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# IMPROVING WATER YIELD FROM SHALLOW ALLUVIAL AQUIFERS (Project Summary Report)

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# IMPROVING WATER YIELD FROM SHALLOW ALLUVIAL AQUIFERS (Project Summary Report)

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*Front cover illustration :*
Typical very mixed poorly sorted alluvial sediment, as found at Dama, Ba



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*This report is one of a series which summarises the findings of individual projects within the Overseas Development Administration (ODA)/ British Geological Survey (BGS) Technology Development and Research Programme. This programme forms part of the British Government's provision of technical assistance to the developing countries. The report is intended for advisers and those concerned with development policy; programme and project officers in the donor agencies and development banks; and planners in the developing countries. Its aim is to draw attention to, and promote the practical application and take-up of, R & D techniques in operational development projects.*

# EXECUTIVE SUMMARY

Unconsolidated alluvial aquifers are important sources of groundwater in many parts of the world. Difficulties may be encountered however in the water yield and life of boreholes in some such aquifers because of the characteristics of the unconsolidated alluvial sediment and the way in which it can affect the initial and later performance of the well.

Field studies carried out at sites in Fiji into sediment type, environment of deposition, geological history, variable borehole water yield over time and well equipment variations have permitted recommendations to be made on how to maximise water-well yield in shallow aquifers, based upon the application of formulae for sediment grain sizes and the installation of appropriate water well screens and pumping techniques adjusted to suit the sediment. Boreholes suffering potential low yields or filter or screen blockage can be identified and suitable precautions taken.

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# 1 BACKGROUND AND OBJECTIVES

## 1.1 Introduction

This report summarises the results, significance and applications of Project 91/12 - Shallow Aquifers Characterised by Poor Sediment Sorting and Mixed Textures. The work was carried out at three sites in Fiji between 1991-1993 (Fig 1) but the procedures developed are of wider relevance and application. This report supplements the technical reports prepared during the project which are listed, with other bibliographic references, at the end of the report. It is directed towards the non-specialist reader.

Unconsolidated alluvial sedimentary aquifers often found adjacent to rivers and watercourses are important sources of groundwater for many rural and urban settlements, industrial schemes and agricultural projects throughout the world. However, many boreholes constructed within such aquifer systems have water yields lower than expected and/or fail after short periods of operation.

Often the alluvial deposits which are the water-bearing rock formations of this study are poorly-graded, having bi-modal grain-size distributions and can be thought of as being a mixture of two different materials; a matrix of fine sands and silts intermingled with a framework of coarser sediments (Cover photograph).

Routinely, borehole design does not take this situation into account and does not maximise on the potential water yields from such mixed materials.

Recent studies supported by ODA have helped in the understanding of borehole performance. These allow better understanding of :-

(a) Water flow through poorly-graded sediments;

(b) Borehole yield-drawdown performance (Herbert and Barker, 1990);

(c) Fine sand movement in poorly graded sediments surrounding boreholes (Kovacs, 1981 and Kezdi, 1969);

(d) The effect of climatic change on the genesis of the alluvium.

There has also been a convincing demonstration of the need for accurate sampling of water-bearing alluvial deposits during rotary drilling of boreholes (Davies, 1992).

The main objective of this project was, through a comparative study of failed and newly constructed boreholes, to determine the usefulness of new concepts and to develop recommended methodologies of site investigation, borehole design and borehole construction for application to mixed sediment aquifers. Methodologies described have worldwide application and will allow improved borehole design and analysis of performance within different poorly-sorted mixed texture alluvial aquifers. The number of borehole failures should thereby be reduced while maintenance and rehabilitation programmes are enhanced. Improved understanding of mixed texture alluvial sediment deposition will lead to improved drill site selection and diagnosis of past borehole failures within such environments.

## 1.2 Project Description

Detailed geological and hydrogeological investigations were conducted at three sites on the island of Viti Levu, Fiji, where borehole yields were unexpectedly low.

At Dubalevu, in the Sigatoka Valley (Davies, 1992) two production boreholes, one constructed using a 6" (152 mm) diameter continuous slot Johnson-type stainless steel screen, and another constructed using a 6" (152 mm) diameter 600 micron filter-mesh screen (Plate 1), were installed 20 m apart within a mixed sediment aquifer system. When tested these boreholes produced very different yields and borehole efficiencies, the borehole with the stainless steel screen being the more efficient.

A programme of borehole rehabilitation and test pumping was undertaken to determine why the filter-mesh screened borehole produced a low yield and if that yield could be improved using borehole development methods. A test/production borehole, constructed using filter-mesh screen, and eight observation boreholes were installed adjacent to the rehabilitated borehole. Data necessary for the characterisation of the geological and hydrogeological nature of the aquifer and comparison of test pumping data comparable from the under-producing and replacement boreholes were produced.

At Vakabalea (Plate 2) at the head of the Navua delta techniques of borehole sampling, development and test pumping were used to determine the hydraulic characteristics of two test/production boreholes, and the geological and hydrogeological characteristics of similar mixed aquifer sediments. One test borehole was constructed using a 6" (152 mm) diameter 600 micron filter-mesh screen, and another using an 8" (203 mm) diameter 2 mm slotted pvc screen. Down-the-hole flow logging of each test borehole was undertaken to ascertain groundwater inflow patterns and possible screen blockage zones. In all, two test and six observation boreholes were constructed at the Vakabalea test site.

The third test site was at Dama, located within a meander complex adjoining the Ba River, to the south of Ba. Similar methods were also applied to the drilling, construction and testing of two exploration boreholes installed within coarse mixed sediments at the Dama test site (Plate 3).

# 2 SCIENTIFIC BASIS

## 2.1 Collection of Geological Data

The test/production and exploration boreholes were drilled using the direct circulation mudflush method. Sediment samples were described on collection at each borehole during drilling, good definition of sediment colour and texture variation with depth being obtained. Full co-operation of the drilling staff facilitated the collection of representative lithological samples and accurate drill penetration rate data. Grain size data resulting from the sieve analyses of 117 sediment samples were used to define the degree of sediment sorting, i.e. the proportion of fine to coarse material (Fig 2). Using these data, patterns of sedimentation were identified, to be correlated with specific environments of deposition.

Sediment sequences exhibited patterns of sedimentation significantly affected by climatic change and sea-level rise following the last glacial period. Radiocarbon dating of interbedded peat deposits helped to define this observation.

According to Kovacs (1981) and Kezdi (1969), movement of fine sandy matrix material through a coarse pebbly sediment framework occurs by the process of suffusion when critical grain-size sorting and groundwater velocity criteria are exceeded. Grain size analysis data were used to identify possible zones of borehole sand invasion and/or screen blockage, both recognised causes of borehole failure in mixed texture sediment deposits.

### 2.2 Borehole Construction and Well Development

The production borehole designs used a 30 l/sec capacity Mono 4011 pump.

At **Dubalevu** a production borehole was constructed using 0.6 mm filter mesh screen in poorly sorted medium to coarse sand with a fairly high proportion of silty fine sand. It initially produced a very poor yield of 2.8 l/sec for 5 metres of drawdown. According to the criteria of Kovacs, these fairly stable, poorly sorted sediments are amenable to borehole development. Repeated application of a suite of borehole development methods including jetting with compressed air and overpumping resulted in an improvement of borehole yield to 22 l/sec for 10.5 metres of drawdown (Plate 4).

At **Navua** two designs of borehole were compared under test conditions following periods of development The first borehole was constructed with a 0.6 mm μ filter mesh screen adjacent to alternating non-self filtering and self-filtering poorly sorted sediments. This borehole had an initial yield of 25.4 l/sec for 3.3 metres of drawdown. Flow logging indicated that this yield-drawdown relationship deteriorated with time as fine sands were mobilised by suffusion passing through the coarser non-self filtering bands to partially block the filter mesh screen.

The second borehole was constructed using a 2 mm slot screen emplaced adjacent to similar sediments. Fine sands mobilised by suffusion pass through the coarse sediment framework without collapse of the latter, as predicted by Kovacs (1981) and Kezdi (1969), through the screen into the borehole thereby enhancing aquifer transmissivity and borehole yield/drawdown characteristics during development and subsequent pumping. A yield of 29.4 l/sec for 2.5 metres drawdown was initially attained, a rate that showed improvement during subsequent flow logging tests.

### 2.3 Borehole Test Pumping and Flow Logging

Observation boreholes were installed at each test site to supply additional geological data and to act as monitoring sites during test pumping exercises (Plate 5).

At **Dubalevu** long term constant discharge rate and multi-rate step tests were undertaken to assess the improved efficiency of the re-developed borehole. Similar tests conducted upon the replacement test borehole, which fully penetrated the alluvial aquifer sequence, indicated that much of the groundwater abstracted came from a pebbly basal unit. Some of the well loss initially recorded in the re-developed borehole can be attributed to the nature of the aquifer material and possible screen blockage, as demonstrated by the improved efficiency of the borehole after development. However, a larger proportion of the observed well loss is probably due to partial penetration losses, indicating that this borehole had not been drilled deep enough or that it had been located to one side of the linear basal conglomerate. Such results indicate that good site geology definition is required if an effective abstraction system is to be installed.

At **Navua** coarse grained sediments interbedded with layers of finer sands occur throughout the deltaic sediment sequence. The occurrence of fine matrix material within these coarse framework sediments must be understood. The results of long term constant discharge and multi-rate step tests show that although this unconfined aquifer has a high transmissivity the presence of fine matrix material can lead to reduced borehole discharges caused by screen blockage. Flow logging data from two test boreholes produced first indications of how borehole development takes place, leading ultimately to screen blockage in the filter-mesh equipped borehole and under-development of the slotted screen equipped borehole. The long term use of these boreholes used as production units as part of the Navua water supply system is being monitored by the MRD in Fiji (Plate 6).

At **Dama** exploratory studies showed the presence of a thin, mixed and very poorly-graded sedimentary deposit. Prolonged development failed to produce a significant groundwater yield from the test borehole.

# 3 RECOMMENDATIONS FOR INVESTIGATION, DESIGN AND DEVELOPMENT OF BOREHOLE SCREEN AND GRAVEL PACKS IN ALLUVIAL AQUIFERS

## 3.1 Sediment Sampling

The study has demonstrated that the collection of representative lithological samples and related data during the drilling of production boreholes using the recommended rotary mudflush drilling methods is possible.

## 3.2 Interpretation of Alluvial Aquifer Systems

Deduction of depositional conditions, together with a knowledge of the effects on the genesis of alluvial systems of climatic, tectonic and associated base level changes, can allow better interpretation of alluvial groundwater systems. This knowledge has already been successfully used to explain the mode of deposition of the Late Quaternary age alluvial aquifers of central Bangladesh (Davies, 1994).

## 3.3 The Selection of Borehole Screen and Gravel Pack

Boreholes in alluvium are constructed having a screen pipe with slots placed opposite the water-yielding layers and surrounded by a gravel pack emplaced during borehole construction. Poorly graded alluvial sediments commonly have bimodal grain size distributions with distinct fine and coarse grain fractions. Terzaghi's (1943) criteria for the selection of gravel pack and screen slot sizes are not suitable for such poorly graded sands. Kezdi (1969) describes criteria used to distinguish between self-filtering and non-self-filtering sediments. He assessed the sediment grain size distribution curve in two parts, about an inflection point $D_n$ where $D_n$ means the n% of the coarse (C) or fine (F) fraction that is finer than grain size D (see Fig 2).

If $D_{15C} \geq 4D_{15F}$

Criteria (A)

and $D_{15C} < 4D_{85F}$

are met the material is self filtering and stable. If the above are not met then suffusion is likely to occur and fine matrix material can be removed. This could result in coarse sediment framework collapse. Kovacs (1981) attempts to determine if the coarse sediment framework will stand up after removal of fine matrix material and at what velocities removal of fine matrix material occurs. We suggest that as a simple rule of thumb, if the criterion $4D_{50F} \leq D_{50C}$ is not exceeded then the coarse sediment framework will not collapse.

Given the above, three alternative material states are recognised:-

(a) When the material is self-filtering, the gravel pack and borehole screen can be selected according to the criteria of Terzaghi (1943). In this case, criteria (A) still apply but $D_{15C}$ is the $D_{15}$ of the gravel pack material and $D_{15F}$ and $D_{85F}$ are the appropriate sizes of the self-filtering aquifer material.

(b) When the material is non-self-filtering and collapsing no attempt should be made to screen.

(c) When the material is non-self-filtering and non-collapsing an appropriate size of gravel pack and screen should be selected using the grain-size distribution of the coarse grained fraction. Thus, criteria (A) are used, $D_{15C}$ becomes the $D_{15}$ of the gravel pack and $D_{15F}$ and $D_{85F}$ are the appropriate sizes of the coarse grained fraction of the natural aquifer material. This demonstrates that a larger screen slot size can be used than would be the case as defined using present criteria, thus reducing the opportunity for screen blockage. The aquifer should be developed as forcefully as possible to ensure removal of fine matrix sediment from aquifer material adjacent to the borehole.

### 3.4 Interpreting Borehole Performance

The work of Barker, Herbert and Davies (1989) can be used to predict borehole yields accurately. This means that boreholes suffering from low yields from filter or screen blockage can be identified.

Application of methodologies 3.1 to 3.4 outlined above will allow better borehole design and better analysis of performance within the difficult, poorly-sorted mixed texture alluvial aquifers thereby reducing the number of borehole failures and permitting suitable maintenance and rehabilitation programmes to be set in place to maximise borehole operational life. Improved understanding of mixed texture alluvial sediment deposition will lead to better drill site selection and diagnosis of past borehole failures within such environments.

## ACKNOWLEDGEMENTS

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Davies J, Kumar P & Herbert, R (1991) Shallow aquifers characterised by poor sediment sorting and mixed textures. BGS Technical Report WD/91/79R, Wallingford, UK.

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Enquiries concerning the BGS Technical Reports listed above should be directed initially to Head, International Division, British Geological Survey, Keyworth, Nottingham NG12 5GG, UK. Fax:(0)602 363200)

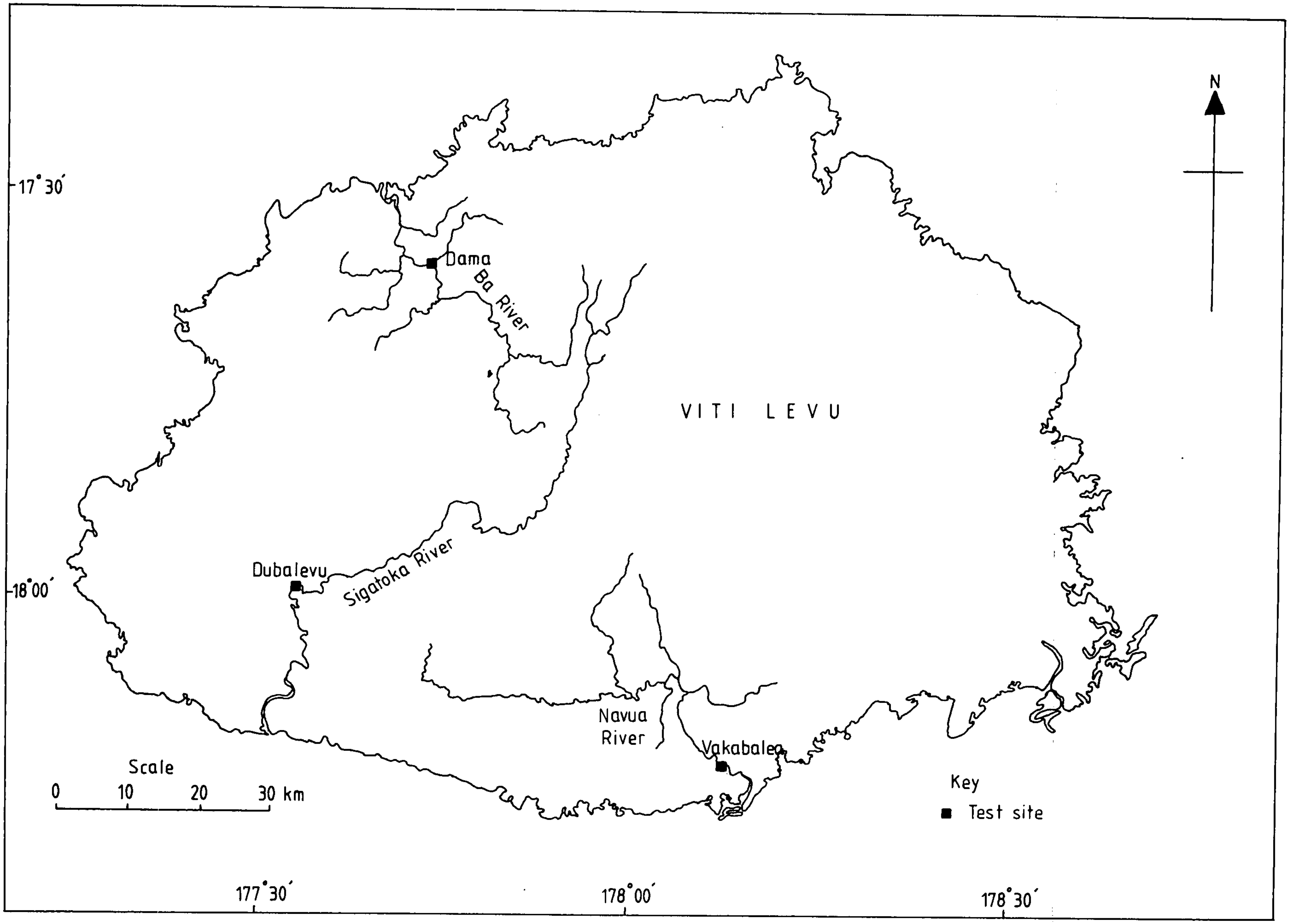


Fig 1 Test Site Location Map

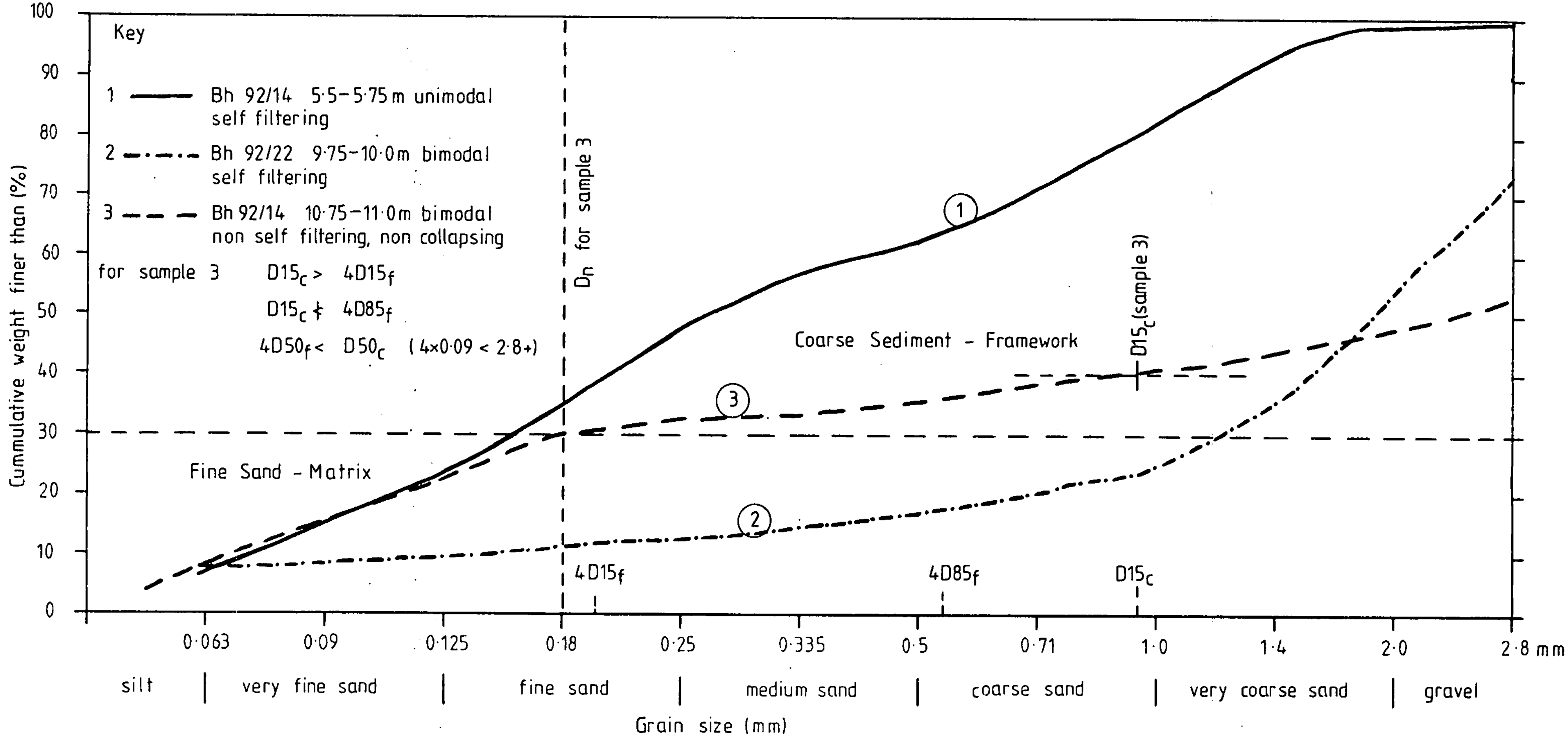


Fig 2 Examples of typical grain size analysis curves showing self filtering and framework collapse capability determination

Plate 1 Installation of 6 inch (152 mm) diameter filter mesh screen with 600 μ mesh at Dubalevu.

Plate 2 Initial cleaning of production borehole by jetting with compressed air at Vakabalea, Navua.

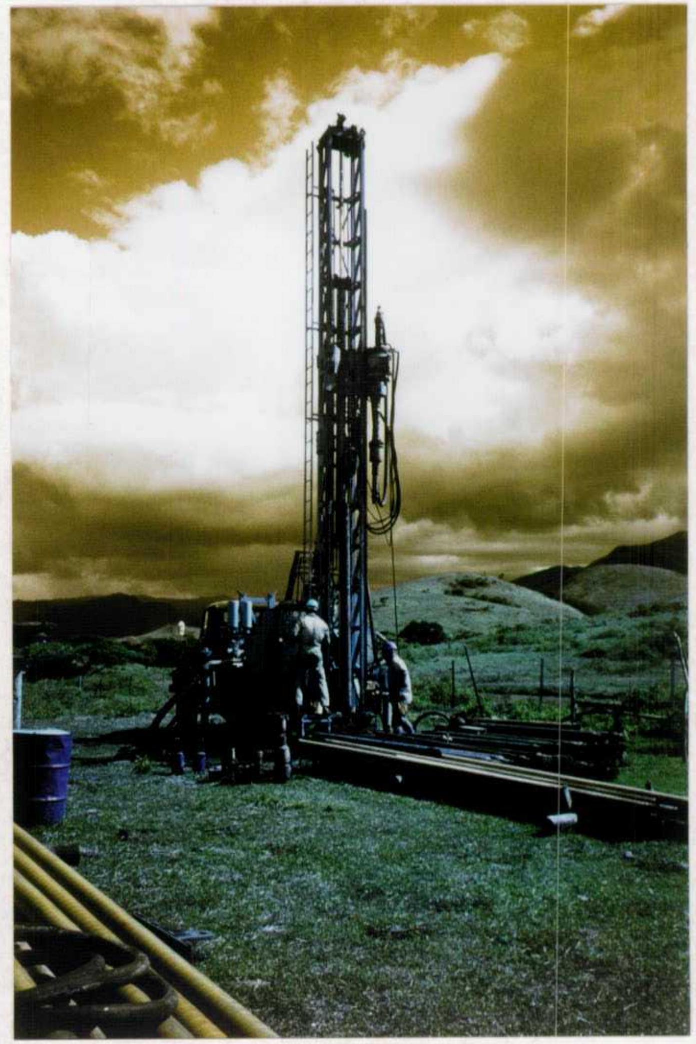

Plate 3 Drilling of exploration borehole at Dama, Ba

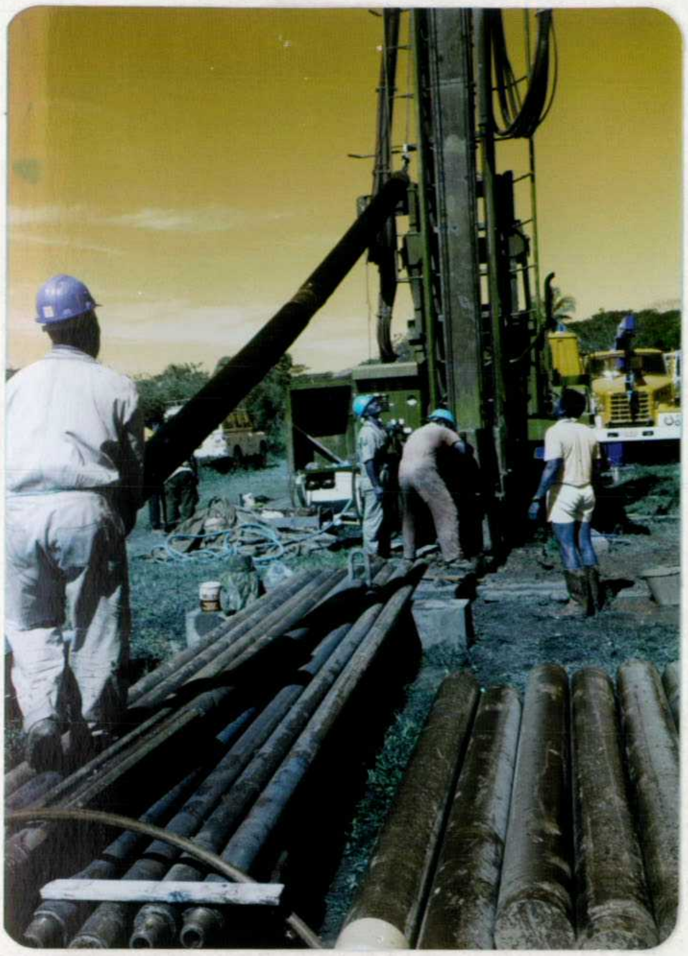

Plate 4 Installation of a geotextile wrap screen.

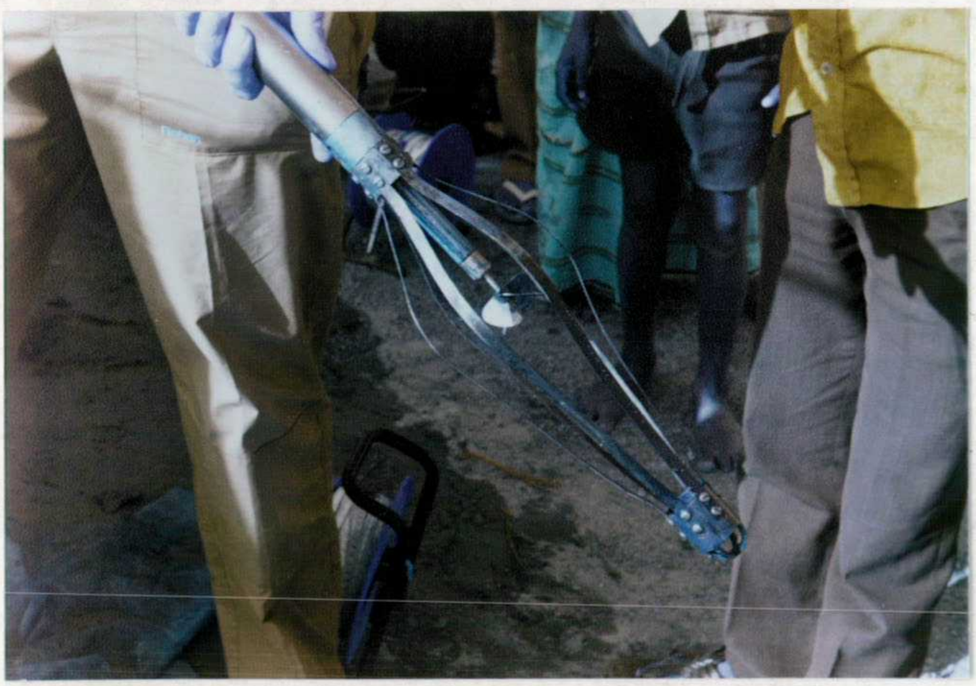

Plate 5 A downhole impeller flow-logger.

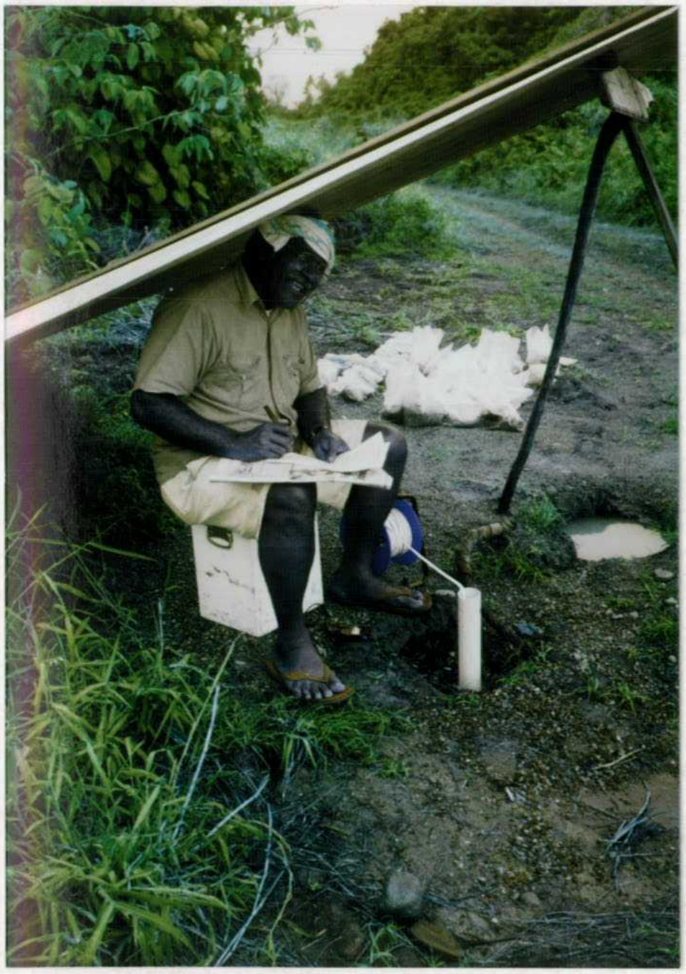

Plate 6 Monitoring water levels in an observation borehole at Navua.