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

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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 June 1996, with a focus on data from April through June 1996 (second 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--Cumulative rainfall for April through June 1996 was 22.64 inches, which is 12 percent more than the mean cumulative rainfall of 20.21 inches for April through June. The period April through June is part of the annual dry season.

2. GROUND-WATER WITHDRAWAL--Ground-water withdrawal during April through June 1996 averaged 1,048,000 gallons per day. Withdrawal for the same 3 months in 1995 averaged 833,700 gallons per day. Withdrawal patterns during the second quarter of 1996 did not change significantly since 1991, with the Cantonment and Air Operations areas supplying about 99 percent of total islandwide pumpage.

3. CHLORIDE CONCENTRATION OF PUMPED GROUND WATER--At the end of June 1996, the chloride concentration of water from the elevated tanks at Cantonment and Air Operations were 52 and 80 milligrams per liter, respectively. The chloride data from all five production areas showed no significant upward or downward trends throughout the second quarter of 1996. Potable levels of chloride concentrations have been maintained by adjusting individual pumping rates, and also because of the absence of long-term droughts.

4. CHLORIDE CONCENTRATION OF GROUND WATER IN MONITORING WELLS--Chloride concentration of ground water in monitoring wells at Cantonment and Air Operations also showed no significant trends throughout the second quarter of 1996. Chloride concentrations have been about the same since the last quarter of 1995.

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 June 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 April through June 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 June 1996
C. Graphs of chloride concentration of pumped water, January 1994 through June 1996

Acknowledgments

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

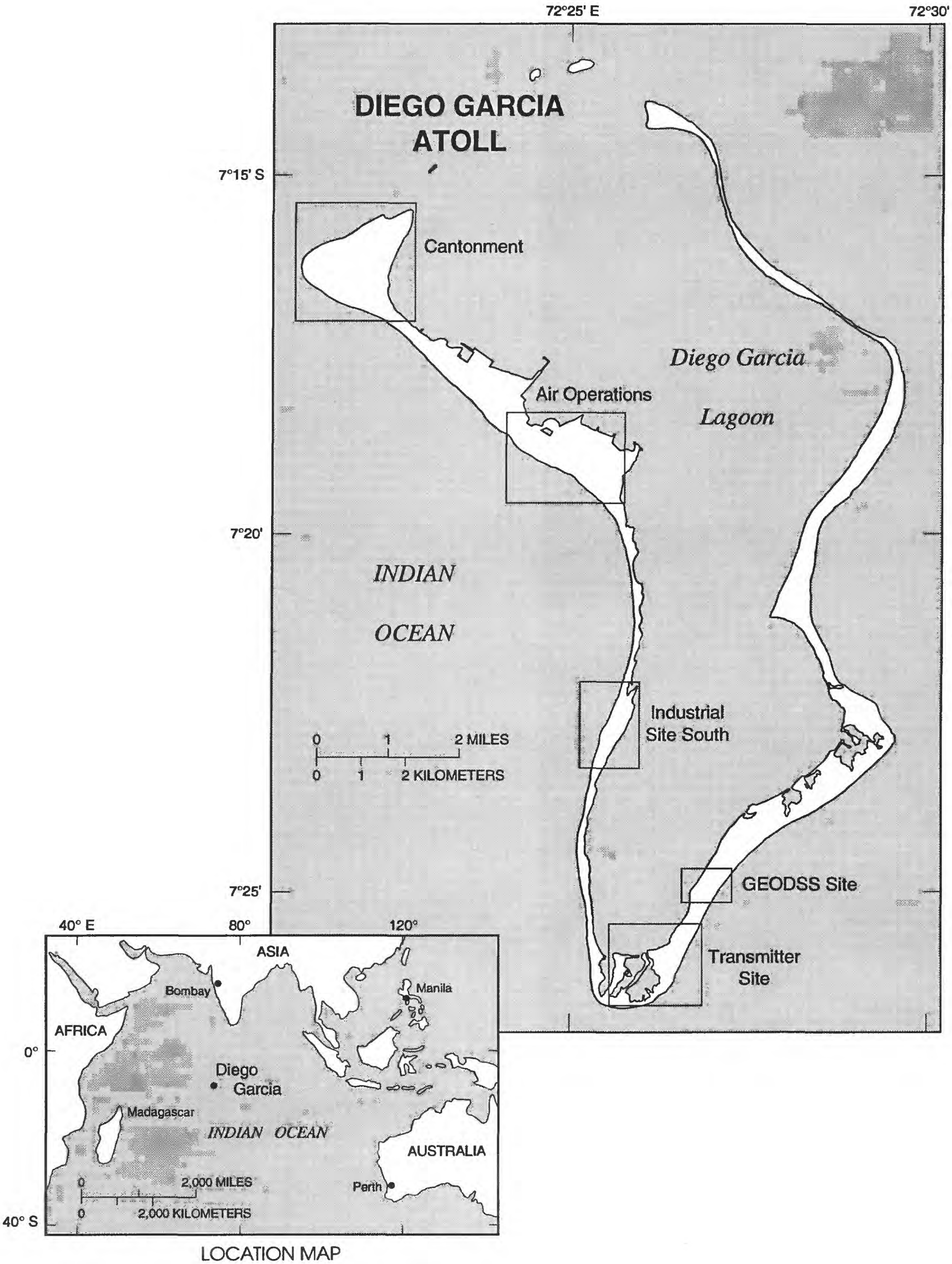


Figure 1. Areas of ground-water production, Diego Garcia.

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.--Cumulative rainfall for April through June 1996 was 22.64 inches, which is 12 percent more than the mean cumulative rainfall of 20.21 inches for April through June. For the same 3 months in 1994 and 1995, the cumulative rainfall was 13.27 inches and 13.67 inches, respectively. For reference, in 1994 the total rainfall of 131.17 inches was 24 percent above the mean annual rainfall, while in 1995 the total rainfall of 111.55 inches was 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. The period April through June is part of the annual dry season. Periods of below average rainfall can be inferred from the graph when the departure from the mean monthly rainfall is less than zero. Rainfall for April and June was less than the respective mean monthly rainfall for April and June, but rainfall was greater than the respective mean monthly value for May.

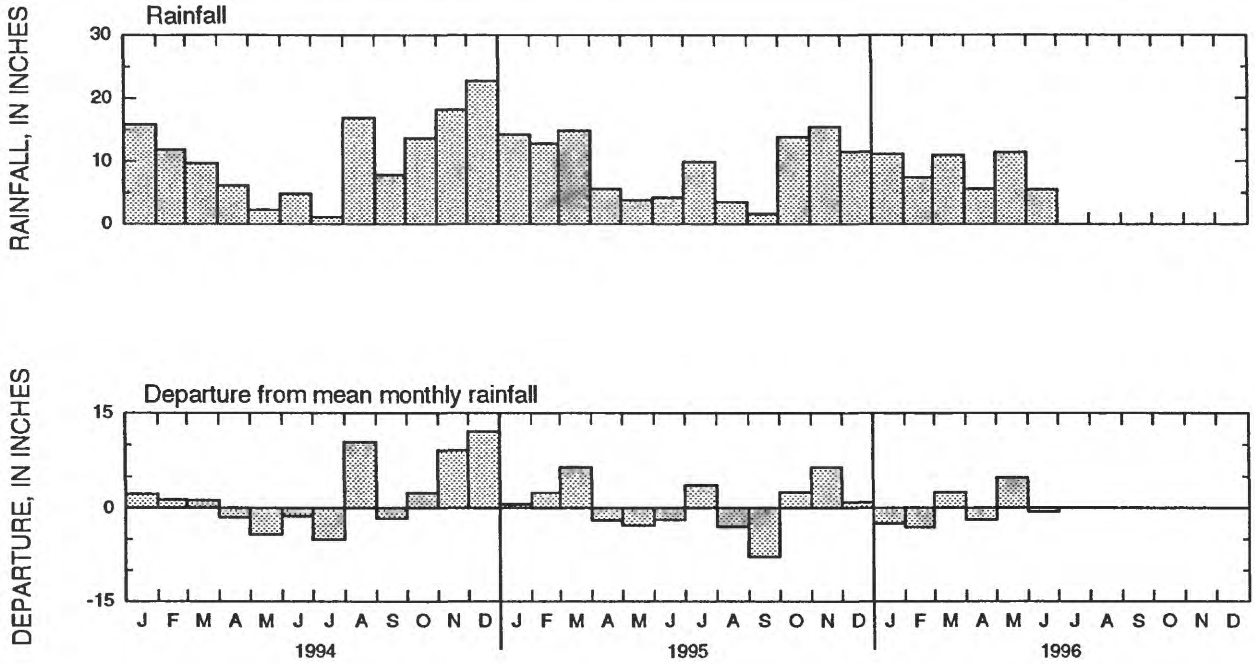


Figure 2. Monthly rainfall and monthly departure from mean monthly rainfall at Air Operations, Diego Garcia, January 1994 through June 1996.

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, of which 80 wells are in the Cantonment area and 18 are in the Air Operations area (figs. A1, 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 remainder 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 secured 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 June 1996. Total islandwide withdrawal increased from 833,700 gal/d during April through June 1995 to 1,048,000 gal/d during April through June 1996. This increase in total withdrawal was supplied from the Cantonment area. Changes in monthly mean withdrawal during the past 18 months at T-Site and GEODSS Site are probably a result of changes in demand because ground water withdrawn from these areas is for local use.

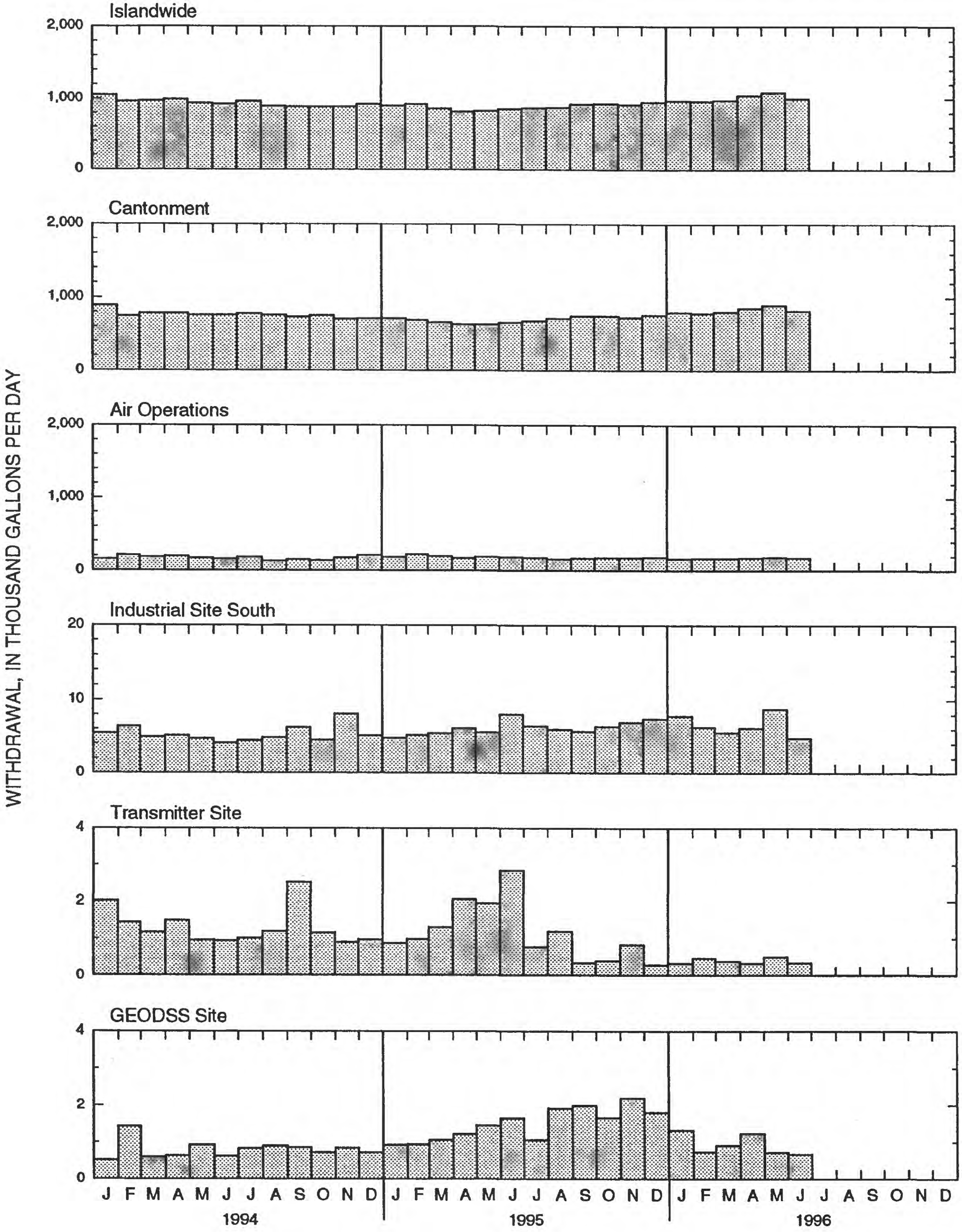


Figure 3. Monthly mean ground-water withdrawal islandwide and in the ground-water production areas, Diego Garcia, January 1994 through June 1996.

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 I-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.--The chloride concentration of water showed no significant upward or downward trends in the five ground-water production areas during the second quarter of 1996 (fig. 4). At Cantonment and Air Operations, which account for about 99 percent of all pumped water, the chloride concentrations have remained at about 50 and 100 mg/L, respectively, since about April 1995. Chloride-concentration data for I-Site, T-Site, and GEODSS Site have decreased by 50 to 100 mg/L since December 1995.

At the end of June 1996, the chloride concentration of water from the elevated tanks at Cantonment and Air Operations were 52 and 80 mg/L, respectively. This is well below the 250 mg/L secondary drinking-water standard.

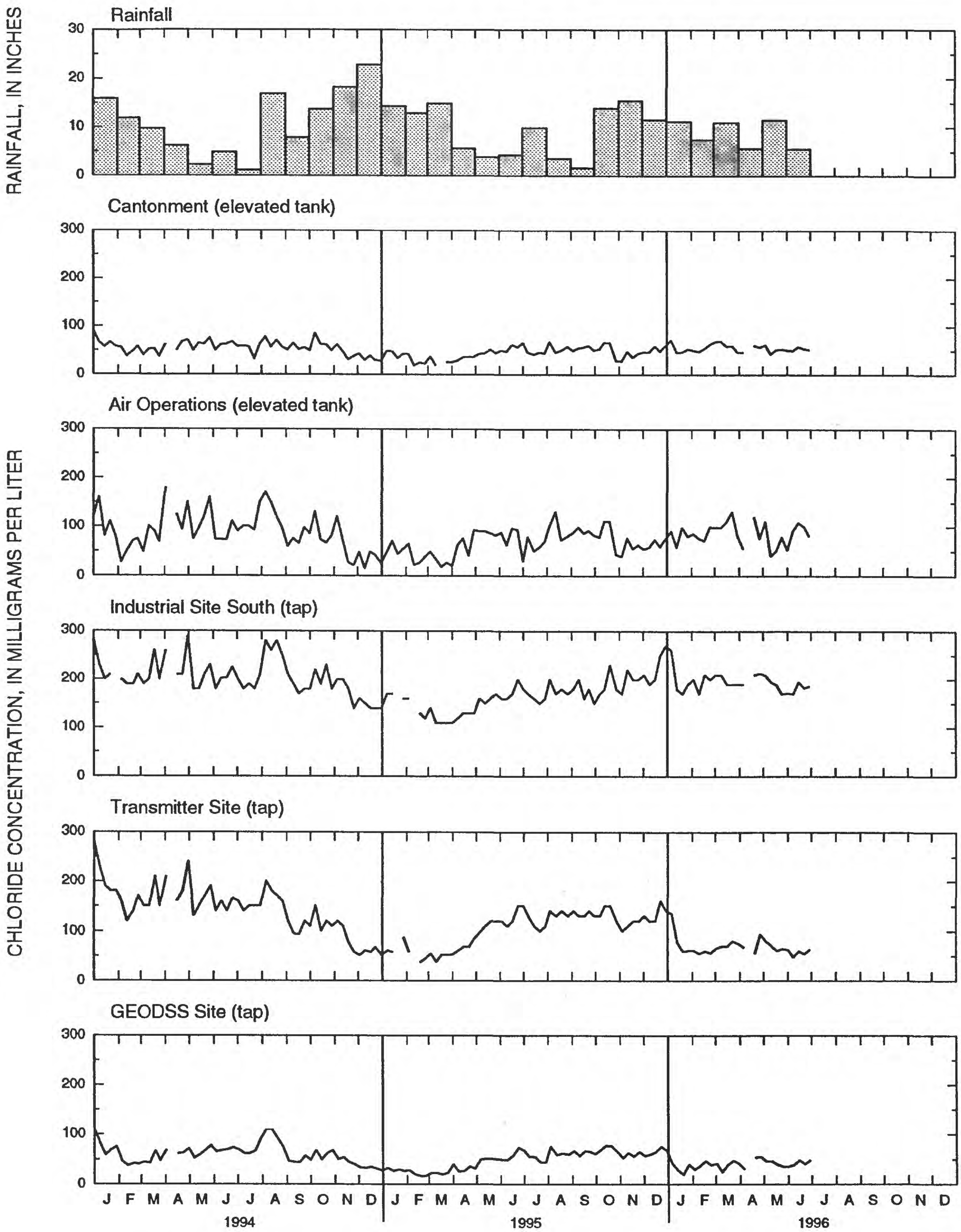


Figure 4. Chloride concentration of pumped water in the ground-water production areas, Diego Garcia, January 1994 through June 1996. Data shown are values from every seventh day extracted from the daily record. Rainfall data are shown for comparison.

CHLORIDE CONCENTRATION OF GROUND WATER IN MONITORING WELLS

Background.--Ground-water chloride concentration is measured monthly at 35 monitoring-well sites (figs. A3, A4) 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. The deeper wells usually 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 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 remained fairly steady at both sites during the period April through June 1996. Chloride concentrations from these selected sites have either slightly decreased or remained about the same since the start of the last annual wet season, which began in September 1995 and ended in February 1996, with the exception of the deepest well at site AW16. The chloride concentration at the 70-foot deep well increased by about 500 mg/L during the second quarter of 1996 (fig. 5). Changes in concentration may lag behind the change in climatic seasons by 1 or 2 months. The period April through June is part of the annual dry season.

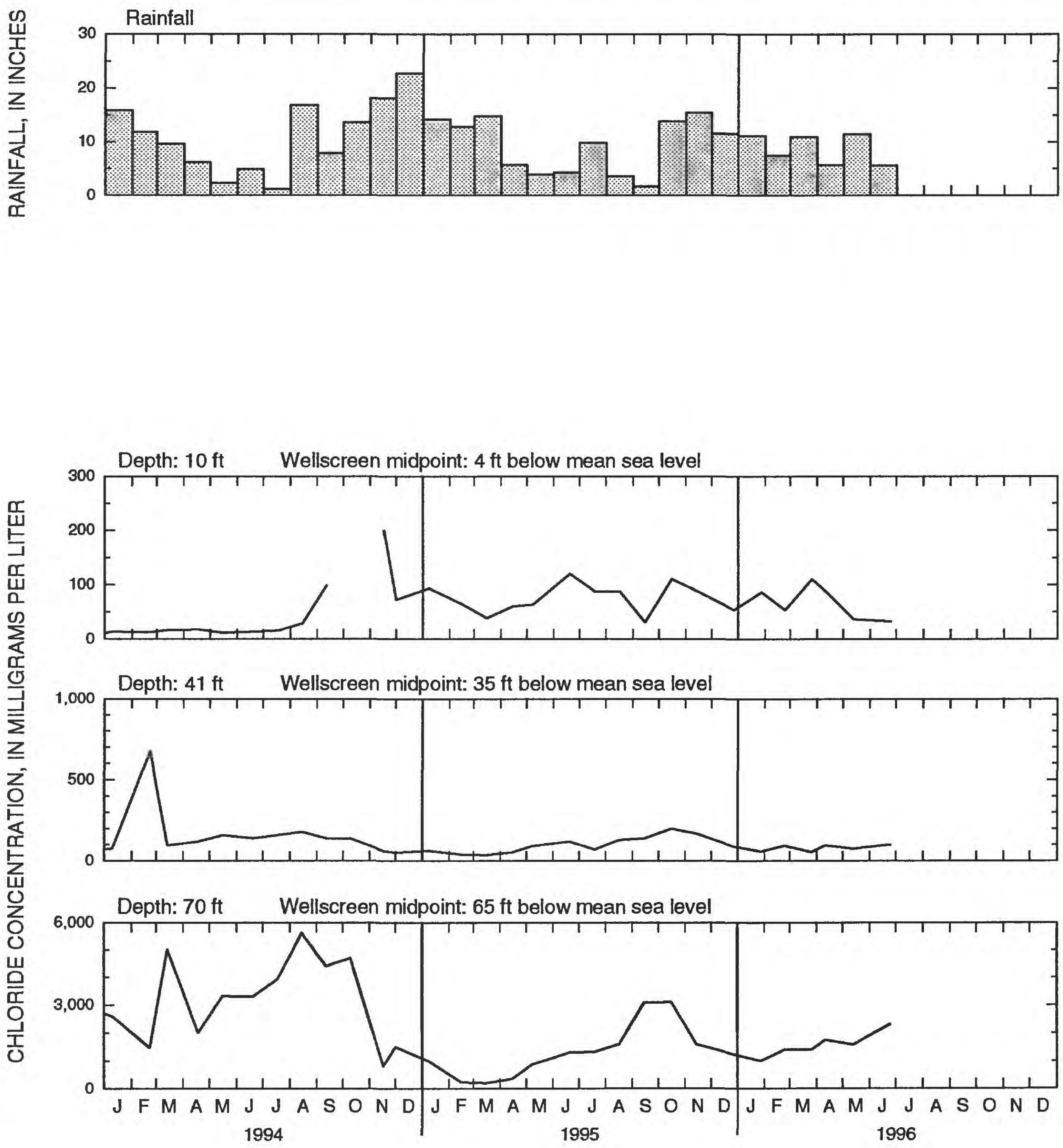


Figure 5. Chloride concentration of ground water (sampled at monthly intervals) in monitoring wells at site AW16 at Cantonment, Diego Garcia, January 1994 through June 1996. Rainfall data are shown for comparison.

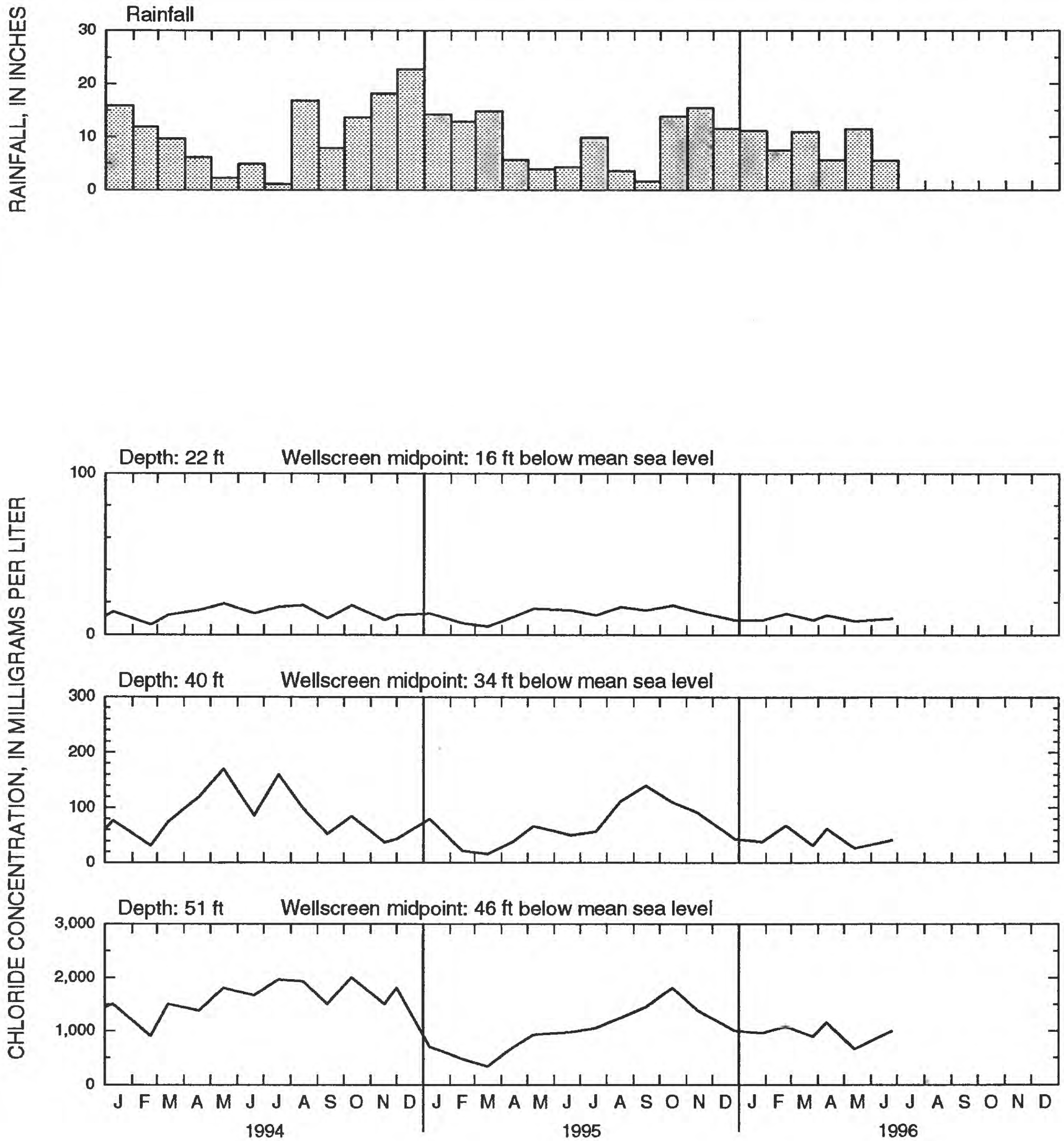


Figure 6. Chloride concentration of ground water (sampled at monthly intervals) in monitoring wells at site BW09 at Air Operations, Diego Garcia, January 1994 through June 1996. Rainfall data are shown for comparison.

FUEL-DIVERSION PROGRAM AT AIR OPERATIONS

Background.--The normal pattern of ground-water withdrawal at Air Operations has been disrupted since May 1991 by a JP-5 jet-fuel leak at the South Ramp parking apron (fig. A2). The leak was about 800 ft upgradient of 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 consists of the injection of water into three wells closest to the leak using water pumped from two other wells. One more well is not pumped at all. An elevated mound in the water table helps to retard the migration of fuel toward the water-supply wells. Subsequent to the leak detection, 10 wells were secured 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.

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 detection 1991 (Torikai, 1995). 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 June 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 April through June 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. [Injection is denoted by negative values; all values are in gallons per day.]

Well	Target rates	Daily mean rates, April through June 1996
AO-10	-30,000	-26,100
AO-11	-50,000	-46,000
AO-12	-70,000	-80,100
AO-13	0	0
AO-14	70,000	66,700
AO-15	80,000	78,000

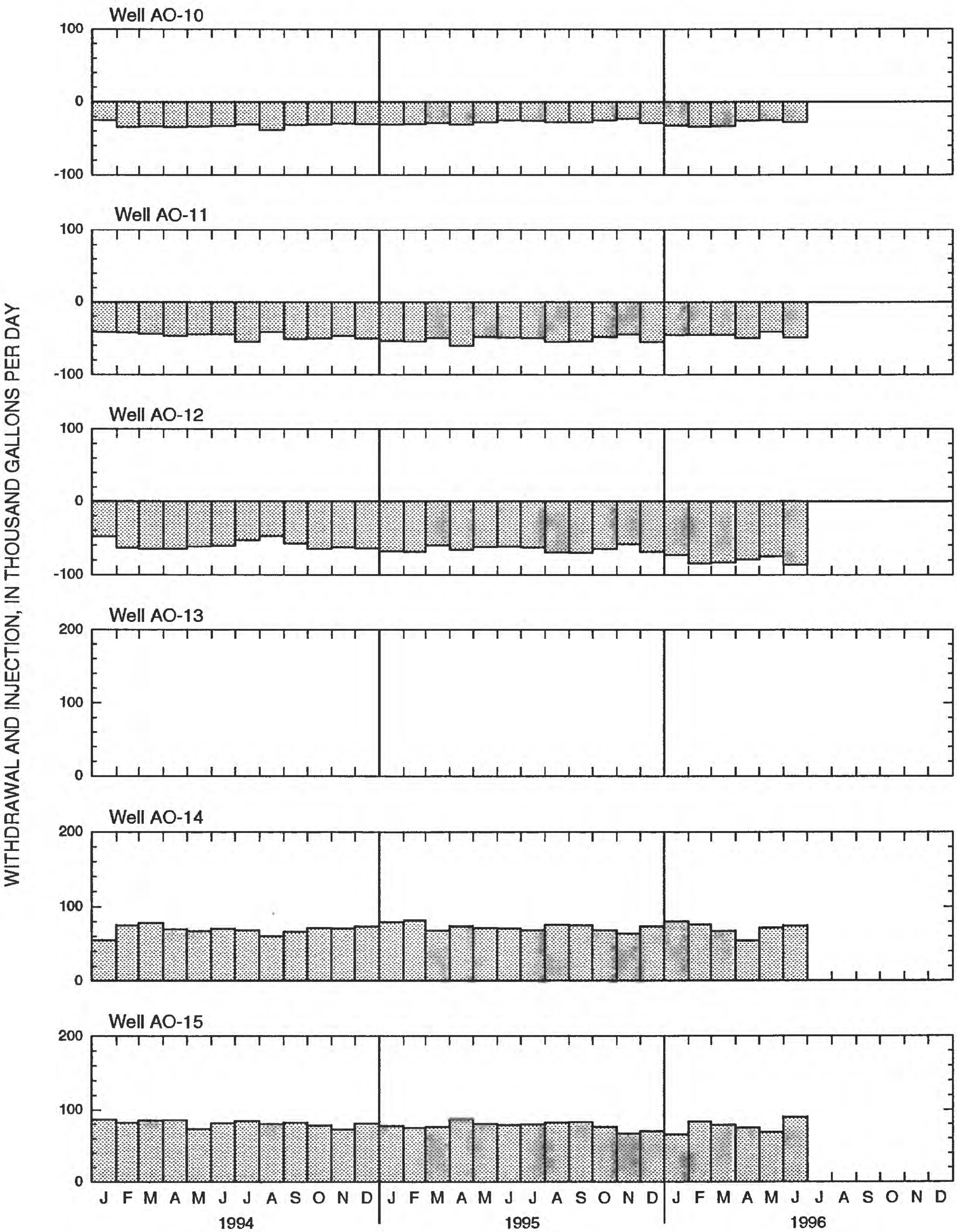


Figure 7. Monthly mean ground-water withdrawal and injection at wells AO-10 through AO-15 at Air Operations, Diego Garcia, January 1994 through June 1996. Injection is plotted as negative.

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 June 1996
C. Graphs of chloride concentration of pumped water, January 1994 through June 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 five to eight vertical wells that are pumped to a common collection/transfer tank.
2. Module B is a horizontal well with a collection/transfer tank; has not pumped since August 1986.
3. Wells H1 through H7 are horizontal wells.
4. Quad wells are a well field of four vertical wells; originally, six wells drilled.
5. Jungle wells are a well field of 11 vertical wells; have not pumped since February 1987.

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

SECTION A

Maps of production and monitoring wells at Cantonment and Air Operations

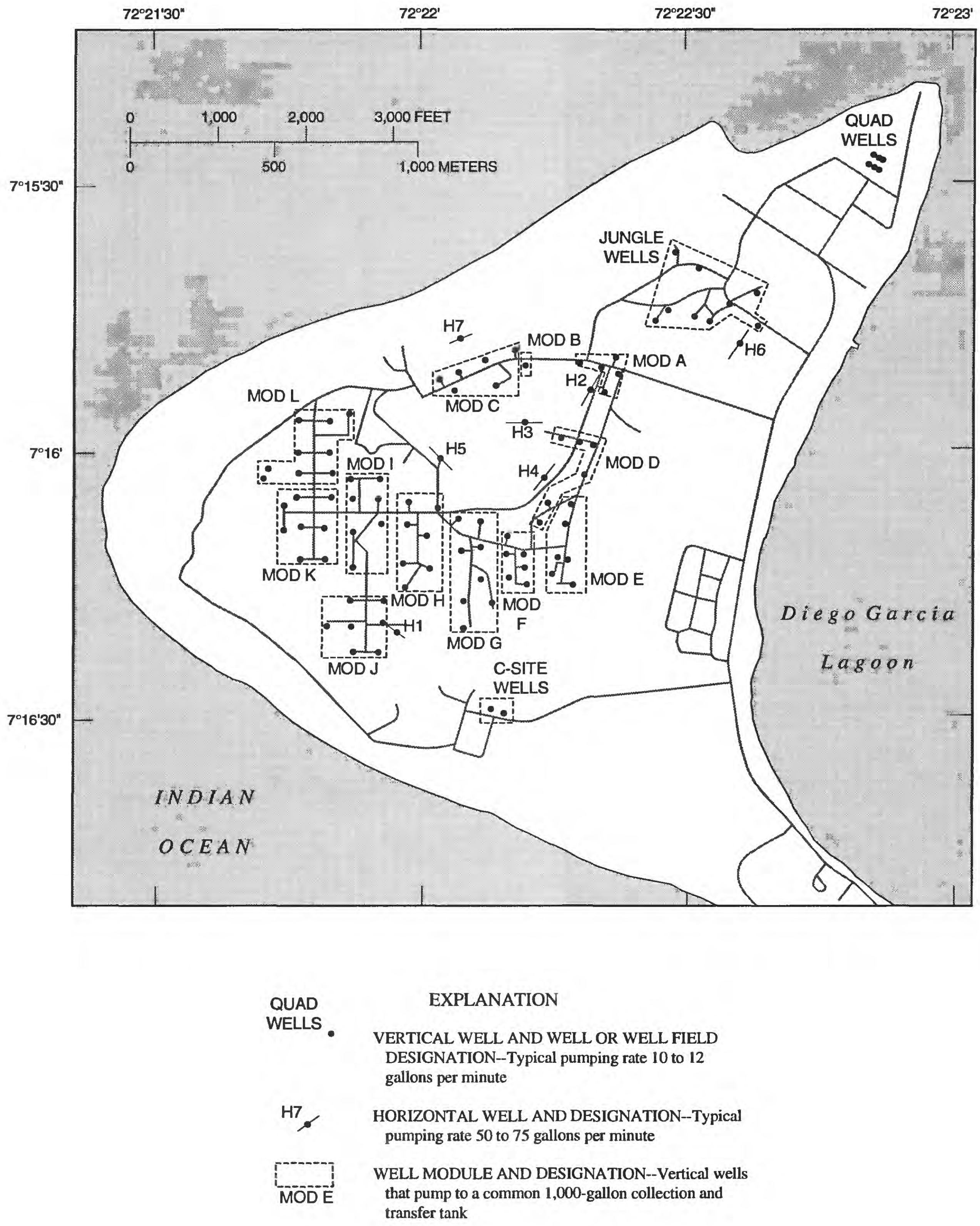


Figure A1. Ground-water production wells and well fields at Cantonment, Diego Garcia.

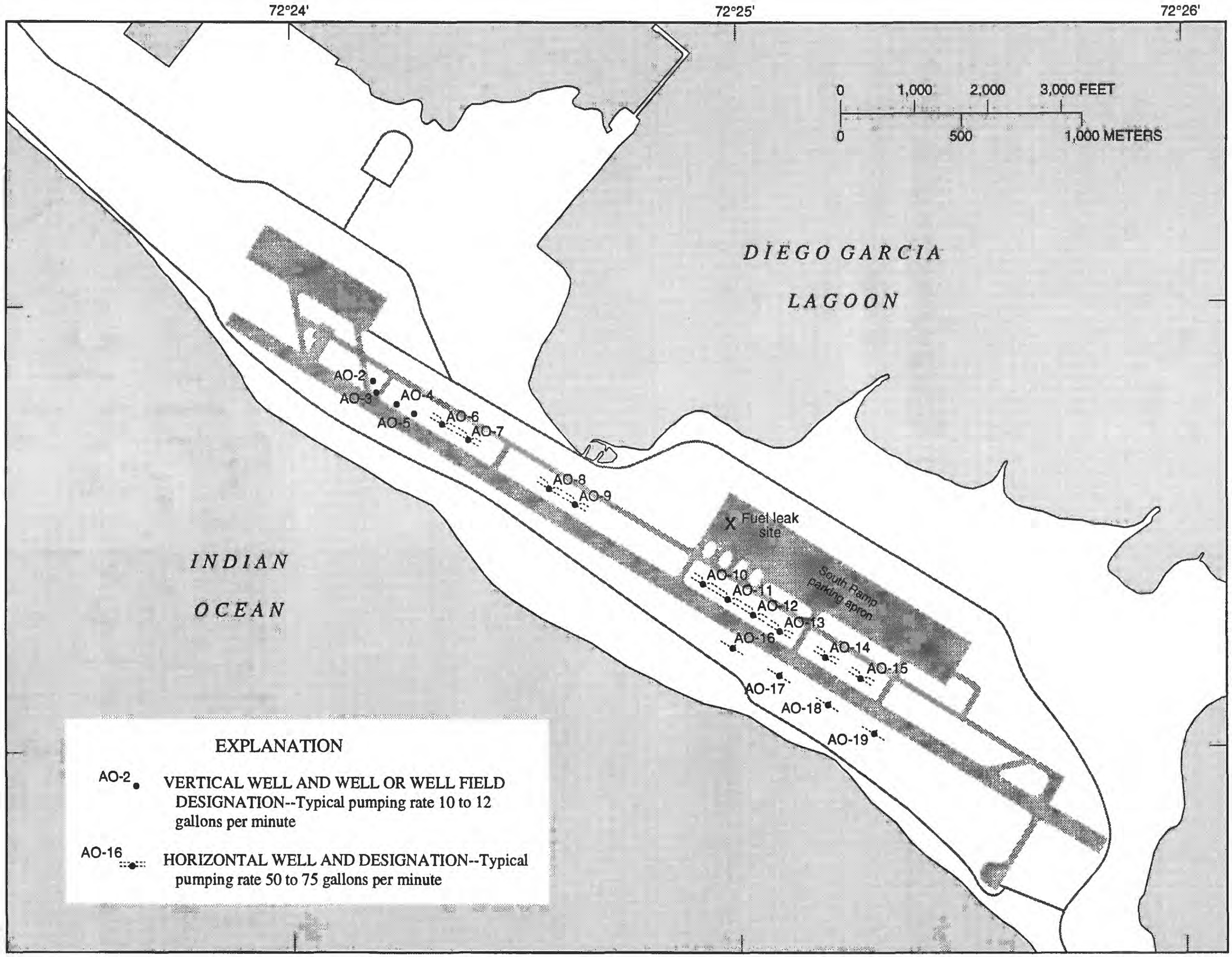
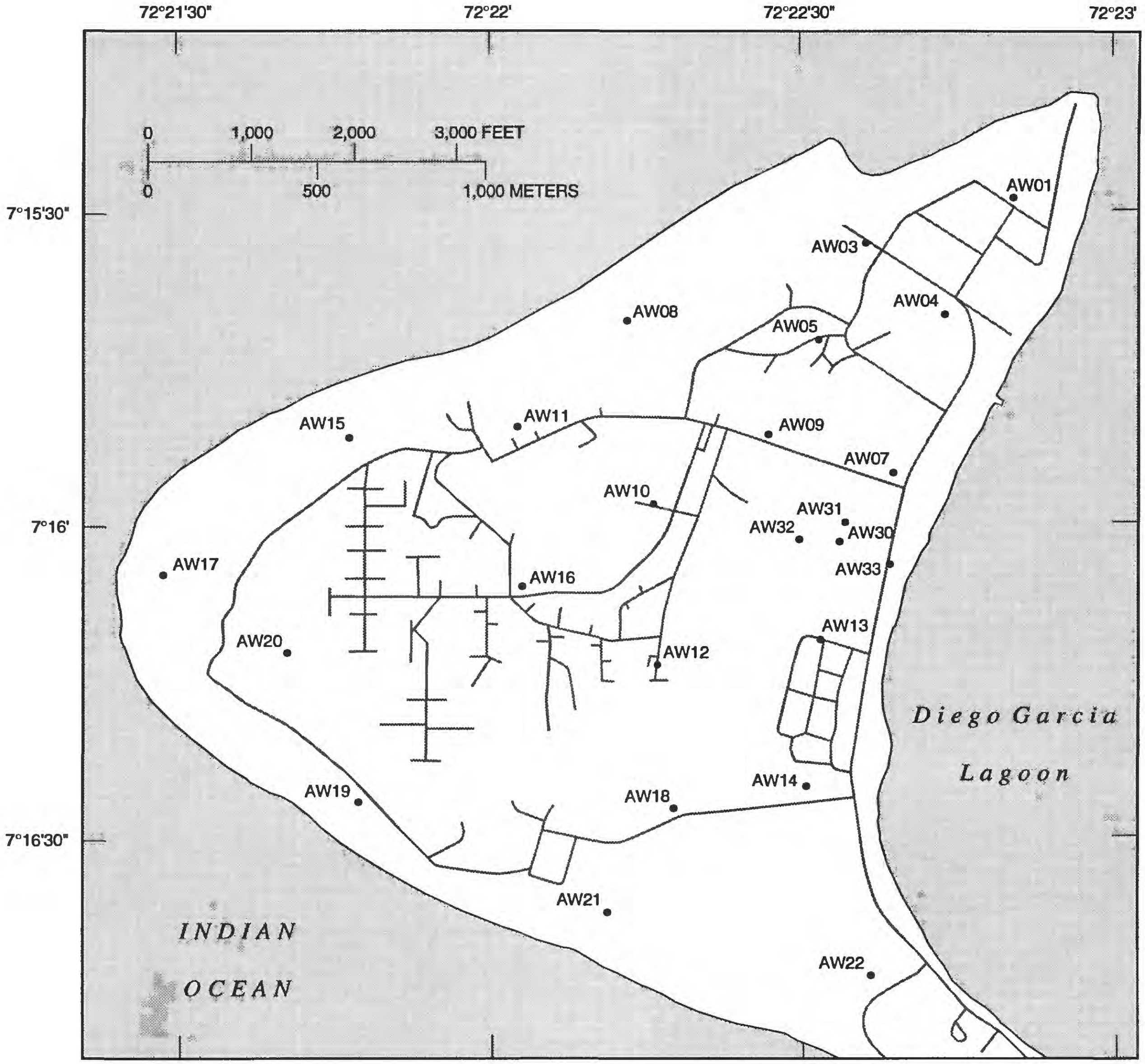


Figure A2. Ground-water production wells at Air Operations, Diego Garcia.



EXPLANATION

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

Figure A3. Monitoring wells at Cantonment, Diego Garcia.

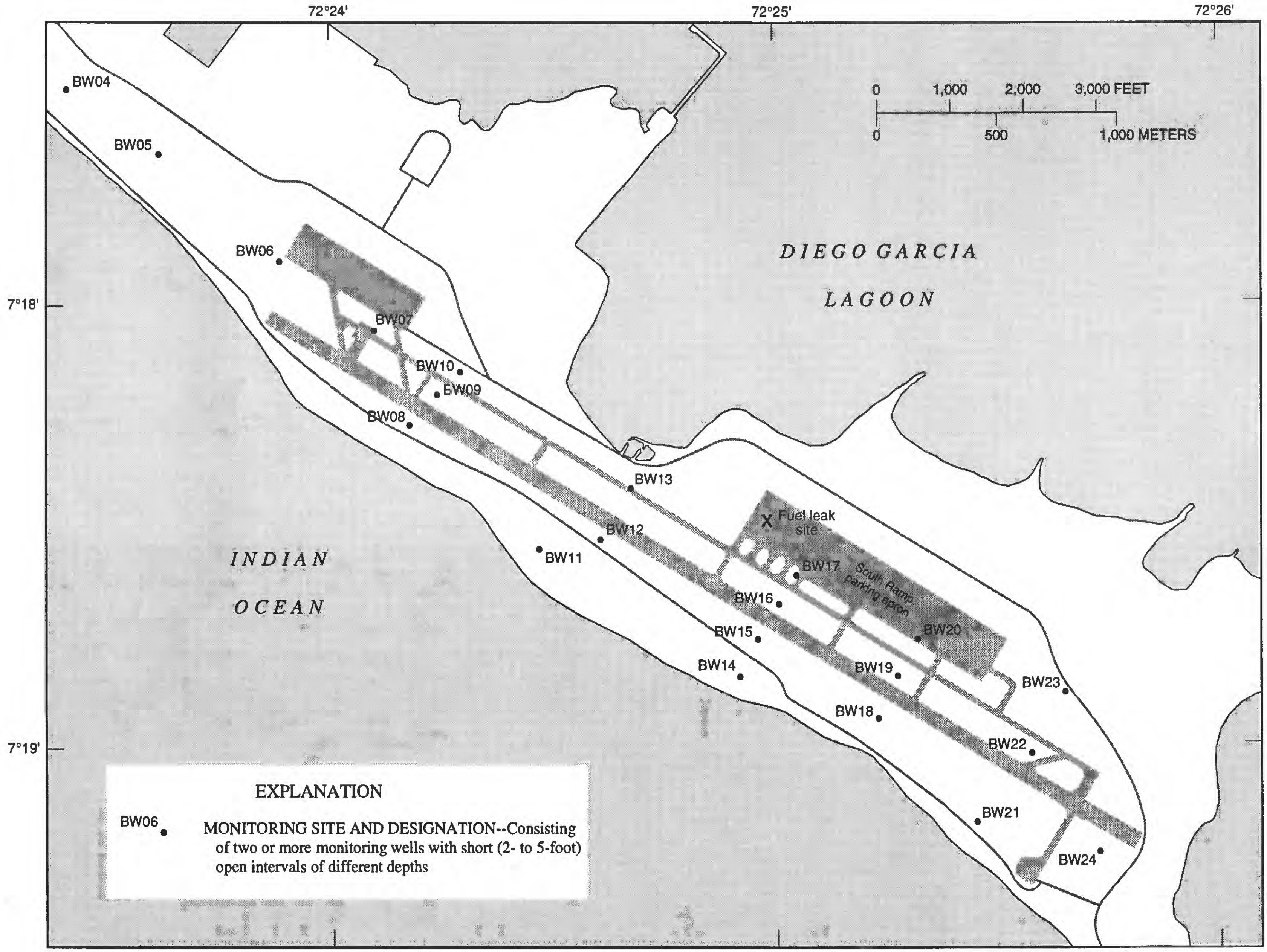


Figure A4. Monitoring wells at Air Operations, Diego Garcia.

SECTION B

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

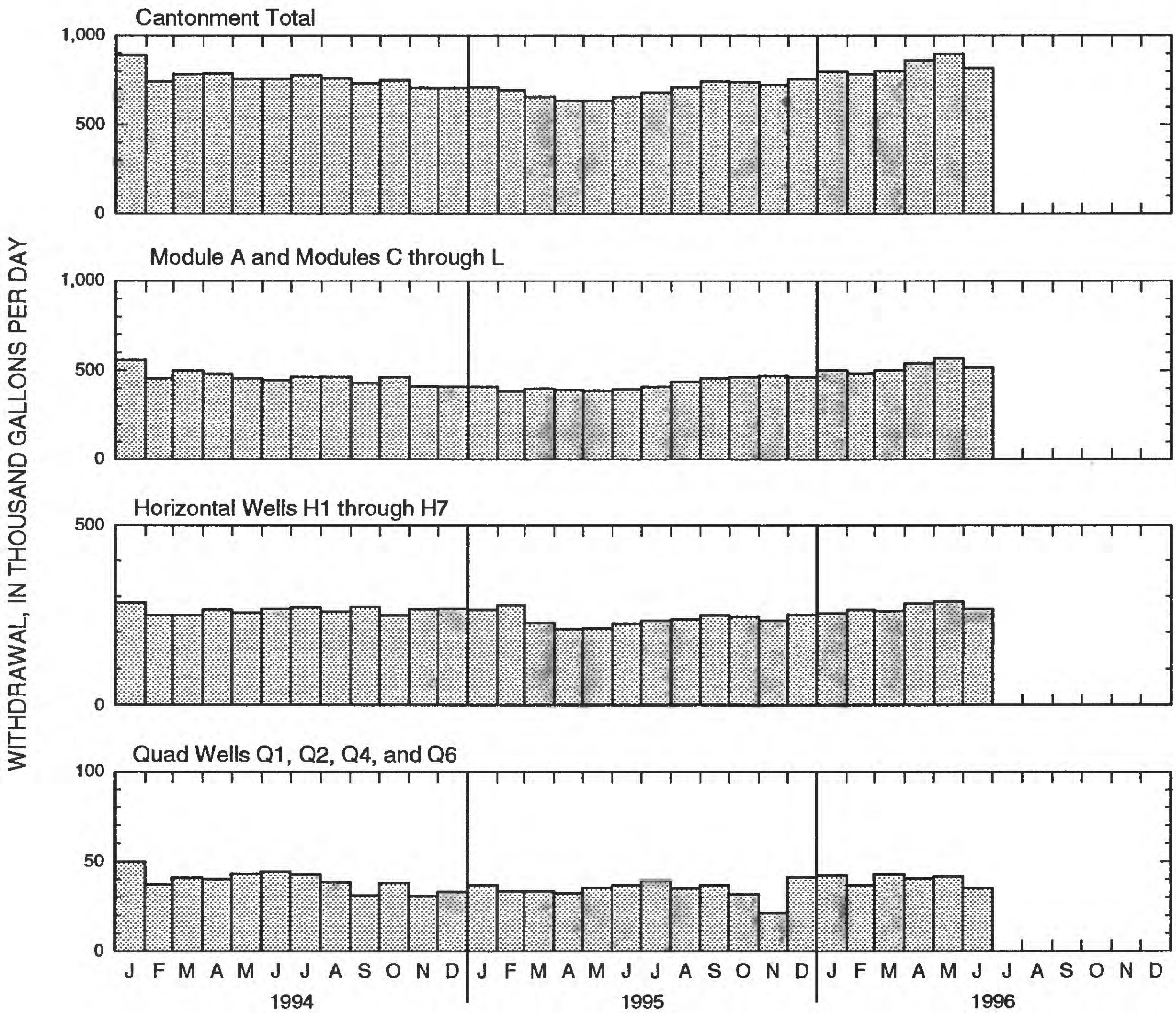


Figure B1. Monthly mean ground-water withdrawal at Cantonment, Diego Garcia, January 1994 through June 1996.

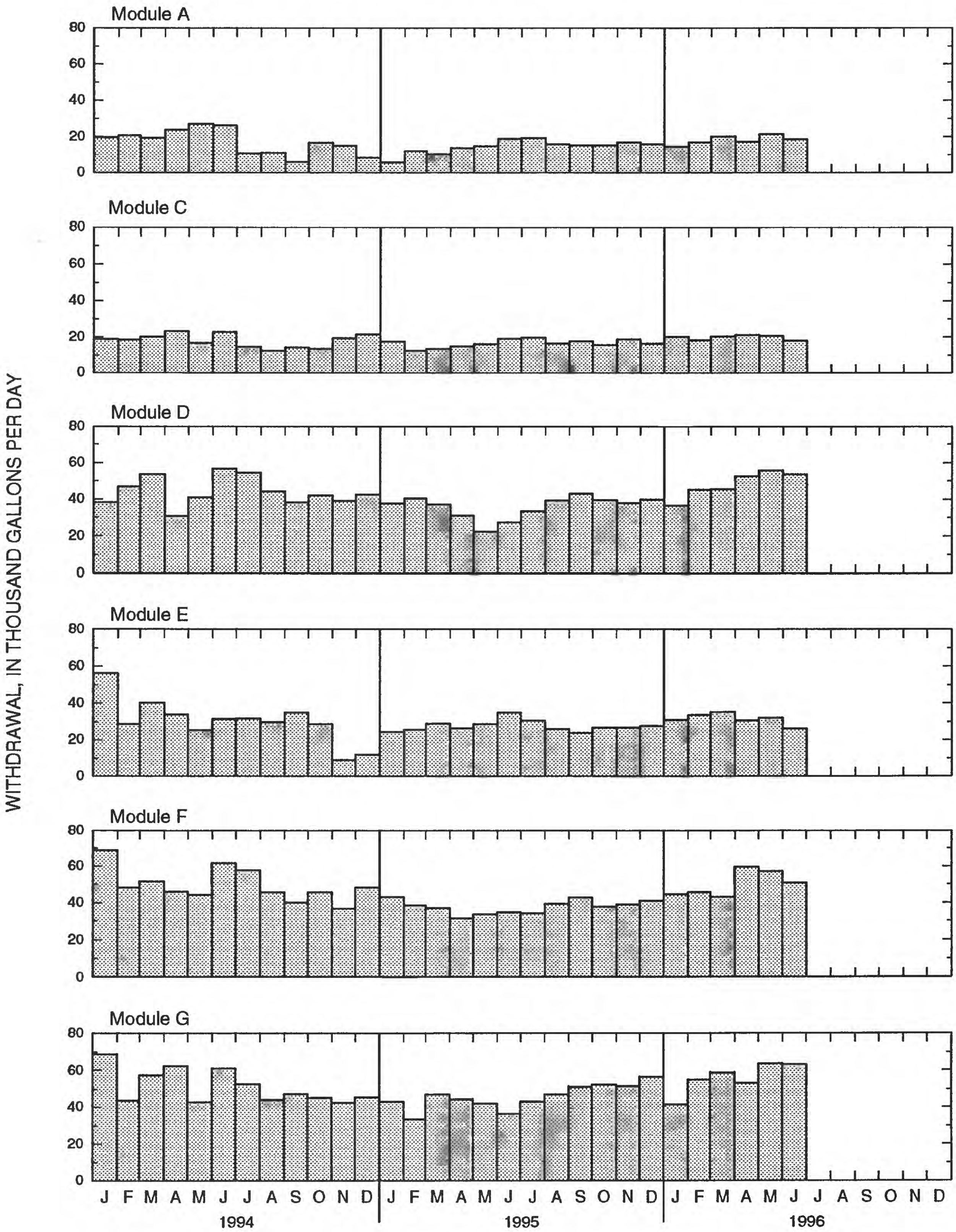


Figure B2. Monthly mean ground-water withdrawal at Module A and Modules C through L at Cantonment, Diego Garcia, January 1994 through June 1996.

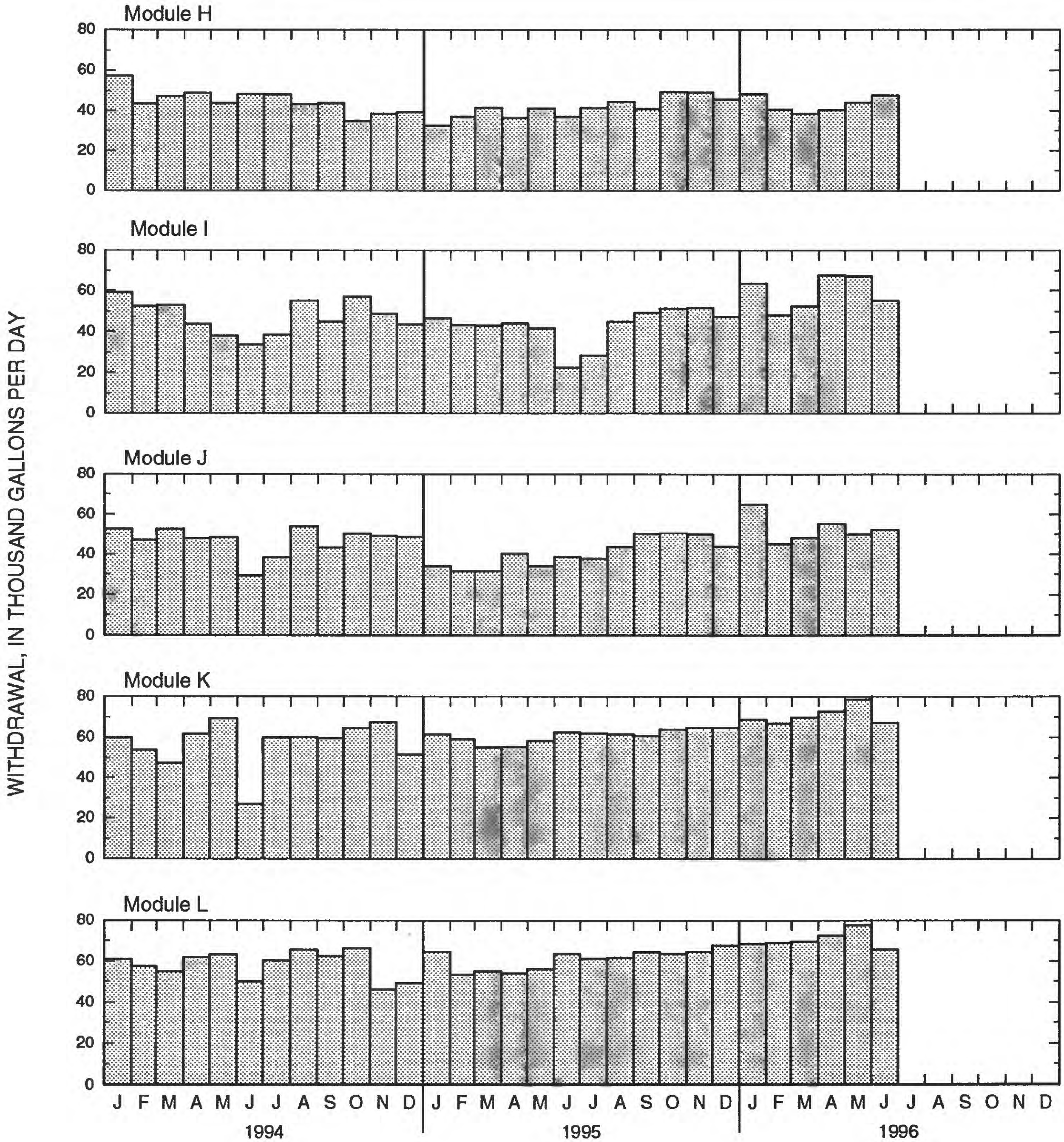


Figure B2. Monthly mean ground-water withdrawal at Module A and Modules C through L at Cantonment, Diego Garcia, January 1994 through June 1996--Continued.

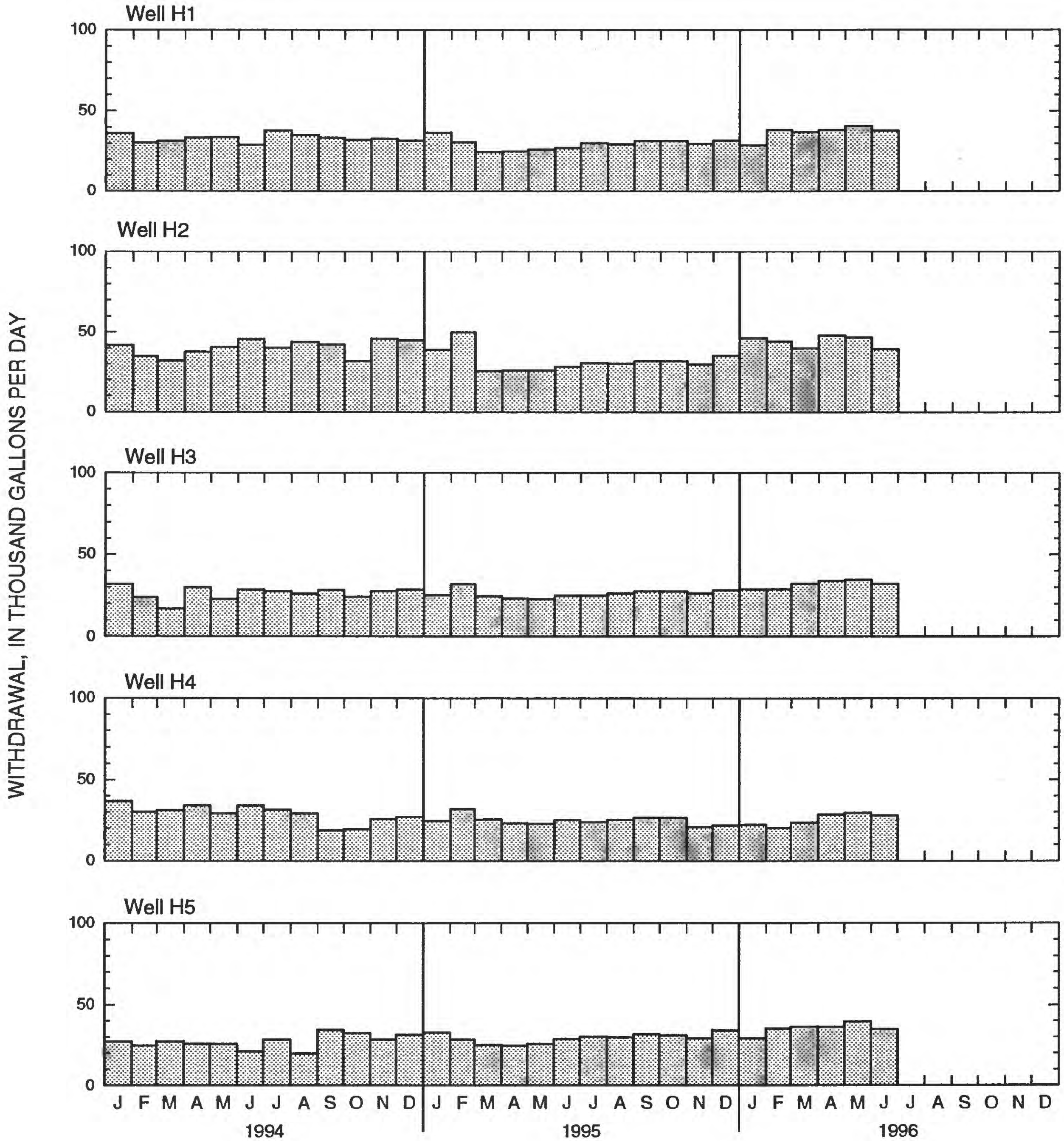


Figure B3. Monthly mean ground-water withdrawal at Horizontal wells H1 through H7 at Cantonment, Diego Garcia, January 1994 through June 1996.

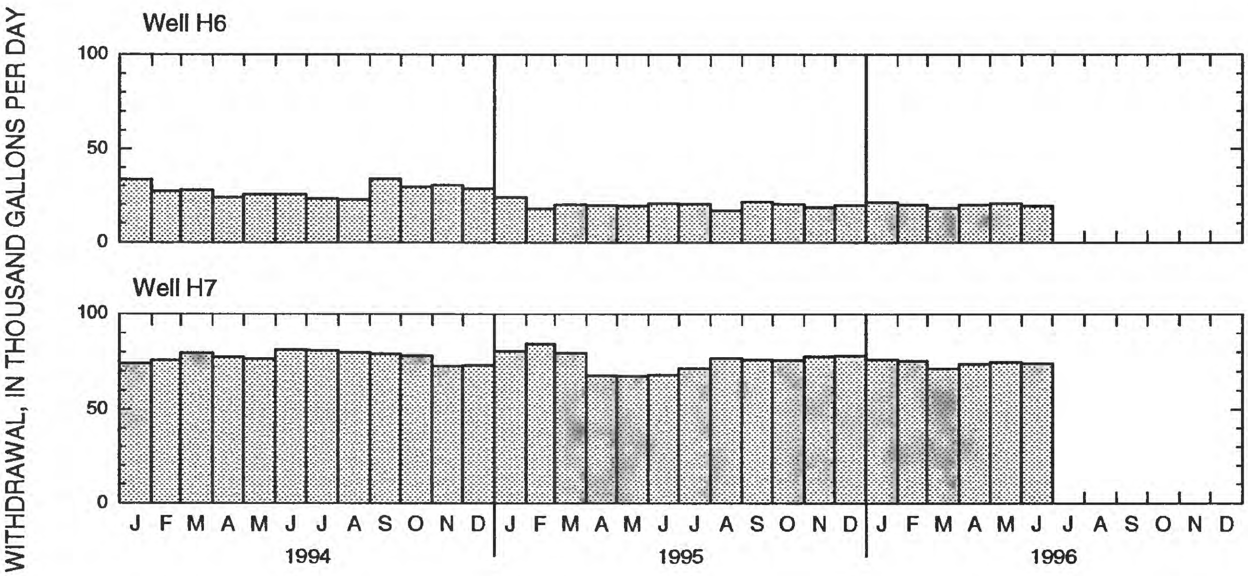


Figure B3. Monthly mean ground-water withdrawal at Horizontal wells H1 through H7 at Cantonment, Diego Garcia, January 1994 through June 1996--Continued.

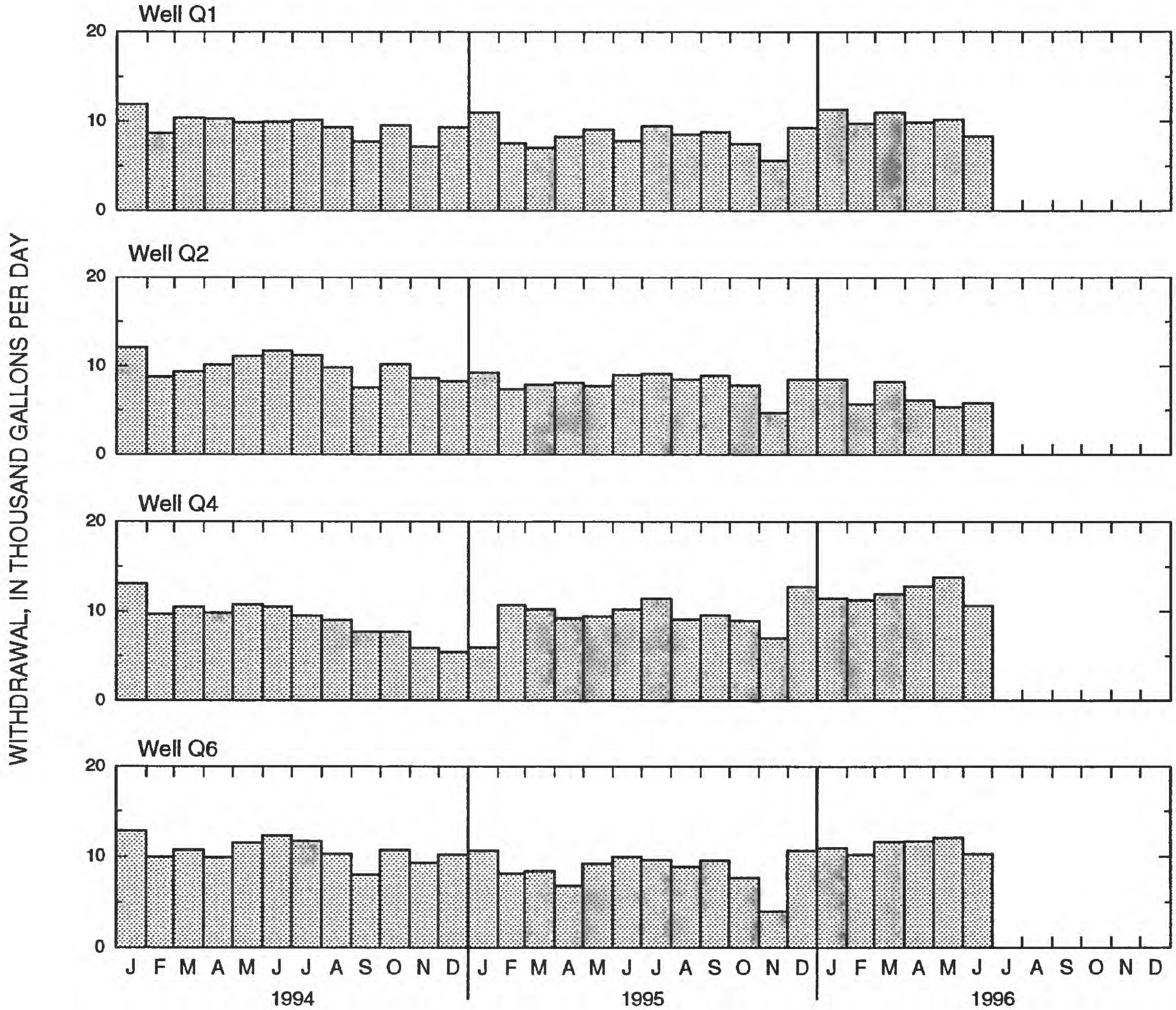


Figure B4. Monthly mean ground-water withdrawal at Quad wells Q1, Q2, Q4, and Q6 at Cantonment, Diego Garcia, January 1994 through June 1996.

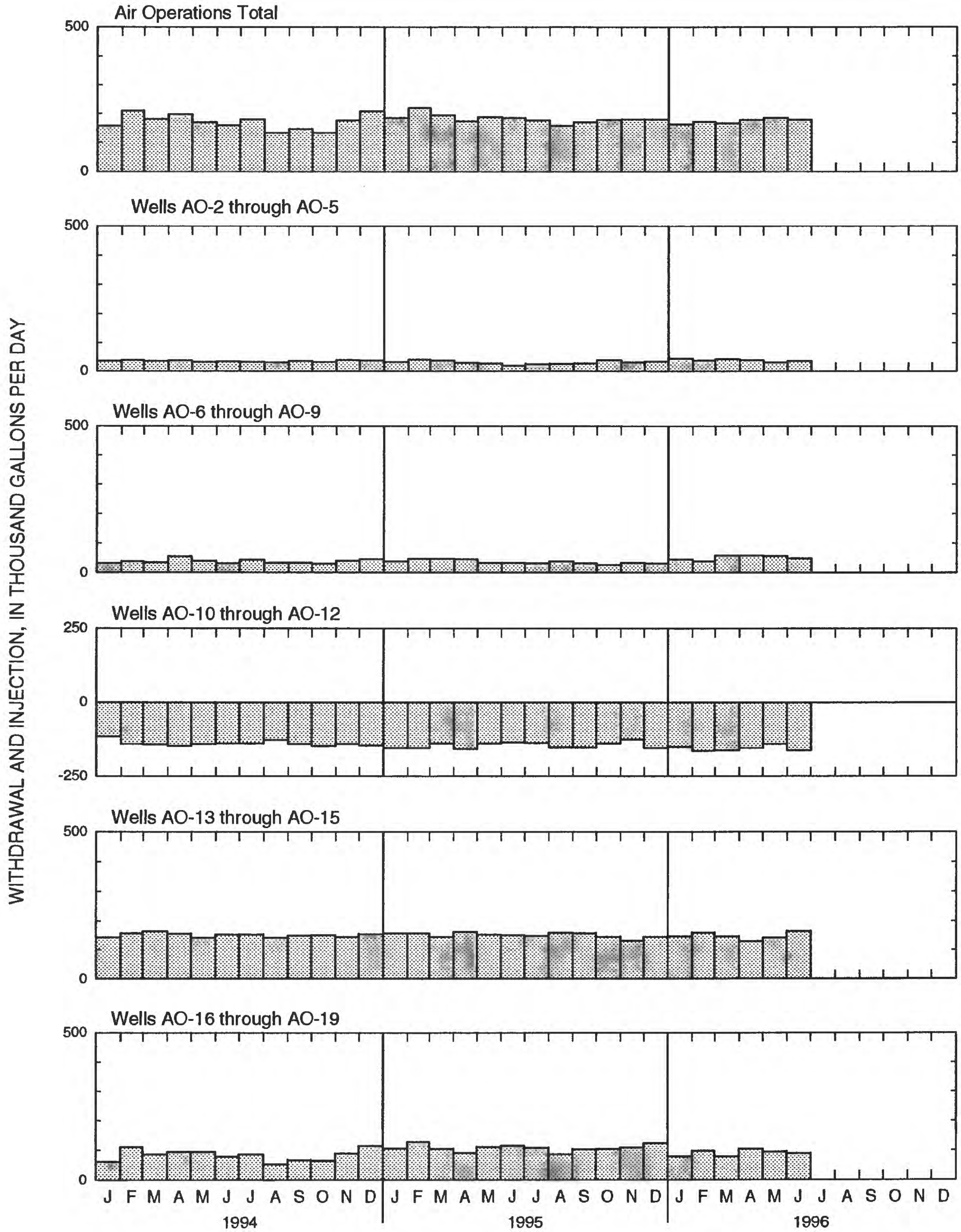


Figure B5. Monthly mean ground-water withdrawal and injection at Air Operations, Diego Garcia, January 1994 through June 1996. Injection is plotted as negative.

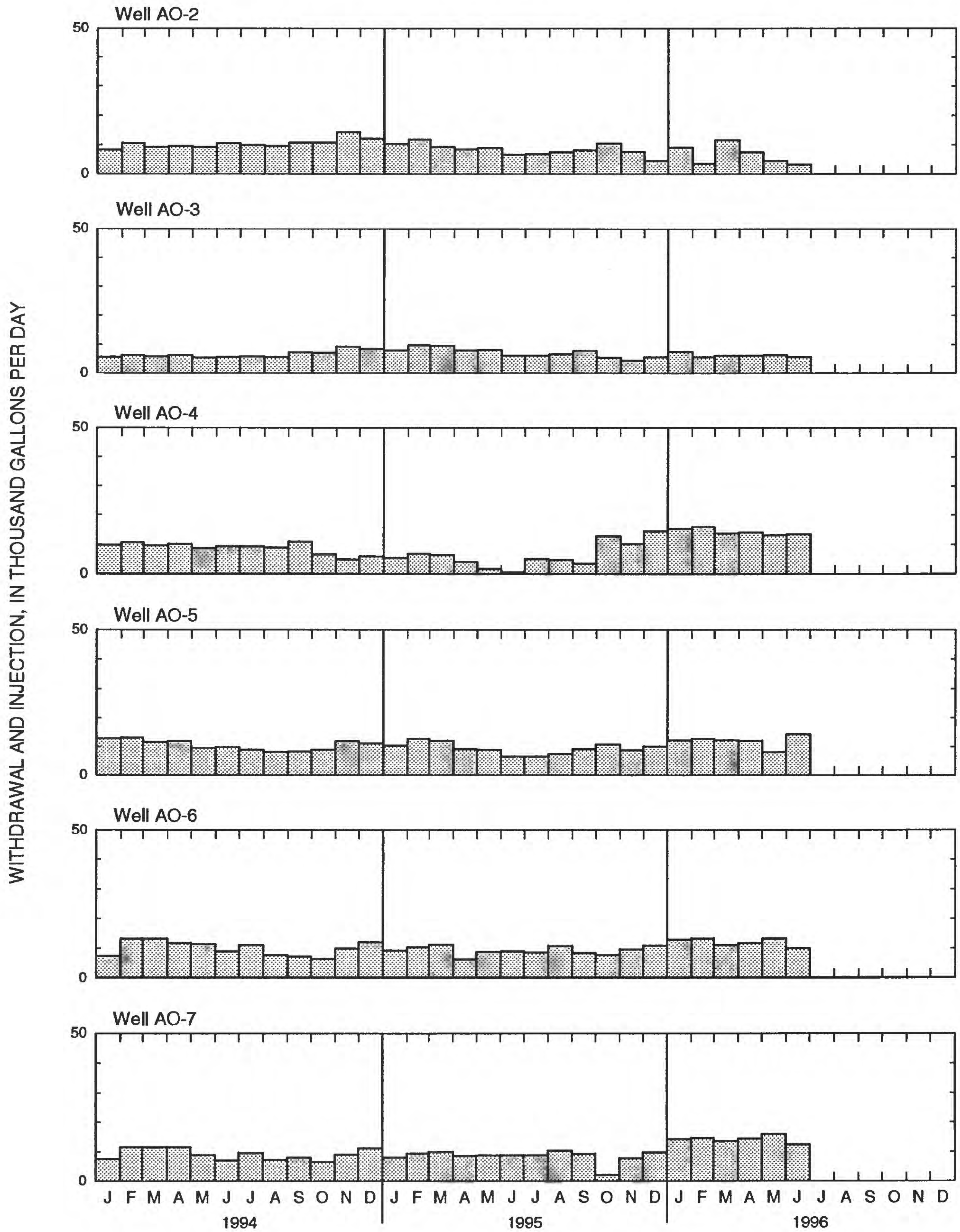


Figure B6. Monthly mean ground-water withdrawal and injection at wells AO-2 through AO-19 at Air Operations, Diego Garcia, January 1994 through June 1996. Injection is plotted as negative.

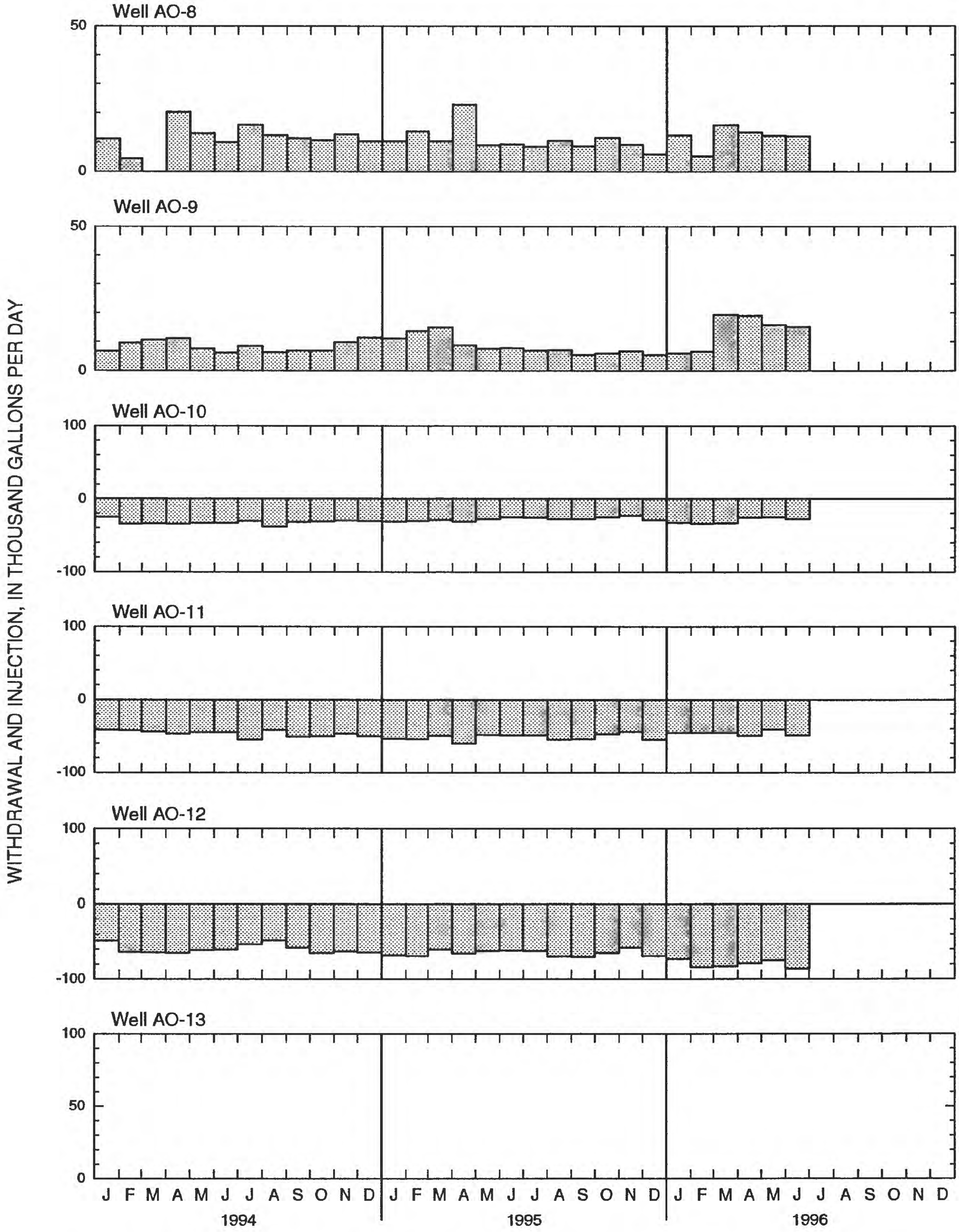


Figure B6. Monthly mean ground-water withdrawal and injection at wells AO-2 through AO-19 at Air Operations, Diego Garcia, January 1994 through June 1996. Injection is plotted as negative--Continued.

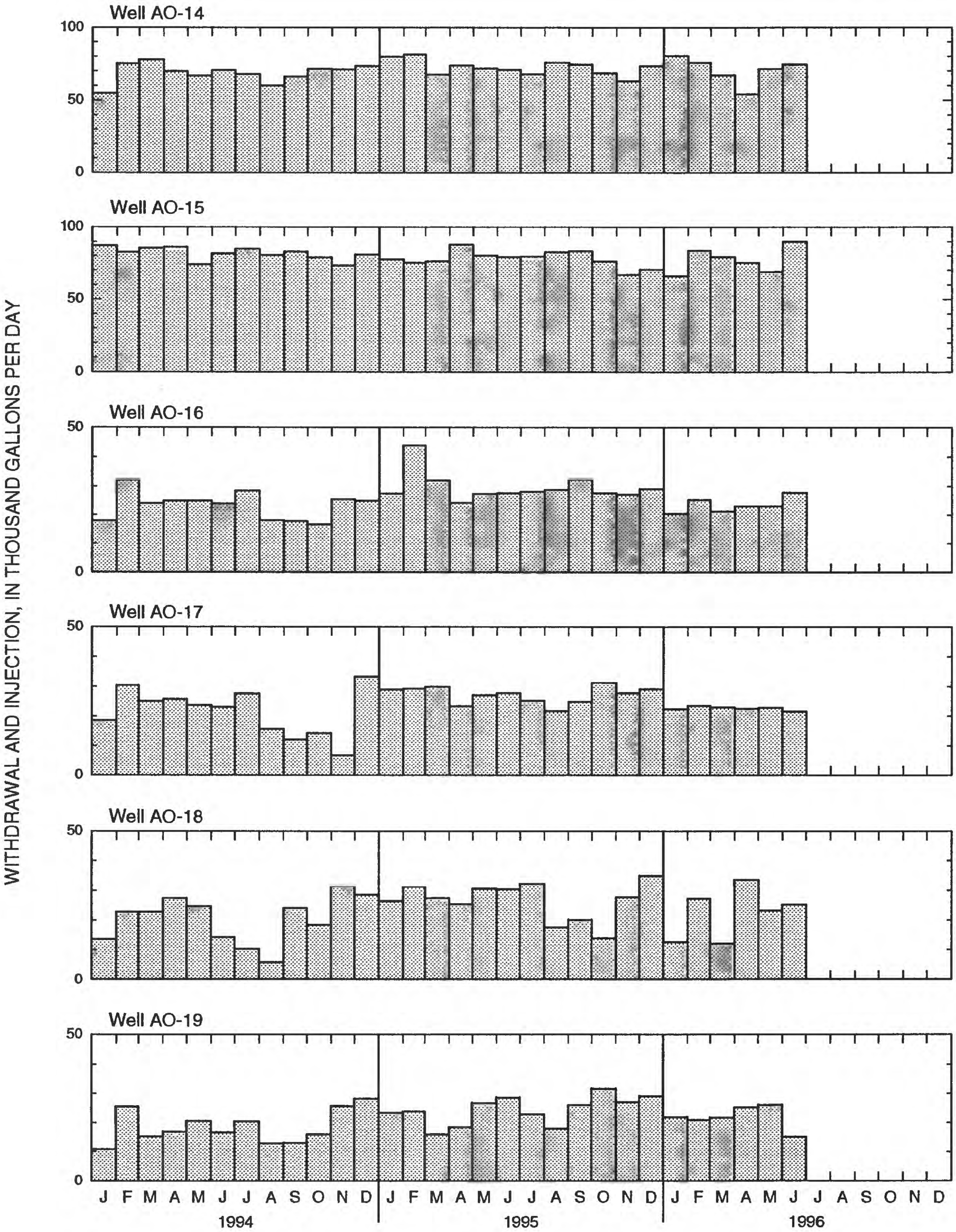


Figure B6. Monthly mean ground-water withdrawal and injection at wells AO-2 through AO-19 at Air Operations, Diego Garcia, January 1994 through June 1996. Injection is plotted as negative--Continued.

SECTION C

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

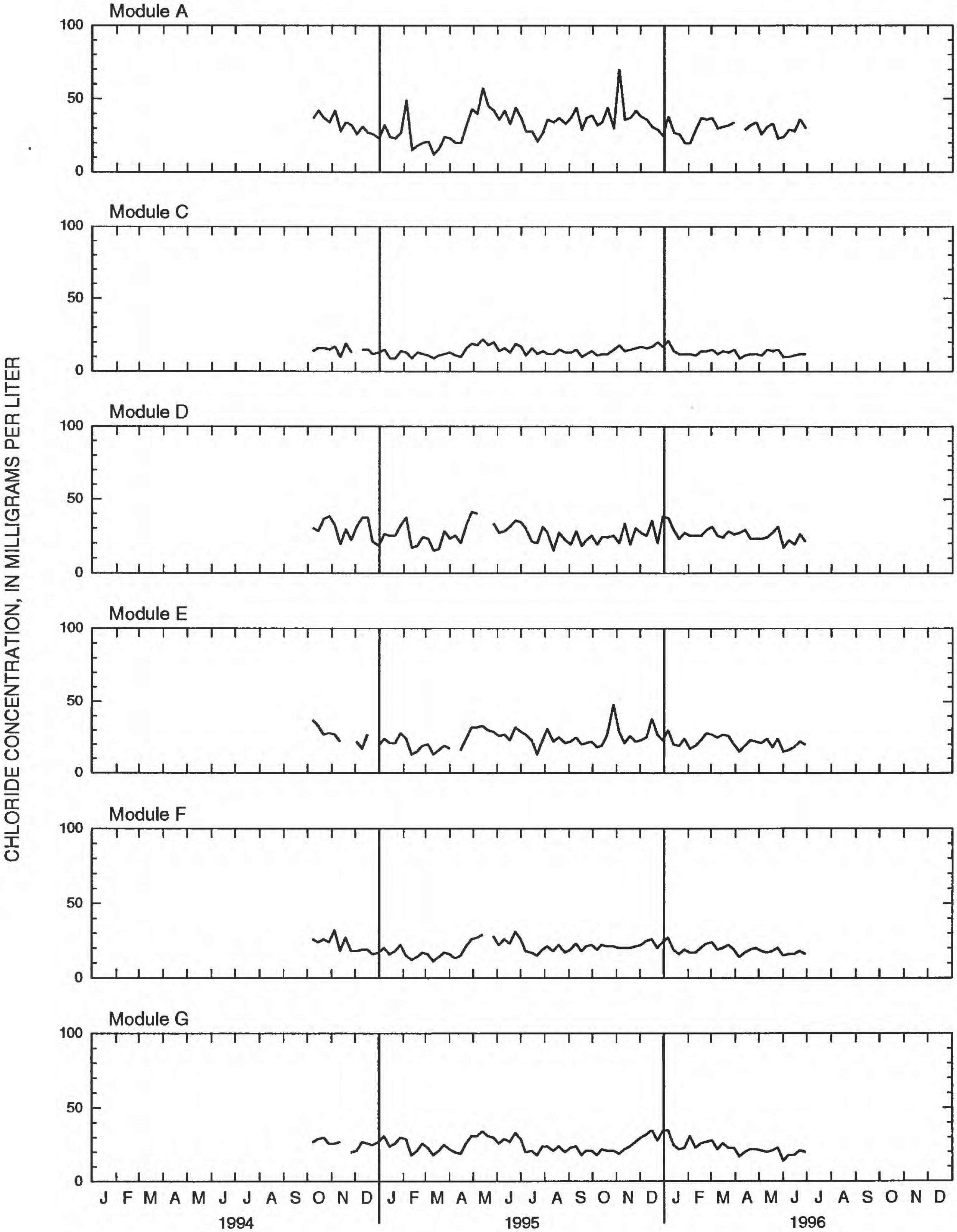


Figure C1. Chloride concentration of pumped water (sampled at weekly intervals) at Module A and Modules C through L at Cantonment, Diego Garcia, January 1994 through June 1996. Data not available for November 1993 through September 1994.

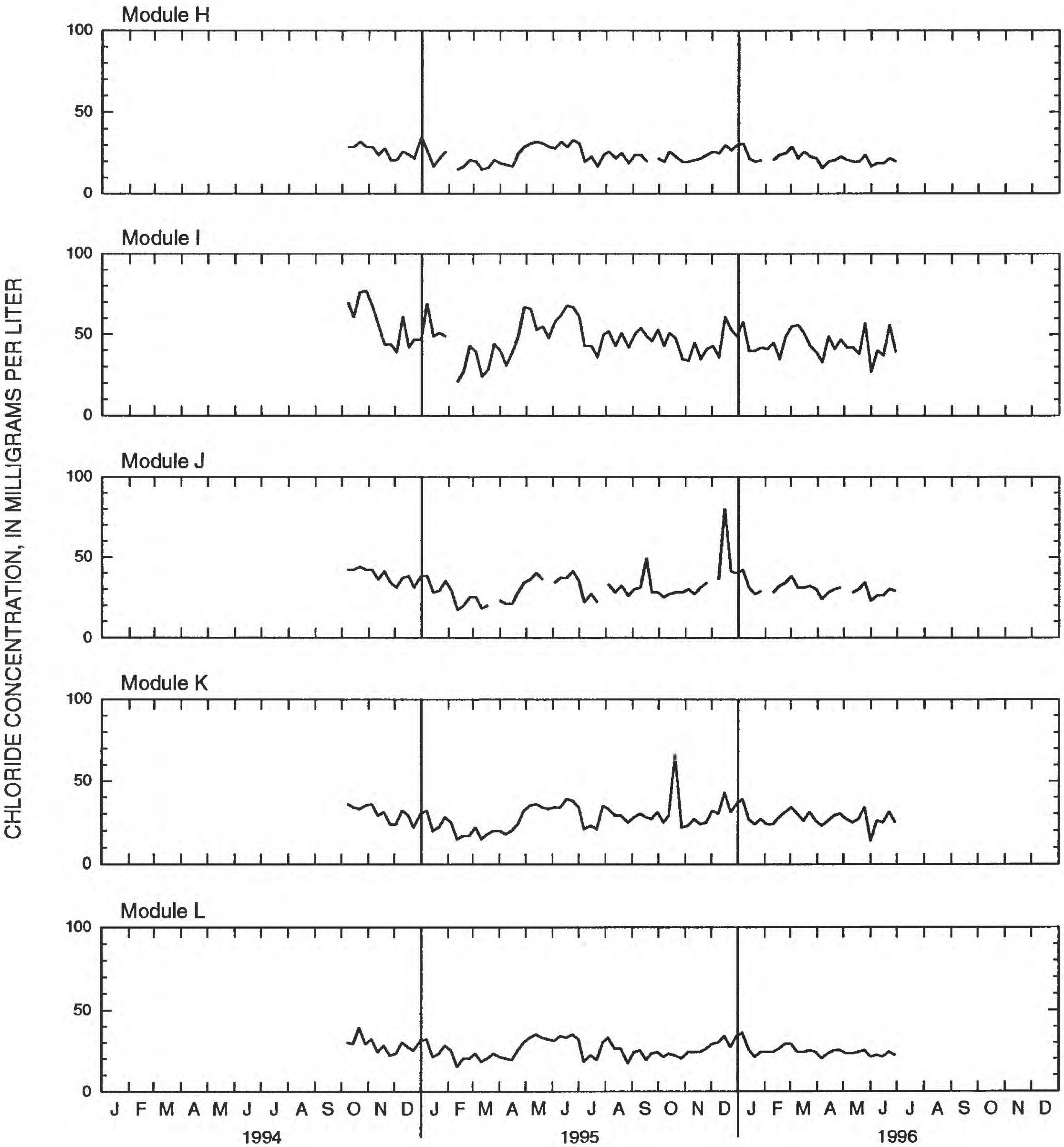


Figure C1. Chloride concentration of pumped water (sampled at weekly intervals) at Module A and Modules C through L at Cantonment, Diego Garcia, January 1994 through June 1996. Data not available for November 1993 through September 1994--Continued.

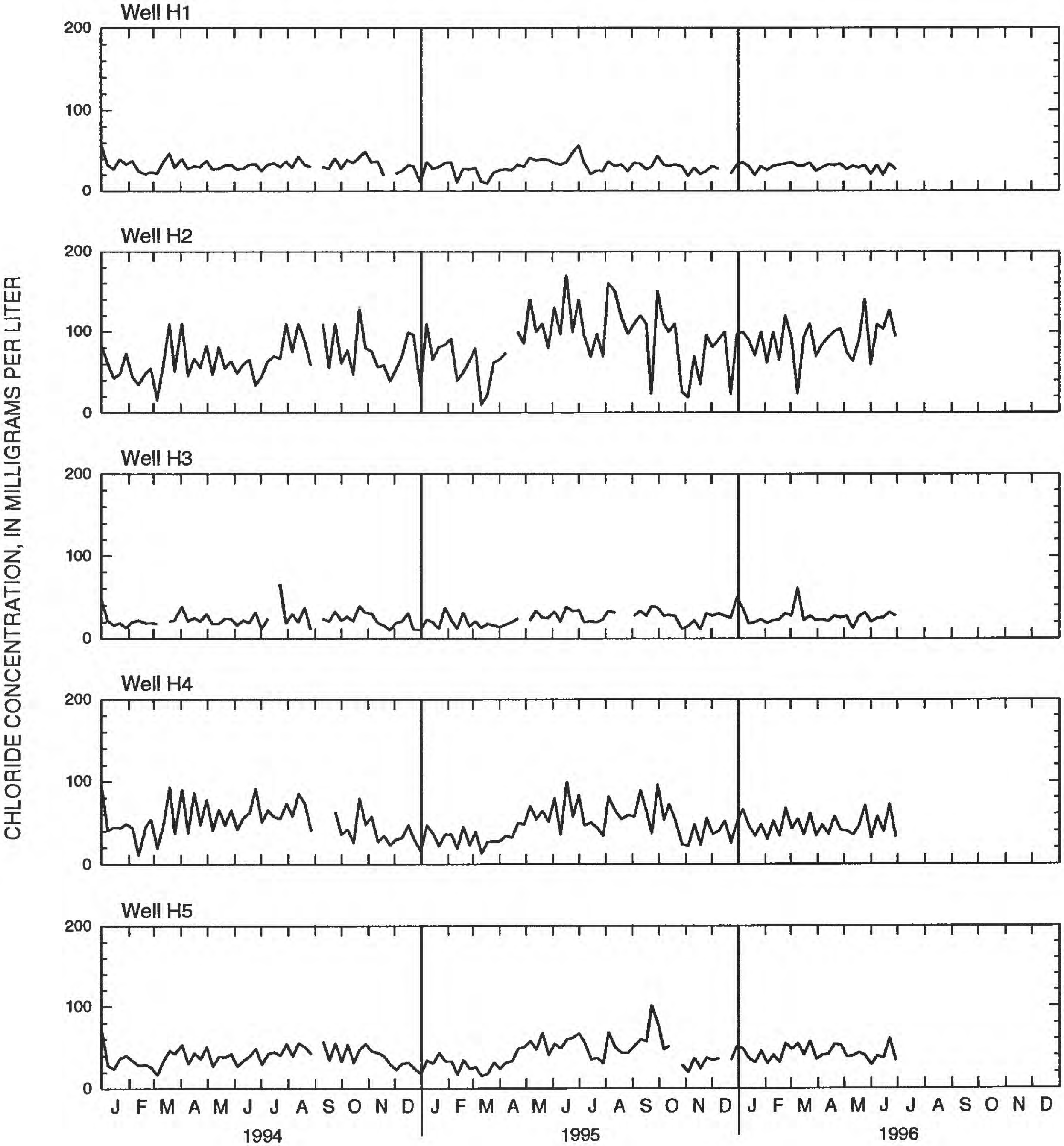


Figure C2. Chloride concentration of pumped water (sampled at weekly intervals) at Horizontal wells H1 through H7 at Cantonment, Diego Garcia, January 1994 through June 1996.

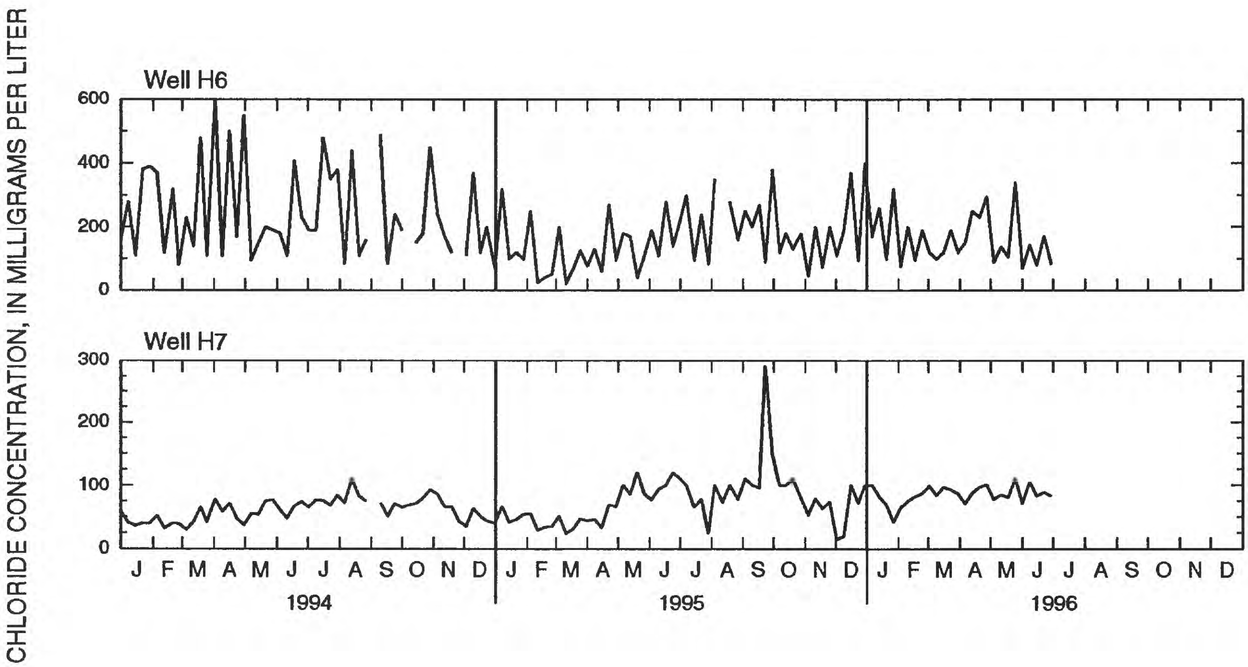


Figure C2. Chloride concentration of pumped water (sampled at weekly intervals) at Horizontal wells H1 through H7 at Cantonment, Diego Garcia, January 1994 through June 1996--Continued.

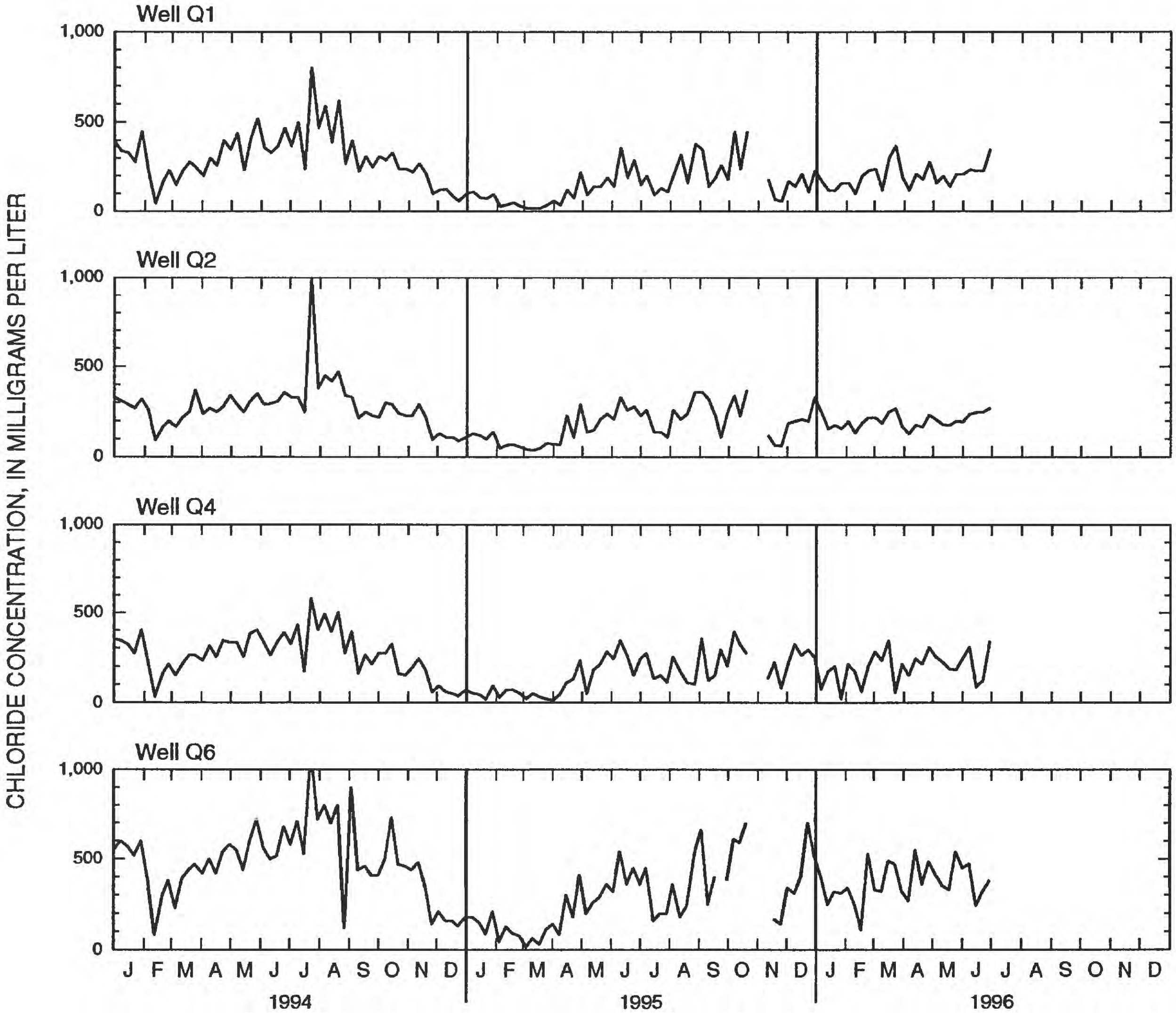


Figure C3. Chloride concentration of pumped water (sampled at weekly intervals) at Quad wells Q1, Q2, Q4, and Q6 at Cantonment, Diego Garcia, January 1994 through June 1996.

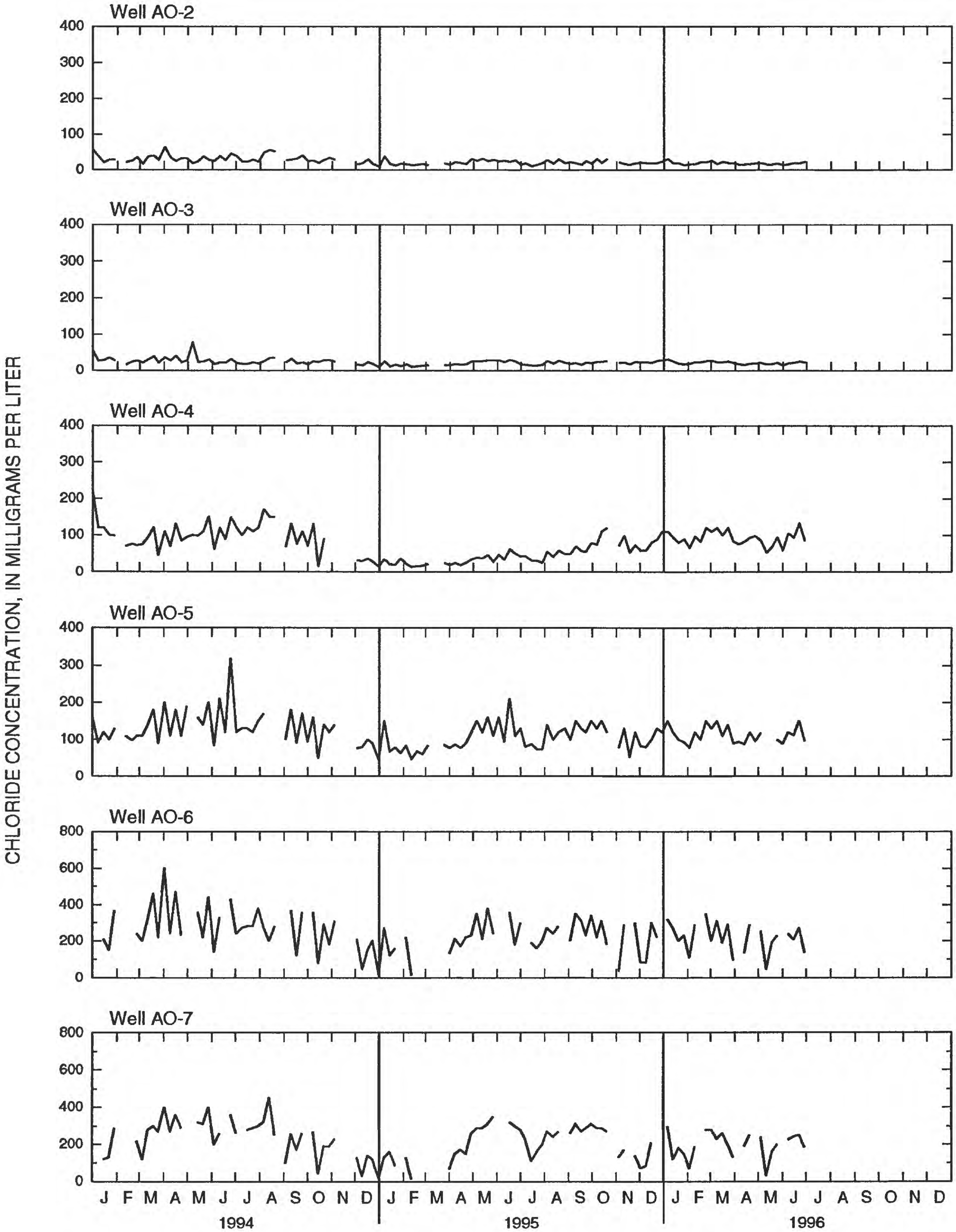


Figure C4. Chloride concentration of pumped water (sampled at weekly intervals) at wells AO-2 through AO-9 and wells AO-13 through AO-19 at Air Operations, Diego Garcia, January 1994 through June 1996. Water from well AO-13 has not been sampled since April 1993.

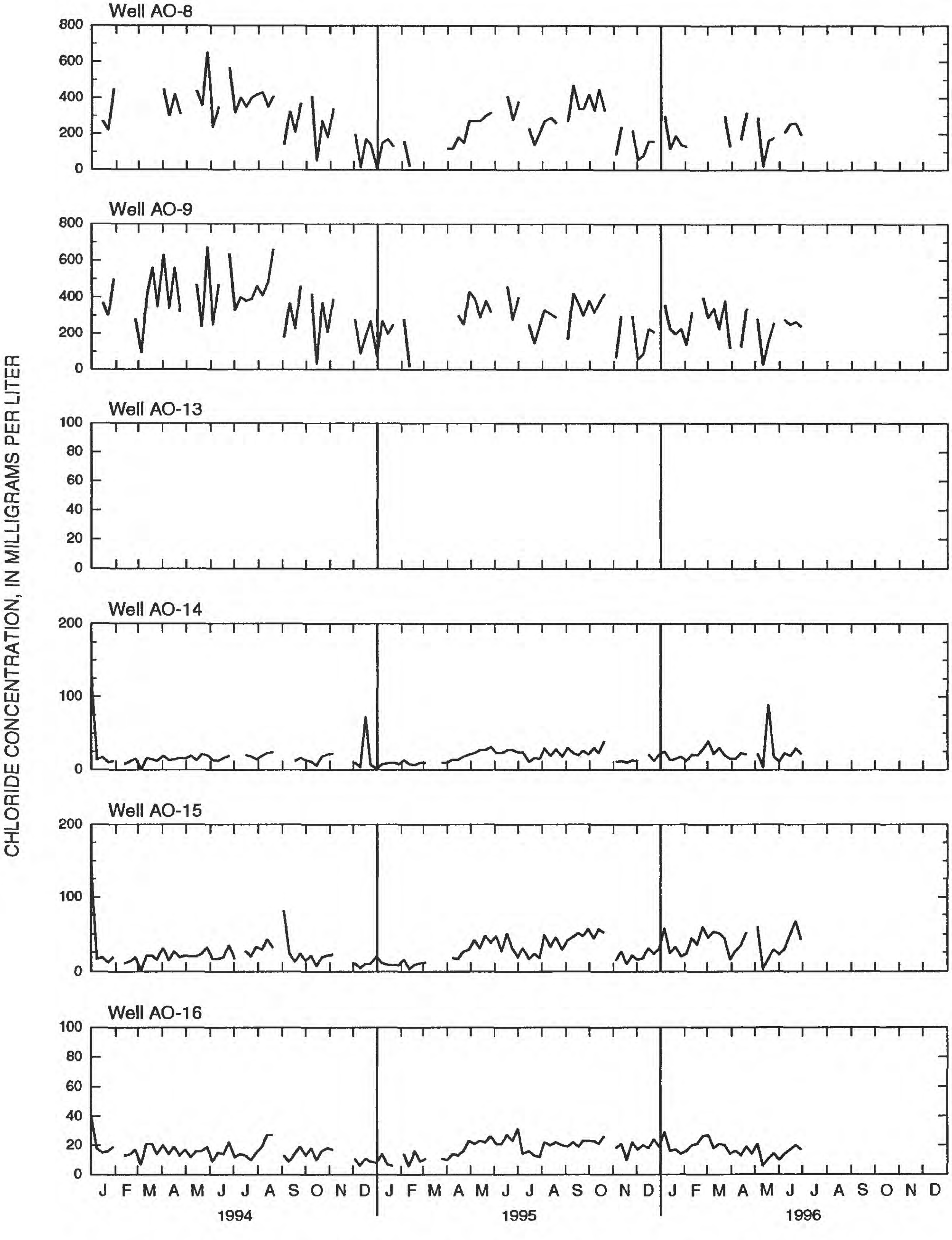


Figure C4. Chloride concentration of pumped water (sampled at weekly intervals) at wells AO-2 through AO-9 and wells AO-13 through AO-19 at Air Operations, Diego Garcia, January 1994 through June 1996. Water from well AO-13 has not been sampled since April 1993--Continued.

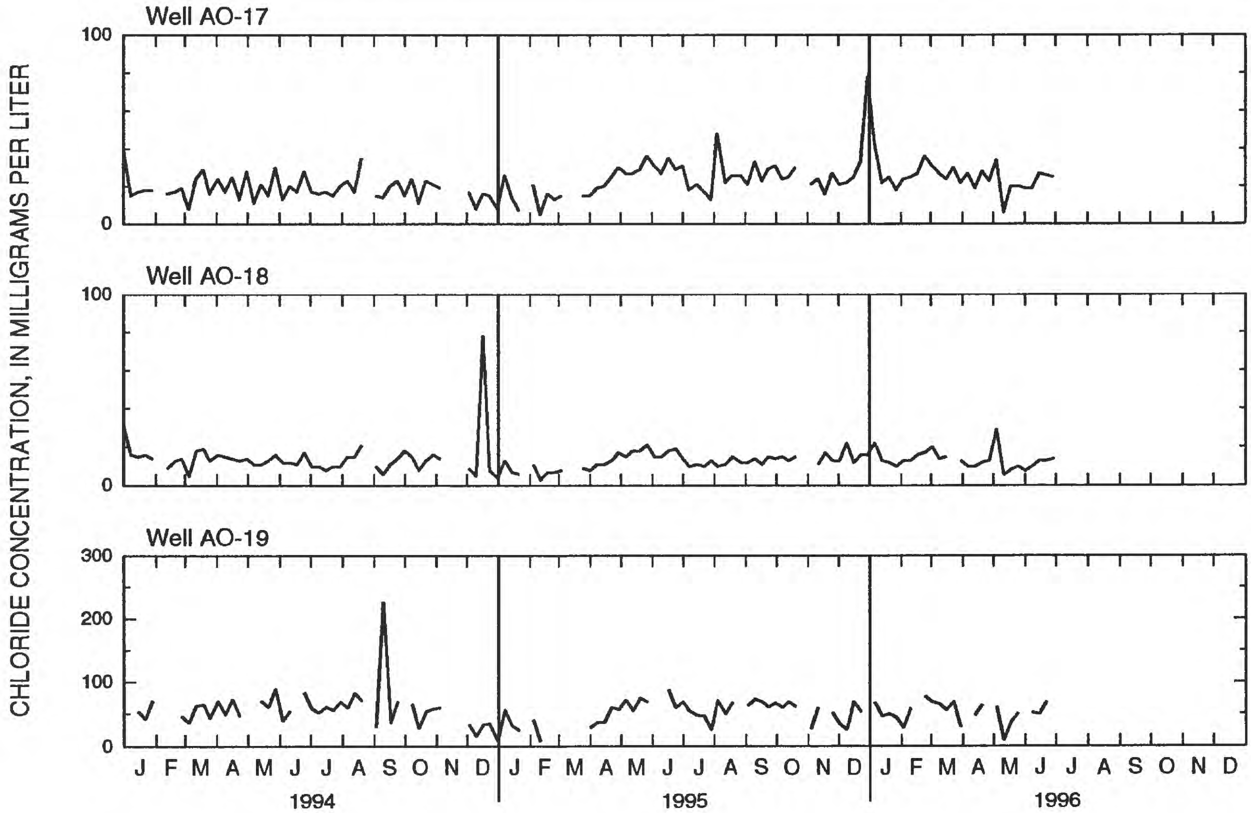


Figure C4. Chloride concentration of pumped water (sampled at weekly intervals) at wells AO-2 through AO-9 and wells AO-13 through AO-19 at Air Operations, Diego Garcia, January 1994 through June 1996. Water from well AO-13 has not been sampled since April 1993--Continued.

REFERENCES CITED

Torikai, J.D., 1995, Status of ground-water resources at U.S. Navy Support Facility, Diego Garcia: Summary of hydrologic and climatic data through September 1993; U.S. Geological Survey Open-File Report 94-306, 51 p.

U.S. Environmental Protection Agency, 1991, Secondary maximum contaminant levels (section 143.3 of part 143, National secondary drinking water regulations): U.S. Code of Federal Regulations, Title 40, Parts 100 to 149, revised through July 1, 1991.