STATUS OF GROUND-WATER RESOURCES AT U.S. NAVY SUPPORT FACILITY, DIEGO GARCIA: SUMMARY OF HYDROLOGIC AND CLIMATIC DATA, JANUARY 1994 THROUGH DECEMBER 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 December 1996, with a focus on data from October through December 1996 (fourth 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 October through December 1996 was 23.21 inches, which is 25 percent less than the mean rainfall of 30.83 inches for the period October through December. The total rainfall in 1996 was 84.40 inches, which is 20 percent less than the mean annual rainfall of 105.78 inches. The period October through December is within the annual wet season.

2. GROUND-WATER WITHDRAWAL--Total islandwide ground-water withdrawal during October through December 1996 averaged 946,000 gallons per day, which was a decrease from 1,038,300 gallons per day in the third quarter of 1996. The trend follows an overall increase in withdrawals since about April 1995.

3. CHLORIDE CONCENTRATION OF PUMPED GROUND WATER--At the end of December 1996, the chloride concentrations of water from the elevated tanks at Cantonment and Air Operations were 62 and 170 milligrams per liter, respectively. The chloride concentration of water levelled off in the Cantonment and Air Operations areas during the fourth quarter of 1996, following increases in chloride concentration that started 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 levelled off or decreased by the end of the fourth quarter of 1996, following increases that started in June or July 1996.

5. FUEL-DIVERSION PROGRAM AT AIR OPERATIONS--A fuel-pipeline leak at Air Operations in May 1991 decreased total islandwide withdrawals by 15 percent. 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. This lost pumping capacity is being offset by increased pumpage at Cantonment.

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

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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 102 active wells in five production areas (fig. 1). Water from the Cantonment and Air Operations areas combined accounts 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 a hydrogeologic investigation 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 December 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 October through December 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 December 1996
C. Graphs of chloride concentration of pumped water, January 1994 through December 1996

This report is part of a series of USGS reports, "Status of ground-water resources at U.S. Navy Support Facility, Diego Garcia: summary of hydrologic and climatic data." The first report in this series began with data for the period January 1985 through September 1993 (Torikai, 1995). Successive reports have been done on a quarterly basis.

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 (NAVPACMETOCDET). Logistical support from the staff of the Public Works Department is greatly appreciated.

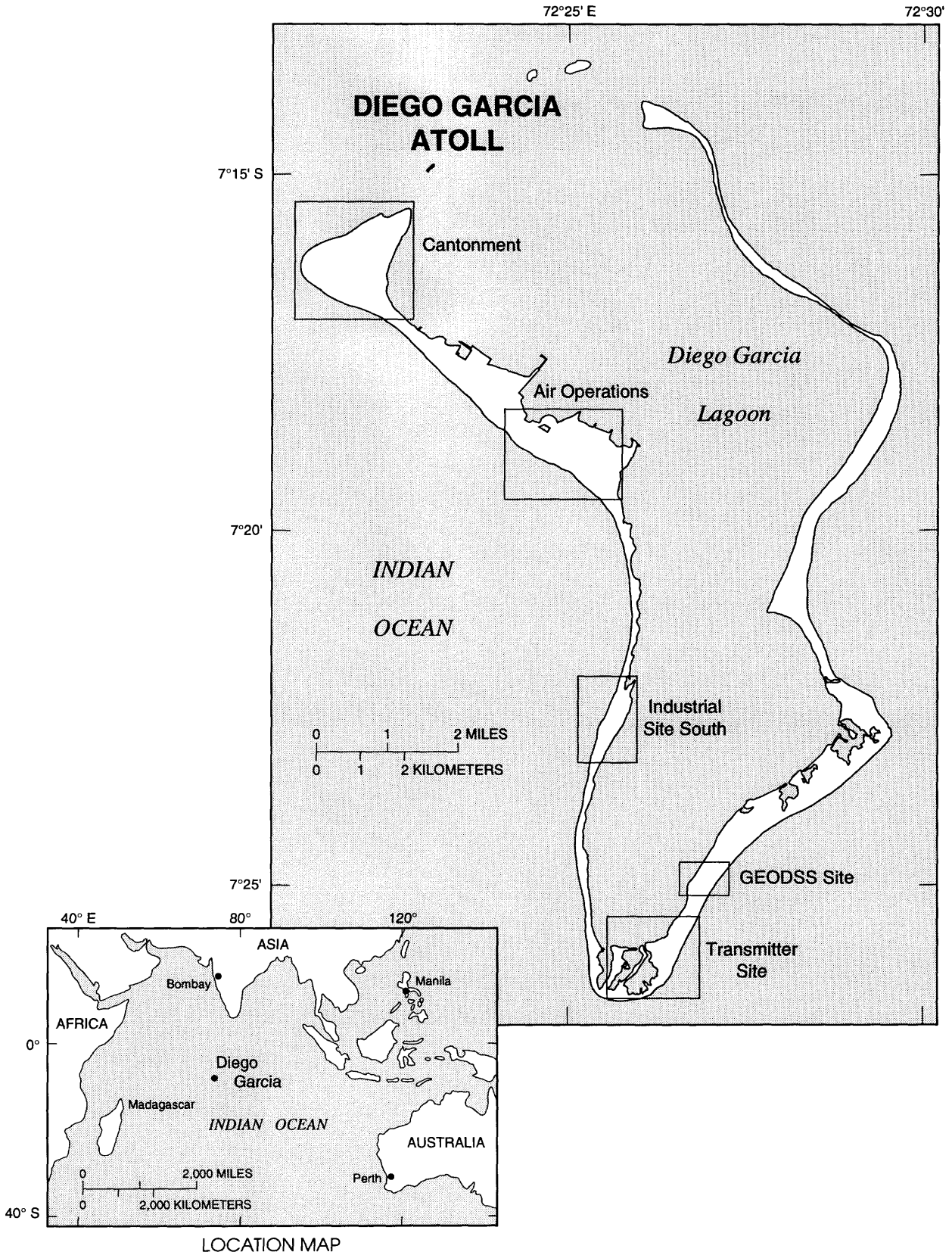


Figure 1. Areas of ground-water production, Diego Garcia.

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 October through December 1996 was 23.21 inches, which is 25 percent less than the mean rainfall of 30.83 inches for the period October through December. For the same 3 months in 1994 and 1995, the rainfall was 54.60 inches and 40.77 inches, respectively. The total rainfall in 1996 was 84.40 inches, which is 20 percent less than the mean annual rainfall of 105.78 inches. 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 recorded rainfall amounts and rainfall departures from mean monthly rainfall values that were averaged for the base period 1951-90. The period October through December is within 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 October 1996 was about 0.5 inches greater than the mean monthly rainfall for October, but monthly rainfall totals for November 1996 and December 1996 were about 3.5 inches and 4.5 inches less than the respective mean monthly rainfall for November and December. Since April 1995, there were 14 months with negative rainfall departures, and 7 months with positive departures.

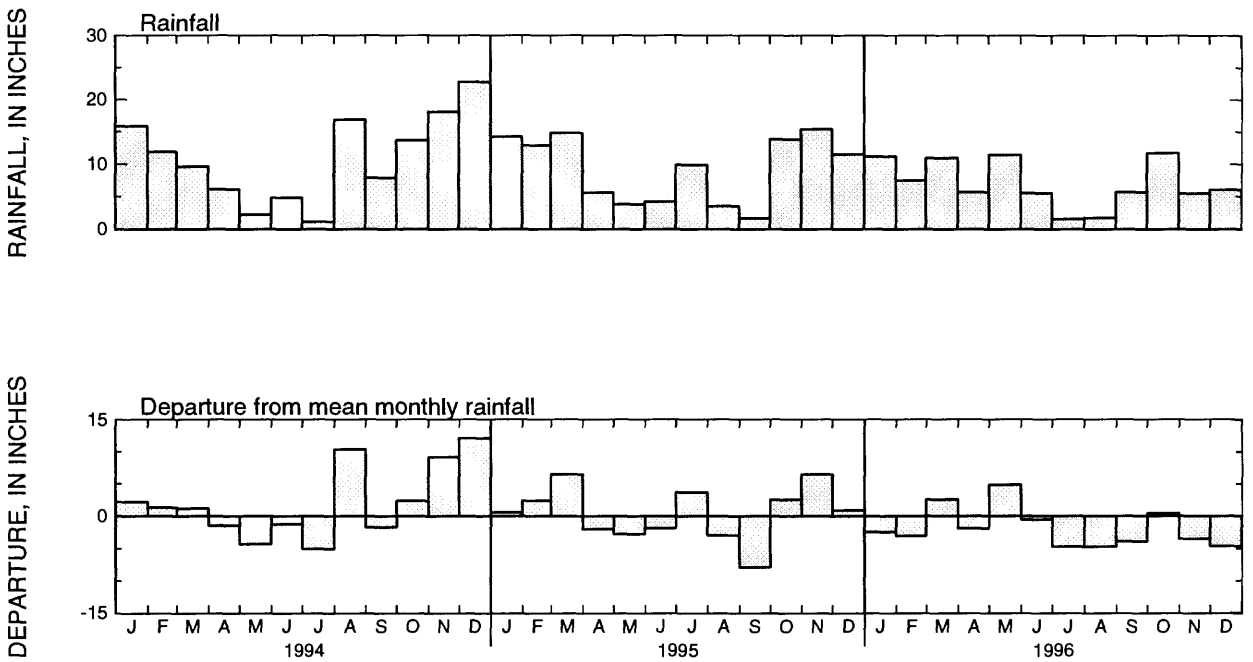


Figure 2. Monthly rainfall and monthly departure from mean monthly rainfall at Air Operations, Diego Garcia, January 1994 through December 1996.

GROUND-WATER WITHDRAWAL

Background.--Withdrawal is measured by flow meters at all production wells and storage tanks in the water system, and was recorded daily through November 1996. Since December 2, 1996, data are collected every Monday, Wednesday, Friday, and Saturday, and thus represent a total of 1 or 2 days of ground-water withdrawal. 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 by sub-group 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 December 1996. Total islandwide withdrawal increased from 931,200 gal/d during October through December 1995 to 946,000 gal/d during October through December 1996. However, total islandwide ground-water withdrawal decreased from 1,038,300 gal/d during the third quarter of 1996 to 946,000 gal/d during the fourth quarter of 1996. This recent trend follows an overall increase in total islandwide withdrawals since about April 1995. The fourth quarter decreases are reflected in the withdrawals for the Cantonment and Air Operations production areas. Ground-water withdrawals at Industrial Site South (I-Site) and Transmitter Site (T-Site) remained fairly steady since July 1996, but the overall withdrawal at GEODSS Site increased about 100 percent from July 1996 to December 1996.

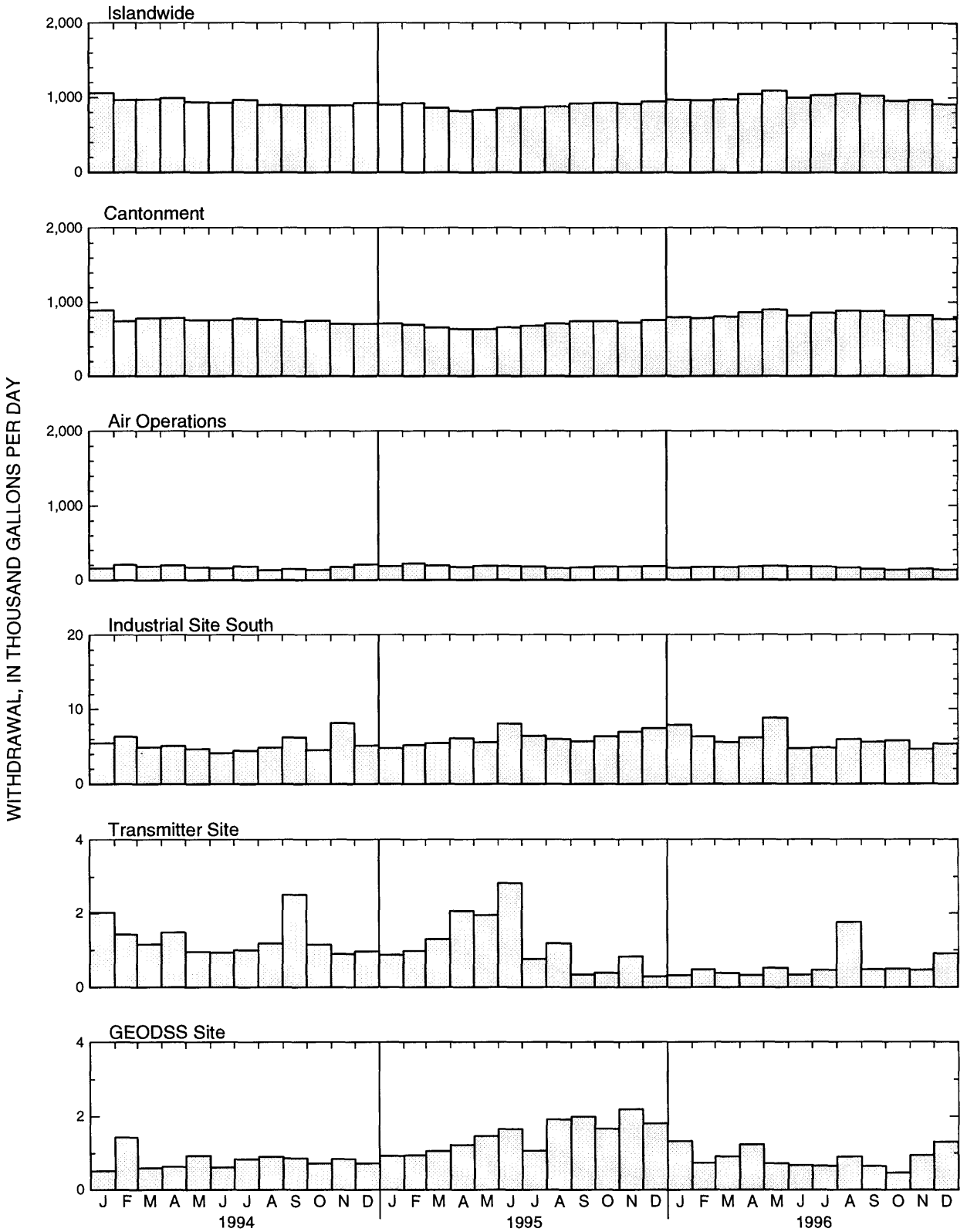


Figure 3. Monthly mean ground-water withdrawal islandwide and in the ground-water production areas, Diego Garcia, January 1994 through December 1996.

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 was analyzed daily through November 1996 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 continues to be analyzed for chloride concentration from these representative samples at weekly intervals. Although daily chloride concentration data were collected at the five production areas, this report only uses the chloride concentrations from every seventh day that were extracted from the daily record through November 1996. Since December 2, 1996, chloride concentrations from the five production areas are only analyzed on a weekly basis.

Recent trends.--At the end of December 1996, the chloride concentrations of water from the elevated tanks at Cantonment and Air Operations were 62 and 170 mg/L, respectively. These concentrations are 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 levelled off in the Cantonment and Air Operations production areas, but increased at the remaining three areas during October through December 1996 (fig. 4). The increases at I-Site, T-Site, and GEODSS Site were about 50 mg/L from the start of the quarter to the end of the quarter. Overall 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). Overall increases in chloride concentration were also recorded at the Air Operations wells, particularly wells AO-4 through AO-9 (fig. C4). Increases in chloride concentration of as much as 200 mg/L were recorded since about July 1996 for these Air Operations area wells.

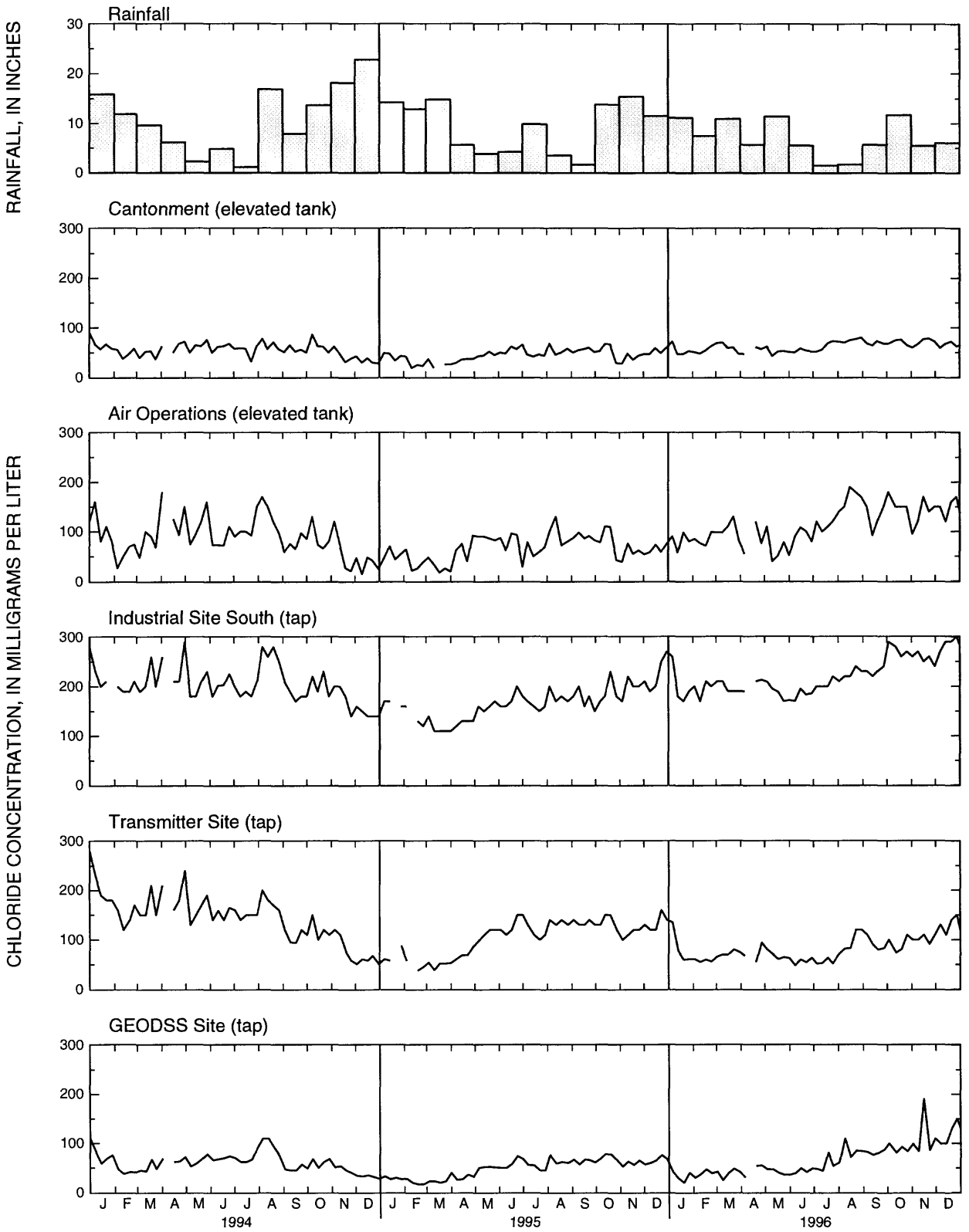


Figure 4. Chloride concentration of pumped water in the ground-water production areas, Diego Garcia, January 1994 through December 1996. Data shown are values from every seventh day extracted from the daily record. Rainfall data are shown for comparison.

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.

Overall chloride concentrations of the water levelled off or decreased by the end of the fourth quarter of 1996 at wells from both sites. This trend follows increases in chloride concentration that started about June 1996 for the two deepest wells at each site, and about July 1996 for the shallowest well at each site. Maximum increases in chloride concentration during the second half of 1996 in the 70-ft well at site AW16, and in the 51-ft well at site BW09, were about 4,000 mg/L and 1,500 mg/L, respectively.

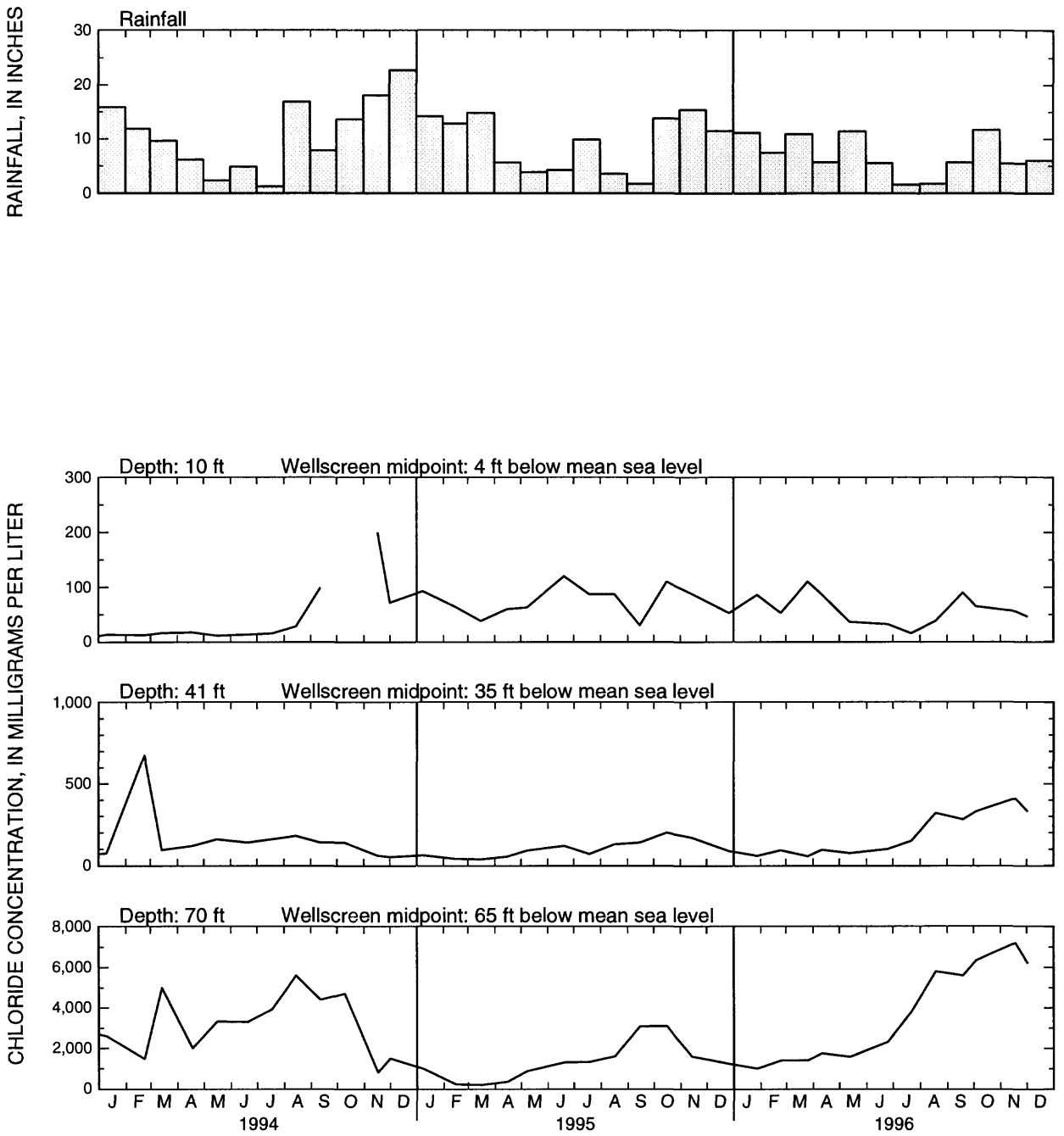


Figure 5. Chloride concentration of ground water (sampled at monthly intervals) in monitoring wells at site AW16 at Cantonment, Diego Garcia, January 1994 through December 1996. Rainfall data are shown for comparison.

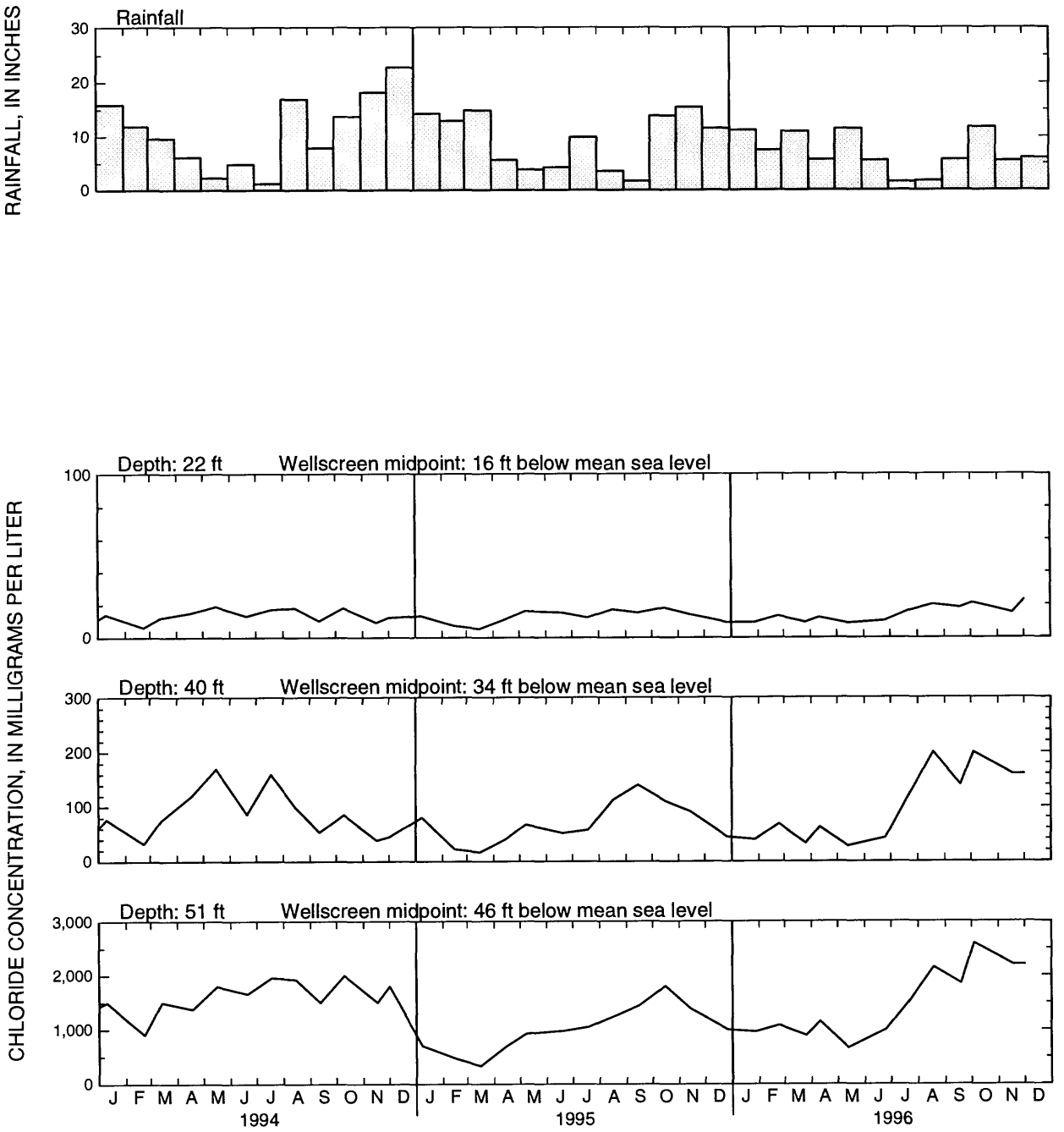


Figure 6. Chloride concentration of ground water (sampled at monthly intervals) in monitoring wells at site BW09 at Air Operations, Diego Garcia, January 1994 through December 1996. Rainfall data are shown for comparison.

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 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 December 1996 are from 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 October through December 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, October through December 1996
AO-10	-30,000	-31,100
AO-11	-50,000	-47,800
AO-12	-70,000	-70,100
AO-13	0	0
AO-14	70,000	70,800
AO-15	80,000	77,900

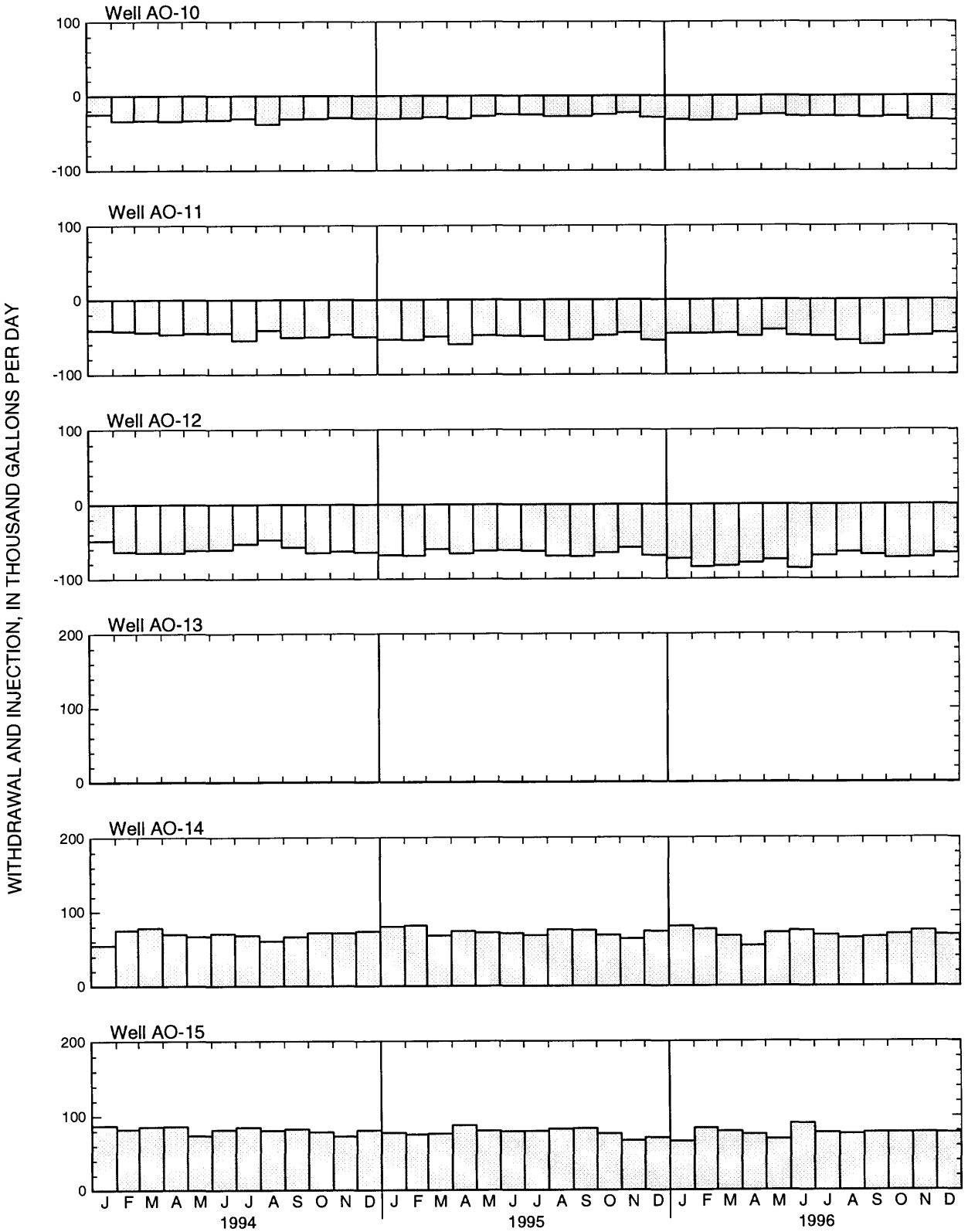


Figure 7. Monthly mean ground-water withdrawal and injection at wells AO-10 through AO-15 at Air Operations, Diego Garcia, January 1994 through December 1996. Injection is plotted as negative.

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

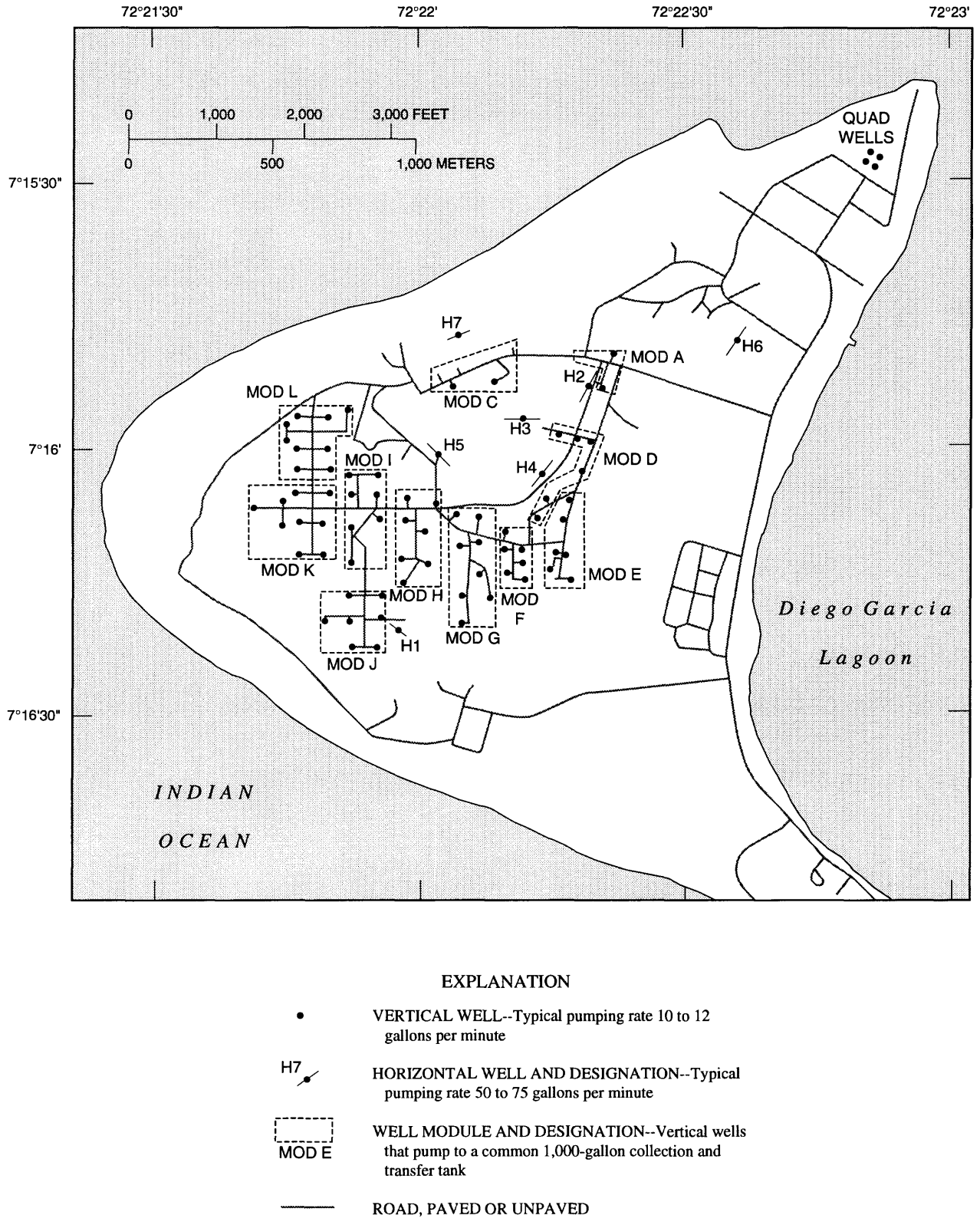


Figure A1. Ground-water production wells and well fields at Cantonment, Diego Garcia.

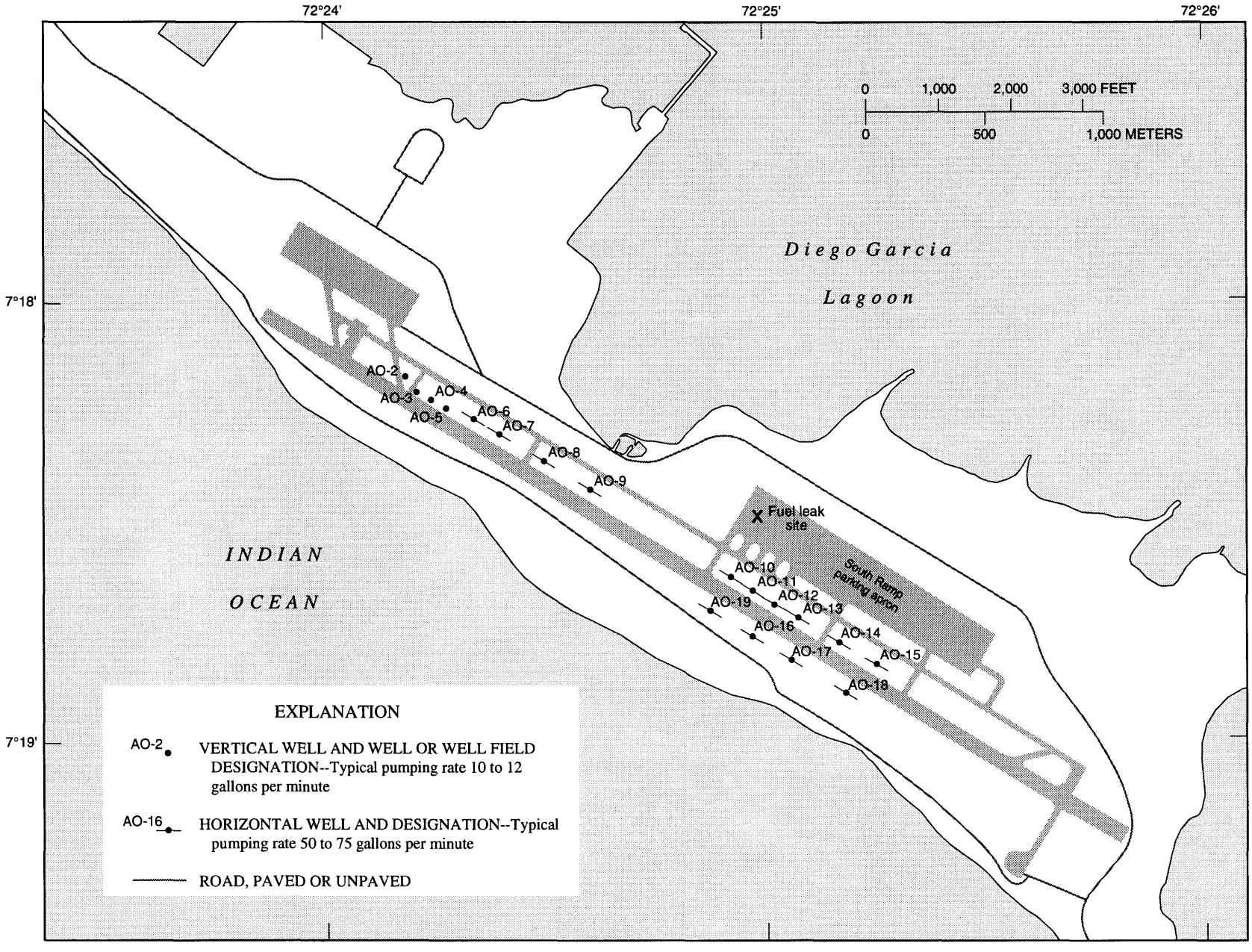
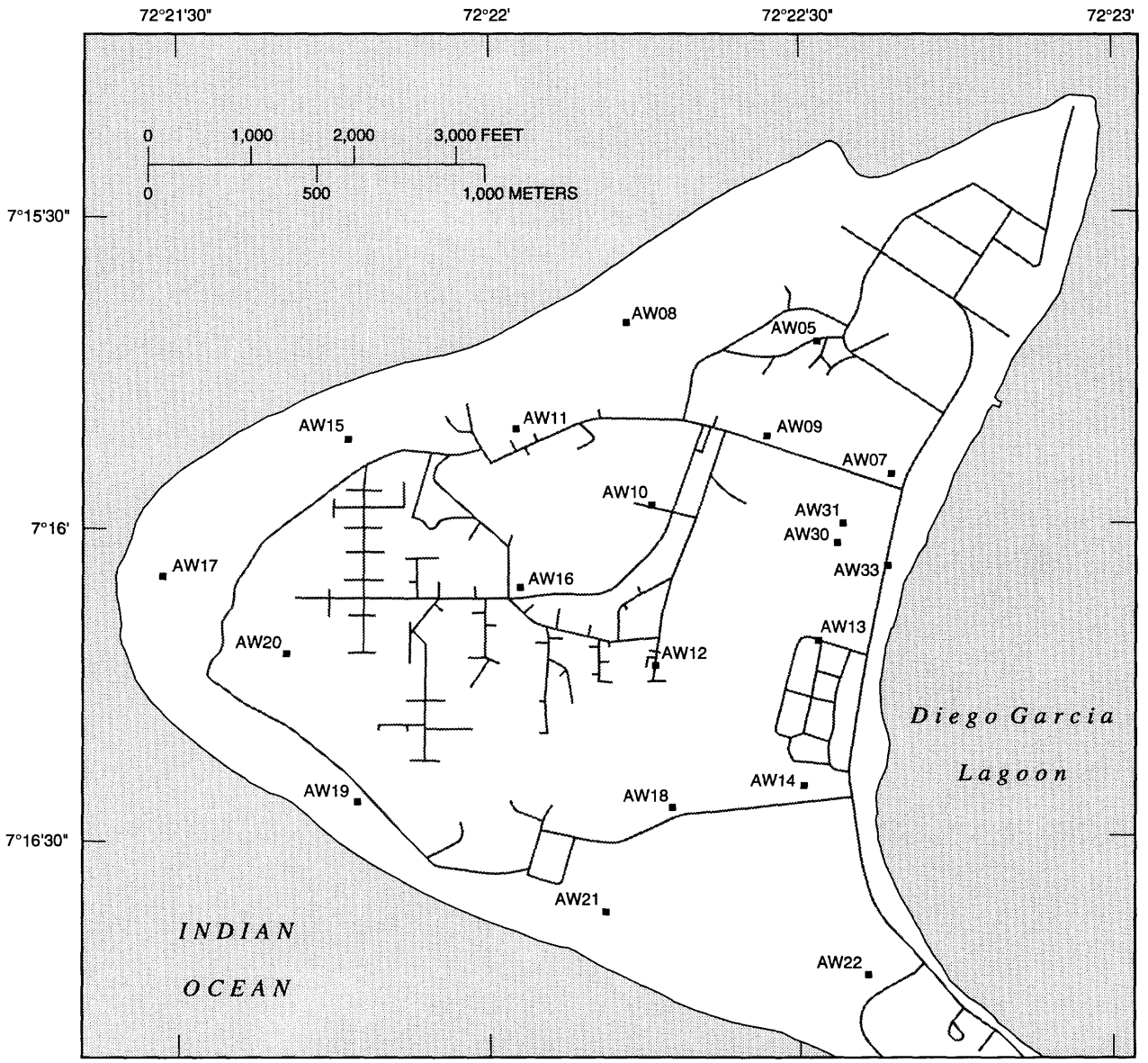


Figure A2. Ground-water production wells at Air Operations, Diego Garcia.



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.

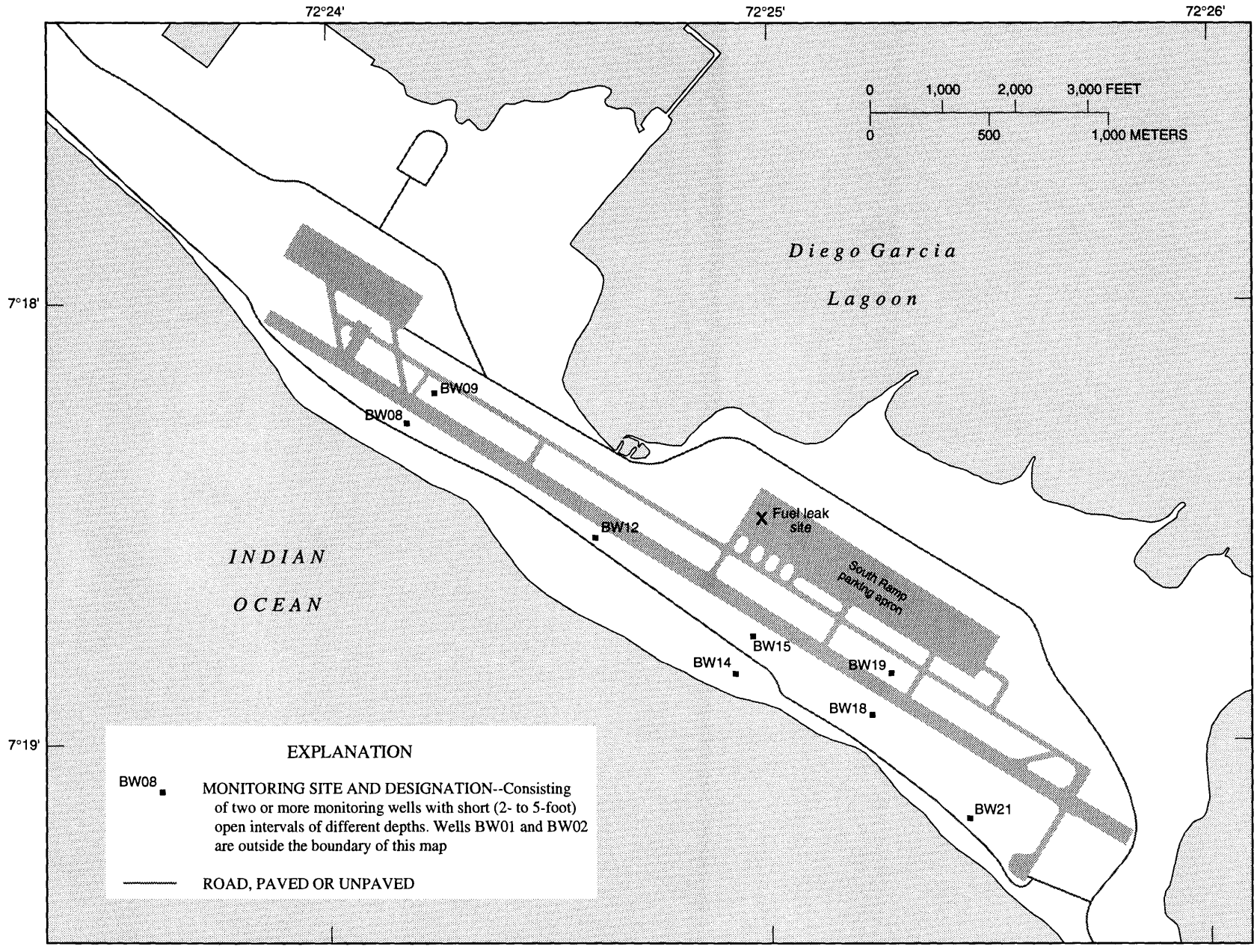


Figure A4. Monitoring wells at Air Operations, Diego Garcia.

SECTION B

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

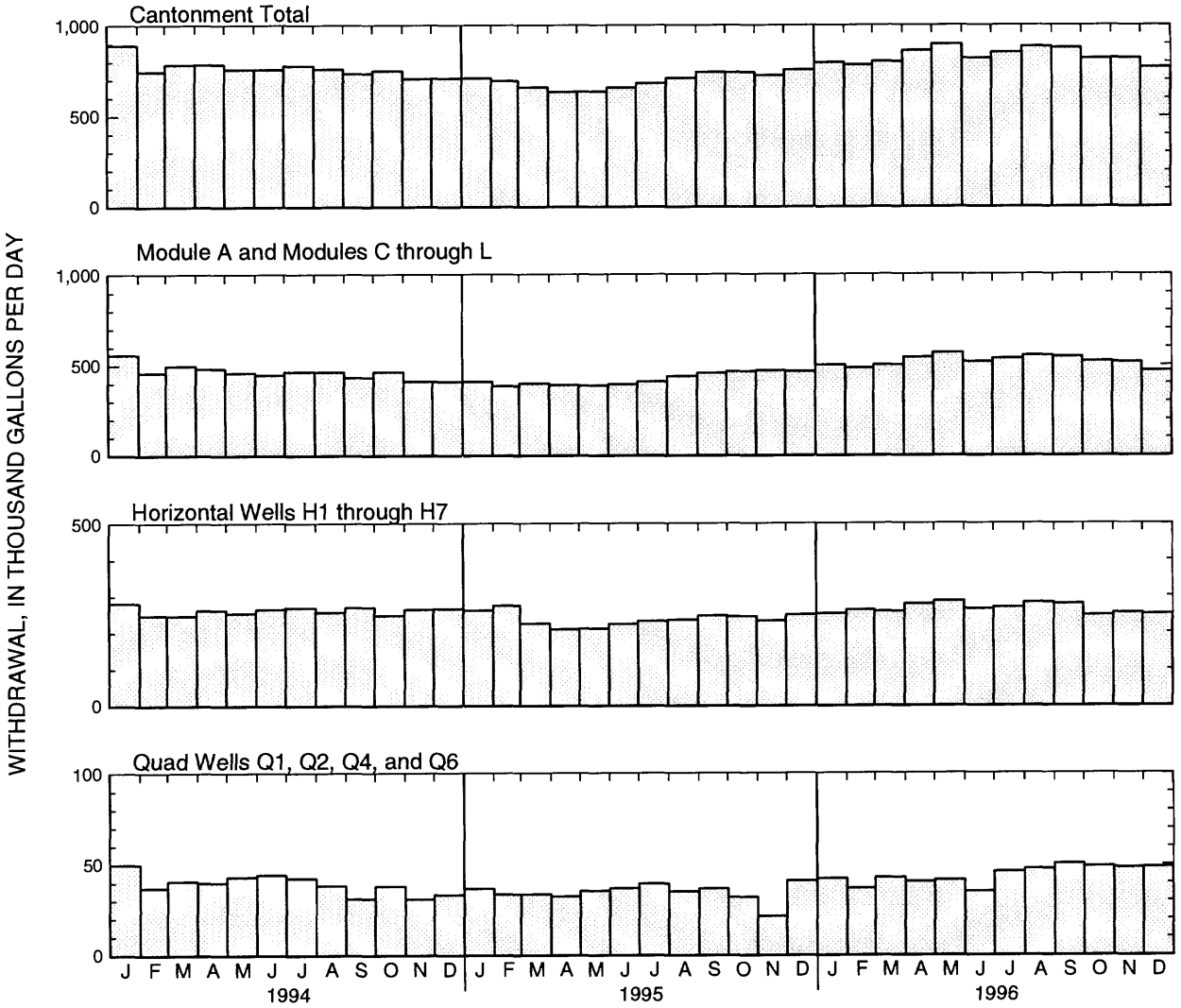


Figure B1. Monthly mean ground-water withdrawal at Cantonment, Diego Garcia, January 1994 through December 1996.

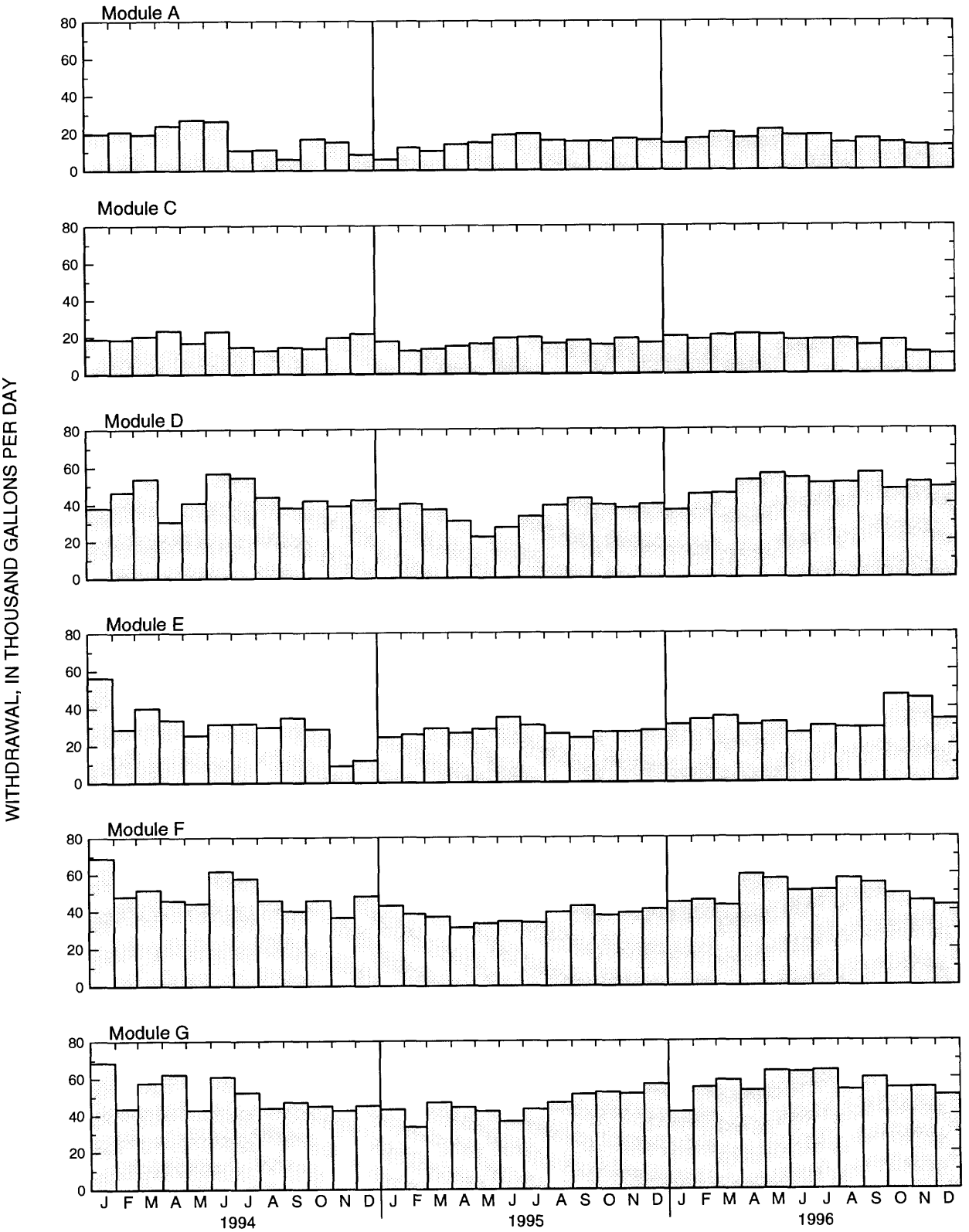


Figure B2. Monthly mean ground-water withdrawal at Module A and Modules C through L at Cantonment, Diego Garcia, January 1994 through December 1996.

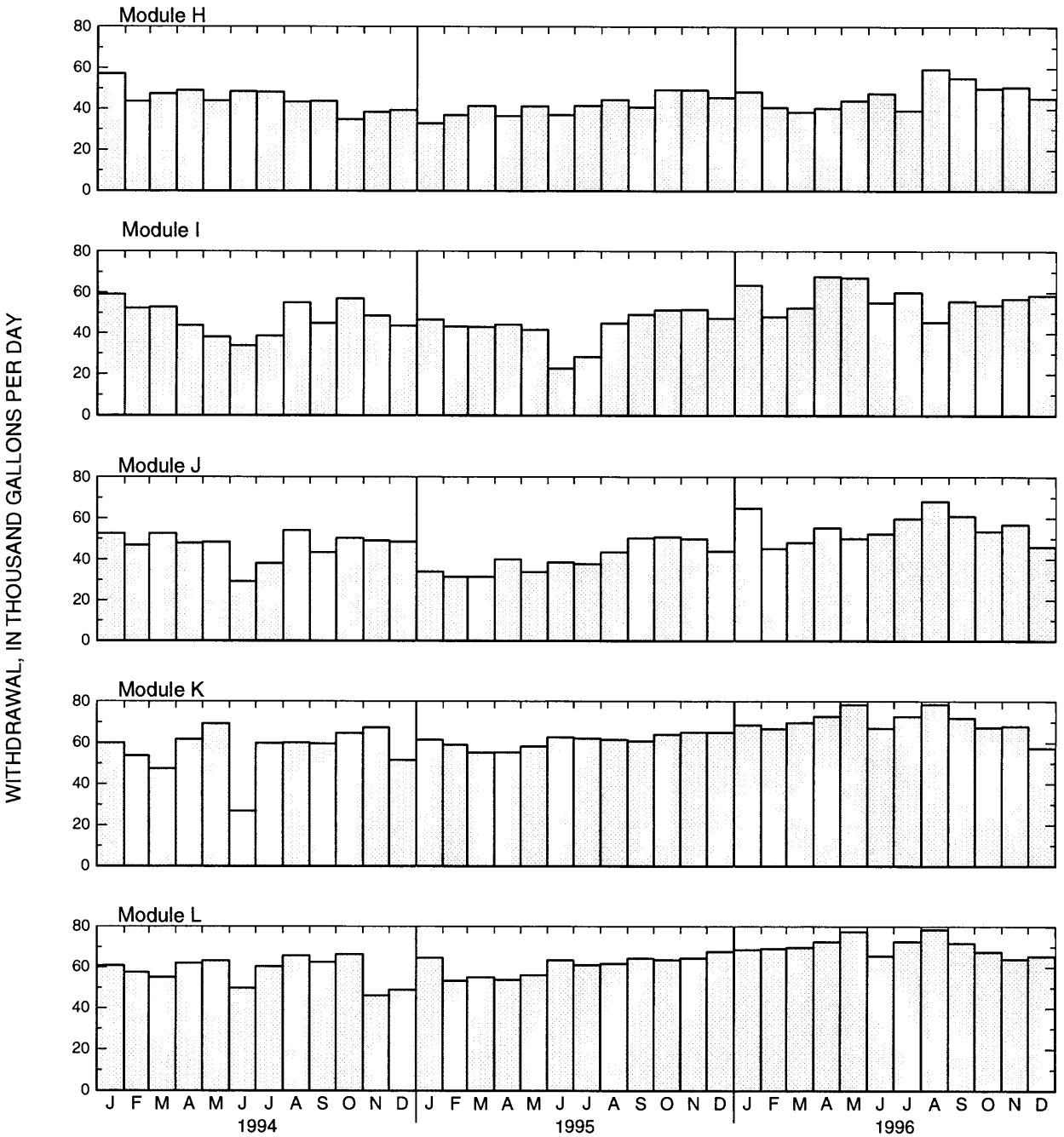


Figure B2. Monthly mean ground-water withdrawal at Module A and Modules C through L at Cantonment, Diego Garcia, January 1994 through December 1996--Continued.

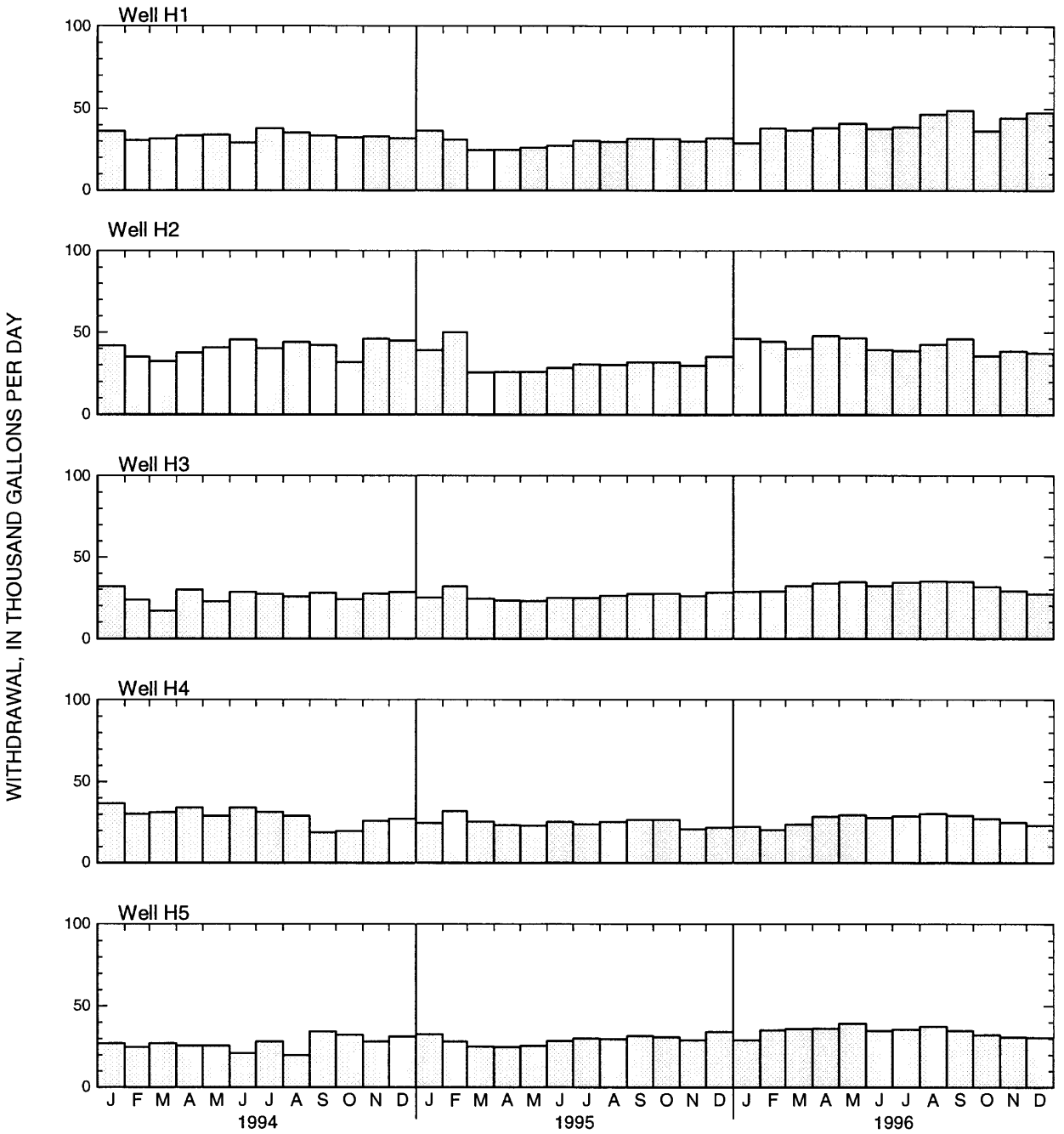


Figure B3. Monthly mean ground-water withdrawal at Horizontal wells H1 through H7 at Cantonment, Diego Garcia, January 1994 through December 1996.

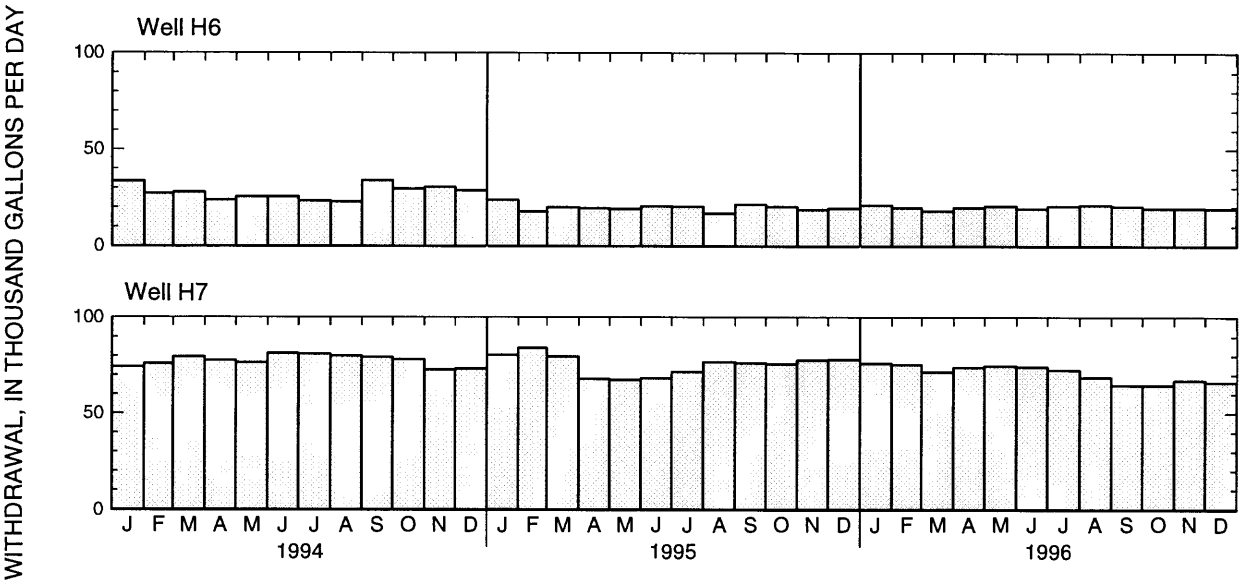


Figure B3. Monthly mean ground-water withdrawal at Horizontal wells H1 through H7 at Cantonment, Diego Garcia, January 1994 through December 1996--Continued.

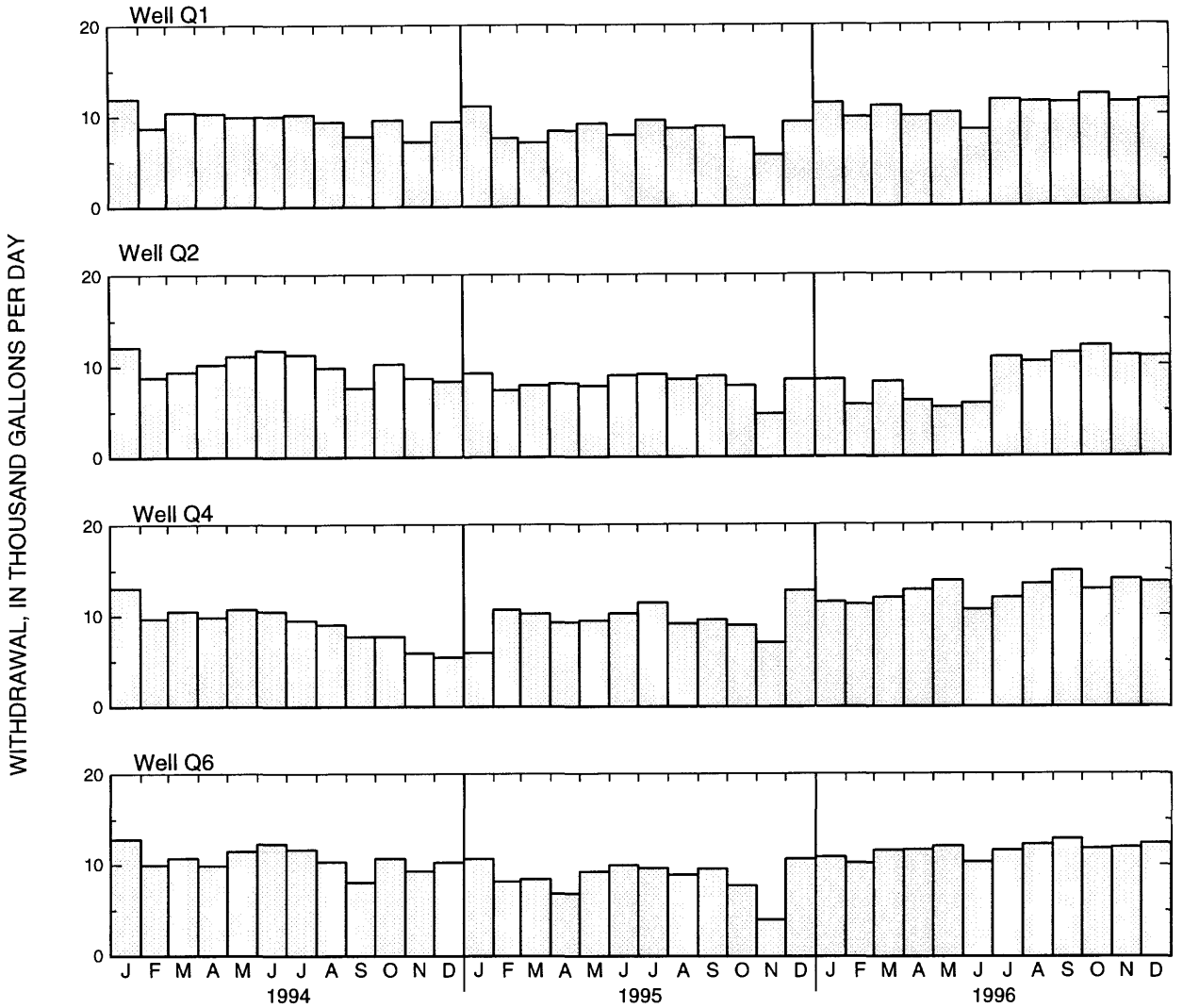


Figure B4. Monthly mean ground-water withdrawal at Quad wells Q1, Q2, Q4, and Q6 at Cantonment, Diego Garcia, January 1994 through December 1996.

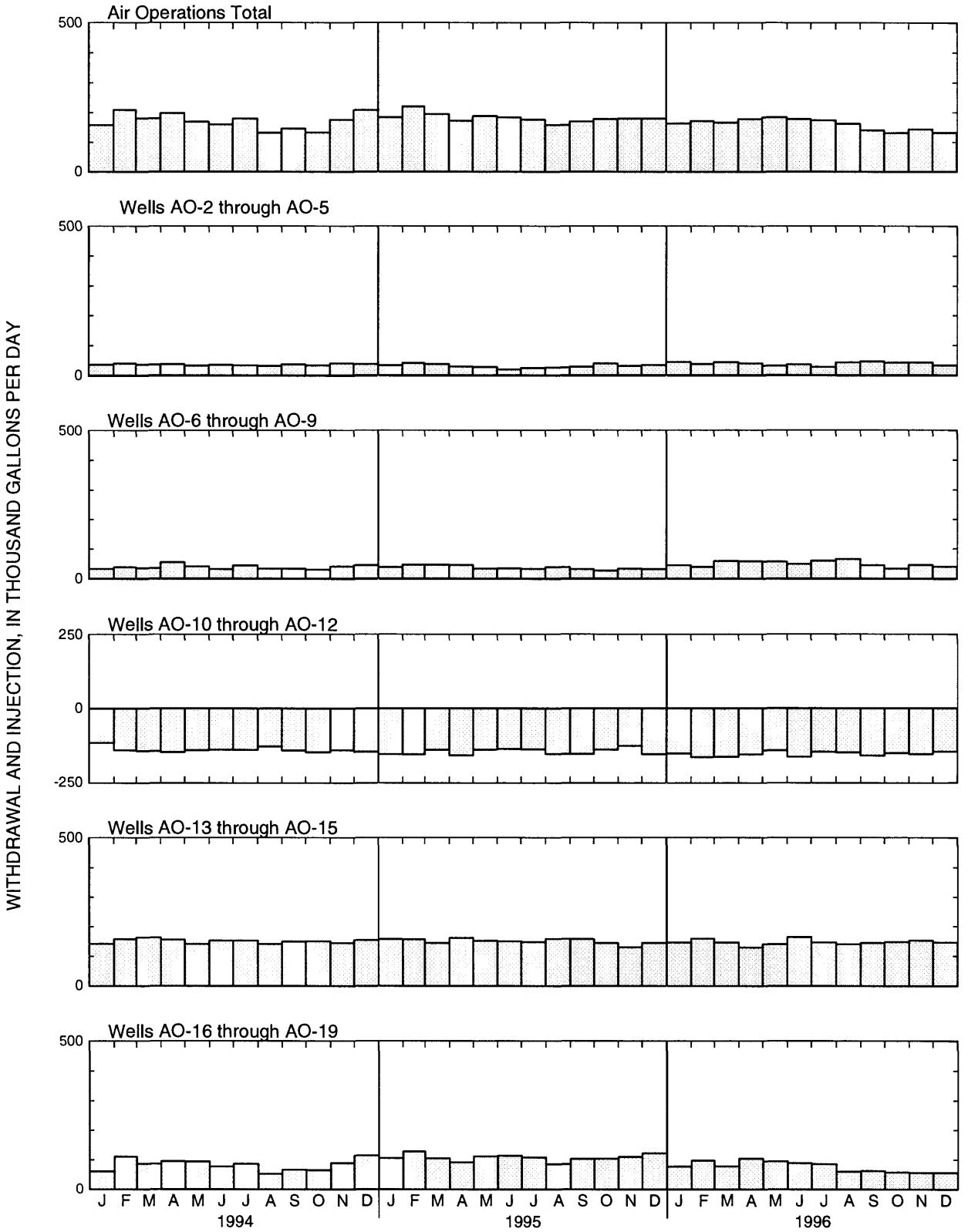


Figure B5. Monthly mean ground-water withdrawal and injection at Air Operations, Diego Garcia, January 1994 through December 1996. Injection is plotted as negative.

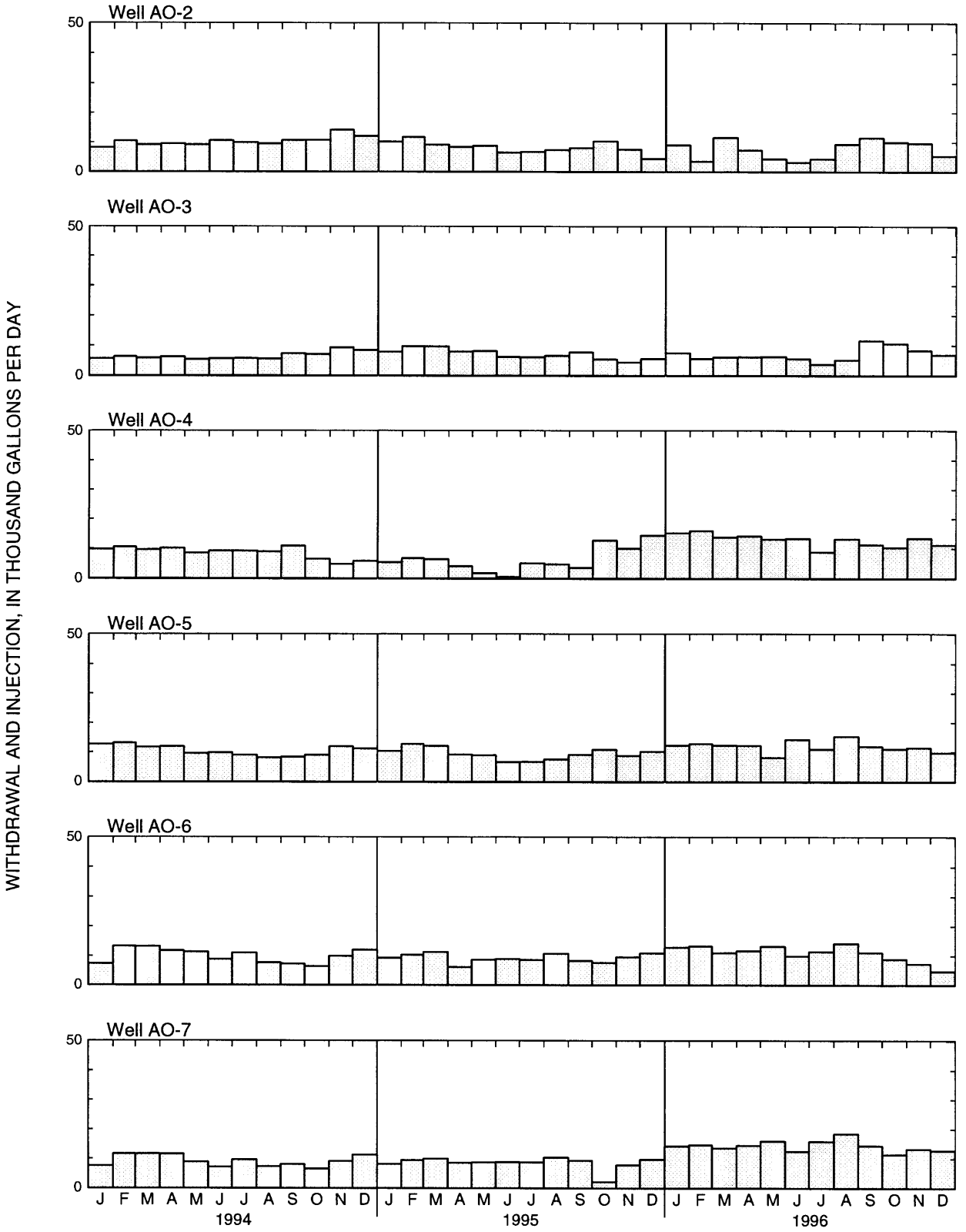


Figure B6. Monthly mean ground-water withdrawal and injection at wells AO-2 through AO-19 at Air Operations, Diego Garcia, January 1994 through December 1996. Injection is plotted as negative.

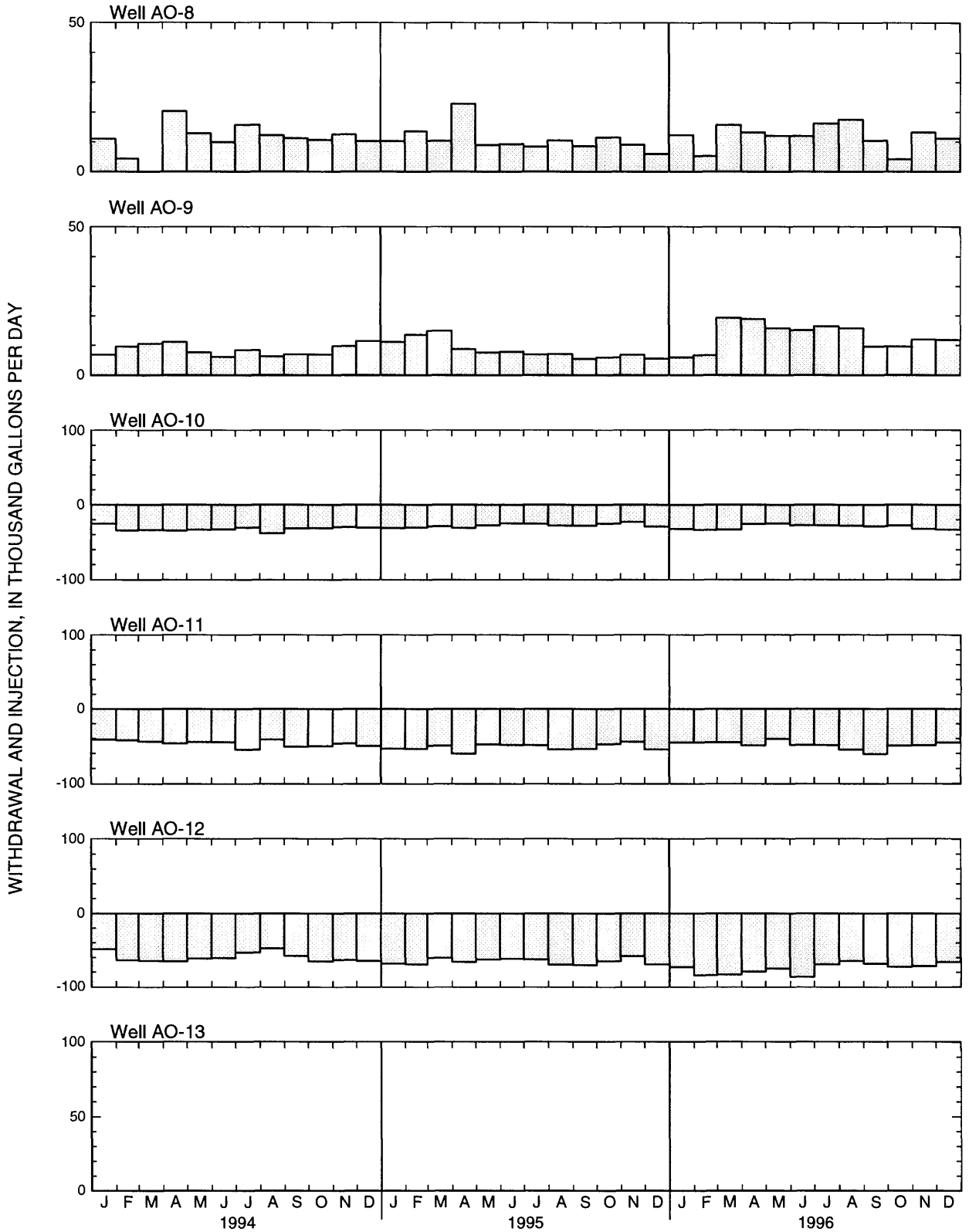


Figure B6. Monthly mean ground-water withdrawal and injection at wells AO-2 through AO-19 at Air Operations, Diego Garcia, January 1994 through December 1996. Injection is plotted as negative--Continued.

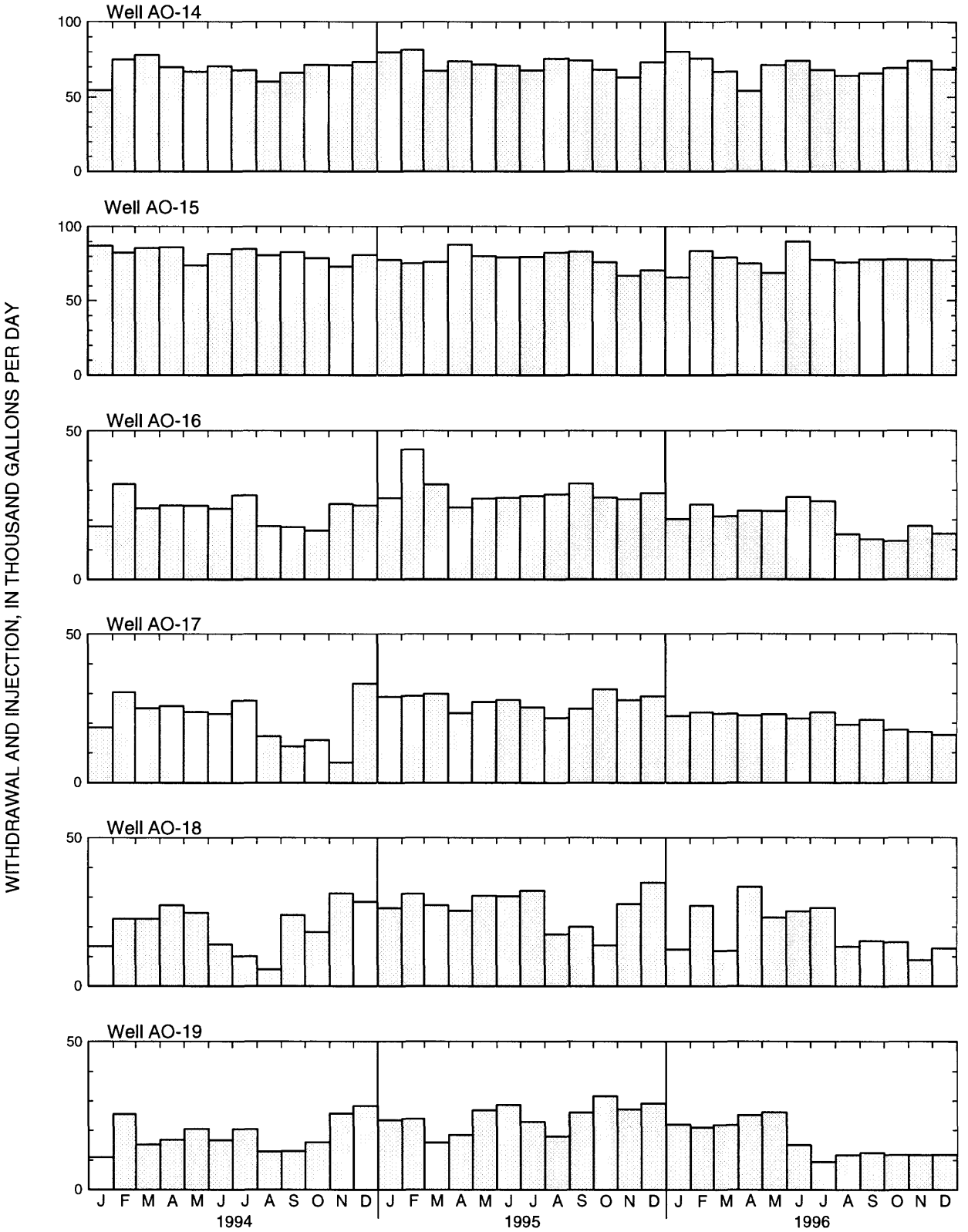


Figure B6. Monthly mean ground-water withdrawal and injection at wells AO-2 through AO-19 at Air Operations, Diego Garcia, January 1994 through December 1996. Injection is plotted as negative--Continued.

SECTION C

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

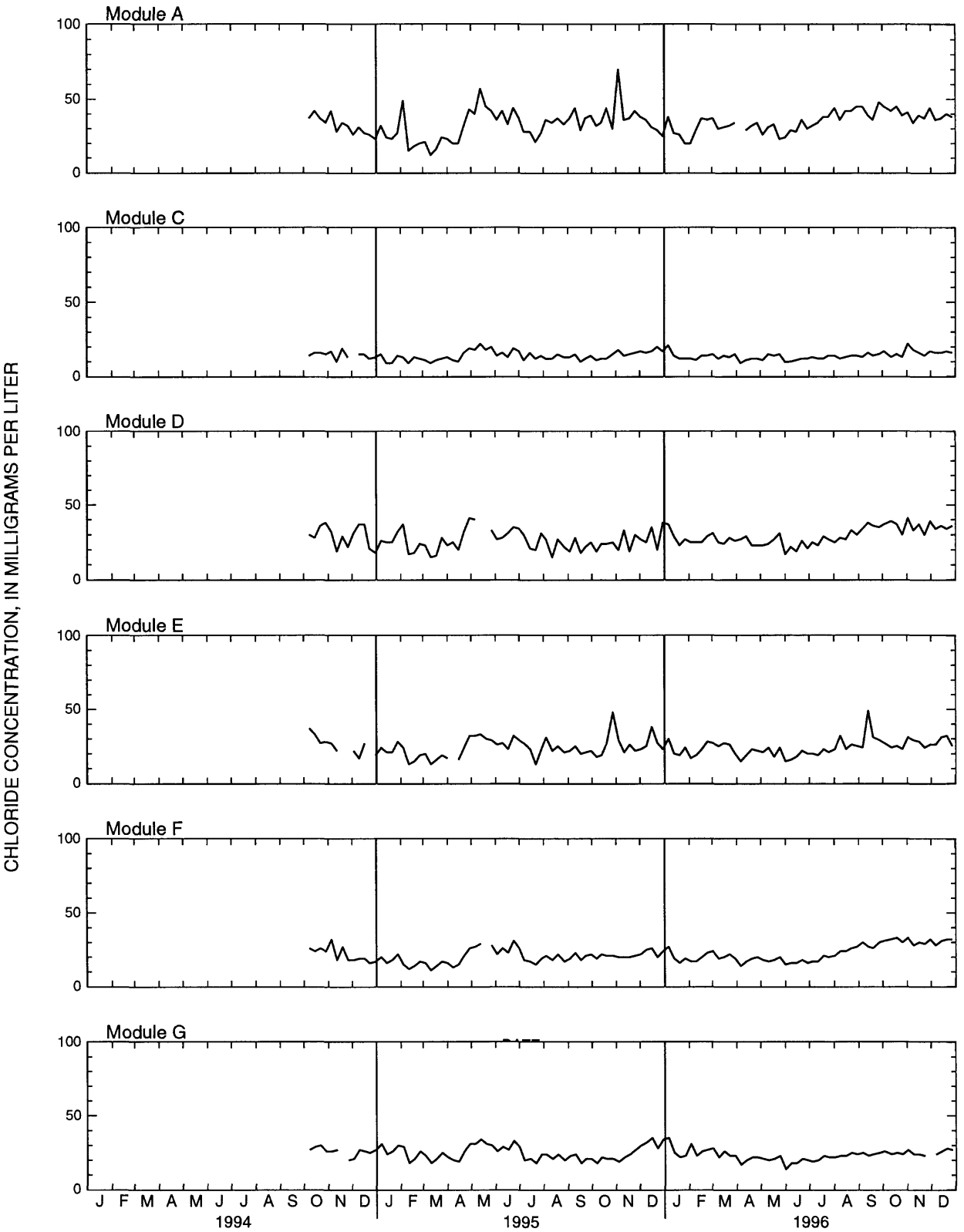


Figure C1. Chloride concentration of pumped water (sampled at weekly intervals) at Module A and Modules C through L at Cantonment, Diego Garcia, January 1994 through December 1996. Data not available for November 1993 through September 1994.

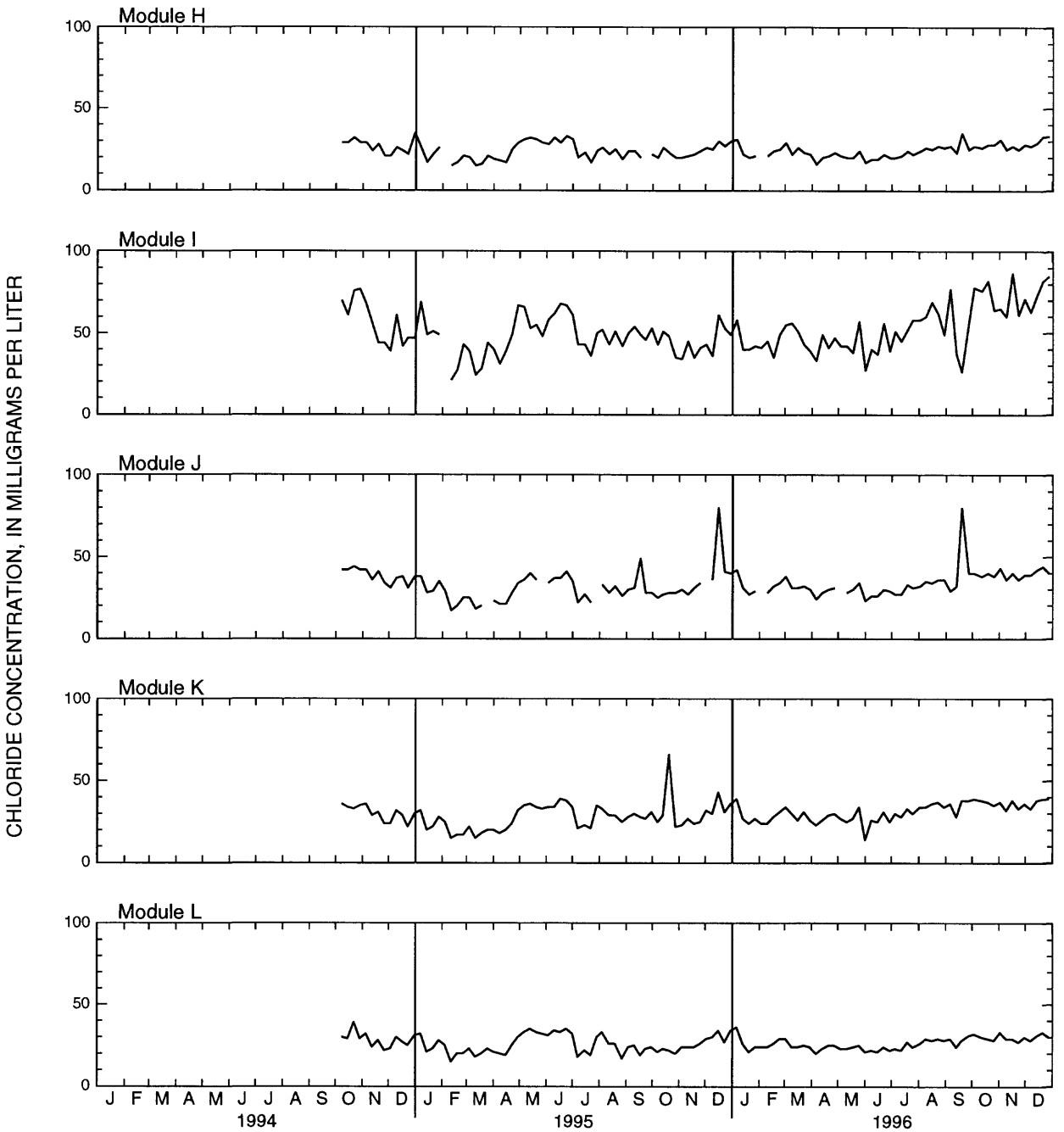


Figure C1. Chloride concentration of pumped water (sampled at weekly intervals) at Module A and Modules C through L at Cantonment, Diego Garcia, January 1994 through December 1996. Data not available for November 1993 through September 1994--Continued.

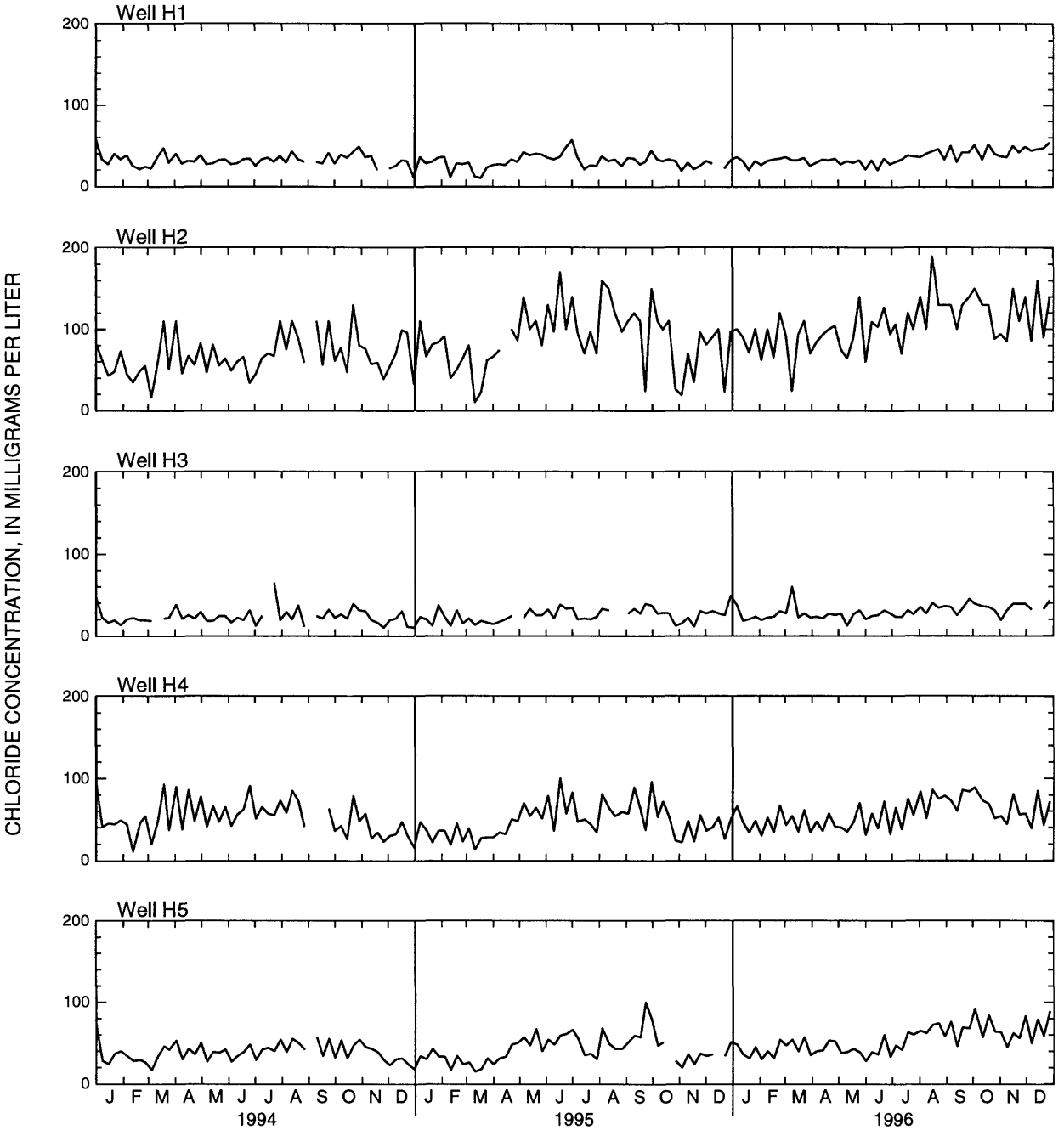


Figure C2. Chloride concentration of pumped water (sampled at weekly intervals) at Horizontal wells H1 through H7 at Cantonment, Diego Garcia, January 1994 through December 1996.

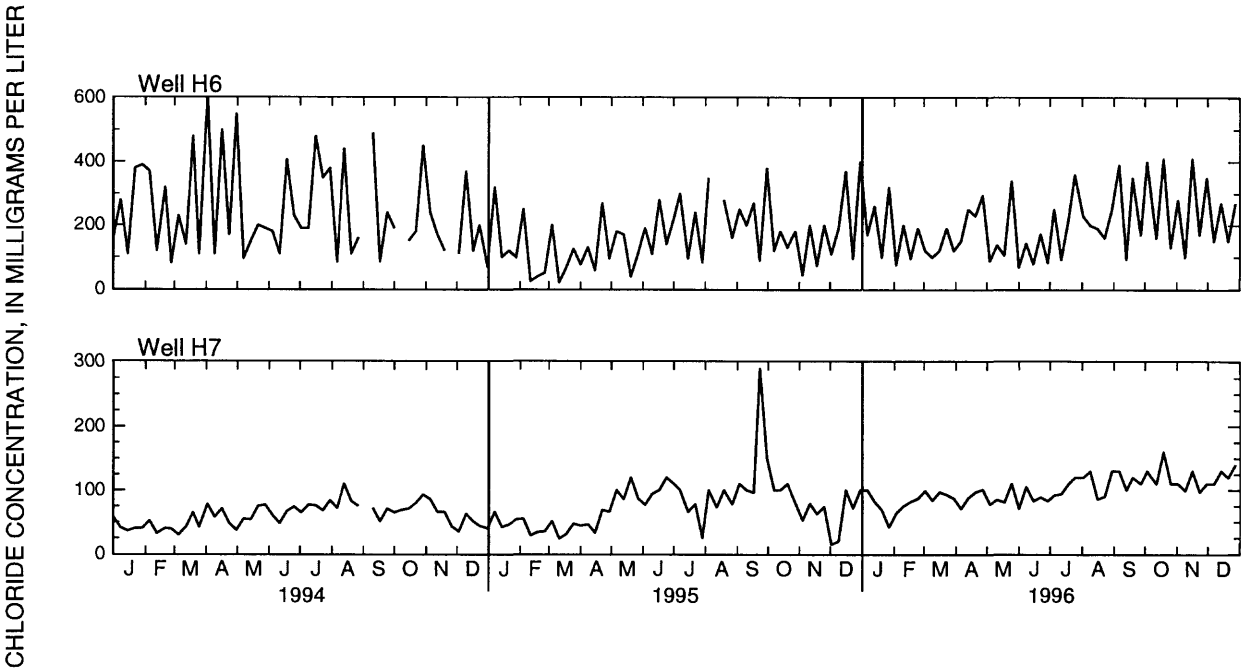


Figure C2. Chloride concentration of pumped water (sampled at weekly intervals) at Horizontal wells H1 through H7 at Cantonment, Diego Garcia, January 1994 through December 1996--Continued.

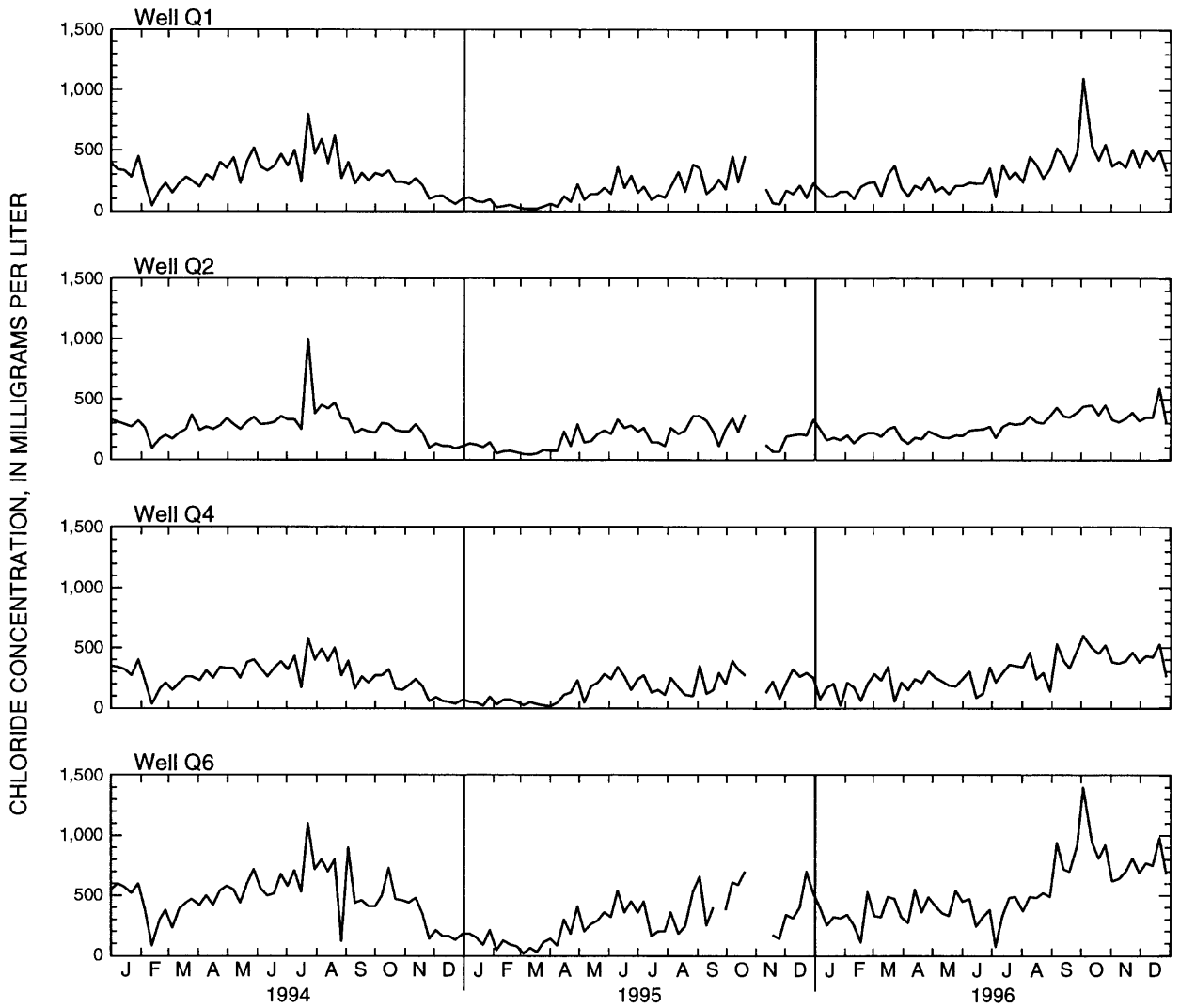


Figure C3. Chloride concentration of pumped water (sampled at weekly intervals) at Quad wells Q1, Q2, Q4, and Q6 at Cantonment, Diego Garcia, January 1994 through December 1996.

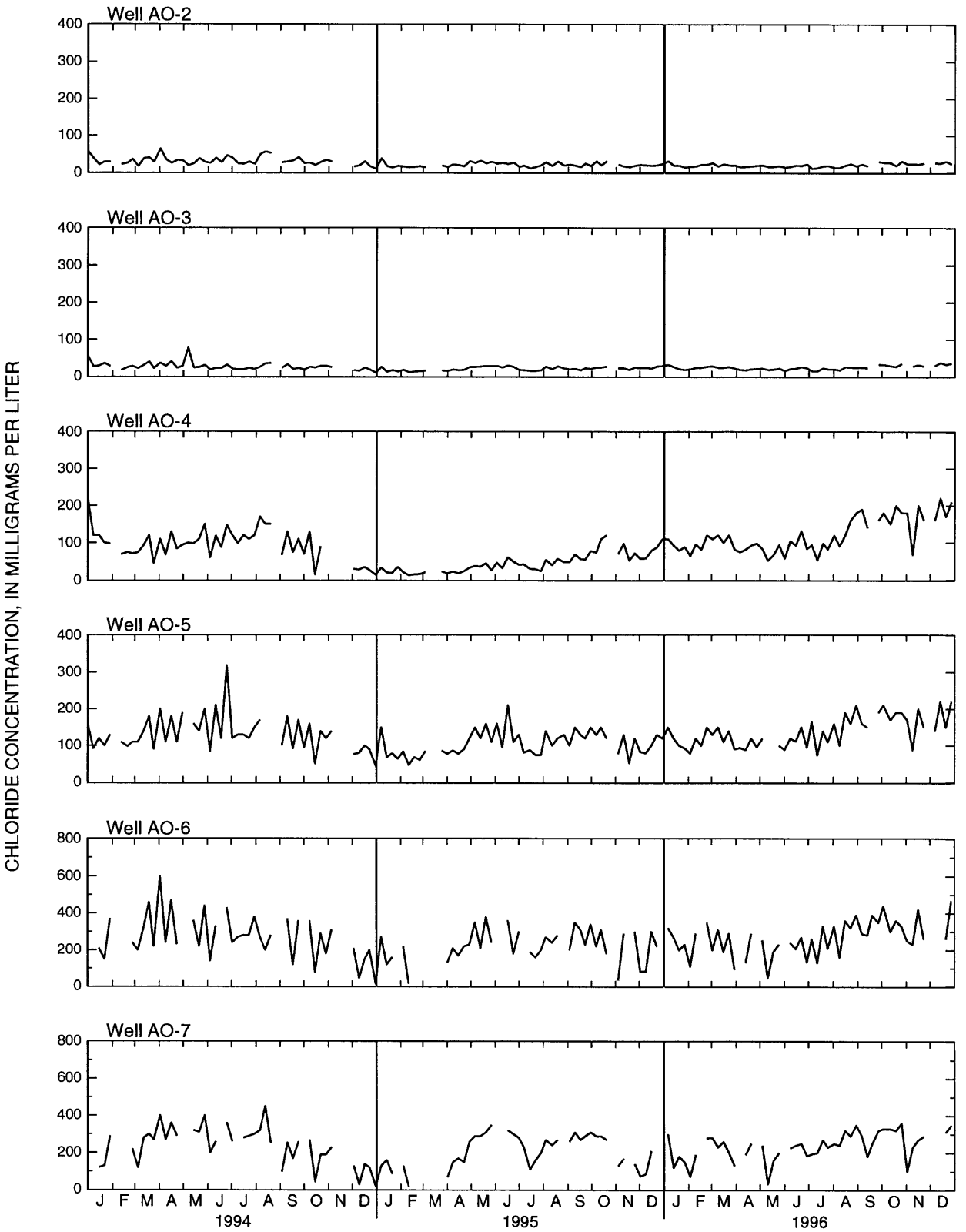


Figure C4. Chloride concentration of pumped water (sampled at weekly intervals) at wells AO-2 through AO-9 and wells AO-13 through AO-19 at Air Operations, Diego Garcia, January 1994 through December 1996. Water from well AO-13 has not been sampled since April 1993.

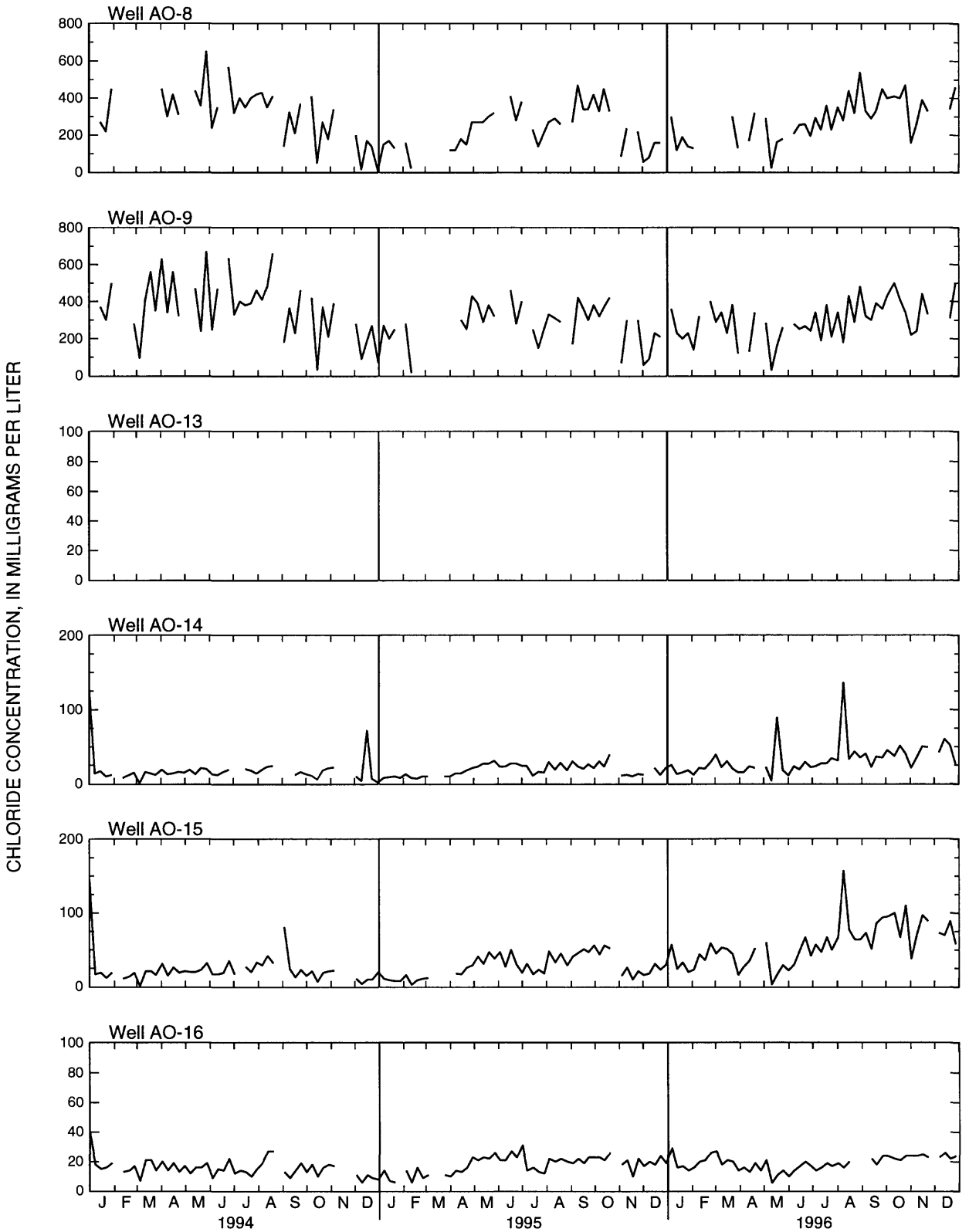


Figure C4. Chloride concentration of pumped water (sampled at weekly intervals) at wells AO-2 through AO-9 and wells AO-13 through AO-19 at Air Operations, Diego Garcia, January 1994 through December 1996. Water from well AO-13 has not been sampled since April 1993--Continued.

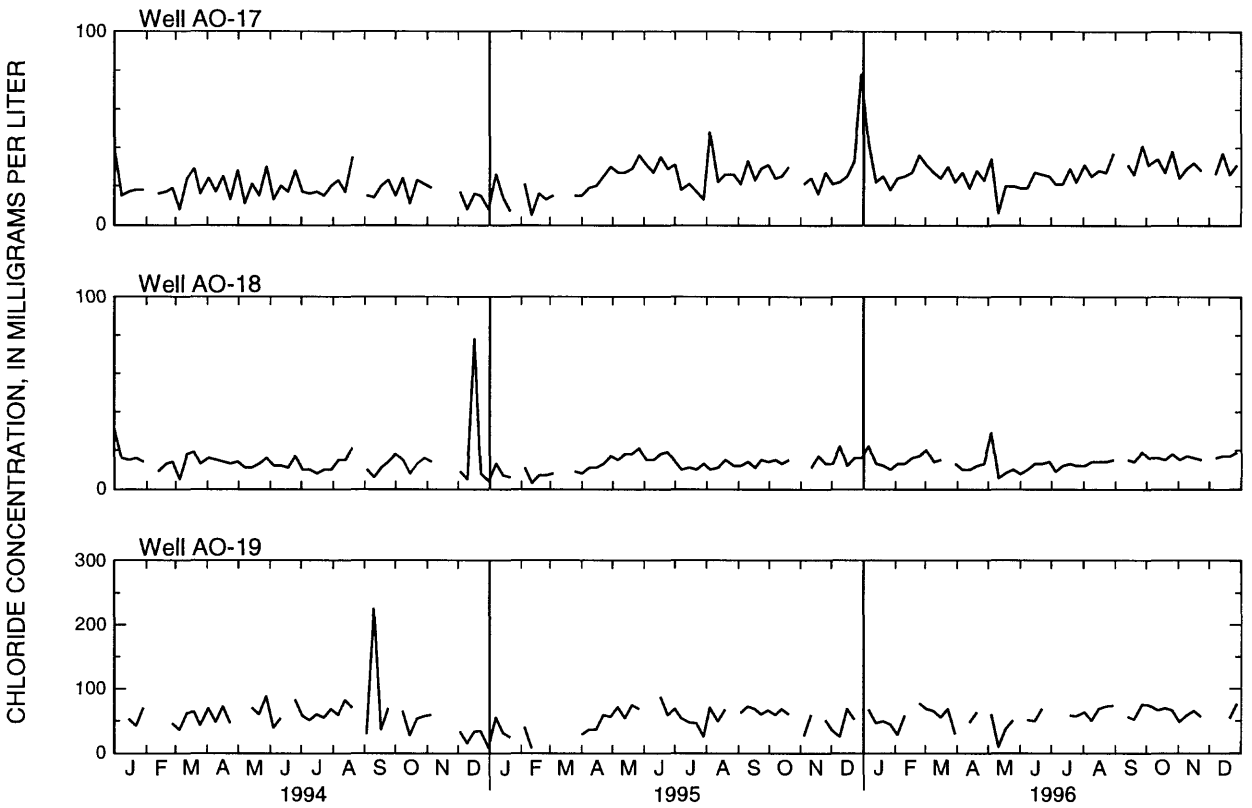


Figure C4. Chloride concentration of pumped water (sampled at weekly intervals) at wells AO-2 through AO-9 and wells AO-13 through AO-19 at Air Operations, Diego Garcia, January 1994 through December 1996. Water from well AO-13 has not been sampled since April 1993--Continued.

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