25-100 | 100-250 | 250-500 | >500 | wells | >250 |
| Depth Interval (feet) | | | | | | | |
| 0-100 | 361 | 311 | 119 | 68 | 91 | 950 | 159 |
| 100-200 | 121 | 101 | 51 | 19 | 43 | 335 | 62 |
| 200-300 | 61 | 40 | 18 | 7 | 23 | 149 | 30 |
| 300-400 | 62 | 21 | 3 | 2 | 6 | 94 | 8 |
| 400-500 | 34 | 12 | 4 | 4 | 6 | 60 | 10 |
| 500-600 | 32 | 7 | 5 | 9 | 6 | 59 | 15 |
| 600-700 | 27 | 6 | 1 | 1 | 4 | 39 | 5 |
| State Total | 698 | 498 | 201 | 110 | 179 | 1686 | 289 |
| Percent Of Wells With Concentrations Greater Than 250mg/L | | | | | | | 17 |

TABLE 20. NUMBER OF STATIONS PER DEPTH AND CONCENTRATION INTERVAL IN OKLAHOMA

| | Concentration Interval (mg/L) | | | | | |
|---|---|---|---|---|---|---|
| | 0-25 | 25-100 | 10-250 | 250-500 | >500 | >250 |
| Depth Interval (feet) | | | | | | |
| 0-100 | 38 | 33 | 13 | 7 | 10 | 17 |
| 100-200 | 36 | 30 | 15 | 6 | 13 | 19 |
| 200-300 | 41 | 27 | 12 | 5 | 15 | 20 |
| 300-400 | 66 | 22 | 3 | 2 | 6 | 9 |
| 400-500 | 57 | 20 | 7 | 7 | 10 | 17 |
| 500-600 | 54 | 12 | 8 | 15 | 10 | 25 |
| 600-700 | 69 | 15 | 3 | 3 | 10 | 13 |

TABLE 21. PERCENT OF STATIONS PER DEPTH AND CONCENTRATION INTERVAL IN OKLAHOMA

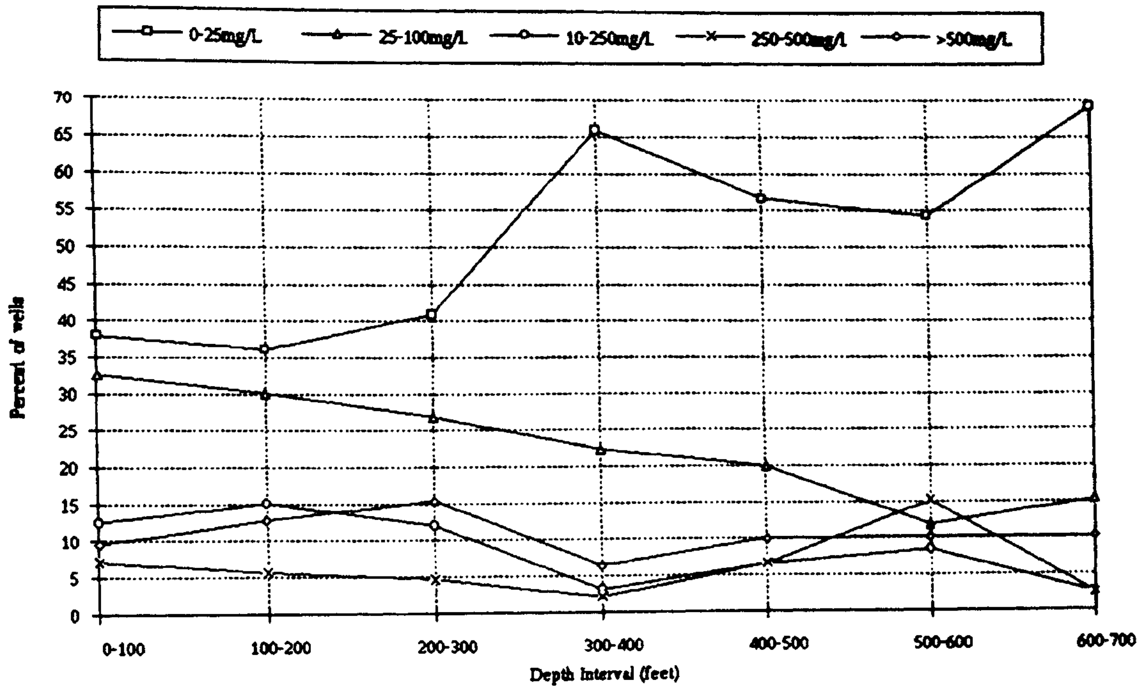



**Figure 135. Oklahoma Percent Of Wells Per Concentration Interval vs Well Depth**

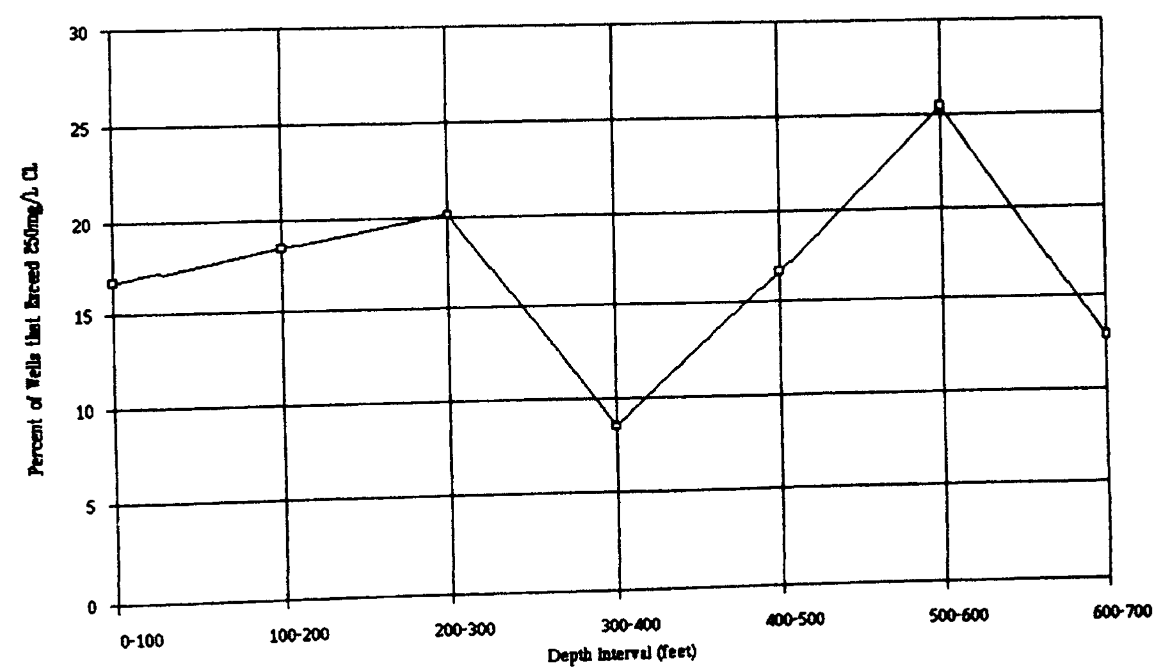



**Figure 136. Oklahoma Percent Of Wells That Exceed 250 mg/L Chloride**

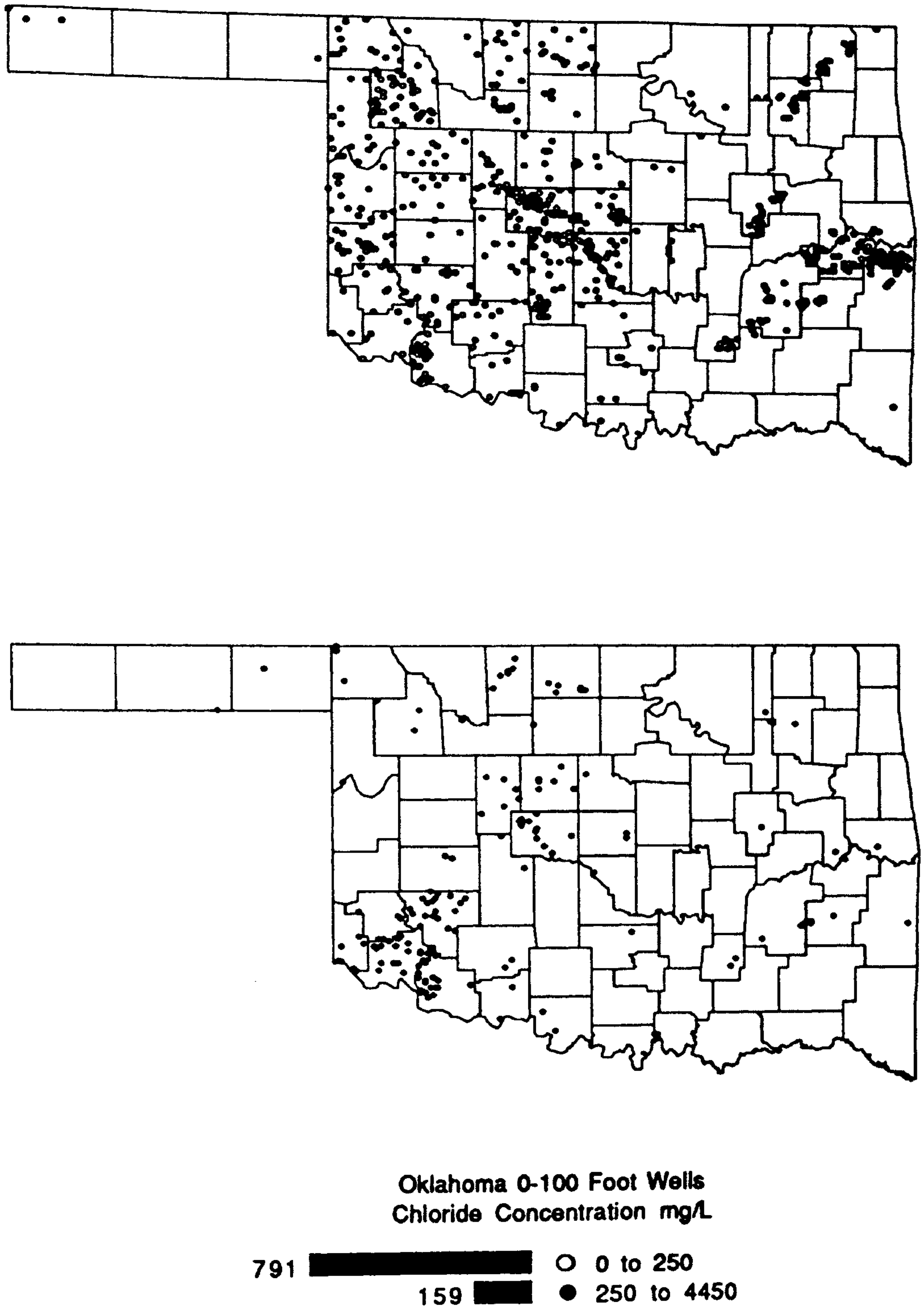



Figure 137. Oklahoma 0-100 Foot Interval Chloride Map

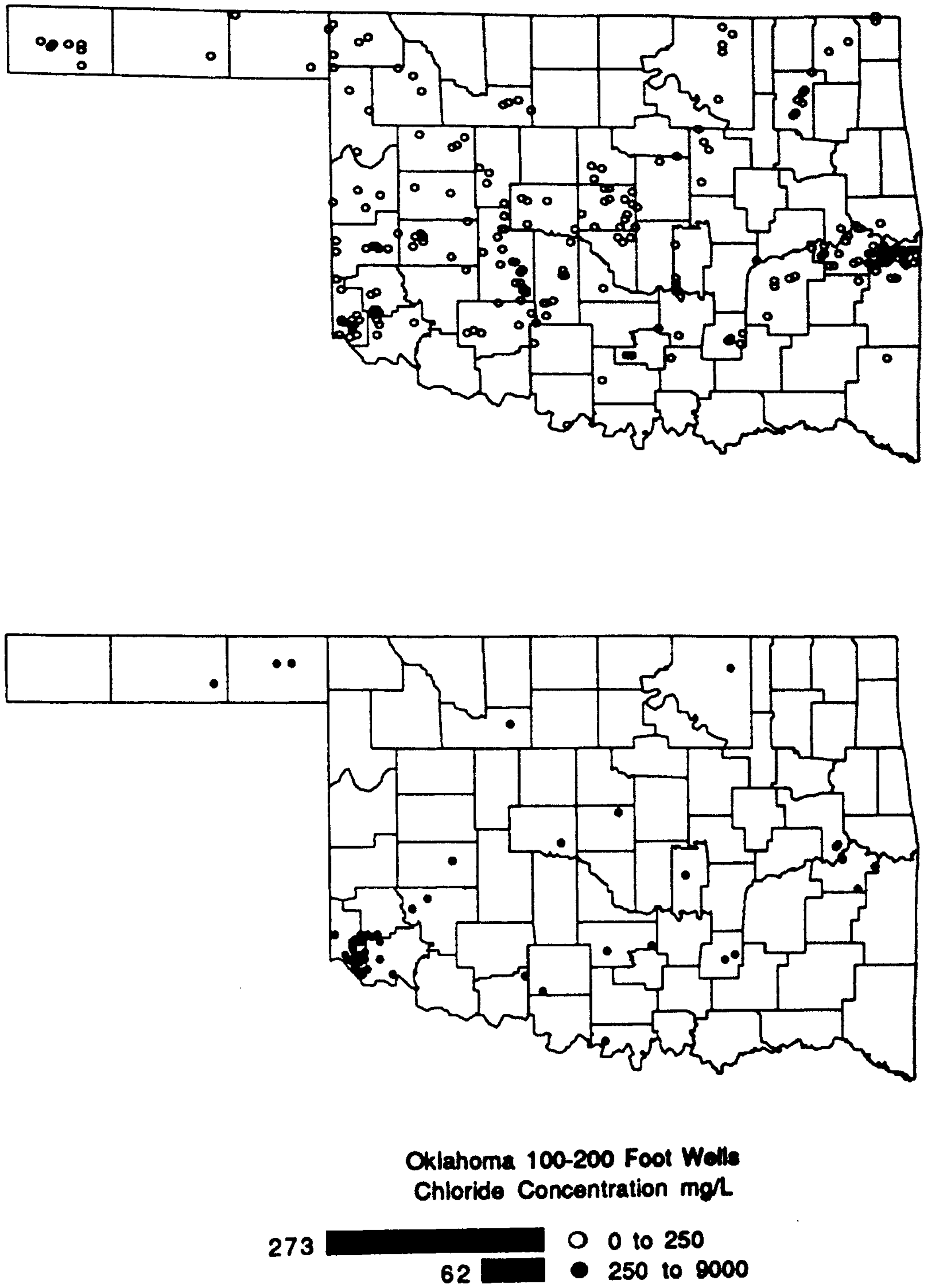



Figure 138. Oklahoma 100-200 Foot Interval Chloride Map

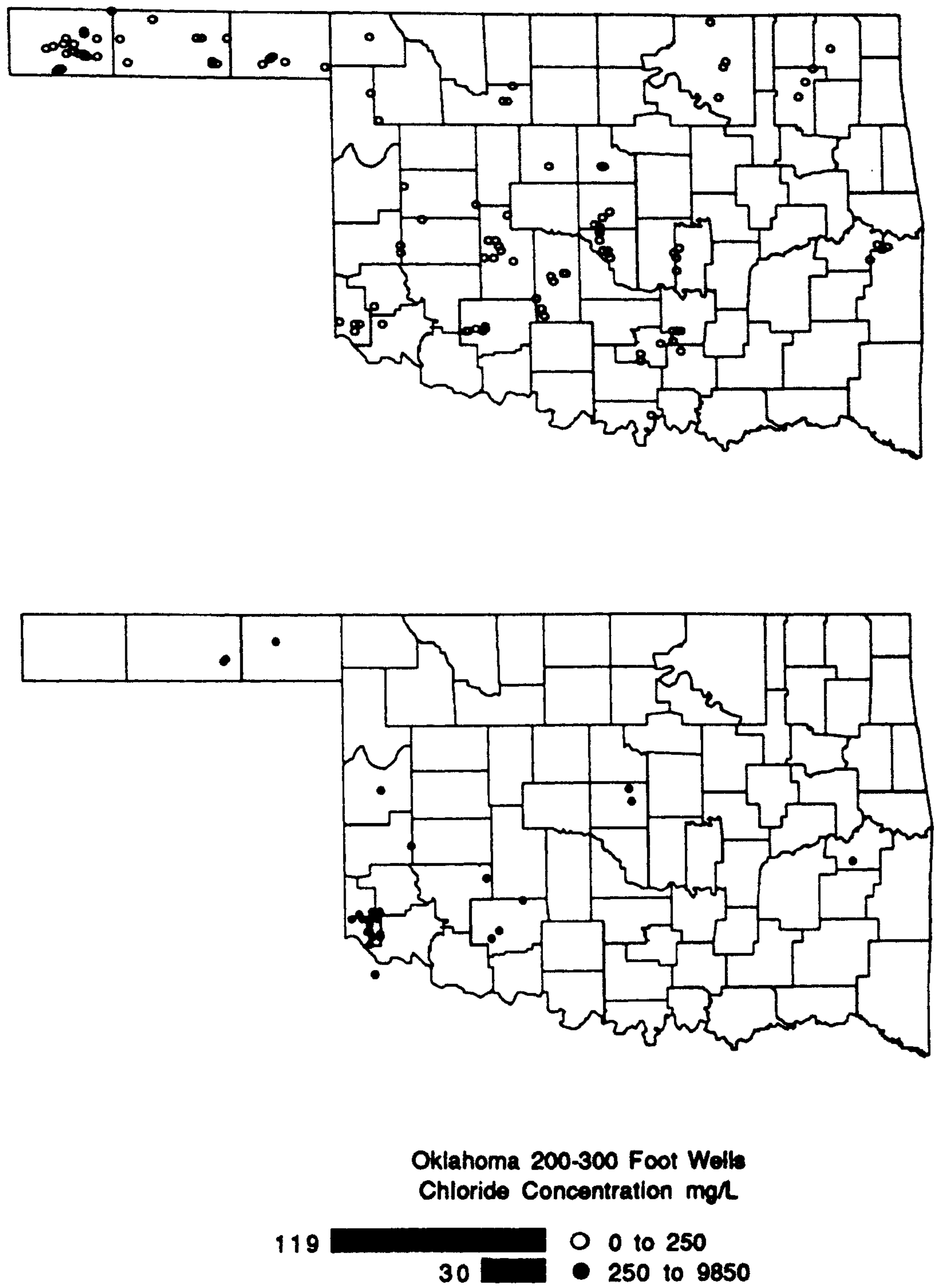



Figure 139. Oklahoma 200-300 Foot Interval Chloride Map

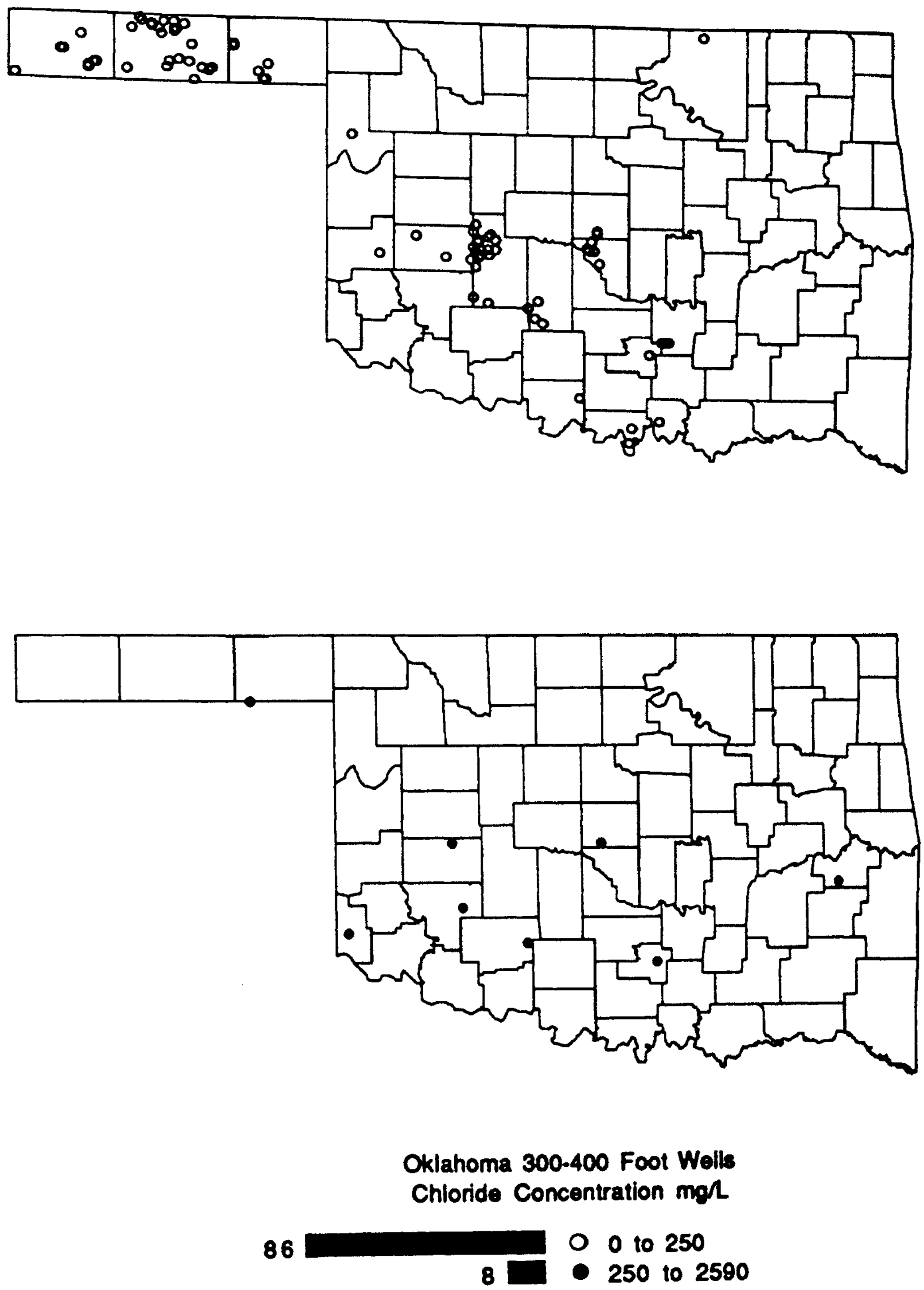



Figure 140. Oklahoma 300-400 Foot Interval Chloride Map

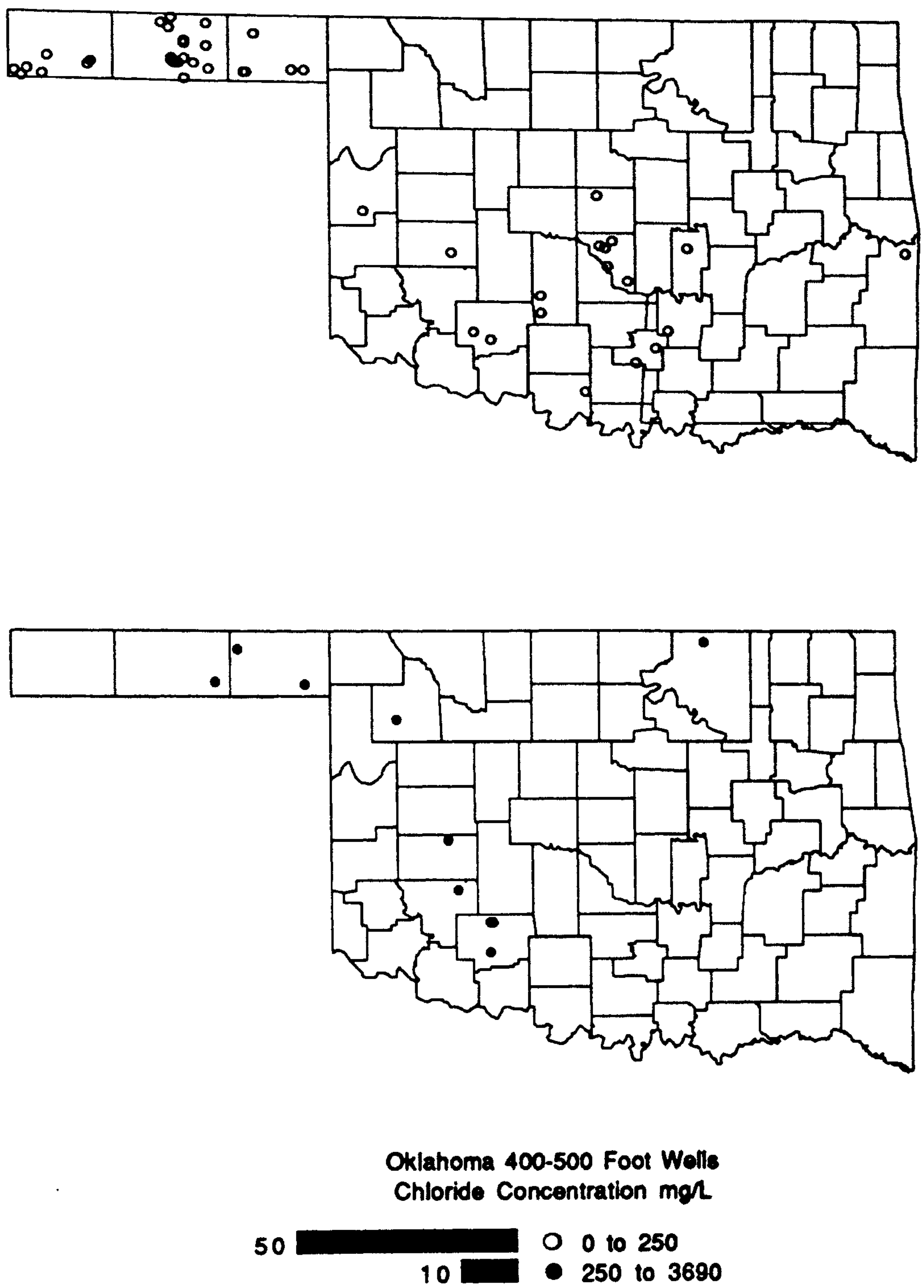



Figure 141. Oklahoma 400-500 Foot Interval Chloride Map

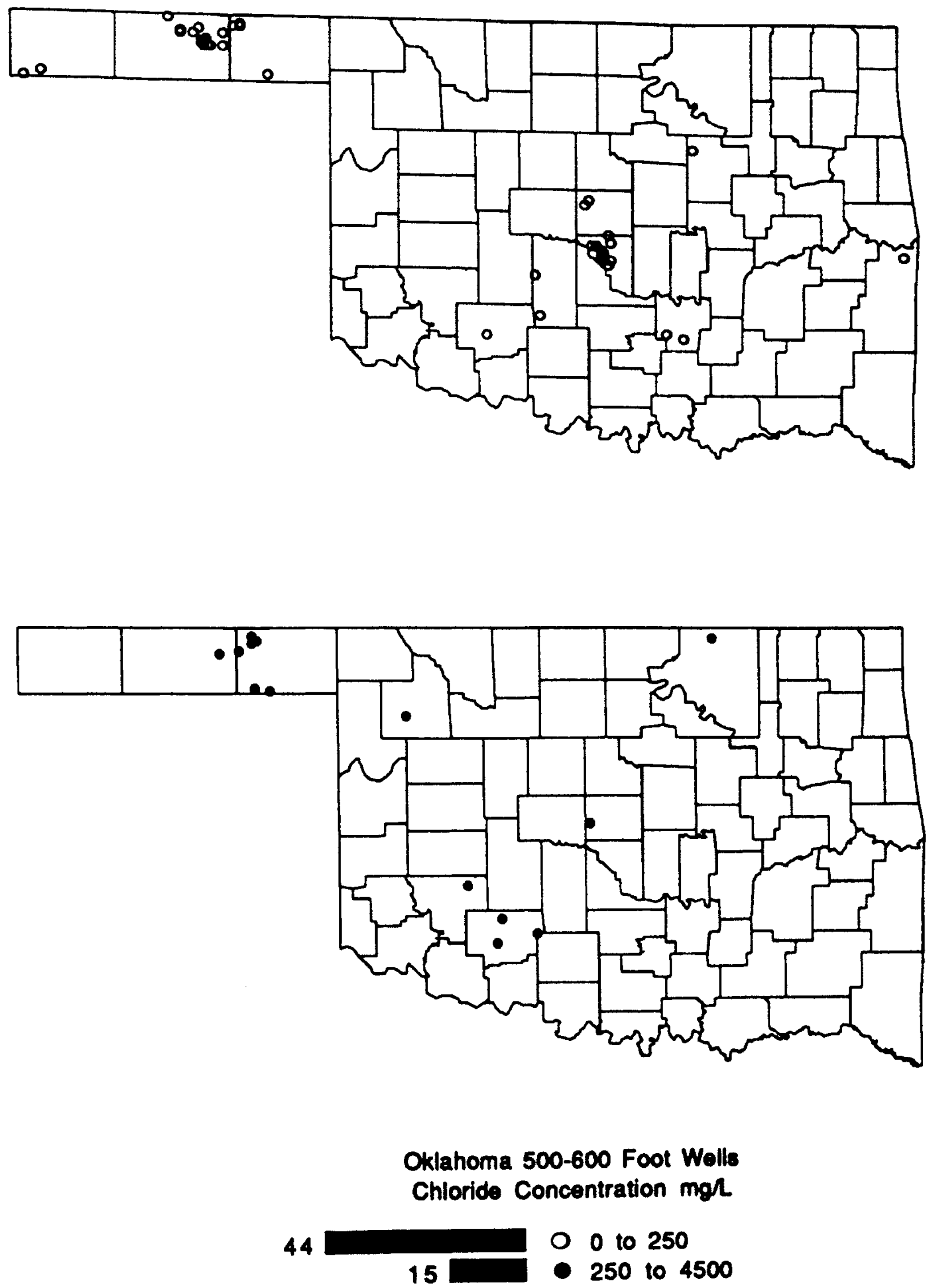



Figure 142. Oklahoma 500-600 Foot Interval Chloride Map

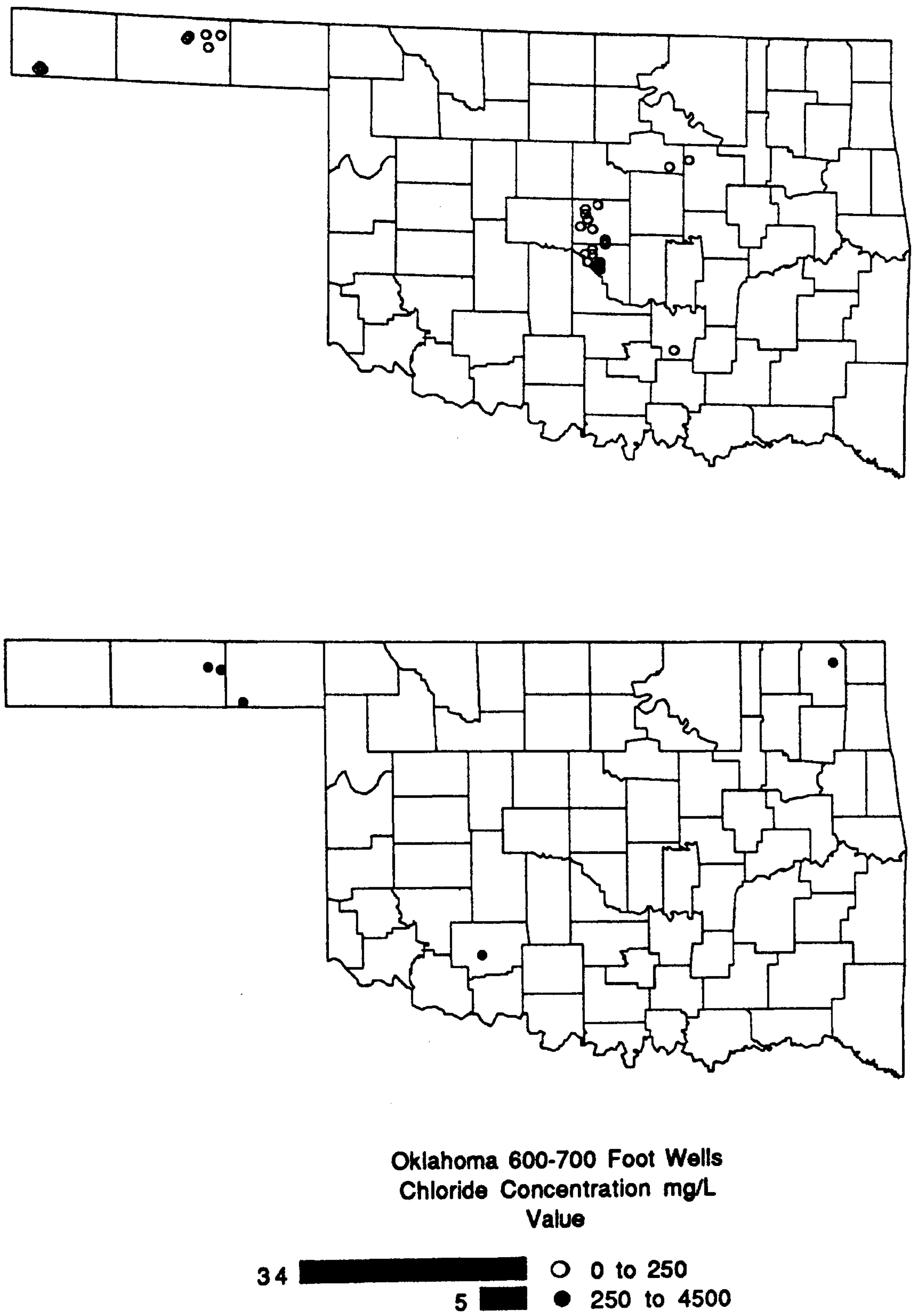



Figure 143. Oklahoma 600-700 Foot Interval Chloride Map

# TEXAS

## General Setting

Texas contains approximately 266,800 square miles and lies in four physiographic provinces. These provinces include the low hills and dissected plains of the Coastal Plain, Central lowland, and Great Plains. The mountainous southwest corner of the State lies within the Basin and Range province. Most of Texas is underlain by gently dipping carbonate and clastic sedimentary rocks of Paleozoic age. These units outcrop throughout the central and north central part of the state. Folded and faulted Paleozoic age rocks, which are intruded and locally overlain by Tertiary age igneous rocks, crop out in the southwest corner of Texas. Exposures of Precambrian age igneous and metamorphic rocks occur within the structural dome and topographic basin of the Llano Uplift of central Texas. Mesozoic age carbonate and clastic rocks, which unconformably overlie the Paleozoic section, are exposed across south central and northeastern Texas. Semiconsolidated, clastic sediments of the Tertiary age Ogallala formation mantle Paleozoic rocks in northwestern Texas. The Coastal Plain is underlain by an eastward thickening wedge of Cretaceous to Holocene age semiconsolidated to unconsolidated, interbedded, sand, silt, clay, gravel, and marl.

Principal Aquifers

The aquifers in Texas though diverse, can be divided into a number of geographic regions(Figures. 144 & 145) including; the Gulf Coast sands and gravels, the Gulf Coastal Carrizo-Wilcox sands, the Ogallala of the High Plains, the Trinity Group of North Central Texas, the Edwards Trinity Plateau, Edwards Balcones Fault zone, and alluvial and bolson deposits of West Texas.

The Gulf Coast aquifers are generally composed of sand and gravels which alternate with silt and clay. The coastal sand deposits include the Goliad, Lillis, Lissie, and Beaumont Formations, along with the Miocene Catahoula, Oakville, and Lagarto Formations. Because the formations of the Gulf Coast are lithologically similar they are considered to act as a single aquifer unit.

The formation designated the Carrizo-Wilcox is actually composed of two distinct units. The Middle Eocene sands of the Carrizo Formation and the more productive sands of the early Eocene Wilcox Group.

The Ogallala of the High Plains consists of interbedded layers and lenses of sand, gravels, silt, clay, and is the principal aquifer in the High Plains of Texas and surrounding states.

There are a variety of formations capable of producing useful amounts of water underlying Central, North Central, and Northeast Texas. The major formations are; the Cretaceous Trinity Sands in the northeast and north central part of the state, the late Cretaceous fine grained sand Woodbine Formation in the northeast, the Ellenberger and San Saba Limestones and Dolomite, along with the Cambrian Hickory Sand Formations of Central Texas, and the Quaternary terrace deposits of the Seymor Formation in North Central Texas.

The Edwards and associated limestones comprise two distinct ground water reservoirs systems in the southwest and south central part of the state, the unconfined system of the Edwards Plateau and the confined system of the Balconies Fault zone.

Quaternary Alluvium deposits consisting of interconnected beds of sand and gravel form the principal ground water aquifers in West Texas. Many of these deposits represent valley fill in the Basin and Range and, locally represent remains of once vast alluvial plain and stream deposits (Scalf, and others, 1977).

## Chloride Distribution

Chloride maps for Texas were constructed using 8191 stations distributed over 29 depth intervals(Table 22). Even with this large number of stations approximately half of the counties in Texas were not reported in the WATSTORE data base. The percentage of wells that exceed 250 mg/L standard varies from a low of five percent at the 2400-2500 foot interval, to a high of 39 percent at the 800-900 foot interval(Table 23, Fig. 147). Regionally 20 percent (1629) of the reported stations have chloride concentrations greater than 250 mg/L. The Data available for Texas is limited ,for the most part, to the eastern and southern part of the state and the Gulf Coast region and therefore stations with elevated chlorides are associated with the Gulf Coast Aquifer system the Carrizo-Wilcox, and the Trinity. There does appear to be a geographic correlation between elevated chloride levels and areas of known oil-production and processing.

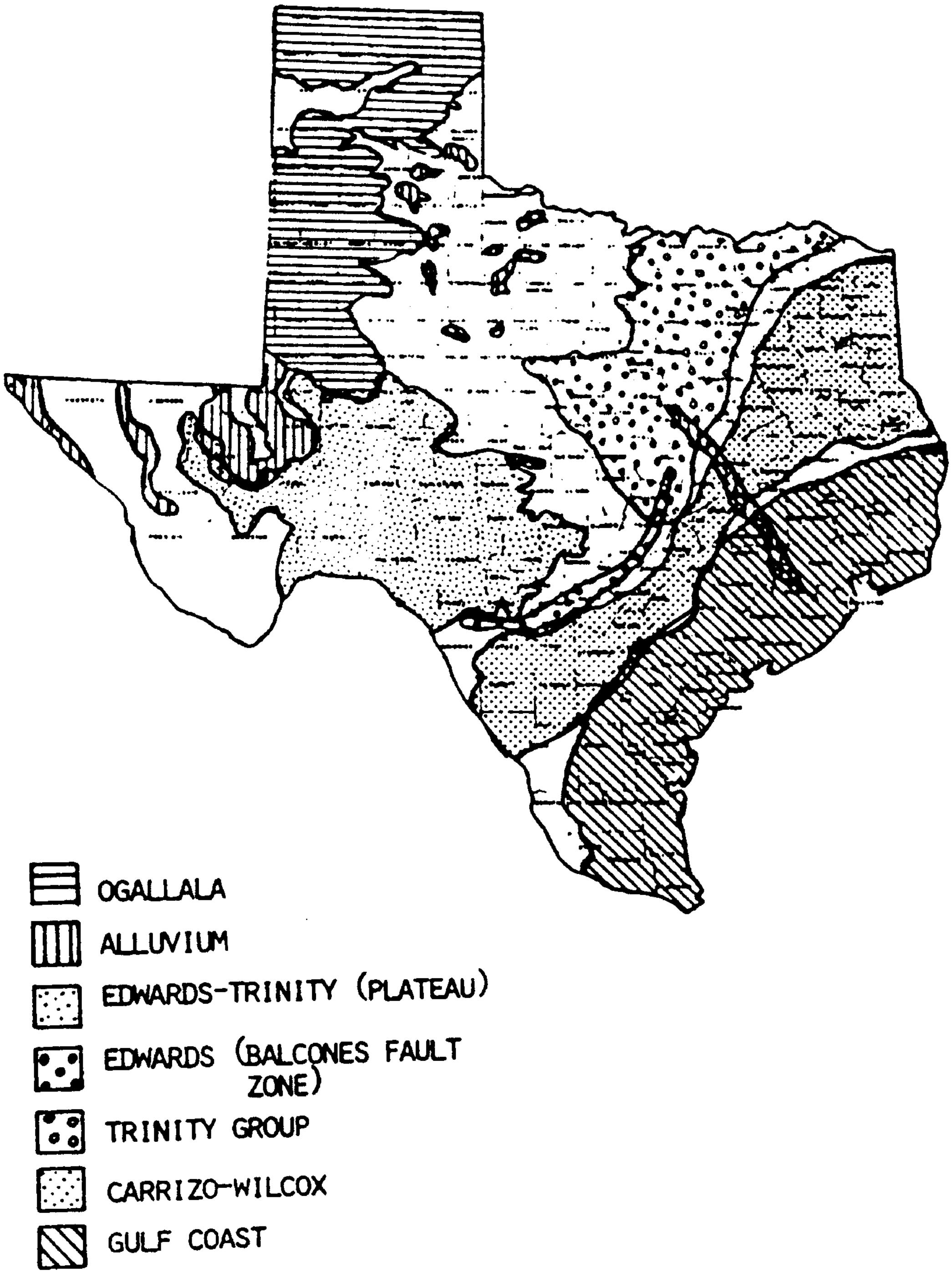



Figure 144. Texas Principal Aquifers Map A
(Modified From Scalf, 1977)

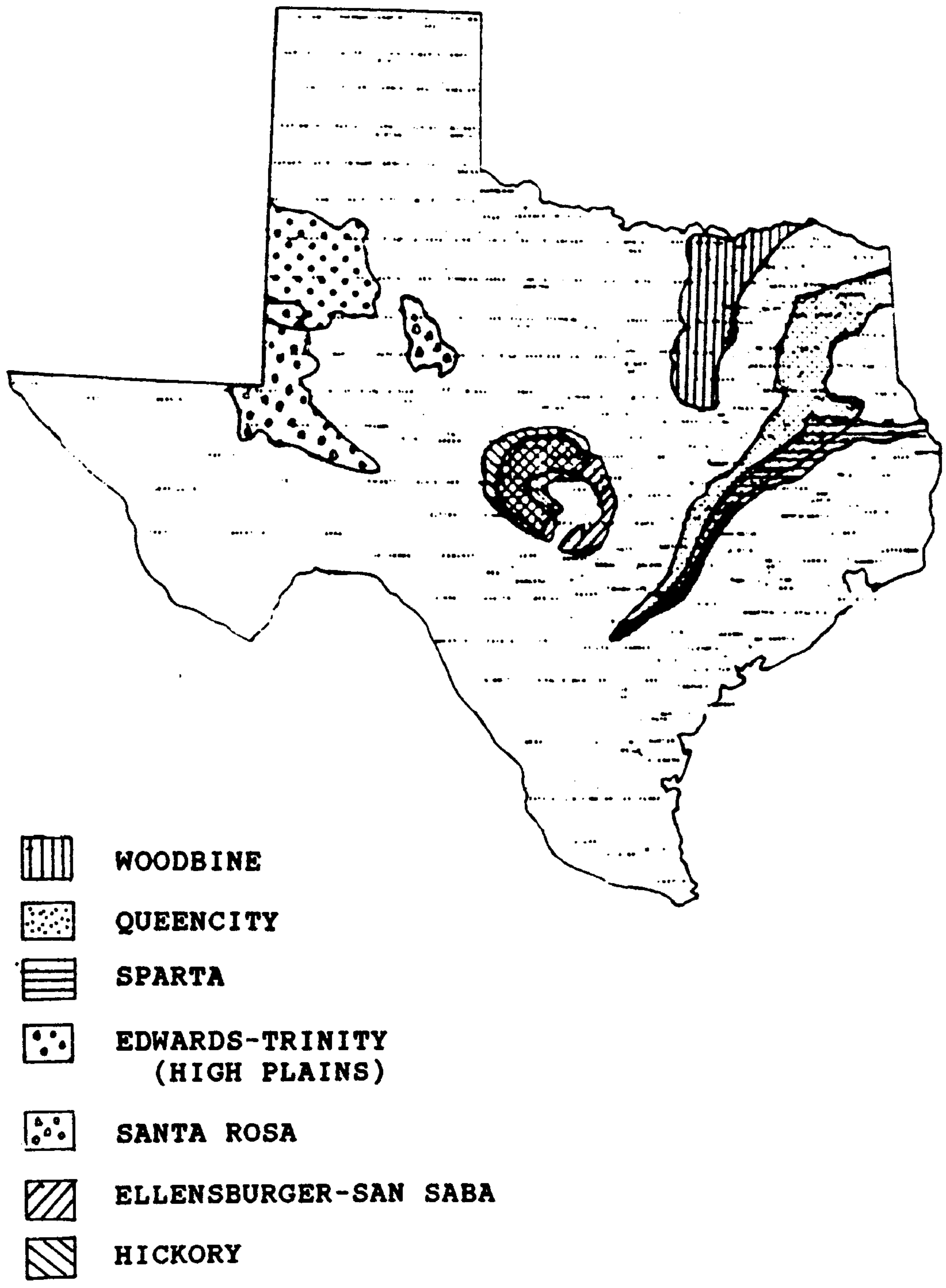



Figure 145. Texas Principal Aquifers Map B
(Modified From Scalf, 1977)

| | Concentration Interval (mg/L) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0-25 | 25-100 | 100-250 | 250-500 | >500 | total wells | wells >250 |
| Depth Interval (feet) | | | | | | | |
| 0-100 | 304 | 556 | 342 | 183 | 157 | 1542 | 340 |
| 100-200 | 509 | 182 | 348 | 51 | 73 | 1163 | 124 |
| 200-300 | 214 | 305 | 189 | 78 | 100 | 886 | 178 |
| 300-400 | 257 | 266 | 145 | 68 | 63 | 799 | 131 |
| 400-500 | 186 | 215 | 120 | 58 | 54 | 633 | 112 |
| 500-600 | 120 | 214 | 130 | 76 | 55 | 595 | 131 |
| 600-700 | 74 | 174 | 118 | 72 | 37 | 475 | 109 |
| 700-800 | 68 | 117 | 82 | 49 | 40 | 356 | 89 |
| 800-900 | 57 | 81 | 36 | 65 | 46 | 285 | 111 |
| 900-1000 | 55 | 75 | 24 | 51 | 32 | 237 | 83 |
| 1000-1100 | 42 | 76 | 14 | 19 | 24 | 175 | 43 |
| 1100-1200 | 20 | 77 | 7 | 14 | 19 | 137 | 33 |
| 1200-1300 | 23 | 60 | 6 | 8 | 11 | 108 | 19 |
| 1300-1400 | 24 | 55 | 10 | 12 | 11 | 112 | 23 |
| 1400-1500 | 24 | 48 | 6 | 8 | 8 | 94 | 16 |
| 1500-1600 | 22 | 42 | 9 | 10 | 3 | 86 | 13 |
| 1600-1700 | 35 | 32 | 7 | 10 | 3 | 87 | 13 |
| 1700-1800 | 19 | 35 | 5 | 5 | 4 | 68 | 9 |
| 1800-1900 | 13 | 24 | 8 | 3 | 3 | 51 | 6 |
| 1900-2000 | 18 | 35 | 8 | 1 | 9 | 71 | 10 |
| 2000-2100 | 14 | 28 | 5 | 1 | 5 | 53 | 6 |
| 2100-2200 | 7 | 24 | 4 | 1 | 5 | 41 | 6 |
| 2200-2300 | 4 | 14 | 2 | 3 | 2 | 25 | 5 |
| 2300-2400 | 7 | 14 | 3 | 2 | 3 | 29 | 5 |
| 2400-2500 | 5 | 11 | 3 | 1 | 0 | 20 | 1 |
| 2500-2600 | 3 | 11 | 1 | 2 | 1 | 18 | 3 |
| 2600-2700 | 1 | 2 | 1 | 3 | 1 | 8 | 4 |
| 2700-2800 | 5 | 8 | 1 | 2 | 0 | 16 | 2 |
| 2800-3000 | 5 | 11 | 1 | 1 | 2 | 20 | 3 |
| State Total | 2135 | 2792 | 1635 | 857 | 771 | 8190 | 1628 |
| Percent Of Wells With Concentrations Greater Than250mg/L | | | | | | | 20 |

TABLE 22. NUMBER OF STATIONS PER DEPTH AND CONCENTATION INTERVAL IN TEXAS

| | Concentration Interval (mg/L) | | | | | |
|---|---|---|---|---|---|---|
| | 0-25 | 25-100 | 100-250 | 250-500 | >500 | >250 |
| Depth Interval (feet) | | | | | | |
| 0-100 | 20 | 36 | 22 | 12 | 10 | 22 |
| 100-200 | 44 | 16 | 30 | 4 | 6 | 11 |
| 200-300 | 24 | 34 | 21 | 9 | 11 | 20 |
| 300-400 | 32 | 33 | 18 | 9 | 8 | 16 |
| 400-500 | 29 | 34 | 19 | 9 | 9 | 18 |
| 500-600 | 20 | 36 | 22 | 13 | 9 | 22 |
| 600-700 | 16 | 37 | 25 | 15 | 8 | 23 |
| 700-800 | 19 | 33 | 23 | 14 | 11 | 25 |
| 800-900 | 20 | 28 | 13 | 23 | 16 | 39 |
| 900-1000 | 23 | 32 | 10 | 22 | 14 | 35 |
| 1000-1100 | 24 | 43 | 8 | 11 | 14 | 25 |
| 1100-1200 | 15 | 56 | 5 | 10 | 14 | 24 |
| 1200-1300 | 21 | 56 | 6 | 7 | 10 | 18 |
| 1300-1400 | 21 | 49 | 9 | 11 | 10 | 21 |
| 1400-1500 | 26 | 51 | 6 | 9 | 9 | 17 |
| 1500-1600 | 26 | 49 | 10 | 12 | 3 | 15 |
| 1600-1700 | 40 | 37 | 8 | 11 | 3 | 15 |
| 1700-1800 | 28 | 51 | 7 | 7 | 6 | 13 |
| 1800-1900 | 25 | 47 | 16 | 6 | 6 | 12 |
| 1900-2000 | 25 | 49 | 11 | 1 | 13 | 14 |
| 2000-2100 | 26 | 53 | 9 | 2 | 9 | 11 |
| 2100-2200 | 17 | 59 | 10 | 2 | 12 | 15 |
| 2200-2300 | 16 | 56 | 8 | 12 | 8 | 20 |
| 2300-2400 | 24 | 48 | 10 | 7 | 10 | 17 |
| 2400-2500 | 25 | 55 | 15 | 5 | 0 | 5 |
| 2500-2600 | 17 | 61 | 6 | 11 | 6 | 17 |
| 2600-2700 | 13 | 25 | 13 | 38 | 13 | 50 |
| 2700-2800 | 31 | 50 | 6 | 13 | 0 | 13 |
| 2800-3000 | 25 | 55 | 5 | 5 | 10 | 15 |

TABLE 23. PERCENT OF STATIONS PER DEPTH AND CONCENTRATION INTERVAL IN TEXAS

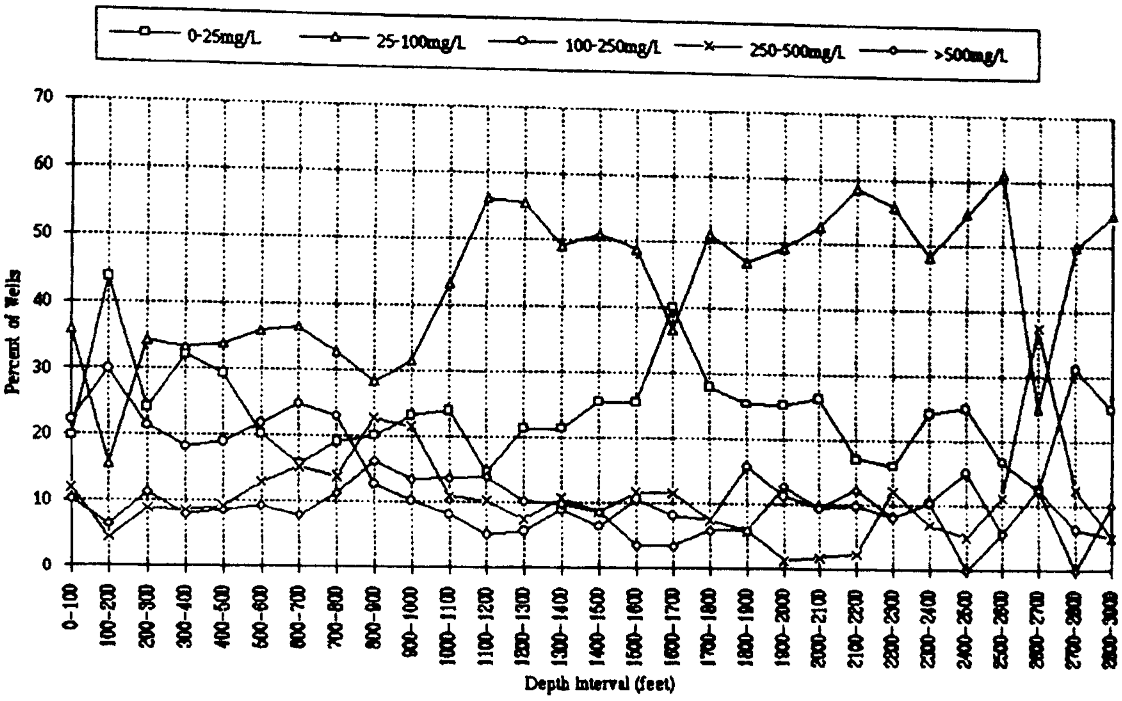



**Figure 146. Texas Percent Of Wells Per Concentation Interval vs Well Depth**

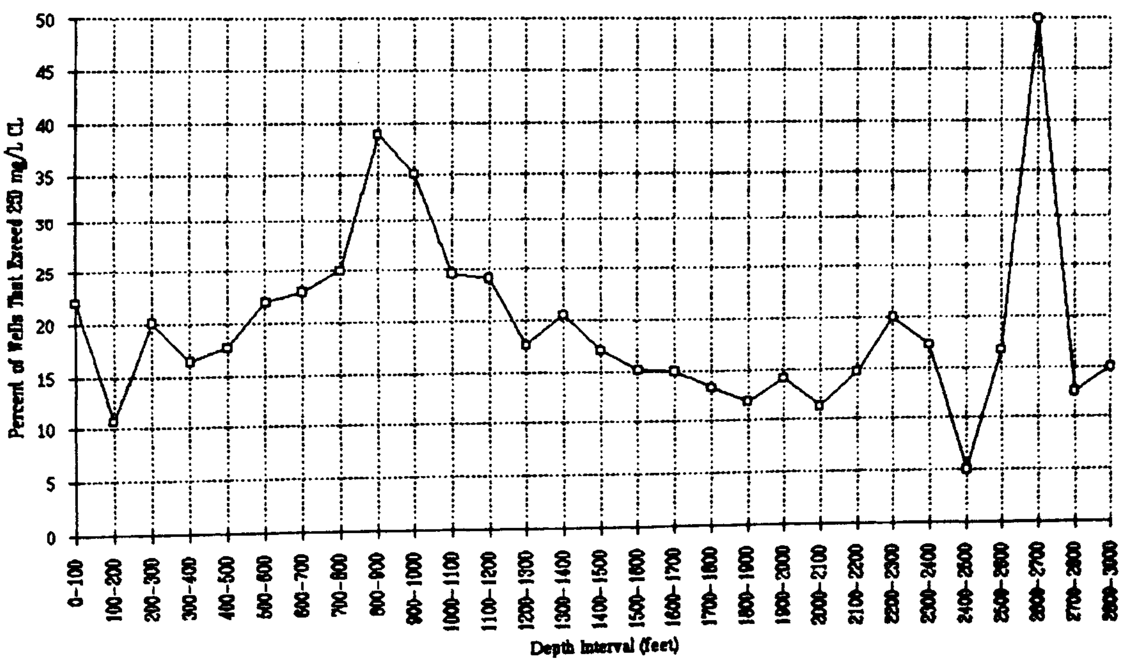



**Figure 147. Texas Percent Of Wells That Exceed 250 mg/L Chloride**

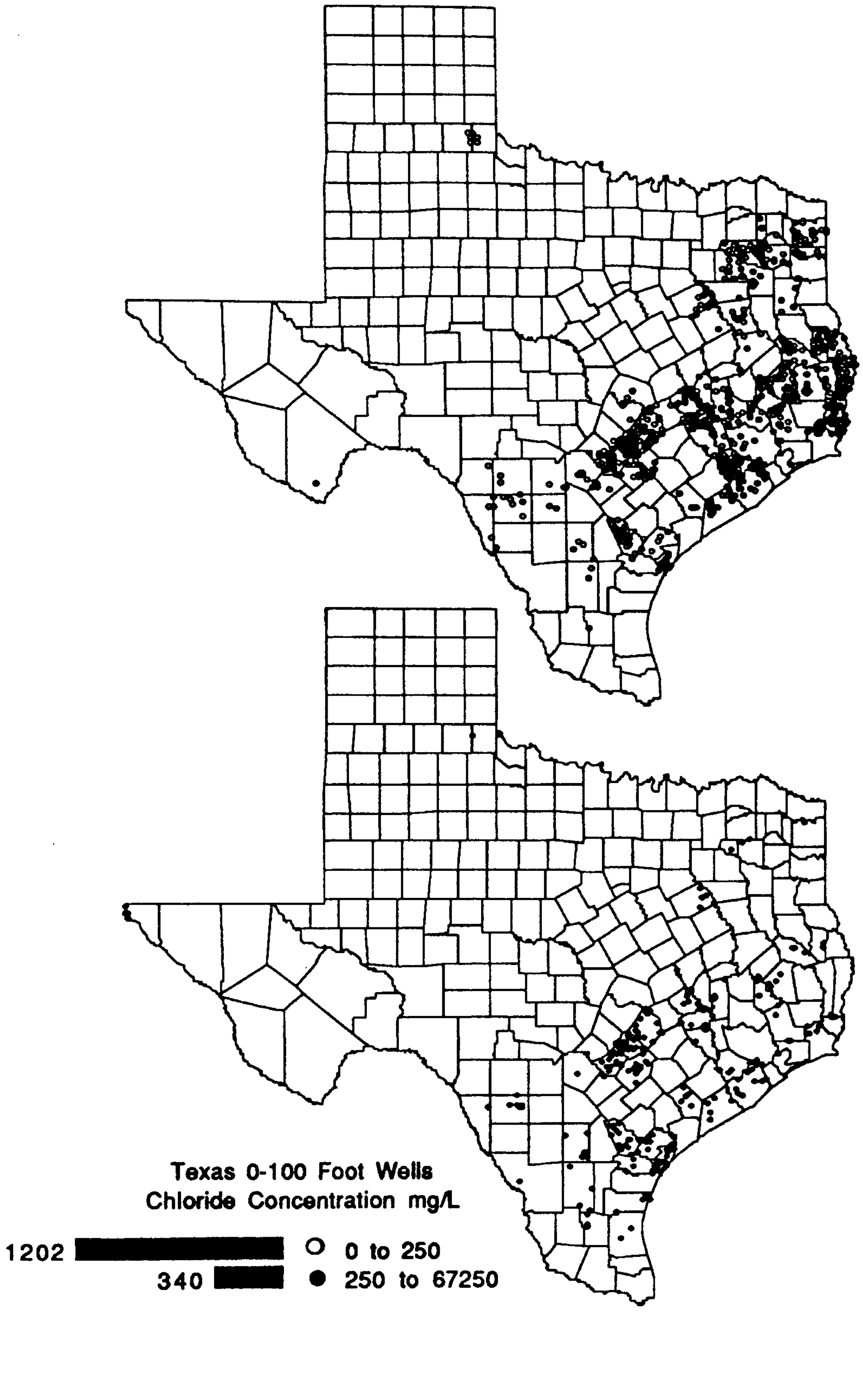



Figure 148. Texas 0-100 Foot Interval Chloride Map

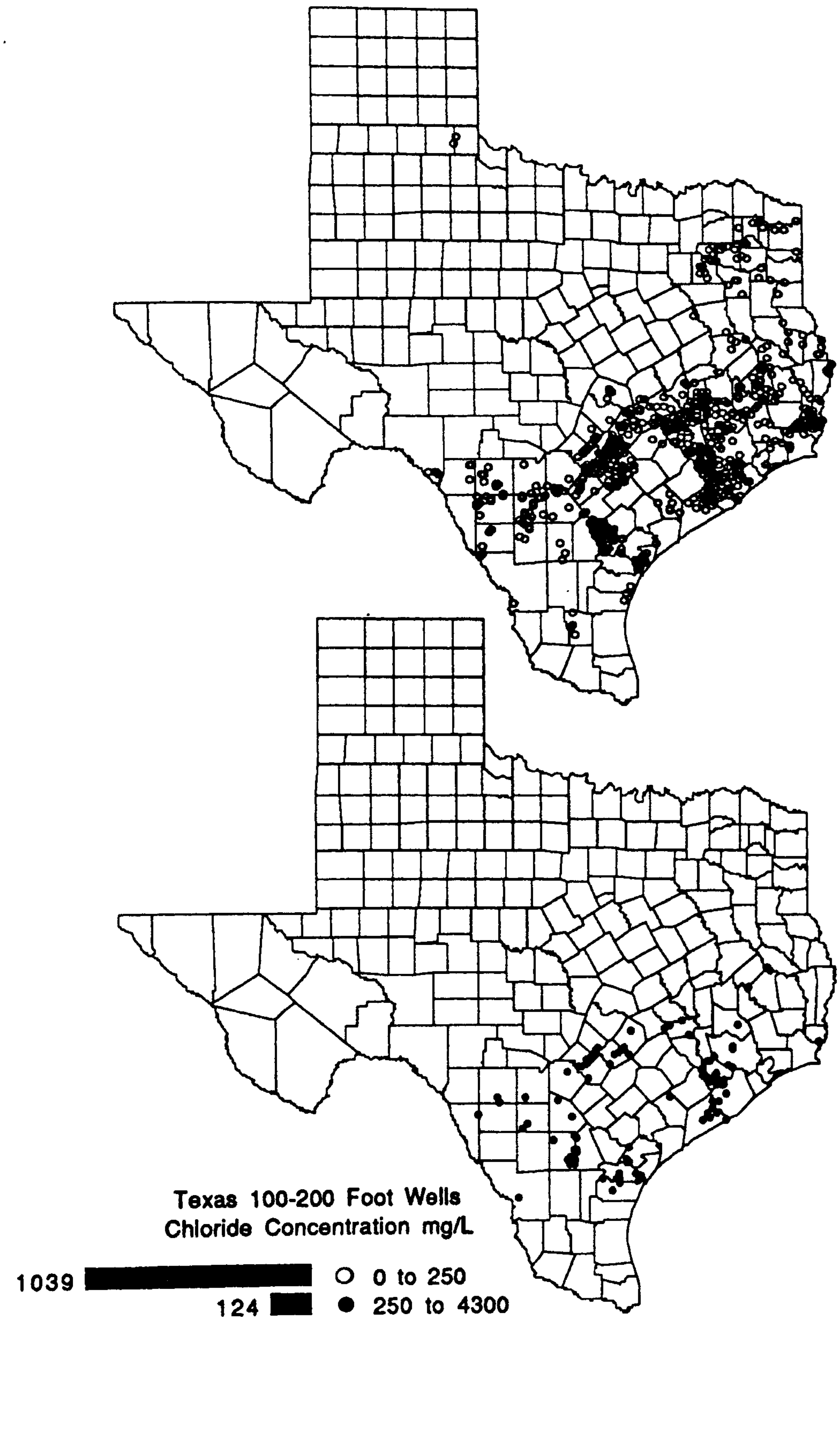



Figure 149. Texas 100-200 Foot Interval Chloride Map

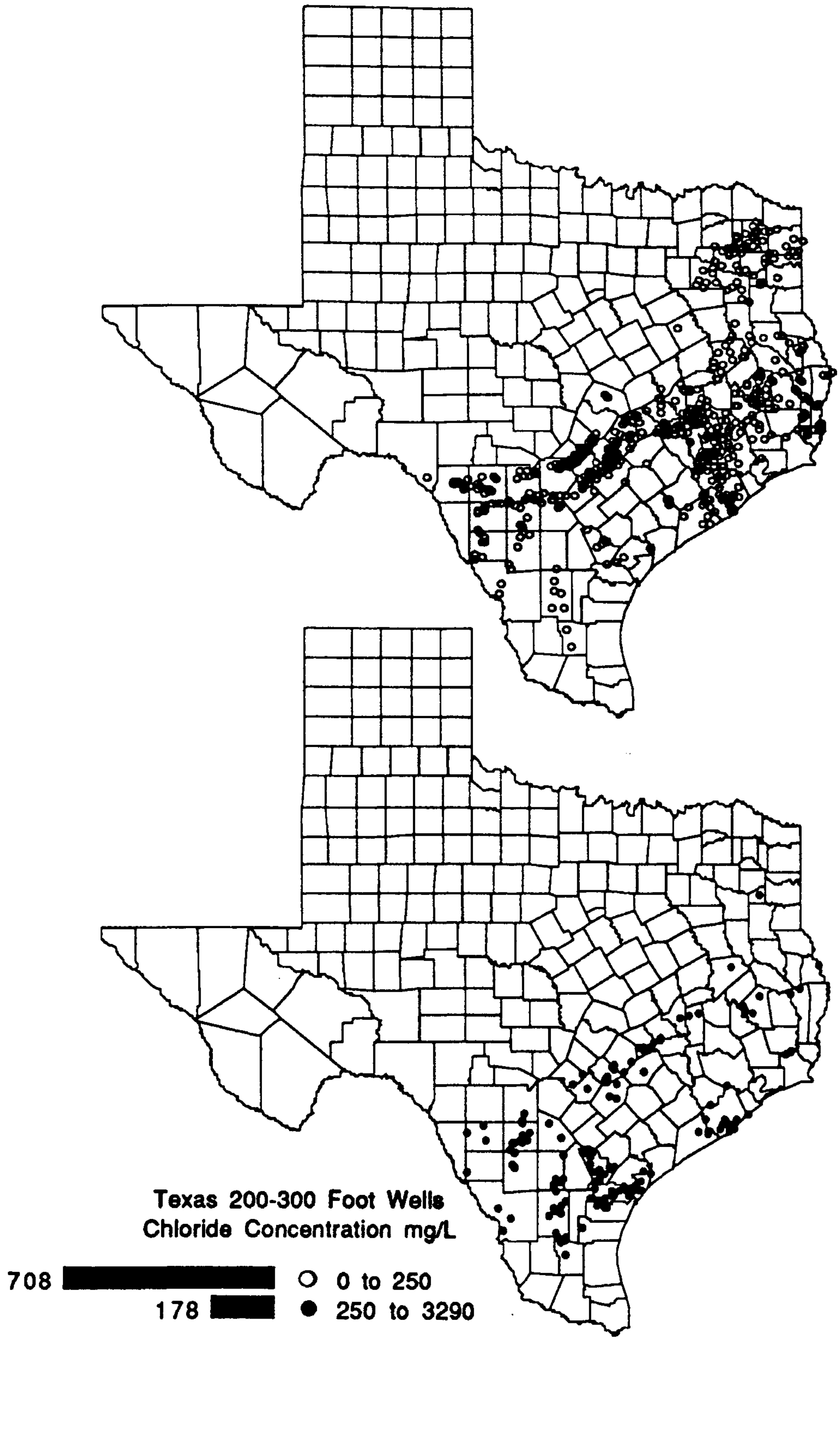



Figure 150. Texas 200-300 Foot Interval Chloride Map

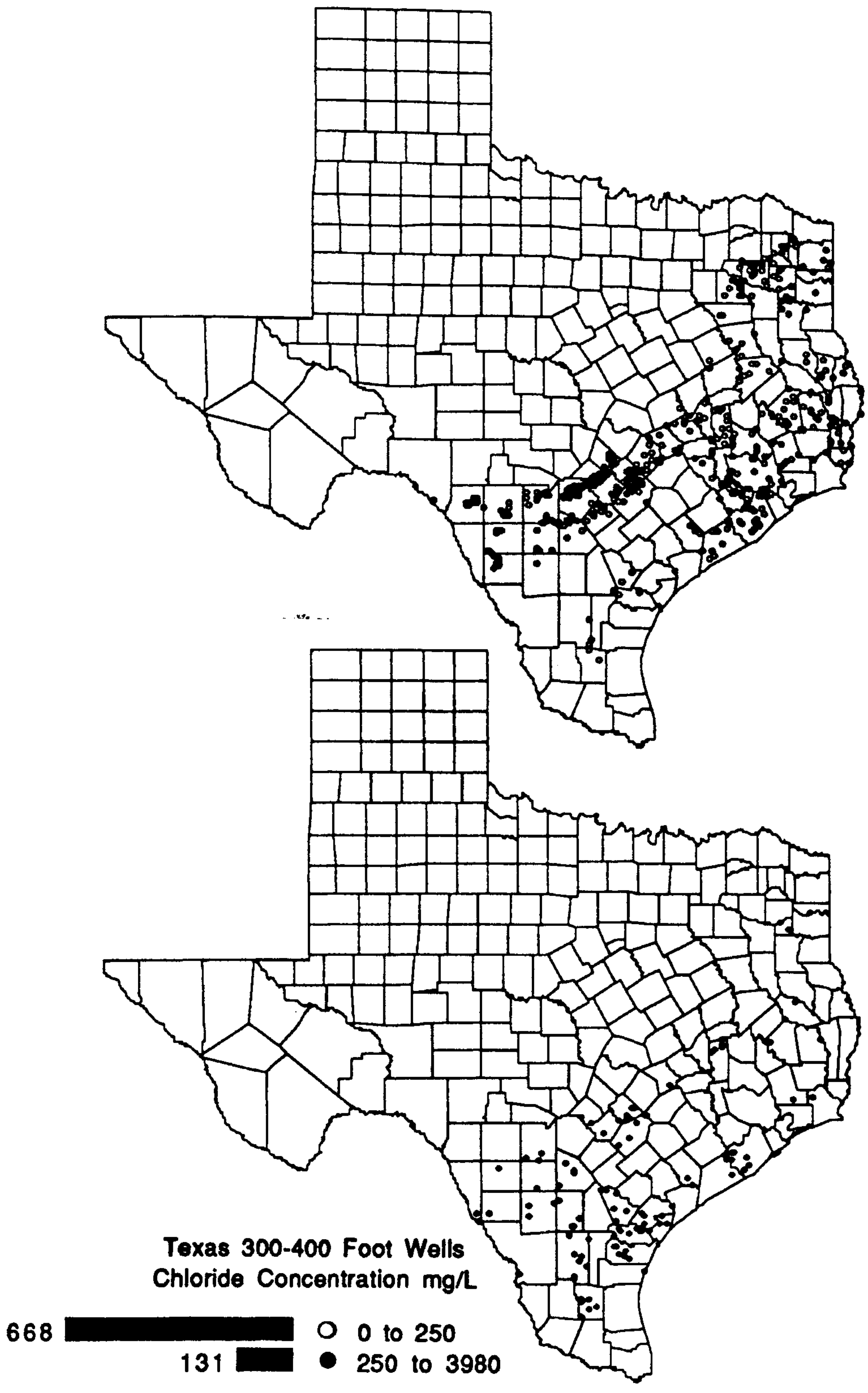



Figure 151. Texas 300-400 Foot Interval Chloride Map

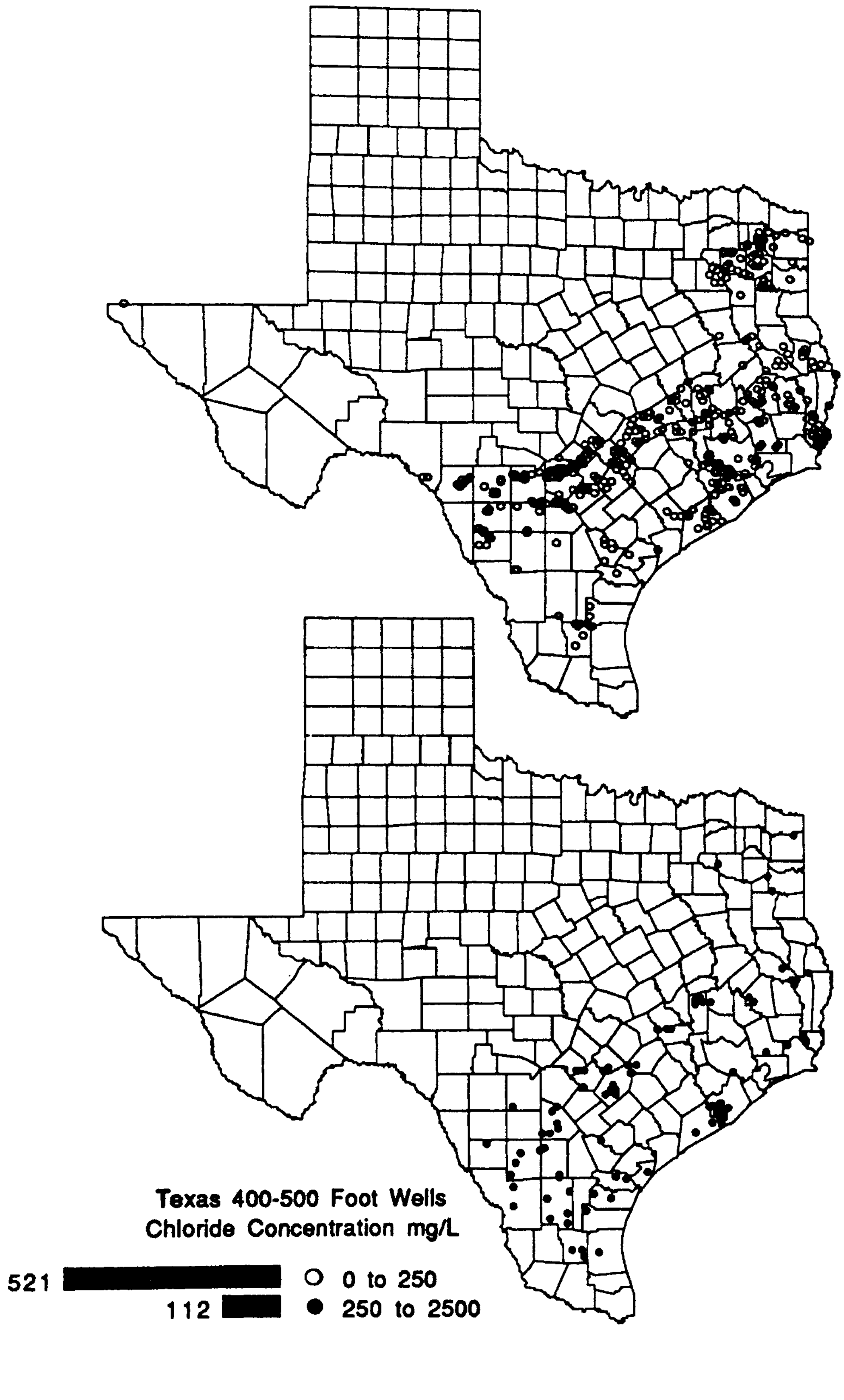



Figure 152. Texas 400-500 Foot Interval Chloride Map

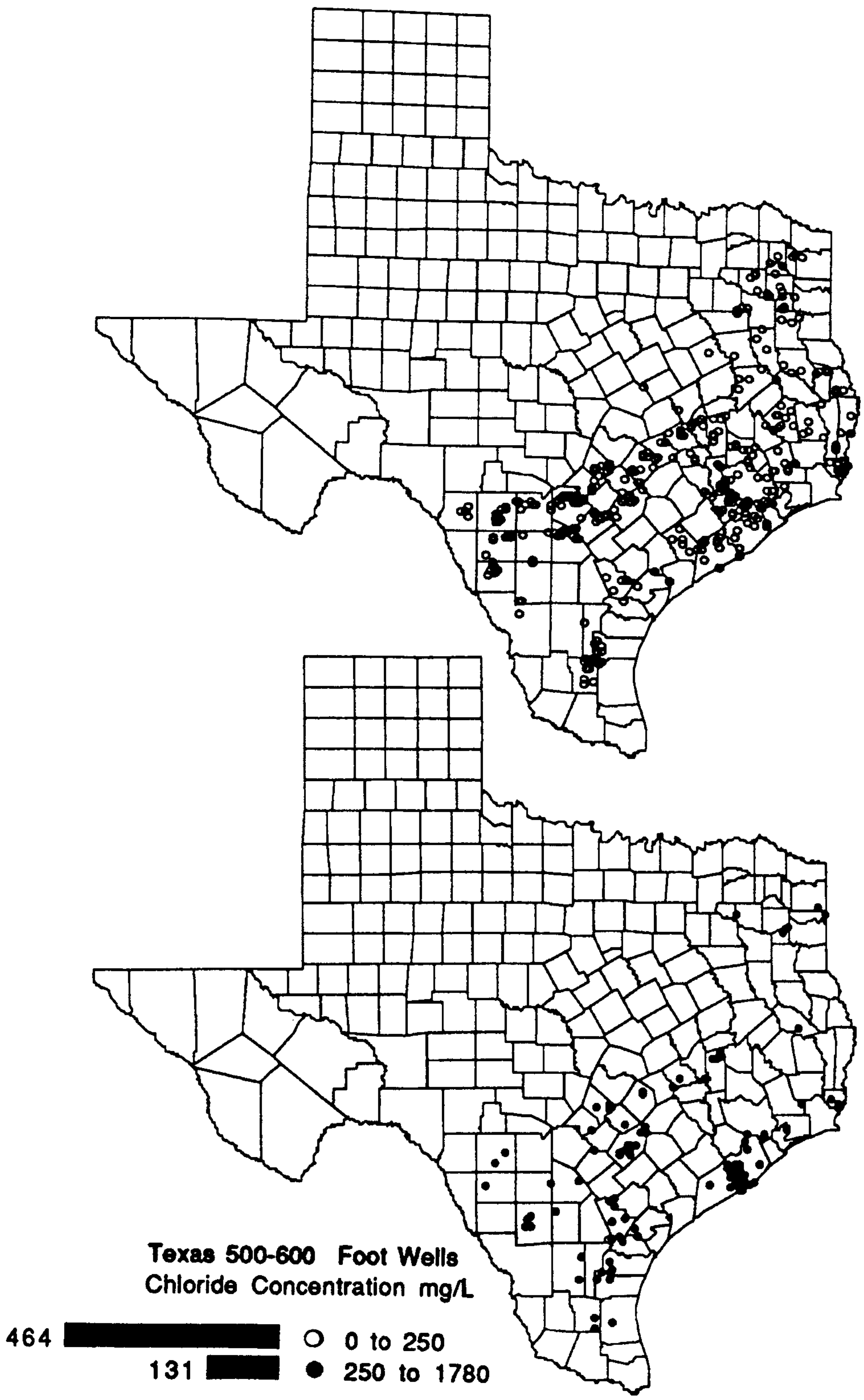



Figure 153. Texas 500-600 Foot Interval Chloride Map

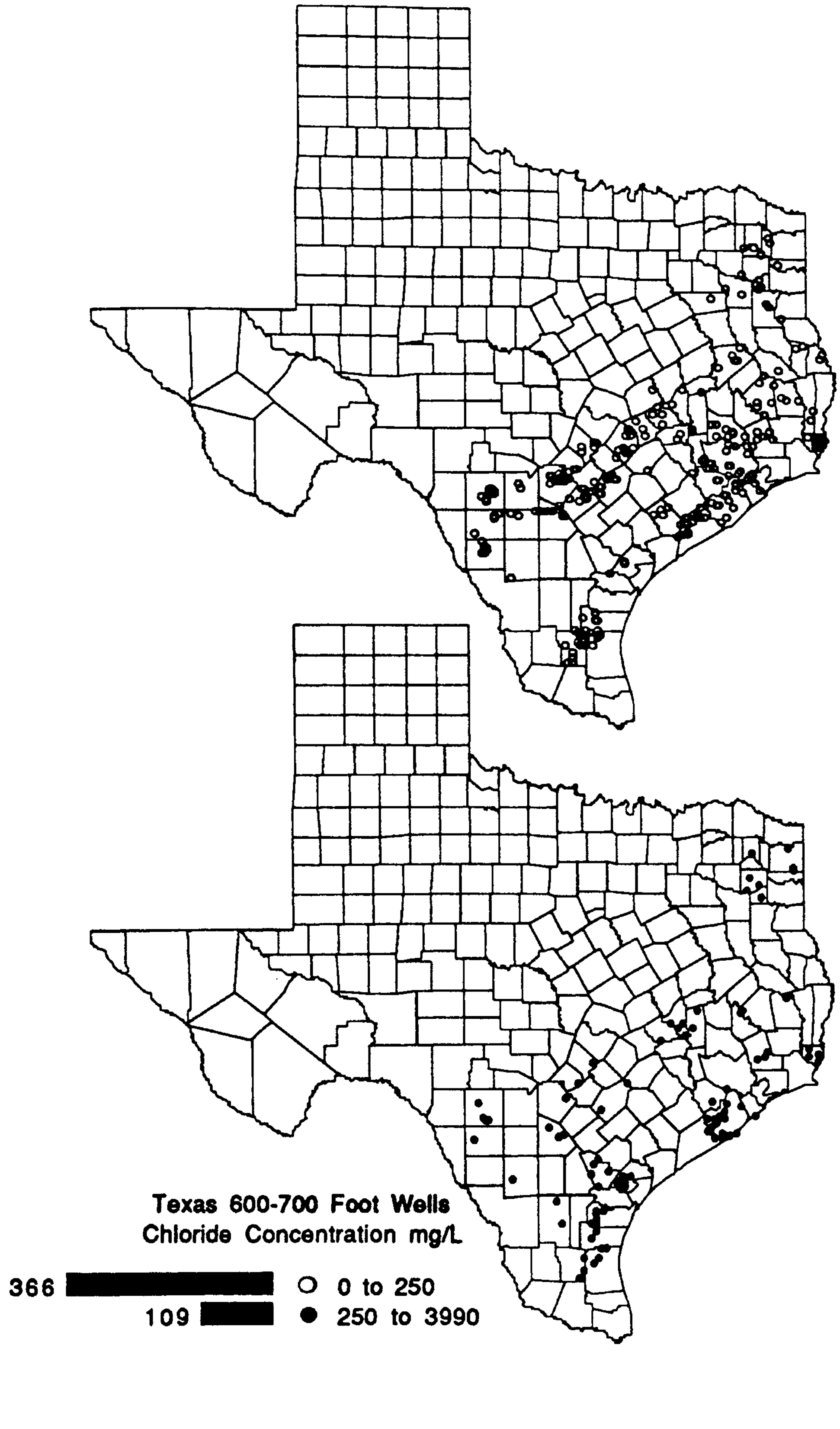



Figure 154. Texas 600-700 Foot Interval Chloride Map

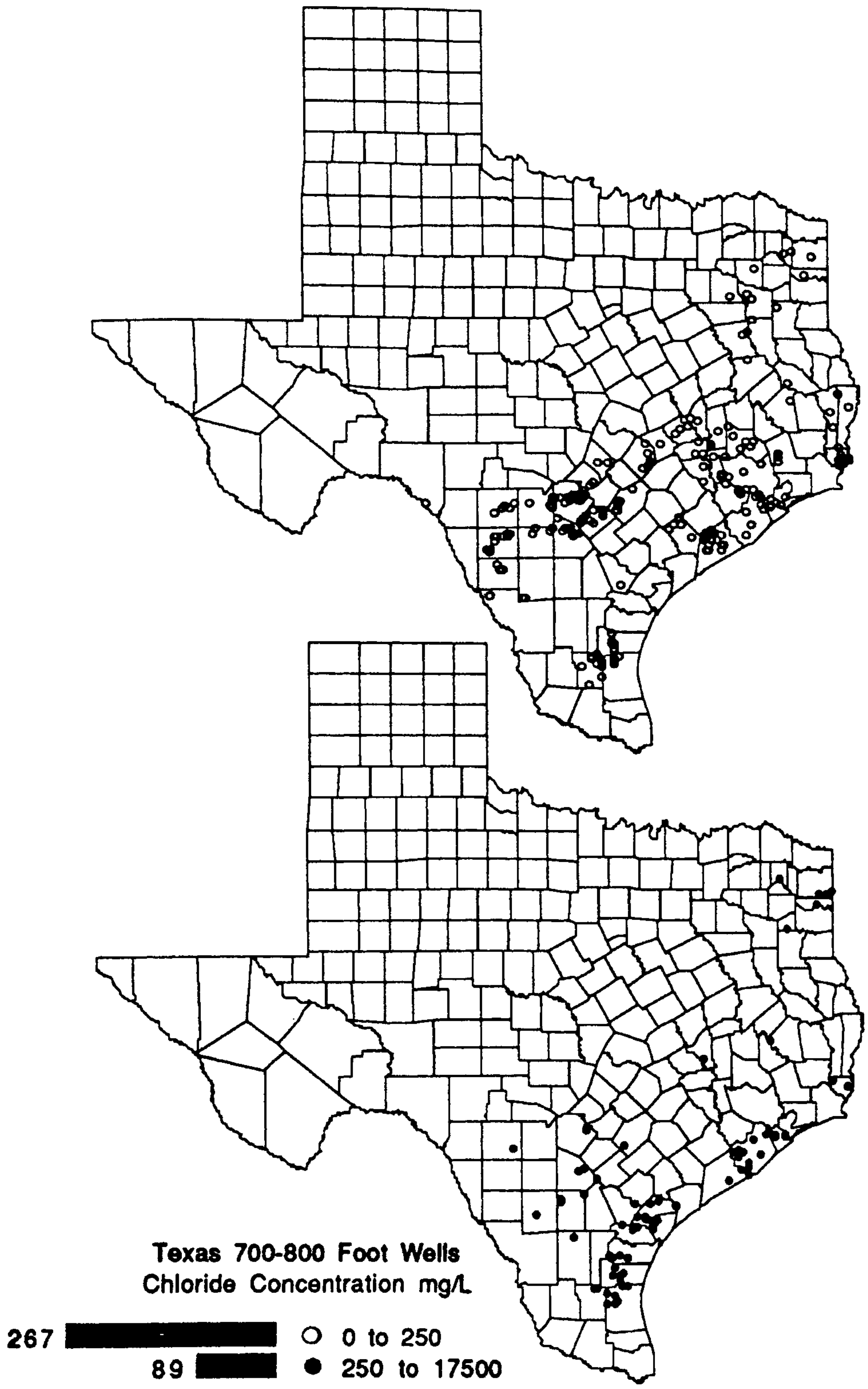



Figure 155. Texas 700-800 Foot Interval Chloride Map

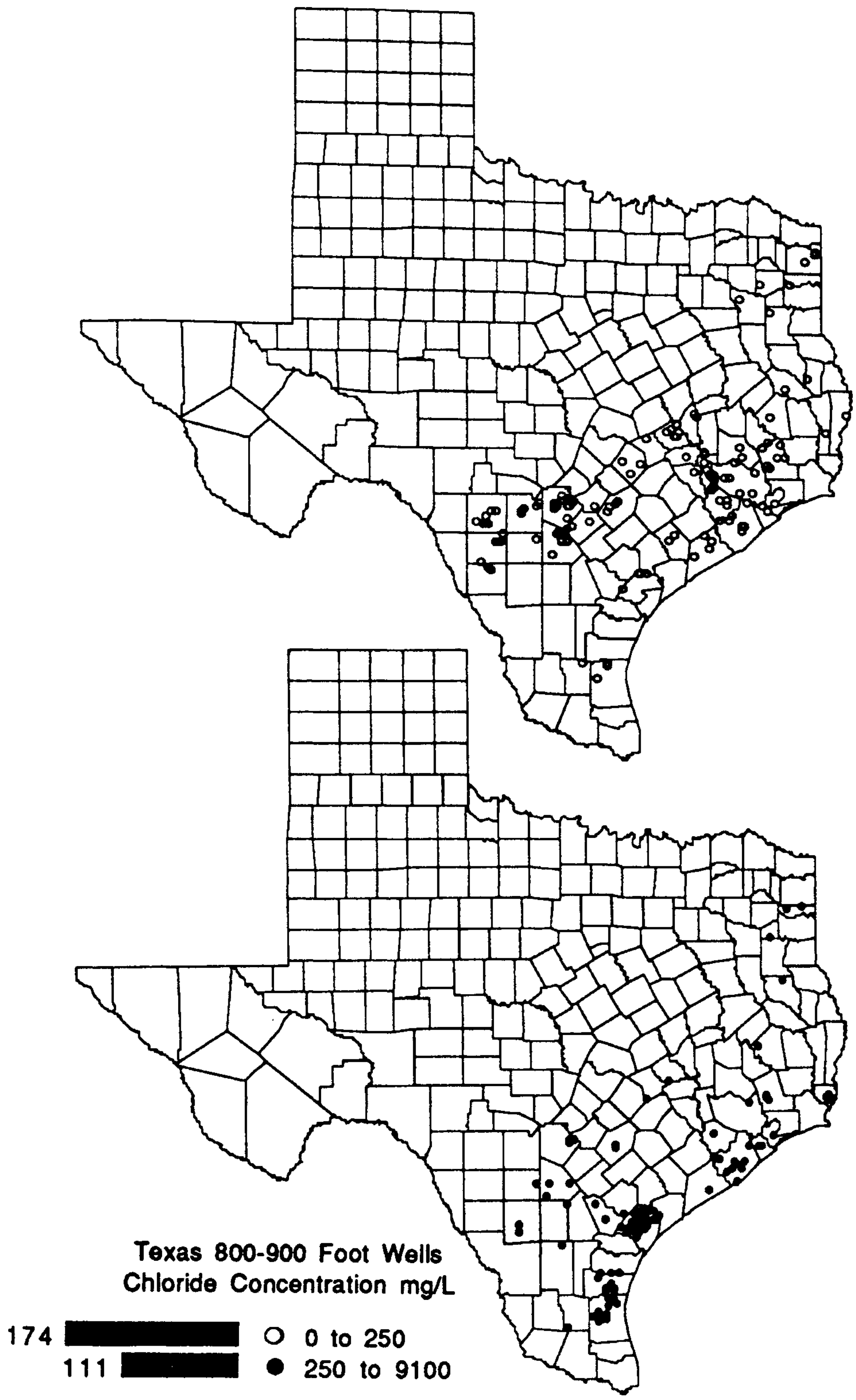



Figure 156. Texas 800-900 Foot Interval Chloride Map

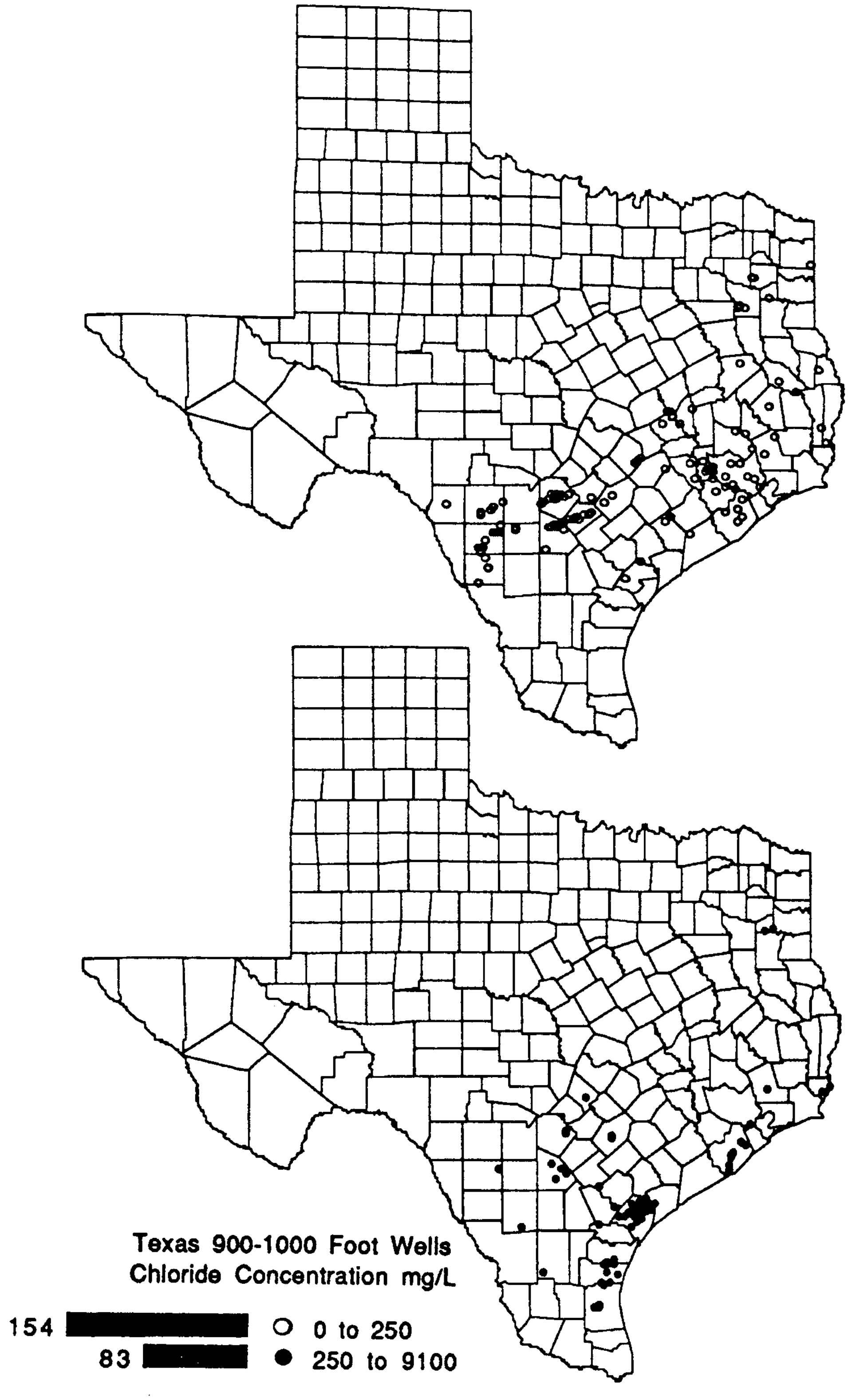



Figure 157. Texas 900-1000 Foot Interval Chloride Map

## CHAPTER IV

## SUMMARY AND CONCLUSIONS

### Summary

The purpose of this study was to examine the quality of water in the subsurface of states involved in the commercial production of crude oil. Chloride was chosen as the indicator parameter due to it's conservative mature. A series of chloride maps were produced at 100 foot intervals throughout eleven Gulf Coast, Mid-Western and Western states. The data used for this investigation were obtained using the computer software package HYDRODATA QW. This system contains water quality data from the United States Geological Survey's National Water Data Storage and Retrieval System (WATSTORE). The data were accessed from a series of compact disks (CD ROM). Once the data were accessed with HYDRODATA QW, it was further processed to format the parameter and latitude and longitude files. Maps for the study were produced with the aid of the computer software package ATLAS PRO. All analysis were mapped by geographic location and range of Chloride concentration in mg/L. Maps were produced in 100 foot vertical increments until data were insufficient to warrent further mapping. Data varied greatly from region to region and therefore map quality and usefulness is variable.

# CONCLUSIONS

Based upon the results of this study the following conclusions may be made:

1) The HYDRODATA QW program is a practical means of obtaining and organizing data due to the large number of data available. The system is versatile in that many different parameters can be accessed.
2) Deficiencies in the data base do exist. Anomalous data are encountered occasionally and many counties do not have data reported. The cost of the system and hardware are moderate.
3) The Chloride maps produced in this study provide a general representation of the distribution of chloride in the subsurface.
4) The Chloride maps may be useful for remediation planning or other management purposes.

## SUGGESTIONS FOR FURTHER RESEARCH

Further research could be accomplished by one concerned with the quality or change in quality of the waters of the United States by completing chloride maps for the seventeen other states involved in the commercial production of oil.

The continuation of this study with an updated data base could significantly enhance the usefulness of maps produced where data was previously lacking.

Related studies might include an examination of chloride in the subsurface over time. This could be accomplished by employing the system and process used in this study to search for stations with multiple observations and evaluate these stations through time. Smaller scale mapping and analysis of regions previously done on a larger scale could provide more specific information for management purposes.

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