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Hydrogeology Series

Establishment of Hydrogeological Monitoring Equipment in the Salomon and Peros Banhos Atolls, British Indian Ocean Territory (BIOT).

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The Government of the British Indian Ocean Territory

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Executive Summary

i. A BGS hydrogeologist, visited the BIOT from 13 March to 29 March 2001. The Government of the BIOT facilitated the visit through the Foreign and Commonwealth Office, (FCO) with logistical support from the British Royal Marines and Naval Party stationed in Diego Garcia. During this period, eight days were spent in the Peros Banhos and Salomon Atolls to the north of Diego Garcia where two recording tide gauges, three recording groundwater water level meters and a recording automatic weather station were commissioned.

ii. The monitoring equipment was established to determine the relationship between the tide and two observation boreholes drilled on Ile Boddam and between the tide and an existing dug well on Ile du Coin. The distances and vertical elevations of equipment relative to fixed local datum points were surveyed. Data generated will assist with evaluation of aquifer performance and potentially for the assessment of a safe pumping yield. The meteorological data will help to establish the amount of effective rainfall (recharge) to the fresh water lenses on the islands.

iii. Preliminary results using test data demonstrate the characteristics of atoll fresh water lenses. These include a clearly discernable lag in groundwater response to tidal effects and a relatively low tidal efficiency.

iv. Dataloggers attached to the commissioned instruments will be downloaded periodically by the Royal Marines during brief visits to the islands. Marines were provided with training and instructions for the downloading procedures. Further training and a simplification of the process including the up-loading of data to personal computer may be necessary.

v. Groundwater protection and management is a critical concern on isolated atoll islands where resident populations are supported. At present in the Chagos Islands there is little understanding of seasonal, inter-annual or long-term fluctuations in groundwater quantity or quality. Issues such as the impact of latrine provision and 'grey water' disposal on shallow aquifers should be considered. The drying-up or deterioration of shallow borehole water quality during extended dry periods may be a seasonal response to reduced recharge and groundwater recessions. Collection of spatial and temporal meteorological and hydrogeological data should help identify areas at risk of quantity or quality problems for future planning purposes.

vi. Valuable insights into the hydrological and hydrogeological nature of and mechanisms of water abstraction and delivery in the atoll environments were gained from all the islands visited. Parts of the groundwater supply system in Diego Garcia provided a useful analogue for a potential supply system in the Chagos Islands. This emerged from the liaison with the resident water engineers working in the Public Works Department with the US NSF Diego Garcia. One day was spent undertaking a comprehensive tour of groundwater supply facilities and within the Public Works Department. The importance of effective characterisation of the fresh groundwater lens systems as well as the importance of long-term monitoring was emphasised. The vulnerability of small atoll island water resources is particularly important and was demonstrated by the serious effects of fuel spillage and the danger of introducing saline conditions by over pumping wells or boreholes, particularly during extended periods without rainfall.

vii. There is a valuable opportunity to increase the amount of information generated by reconfiguring existing sensors and modest expenditure on additional sensors on the islands. The cost implications of failing to maximise information gathering from existing monitoring programmes are significant. To gain the same information that could be routinely collected during ongoing monitoring would require significant investment in exploratory testing. Simple techniques such as the ones used during the BGS visit could be used to collect reliable information from ongoing programmes. A supplementary project proposal is included as an appendix to this report.

List of Acronyms

BIOT	British Indian Ocean Territory
BGS	British Geological Survey
BritOps	British (Royal Marines) Operations
DG21	Main Contractor Company on Diego Garcia
FCO	Foreign and Commonwealth Office
FPV	Fisheries Protection Vessel
GIS	Geographical Information System
GPS	Global Positioning System
HDPE	High Density Polyethylene
l/s	litres/second
mbct	metres below casing top (or mark on frame top for dug wells)
mbgl	metres below ground level
msl	mean sea level
µs/cm	micro-seimens per centimetre
NSF	Naval Support Facility (US)
PWD	Public Works Department (DG21)
ppm	parts per million
Sc	Specific Capacity
Smax (m)	maximum Drawdown
T (m/d)	Transmissivity
WHO	World Health Organisation

Borehole and Well Coding

B	*Ile Boddam*
C	*Ile du Coin*
W	*Well*
L	*Lagoon Side*
T	*Tide (tide level)*
O	*Ocean Side*
S	*Shallow (groundwater level)*
D	*Deep (groundwater level)*

BLS1 refers to Ile Boddam, Lagoon Side Shallow groundwater level 1.
CW1 refers to Well 1 on Ile du Coin.

1. INTRODUCTION

During March 2001 a hydrogeologist from the British Geological Survey undertook a project mission in the British Indian Ocean Territory (BIOT) to install equipment to monitor and investigate the occurrence of groundwater on two small atoll islands. The project mission was carried out as a precursor to and in conjunction with a much larger water resources study. This in turn is part of the ongoing feasibility study for resettlement of the Salomon and Peros Banhos Atolls. The bulk of work was carried out in the northern atolls of the Chagos Archipelago. Additional work was undertaken in Diego Garcia from where the project was undertaken and facilitated. The location of the study area is shown in Figure 1.1.

The investigation forms a preliminary part of a second phase of the study. During the first phase of the study, a team of five specialist environmentalists including a Water Engineer visited two islands in the atolls, Ile Boddam and Ile du Coin during May 2000. These were previously settled and managed as copra plantations but were depopulated in 1972. The team's report, 'Resettlement of the Salomons and Peros Banhos Atolls by D. Crapper et. al., June 2000) detailed several requirements for hydrogeological monitoring prior to a more comprehensive study.

The programme for the mission on Ile Boddam and Ile du Coin was designed to establish monitoring equipment in order to investigate tidal influences on shallow groundwater and to establish a meteorological station to provide data relevant for water balance studies. It also resulted in the initialisation of a meteorological record. Preliminary data derived from the mission and subsequent data recorded with the equipment installed will be used to consider the groundwater development potential for the islands. These studies could also serve as useful analogues for other islands in the atolls where the siting of sustainable groundwater supplies might subsequently be required.

The BGS hydrogeologist, Andrew Butcher, visited the BIOT from 13 March to 29 March 2001. The Government of the BIOT facilitated the visit through the Foreign and Commonwealth Office, (FCO) and with logistical support from the British Royal Marines and Naval Party stationed in Diego Garcia as well as the Captain and crew of the Fisheries Protection Vessel, 'Pacific Marlin'. An itinerary for the visit is given in Appendix B. Terms of reference are provided in Appendix A and summarised below:

- Install and operate an Automatic Weather Station in an appropriate position on one island
- Install and operate a recording tide gauge on the lagoon shores of Ile Boddam in the Salomon Islands and Ile du Coin in Peros Banhos Atoll and one ocean side shore on one island for a duration sufficient to establish a sea level datum for both coasts (provisionally 1 year)
- Carry out instrument and site levelling as necessary to relate inland water table (and ground level) elevations at well sites to lagoon and open sea levels.
- Install and operate water level recorders on selected shallow wells to derive tidal efficiencies and other aquifer properties from the response of the lens to lagoon and open sea tides
- Carry out initial pumping tests on selected existing shallow wells and other field investigations to investigate freshwater lens characteristic and safe abstraction rates.
- Where possible, hand-auger and establish shallow peizometers to derive tidal efficiencies and other aquifer properties including electrical conductivity from the response of the deeper part of the lens to lagoon and open sea tides. Investigate the applicability of auguring or lightweight drilling for subsequent tubewells.

Figure 1.1 Location of Study Area.

Indian Ocean Area

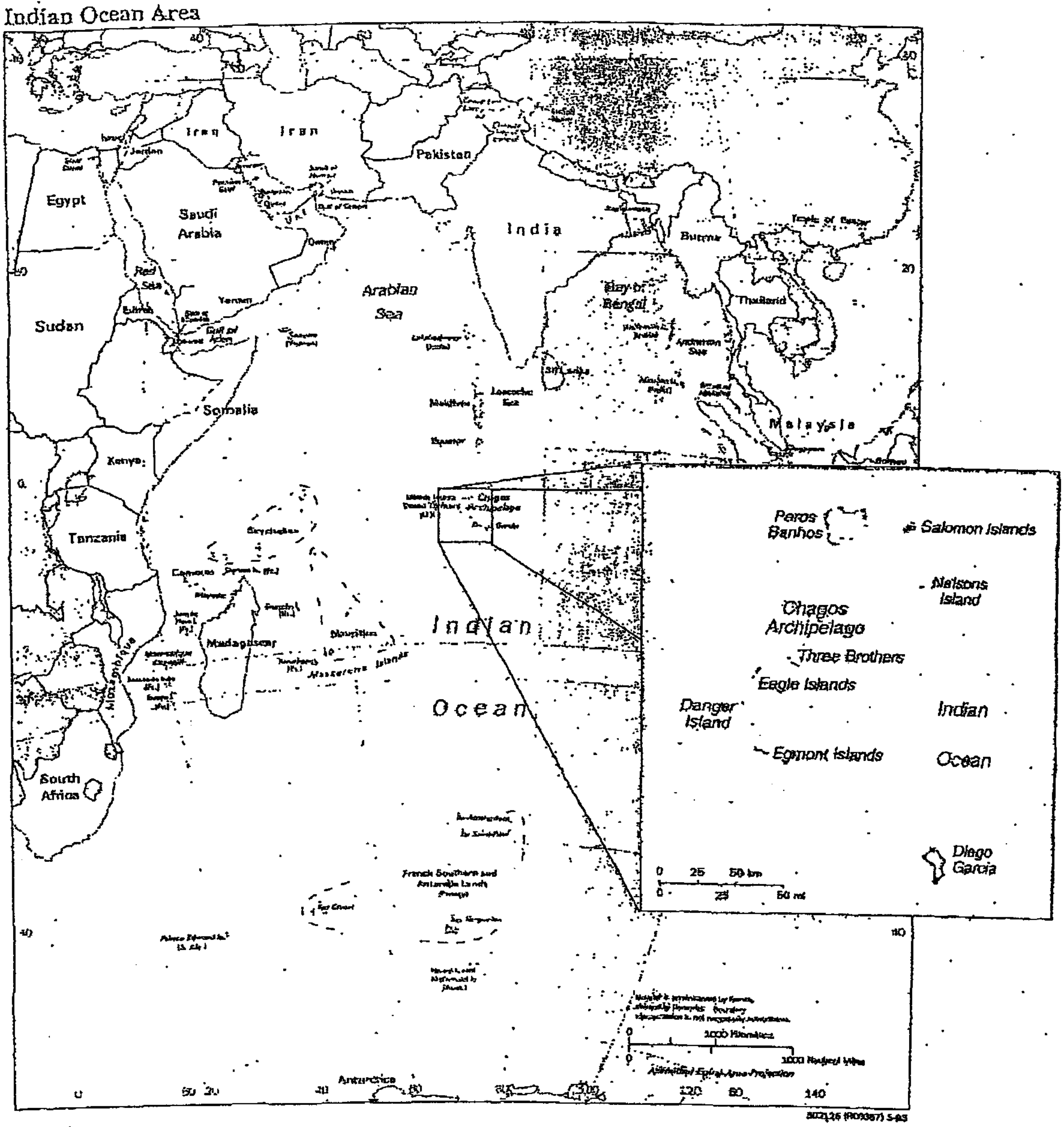


Figure 1.2 View of Salomon Atoll (from North)

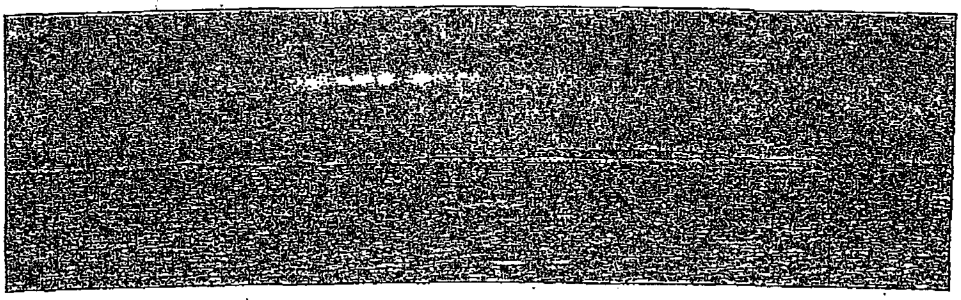


Figure 1.3 Study Area (computer graphic, not true cartographic representation)

2. BACKGROUND INFORMATION ON THE STUDY AREA

The study was undertaken on the northern atoll islands of the Chagos Archipelago in the central Indian Ocean, in the following locations:

Salomon Atoll: 72°12'-72°17' east and 5°18'-5°22' south.

Peros Banhos Atoll: 71°44'-72°01' east and 5°14'-5° 28' south.

The area is extremely isolated being some 500 kilometres south of the Maldives and has no regular communications. Preparatory work and post study work was undertaken at the British/US defence facility on Diego Garcia approximately 220 kilometres to the south from where the mission was facilitated using the fisheries protection vessel, 'Pacific Marlin'.

The Salomon Atoll has a length of approximately 8km whilst Peros Banhos is approximately four times larger with a length of 32 km. The atolls visited have a very limited land extent, comprising 35 to 45 small islets/islands depending on tidal conditions, the largest of which is only approximately 110 hectares in area (*2000 study report*). The land extent is remarkably continuous on Diego Garcia except for inlets at the northern end. In the Salomon Atoll the 11 islands/islets are more dispersed with several inlets but one main navigable passage. In the Peros Banhos Atoll the 33 or so islets/islands are very dispersed with many inlets and navigable passages. Fringing reefs are present on all atolls but there are navigable channels into and within Diego Garcia and Peros Banhos. Access into the lagoon to islands within the Salomon Atoll is only possible by smaller 'Rigid Raider' craft.

'Rigid Raiders' are also required to access Ile Du Coin where the jetty has collapsed and extensive corals restrict shore access except at high tide. On Ile du Coin the transfer of bulky or sensitive equipment such as geophysical sensors, borehole casing or lightweight drilling equipment requires scheduling with the high tide. It may be necessary to wade for 200m or so at other times (Figs. 2.1 and 2.2). Access to Ile Boddam is easier, where although the jetty is in poor condition it is still accessible from the island and ocean sides (Fig. 2.3).

The topography over the atolls is flat with elevations not exceeding a few metres although no complete topographic survey was undertaken of either of the main islands studied. Coconut Palms and Takamaka trees can reach 25 metres in height. At ground level vegetation can be extremely thick but there are also patches where vegetation has not recovered perhaps after being cleared near to previous dwellings perhaps as domestic gardens.

The Climate in the atolls is dominated by two monsoon periods which result in a wetter period from October to April when light to moderate NW winds predominate and between May to September when strong south east trade winds dominate. Rainfall derived from Isohyet maps (NSF 1999 and Stoddart 1971) rather than direct records suggest an annual average of over 3500 mm for the atolls. This is rather more than the 2600mm average (based on a 47 year record) on Diego Garcia. A variation of approximately 10% of the averaged annual rainfall has been noted in measurements at different localities on Diego Garcia over the year. This is reported to be typical for atolls and trends to an average over a longer meteorological record (NSF 1999 and Stoddart 1971). The variation of annual rainfall for Diego Garcia as a whole about the long term annual average can be up to 40%. The establishment of a Automatic Weather station will provide a clearer indication of the variation in rainfall between Diego Garcia and the Chagos Islands. If the record is maintained, it will also identify periods of extreme conditions, which should be expected to lead to significant effects on the shape of the freshwater lens and the amount of potable groundwater available.

The weather in the atolls is consistently warm with a diurnal range typically of less than 10°C.

The occurrence of groundwater on the islands is within the porous matrix of the carbonate sand and subsurface rock in near flat lens shaped bodies of fresher and less dense water overlying more saline and denser water. The actual dimensions of the water surface and thickness of the fresh lens depends on several factors but include the dimensions and topography of the land, the physical properties of the rock and the water balance determined by the amounts of effective rainfall, evapotranspiration and losses to the ocean. The traditional conceptual model of groundwater occurrence in an island is the Ghyben-Herzberg lens also considered with assumptions of horizontal flow of water proposed by Dupuit. However, several assumptions relating to horizontal water flow that may be quite valid for large homogeneous islands are probably not so for small island cases. The assumptions lead to a simplified model of a lens containing fresh water to a depth of 40 times the head (of water above mean sea level). Also the ideal conceptual model results in a sharp interface between fresh and saline water (Fig. 2.4). A simple and useful visual analogy would be of an iceberg with 1 m of fresh (albeit frozen) water exposed above the mean sea level and a root of 40 m below, surrounded and underlain by seawater. The actual shape of the lenses are much flatter than a usual iceberg analogy suggests. Where the land subsurface is not uniform and/or there are seasonal variations in the water balance, the figure is usually considered to be more typically 20 times the head. Theoretically, this figure also refers to the depth to the centre of the transition zone between saline and fresh water. The thickness of the transition zone is often much broader in non-uniform cases due to dispersion and diffusion. This is particularly the case where seasonal effects are significant.

The flow in a freshwater lens is theoretically from the centre of an island to the ocean at or near the mean sea level. Hydraulic gradients are generally shallow as would be expected in such low-lying environments. Mixing at the edges of the lens due to tidal fluctuations can be significant but in shallow wells is considered like the fluctuations themselves to decrease rapidly with distance away from the shoreline (edge of the lens). The lag time for tidal response on the surface of the freshwater lens is expected to increase with distance away from the shoreline. The main control on the tidal efficiency and lag time is the hydraulic conductivity, K (permeability to water) of the subsurface.

Where the hydraulic conductivity is high as in the case of clean well-sorted sand, the tidal lag should be relatively short and the ratio of the amplitude of the variation of the level of the lens water to that of the ocean tidal variation should be relatively high. This ratio is often stated as a percentage and referred to as the tidal efficiency.

By monitoring the lag time and tidal efficiency at selected points on the islands, it should be possible to calculate an estimate of the hydraulic conductivity and from this and other information, an evaluation of the safe yield of the freshwater lens.

The measurements required include accurate and extended monitoring of ocean tide levels and the response of the water level in wells or boreholes on land to the tidal fluctuations. Tidal lags and tidal efficiencies can be derived from the recorded data. Where the levels can be referenced to a local datum point, the change in the level of the fresh water lens towards the shoreline can also be plotted.

A record of meteorological parameters including rainfall, evaporation, solar radiation and humidity provides important information on the water balance of an island and about how the shape of the freshwater lens may be modified with time.

Chemical analysis linked to rainfall monitoring and water level records in wells and boreholes will also provide evidence about how the lens is affected by external influences.

Despite the limited amount of time available on each island for recognisance, over twenty wells were identified, many of which contained substantial amounts of debris. It appeared that most of the dwellings might have had separate wells. The distributed wells along with boreholes or simple peizometers constructed during this project will useful in assessing the spatial variations in the freshwater lenses on the islands. Reports from visiting yachtspersons suggested that an informal inventory of 36 wells had been gathered on Ile Boddam alone. Several pits, often containing mature coconut palms may have been mistaken for shallow wells but these have no engineered structures.

The tides in the Chagos Islands are semi diurnal and typically range from 0.2 metres for neap tides to 1.35 for spring tides (Pangolin™ tide tables). Tide prediction charts are also available from the NSF Diego Garcia for Eclipse Point in Diego Garcia.

Figure 2.1 View of jetty on Ile Boddam. Note tide gauge at extreme left edge of jetty

Figure 2.2 Jetty front, tide gauge and drop off point for wading, Ile du Coin, close up of jetty inset.

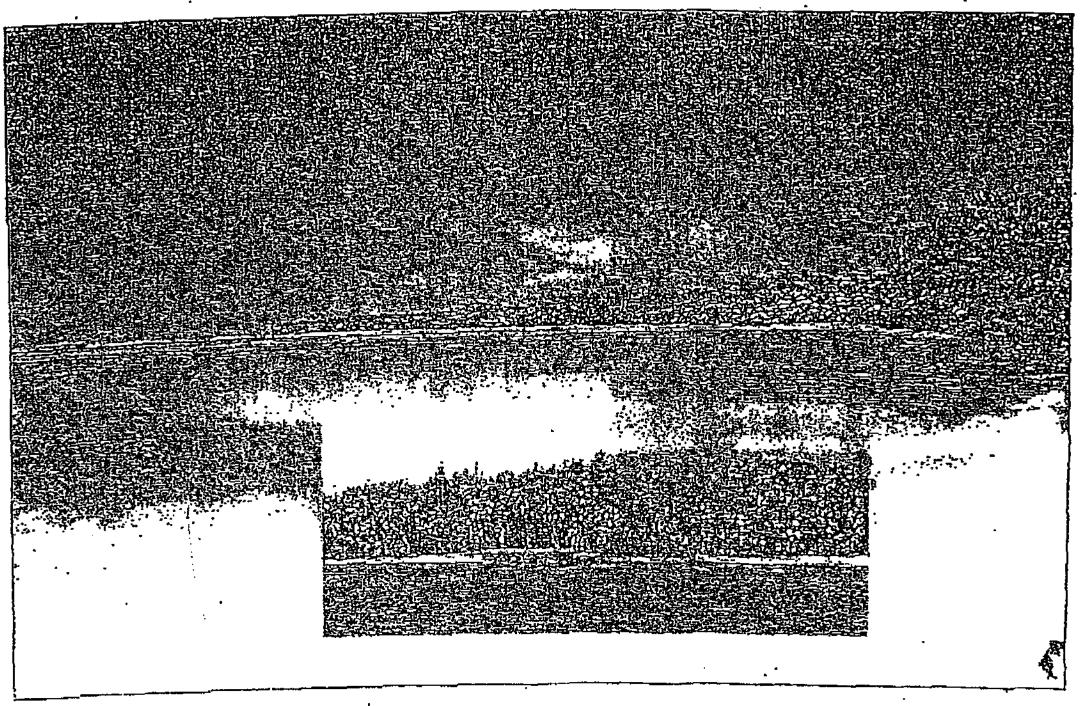


Figure 2.3 Wading ashore on Ile du Coin, note collapsed jetty structure in foregound

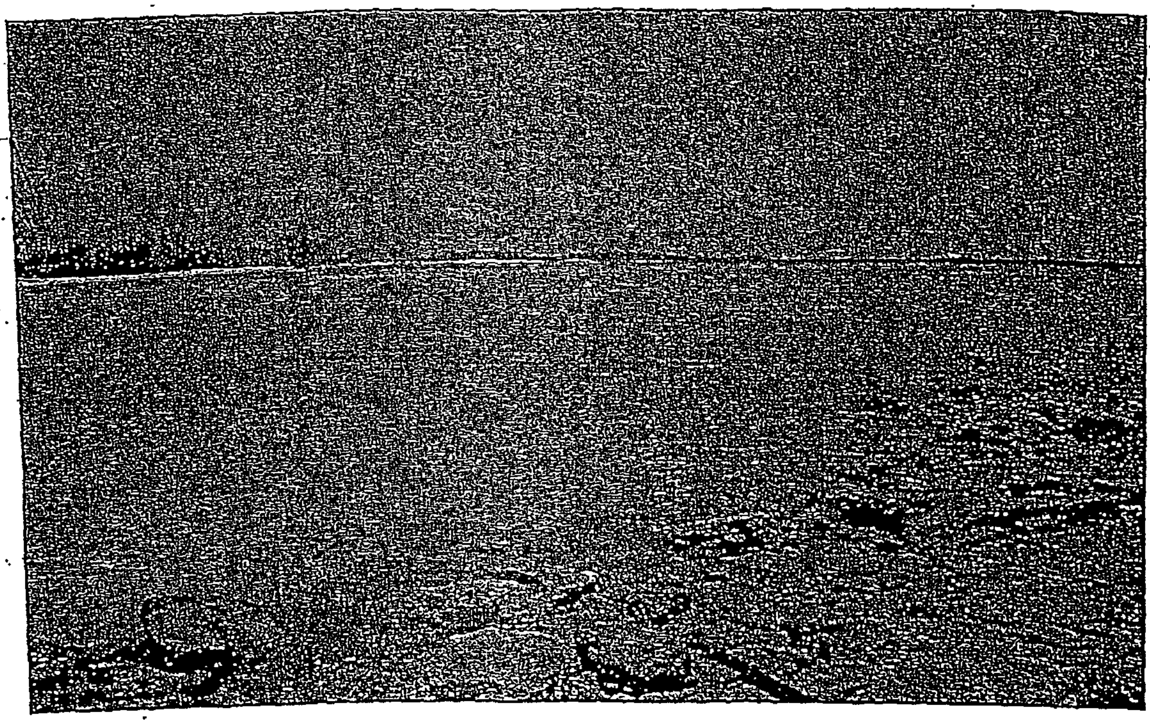
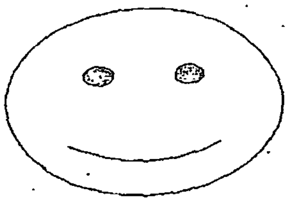


Figure 2.4 Ghyben-Herzberg conceptual model of groundwater occurrence in an island



3. PREVIOUS AND CURRENT WATER SOURCES

Traditional sources of water in the Chagos Islands are rainwater and groundwater derived from shallow hung dug wells. There is no evidence of distributed rainwater catchment systems except for relatively modern iron tanks and some guttering that remains adjacent to the former manager's house in Ile du Coin and alongside a derelict barn on Ile Boddam. Several wells were noted on both islands and appear to be either simple and relatively small diameter iron-lined wells, or larger structures typically of up to three metres depth by one metre diameter. These larger diameter wells were lined with beachrock or coral with a sandy unlined base. The better-constructed wells also had a sloping cast concrete slab and often a hinged metal cover, now missing (Fig. 3.1). The rain tanks on Ile Boddam are still plumbed to a primitive roof catchment with makeshift guttering. These are used by visiting yachtspersons for drinking water supplies and some care is taken to limit use. Well water is mainly used for personal washing and for laundry purposes. Three sources (Wells BW1, BW2 and BW4) within about 200 m of the jetty are used by visitors (Fig 3.2). On Ile du Coin, only one well CW1 adjacent to the former Manager's residence appeared to be used by yachtspersons and the rainwater tank was unserviceable. No sanitary facilities are available on the islands.

Electrical Conductivity tests undertaken to determine the degree of salinity of the water at the sources are detailed in Table 5.2. The results indicate that the sources are all potable according to the WHO drinking water guidelines although some are marginal. The water was not sampled for a more comprehensive suite of hydrochemical or bacteriological analyses during this phase of the study. One common feature associated with the well water in the Northern Atolls and also particularly noted during testing pumping the boreholes was the presence of hydrogen sulphide gas H_2S (characterised by a 'rotten eggs' odour). This is commonly the case where bacteria break down sulphates and organic materials in the soil and water. This is also the case in Diego Garcia where water is aerated at the pumping hubs prior to distribution.

Current BIOT Government policy on island water supplies emphasises the need for visiting yachtspersons to boil water before drinking. A warning to this effect is detailed on signs adjacent to the main wells on Ile du Coin (CW1) and Ile Boddam (BW1).

Figure 3.1 Example of Well (C7) on Ile du Coin.

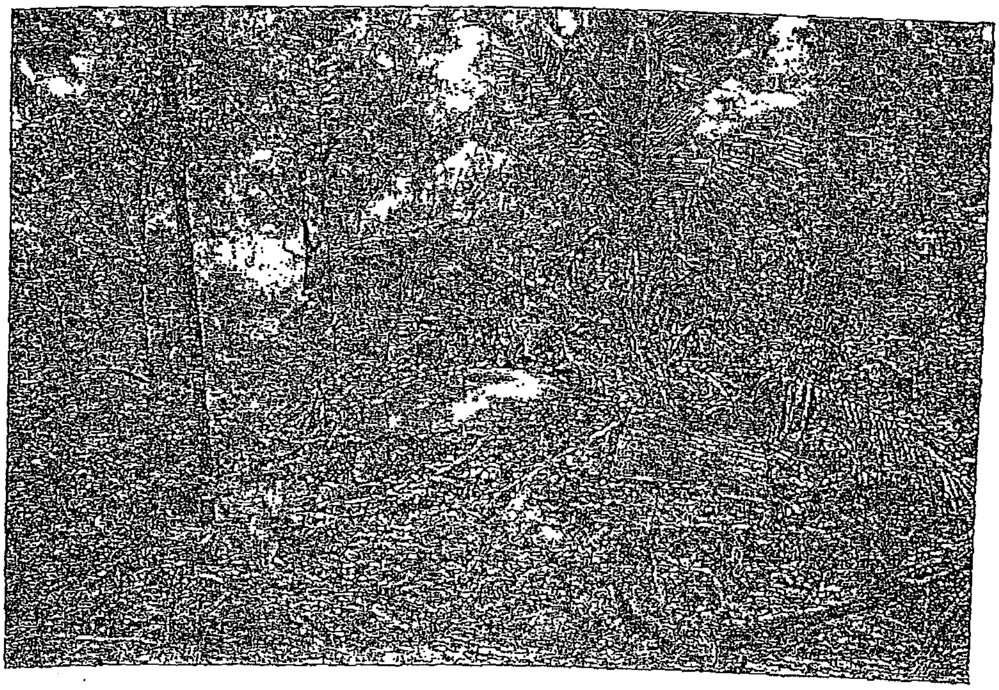


Figure 3.2 Visiting yachtsperson collecting water from main well (BW1) on Ile Boddam. Note red rainwater tanks either side of derelict barn in background.

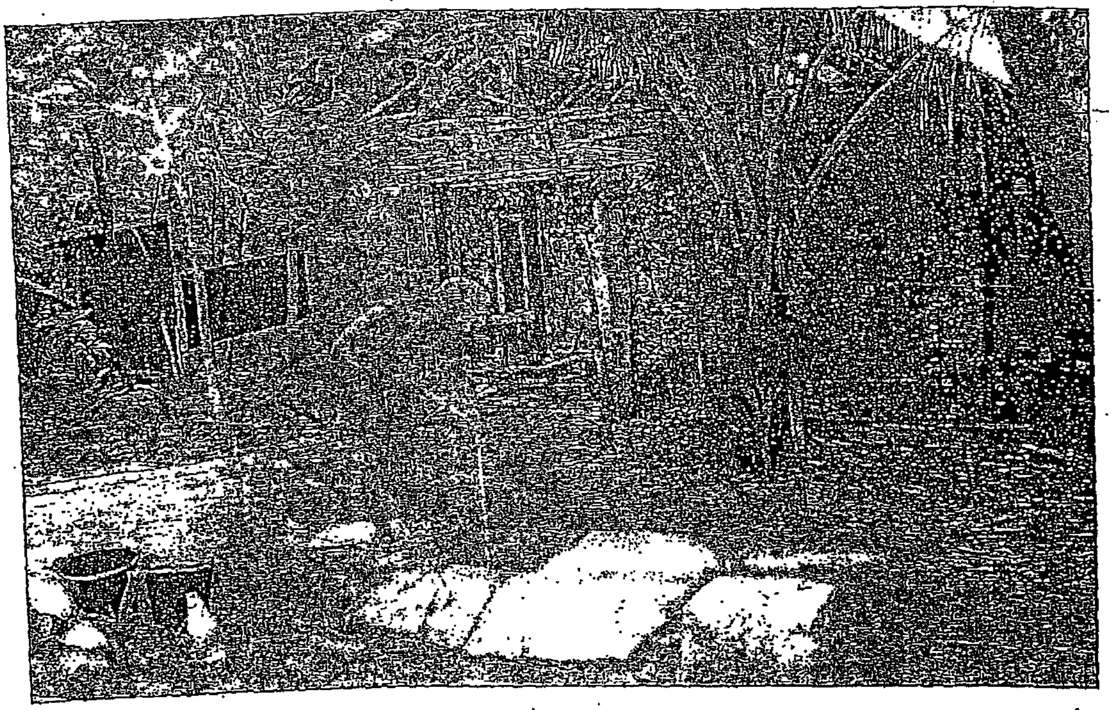
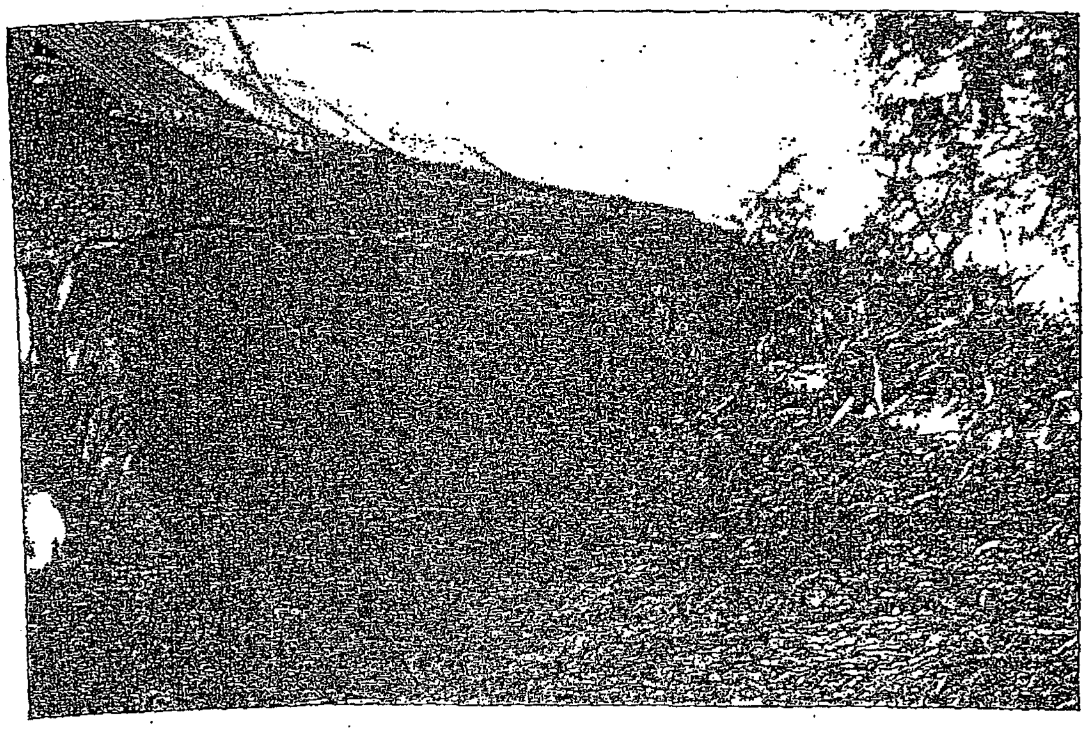


Figure 3.3 Rainwater collection tank and guttering, Ile Boddam



4. AVAILABLE INFORMATION AND EXPERTISE

Contacts made with members of the Public Works Department of the Naval Support Facility (staffed mainly by 'DG21' contractors) are listed in Appendix C. A bibliography of international papers and reports describing aspects of the geology and hydrogeology relevant to or relating to this project are listed in Section 8.

Published maps are restricted to Admiralty charts at scales of 1:360,000 (Chagos Archipelago) 1:38,180 (Ile Boddam), 1:72,600 (Ile Du Coin) and 1:25,000 (Diego Garcia). Aerial photographs at approximately 1: 6,000 and approximately 1:20,000 scale have been identified for Ile Boddam but their availability and those for other islands in the area are uncertain.

No copies of well completion records for the Chagos Islands are available if indeed they ever existed. No routine or long-term water level monitoring of wells has previously been recorded. The water supply system of Diego Garcia however is well documented and historical information will serve as a useful source of comparison albeit on a much larger scale. All of the modern groundwater supply on Diego Garcia is derived from horizontal gallery wells or networks of small diameter boreholes, however, an example of the type of well previously used for abstraction was found close to the current 'well fields' in the Cantonment area. This is virtually identical in construction to many wells found in the Northern Atolls.

The hydrochemical properties of well and borehole water samples have not been measured. There is no routine or long term monitoring of groundwater chemistry on any water from the atolls. For Diego Garcia, the NSF arrange for regular tests at a US laboratory for a comprehensive suite of parameters for groundwater pumped from several sites. The NSF Public Works Department (PWD) is responsible for long term water sector planning and for water quality. The PWD have some water quality testing equipment and several staff who can carry out the testing either in the field or at the water centre. Other 'DG21' contractors provide logistical support, operation and maintenance for the Diego Garcia water supply system under the direction of the military personnel staffing the PWD

Drinking water on Diego Garcia is distributed through bowsers and in one-gallon bottles to certain filing points generally close to accommodation centres. The drinking water is treated groundwater, filtered by use of a reverse osmosis (nanofiltration) unit. This is a recent development after the discovery of trace concentrations of Trihalomethanes (THMs). These are disinfection by-products created when chlorine is used to treat water containing natural organic matter. Although the health effects of THMs are not fully understood, any potentially adverse effects are small and difficult to measure compared to the health risks associated with inadequate disinfection. The US Environmental Protection Agency has set the limit of total THMs in treated water at 0.1 milligrams/litre. Although this not regularly exceeded on Diego Garcia, the general policy of providing separate drinking water supplies will remain for the foreseeable future.

5. WORK DONE DURING BGS VISIT, AND PRELIMINARY RESULTS

Diego Garcia

13th -15th March

Project discussions with Maj. Blyth, Capt. Rob Edie, Training Officer and Mne. Barry Jones, Brit Ops Team Leader to discuss the forthcoming joint Brit Ops/ Water Survey to the Chagos Islands. Discussed possible flexibility in programme to accommodate other activities in BritOps.

Meeting with US Navy and DG21 (contractor) Water Engineers led by Cmdr Souba. Held general discussions including brief details of intended work in the Chagos Islands and likely similarities with the groundwater regime in Diego Garcia with the PWD staff and Seabees. Arranged to tour DG facilities and meet separately with key staff to discuss particular hydrogeological issues on return from trip to islands.
Attempted to install data handling software on Training Officer's computer.
Joined British Marines on liaison visit to US Freighter Franklin Phillips. Discussed vessel water production, supply and transfer systems with Master and Chief Engineer and toured decks to view other 'hardware'.
Checked air-freighted equipment was complete and loaded onto FPV Pacific Marlin.
Walked in Cantonment area to inspect US installed horizontal gallery system.

Met Mr Topp and Cmdr Souba for breakfast and discussed forthcoming trip.
Visited Water Plant to refer to file reports.
Briefing meeting with Maj. Blyth and Mne.. Jones to confirm time requirements for the water survey tasks during the 'Brit Ops'.
Packed and transferred to the FPV Pacific Marlin.
Met other team members, Master and crew. Received safety briefing and tour of vessel.
Checked and set electronic equipment and tools.

24th-28th March

Returned from Chagos Islands to small boats harbour, Diego Garcia.
Unloaded equipment to Marines Stores for drying and cleaning and rechecked into Bachelor Quarters.

Short debriefing meeting with XO.
Continued computing aboard FPV Pacific Marlin.

Computing in Library and aboard FPV Pacific Marlin. (Installed and tested software for downloading data). Formatted and plotted existing downloaded data.

US Water Engineers and DG21. Visited NSF water facility from where groundwater pumping system is remotely controlled by telemetry system. Referred to historical development of the water supply system in Diego Garcia and toured well fields including pumping hubs.
Visited Airport apron area where clean-up processes continue after a jet fuel spill.
Visited Nanofiltration (reverse osmosis) plant which supplies filtered groundwater in bottles and bowsers for drinking water.
Unsuccessfully attempted to install data handling software onto British XO's computer. Suspect a fault with the computer's 9 pin 10101 'comms' port as software installs on equivalent computers and operating software elsewhere.

Installed data handling software onto Brit Rep Secretary's computer.
Cleaned and packed field equipment for storage.
Completed computing in Library.

20th March

Attempted to revisit dataloggers to download 3 days data. Abandoned this due to failing light and difficulties navigating through coral.

Salomon Atoll: Ile Boddam

16th-20th March

Arrived and anchored off the Salomon Atoll at dawn.
Loaded equipment to Marine's Raider craft and transferred to Ile Boddam with four marines and three FPV crew. Offloaded equipment supplies and camping gear.
Toured island with Mne. Jones and Mne. Bullivant to investigate wells, structures and tracks. Attempted to find location of Doppler positioning point.
Temporarily placed monitoring sensors into main well W1and alongside jetty to check responses and dataloggers. Set up camp.

Identified likely 'host' wells for monitoring equipment and examined jetty for secure fixture for tide gauge.
Conducted well water and rain tank salinity survey. Explored for additional wells in centre of island.
Cleared vegetation from Well 3 for recording water level sensor and datalogger.
Downloaded first 24 hours data from main well W1.

Established and tested Automatic Weather Station.
Constructed (by auger and bailing) first shallow borehole (Boddam LS1).
Established depth recorder and completed datalogger testing.
Undertook simple pump test to investigate test changes in conductivity and drawdown.
Established and secured tide gauge to jetty.

Constructed (by auger and bailing) second shallow borehole Boddam LS2.
Established depth recorder and completed datalogger testing.
Completed bail tests and simple single rate pump tests to investigate changes in conductivity and drawdown.

Repeated downloading routines.
Levelled gauges and borehole casing using survey equipment.
Downloaded all logging equipment.
Photographed wells and monitoring installations.
Packed and transferred equipment to the FPV.
Downloaded PSION Metrolog and AWS Datalogger data to ships computer.

Peros Banhos Atoll: Ile du Coin

21st-23rd March

Sailed the three-hour transit from Ile Boddam before first light into Peros Banhos Atoll anchoring off Ile du Coin.
Transferred equipment ashore and unpacked.
Toured north-eastern part of island with Mne. McGuiness to investigate wells, structures and tracks attempting to use GPS tracking but vegetation cover was generally too great and limited accuracy.
Temporarily placed monitoring unit into main well (Well C1) adjacent to the former manager's residence to record groundwater fluctuations overnight.

Re-visited wells the following morning, tested salinity and marked eight wells with identification tags.
Established a tide gauge on the island side of the outer Jetty structure. This structure is an isolated large concrete block approximately 10 m square originally connected to the shore by a boardwalk and light rail track. All but a few of the supporting steel beams have collapsed.
Completed bail tests and simple single rate pump tests to investigate changes in conductivity and drawdown.
Cleared vegetation out of host well (Well C2) to use as land based water level datalogger and tested depth sensor in well overnight.

Completed installation of depth datalogger in Well C2. The use of a well rather than construct another borehole was considered to be acceptable as it was obvious that the yachtspersons did not access the wells on Ile du coin as much as on Ile Boddam and restricting access to one well would not create any difficulties.

Photographed l exteriors and interiors of wells and the monitoring installations.
Levelled gauges using survey equipment.
Supervised downloading procedures for land gauge and tide gauge logging equipment by marines.
Downloaded PSION Datalogger data to ships computer.
Sailed for Diego Garcia.

Establishment of Well and Borehole Based Water Level Recorders

Three groundwater level sensors were established during the project. Two boreholes were drilled to accommodate the sensors on Ile Boddam (Fig 5.1). An unused well was used as a 'host' for the sensor on Ile Du Coin (Fig 5.2 and Fig 5.3). The method used for drilling the shallow boreholes was a combination of auguring above the water table and washing/bailing below. Lightweight 'Eijkelkamp' hand-drilling equipment was used due to its extreme portability. The boreholes were drilled within High Density Polyethylene (HDPE) borehole casing. This general purpose injection moulding material's particular advantage lies in the fact that it resists environmental stress cracking significantly better than other plastics. The water table was encountered at approximately 1.2 metres below the surface in each case. The bailer was periodically removed after several blows and the unconsolidated material transferred to a split tube for inspection. Summary details of the boreholes drilled are given in Table 5.1. A scaled composite photograph (*B_LS1 material composite.jpg*) of the aquifer material is included in the attached CD ROM.

Table 5.1 **Summary information for boreholes drilled on Ile Boddam.**

Borehole ID	Location	Aquifer Material	Rest Water Level (mbct)	Date drilling completed	Drilled depth (m)
BLS1	Clearing 50m from Jetty tide gauge	Unconsolidated coral/carbonate sand	1.22	17/03/01	2.9
BLS2	Clearing 100 m from jetty tide gauge	Unconsolidated coral/carbonate sand	1.25	19/03/01	2.9

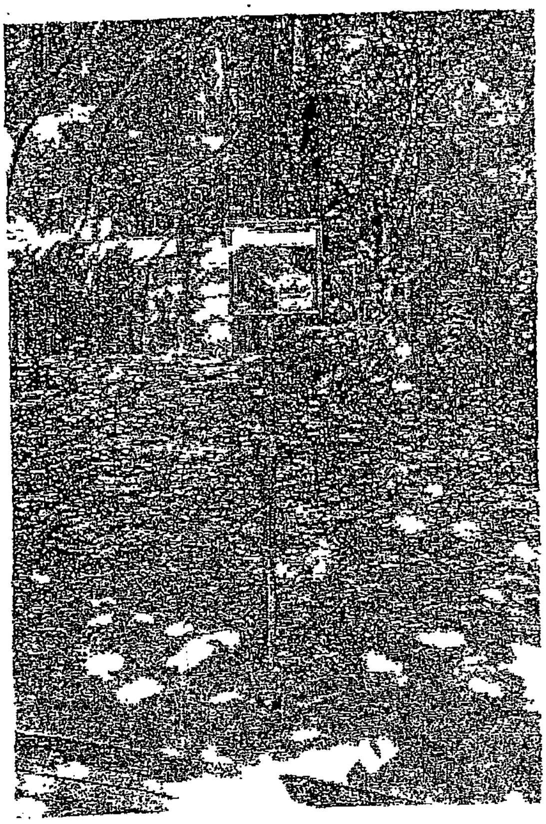


Figure 5.1 Completed Installation for Borehole-Based Water Level Logger (BLS1) on Ile Boddam

The installation comprises a 50mm external diameter plastic coated steel scaffold tubes cut to between 2-3 metre length. Where the depth logger is installed into a shallow borehole as for BLS1 and BLS2, the depth sensor is established at a depth of 2m below the borehole casing top and the vented cable is wrapped in reinforcing tubing, taped to the scaffold and then enters an electronics enclosure through a sealed gland. The shallow borehole is capped and comprises 3 metres of 90mm external diameter HDPE casing, slotted in the lower 1 metre of the hole. The electronics enclosure is clamped to the scaffold with 'U' bolts and contains excess cable, a silica gel pack (to reduce moisture content) and the datalogger. The enclosure is sealed with security bolts.

In Figure 5.1 the carbonate sand bailed from the borehole during construction surrounds the installation and fills a split plastic tube alongside a scale used for photography.

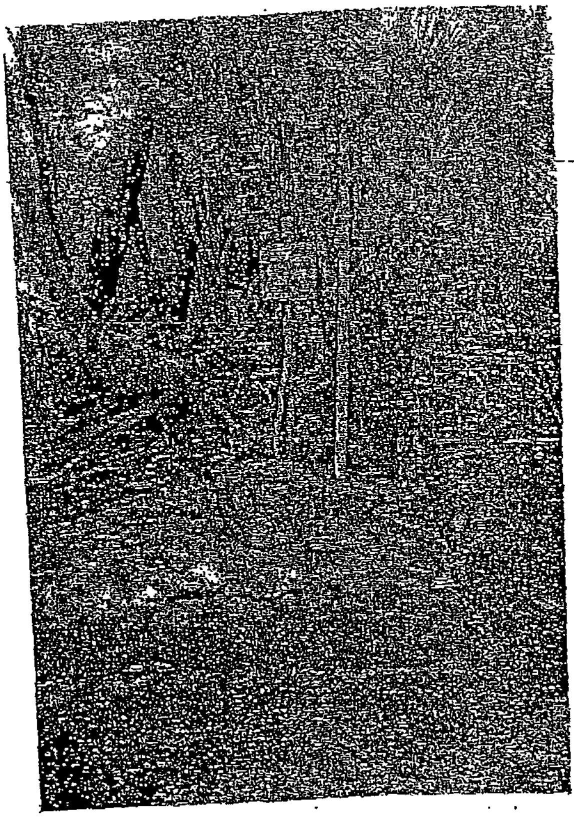


Figure 5.2 Completed Installation for Well-Based Water Level Logger (CLS1) on Ile du Coin

The installation comprises a 50mm external diameter plastic coated steel scaffold tubes cut to between 2-3 metre length. Where the depth logger is installed into a shallow well as for CLS1 (Well C2), the depth sensor rests at the base of the well and a depth is established to a reference point on the well top which is then levelled by a survey.

The Well C2 in Figure 5.2 was lined with coral and beachrock blocks. On completion it was covered with an iron sheet and concrete block.

The well was cleared of roots and fallen vegetation prior to use. Some very simple pumping tests were also undertaken.

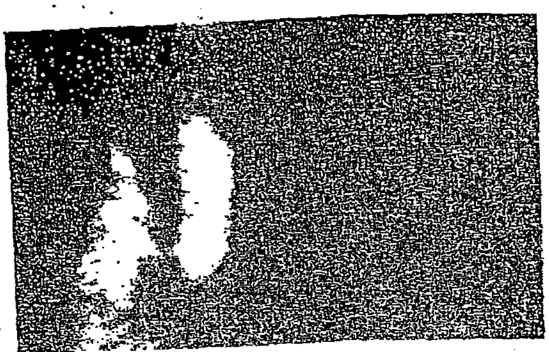


Figure 5.3 Interior of Well CW2 indicating coral block lining

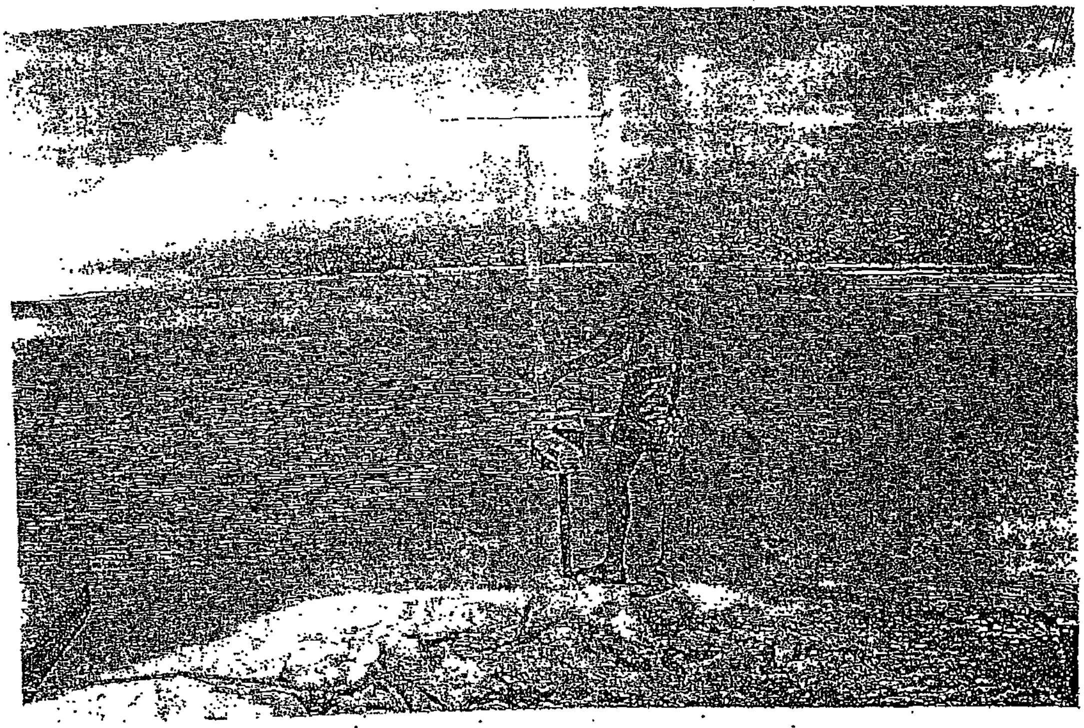
Note: water level centre top, reflecting sunlight

Establishment of Tide Gauges

Two tide gauges were established during the project mission, one each on the lagoon shores of Ile Boddam and Ile du Coin. Both units comprise the basic elements of the groundwater level loggers but cables and sensors are suspended within the scaffold tubes for protection. Small holes are drilled into the scaffold tubes that act as stilling wells to allow seawater to enter. The bodies of the sensors are constructed from titanium rather than stainless steel (as in the case of the groundwater sensors). This is to prevent corrosion by the seawater. The tide gauges are secured to protected parts of the jetties by stainless steel wires cemented into the jetties and by heavy-duty nylon cable ties. The depths to the sensor from the top of the casing were measured for levelling purposes (Fig. 5.4).

Examples of preliminary test data for the groundwater response to tidal fluctuation are provided in Appendix F. On each island the depth sensors were tested overnight before actual establishment in a host borehole or well. On Ile du Coin the main well CW1 was tested and on Ile Boddam the main well BW1 and borehole BLS1 were used to test the sensors. Test data suggests a shallow groundwater efficiency of approximately 10% with a tidal lag of approximately 3 hours on Ile du Coin.

Figure 5.4 Completed Installation of Tide Gauge (BLT1) on Ile Boddam



Establishment of Automatic Weather Station

An Automatic Weather Station (AWS) was established on Ile Boddam to provide a record of meteorological data in the Chagos Islands. The particular unit was supplied by the UK Institute of Hydrology and selected due to its portability and proven robustness. The project was initially limited to a single AWS on cost grounds and also due to the uncertainty of identifying a suitable location.

After discussions with the marines and crew of the FPV Pacific Marlin who have regularly visited the island, a site on Ile Boddam was selected. The clearing behind the structures close to the jetty on Ile Boddam proved to be the largest encountered on the islands. Although the thick vegetation surrounding the clearing will effect the wind measurements, the site is not shaded except at the extremes of the day (Fig 5.4 taken at 5 pm local time). Some clearing of ground cover will be necessary periodically.

The following meteorological parameters are recorded to a datalogger on an hourly basis (Table 5.2). Air and soil temperature, relative humidity, total and net radiation, rainfall intensity, wind velocity. Data can be imported into an 'MS Excel' spreadsheet for analysis.

Table 5.2 Example of test download of AWS data from Ile Boddam.

AWS No.	Year	Day Ref	Time	Air T	Soil T	Wind Sp	Wind Dir	R Humid.	Tot Radiation	Rainfall
109	2001	80	1400	32.93	35.85	0.858	159.6	69.77	1021	0
109	2001	80	1500	32.96	37.44	0.862	167.1	69.54	946	0
109	2001	80	1600	32.4	37.76	0.729	184	75.5	721	0
109	2001	80	1700	31.99	37.13	0.706	211.1	76	576.4	0

Table 5.3 Summary information for current wells and boreholes drilled on Ile Boddam.

Borehole /Well ID	Location	Rest Water Level (mbct)	Electrical Conductivity µs/cm	Water depth (m)	Other Details
BW1	Ile Boddam	1.36-1.43	864-906	0.62-	Main well
BW2	Ile Boddam		747-785		
BW3	Ile Boddam	1.67-	804-855		
BW4	Ile Boddam	1.70-	809-821		
BLS1	Ile Boddam	1.22-1.27	540-580-605	2.9-	Logged 50 m to ocean.
BLS2	Ile Boddam	1.25-		2.9-	Logged 100 m to ocean
CW1	Ile Du Coin	1.94-	930-960-1048	0.58-	Main well
CW2	Ile Du Coin	1.61-	1317-1626		Logged 112 m to ocean
CW3	Ile Du Coin	1.53-	913-999	0.12-	
CW4	Ile Du Coin	2.27-	375-481		
CW5	Ile Du Coin	1.45-	820-821	0.20-	
CW6	Ile Du Coin				Blocked
CW7	Ile Du Coin	1.74-	670-729		
CW8	Ile Du Coin	1.69-	478-570		

B= Ile Boddam.
C= Ile du Coin.
L=Lagoon Side Gauge (borehole for groundwater level monitoring)
W=Well.
S=Shallow.
elsewhere T= Tide Gauge

Note 1: Rainwater in tanks was tested for electrical conductivity (ec) which was 25 µs/cm.

Note 2: Conversion of electrical conductivity to a chloride concentration in ppm or mg/l is not strictly linear and varies with the concentration of the chloride and other dissolved ions. PRC Toups plotted all ec tests undertaken on Diego Garcia against the laboratory determined chloride content for low and high chloride contents. The plots are copied and included as Fig 5.7.

Figure 5.5 Completed installation for Automatic Weather Station, Ile Boddam

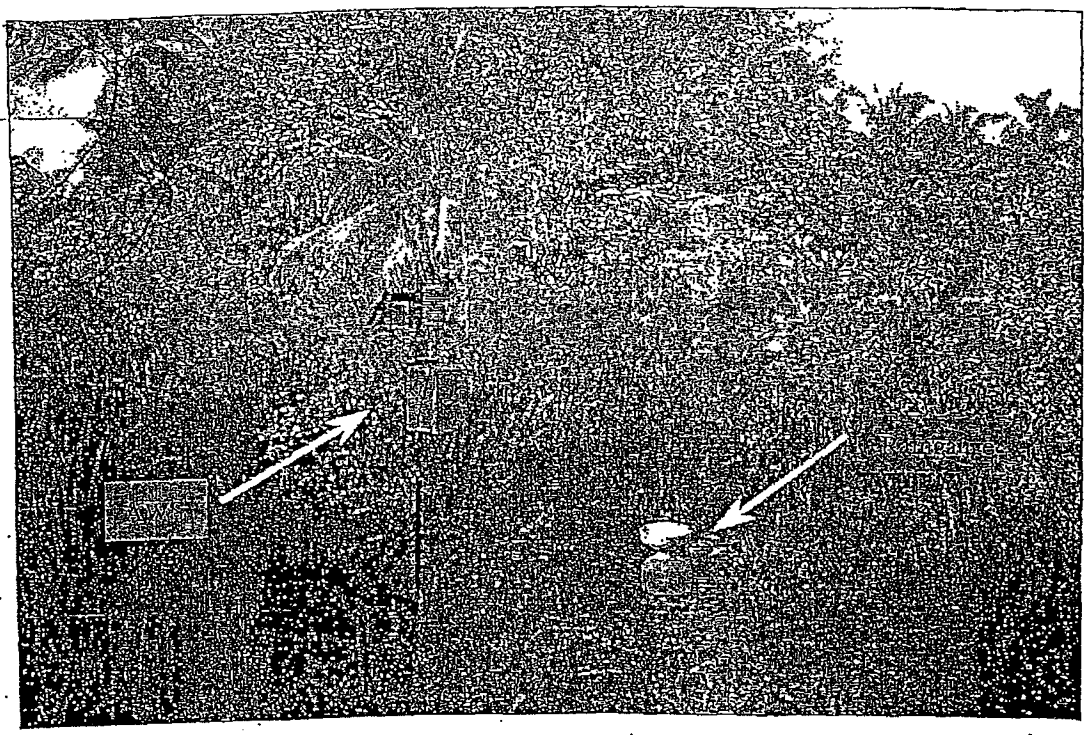
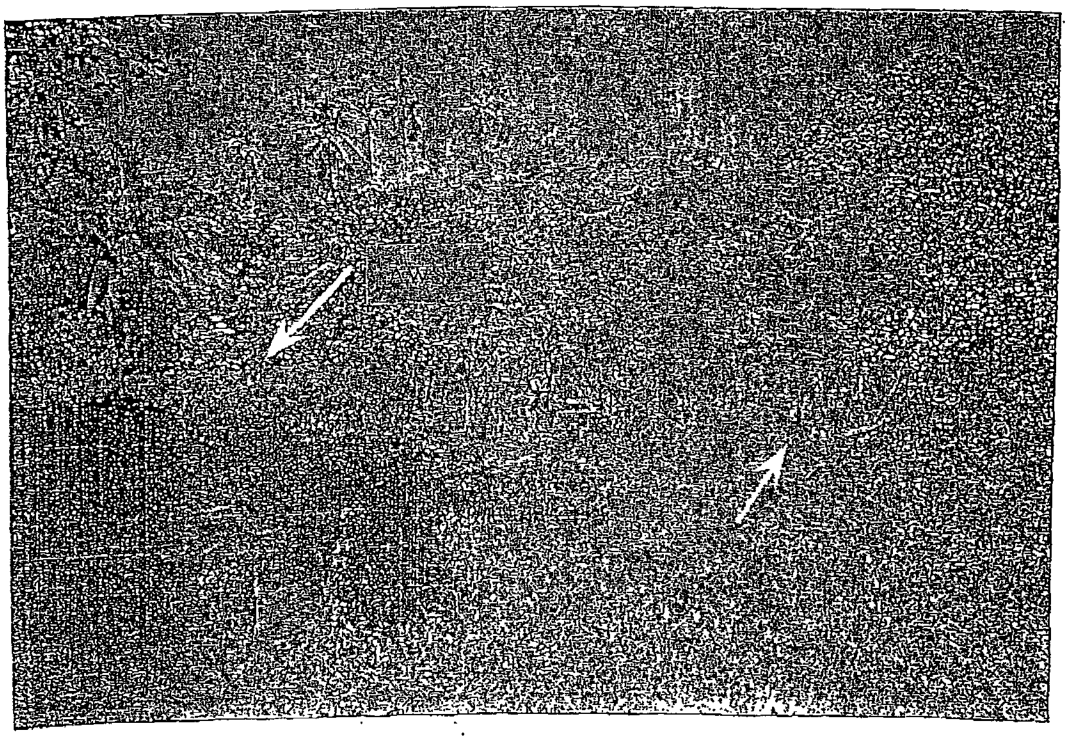


Figure 5.6 Automatic Weather Station and Borehole BLS2 in clearing behind jetty/Managers house, Ile Boddam



The AWS datalogger will store up to six weeks of data. It can be downloaded onto a memory module in an extremely simple process or be interrogated for individual readings using a separate keypad.

During the project mission on Ile Boddam the temperatures reached 33°C their peak during the day reducing to 25°C at night. The relative humidity was recorded around 75% during the day. Most of the days on both islands were hot, clear and sunny except for an extremely heavy storm on the last day on Ile Du Coin (during which several yachts and the FPV Pacific Marlin were struck by lightning, disabling some communications). Despite the intensity of the rainfall, no surface run-off or ponding was noted on either Ile Boddam or Ile du Coin. Other isolated rainstorms were seen to affect single islands or patches of ocean and passed close to the vessel in transit.

Well and borehole tests undertaken

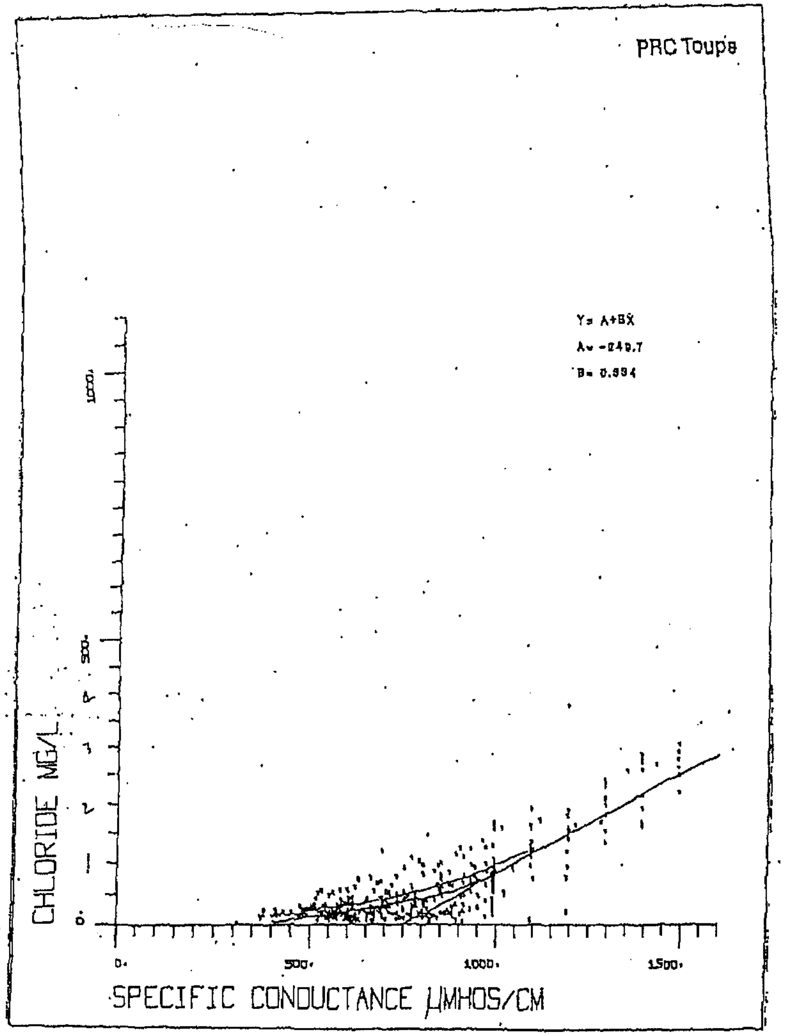
(i) Bail tests – these simple tests using a well bucket or customised bailer can give a first approximation of aquifer properties immediately surrounding a borehole. This method is based on the slug test developed by Cooper et al (1967). A measured volume of water is abstracted from a borehole over a measured length of time. The water level is then monitored until it recovers to 75 % of its original level. Water level measurements are taken at short time intervals (e.g. every 0.5 minutes) at the start of recovery, but decrease with time (e.g. to every 10 minutes after 120 minutes of recovery if appropriate). The resulting recovery curve can be interpreted quantitatively, or analysed using simple, quick techniques and basic criteria to indicate whether or not the borehole can provide a sufficient yield to support a hand pump.

(ii) Whale pump tests – these simple pumps originally designed for marine and caravan water delivery can be applied for testing low yielding boreholes. The maximum hydraulic lift of the single pump is approximately 12 m which limits their application to pumping from relatively shallow water levels, however in atoll environments these are adequate.

The bail tests carried out are summarised in Table 5.4 and the Whale pump tests are summarised in Table 5.5.

The data collected in a more comprehensive study from the wells and boreholes should be digitised and managed using spreadsheets and a geographical information system (GIS) such as ArcView, a desktop (GIS). All tabular data for spatially referenced data points (e.g. EC (specific electrical conductance) measurements for individual boreholes should be stored within the system. All of the data collected are spatial in nature, and a GIS is therefore ideal for data display and analysis. Data points should include all wells and borehole sites and sites where water samples for hydrochemical analysis were collected. Two particular advantages of a GIS are the ability to easily and effectively produce maps that can be tailored to project needs, and to easily analyse collected data for spatial patterns.

Figure 5.7 Plots of electrical conductance vs chloride ion content from Diego Garcia (from PRC Toups)



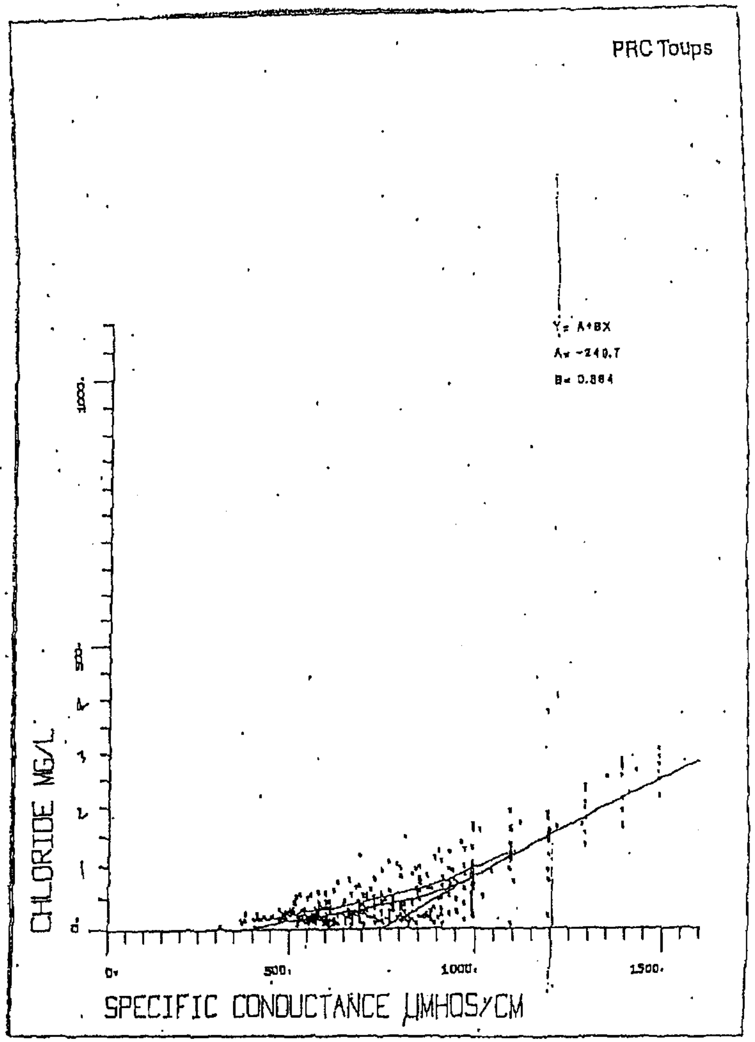


Table 5.4 Summary of well test data from Ile Boddam BW1, BW2 and BW3 and Ile Du Coin CW1 and CW2.

Incomplete

Well/Borehole	Site	RWL (metres below cover)	time bailed (min)	Effective pump rate (l/s)	Smax (m)	Sc (l/s/m)	t_{WL50} (s)	t_{WL75} (s)	Comments
BW1	Ile Boddam		20	1	0.26	3.8	240	290	20 litre bail bucket
BW2	Ile Boddam		20	0.66	0.35	1.9	305	325	20 litre bail bucket
BW3	Ile Boddam		20	1	0.42	2.4	450	570	20 litre bail bucket
CW1	Ile du Coin		10	0.33	.16	2.0	470	-	10 litre bail bucket
CW2	Ile du Coin		15	0.66	.20	3.3	320	400	20 litre bail bucket

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Table 5.5 Summary of Whale pump test data from Boreholes BLS1 and BLS2 on Ile Boddam and Well C2 on Ile Du Coin.

Incomplete

Borehole /Well	Site	RWL (metres below casing or well top)	Pump rate (l/s)	Smax (m)	Sc (l/s/m)	t_{WL50}	t_{WL75}	Comments
BLS1	Ile Boddam		0.16	0.17	0.94	55	90	
BLS2	Ile Boddam		0.16	0.22	0.73	50	90	
CW2	Ile du Coin		0.16			-	-	s not discernable

6. SUMMARY AND CONCLUSIONS

A BGS hydrogeologist, visited the BIOT from 13 March to 29 March 2001. The Government of the BIOT facilitated the visit through the Foreign and Commonwealth Office, (FCO) with logistical support from the British Royal Marines and Naval Party stationed in Diego Garcia. During this period, eight days were spent in the Peros Banhos and Salomon Atolls to the north of Diego Garcia. The mission to the atolls was undertaken from Diego Garcia aboard the FPV Pacific Marlin. An island party camped whilst working on Ile Boddam in the Salomon Atoll and transited daily whilst working on Ile Du Coin in the Peros Banhos Atoll. Transits made between the main FPV and the island was by small 'Rigid Raider' craft.

Preliminary recognisance surveys were undertaken to identify suitable sites for the instrumentation. This included locating, clearing and testing existing hand-dug wells to determine the electrical conductivity and hence, salinity by of the water, the depth to the water table below a fixed point and the standing water depth. Water level and electrical conductivity fluctuations were noted in preliminary tests on some wells. It is likely that existing wells would provide useful sites for subsequent testing or observation points for test pumping.

Two shallow boreholes were drilled on Ile Boddam. Enclosures were installed adjacent to these sites to house water level sensors and dataloggers.

Suitable locations for tide gauges were identified on the derelict jetties on the two islands and simple protective enclosures constructed and fixed to these.

A recording tide gauge, two recording groundwater water level meters and a recording automatic weather station were commissioned on Ile Boddam whilst a single recording tide gauge and a recording groundwater level meter were established on Ile du Coin.

Initial testing, calibration and the downloading of initial data preceded the final establishment of the recording instruments. The dataloggers were programmed to record each 15 minutes for the tide gauges and water level sensors and every hour for meteorological variables. The distances to the ocean and vertical elevations of equipment relative to fixed local datum points were surveyed.

Preliminary results using the test data demonstrate characteristic effects of atoll fresh water lenses. These include a clearly discernable lag in groundwater response to tidal effects and a relatively low tidal efficiency. Initial tests on the electrical conductivity of water in the wells suggest that much was of was marginal quality to levels of salinity close to or in some cases exceeding WHO guidelines.

The British Royal Marines will download data stored in the dataloggers attached to the commissioned instruments periodically during brief visits to the islands. Marines were provided with training and instructions for the downloading procedures. Further training and a simplification of the process including the up-loading of data to personal computer may be necessary.

Data generated will assist in determining the nature of the fresh water lens aquifer, assist in quantifying groundwater resource provide a long-term climatic record.

Valuable insights into the hydrological and hydrogeological nature of and mechanisms of water abstraction and delivery in the atoll environments were gained from all the islands visited. Parts of the groundwater supply system in Diego Garcia provided a useful analogue for a potential supply system in the Chagos Islands. This emerged from the liaison with the resident water engineers working in the Public Works Department with the US NSF Diego Garcia. Some of the staff contracted to work with the US Navy have worked in Diego Garcia for more than decade. The importance of effective characterisation of the fresh groundwater lens systems as well as the importance of long-term monitoring was emphasised. The vulnerability of small atoll island water resources is particularly important and was demonstrated by the serious effects of fuel spillage and the danger of introducing saline conditions by over pumping wells or boreholes, particularly during extended periods without rainfall.

Groundwater protection and management is a critical concern on isolated atoll islands where resident populations are supported.. At present in the Chagos Islands there is little understanding of seasonal, inter-annual or long-term fluctuations in groundwater quantity or quality. Issues such as the impact of latrine provision and 'grey water' disposal on shallow aquifers should be considered. The drying-up or deterioration of shallow borehole water quality during extended dry periods may be a seasonal response to reduced recharge and groundwater recessions. Collection of spatial and temporal meteorological and hydrogeological data should help identify areas at risk of quantity or quality problems for future planning purposes.

There is a valuable opportunity to increase the amount of information generated by reconfiguring existing sensors and modest expenditure on additional sensors on the islands. The cost implications of failing to maximise information gathering from existing monitoring programmes are significant. To gain the same information that could be routinely collected during ongoing monitoring would require significant investment in exploratory testing. Simple techniques and methods such as the ones used during the BGS visit could be used to collect reliable information from ongoing programmes. A proposal to supplement current monitoring is included in this interim report as Appendix H.

7. FURTHER ACTIONS AND RECOMMENDATION

Actions to be taken immediately as part of the current project are:

(i) The preparation of a technical report describing the BGS field investigations and associated work in the Chagos Archipelago, including an assessment of the tidal-groundwater relationships and their implications.

(ii) The preparation of simplified laminated field slips incorporating flowcharts for downloading the dataloggers and uploading of data to a desktop computer (or a budget laptop computer dedicated for project use).

Future actions that are recommended further to the current project:

(iii) In the light of the number and distribution of wells already encountered, the likelihood of a more comprehensive network of wells suggests that there is an urgent need for a more systematic search for wells that would assist in the planning process for future investigations.

(iv) Adding additional sensors to the groundwater depth monitoring network on the islands and/or reconfiguring the existing sensor layout after several months recording in the current configuration. A supplementary project proposal is included in Appendix H

(v) Consideration of adding an Automatic Weather Station on Ile du Coin to compare and contrast conditions on Ile Boddam and with Diego Garcia (where a longer term record is available).

(vi) A comprehensive assessment of the groundwater resources of the two islands under study perhaps complemented by investigations on adjoining islands in the atolls.

(vii) Longer-term advice and support should be given to the Government of BIOT to ensure that the meteorological and hydrogeological records are sustained. Field teams can conduct appropriate surveys designed to collect the detailed data required for long term planning purposes. Support is also needed to develop and maintain databases for long-term management of monitoring data to consider trends that may provide indicators as evidence of the effects of global warming.

8. REFERENCES

Cooper H H, Bredehoeft J D and Papadopulos I S 1967. Response of a finite diameter well to an instantaneous change in water level. Water Resources Research, vol 3, pp 263-269.

Government of the BIOT 2000. Resettlement of the Salomons and Peros Banhos Atolls – Preliminary feasibility study.

Add other 32 from Chagos List….

Acknowledgements

The author of this report wishes to express his thanks to all those who facilitated and assisted with field work and other tasks during his visit to the BIOT, in particular Major Mike Blyth RN XO, Marine Barry Jones RN and Captain Bob Goodwin, of the FPV Pacific Marlin whose efforts ensured that the visit was efficient and as comfortable as could be expected.