PREPARED IN COOPERATION WITH THE
U.S. DEPARTMENT OF THE NAVY, NAVY SUPPORT FACILITY, DIEGO GARCIA
AND THE
U.S. DEPARTMENT OF THE AIR FORCE, PACIFIC AIR FORCES

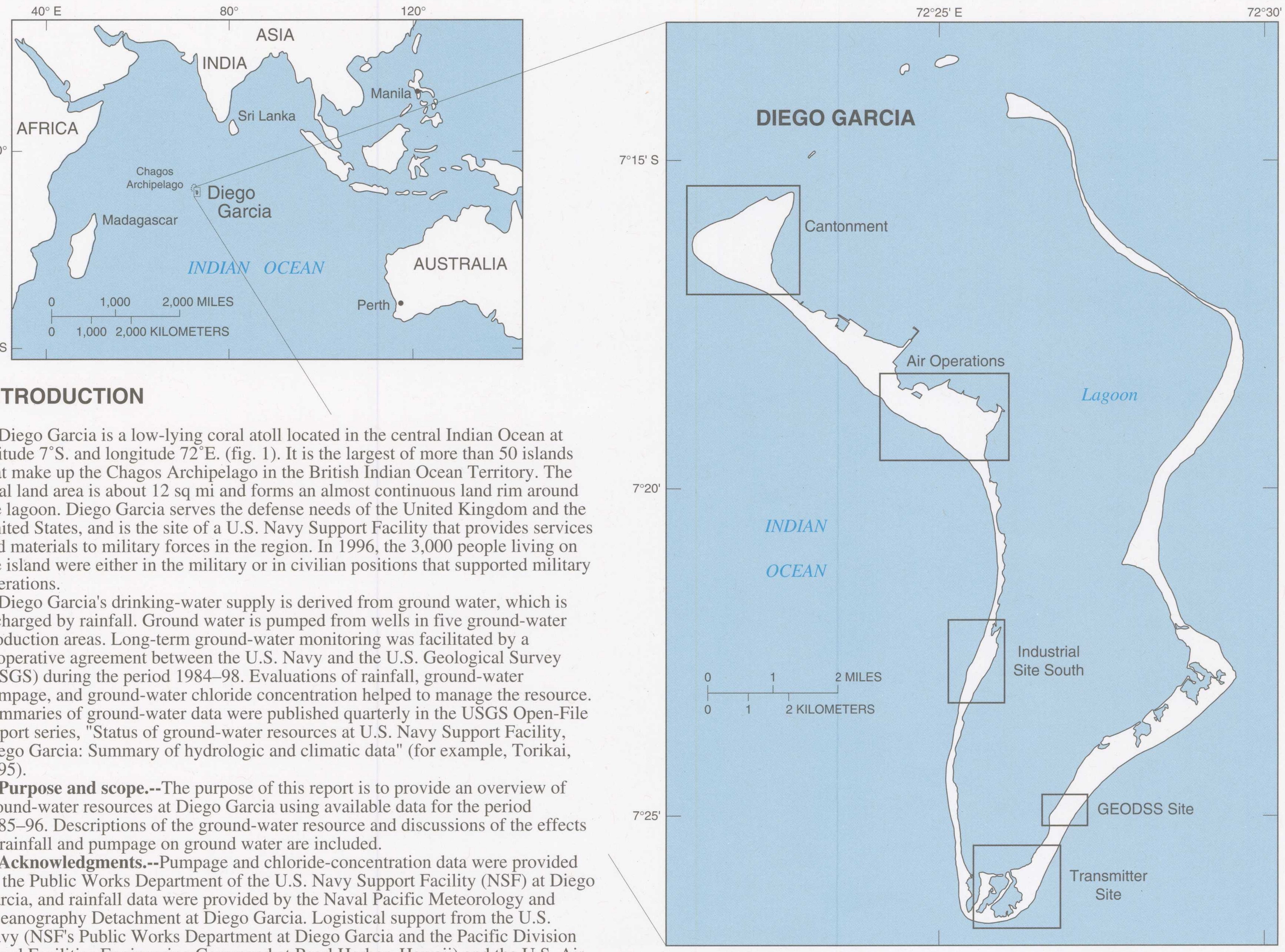

Figure 1. Areas of ground-water production, Diego Garcia.

INTRODUCTION

Diego Garcia is a low-lying coral atoll located in the central Indian Ocean at latitude 7°S. and longitude 72°E. (fig. 1). It is the largest of more than 50 islands that make up the Chagos Archipelago in the British Indian Ocean Territory. The total land area is about 12 sq mi and forms an almost continuous land rim around the lagoon. Diego Garcia serves the defense needs of the United Kingdom and the United States, and is the site of a U.S. Navy Support Facility that provides services and materials to military forces in the region. In 1996, the 3,000 people living on the island were either in the military or in civilian positions that supported military operations.

Diego Garcia's drinking-water supply is derived from ground water, which is recharged by rainfall. Ground water is pumped from wells in five ground-water production areas. Long-term ground-water monitoring was facilitated by a cooperative agreement between the U.S. Navy and the U.S. Geological Survey (USGS) during the period 1984–98. Evaluations of rainfall, ground-water pumpage, and ground-water chloride concentration helped to manage the resource. Summaries of ground-water data were published quarterly in the USGS Open-File Report series, "Status of ground-water resources at U.S. Navy Support Facility, Diego Garcia: Summary of hydrologic and climatic data" (for example, Torikai, 1995).

Purpose and scope.--The purpose of this report is to provide an overview of ground-water resources at Diego Garcia using available data for the period 1985–96. Descriptions of the ground-water resource and discussions of the effects of rainfall and pumpage on ground water are included.

Acknowledgments.--Pumpage and chloride-concentration data were provided by the Public Works Department of the U.S. Navy Support Facility (NSF) at Diego Garcia, and rainfall data were provided by the Naval Pacific Meteorology and Oceanography Detachment at Diego Garcia. Logistical support from the U.S. Navy (NSF's Public Works Department at Diego Garcia and the Pacific Division Naval Facilities Engineering Command at Pearl Harbor, Hawaii) and the U.S. Air Force (Headquarters Pacific Air Forces) is gratefully acknowledged.

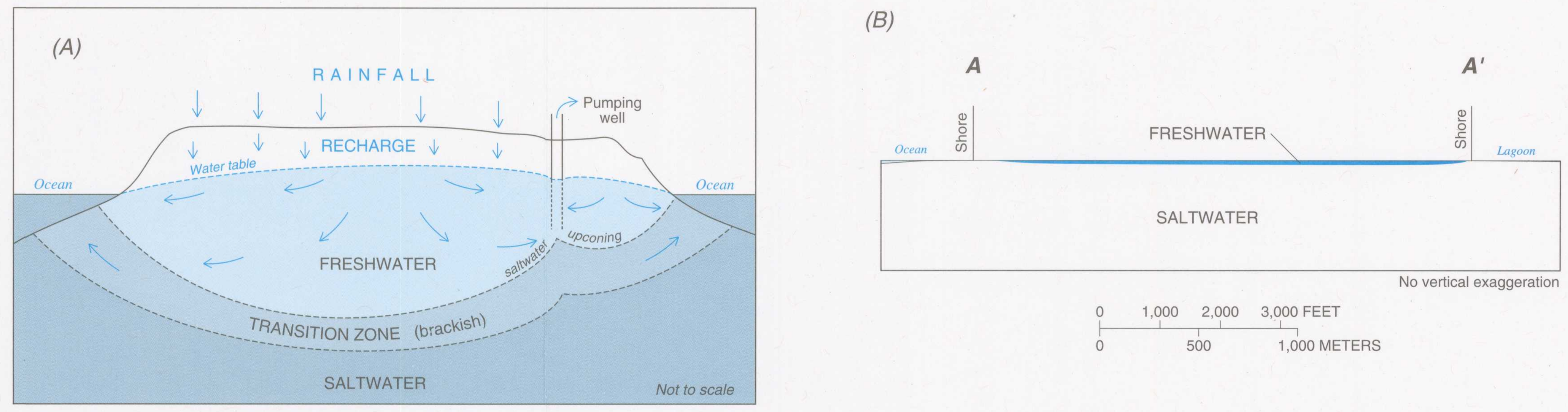

Figure 2. Diagrams of an island freshwater lens. (A) a typical freshwater lens showing the distribution of freshwater and saltwater, with vertical dimension greatly exaggerated; (B) the freshwater lens at Diego Garcia with no vertical exaggeration. Line of section is shown in figure 7.

THE FRESHWATER LENS

The freshwater lens constantly changes in response to fluctuations in rainfall and ground-water pumping.

Diego Garcia is composed of unconsolidated calcareous sediments underlain by limestone. Freshwater, brackish water, and saltwater occupy the small spaces between sand, gravel, and coral fragments, and also the larger spaces in the limestone. Ground water on Diego Garcia is found as lens-shaped bodies of freshwater overlying denser saltwater (fig. 2A). The source of water in a freshwater lens is from rainfall that infiltrates the ground surface and recharges the lens. Water naturally discharges from a lens by seepage into the ocean along the coast, with discharge varying naturally in response to recharge. Pumping is an additional component of discharge. A freshwater lens at Diego Garcia is drawn with no vertical exaggeration to show the thinness of the freshwater lens (fig. 2B). Between the freshwater and the underlying saltwater, there is a transition zone in which freshwater and saltwater mix. This mixing produces brackish water of varying saltiness.

Freshwater is defined in this report as water with a maximum chloride concentration of 250 mg/L. Chloride concentration is an indication of the relative saltiness of the water. For comparison, the chloride concentration of seawater at Diego Garcia is about 19,400 mg/L (Tribble, 2001). The U.S. Environmental Protection Agency (1991) established 250 mg/L chloride concentration as the recommended level for the aesthetic qualities of drinking water. The chloride concentration of brackish water in the transition zone is more than 250 and less than 19,400 mg/L.

Theoretical freshwater lens.--The thickness of freshwater below mean sea level is commonly estimated using the Ghyben-Herzberg relation, which relates the density difference between freshwater and saltwater to the depth of the interface separating freshwater and saltwater. The commonly used definition of the relation states that the depth to the freshwater-saltwater interface below sea level is 40 times the elevation of the water table above mean sea level (Todd, 1980). The Ghyben-Herzberg relation assumes the change from freshwater to saltwater is a sharp interface. But in reality, the change from freshwater to saltwater is gradual through the transition zone, and is indicated by increasing saltiness with depth.

Variations in lens size.--The size of a freshwater lens fluctuates naturally with time in response to changes in recharge and discharge. The lens is a fixed size if recharge and discharge remain steady. The lens could shrink during periods of low rainfall or high pumpage, whereas the lens could expand during periods of high rainfall or low pumpage. Ground-water pumping rates that are too high, or pumping from wells that are too deep or too closely spaced could cause upconing of salty water at the base of the lens (fig. 2A), by which the saltier water could contaminate the well. Water levels in the lens also change in response to ocean tides and other sea-level changes. Water-level fluctuations in the lens are influenced by sediment and rock type, and increase with depth and proximity to the shore (PRC Toups, 1983; Hunt, 1997). The fluctuations can be as much as 5 ft at Diego Garcia in response to ocean tides (J.D. Torikai, USGS, written commun. to U.S. Navy, 1994).

The size of a freshwater lens is described in this report by areal extent and thickness. Maps of areal extent show the boundary of the top of the lens, and cross sections of freshwater thickness show the vertical extent of the lens.

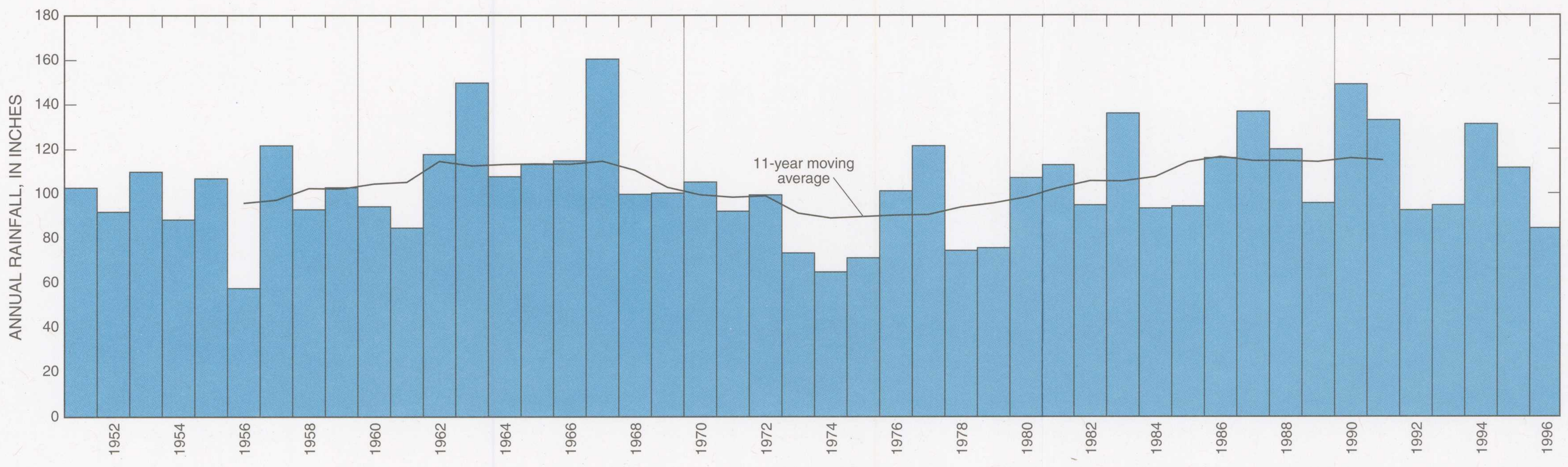

Figure 3. Annual rainfall at Diego Garcia, 1951–96. Annual rainfall for 1976–77, 1979, 1987–88 includes estimated values for months with missing data.

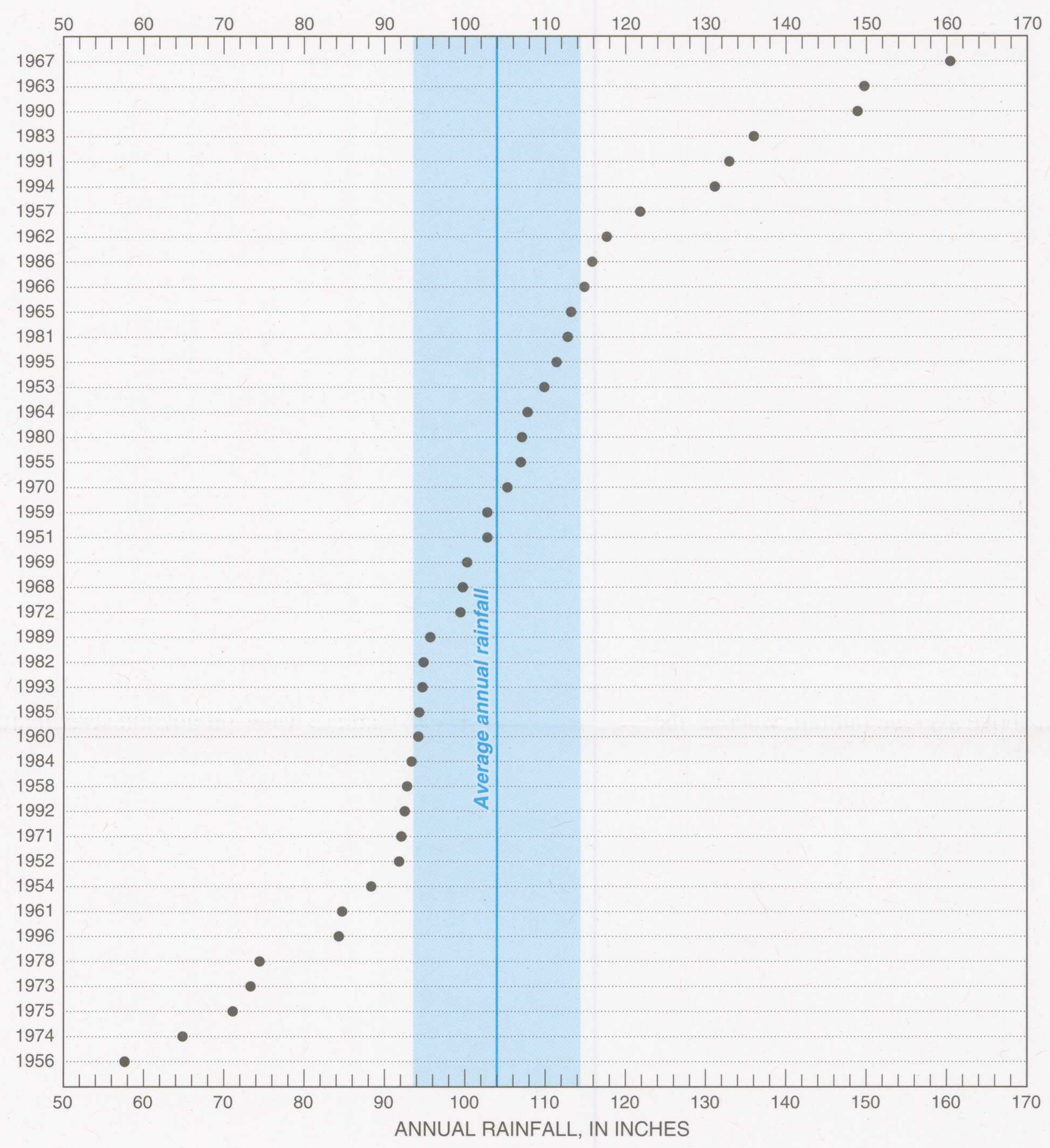

Figure 4. Annual rainfall, with years ranked in order of rainfall amount (for 41 years of complete record, 1951–96).

RAINFALL

The amount of ground-water recharge depends on rainfall, which varies considerably from month to month and from year to year.

Abundant rainfall on Diego Garcia provides recharge to the freshwater lenses. The average annual rainfall on Diego Garcia is about 104 in/yr for the period 1951–96 (U.S. Department of Commerce, 1968, 1979, 1995; U.S. Navy, 1978; Naval Pacific Meteorology and Oceanography Detachment at Diego Garcia, unpub. data, 1994–96). A wet season occurs from about September through February, and a dry season from about March through August (Hunt, 1997), although March through May can be considered a transitional period with characteristics of either the wet or dry season (Naval Pacific Meteorology and Oceanography Detachment at Diego Garcia, written commun., 1997). Rainfall varies considerably from month to month and ranged from less than 1 inch to almost 30 inches during any 1 month throughout the period of record.

Long-term trends.--Annual rainfall for the period 1951–96 is highly variable with a range of 58 to 160 in/yr (figs. 3 and 4). For 5 years during this period, annual rainfall was estimated because 1 or 2 months of data were missing. The missing monthly rainfall were: March and May 1976; September 1977; February and August 1979; June 1987; and May 1988. For these 5 years, the average monthly rainfall for the given calendar month was substituted for the missing data, and the annual totals were estimated using these averages. A long-term trend line of an 11-year moving average shows cycles of high rainfall and low rainfall represented by peaks and troughs in the trend line, respectively. The decades of the 1960's and 1980's were periods with above average rainfall, whereas the 1970's was a period with below average rainfall. The moving average is calculated for each year using annual rainfall for an 11-year period starting 5 years prior and ending 5 years after. The moving average is not calculated for the first 5 years and last 5 years of the period of record.

Variability in rainfall is shown in figure 4 in which annual rainfall is ranked in order of rainfall amount, but excludes the 5 years with estimated annual rainfall. The shaded area represents annual rainfall that is 10 percent above and 10 percent below the average annual rainfall of 104 in/yr. The annual rainfall for 18 of the 41 years that have no missing record is within 10 percent of the average annual rainfall. The other 23 years of rainfall range from as much as 54 percent above the average annual rainfall (160 in/yr in 1967) to 44 percent below the average (58 in/yr in 1956).

Drought periods on Diego Garcia can be short in duration, as in below average rainfall during a dry season; or they can be longer in duration, as in several consecutive years. Changes in rainfall from month to month and from year to year at Diego Garcia cause variability in the size of the freshwater lenses.

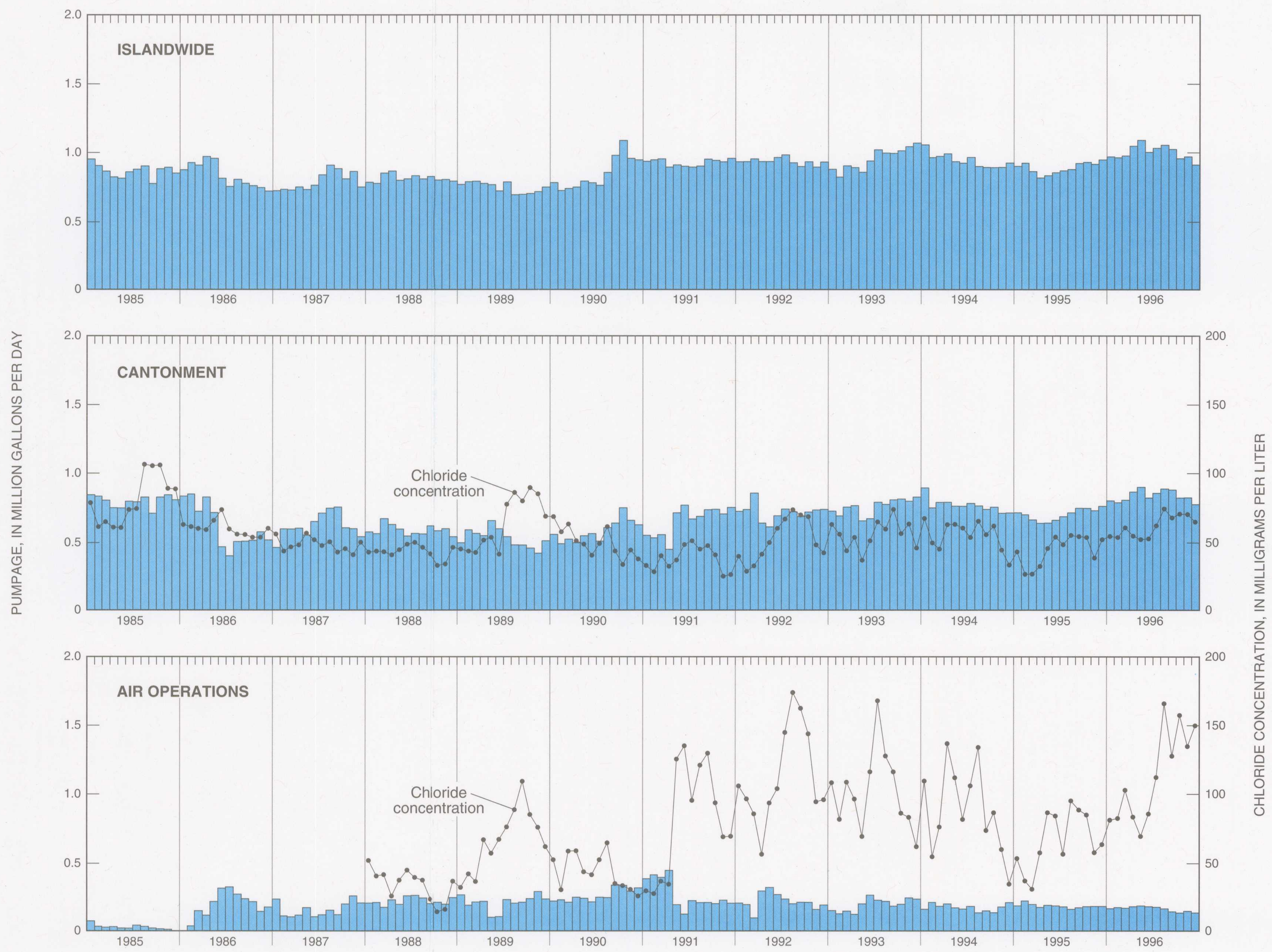

Figure 5. Monthly average ground-water pumpage and chloride concentrations, Diego Garcia, 1985–96.

THE WATER-PRODUCTION SYSTEM

Dispersed pumping and low pumping rates help to limit chloride concentration in pumped ground water.

Diego Garcia's water-production system produced about 1 Mgal/d of ground water from more than 100 shallow wells for the period 1985–96. Vertical and horizontal pumping wells were distributed in five ground-water production areas (fig. 1). The areally distributed pumping and low pumping rates were designed to minimize upconing of salty water (D.A. Davis, USGS, written commun. to U.S. Navy, 1979). The shallow well system proved to be operationally simple, reliable, and inexpensive, compared with alternatives such as rain catchment and desalination, which were deemed more expensive and less feasible (Surface and Lau, 1988).

Pumping patterns.--On the basis of monthly averages, islandwide pumpage fluctuated between 0.8 to 1 Mgal/d for the period 1985–96 (fig. 5). Water from the Cantonment and Air Operations areas combined accounted for at least 95 percent of islandwide pumpage during this period. During the period 1992–96, about 80 percent of islandwide pumpage came from Cantonment and about 19 percent from Air Operations, with the remaining 1 percent of islandwide pumpage from Industrial Site South, Transmitter Site, and GEODSS Site.

Islandwide pumpage increased by more than 20 percent in mid-1990 because of increased military activity in the region. The pumping distribution between Cantonment and Air Operations changed in May 1991 because of ground-water contamination that initially shut down 10 wells at Air Operations. Consequently, pumpage at Air Operations decreased by about 0.2 Mgal/d, and this lost pumping capacity was offset by increased pumping at Cantonment.

Chloride concentration of pumped ground water.--The monthly average chloride concentration of water sampled from the elevated distribution tank at Cantonment was less than 100 mg/L during the period 1986–96, while water sampled from the elevated tank at Air Operations was less than 200 mg/L during the period 1988–96 (fig. 5). The elevated tanks were composite supplies of water from the many individual wells in each area. The chloride concentration of water from Cantonment was greater than 100 mg/L only in late 1985 when 92 percent of islandwide pumpage was from Cantonment. A sharp increase in chloride concentration at Air Operations in May 1991 coincided with the shutdown of 10 wells. The chloride concentration of water from these 10 individual wells was typically less than 20 mg/L prior to their shutdown in 1991, while other Air Operations wells that remained operating produced water with chloride concentrations as high as 200 mg/L in early 1991 (Torikai, 1995). The shutdown of these 10 wells increased the chloride concentration of the composite water at Air Operations since the composite supply no longer contained water from wells with relatively low chloride concentration.

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GROUND-WATER RESOURCES AT DIEGO GARCIA, 1985–96

by
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