STATUS OF GROUND-WATER RESOURCES AT U.S. NAVY SUPPORT FACILITY, DIEGO GARCIA: SUMMARY OF HYDROLOGIC AND CLIMATIC DATA, JANUARY 1994 THROUGH SEPTEMBER 1996

By Jill D. Torikai

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CONVERSION FACTORS AND ABBREVIATION

Multiply	By	To obtain
foot (ft)	0.3048	meter
gallon (gal)	3.785	liter
gallon per day (gal/d)	3.785	liter per day
million gallons per day (Mgal/d)	0.04381	cubic meter per second
inch (in.)	25.4	millimeter
inch per year (in/yr)	25.4	millimeter per year

Abbreviation used in water-quality descriptions
mg/L = milligrams per liter

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EXECUTIVE SUMMARY

This report describes the status of ground-water resources at U.S. Navy Support Facility, Diego Garcia. Data presented are from January 1994 through September 1996, with a focus on data from July through September 1996 (third quarter of 1996). A complete database of ground-water withdrawals and chloride-concentration records since 1985 is maintained by the U.S. Geological Survey.

1. RAINFALL--Total rainfall for the period July through September 1996 was 8.94 inches, which is 60 percent less than the mean rainfall of 22.23 inches for the period July through September. July and August are part of the annual dry season, while September is the start of the annual wet season.

2. GROUND-WATER WITHDRAWAL--Ground-water withdrawal during July through September 1996 averaged 1,038,300 gallons per day. Withdrawal for the same 3 months in 1995 averaged 888,500 gallons per day. Ground-water withdrawals have steadily increased since about April 1995.

3. CHLORIDE CONCENTRATION OF PUMPED GROUND WATER--At the end of September 1996, the chloride concentration of water from the elevated tanks at Cantonment and Air Operations were 68 and 150 milligrams per liter, respectively. The chloride concentration from all five production areas increased throughout the third quarter of 1996, and started the upward trend in about April 1995.

4. CHLORIDE CONCENTRATION OF GROUND WATER IN MONITORING WELLS--Chloride concentration of ground water in monitoring wells at Cantonment and Air Operations also increased throughout the third quarter of 1996, with the largest increases from water in the deepest monitoring wells. Chloride concentrations have not been at this level since the dry season of 1994.

5. FUEL-DIVERSION PROGRAM AT AIR OPERATIONS--A fuel-pipeline leak at Air Operations in May 1991 decreased total islandwide withdrawals by 15 percent. This lost pumping capacity is being offset by increased pumpage at Cantonment. Six wells do not contribute to the water supply because they are being used to hydraulically divert fuel migration away from water-supply wells by a program of ground-water withdrawal and injection.

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INTRODUCTION

Background

Diego Garcia Atoll is part of the British Indian Ocean Territory and the site of a U.S. Navy Support Facility. The island's drinking-water supply is derived from ground water, and recharge to the ground-water system is from rainfall. Since 1985, the island's water-supply system has produced about 1 Mgal/d by maintaining low individual pumping rates at the many scattered wells (Torikai, 1995). Ground water is pumped from lens-shaped bodies of freshwater floating on seawater. Chloride concentrations of the water have been kept at acceptable levels for drinking by adjusting individual pumping rates. The water-supply system, which has been in operation since 1978, has more than 100 active wells in five production areas (fig. 1). Water from the Cantonment and Air Operations areas combined account for about 99 percent of total islandwide pumpage. The remainder is pumped for local use at Industrial Site South (I-Site), Transmitter Site (T-Site), and GEODSS Site.

Long-term ground-water management has been facilitated by a cooperative agreement between the Navy Support Facility (NAVSUPPFAC) and the U.S. Geological Survey (USGS) since 1984. However, USGS involvement at Diego Garcia began in 1978 with hydrogeologic investigations for the Naval Facilities Engineering Command, Pacific Division. The study provided estimates of ground-water resource potential, and helped with the subsequent design, layout, and testing of the water-supply wells (D.A. Davis, USGS, 1979, written commun. to U.S. Navy).

Organization of Report

This data summary contains hydrologic and climatic data that describe the status of ground-water resources at Navy Support Facility, Diego Garcia. Data presented are from January 1994 through September 1996. Data of primary relevance to the water supply are:

1. Rainfall
2. Volume of ground water withdrawn at production wells
3. Chloride concentration of pumped ground water
4. Chloride concentration of ground water sampled from monitoring wells
5. Volume of ground water injected at Air Operations

The following narrative highlights trends in the data for July through September 1996, and makes comparisons with historical data. Ground-water withdrawal and chloride concentrations of water from individual wells are presented in the "Hydrologic-Data Section." The data section contains the following:

A. Maps of production and monitoring wells at Cantonment and Air Operations
B. Graphs of monthly mean ground-water withdrawal, January 1994 through September 1996
C. Graphs of chloride concentration of pumped water, January 1994 through September 1996

Acknowledgments

Ground-water data were provided by the NAVSUPPFAC, Public Works Department, and rainfall data were from Naval Pacific Meteorology and Oceanography Detachment Diego Garcia (NAVPACMETOC DET). Logistical support from the staff of the Public Works Department is greatly appreciated.

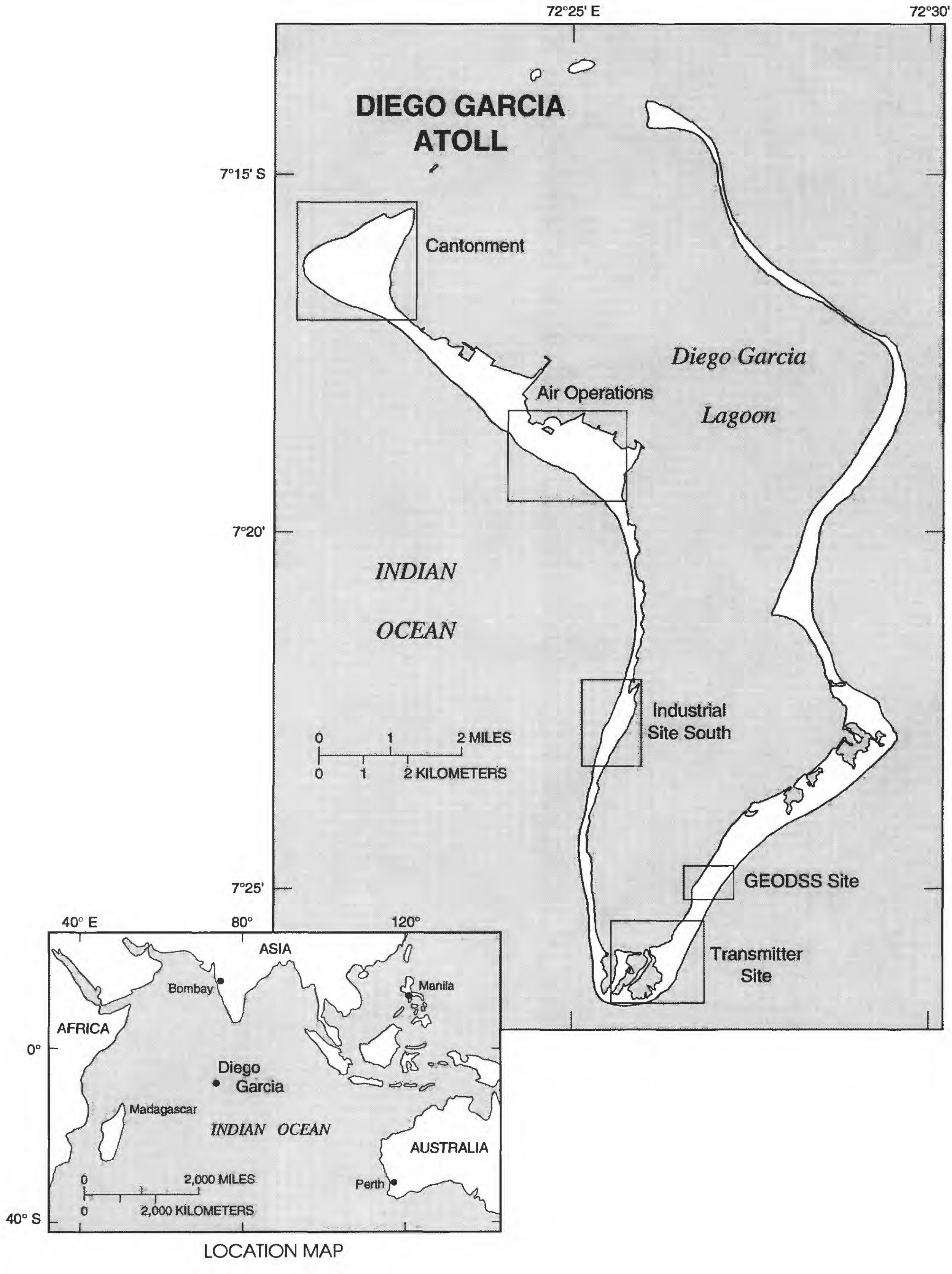


Figure 1. Areas of ground-water production, Diego Garcia.

RAINFALL

Background.--Rainfall data are available since 1951, and all mean rainfall values in this report are calculated for the fixed base period 1951-90. The mean annual rainfall at Diego Garcia is 105.78 in/yr. Rainfall varies considerably from month to month and from year to year. A wet season occurs from about September through February, and a dry season occurs from about March through August.

Recent trends.--Total rainfall for the period July through September 1996 was 8.94 inches, which is 60 percent less than the mean rainfall of 22.23 inches for the period July through September. For the same 3 months in 1994 and 1995, the rainfall was 25.93 inches and 15.13 inches, respectively. For reference, the total rainfall in 1994 was 131.17 inches, which is 24 percent above the mean annual rainfall; the total rainfall in 1995 was 111.55 inches, which is 5 percent above the mean.

Figure 2 shows graphs of recorded rainfall amounts and rainfall departures from mean monthly rainfall values that were averaged for the base period 1951-90. July and August are part of the annual dry season, while September is part of the annual wet season. Periods of below average rainfall can be inferred from the graph when the departure from the mean monthly rainfall is less than zero. Monthly rainfall for each month of the third quarter of 1996 was less than the respective mean monthly rainfall for each month of the quarter. Since April 1995, there were 12 months with negative rainfall departures, and 6 months with positive departures.

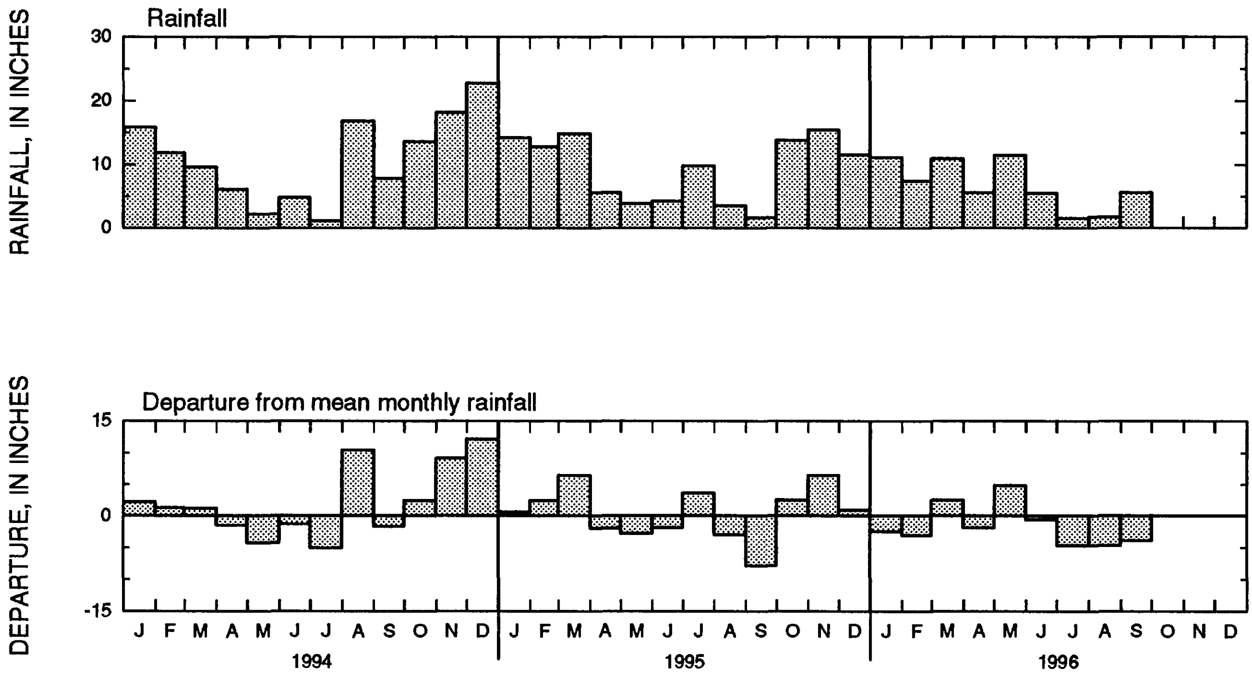


Figure 2. Monthly rainfall and monthly departure from mean monthly rainfall at Air Operations, Diego Garcia, January 1994 through September 1996.

GROUND-WATER WITHDRAWAL

Background.--Withdrawal is measured by flow meters at all production wells and storage tanks in the water system, and is recorded daily. There are 102 production wells in 5 ground-water production areas. The primary production areas are in the Cantonment area (80 wells; fig. A1) and the Air Operations area (18 wells; fig. A2). The wells in the Cantonment area are further separated into sub-groups, and the measured ground-water withdrawals are presented as such in this report. About 80 percent of total islandwide pumpage is from Cantonment, and about 19 percent is from Air Operations, with the remaining 1 percent from the other three ground-water production areas.

Pumpage from the Cantonment area increased in 1991 because of decreased pumpage at Air Operations (Torikai, 1995). From May 1991 through April 1992, 10 wells at Air Operations were temporarily shut down because of an underground fuel-pipeline leak near those wells. Pumping resumed at four wells in May 1992, but six Air Operations wells still do not contribute to the water supply because of their proximity to the fuel leak. The lost pumping capacity is about 15 percent of the total islandwide withdrawal, and is being offset by increased pumpage at Cantonment.

Recent trends.--Figure 3 shows time-series graphs of monthly mean withdrawal islandwide and in each ground-water production area from January 1994 through September 1996. Total islandwide withdrawal increased from 888,500 gal/d during July through September 1995 to 1,038,300 gal/d during July through September 1996. This increase in total withdrawal was supplied from the Cantonment area. This trend of increasing islandwide withdrawals has persisted since about April 1995.

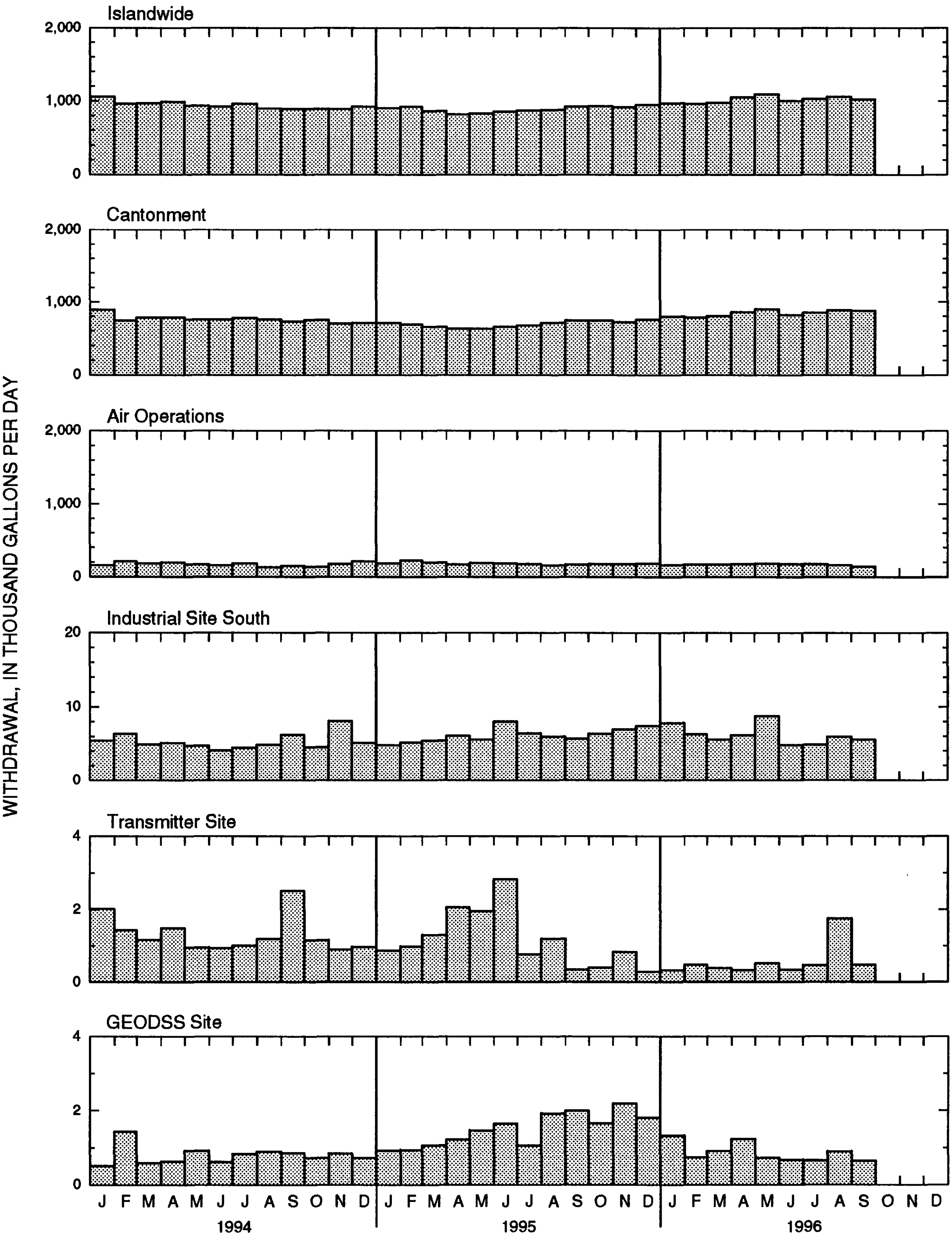


Figure 3. Monthly mean ground-water withdrawal islandwide and in the ground-water production areas, Diego Garcia, January 1994 through September 1996.

CHLORIDE CONCENTRATION OF PUMPED GROUND WATER

Background.--In this report, chloride concentration is used as a quantitative measure of salinity. Chloride concentration in seawater at Diego Garcia is about 19,500 mg/L whereas a concentration of 250 mg/L is the secondary maximum contaminant level (SMCL) under secondary drinking-water standards (U.S. Environmental Protection Agency, 1991). Secondary standards are not enforceable limits, but instead establish goals for constituents that may affect the aesthetic qualities of drinking water, such as taste or color.

Chloride concentration is analyzed daily from water samples collected from the elevated tanks at Cantonment and Air Operations, and from the tap at Industrial Site South (I-Site), Transmitter Site (T-Site), and GEODSS Site. These samples are representative of each of the five ground-water production areas. Water is also sampled at weekly intervals for chloride concentration at all individual wells and storage tanks in the water-supply system. Although daily chloride concentration data are collected at the five production areas, this report only uses the chloride concentrations from every seventh day that are extracted from the daily record.

Recent trends.--At the end of September 1996, the chloride concentration of water from the elevated tanks at Cantonment and Air Operations were 68 and 150 mg/L, respectively. This is well below the 250 mg/L secondary drinking-water standard. The Cantonment and Air Operations areas combined account for about 99 percent of all pumped water.

The chloride concentration of water increased in the five ground-water production areas during July through September 1996 (fig. 4). The increase at Cantonment was about 25 mg/L from the start of the quarter to the end of the quarter, and the increase at the other four areas was about 50 mg/L. Persistent upward trends in chloride concentration started about April 1995. The Quad wells Q1, Q2, Q4, and Q6 at Cantonment show a similar trend of increasing chloride concentration since about April 1995 (fig. C3).

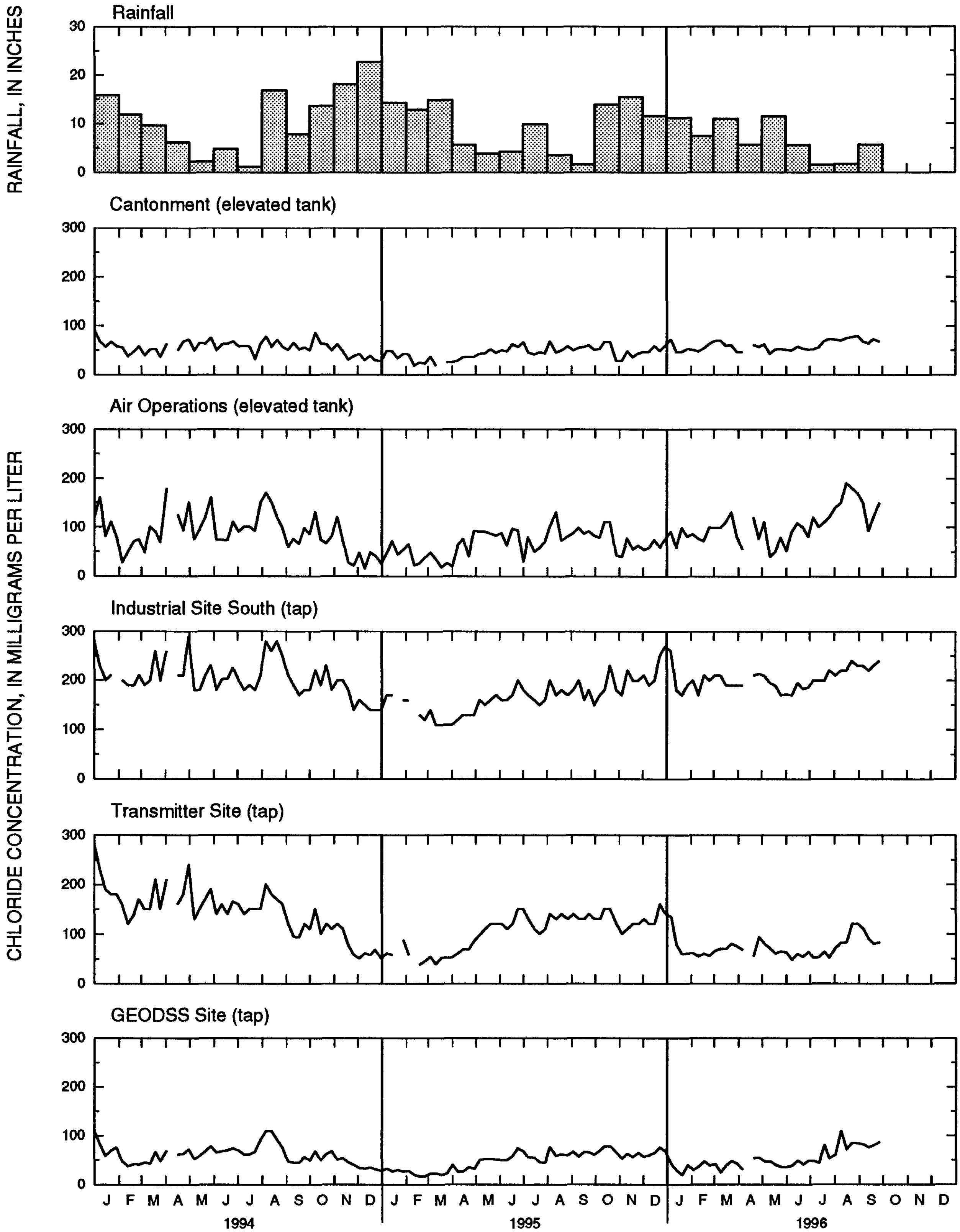


Figure 4. Chloride concentration of pumped water in the ground-water production areas, Diego Garcia, January 1994 through September 1996. Data shown are values from every seventh day extracted from the daily record. Rainfall data are shown for comparison.

CHLORIDE CONCENTRATION OF GROUND WATER IN MONITORING WELLS

Background.--Chloride concentration of ground water is measured monthly at 35 monitoring-well sites to help estimate the thickness of the freshwater lenses. Each site comprises several wells, with each well having a short screened (open) interval that bottoms at a different depth. Most deeper wells tap the freshwater-saltwater mixing zones that underlie the freshwater lenses. Chloride concentrations of water from these deep monitoring wells will typically provide the earliest indication that the freshwater lenses may be constricting.

Recent trends.--Monitoring sites AW16 and BW09 (figs. A3, A4) were selected to show trends in ground-water chloride concentration at Cantonment and Air Operations, respectively. Figures 5 and 6 show time-series graphs of chloride concentration at three depths at the Cantonment and Air Operations sites, respectively, with rainfall data included in the figures for comparison.

Chloride concentrations of the water increased at both sites during July and August 1996, then slightly decreased by the end of September 1996 at most wells from both sites. Chloride concentration of water from the 10-ft well at AW16 was still increasing at the end of the quarter. The largest increases in chloride concentration were at the deepest monitoring wells at both sites, and were about 4,000 and 1,000 mg/L at AW16 and BW09, respectively, while increases at the shallower wells were between 50 and 100 mg/L. Chloride concentrations from these selected sites have increased since the start of the annual dry season, and have not been at this level since the dry season of 1994.

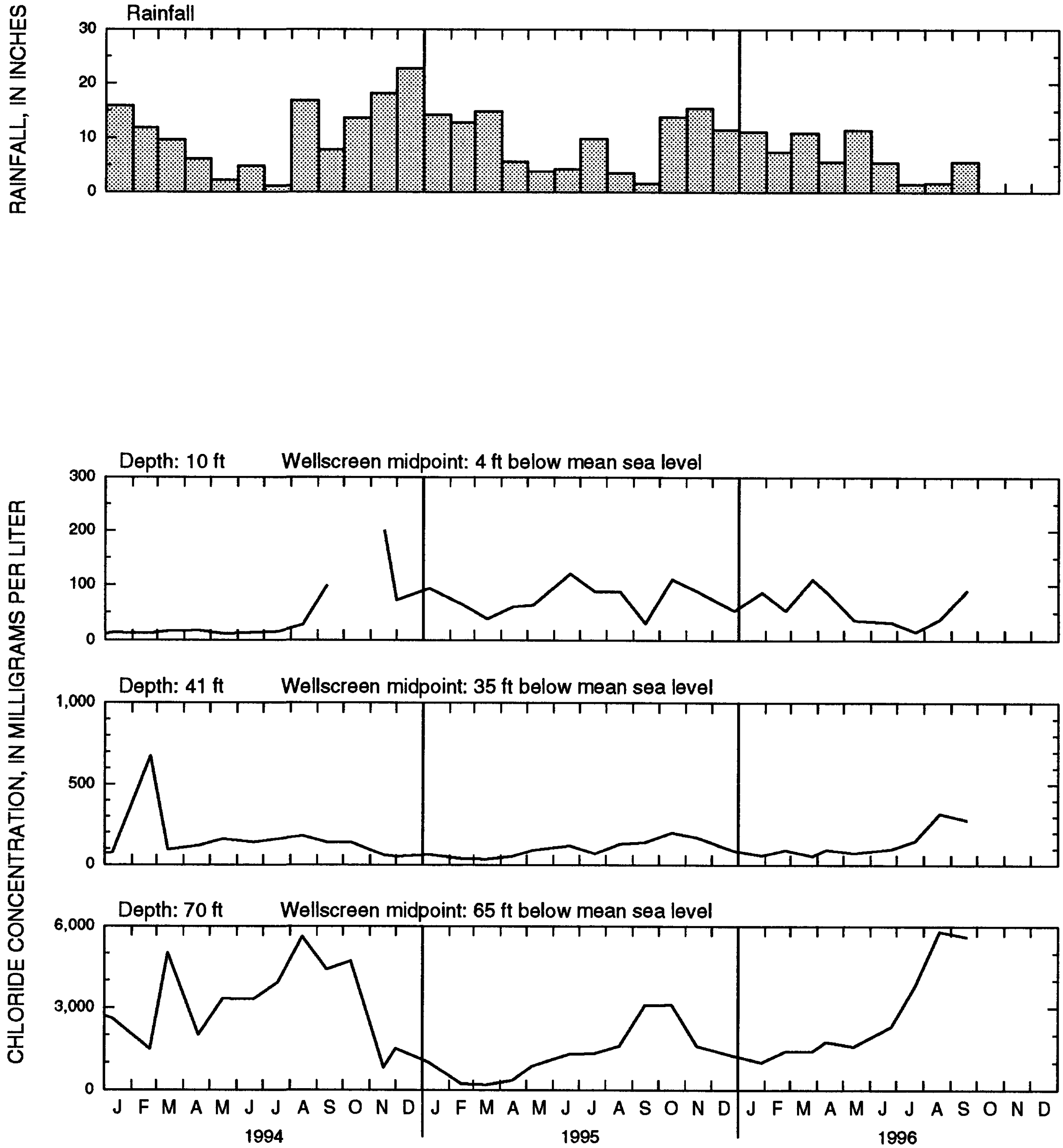
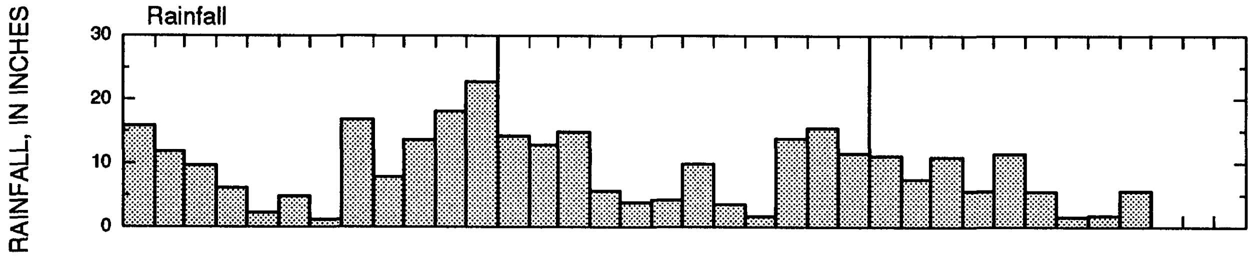


Figure 5. Chloride concentration of ground water (sampled at monthly intervals) in monitoring wells at site AW16 at Cantonment, Diego Garcia, January 1994 through September 1996. Rainfall data are shown for comparison.



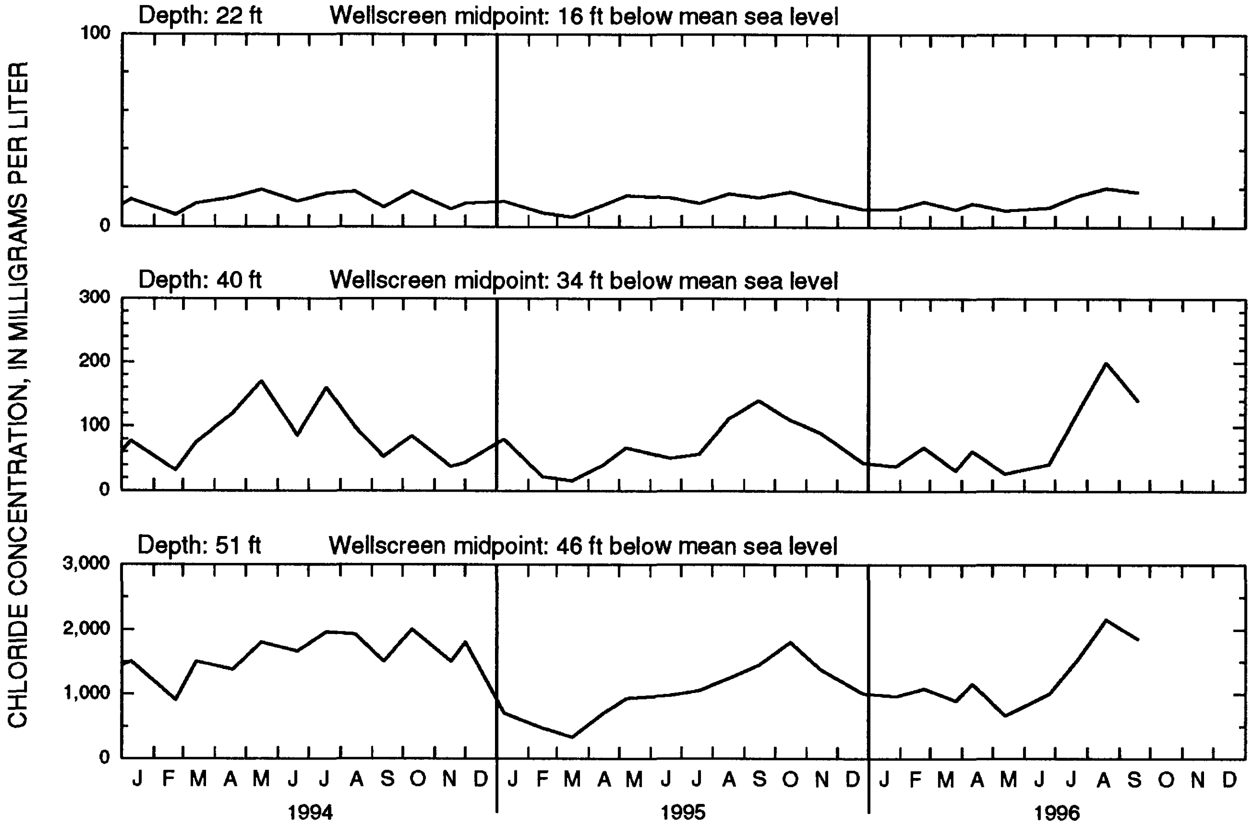


Figure 6. Chloride concentration of ground water (sampled at monthly intervals) in monitoring wells at site BW09 at Air Operations, Diego Garcia, January 1994 through September 1996. Rainfall data are shown for comparison.

FUEL-DIVERSION PROGRAM AT AIR OPERATIONS

Background.--The normal pattern of ground-water withdrawal at Air Operations has been disrupted since May 1991 by an underground JP-5 fuel-pipeline leak at the South Ramp parking apron (fig. A2). The leak was about 800 ft from several water-supply wells.

In August 1991, the USGS suggested a scheme to hydraulically alter the natural ground-water flow direction in the Air Operations area, and in April 1992, the program to divert fuel away from the production wells was initiated. The fuel-diversion program is a closed recirculation loop of withdrawal and injection. It utilizes six wells (AO-10 through AO-15), and consists of pumping about 150,000 gal/d of water from wells AO-14 and AO-15 and directing this water through the common collection main to the wells nearest the leak (AO-10 through AO-12), where it is injected back into the ground. Well AO-13 has been used only intermittently since the fuel leak was detected in 1991 (Torikai, 1995).

An elevated mound in the water table created by the injection water helps to retard the migration of fuel toward the water-supply wells. Subsequent to the leak detection, 10 wells were shut down from May 1991 to April 1992. However, with the inception of the diversion program, only six wells still do not contribute to the water supply. Lost production capacity is about 15 percent of total islandwide pumpage prior to the leak detection. It is expected that the fuel-diversion program will continue until the site is remediated.

Injection data for wells AO-10 through AO-12 from May 10, 1993 through September 1996 are actual water-meter readings. From April 1992 through early May 1993, meter readings of injection were not available, and daily injection at each of the three wells was estimated to be one-third of the total daily withdrawal from wells AO-13 through AO-15 which provided the injection-supply water (Torikai, 1995). Monthly mean withdrawal and injection at wells AO-10 through AO-15 are shown in figure 7.

Recent trends.--Withdrawal and injection rates for wells in the fuel-diversion program did not change significantly during the period July through September 1996. Actual pumping rates of these six wells have been very close to the established target rates. Target withdrawal and injection rates are listed in table 1 for wells AO-10 through AO-15. Daily mean withdrawal and injection rates for these wells are also shown.

Table 1. Target and actual withdrawal and injection rates for fuel-diversion program, Diego Garcia.
[Injection is denoted by negative values; all values are in gallons per day.]

Well	Target rates	Daily mean rates, July through September 1996
AO-10	-30,000	-28,100
AO-11	-50,000	-54,900
AO-12	-70,000	-67,400
AO-13	0	0
AO-14	70,000	66,300
AO-15	80,000	77,300

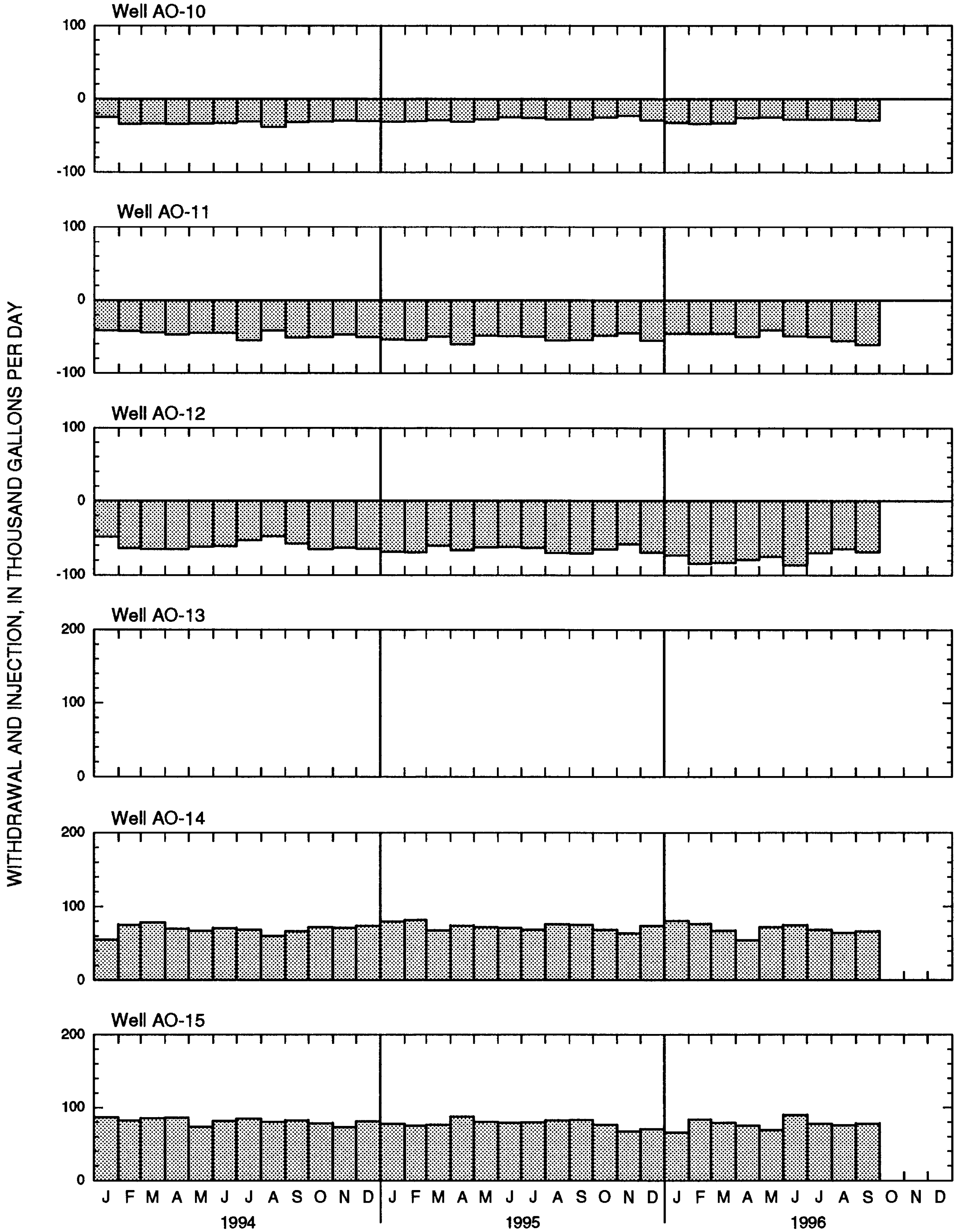


Figure 7. Monthly mean ground-water withdrawal and injection at wells AO-10 through AO-15 at Air Operations, Diego Garcia, January 1994 through September 1996. Injection is plotted as negative.

HYDROLOGIC-DATA SECTION

TYPES OF DATA INCLUDED

A. Maps of production and monitoring wells at Cantonment and Air Operations
B. Graphs of monthly mean ground-water withdrawal, January 1994 through September 1996
C. Graphs of chloride concentration of pumped water, January 1994 through September 1996

DESCRIPTIONS OF PRINCIPAL PRODUCTION SOURCES AT CANTONMENT AND AIR OPERATIONS AREAS

Cantonment Area

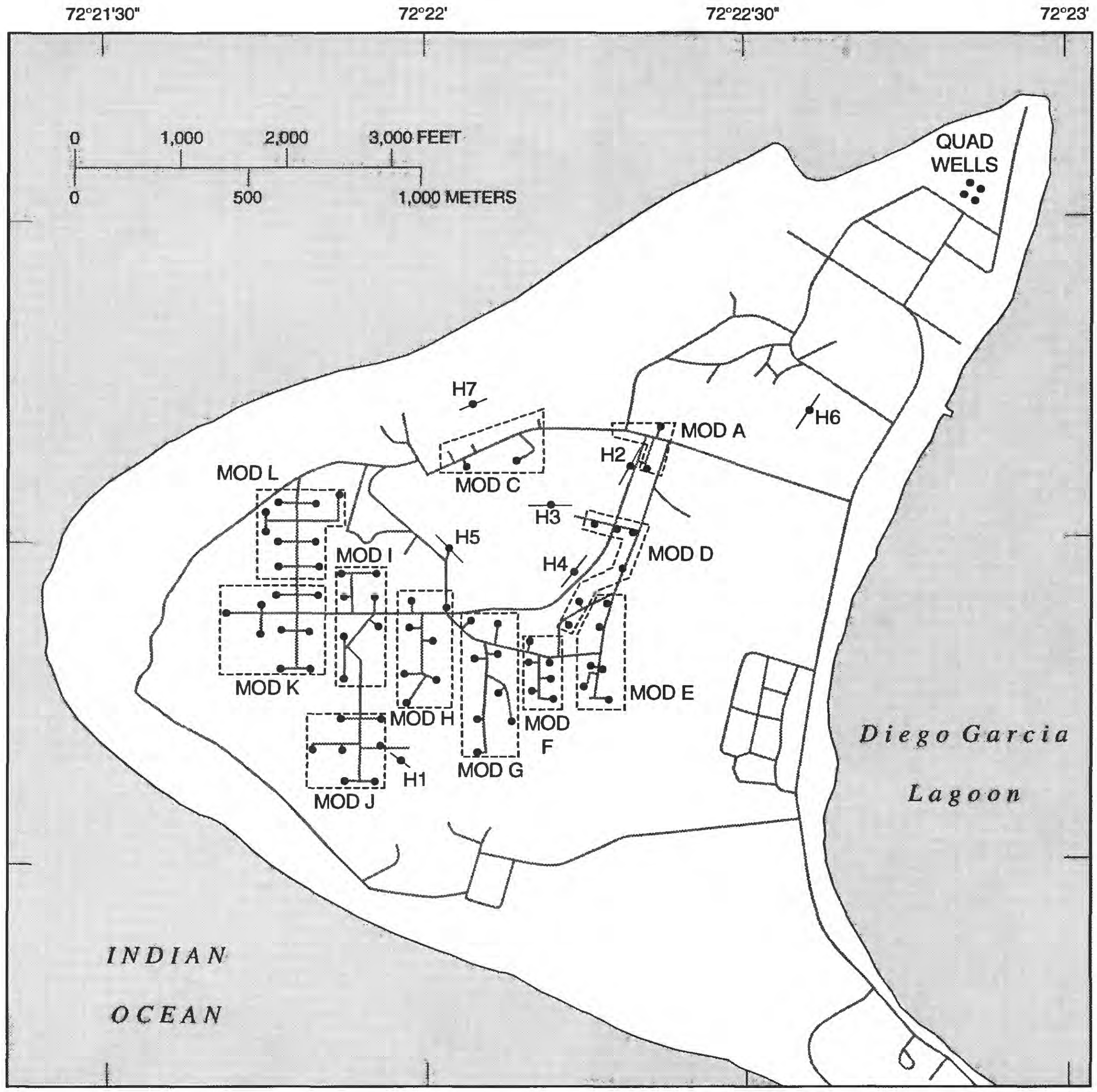
1. Modules A, C through L - each module is a well field of two to nine vertical wells that are pumped to a common collection/ transfer tank.
2. Wells H1 through H7 are horizontal wells.
3. Quad wells are a well field of four vertical wells

Air Operations Area

1. Wells AO-2 through AO-5 are vertical wells.
2. Wells AO-6 through AO-9 are horizontal wells.
3. Wells AO-10 through AO-15 are horizontal wells. AO-10 through AO-12 are currently receiving injection water from water pumped at wells AO-14 and AO-15 to divert contaminants from a nearby fuel leak; AO-13 is not pumping. No samples are currently collected for chloride-concentration analysis.
4. AO-16 through AO-19 are horizontal wells.

SECTION A

Maps of production and monitoring wells at Cantonment and Air Operations



EXPLANATION

•	VERTICAL WELL--Typical pumping rate 10 to 12 gallons per minute
H7	HORIZONTAL WELL AND DESIGNATION--Typical pumping rate 50 to 75 gallons per minute
MOD E	WELL MODULE AND DESIGNATION--Vertical wells that pump to a common 1,000-gallon collection and transfer tank
——	ROAD, PAVED OR UNPAVED

Figure A1. Ground-water production wells and well fields at Cantonment, Diego Garcia.

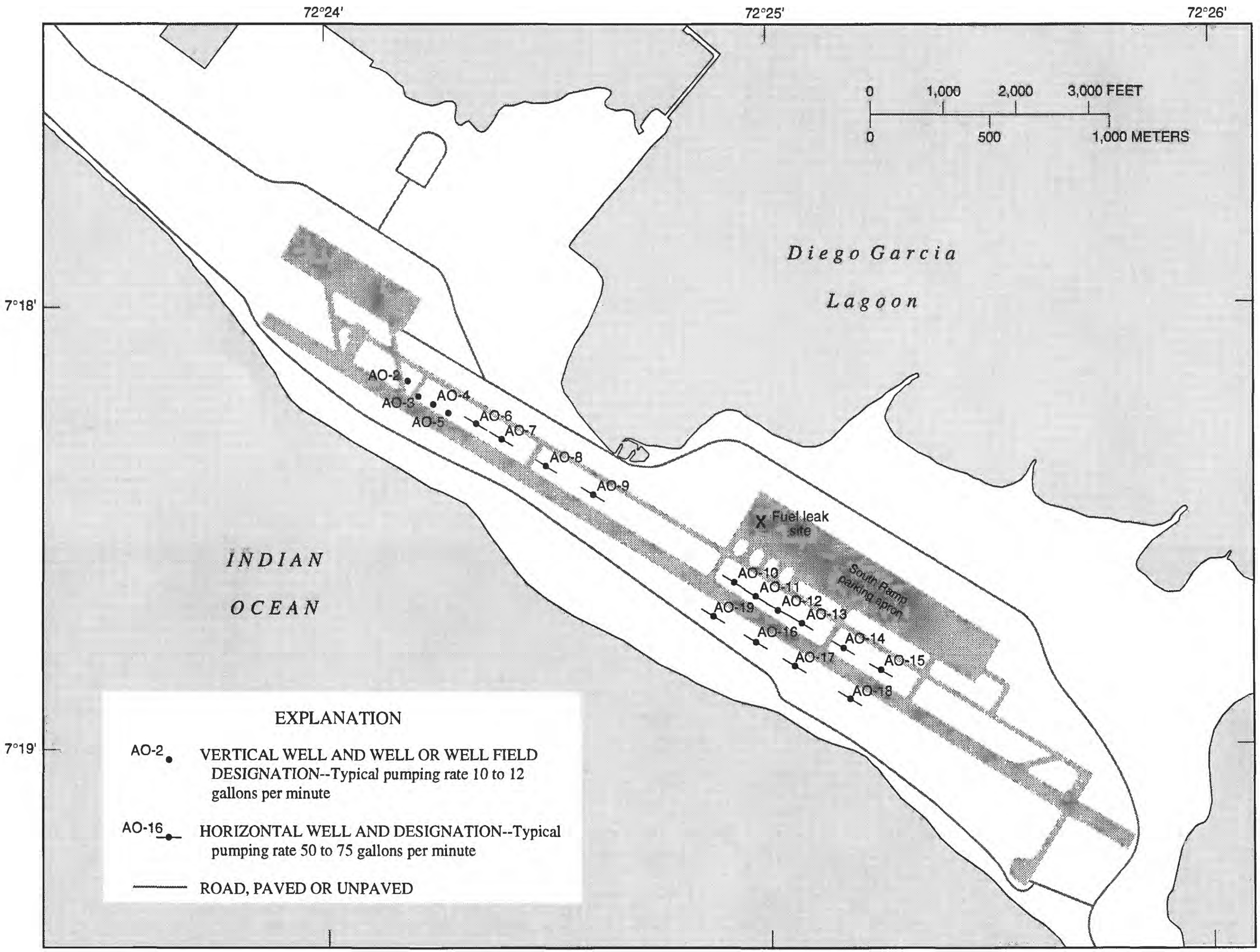
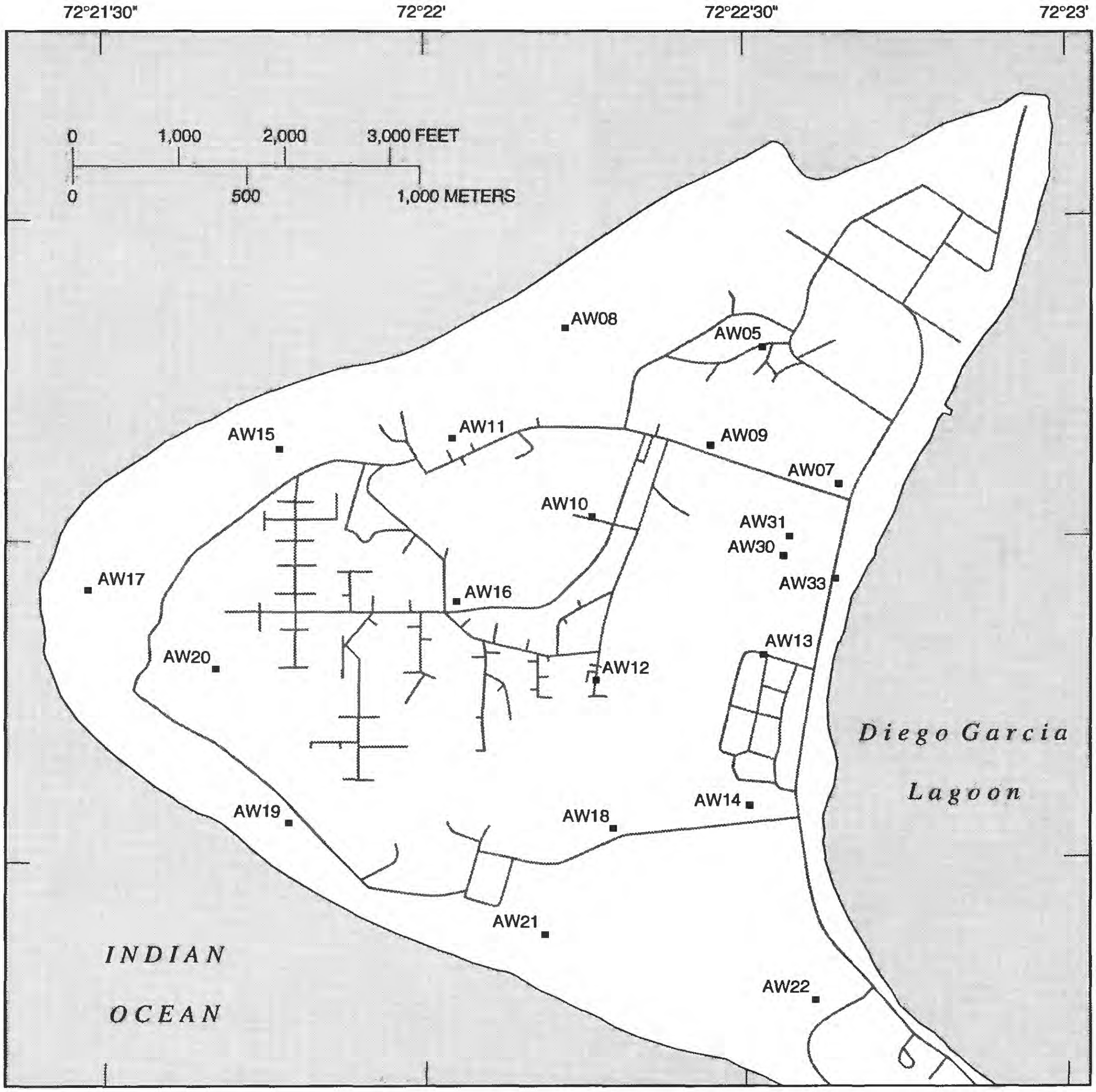


Figure A2. Ground-water production wells at Air Operations, Diego Garcia.



EXPLANATION

AW21 ▪ MONITORING SITE AND DESIGNATION--Consisting of two or more monitoring wells with short (2- to 5-foot) open intervals of different depths

——— ROAD, PAVED OR UNPAVED

Figure A3. Monitoring wells at Cantonment, Diego Garcia.

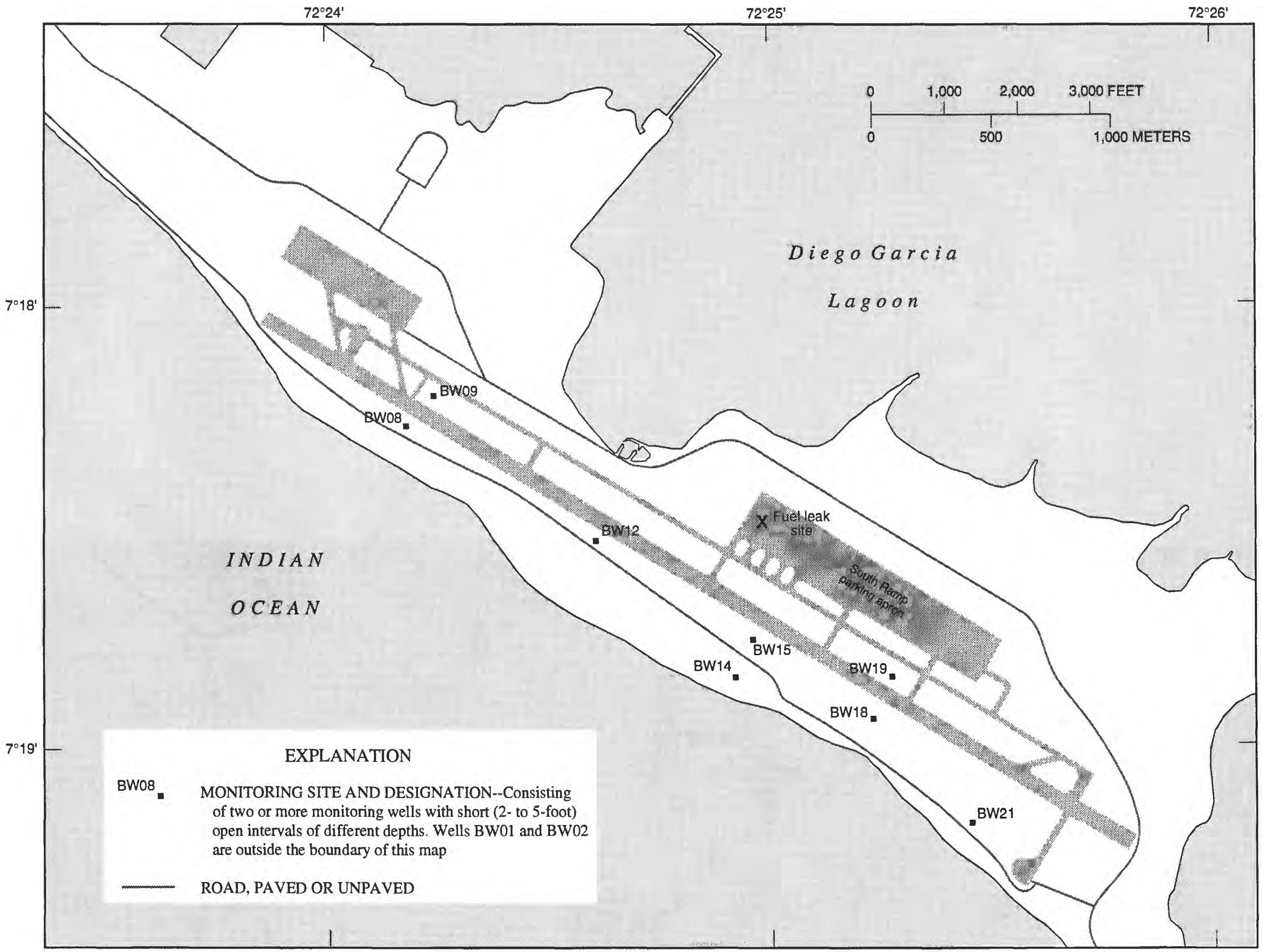


Figure A4. Monitoring wells at Air Operations, Diego Garcia.

SECTION B

Graphs of monthly mean ground-water withdrawal, January 1994 through September 1996

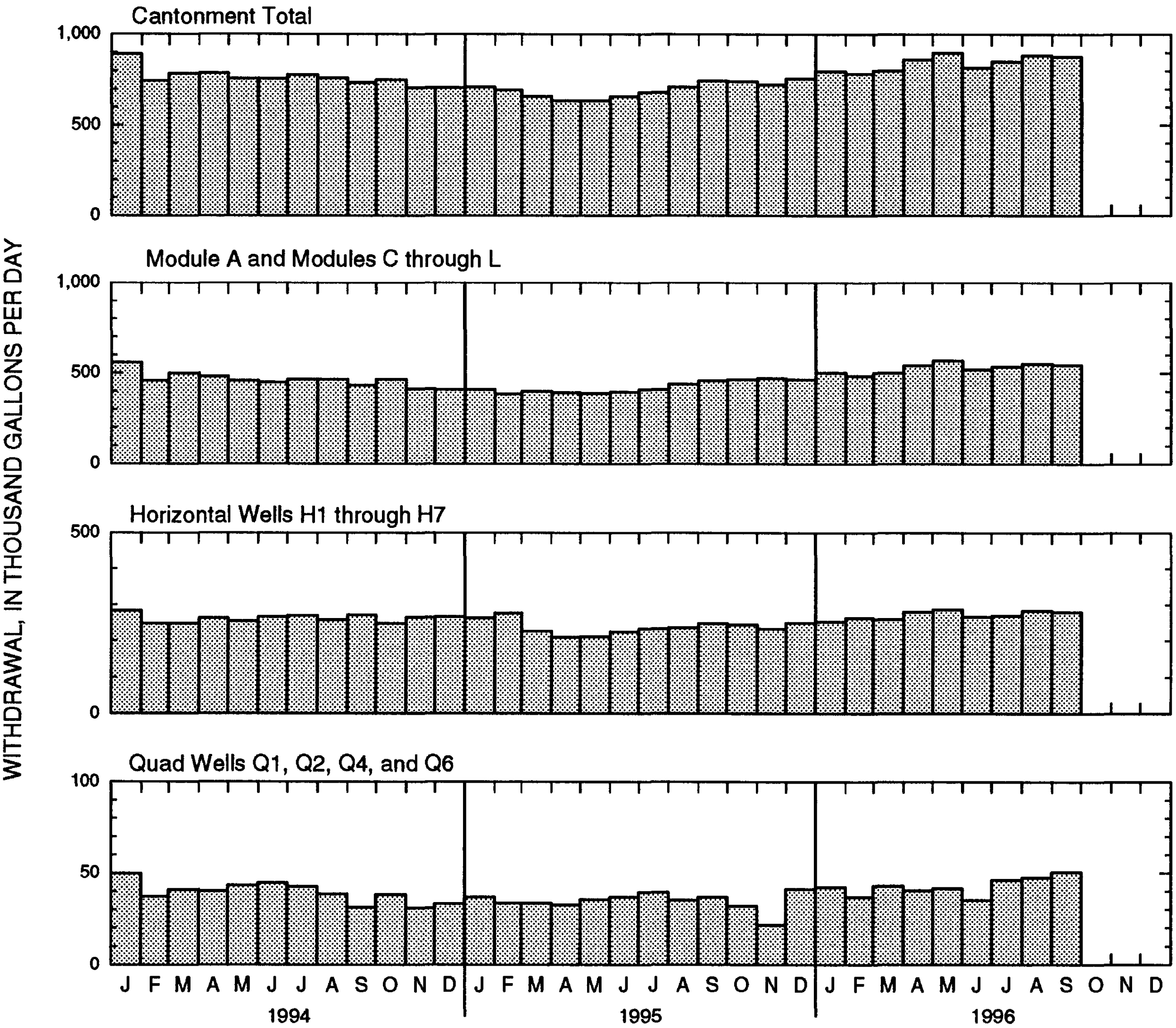


Figure B1. Monthly mean ground-water withdrawal at Cantonment, Diego Garcia, January 1994 through September 1996.

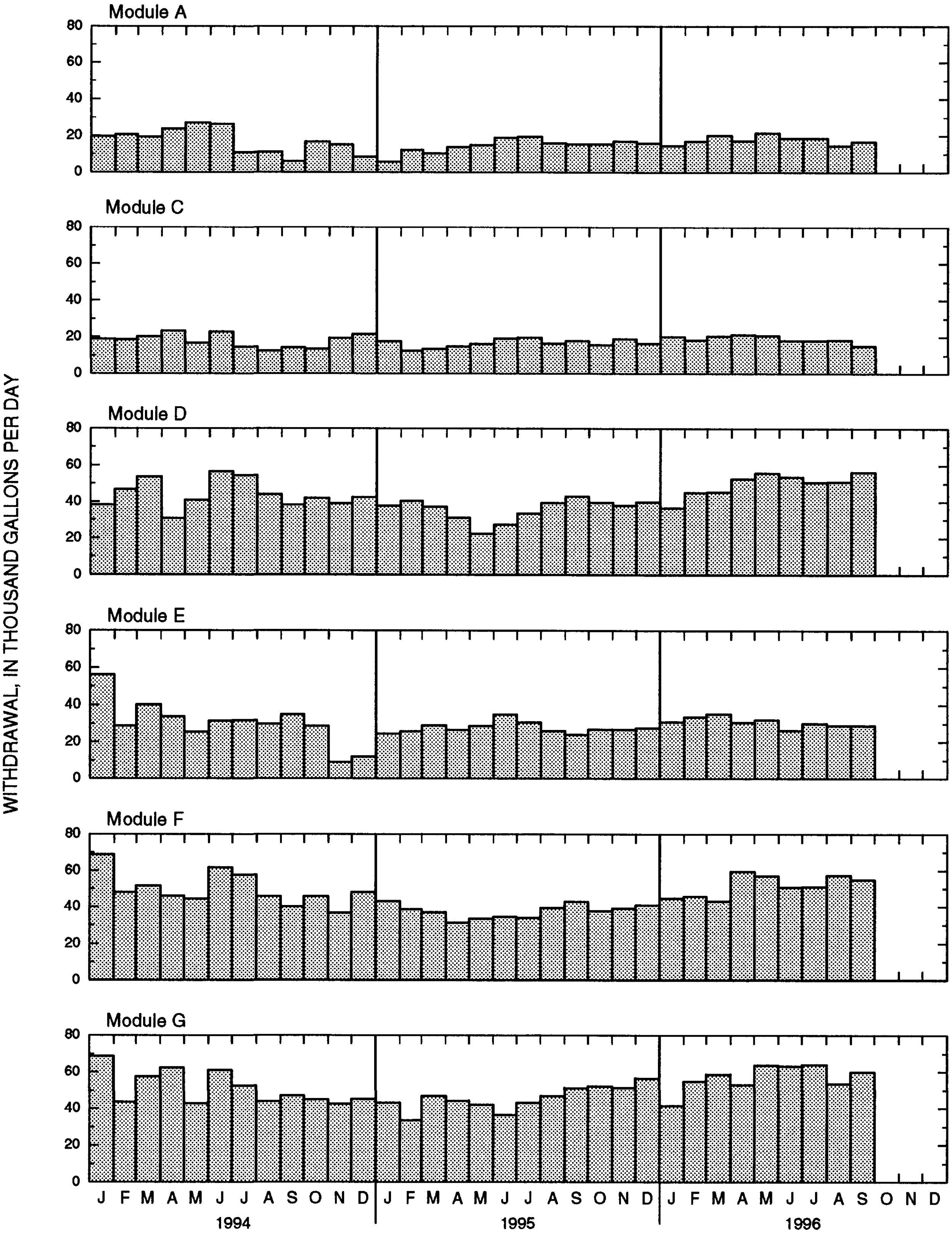


Figure B2. Monthly mean ground-water withdrawal at Module A and Modules C through L at Cantonment, Diego Garcia, January 1994 through September 1996.

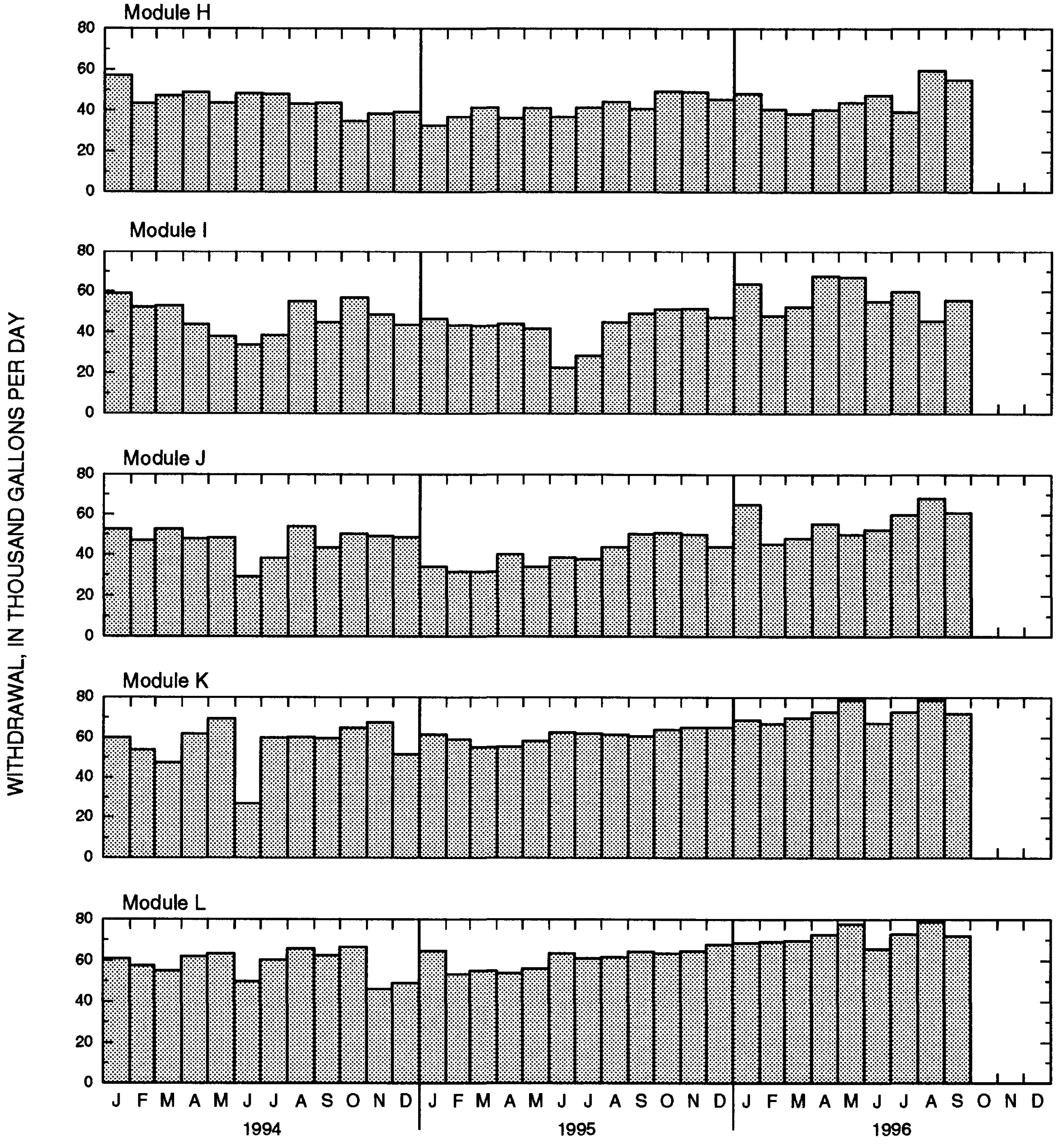


Figure B2. Monthly mean ground-water withdrawal at Module A and Modules C through L at Cantonment, Diego Garcia, January 1994 through September 1996--Continued.

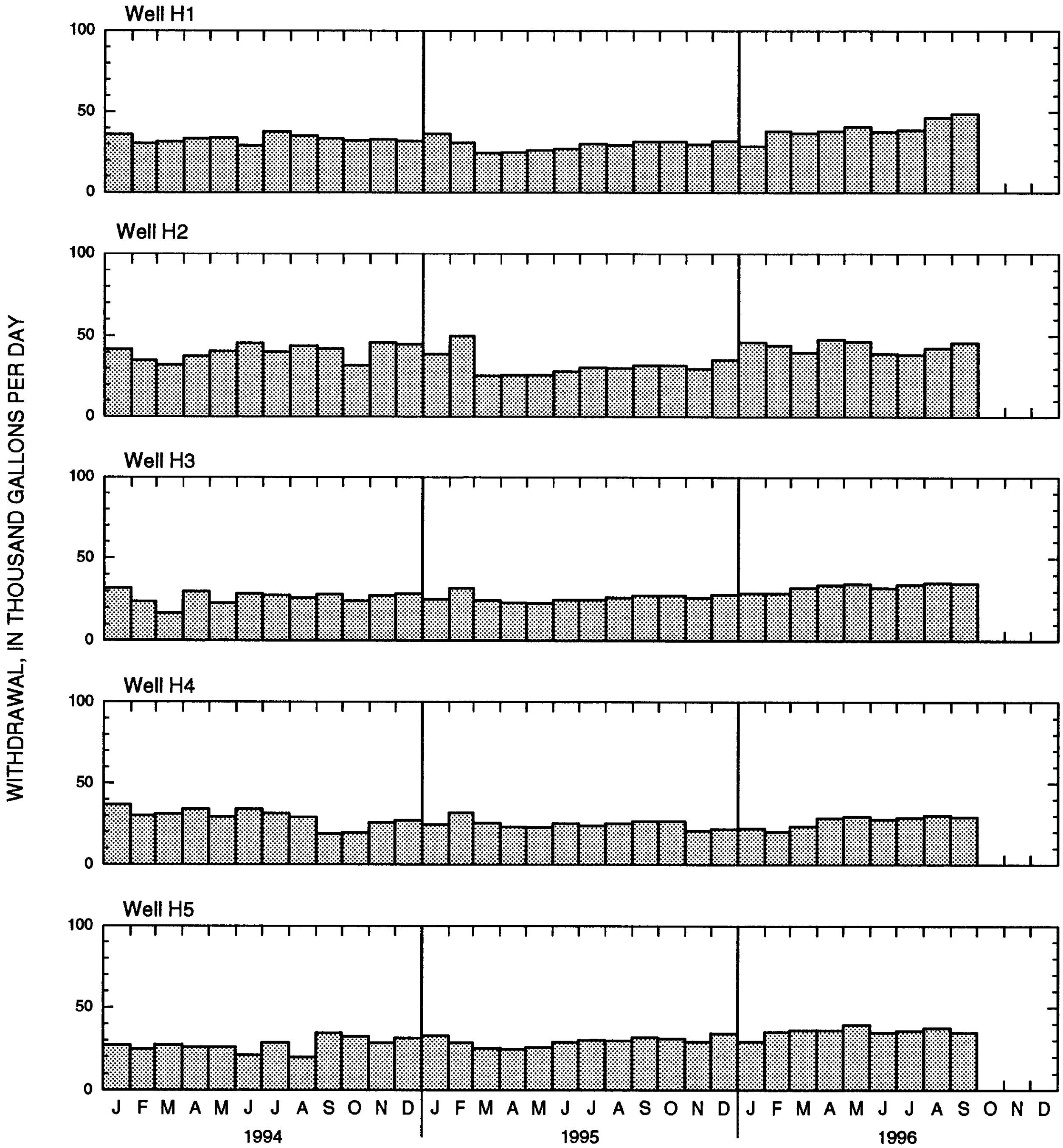


Figure B3. Monthly mean ground-water withdrawal at Horizontal wells H1 through H7 at Cantonment, Diego Garcia, January 1994 through September 1996.

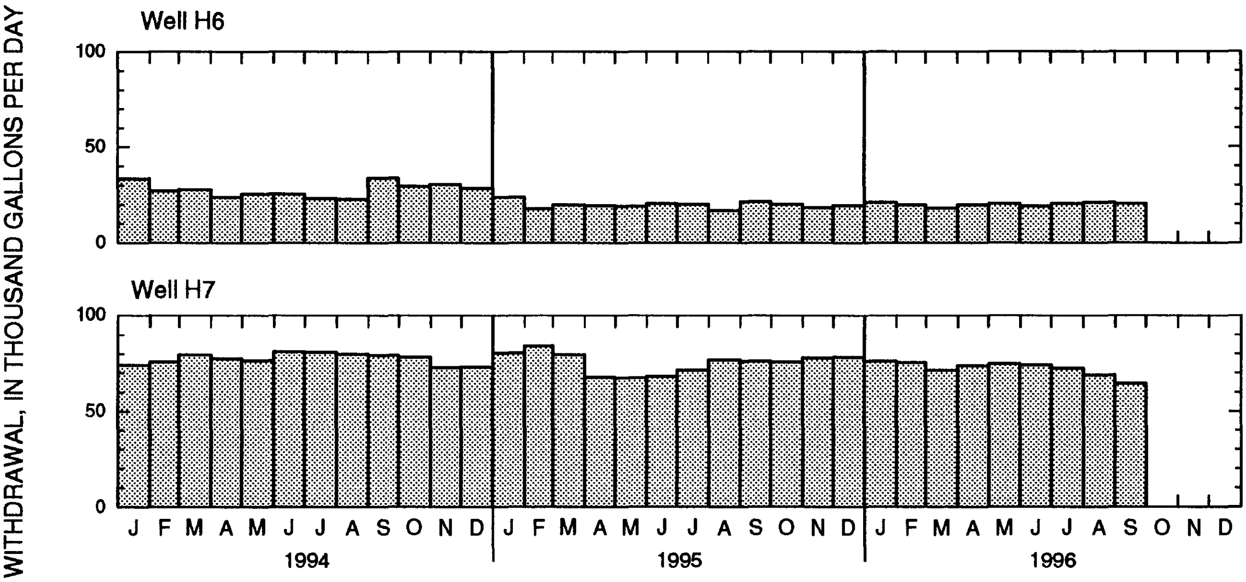


Figure B3. Monthly mean ground-water withdrawal at Horizontal wells H1 through H7 at Cantonment, Diego Garcia, January 1994 through September 1996--Continued.

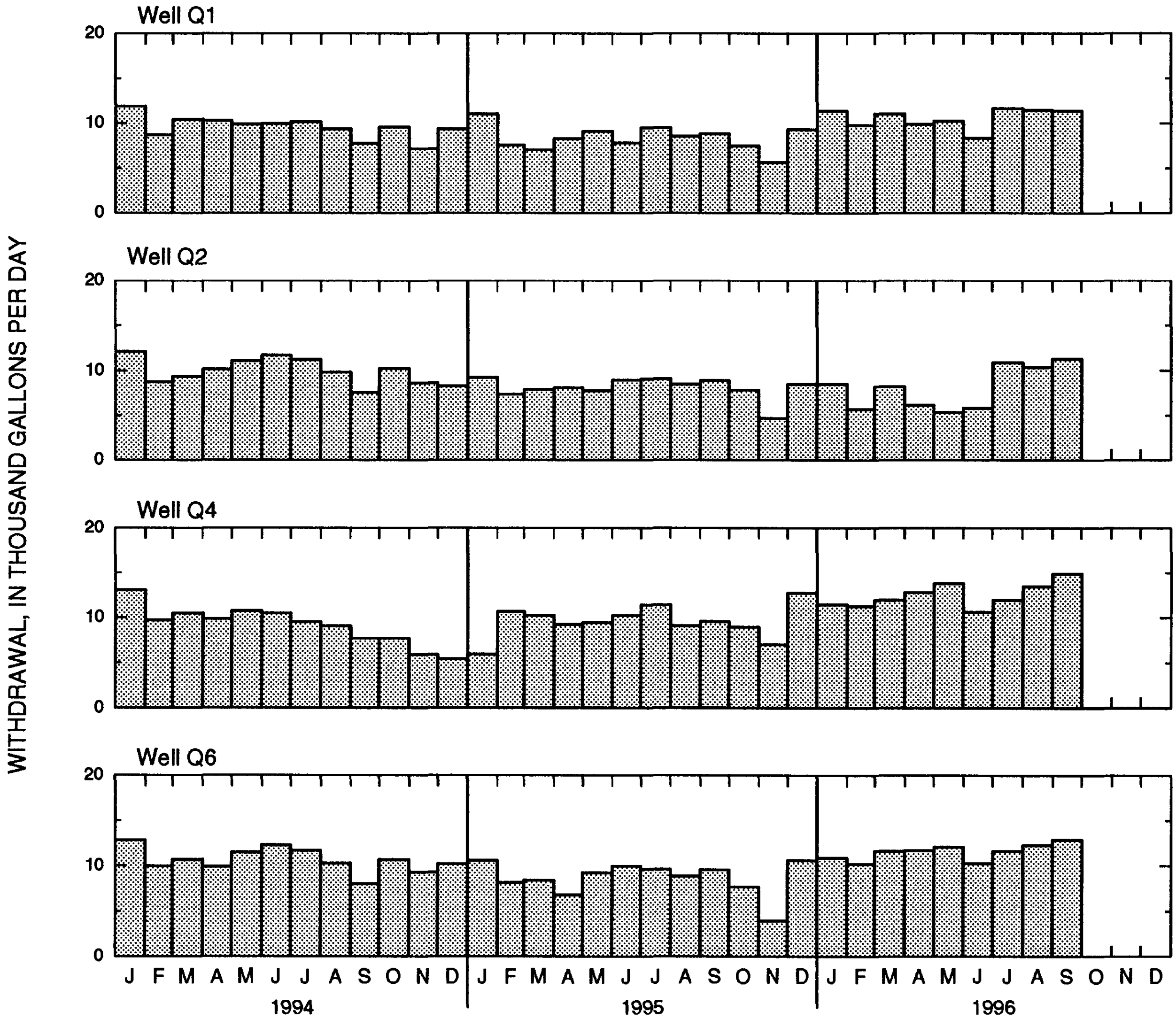


Figure B4. Monthly mean ground-water withdrawal at Quad wells Q1, Q2, Q4, and Q6 at Cantonment, Diego Garcia, January 1994 through September 1996.

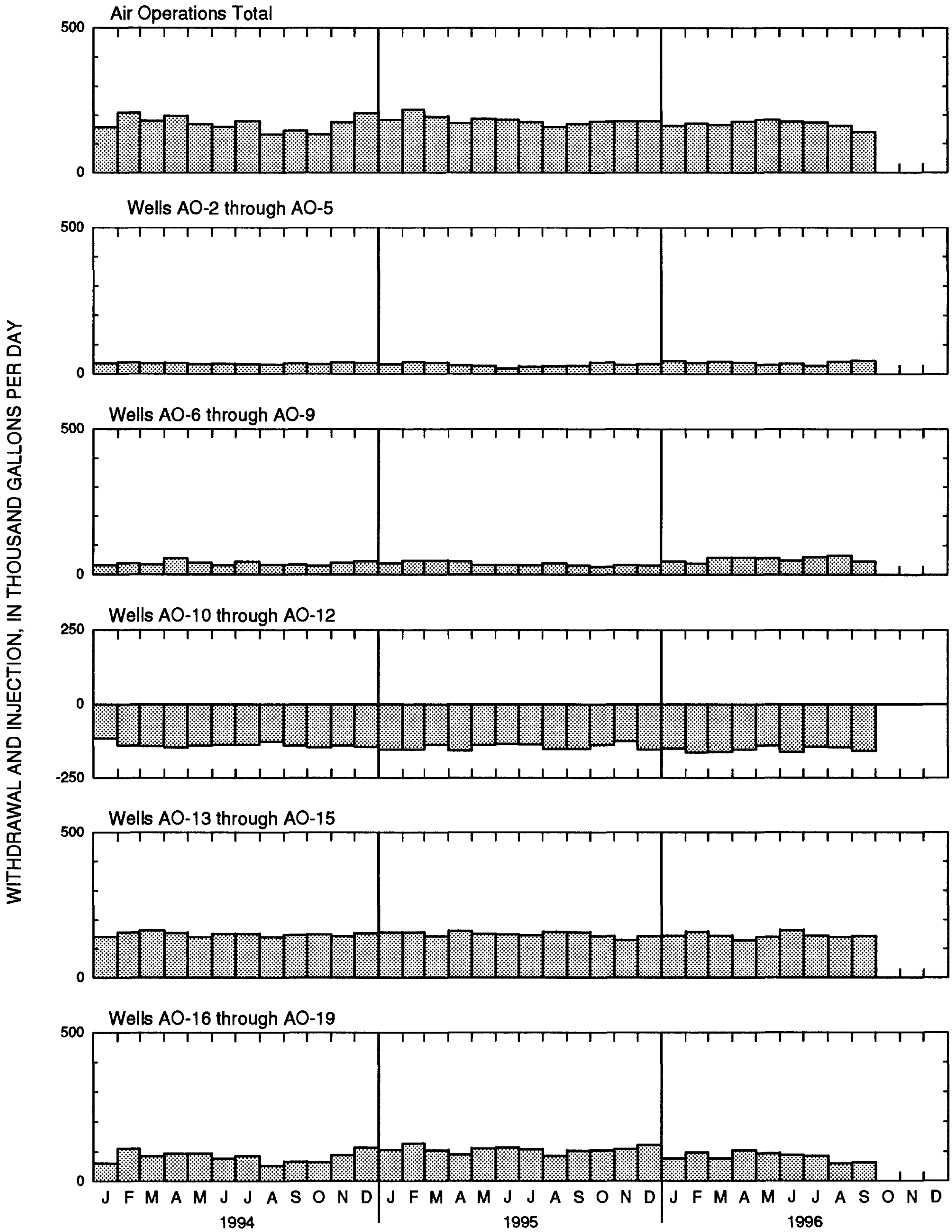


Figure B5. Monthly mean ground-water withdrawal and injection at Air Operations, Diego Garcia, January 1994 through September 1996. Injection is plotted as negative.

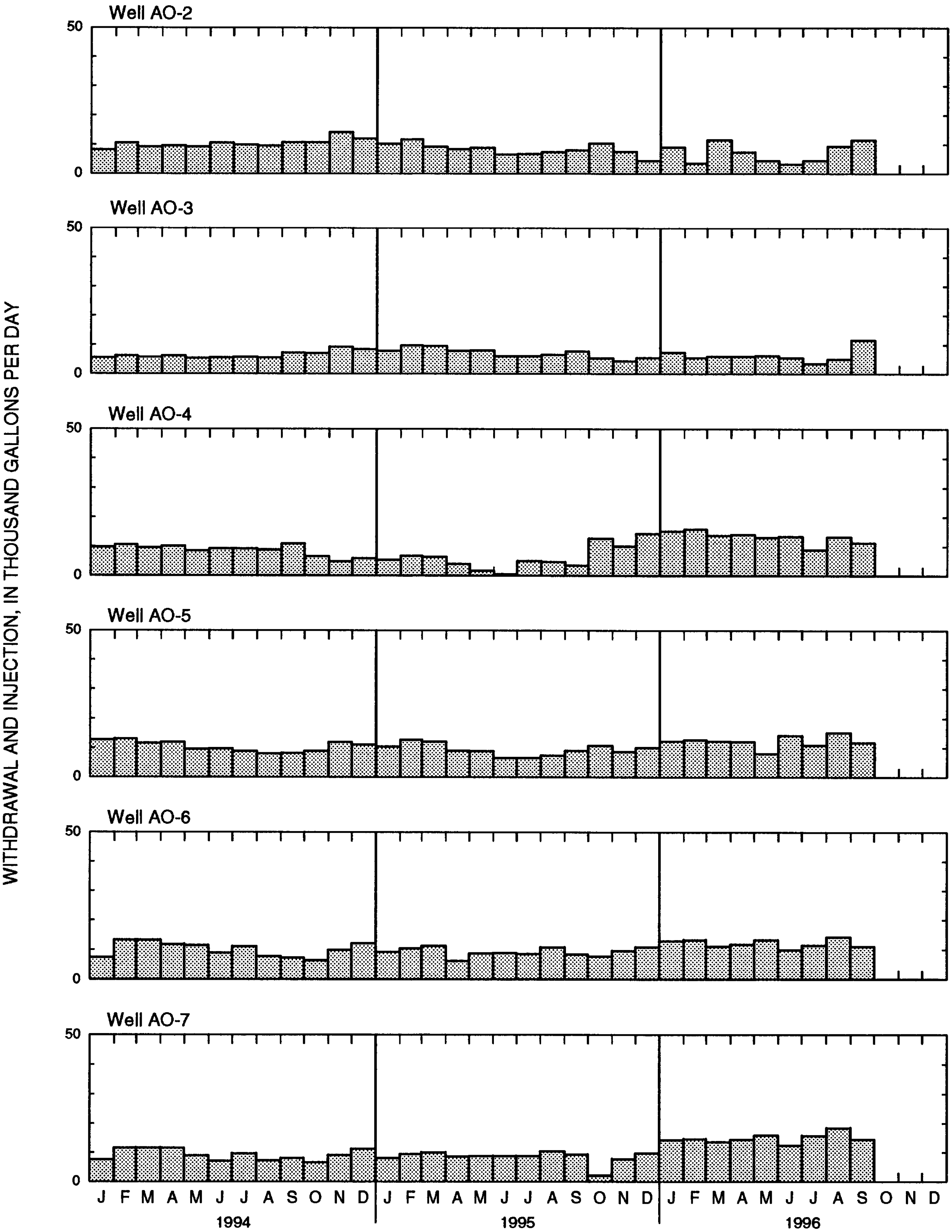


Figure B6. Monthly mean ground-water withdrawal and injection at wells AO-2 through AO-19 at Air Operations, Diego Garcia, January 1994 through September 1996. Injection is plotted as negative.

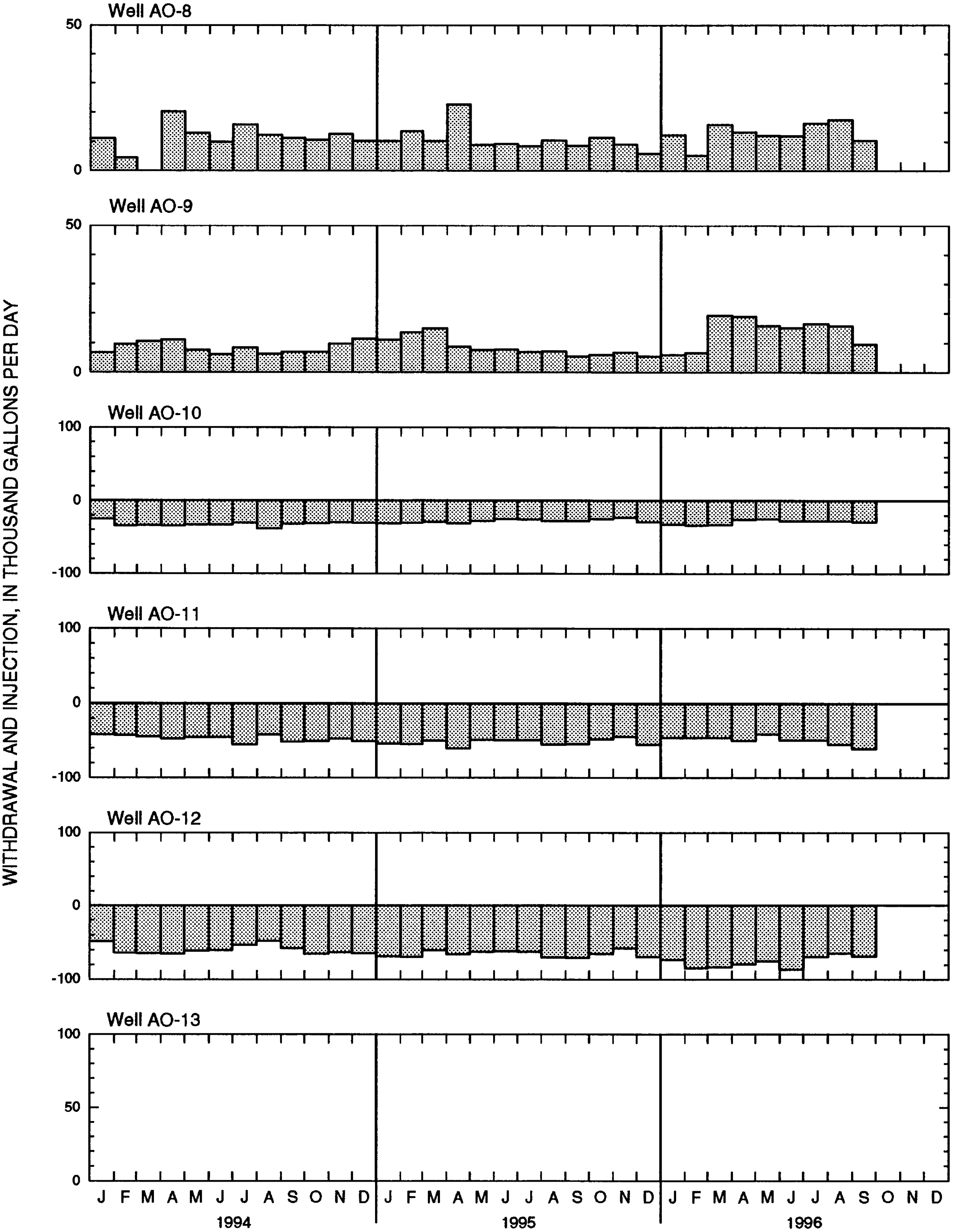


Figure B6. Monthly mean ground-water withdrawal and injection at wells AO-2 through AO-19 at Air Operations, Diego Garcia, January 1994 through September 1996. Injection is plotted as negative--Continued.

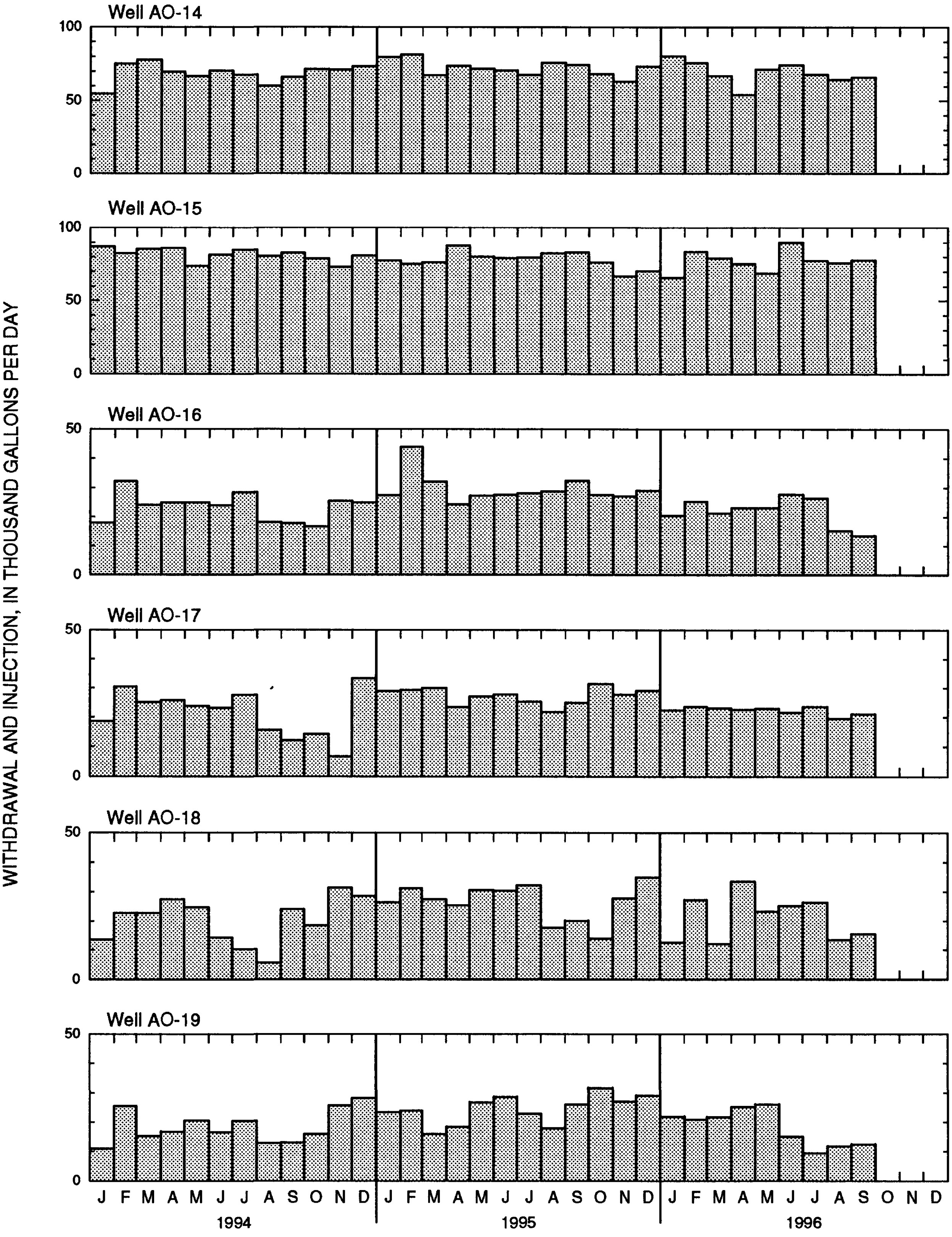


Figure B6. Monthly mean ground-water withdrawal and injection at wells AO-2 through AO-19 at Air Operations, Diego Garcia, January 1994 through September 1996. Injection is plotted as negative--Continued.

SECTION C

Graphs of chloride concentration of pumped water, January 1994 through September 1996

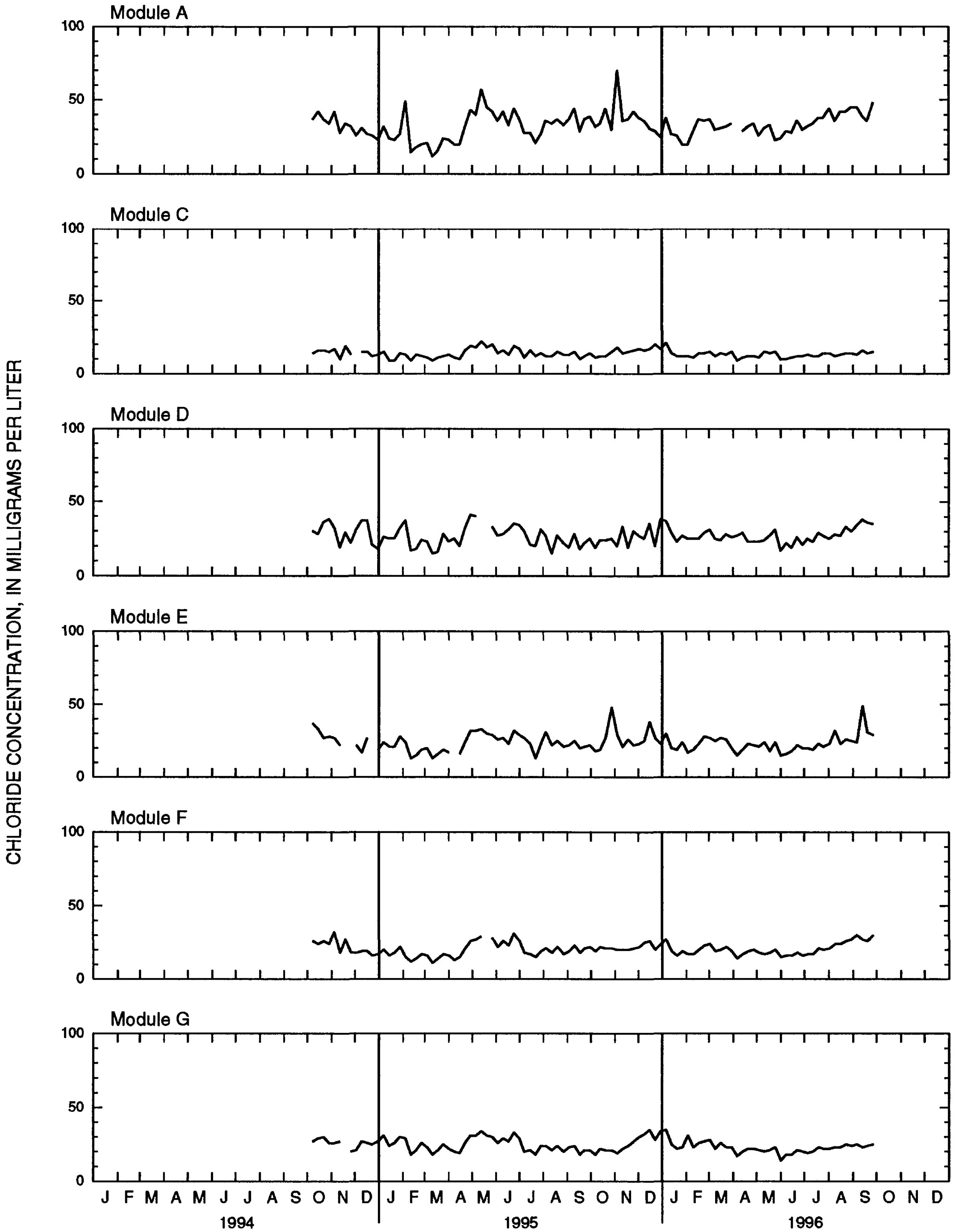


Figure C1. Chloride concentration of pumped water (sampled at weekly intervals) at Module A and Modules C through L at Cantonment, Diego Garcia, January 1994 through September 1996. Data not available for November 1993 through September 1994.

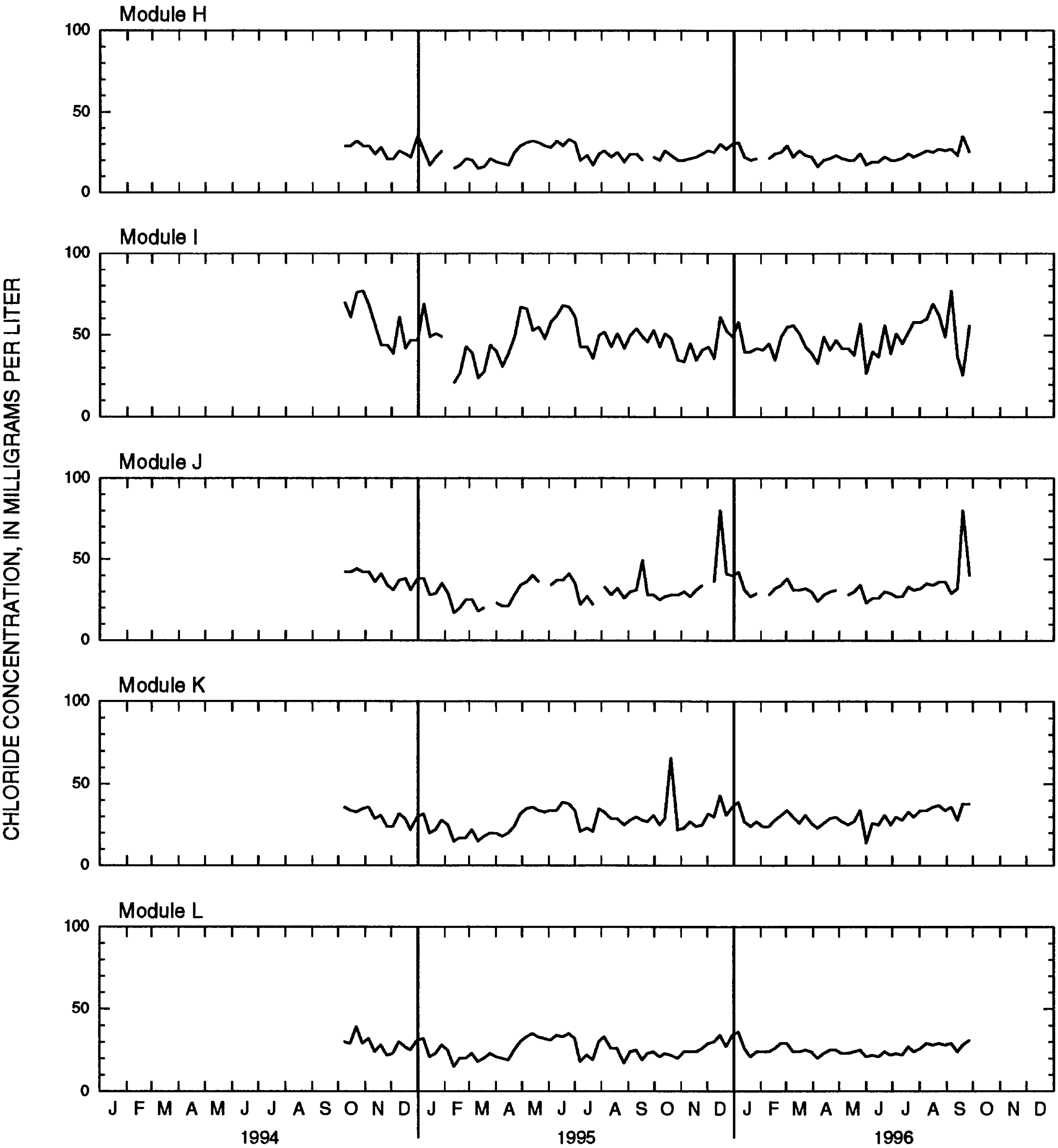


Figure C1. Chloride concentration of pumped water (sampled at weekly intervals) at Module A and Modules C through L at Cantonment, Diego Garcia, January 1994 through September 1996. Data not available for November 1993 through September 1994--Continued.

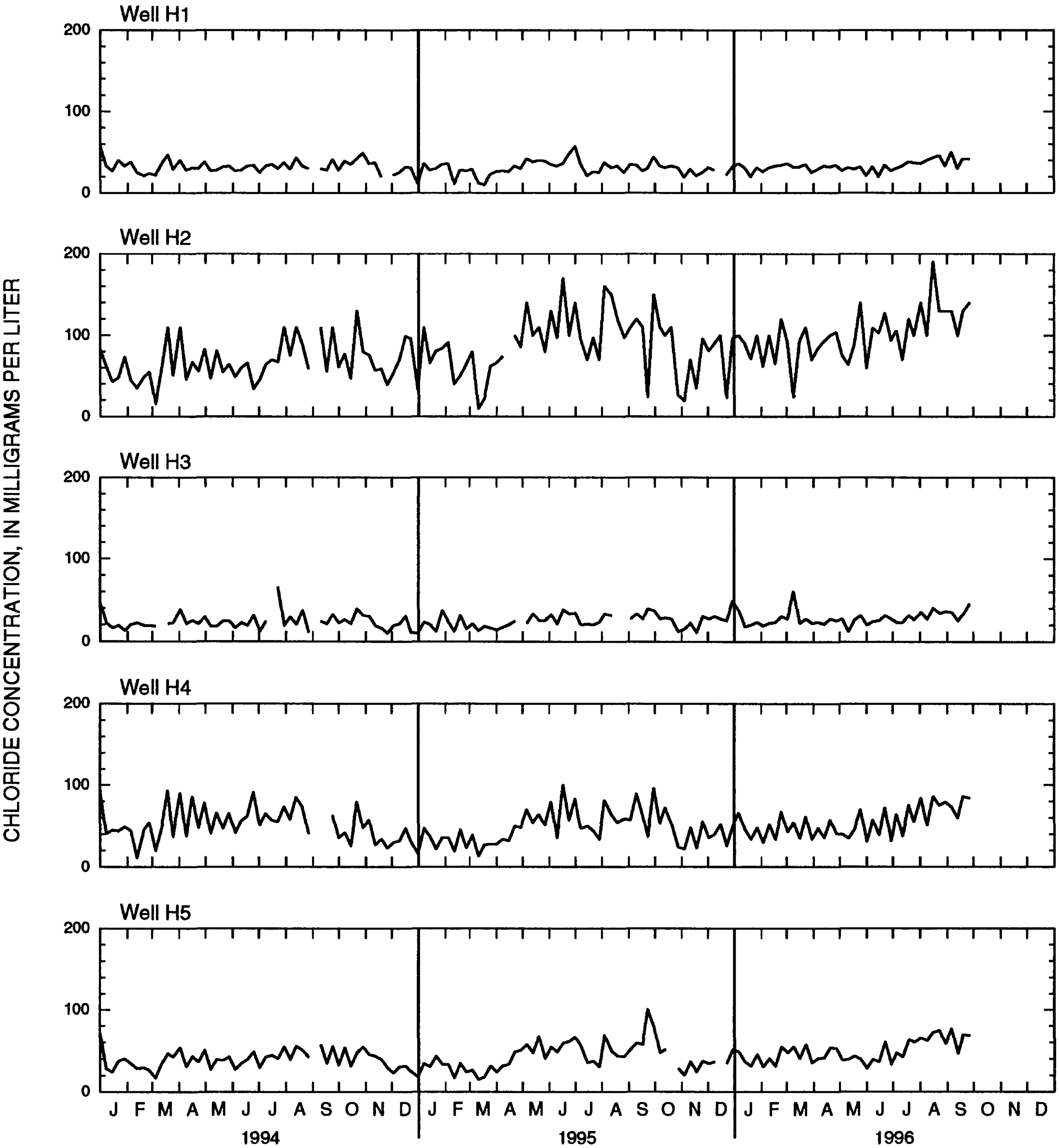


Figure C2. Chloride concentration of pumped water (sampled at weekly intervals) at Horizontal wells H1 through H7 at Cantonment, Diego Garcia, January 1994 through September 1996.

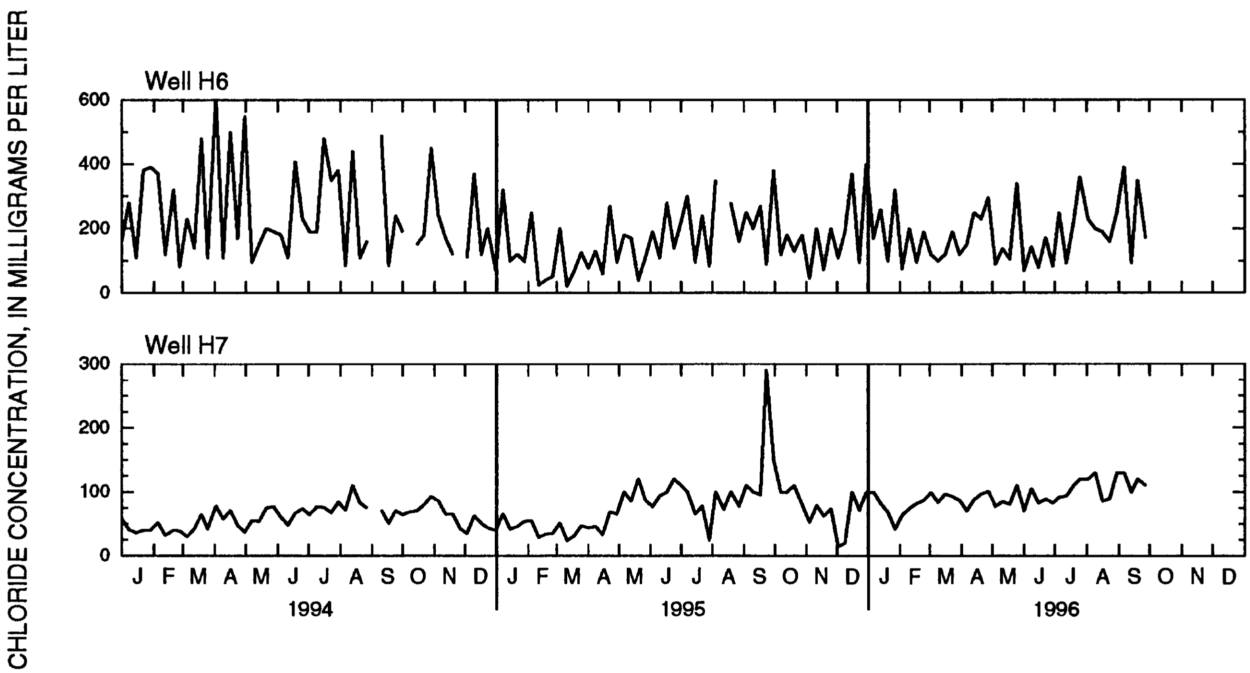


Figure C2. Chloride concentration of pumped water (sampled at weekly intervals) at Horizontal wells H1 through H7 at Cantonment, Diego Garcia, January 1994 through September 1996--Continued.

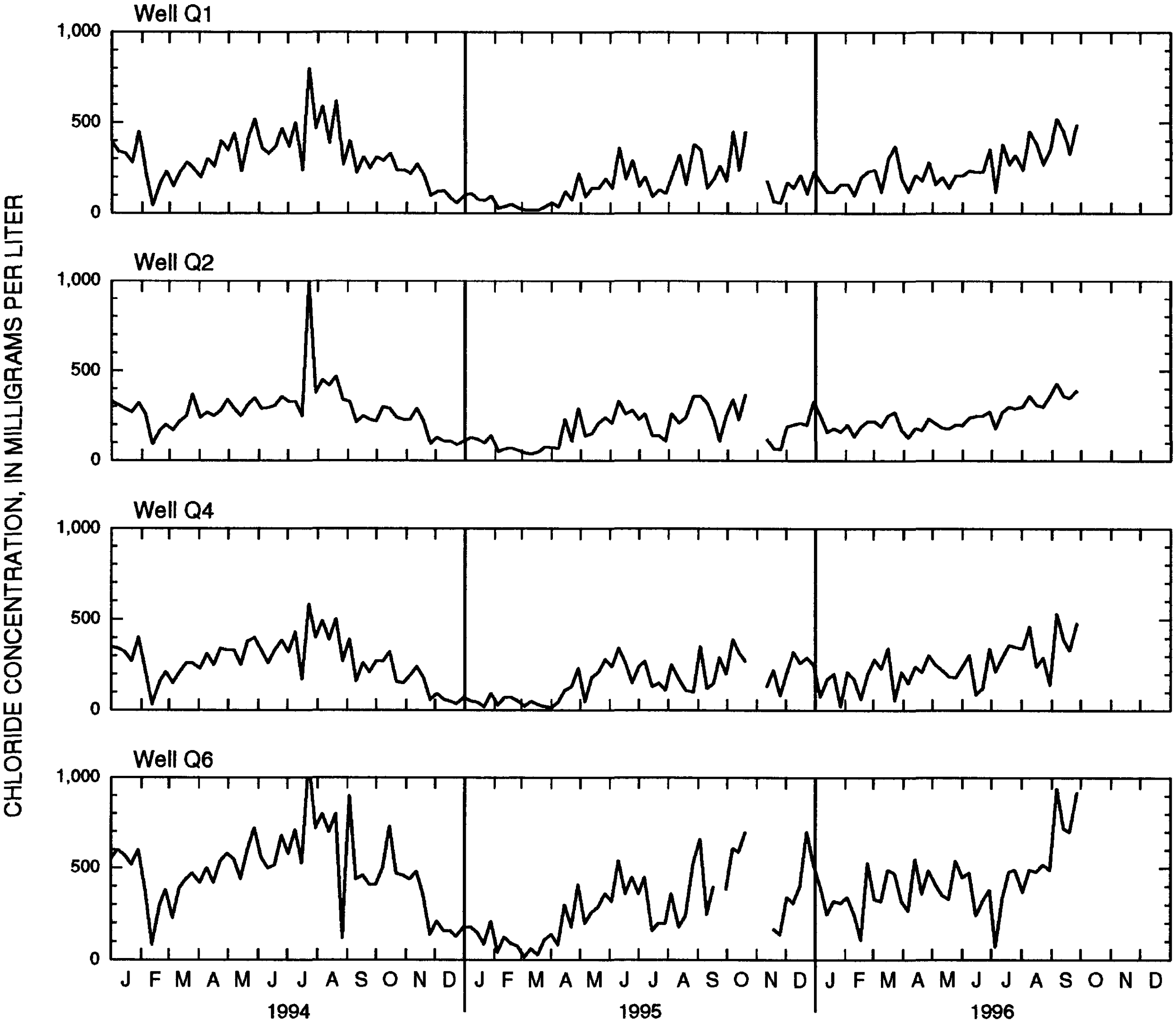


Figure C3. Chloride concentration of pumped water (sampled at weekly intervals) at Quad wells Q1, Q2, Q4, and Q6 at Cantonment, Diego Garcia, January 1994 through September 1996.

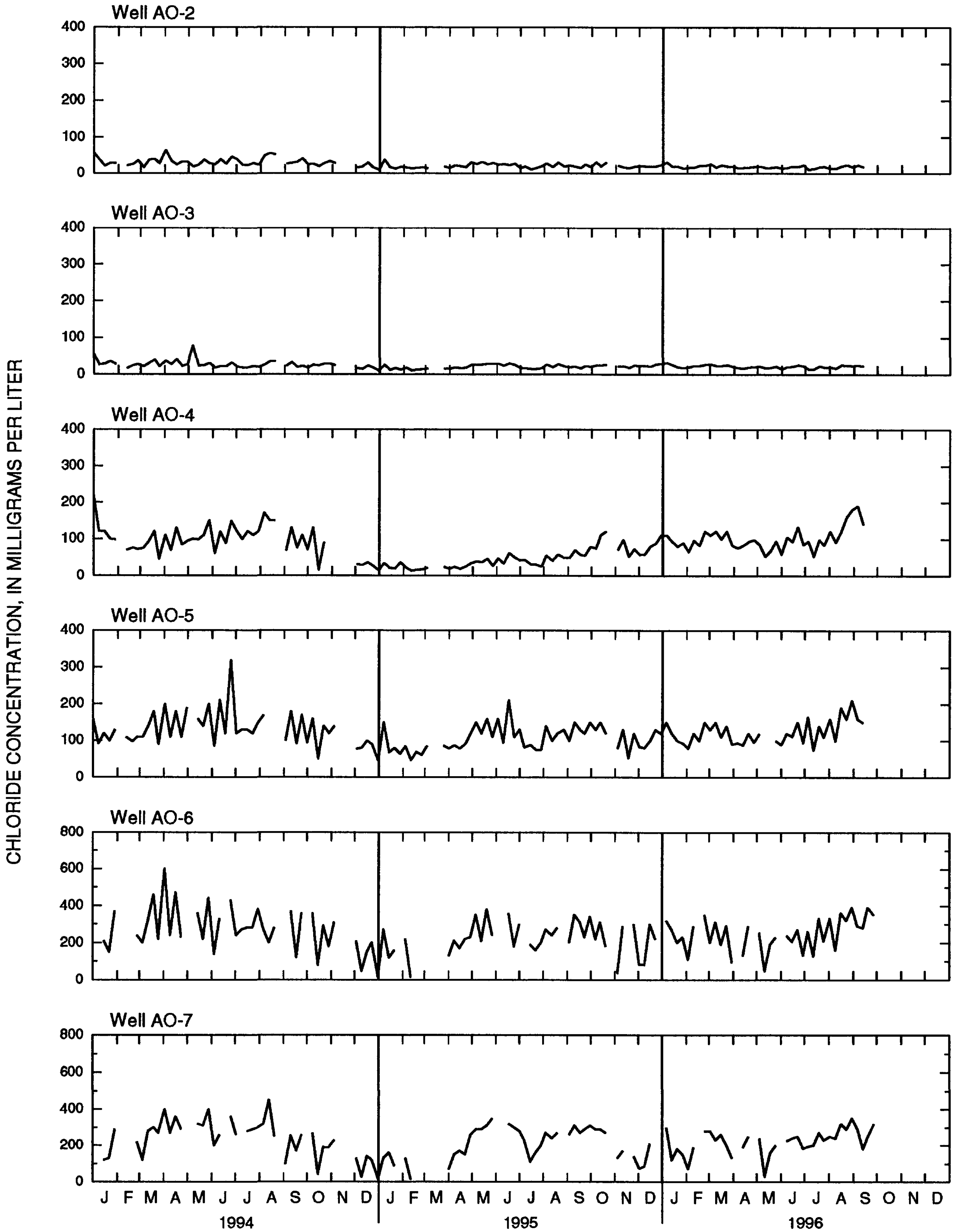


Figure C4. Chloride concentration of pumped water (sampled at weekly intervals) at wells AO-2 through AO-9 and wells AO-13 through AO-19 at Air Operations, Diego Garcia, January 1994 through September 1996. Water from well AO-13 has not been sampled since April 1993.

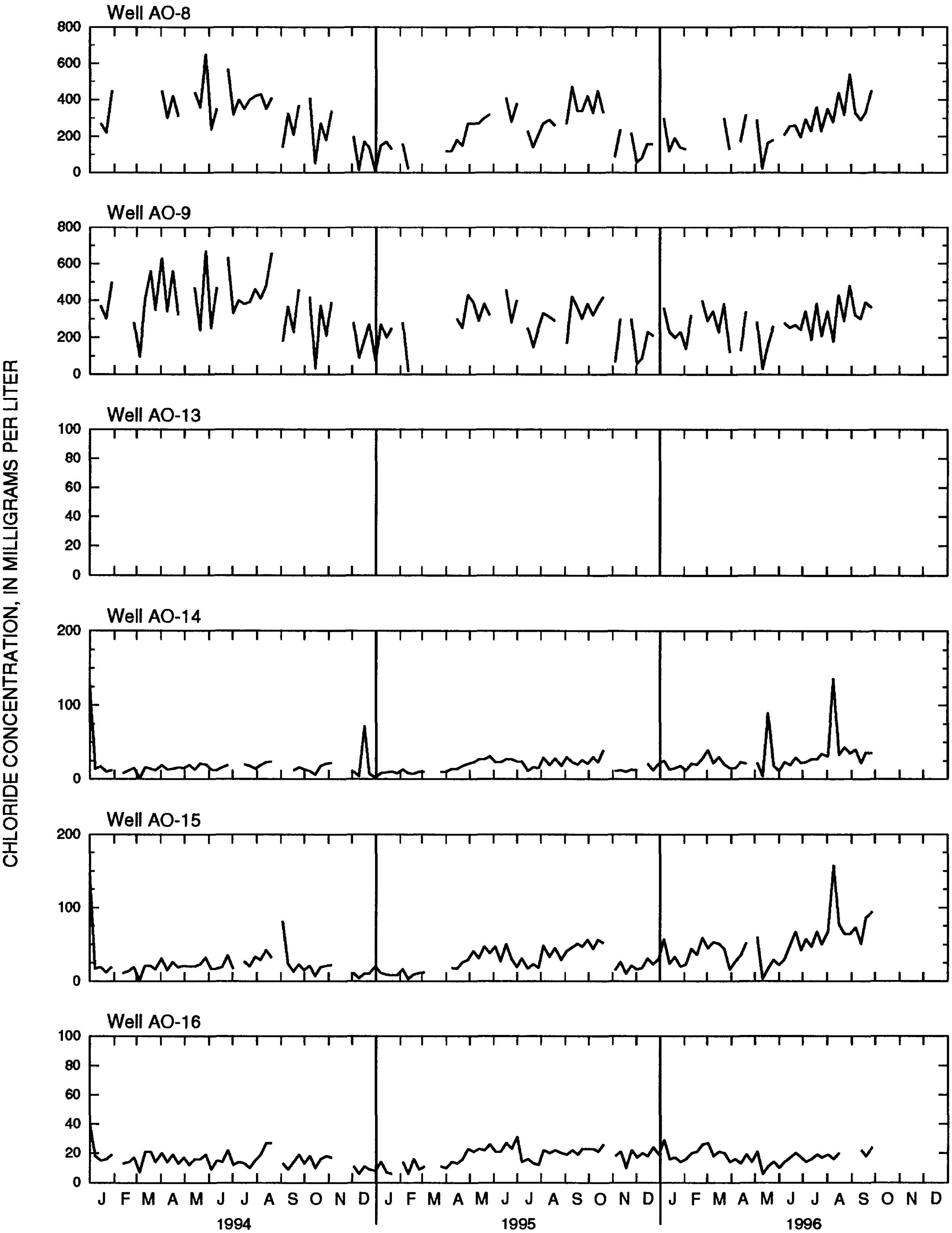


Figure C4. Chloride concentration of pumped water (sampled at weekly intervals) at wells AO-2 through AO-9 and wells AO-13 through AO-19 at Air Operations, Diego Garcia, January 1994 through September 1996. Water from well AO-13 has not been sampled since April 1993--Continued.

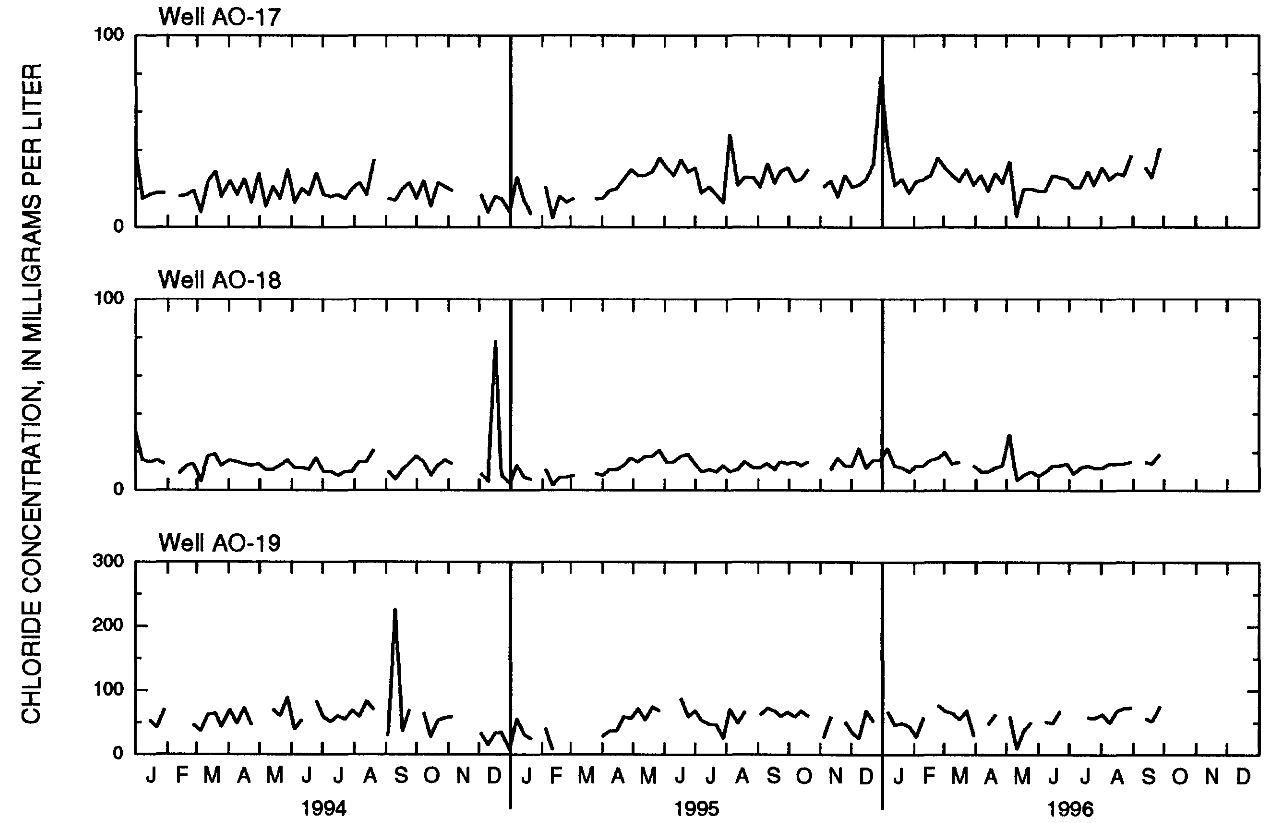


Figure C4. Chloride concentration of pumped water (sampled at weekly intervals) at wells AO-2 through AO-9 and wells AO-13 through AO-19 at Air Operations, Diego Garcia, January 1994 through September 1996. Water from well AO-13 has not been sampled since April 1993--Continued.

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