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U.S. ARMY SPACE AND STRATEGIC DEFENSE COMMAND
U.S. ARMY KWAJALEIN ATOLL

Gingerich, S.B., 1996, Ground-water resources and contamination at Roi-Namur Island, Kwajalein Atoll, 1990-91

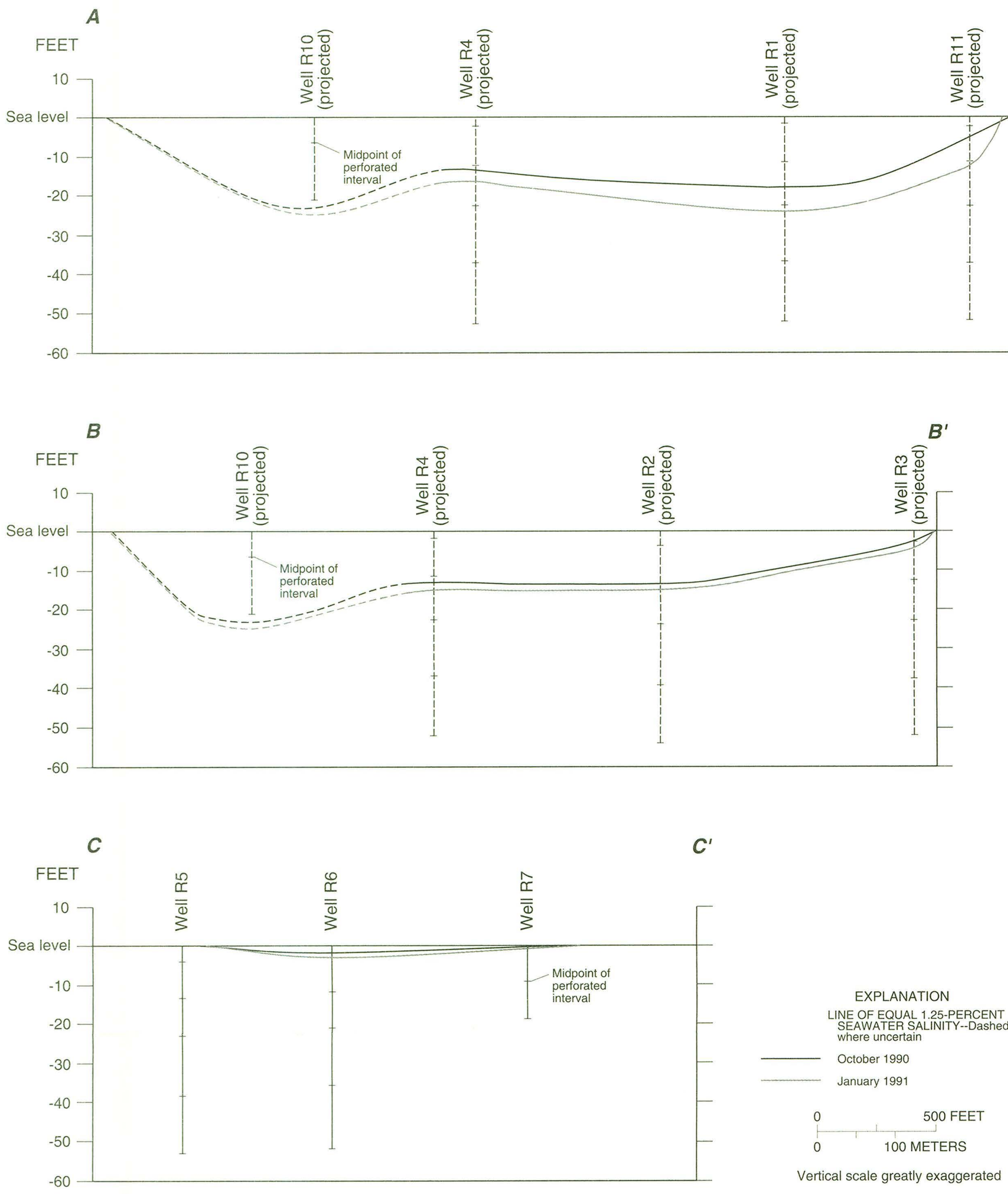

Figure 10. Seasonal change in thickness of the freshwater lens, Roi-Namur Island.

SEASONAL CHANGES IN THICKNESS OF THE FRESHWATER LENS

The freshwater lens shrank and expanded in a seasonal cycle, although changes were subtle because rainfall was steadier than normal. Freshwater thickness changed as much as 3 ft near ground-water withdrawal wells.

Temporal variations in recharge, natural discharge, and ground-water withdrawal cause the freshwater lens to expand and contract. Four water-sampling surveys were conducted to detect such changes: in October 1990 and January, May, and July, 1991. The most extreme change in position of the 1.25-percent seawater salinity line, between the October 1990 and January 1991 samplings, is shown in figure 10.

The lens was thinnest at most monitoring wells in October 1990. Changes in lens thickness were systematic in sections *A-A'* and *B-B'* in that the lens was thinnest everywhere in October 1990 and thickest in January 1991. Changes in *C-C'* were small (about 1 ft).

Rainfall was uncharacteristically steady during the study period; that is, the seasonal variation was less extreme than normal. As a result, the observed changes in lens thickness were subtle. Greater changes would be expected to accompany a more strongly seasonal rainfall pattern.

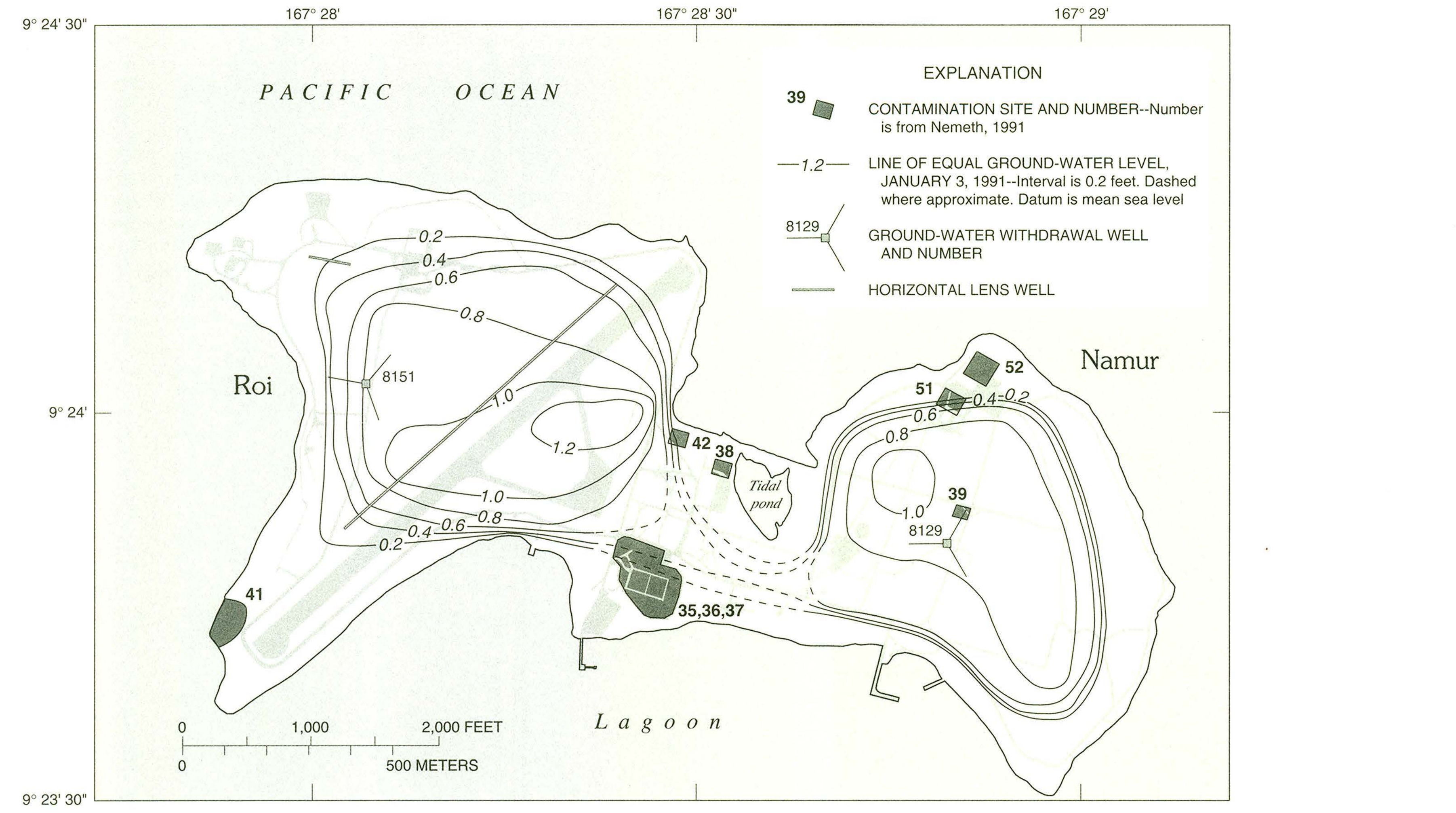

Figure 12. Known sites of environmental contamination (modified from Nemeth, 1991), and ground-water levels, Roi-Namur Island.

CONTAMINATION SITES AND MIGRATION OF CONTAMINANTS

Most known sites of contamination overlie the outer slopes of the water table where natural ground-water flow will tend to carry contaminants toward the shore. However, a possible source near the central water-table mound on Roi has greater potential to contaminate possible new well locations.

Activities at Roi-Namur Island have released a variety of contaminants to the environment at a number of sites (fig. 12 and table 3), and some of these contaminants have the potential to contaminate ground water. The U.S. Army Environmental Hygiene Agency surveyed potential sites of environmental contamination and selected high-priority sites for sampling and analysis of soil and ground water (Nemeth, 1991). Only the types of contaminants exceeding background levels at each site are listed in table 3. Pertinent findings by Nemeth (1991) include:

(1) soil contamination was confirmed at nearly all of the sites that were sampled;
(2) ground-water contamination was not found or was slight at most sites, and was most widespread and at the highest levels in and near sites 35, 36, and 37 (power plant area);
(3) several inches of fuel oil lay on top of the water table downgradient of the power plant and associated fuel storage tanks; and
(4) ground water was contaminated by chlorinated solvents at most former solvent storage sites, but the concentration of solvents in ground water was generally low.

Ground water will flow from areas of higher water level to areas of lower water level, in directions perpendicular to the water-level contours. Generalized flow lines drawn perpendicular to the water-level contours shown in figure 12 indicate the probable directions of contaminant migration from the sites under non-pumping conditions. Most of the contamination sites are located in the central isthmus or on Namur. The exception is site 41, which lies at the west end of the runway on Roi. This site lies at the periphery of the freshwater lens along the outer water-level contours where natural ground-water flow will tend to carry contaminants to the shore.

Low, but noteworthy levels of chlorinated solvents were detected in lens well 8151. Maximum contaminant levels (MCL's) have been established for several of the compounds (U.S. Environmental Protection Agency, 1989). The concentrations of trichloroethylene and tetrachloroethylene in the well 8151 were 0.014 and 0.007 mg/L, respectively, slightly exceeding their respective MCL's (both 0.005 mg/L). This location is far enough downgradient from the existing water-supply well so that it is unlikely that contaminants will migrate to the well. But the contaminants may be a problem if an additional water-supply well is considered for this area. The exact source of the contaminants will need to be determined from further investigation.

Table 3. Contamination sites and contaminants, Roi-Namur Island (summarized from Nemeth, 1991)
[POL, petroleum, oil, lubricants; PCB, polychlorinated biphenyl]

Site no.	Site description	Contaminants released at site
35	Oil/solvent pit	POL, Solvents
36	Drummed material storage area	Solvents
37	Wash rack discharge ditch	Metals, PCB's, POL
38	Building 8197 sandblast facility	Metals
39	Film burning cage	Metals
41	Roi-Namur landfill	Solvents, metals, POL, PCB's
42	Former landfill/dump	POL, metals
51	Aluminum etching facility	Metals, cyanide
52	TRADEX antenna facility	Metals, solvents, PCB's

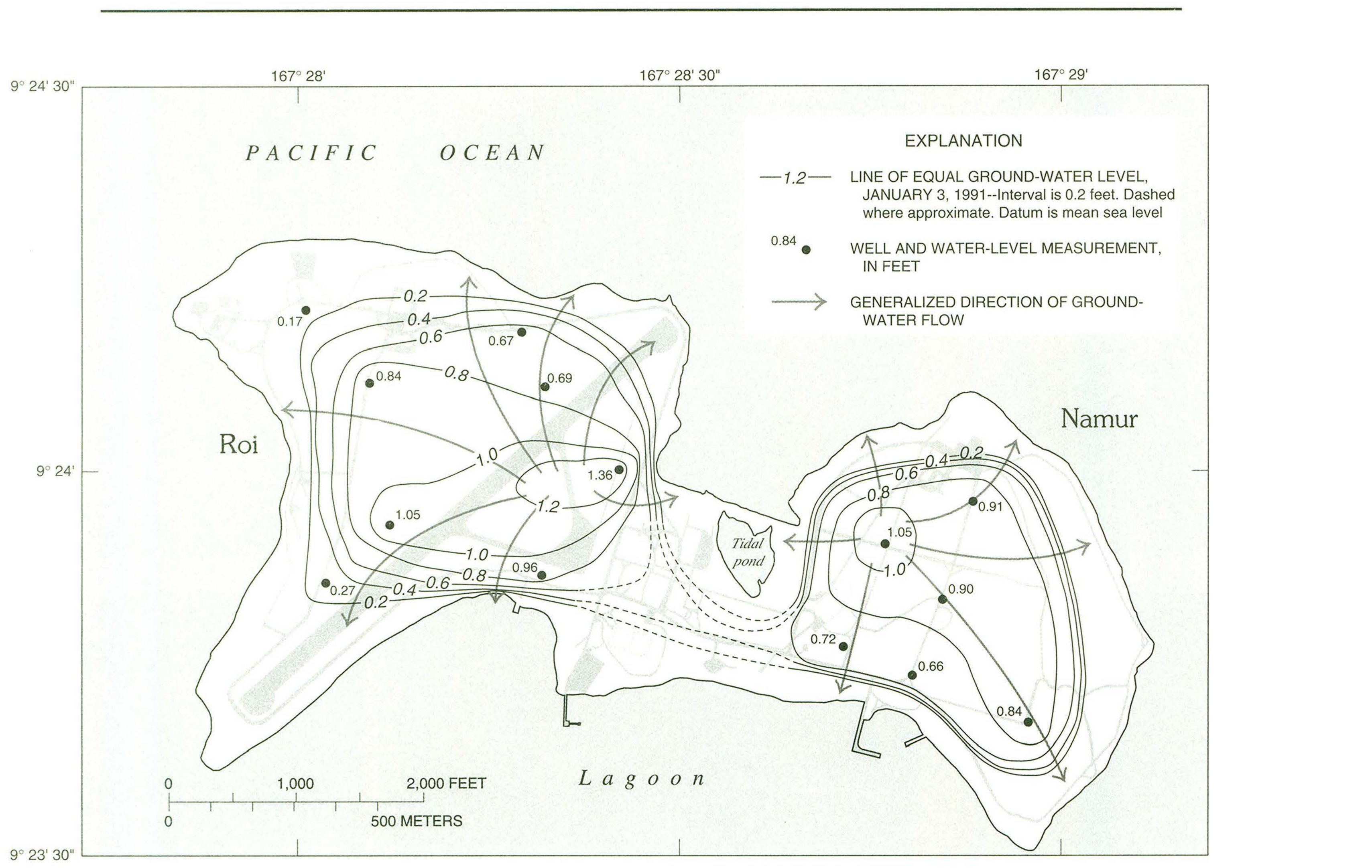

Figure 11. Ground-water levels and the configuration of the water table for non-pumping conditions, Roi-Namur Island.

WATER-TABLE CONFIGURATION AND DIRECTIONS OF GROUND-WATER FLOW

The water table forms a broad mound near the center of Roi; this general feature persisted over the year-long study.

The water-table defines the top surface of the freshwater lens. Contour lines showing the altitude of the water-table for January 3, 1991 (fig. 11) define a circular mound near the center of Roi. The location of the mound is influenced by several factors, most notably the shape of the island and the spatial distributions of recharge, aquifer properties, and pumping. The high point of the water table, 1.36 ft above mean sea level on the day of the survey, is located to the east side of the mound, not in the center as might be expected. The water table on Namur forms a similar shape indicating that sediment deposition patterns, which are expected to be similar on both islands, are controlling lens development.

In an unconfined aquifer, water-table altitude is commonly a good approximation of hydraulic head, which can be used to infer directions and rates of ground-water flow, as well as the movement of contaminants dissolved in the flowing ground water. A water-table map can also indicate the migration direction of floating contaminants such as fuels, which tend to flow down the slope of the water table. Fresh ground water will flow from areas of higher water level to areas of lower water level, in directions roughly perpendicular to the water-level contours. The contours indicate that ground-water moves radially from the center of the water-table mound and flows oceanward and lagoonward.

Figure 11 shows the water table only on the day of the survey. The map reflects non-pumping conditions (for 2 months before the survey, ground-water withdrawal was halted). Data for October 1990, May 1991, and July 1991 were similar to the January 1991 data and were collected under similar conditions. At each time, therefore, the lens was in a state of slow depletion by natural discharge, with a comparatively smooth water table that lacked steep, localized mounds or drawdown cones caused by concentrated recharge or withdrawal. Different water-table configurations would reflect different patterns of ground-water flow from that shown in figure 11. Drawdown from pumping would divert some of the oceanward and lagoonward flow to wells, and recharge would modify flow directions locally causing mounds, perhaps even temporarily reversing flow in some areas. To what degree the measured configuration represents general conditions or approximates some long-term average configuration of interest is not known. An average configuration could be determined by operating continuous water-level recorders at numerous wells and averaging the data over the desired time period, such as a year. Effects of withdrawal and recharge could also be analyzed with data from such a recording network.

Preparation of the water-level map.--Four water-level surveys were done during the study, in October 1990 and January, May, and July 1991. Each survey was done in a single day to approximate a simultaneous measurement of water-table configuration, and ground-water withdrawal was halted for several days to weeks before so that results would reflect non-pumping conditions.

Measuring-point elevations at each R-series well were surveyed by turning-point leveling to an accuracy of about 0.02 ft. The leveling surveys started and ended at official benchmarks that are accurately referenced to the local mean-sea-level datum, which is the average of sea level over the 19-year National Tidal Datum Epoch 1960-78 (National Oceanic and Atmospheric Administration, 1992). The depth to water in each well was measured with a graduated electrical tape and subtracted from the measuring-point elevation to obtain the height of water above mean sea level.

Because ocean tides can cause water levels in wells to fluctuate several feet on atolls, measurements were synchronized with the tides. The survey was run twice on a given day, once each for a consecutive high and low tide about 6 hours apart. Measurements were made repetitively at 20- to 40-minute intervals to capture the tidal peak and trough in each well. The maximum and minimum water levels were averaged to obtain an average water level over the tidal half-cycle. Average water levels were corrected for water density, where necessary, to convert them to equivalent freshwater levels (in a freshwater-saltwater system, water levels depend on the salinity and density of the water and will not provide an accurate indication of hydraulic head and ground-water flow direction unless corrected: Lusczynski, 1961). At each multi-depth monitoring site, the shallowest reliable measurement was selected as most representative of the water table. The tidally averaged, density-corrected water levels were plotted on maps, and contour lines were hand-drawn by visual interpolation.

The measured water levels are referenced to a fixed, mean-sea-level datum. Variations in sea level from day to day impose a moving datum, and it is difficult to determine an exact datum correction that would allow the water-table heights to be converted to absolute hydraulic heads. Determination of absolute head is important for comparing surveys from different dates (only after adequate datum correction could one be assured that differences in head from date to date truly reflect hydraulic phenomena of interest, such as change in lens thickness). The average sea level during this survey does not provide an adequate datum correction, because of the asymmetric character of the tides on the day of the survey. The problem of datum correction requires further analysis that is beyond the scope of this discussion.

SUMMARY AND CONCLUSIONS

This report presents findings of a study of ground-water resources and contamination at Roi-Namur Island. The government of the United States has proposed increases in population and activities at Kwajalein Atoll, and has undertaken studies to assess the likely effects of the proposed expansion. This report emphasizes results of field surveys at Roi-Namur Island from September 1990 through August 1991 to define the extent and character of ground-water resources.

Ground-water resources and development.--The ground-water resource is a lens of freshwater that floats on saltwater in the island. A transition zone of mixture separates the freshwater and saltwater, and in most places this zone is thicker than the freshwater itself. The freshwater lens is recharged by rainwater, and it shrinks and expands in response to variations in recharge and ground-water withdrawal. Some fraction of the recharge can be withdrawn continually, but the salinity of the pumped water will rise if withdrawal is too great or if rainfall is low for prolonged periods. Long horizontal wells are used to skim water from the thin freshwater lens and prevent upconing of the transition zone, which would raise salinity.

Water-production system.--Freshwater is produced by a joint system of rain catchments and shallow wells. Water production has averaged about 30,000 gal/d in recent years. Rainfall is seasonal, and ground-water withdrawal is heaviest during the annual dry season. During the year, catchment yield provides an adequate supply most of the time, although it must be supplemented occasionally with ground-water during the dry season. Particularly dry years require more ground-water withdrawal than usual to make up for the shortfall in catchment yield.

Extent and thickness of the freshwater lens.--The freshwater lens on Roi reflects the roughly circular shape of the island and attains a maximum thickness of nearly 23 ft. The lens is thickest and widest in the central area of Roi where the aircraft runway is located. Recharge is higher in the center of the island than elsewhere because of a greater proportion of grassy areas, and enhanced surface-water runoff from the runways. Fresh ground water is thin or absent on Namur because of the thick vegetation. The configuration of freshwater on the isthmus is not known because of lack of wells.

Changes in thickness of the freshwater lens.--During the year of study, the lens shrank and expanded in a seasonal cycle, as much as 3 ft near withdrawal wells. Rainfall was steadier than normal during the study, however, and observed changes in thickness were subtle as a result. Greater changes would be expected to accompany a more strongly seasonal rainfall pattern.

Directions of ground-water flow and contaminant migration.--The top of the freshwater lens, or water table forms a broad mound in the center of the island. Fresh ground water will flow from the mound and move oceanward and lagoonward. Most known sites of contamination are on the central isthmus and Namur or at the periphery of this flow system, where flow will tend to carry contaminants toward the shore. However, lens well 8151 shows low levels of several chlorinated solvents from an undetermined source and there is slight potential to contaminate the nearby airfield lens well.

Potential for additional ground-water development.--The central area of Roi between wells R1 and R10 holds the greatest potential for developing additional potable ground water with new wells as indicated by the maps of the thickness and areal extent of freshwater. Contamination potential is low except in the vicinity of well 8151, where an unknown source of contamination may be present. Outlying areas hold little potential for development of ground water, except for landscape irrigation or other nonpotable uses.

Surplus water from the catchment basins could be retained for future use if it were used to recharge the aquifer through the existing well system or if more storage capacity were available. There is potential for about 47 Mgal/yr of rainwater to be captured by the catchment basins although some will be lost to evaporation and by leakage.

CONVERSION FACTORS AND ABBREVIATION

Multiply	By	To obtain
acre	4,047	square meter
foot (ft)	0.3048	meter
inch (in.)	25.4	millimeter
inch per month	25.4	millimeter per month
gallon (gal)	3.785	liter
gallon per day (gal/d)	3.785	liter per day
gallon per day (gal/d)	0.003785	cubic meter per day
million gallons (Mgal)	3,785	cubic meters
million gallons per day (Mgal/d)	0.04381	cubic meters per second

Abbreviation used: mg/L, milligrams per liter

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by
STEPHEN B. GINGERICH

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