THE CONSTRUCTION AND PUMP TESTING OF WATER BOREHOLES IN FOUR PROVINCIAL CENTRES : PART OF THE JICA GROUNDWATER PROJECT

1. INTRODUCTION

Central Drillers based in Port Moresby, National Capital District (NCD) was contracted to carry out test drilling and pump testing of water boreholes in, four provincial centres in Central and Western Provinces by consultants Japan Techno. The test drilling was part of the study on groundwater for water supply systems in Papua New Guinea (PNG) funded by the Japanese International Co-operation Agency (JICA). JICA in co-ordination with PNG Waterboard, were responsible for conducting the study, which included a total of eight (8) provincial towns and centres, in four provinces, Morobe, Oro, Central and Western in mainland PNG. This report covers work carried out in two of the provinces Central and Western.

The consultants, Japan Techno, provided a multi-disciplinary team consisting of ten experts to carry out the study. Prior to the drilling phase, ground geophysical investigations using resistivity and/or conductivity methods were conducted at eight selected locations and several potential borehole drill sites were selected at each location.

Upon completion of drilling, the test boreholes were geophysically logged and based on the results were screened, cased and developed. Finally the boreholes were pump tested to assess their yield. Water samples were also taken and analysed at the National Agricultural Research Institutes (NARI) laboratory at Kila Kila in Port Moresby, to assess their chemical quality (Table 1).

2. BACKGROUND INFORMATION

2.1 Aim of Study

The JICA Groundwater Project study was aimed at assessing the groundwater potential of the eight selected areas by constructing a series of exploration boreholes, developing the groundwater resources, formulating plans for the design of water supply facilities, and also plans for operation, management and maintenance of the completed systems.

2.2 Personnel

The drilling and testing crew from Central Drillers involved in the study programme included the following personnel:
Simon Brown - Manager, Central Drillers
Thomas Aisa - Driller
Albert Tonia - Assistant Driller
Sam Banaso - Mechanic
Aron Aisa - Offsider
Viva Hage'o - Driver/Field Assistant
Simon Egara, Hydrogeologist, was seconded from the Geological Survey to Central Drillers to supervise the drilling and pump testing of the boreholes and to liaise with consultants, Japan Techno.

2.3 Schedule and Duration of Investigations

ACTIVITY	DATE	DEPARTURE TIME	ARRIVAL TIME
BEREINA			
Mobilisation (Port Moresby to Bereina by road)	16/07/2000	10.00 a.m.	7.00 p.m.
Drilling commenced	17/07/2000		
Testing completed	28/07/2000		
Demobilisation (Bereina to Port Moresby by road)	29/07/2000	10.00 a.m.	2.00 p.m.
KWIKILA			
Mobilisation (Port Moresby to Kwikila by road)	01/08/2000	11.00 p.m.	2.30 p.m.
Drilling commenced	02/08/2000		
Testing completed	25/08/2000		
Demobilisation (Kwikila to Port Moresby by road)	25/08/2000	11.30 p.m.	1.30 p.m.
DARU			
Mobilisation (Barge : Port Moresby to Daru - M.V. Kristina)	11/09/2000	2.00 p.m.	3.30 p.m.
Drilling crew departed on MBA Fligh CG 330 for Daru	13/09/2000		
Commenced drilling	14/09/2000		
Completed testing	06/10/2000		
Demobilisation (Daru to Port Moresby - Barge M.V. Goada Chief)	20/10/2000		
Drilling crew returned to Port Moresby on MBA Flight 331	08/11/2000	6.25 p.m.	7.45 p.m.
KUPIANO			
Mobilisation (Port Moresby to Kupiano by road)	30/10/2000	10.00 a.m.	4.40 p.m.
Compound drilling	31/10/2000		
Completed testing	08/11/2000		
Demobilisation (Kupiano to Port Moresby by road)	08/11/2000	12.30 p.m.	7.30 p.m.

2.4 Equipment/Drilling Methods

A Mobil Fox B40 modified THD rotary drilling rig with a compressor unit mounted on a Hino FP27 truck was used for the test drilling programme. Accessories and support equipment included a 7,000 litre water tanker, and pump, two support trucks (Plate 1), a 70 Kva Ac generator (Plate 17), a 7.5 Kw 10 hp submersible pump, 6½" - 12" blade bits, 7½", and 9 ⅝" roller and blade bits: 9 ⅝" stabilizer (Plate 2) was also employed.

All test boreholes drilled were completed with a 310 mm diameter hole to a depth of about 5.5 m for the installation of 6 m of 254 mm diameter steel surface casing (Plate 5) and with a cap. Except for KKBH-1, all boreholes were cased with 150 mm diameter blank PVC casing with glued joints and screened with factory slotted 150 mm diameter PVC screen with 0.8 mm slot size (Plates 7 & 8).

Geophysical logging of the boreholes was carried out by Siam Tone Co. of Thailand using Geolog logging equipment (Plate 11a) with gamma and resistivity probes. A Lowara 3 phase, 7.5 kw, 10 hp submersible pump with a maximum capacity of 4 l/s (Plate 12a) was used for the pumping tests. In addition, a 2 hp Redjacket single phase submersible pump (Plate 12b) was used for testing low yielding boreholes such as KKBH-1.

3. PROVINCIAL CENTRES INVESTIGATED

Four provincial centres were investigated and boreholes were constructed in the following order: Bereina, Kwikila, Daru and Kupiano.

3.1 Bereina

3.1.1 *Physiography and climate*

The borehole site (BRBH-1) is located within Bereina town (Figure 1), headquarters of Kairuku-Hiri District. The town is situated on the flat-lying fluvial plain formed by old courses of the nearby unstable Angabunga river.

The surrounding area is covered with thick shrubs and tall grasses and patches of kunai grass. Most of these bushes are dotted with coconut palms, trees and garden patches. The soil is very porous hence natural drainage patterns are almost non-existent. A few depressions occur in and around the vicinity of the township and are remnants of the former meandering Angabunga river channel.

Bereina experiences distinct rainfall patterns with the wet season normally extending from about December through to April with a mean monthly average of 215 mm. The dry seasons prevails from May to November with a mean monthly average of 25 mm. The mean annual rainfall for Bereina is about 1,193 mm as shown by the mean annual rainfall distribution of Papua New Guinea in Figure 5.

3.1.2 Geology/Hydrogeology

The geology of the area consist of Quaternary fluvial plain deposits comprising unconsolidated, rounded gravel, sand, silt and mud and at depth, bounders and cobbles with gravel and sand mixtures deposited by the Angabunga river. Total thickness of these formations is unknown but thought to exceed 100 m.

Hydrogeology

Bereina town area has excellent groundwater potential. The extensive alluvial plain is predominantly underlain by silt and sand with some clay lenses and at depth coarse boulders, cobbles, gravel and sand with excellent aquifer potential. Currently, many town residents have shallow hand dug wells in the alluvium to supply water for their household needs as the existing town water supply system no longer operates. The shallow wells which are no more than 6 m in depth, dry up during dry season indicating that for a continuous supply, wells must be deeper then 6 m. There are several boreholes within Bereina town drilled to depths ranging between 18 m and 25 m but require deep borehole pumps to enable abstraction to take place.

3.1.3 Existing water supply

Bereina currently has a reticulated water supply system but the system does not function due to various problems which include lack of electricity to run the pump, burnt out pump electrical switch gear, lack of maintenance to overhead tanks, etc. Town residents and nearby villagers collect water from privately constructed shallow hand dug wells. Occasionally, a communal shallow well dug in the old river bed about 300 metres away from the town, is used as a water source.

Present Investigations

3.1.4 Borehole construction, BRBH-1

The borehole, BRBH-1, located within the Bereina township, was drilled using air and 310 mm diameter blade bit to 5.6 m depth (Plate 3). Six metres of 254 mm diameter steel surface casing was installed to 5.6 m depth with a 0.4 m stick up. The annulus was grouted with cement as shown in plate 6. The borehole was drilled to 36 m at a reduced diameter before encountering circulation loss and cave-ins caused by large boulders and cobbles, samples of which could not be washed up by the drilling mud.

A polymer-based mud mixed with water was used for hole stabilisation. However, the polymer was not strong enough to hold the boulders and cobbles that continuously caved into the hole and caused the hole to backfill to a depth of about 28 m. The borehole was logged using downhole geophysical logging equipment (Plates 11b & 11c). Based on gamma and resistivity results and the lithological log, the optimum length and position of the screen was decided. Subsequently, BRBH-1 was screened and cased from 0-26 m (Plate 9). and the annulus gravel packed with rounded river gravels (maximum diameter 14 mm). Details of borehole construction and lithological log are shown in Figure 6. The borehole was developed by airlifting for more than 6 hours until sand free as shown in Plate 10.

An earlier borehole drilled to 26 m by Ranuguri Investments is reported also to have been developed by airlifting (Plate 4). However a mixture of gravel, sand, silt and mud continuously upwelled to about 18 m, causing blockage to the pump impeller and riser pipe when a pumping test was attempted. The borehole appeared to have no end cap to prevent upwelling therefore work was discontinued and the borehole abandoned. Borehole log and construction details are not available.

3.1.5. Pump testing

After the development has been completed, the borehole was pump tested. A step drawdown test was attempted, however, the pump continuously tripping off during the test. A 24 hour constant discharge test was subsequently conducted with a discharge rate of 3.36 l/s and a final drawdown of 3.86 m. It was followed by a 12 hour recovery test.

From the constant discharge test, it can be deduced that the bore can safely produce more than 7 - 10 litres a second with a drawdown of no more than 12m and sufficient to cater for any increase in the town's population. A yield of 3.36 - 4 litres a second is considered adequate to cater for the current population's water requirements. The maximum available drawdown is about 20m.

3.1.6 Conclusions

1. The Bereina town area has excellent groundwater potential with relatively good water quality.
2. There is a high risk of groundwater being contaminated from open pit latrines and the unprotected open shallow handdug wells that are common in the town builtup area.
3. A large diameter (200 mm) borehole drilled to about 60 m depth and screened with a continous slot type screen would be adequate to sustain the water supply requirements for current and future increase in population.

3.2 Kwikila

3.2.1 Physiography and climate

Kwikila Township is located on a gentle sloping foothill that spreads out into a narrow valley and forms part of a drainage course that runs into the Kemp Welsh river to the east. The drainages are flanked by low-lying rounded hills towards the north, south and west, with the highest elevations in the hills at the western edge of the town. The main road from Port Moresby enters the town at the foot of this hill. Part of the built-up area including the current town water supply overhead tanks is located on the footslopes of this hill. The hills are sparsely vegetated with eucalyptus trees and a thin grass cover and moderately dissected by dendritic intermittent drainage.

Rainfall records for Kwikila shows distinctive seasonal patterns. The wet season normally extending from December through to May with a mean monthly average of 133 mm. The dry spell is between June and November with a mean monthly average of about 52 mm. The recorded mean annual rainfall is about 1,147 mm and falls within the same subhumid coastal lowland belt as Bereina.

3.2.2 Geology/Hydrogeology

The hills around Kwikila are predominantly composed of fine grained gabbro of the Sadowa Gabbro Complex. Footslopes and valley floors deposits are composed of unconsolidated colluvium and alluvium and are underlain by a moderately weathered fractured agglomerate. The footslopes of the hills are filled with angular colluvium thickening out toward the valley floors where it most likely interfingers with the alluvium deposited by the intermittent creeks. A series of small subsidiary faults ≤ 0.5 m in width with a northwest trend resulting from the main Owen Stanley Fault System occurs sporadically and are filled with whitish kaolinite. The low-lying rounded hills to the northeast and east on which the District Administration office is located are composed of Pliocene Kwikila Agglomerate consisting of large rounded boulders and cobbles cemented by a finer matrix.

Hydrogeology

The hill slopes within Kwikila town area have little potential for groundwater. However, the lower narrow alluvial valleys appear to have some potential. Results of test drilling and current Kwikila High School water supply borehole indicated that groundwater is present but may not be sufficient to supply the township's water demands continuously and throughout an extended dry season. The valley floor deposits vary in thickness and consists of clay, silt and sand with angular to sub-rounded gravel. The alluvium is thought to increase in thickness and permeability towards the east where is meets the Kemp Welsh river.

3.2.3 Existing water supply

Residents of Kwikila, at the time of test drilling, used rainwater catchment for their water supply. The current town water supply encountered problems with the pump and storage facilities and subsequently could not operate to cater for the town resident's needs. Kwikila High School has a borehole which is located in the alluvial valley (Figure 2) and is used for all the school's water supply needs.

Present Investigations

3.2.4 Borehole construction, KKBH-1 and KKBH-2

Two boreholes were drilled at Kwikila, KKBH-1 and KKBH-2 (Figure 2). KKBH-1 was initially drilled to 4 m depth using a 310 mm blade bit. 4.5 m of 254 mm diameter steel surface casing was installed to 4 m with a 0.5 m stick up and the annulus grouted with cement. KKBH-1 (Figure 7) was then drilled to 100.2 m with a 6½" (175 mm) blade bit and then reamed out to 9⅝" (250 mm) diameter. However, KKBH-1 was not cased or screened as its yield was negligible. Soon after completion it was vandalised, filled with human waste and was subsequently abandoned.

A second borehole, KKBH-2, was drilled to a depth of 44.05 m in an alluvial valley using the same method. A 310 mm diameter hole was drilled to 1 m and 1.5 m of 254 mm diameter steel surface casing installed and the annulus grouted with cement. A 250 mm diameter hole was then drilled to a depth of 44.05 m. KKBH-2 was screened and cased to a depth of only 31 m as the borehole was filled with caved-in material from 40.05 m to 31 m. It was then gravel packed with 14 mm rounded river gravel and developed by airlifting until it was free of sand. Borehole construction details are given in Figures 7 and 8.

3.2.5 Pump testing

A brief pump test conducted on the open borehole (KKBH-1) was unsatisfactory. It was subsequently capped and abandoned as a non-viable borehole.

Pump test conducted on KKBH-2 produced satisfactory results. The bore was pump tested at a maximum constant discharge rate of about 2.5 l/s for 24 hours for a drawdown of about 4.62 m. Maximum available drawdown is about 19 m, however, this was considered inadequate to supply all the water requirements of the population of Kwikila township during an extended drought.

The drilling and pump testing was conducted during a period when Kwikila had experienced some rainfall. Subsequently the static water level and pumping rate was considered to have been affected hence the possibility of the results being biased.

A wellfield consisting of 4 to 5 large diameter bores with a combined production rate of about 4 l/s would be adequate to cater for the town's current population water supply requirements.

3.2.6 Conclusions

1. KKBH-1 drilled on a gentle sloping foothill to 100 m depth in volcanics, produced a negligible quantity of water and was subsequently capped and abandoned as a non-viable bore.

3. KKBH-2 drilled in a narrow alluvial valley with limited thickness produced reasonably good quality groundwater, however, it is considered inadequate to sustain the water requirements of Kwikila town residents.

4. A wellfield consisting of 4-5 large diameter boreholes with a total output of 4-6 l/s would suffice water requirements for the residents of Kwikila township.

3.3 Daru

3.3.1 Physiography and climate

Daru is a low-lying island with a relief of about 12 metres at the highest point at the north eastern end and tappering off to a low mangrove-covered tidal swampy shore on almost all sides. The raised central part of the island forms a horse shoe-shapped spine with a NE-SW trend. The central rise slopes gently into the low-lying swampy mangrove-covered shore (Figure 3, Plate 15b).

Climate in Daru is hot, however, sea breezes makes weather conditions pleasant. Daru experiences distinctive rainfall patterns with the dry season extending from around June to November with a mean monthly average of 76 mm of rainfall. The wet season commencing around December and ends around May with a mean monthly average rainfall of about 267 mm. Daru has a recorded mean average annual rainfall of over 2,000 mm and lies in the coastal lowland subhumid area that is characterised by savanna and open grassland.

3.3.2 Geology/Hydrogeology

The central raised areas of Daru Island are underlain by volcanically derived tuffaceous sandstone overlying shallow marine sedimentary deposits. The sediments consist of shallow marine mudstone with siltstone interbeds which in turn are underlain by a highly porous coralline limestone.

Hydrogeology

Daru Island is relatively small in aerial extent, low-lying, surrounded by sea and as a result the island has very poor groundwater potential. An impermeable layer consisting of siltstone and mudstone interbeds overlies a saline water bearing, highly porous limestone formation. The limestone is directly recharged by the sea water.

Overall, Daru Island has very limited potential for groundwater on any scale and as such further work in relation to groundwater exploration or exploitation should be discontinued.

3.3.3 Existing water supply

Since there is insufficient surface water and unsuitable groundwater on Daru Island, Daru township residents are supplied with water taken from a surface water source and piped in from the mainland. The water is treated at the PNG Waterboard's facility on Daru Island and then reticulated throughout the town.

Present investigations

3.3.4 Borehole construction, DABH-1 and DABH-2

Two boreholes were drilled on Daru Island, DABH-1 and DABH-2 as shown on location map (Figure 3).

DABH-1 was drilled on the northeastern flank of Daru Island to a depth of 80 metres using a 6½ inch (160 mm) diameter blade bit and then reamed out using 9⅝ inch (250 mm) blade bit. Because of the semi-confined nature of the water bearing limestone formation, water rose up the borehole causing upwelling of loose material and the *uncased borehole to backfill to 64 metres. The borehole was screened and cased to 64* m using 150 mm diameter blank PVC casing and 150 mm diameter factory slotted PVC screen (0.8 mm slot size). The annulus between the casing and the borehole was gravel packed using 14 mm diameter rounded river gravel. The borehole was then developed by airlifting for 7 hours until it reached a sand-free state (Plate 15a).

Initially, a 310 mm diameter hole was drilled using a blade bit and compressed air to a depth of 5.4 m depth. Six metres of 254 mm diameter steel surface casing was installed to 5.4 m with a 0.6 m stickup. The annulus was grouted with cement and left to dry before drilling resumed. Light mud-based polymer was used to stabilise the open walls of the borehole from 5.4 m to a depth of about 55 m. Below 55 m, bentonite mud with 1% cement was mixed and cured before using it for drilling in the porous coralline limestone. Borehole design and construction details are outlined in Figure 9.

The borehole was geophysically logged to a depth of 72 m using gamma and resistivity before the resistivity probe developed a fault and could not be used again.

DABH-2, located in the central part of the island, is approximately 100 m away from the Daru Airstrip (Figure 3, Plate 16). The same methods applied in the drilling of DABH-1 were applied in the construction of DABH-2. Borehole DABH-2 was drilled to a depth of 42 m and then cased and screened to only 35 m with 150 mm PVC blank casing and 150 mm diameter factory slotted uPVC screen (0.8 mm slot size). It intercepted similar formations as DABH-1 and upwelling of loose formation material also resulted in a final borehole depth of 35 m. Borehole design and construction details are outlined in Figure 10.

DABH-2 was logged using only the gamma probe due to technical problems with the resistivity probe.

3.3.5 Pump testing

DABH-1 was tested by a 12 hour step drawdown test and a 24 hour constant discharge test followed by a 12 hours recovery test. Throughout the pumping test, it was observed that water levels fluctuated with the changing sea levels during high and low tides. Water level in DABH-2 was also directly influenced by the rising and falling sea levels. Recovery measurements in DABH-2 were terminated after 6 hours because of constant changes in water levels due to tidal influence.

Pump testing of the two boreholes drilled on Daru Island indicated they could produce very large quantities of water with very little drawdown from the type of aquifer encountered, however; the water was very saline with very high TDS (Total Dissolved Solids) in excess of 2,400 mg/l and sulfur dioxide which exceeds the WHO drinking water quality standards thus rendering it unsuitable for human consumption.

3.3.6 Conclusions

1. Daru Island has no suitable groundwater resources for exploitation for a town water supply system.
2. Groundwater in Daru has very high salinity and is not suitable for drinking.
3. Maintaining and upgrading of the existing water supply system is the only and best solution.

3.4 Kupiano

3.4.1 Physiography and climate

Kupiano township is located on the eastern edge of Marshall Lagoon (Figure 4) in the Central Province. The township is sprawled on low-lying rounded undulating hills reaching a maximum height of about 15 metres in the town area and extends inland to the east. The hills are dissected by narrow dendritic drainage systems. The western and northern edges of the township are flanked by the saltwater lagoon. The coastal

margins south of Kupiano town and the lagoon are are covered by heavy mangrove foliage and tidal swamps.
Rainfall records over 16 years for Wanigela show only a slight distinction between the dry and wet seasons although Kupiano lies in the same rainfall zone as most of the Central Province coastal areas (Figure 5). Rainfall records kept at Wanigela shows the the dry season is shorter with little noticeable change, starting in May and ending in October with a mean monthly average of about 112 mm. The driest months are July and August with a mean monthly average of 78 mm. The dry season which is also less discernable appears to start in September and ends in April. The mean monthly average rainfall is about 264 mm while the recorded mean annual average is around 2,488 mm.

3.4.2 Geology/Hydrogeology

The geology of the Kupiano area consists of the Pleistocene Araruba Conglomerate composed of conglomeratic sandstone and siltstone overlying unconformably finer early Miocene to Late Pliocene lagoonal sediments composed mainly of siltstone and sandstone. Further east are hills with isolated caps of the Middle Miocene Gidiobada Limestone composed mainly of reefal limestone, calcarenite and calcirudite.

Hydrogeology

The area on which the township of Kupiano is situated appears to have very little groundwater potential, however, deep drilling in the area is required to fully assess its groundwater potential. The area further of the east may have some good groundwater potential but again further investigations and test drilling would be required to fully assess its potential.

The area selected for drilling KUBH-1 is only a few metres away from the edge of the brackish swamp (Figure 4) and is underlain by fine siltstone and mudstone. Although it has some water bearing characteristics, it is considered inadequate to supply the quantity required by the town of Kupiano. Deep borehole drilling would be required to investigate any potential water bearing formations which may be present at depth.

3.4.3 Existing water supply

Kupiano township has a reticulated water supply system operated by the Division of Works Department, Central Province. Water is pumped from a pumping station located along Loko river but was un-operational due to various technical problems encountered with the pump, compounded by the equipment being vandalised and financial problems in maintaining them. The town has been without a reticulated water supply for more than two years.

Present investigations

3.4.4 Borehole construction, KUBH-1

KUBH-1 located at the edge of a brackish swamp, was drilled initially with a 325 mm diameter flight auger to 5.5 m depth and a 254 mm diameter steel surface casing installed and the annulus grouted with cement and left to dry before drilling resumed.

It was drilled at a reduced diameter using a 6½ inch blade bit with air to 62 m and then reamed out to 310 mm diameter using $9\frac{6}{8}$ inch blade bit and air. However, because of the friable nature of the mudstone the borehole caved up to about 35 m depth.

The borehole was then screened and cased using 150 mm diameter PVC blank casing and 150 mm diameter factory slotted (0.8 mm) PVC screen (Figure 11). It was gravel packed with 14 mm diameter rounded river gravel and developed for more than 7 hours to a sand free state before conducting the pump tests.

3.4.5 Pump testing

The maximum rate at which the bore can be pumped without dewatering is about 1 l/s therefore a 4 stage step drawdown test was done at 0.15 l/s, 0.3 l/s, 0.4 l/s and 0.6 l/s rates. A 24 hour constant discharge test was then conducted at a discharge rate of 1 l/s to assess its yield and followed by a 12 hours recovery test. From the pump test results it can be deduced that the bore can produce less than 1 l/s however, this could be a biased assumption as there had been some recent heavy rainfall in the area.

Ideally, a pump test conducted in peak dry season would give a simple but a better understanding of the borehole's capacity and other properties. Hence, the bore is considered to be inadequate to supply the water requirements of the residents of Kupiano town.

3.4.6 Conclusions

Current investigations revealed that the area on which the town is located and its surroundings does not have good groundwater potential, however, further deep drilling to depths of 150 m should be conducted to asses it's potential fully.

The hilly areas further to the NE should further be investigated as it is thought to have relatively good groundwater potential.

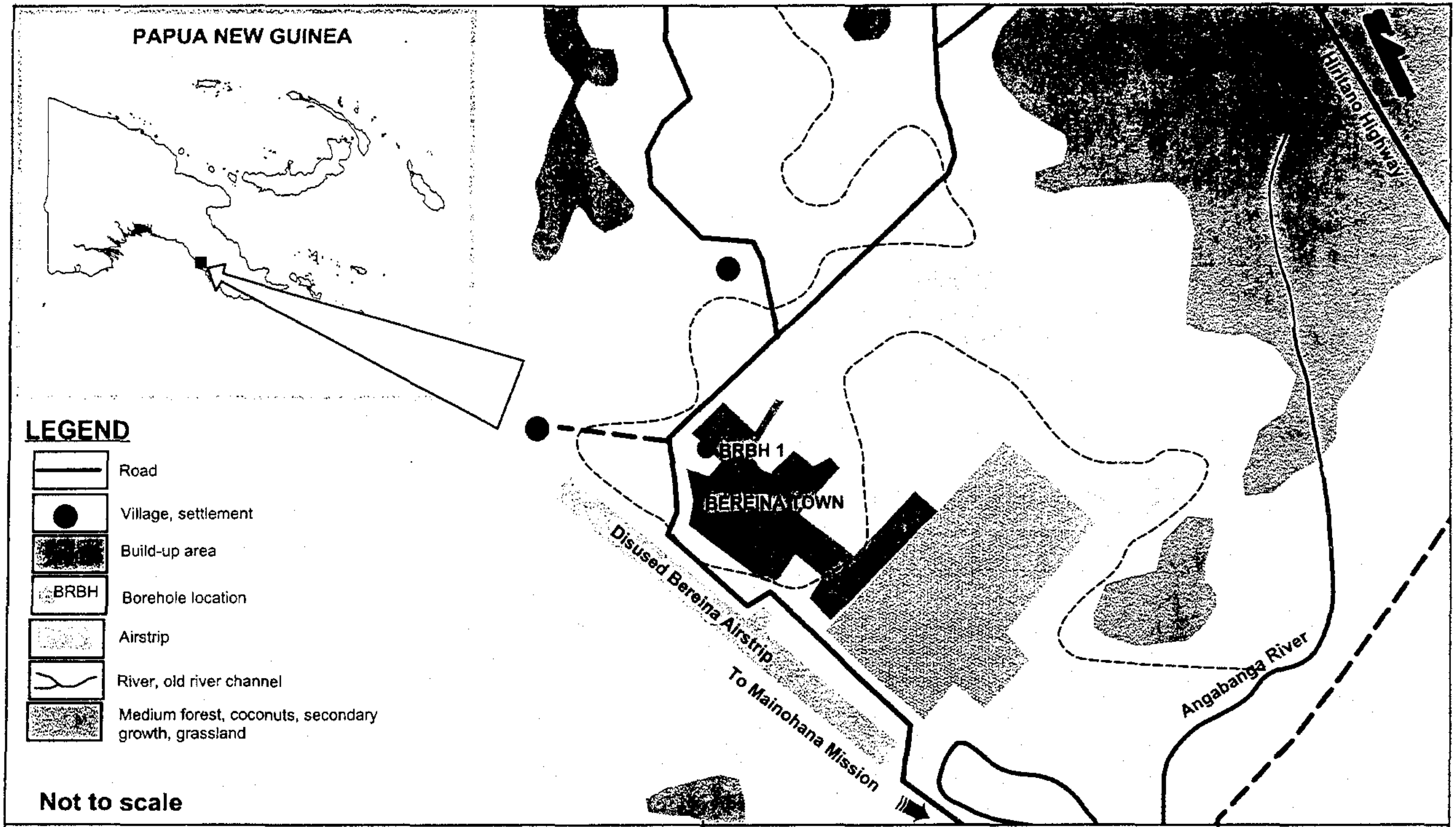
If the above fail to intercept good water bearing formation capable of producing sufficient water for Kupiano town's water supply needs then, the current surface source (Loko river) should be upgraded.

4. WATER QUALITY

The results of analysis of water samples from 5 boreholes are summarised in Table 1. A Piper Plot of major cations and anions in shown in Figure 12.

At Daru, the water is a K-Na /Cl-type with high salinity (TDS range 1,940-2,400 mg/l) which exceeds WHO's drinking water standards and is therefore unsuitable for exploitation for the town's water supply.

Water from boreholes at Kupiano, Bereina and Kwikila are all similar but contrast with that of Daru. The waters have no dominant cation, and are best described as Ca-Mg-Na+K/ bicarbonate-types. The salinities are moderate in the TDS range 440-745 mg/l; the latter, from Kupiano marginally exceeds the WHO drinking water standard *but is within the maximum allowable limit with a TDS of 1,000 mg/l. In* terms of water quality, the 3 boreholes are suitable for the town water supplies.



MAP OF BEREINA TOWN SHOWING LOCATION OF BRBH 1.

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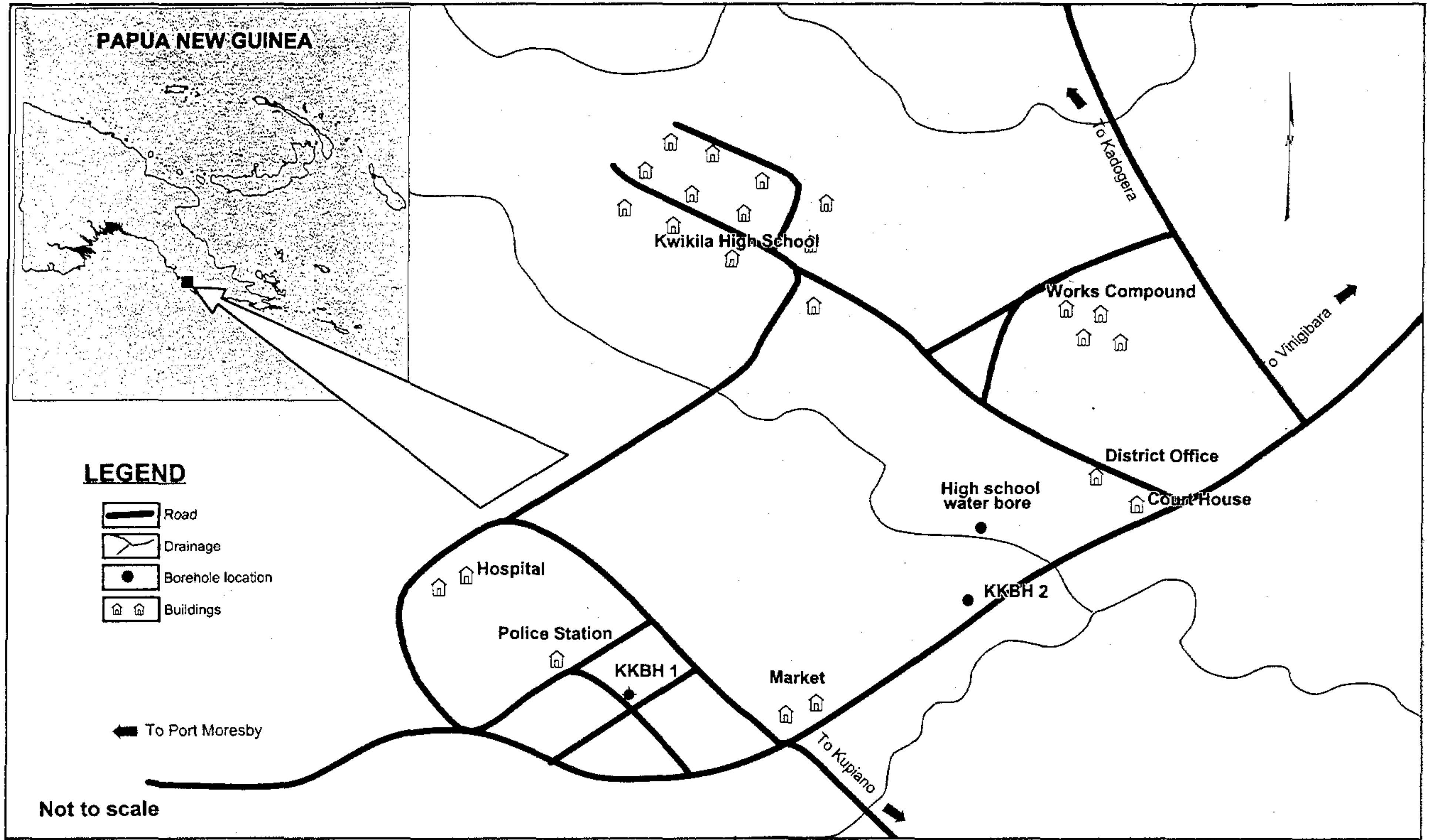
Figure: 1



MAP OF KWIKILA TOWN SHOWING LOCATION OF KKBH 1 & KKBH 2.

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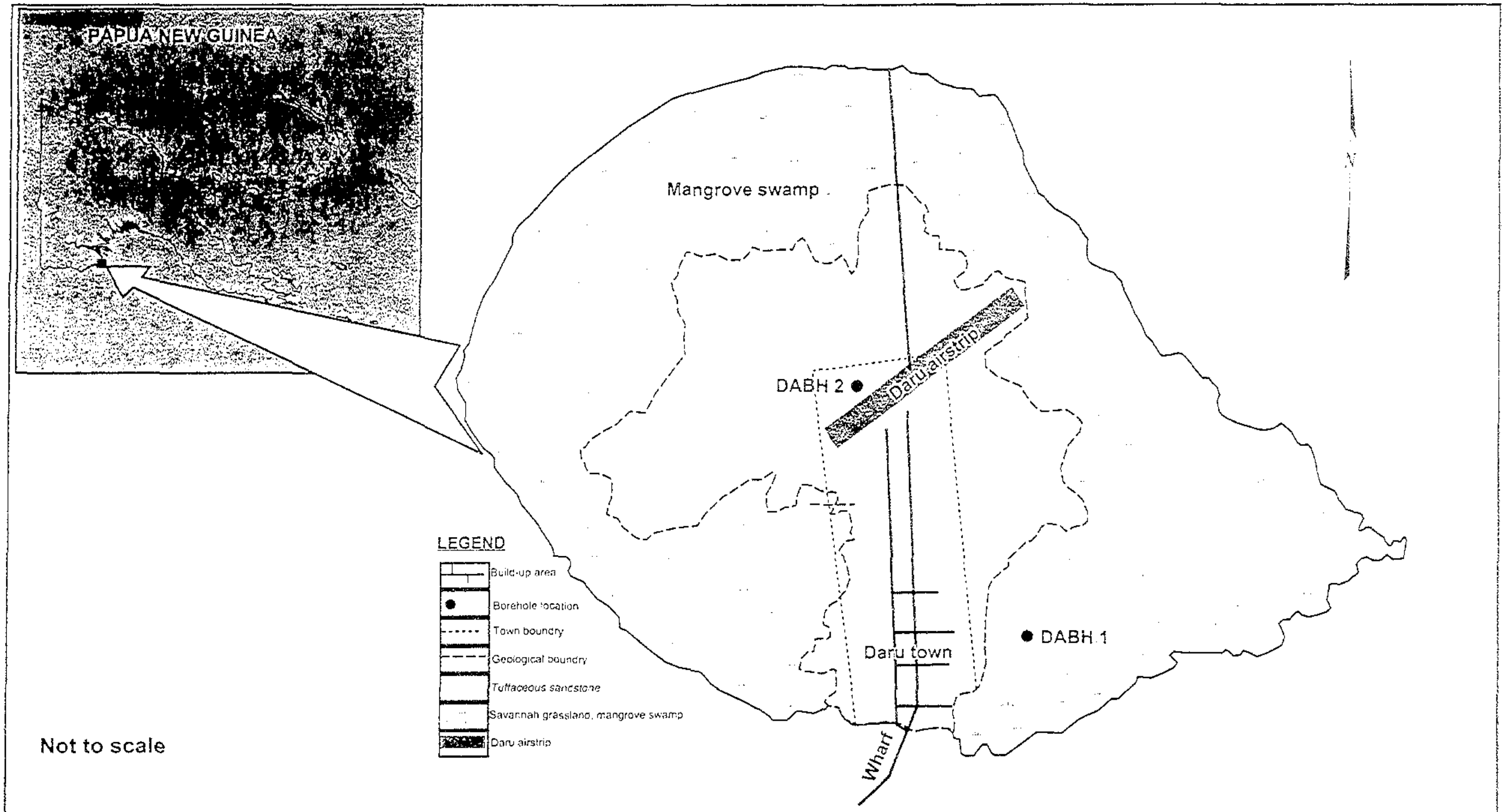
FIGURE: 2



MAP OF DARU ISLAND SHOWING GENERAL GEOLOGY AND BOREHOLE LOCATIONS (DABH 1 & DABH 2).

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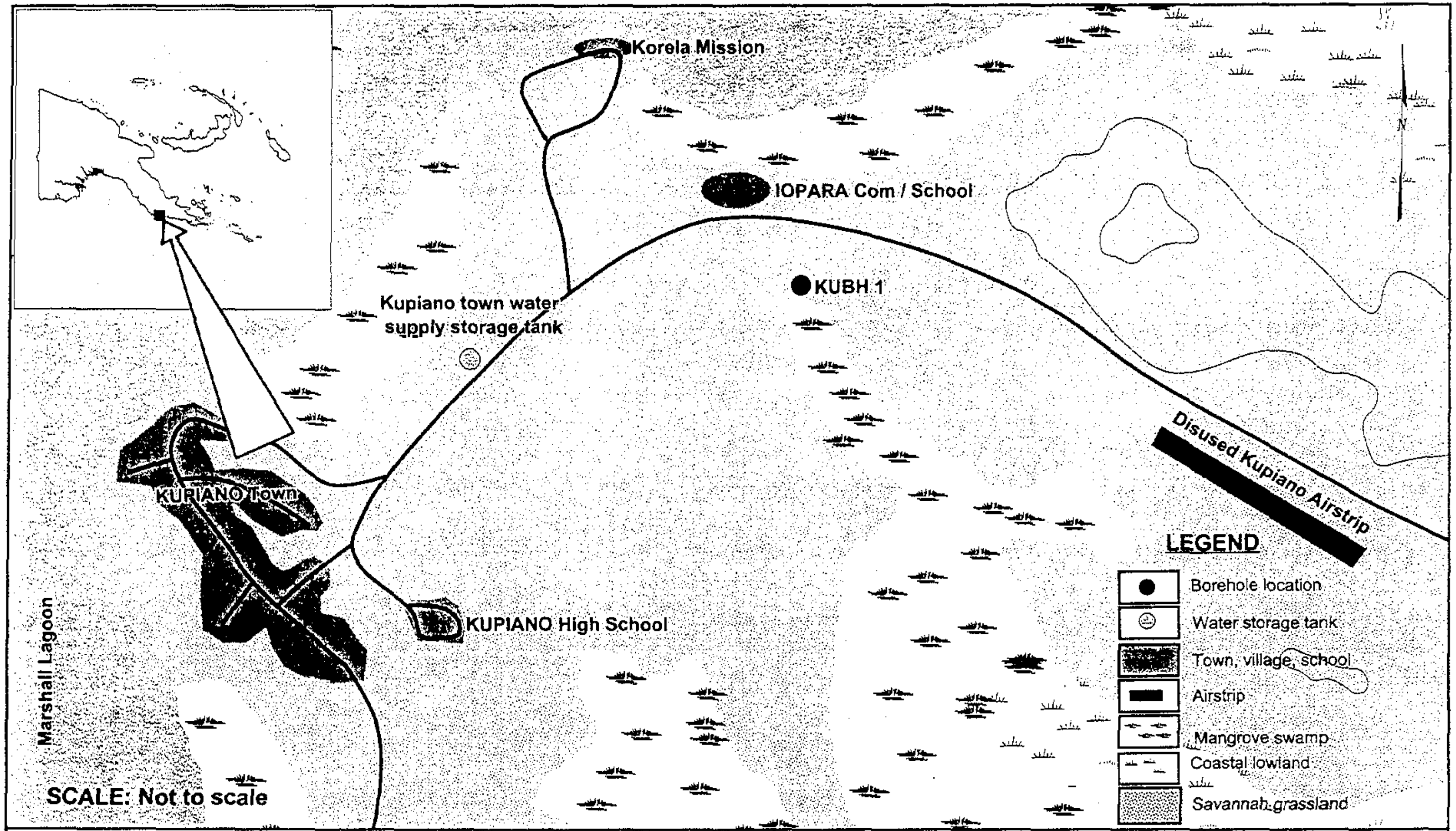
FIGURE: 3



LOCATION MAP OF KUPIANO

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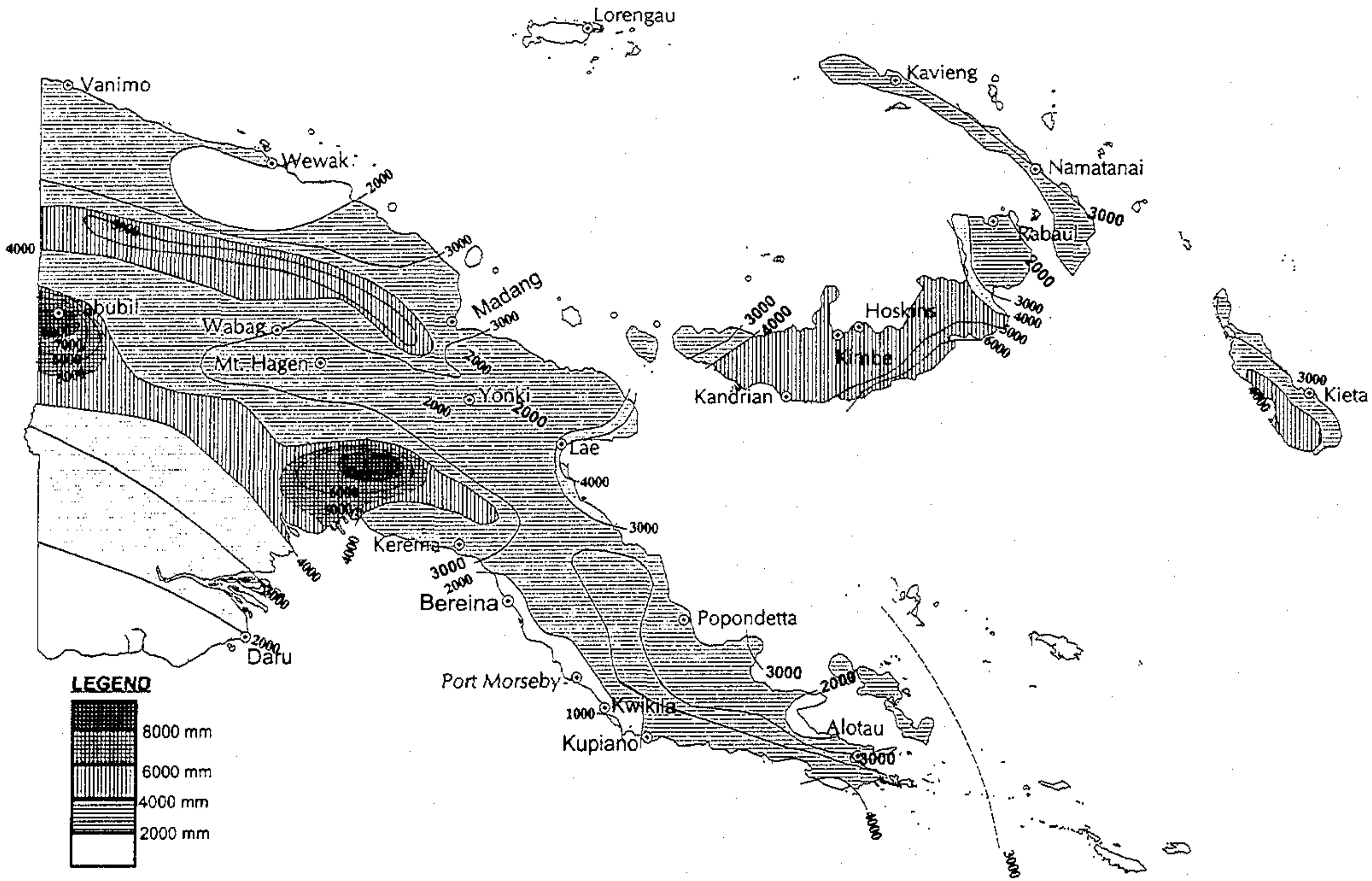
FIGURE: 4



Mean annual rainfall distribution over Papua New Guinea.

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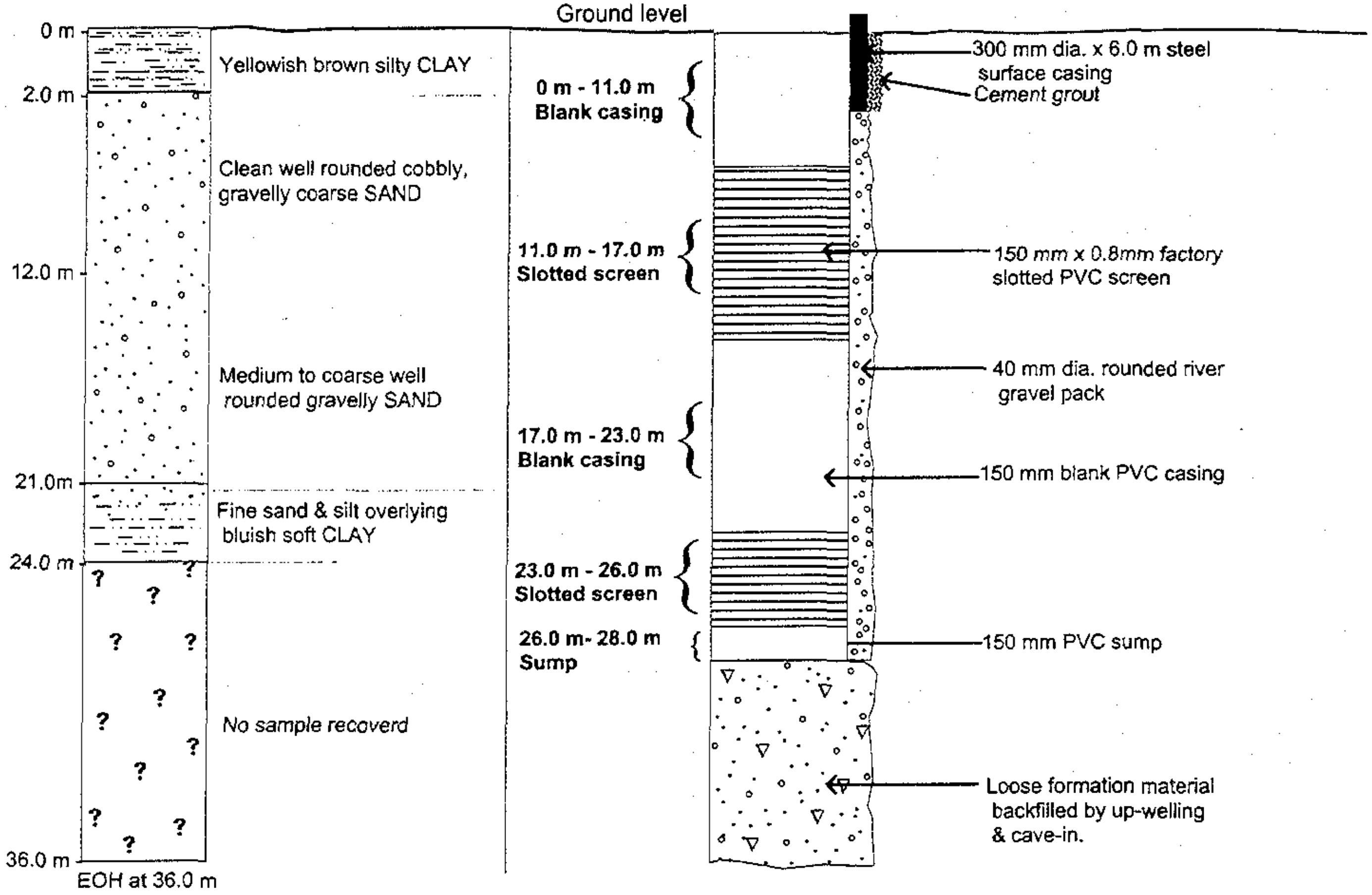
FIGURE: 5

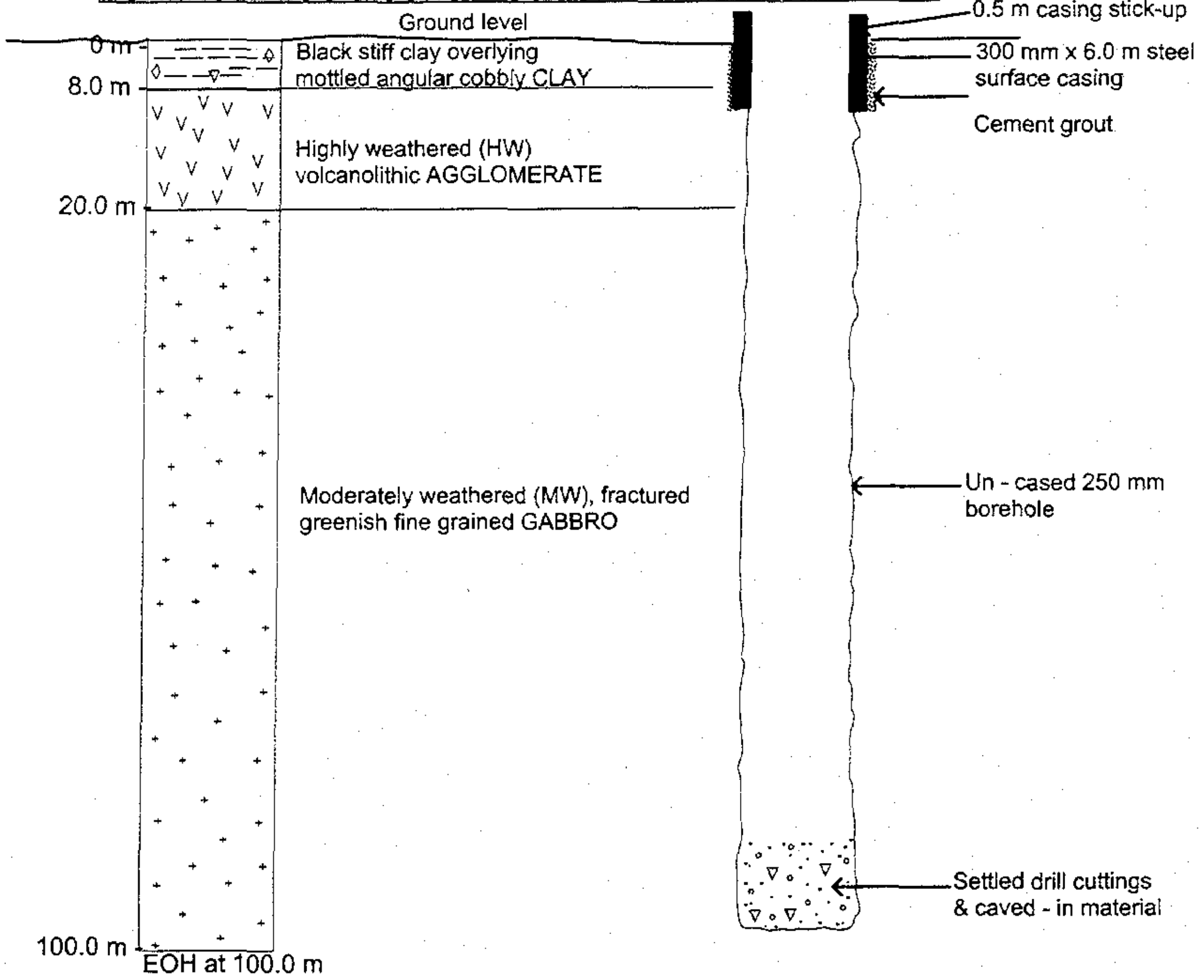
BOREHOLE LOG & CONSTRUCTION DESIGN DETAILS FOR BEREINA (BRBH 1)



Not to scale

BOREHOLE LOG & CONSTRUCTION DESIGN DETAILS FOR BEREINA WATER BORE (BRBH 1)	Geotechnical & Hydrogeology Branch Geological Survey Division Department of Mining	**FIGURE: 6**
The construction and pump testing of water boreholes in for Provincial Centres. Part of the JICA funded groundwater project.		

BOREHOLE LOG & CONSTRUCTION DETAILS FOR KKBH 1



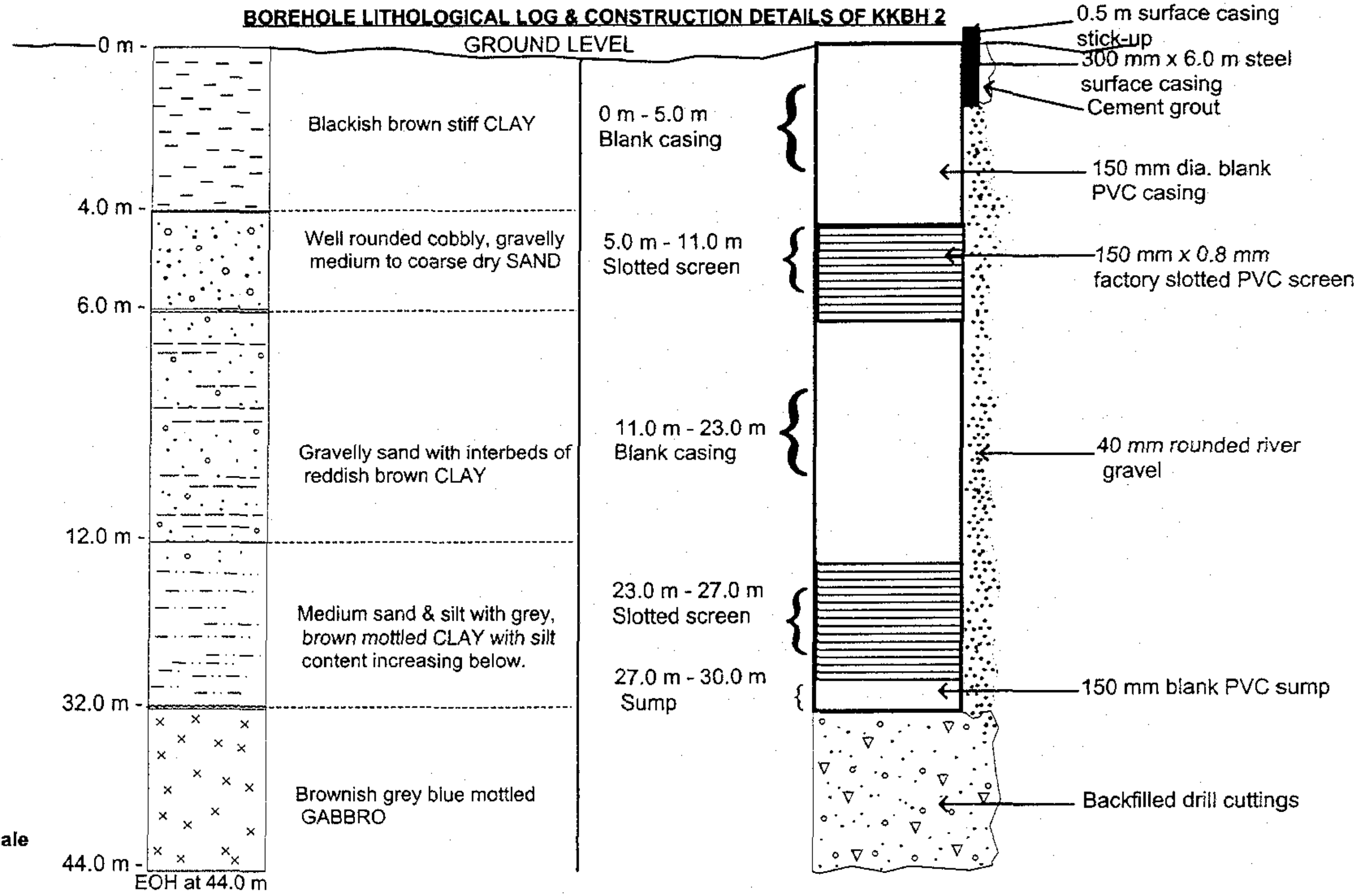
Not to scale

LITHOLOGICAL LOG & CONSRUCTION DETAILS FOR KWIKILA WATER BORE 1 (KKBH 1)

The construction and pump testing of water boreholes in four Provincial centres. Part of the JICA funded groundwater project.

Geotechnical & Hydrogeology Branch
Geological Survey Division
Department of Mining

FIGURE: 7



BOREHOLE LOG & CONSTRUCTION DETAILS OF KWIKILA BORE 2
(KKBH 2)

The construction and pump testing of water boreholes in four Provincial Centres. Part of the JICA funded groundwater project.

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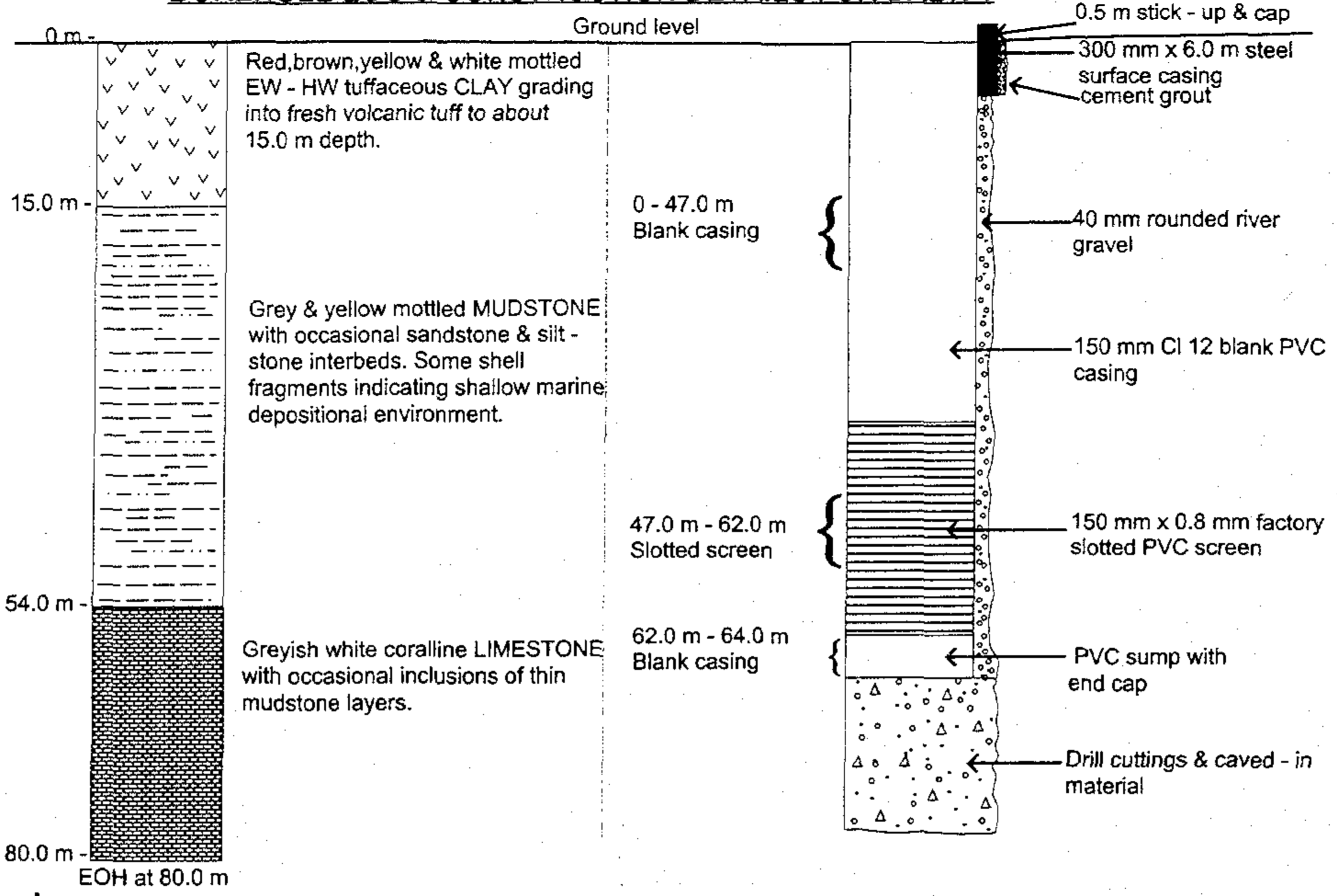
Geological Survey Division
Department of Mining

FIGURE: 8

BOREHOLE LOG & CONSTRUCTION DETAILS FOR DABH 1



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BOREHOLE LITHOLOGICAL LOG & CONSTRUCTION DETAILS
FOR DARU WATER BORE 1(DABH 1)

The construction and pump testing of water boreholes in four Provincial Centres. Part of the JICA funded groundwater project.

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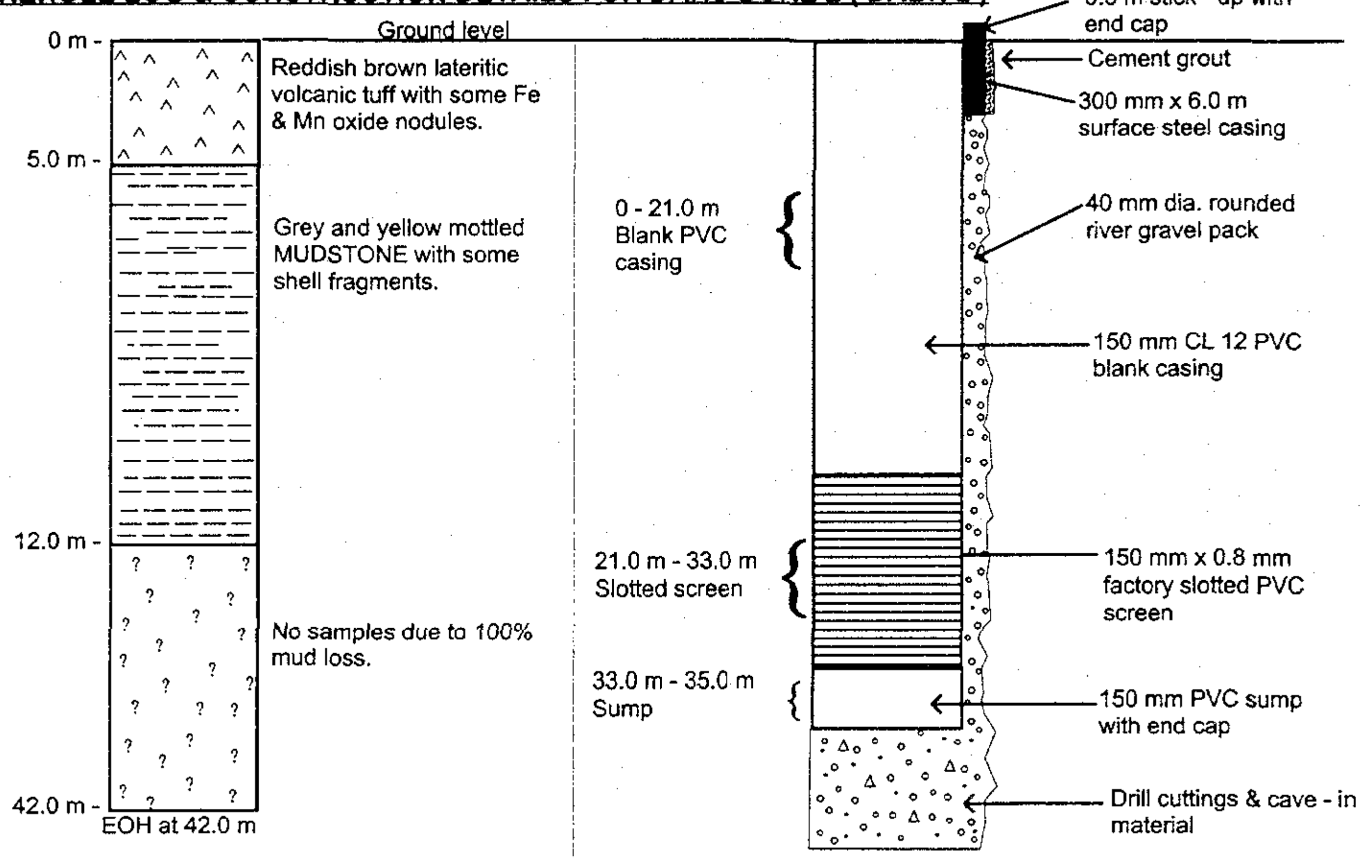
FIGURE: 9

BOREHOLE LOG & CONSTRUCTION DETAILS FOR DARU BORE 2 (DABH 2)



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BOREHOLE LITHOLOGICAL LOG & CONSTRUCTION DETAILS FOR DARU WATER BORE 2 (DABH 2)

The construction and pump testing of water boreholes in four Provincial Centres. Part of the JICA funded groundwater project.

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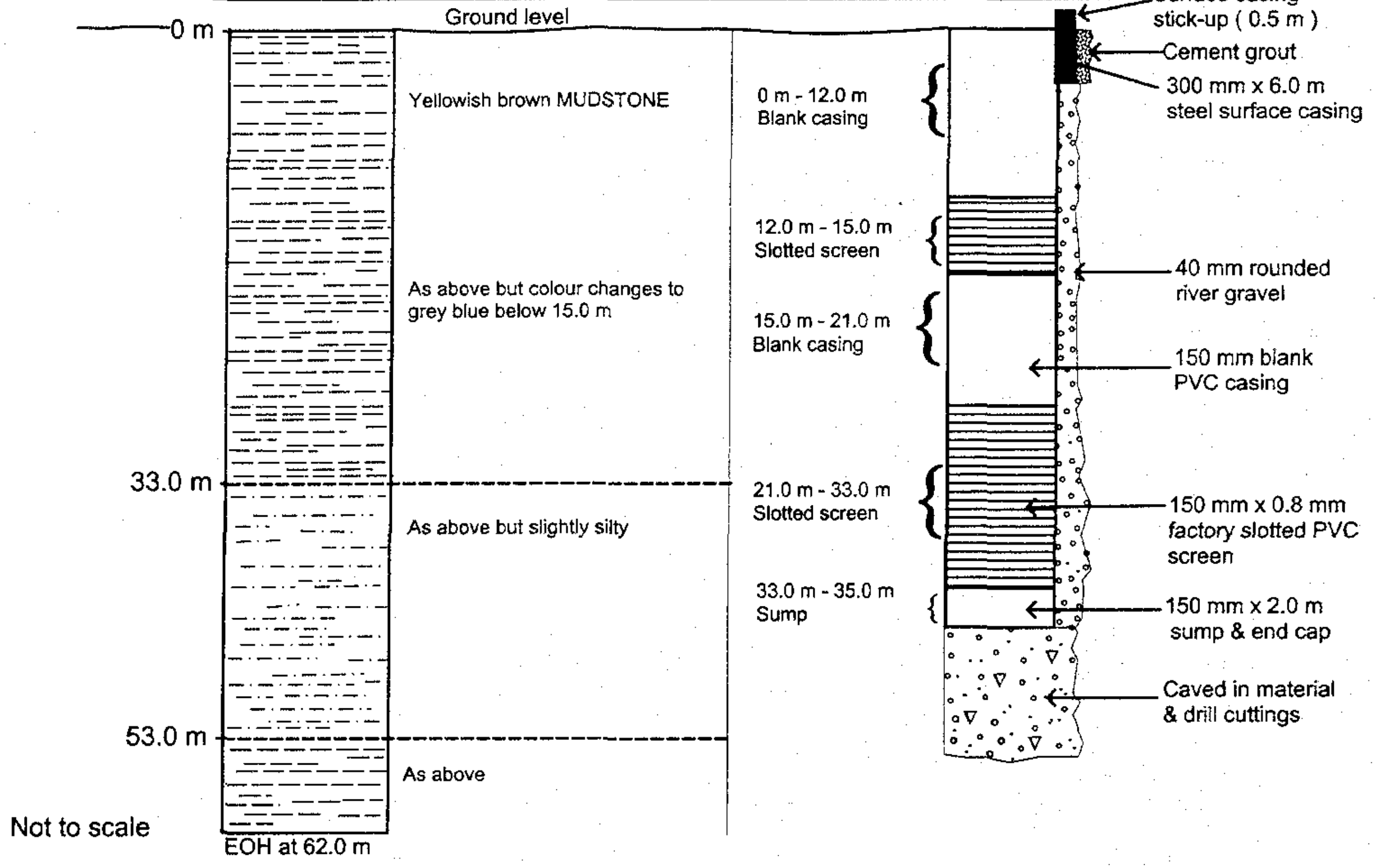
FIGURE: 10

BOREHOLE LITHOLOGICAL LOG & CONSTRUCTION DETAILS, KUBH 1.



BOREHOLE LITHOLOGICAL LOG & CONSTRUCTION DETAILS FOR KUPIANO WATER BORE (KUBH 1).

The construction and pump testing of water boreholes in four Provincial Centres. Part of the JICA funded groundwater project.

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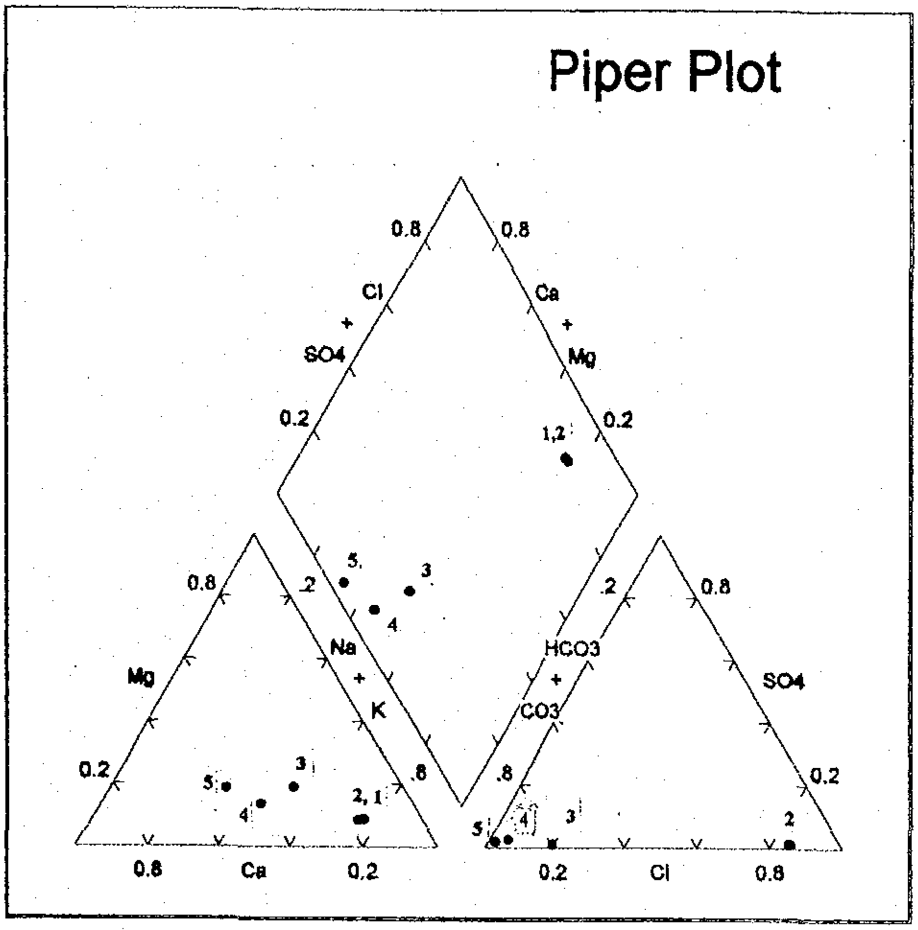
FIGURE: 11

FIGURE 12 :Water Analysis Results - Piper Plot



Sample List for Piper Plot:

Label	Sample ID	TDS
1	DARU BH-1	1,940
2	DARU BH-2	2,402
3	KUPIANO BH-1	745
4	BEREINA	516
5	KWIKILA BH-2	440

ENVIRONMENTAL STUDY IN BINATURI RIVER

EXECUTIVE SUMMARY

Hydrological and salinity investigations were carried out in the lower reaches of the Binaturi River during the period 10th –14th December, 2000. The field investigations involved measurements and sampling of water at five different survey stations. These included the mouth of the River (Mawata), 10 kilometres of upstream (Kunini), 15 kilometres of upstream (Boze), and two points 20 kilometres upstream at Ume 1; one was 50 meters downstream of the pumping station (Ume No.1) and the other was 30 meters upstream of the pumping station (Ume No.1). These stations are depicted in Figure 2 of this Report.

Hydrological survey involved river discharge measurements at the five different stations mentioned above both at high tide and low tide. Data collected from these measurements has been presented in the form of river cross-sections and are included in this Report. On the other hand salinity survey focused on the collection of 35 water samples from the River at five different stations at high tide and two points at mouth of the River at low tide. These samples were then analysed for Sodium chloride and other elements.

It was important also to assess tidal influence along the lower reaches of the Binaturi River. A total of 35 water samples were collected from each depth of the River at 25 centimetres, 50 centimetres, 100 centimetres, 200 centimetres, and 300 centimetres at five points. This would enable us to determine the concentration of sodium, potassium and other elements in the River, which result from low and high tide influences. In addition water samples collected were tested for Chloride concentration, EC (electrical conductivity), pH and water temperature. The methodologies employed in this exercise are discussed in Section 4.0 of this Report.

Vegetation along the Binaturi River and its surrounding areas was also surveyed. The survey was especially done in relation to mangroves, sago palms, nipa palms and other salt tolerant vegetation types. This relationship of different vegetation types would give an indication of the nature of salinity or fresh water condition along the River system.

Other environmental issues related to the daily activities of the village communities were also taken into account. This would give an indication of any major environmental changes that are taking place in the vicinity of the study area.

Levett's (1994) hydrological and salinity investigation of the Binaturi River was carried out during the wet season. On the other hand, this survey was expected to be conducted during the dry season so that it would enable us to compare the present results with Levett's (1994) hydrological and salinity data. The study commenced on December 2000 just as the wet season had begun.

ACKNOWLEDGEMENT

The study was funded by JICA and survey of the environmental study was carried out as a part of Pilot Project for Ground-water Development for Water Supply System in Papua New Guinea in December 2000. The study team (Dr. Budai.Tapari, Mr. Robin Totome, Mr. Ralph Kimbu and Mr. Phille Daur) wishes to thank the following people who provided assistance in making field investigations along the Binaturi River possible. Their assistance is greatly acknowledged. They include:

Mr Ungu Ase - Boat owner/operator
Mr Elepe Kaia - Council Committee
Mr Padeam Asiri - Villager
Mr Kewong Tom – Villager
Mr James Ase – Social Planner (Fly River Provincial Government)
Mr Drimium Lega- Chairman, Binaturi Water Issue Committee
Mr Jublie Sido- Pump Operator (Ume 1 village)
Mr Sam Gebia- Executive Officer- Fly River Provincial Government

The villagers of Old Mawata, Kunini, Masingara, Boze, Ume No.1 and Ume No.2 are also acknowledged for their concerned assistance in allowing us access to their shallow wells to test for salinity conditions. The efforts of Mr. Vagoli Bouauka and Mr. John Diala of the Geography Strand (UPNG) is also much appreciated for the cartographic work presented in this report.

1.0 BACKGROUND

The Papua New Guinea Water Board agreed with the Japanese International Cooperation Agency (JICA) to conduct a development study titled "The Study on Groundwater Development for Water Supply Systems in Papua New Guinea" under the Technical Cooperation of the Government of Japan on May 4th 2000 in Port Moresby. As part of the second phase of "the Study on Groundwater Development for Water Supply Systems in Papua New Guinea" a study team consisting of experts in various fields related to the study, was dispatched to the Binaturi River basin on the 9th December 2000. Based on the original Scope of Work with relevant amendments, the Environmental study in the Binaturi catchment in the Western Province of PNG was approved and field investigations were carried out between 10th and 14th, December 2000.

2.0 OBJECTIVE

The objective of the study was to survey and analyse the impact of salinity on the Binaturi River basin where the intake of water for Daru Island is located (Figure 1). Other JICA project sites include Bereina, Kwikila, Mutzing and Daru Township. The study received the full co-operation and support from local inhabitants who had been expressing their concern with the Fly River Provincial Government (FRPG) over the increasing salinity levels in the Binaturi River system. The study and the Report presented here therefore constitute the following items;

a) Hydrological Survey
b) Salinity survey including water quality analysis
c) Vegetation Survey
d) Other environmental issues related to the activities of the village communities residing within the vicinity of the study area.

3.0 THE HYDROLOGICAL ASPECTS OF THE BINATURI RIVER

The Binaturi River drains a catchment area of approximately between 170 and 180 square kilometres some 20 kilometres West and Northwest of Daru Island (Figure 3). According to the Climatic Classification for Papua New Guinea devised by McAlpine, et al. (1983), the Binaturi area can be classified as having a Lowland Sub-humid climatic regime. Annually the area experiences a prolonged tropical rainy season with a mean annual rainfall of 1800mm. This is followed by a short but pronounced dry season occurring between June and October.

Although soil moisture falls during the dry season, with an annual water surplus of between 500 and 1000 mm, the area experiences little or no water deficit. In addition, the water depletion period is not as regular or as prolonged as for areas such as Port Moresby that experiences a Lowland dry sub-humid climate. The vegetation of the area is either dry evergreen or savannah grassland with sultry days and warm nights.

Figure 1: Locality map

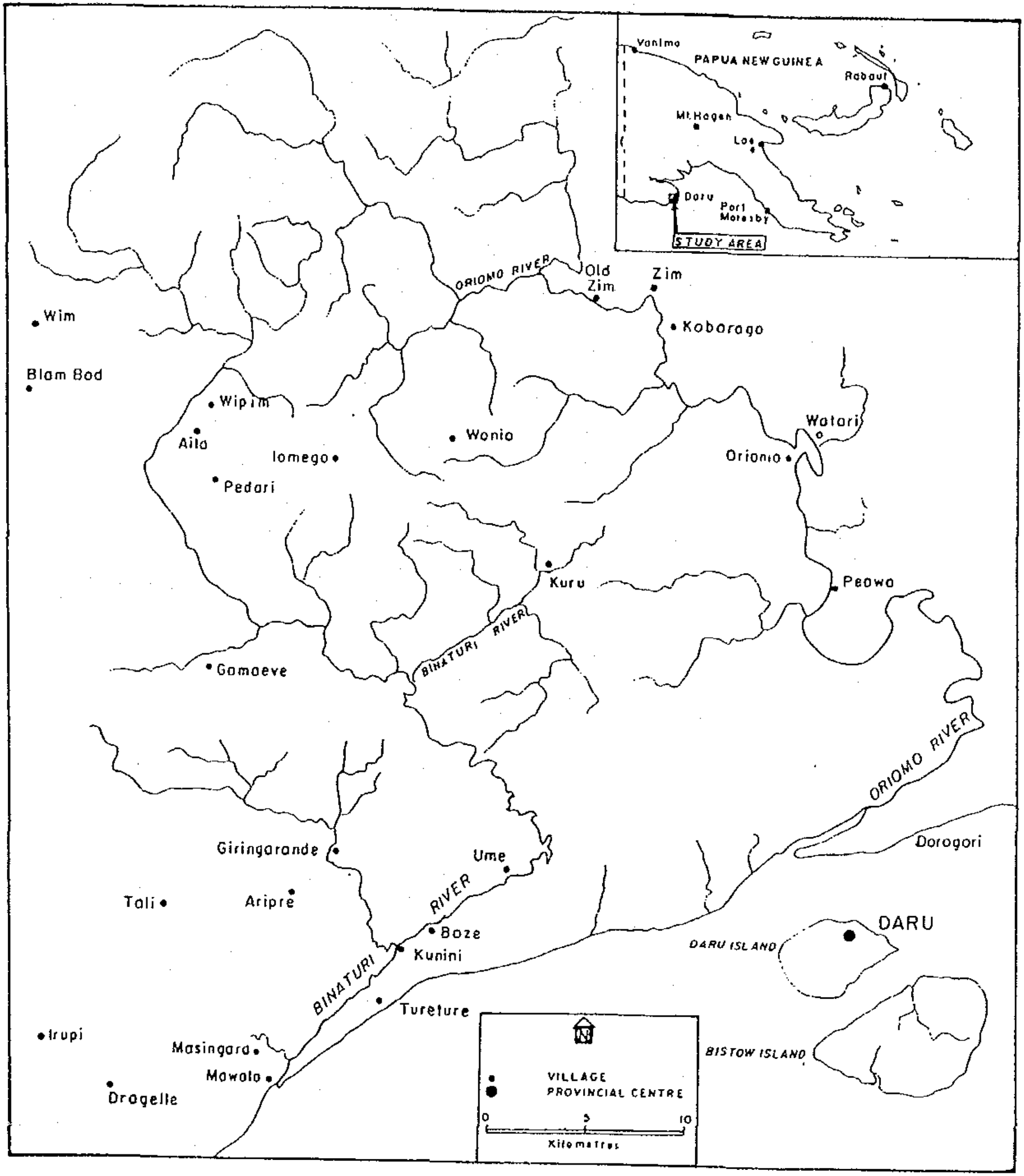


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Figure 2: Location of villages along the Binaturi River.

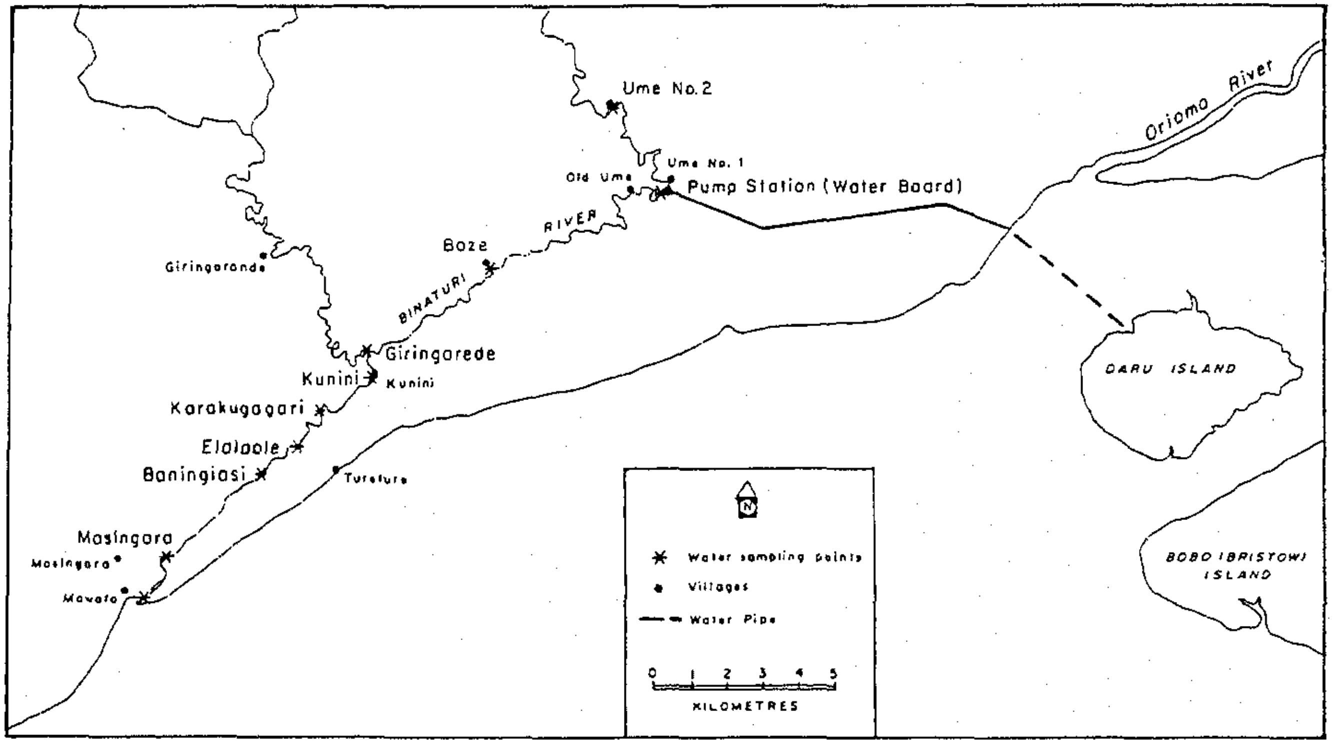

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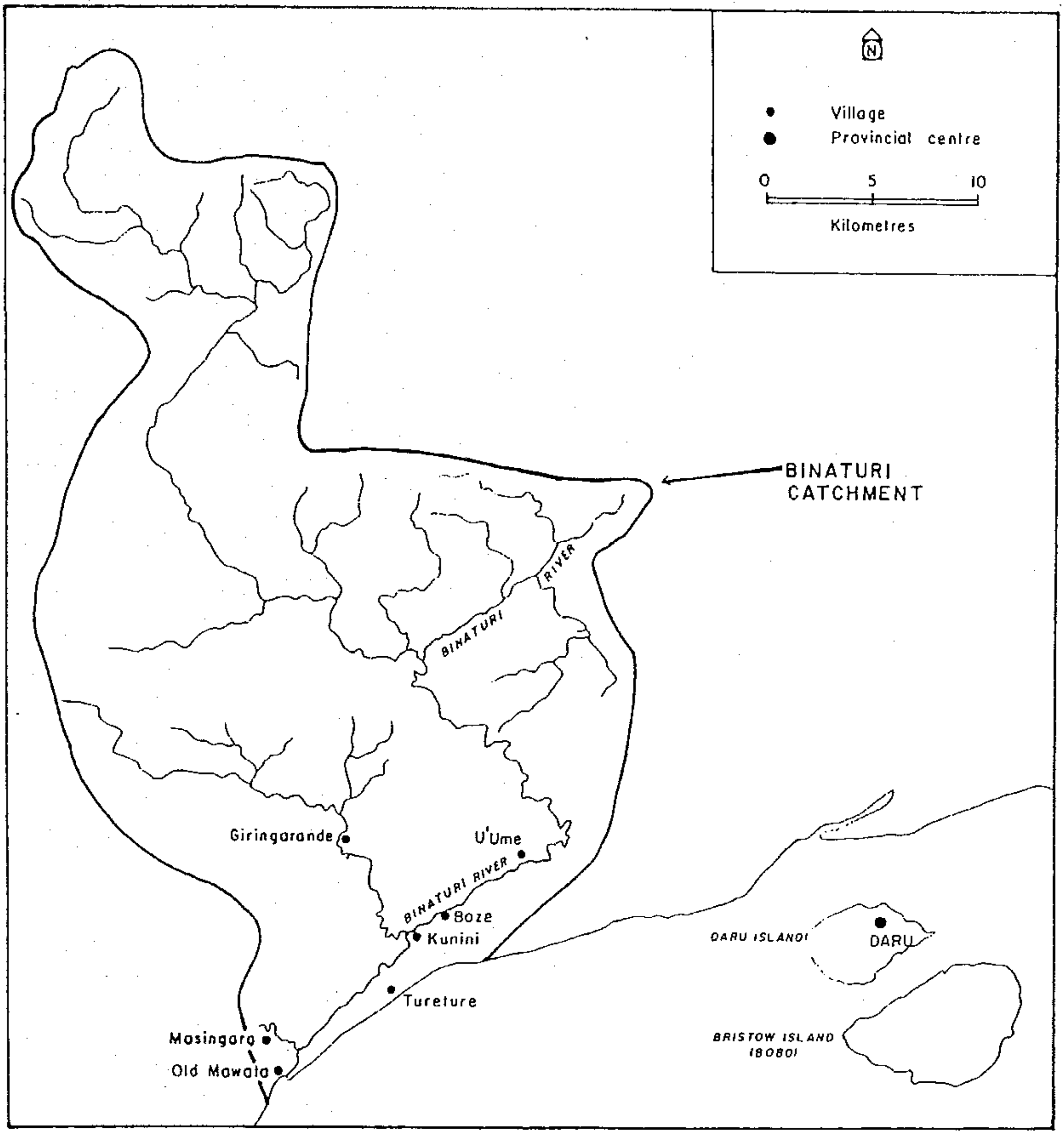
Figure 3: Binaturi River Catchment area.



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When we consider the changing conditions of a river system in terms of the composition of its transport load, we have to consider the efficiency of that river system to perform hydrological work. In this case, the most important factors to consider are its rainfall and runoff regimes. Rainfall and runoff are usually described as hydrological phenomena. They can also be viewed as the end products of the climatological processes involving precipitation, evaporation and water balance of a region

Runoff represents the excess of precipitation over evapotranspiration losses when allowance has been made for infiltration and surface detention. It is runoff or stream flow that is responsible for the evacuation of excess water and sediment load (bed, suspended and solute) out into the sea. There are four major components of catchment runoff. These are channel precipitation, overland flow, inter-flow and groundwater flow (also called base-flow).

There are a number of important factors that influence runoff, but for the purposes of this study the most important of them include; rainfall intensity and duration, antecedent rainfall and soil moisture conditions, channel slope and elevation, soil type, land use and vegetation cover, channel storage capacity and size and a shape of river cross-section.

As already pointed out in the discussion above the rainfall regime of the Binaturi area, (with a surplus of between 500 and 1000mm), is high in relation to evaporation and soil moisture storage. This situation permits that the soils are normally super-saturated and the water table is usually at or near the surface. Field observations in the study area indicate that rainfall in the catchment is typically intense and prolonged and given the antecedent soil moisture conditions and the low water retention capacity of the catchment, most rainfall is converted to runoff.

For the river to effectively evacuate the excess water and the sediment and debris the water must be flowing at a considerable velocity. One of the major determinants of stream velocity is the channel gradient. For the Binaturi River, the change in elevation from the mouth (Old Mawata) to the Pump Station at Ume No.1 is only 3 meters over a distance of 20 kilometres. That gives a channel gradient of 3:20,000 or 1:6666.67, which is extremely low for effective flow and hence sediment transport. Also due to this reason the river is incapable of flushing out sediments and other debris provided through human activity.

Added to the above, the notion of 'green house effect' is very real and the sea level has been changing considerably. The evidence for this change has been observed in the coastal village of Tureture, which has moved inland by about 500 meters from its original location. Given the above channel gradient and a rise in sea level, the river is already flowing at almost sea level during normal flow. During high tides, the Binaturi River flows below sea level. During high tide and ebb-flow the water backs up into the headwaters of mainstream Binaturi (> 25 kilometres) and well into the main tributaries.

Siltation along the lower reaches of the Binaturi River is common and this contributes to the development of sand banks that are submerged during the high tides as well as during the wet season. Relocation of these sand banks does take place during the year and this results from natural erosion processes along the Binaturi River system. A lot of river debris is also continuously transported up the river during the high tide and is transported back during the low tide. Due to a low gradient of the Binaturi River system, it is naturally apparent that much of this debris is not completely flushed out into the open sea, a phenomena commonly associated with relatively low rates of water movement.

Levett (1994) reports that the major contribution to the process of soil erosion and siltation in the Binaturi River is caused by human activity for gardening activities and access to the river. These activities also "contribute to the amount of floating logs and other debris in the river" (Levett, 1994:25).

3.1 Siltation and river debris

These problems are further compounded by the fact that the silt-based alluvial soils of the river basin are some of the most easily erodable soils. Apart from the physical processes associated with heavy rainfall and runoff, there are several human factors that contribute to the erodability of the soils. These include:

a) The local people of the river tend to make almost all their food gardens right on the banks of the river. There are two understandable reasons for this, the first is that the soils on the banks are the most fertile and secondly for purposes of easy accessibility whereby the principal means of movement of people and garden produce is either by out-boat motored dinghies or dugout canoes.

b) The area is too low-lying and waterlogged for the construction of a genuine road system. Therefore, apart from walking, the only means of transport anywhere along the river is by a dugout canoe or a motorized dinghy. Most of the out-board motors in use along the river are high powered (40-60 horse power engines) which cruise at high speeds. This movement creates large waves, which allow soil erosion along the riverbanks to take place.

c) Any vegetation that overhangs or grows too close to the river is considered as an obstruction to the river traffic and is normally removed or cut back. The net effect of all these factors is an increase in riverbank erosion and hence an increase in siltation in the river.

d) Another effect on the environment and which is linked to point (c) above is that some fish use vegetation that overhang as their habitat. However, when this vegetation is cleared by the local people to allow for easy navigation it disturbs fish populations. Consequently they have to migrate to a suitable spot where there is shade along the river edge. There is little wonder that local people at Boze village had complained of not catching many prawns and other types of fresh water fish from the river, a situation which appears to be quite different from their past experience.

4.0 Hydrology and Water Quality of the Binaturi River

4.1 Hydrological Methods

This survey was undertaken with the aim of providing the complimentary dry season information that would be used to compare against data from the wet season preliminary Unisearch survey carried out in 1994. For purposes of comparability the hydrological measurements for this survey were also carried out as close as possible to the sites described in the 1994 investigation. Two profiles of the river cross section were taken during low tide, one at 30 metres upstream of the intake pipes and the second 50 metres downstream from the pumping station. These two profiles are shown in Figure 4.

4.2 Discharge measurements

4.2.1 Equipment

The type of current meter used for this survey was a San - Ei Digital System (model 2). A linear relationship exists between velocity and the number of propeller revolutions per unit time. This relationship for the current meter employed is given **below**:

A beeper sound indicated the end of a fixed number of revolutions (adjustable) of the propeller. A setting of 5 on the meter represented 5 revolutions and 10 to represent 10 revolutions etc. The settings on the meter were adjusted (5, 10, 20 etc) to match the river flow at respective cross sectional segments. The faster the river flow the higher the setting. The measurements were standardized by timing 20 beeper counts at each setting on the meter.

$$V = 0.161N + 0.012$$

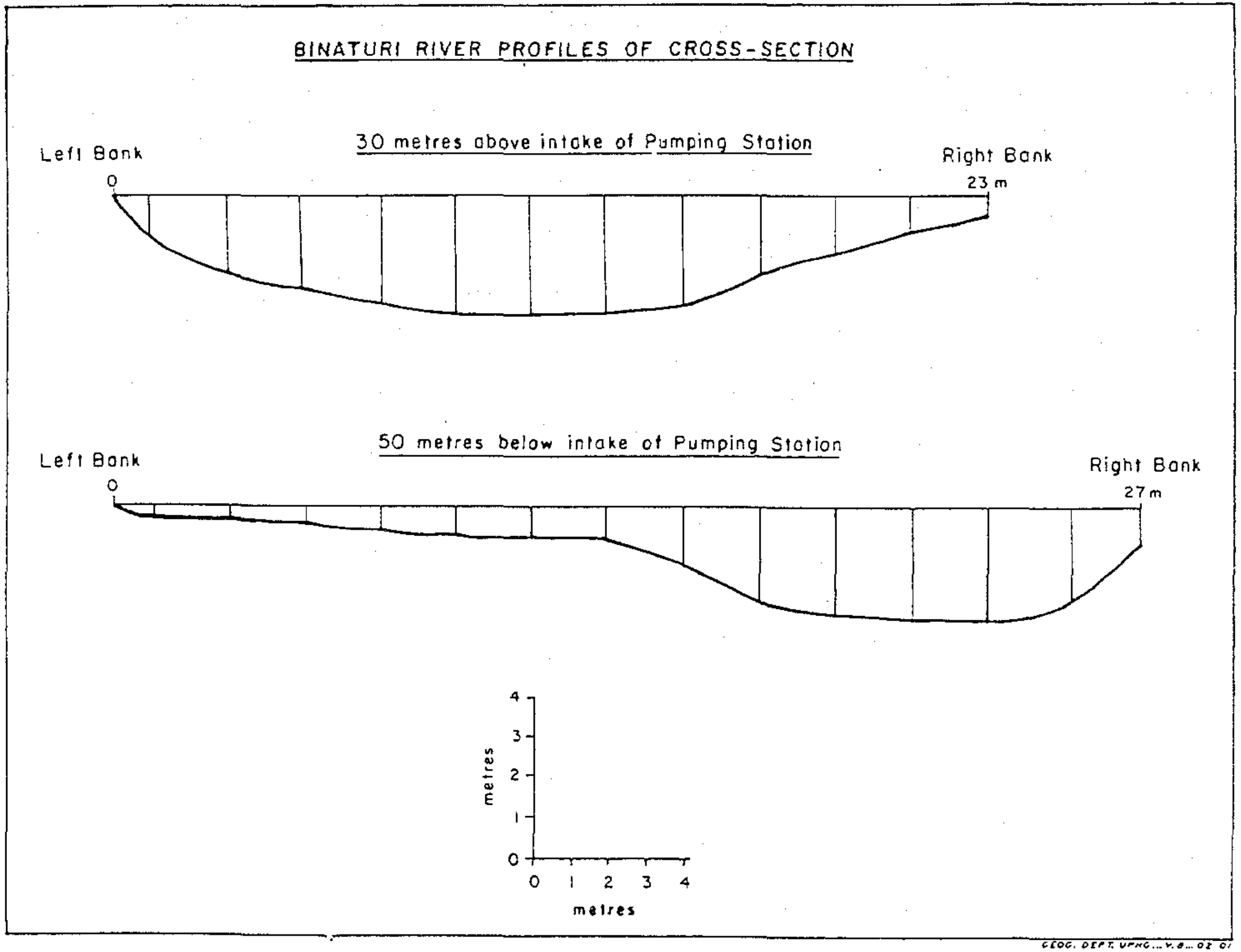
Where:

V = velocity in metres per second
N = number of propeller revolutions per unit time

4.2.2 Current measurements

Currents were measured at a depth that was 60% of stream depth at each 2-metre interval along the profile line that was drawn across the river (Table 1). A relatively straight stretch on the river was chosen for profiling. Reason being that under such uniform channel morphometry velocity decreases as a function of the logarithm of depth (Allan, 1995). The mean column velocity for the stream occurs at 0.6 of the stream depth from the surface (Allan, 1995). The velocity for any particular point along the stream transect line can then be obtained with a current meter at 0.6 of the respective depths. The mean velocity (V_m) for the river cross section was obtained by summing the segment velocities (V) and dividing this value by the number of segments measured.

Figure 4: Channel cross-sectional profiles.



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4.2.3 Discharge (Q) and Recharge (R) calculation.

The overall mean velocity (V_m) for the profile was used to calculate the discharge (Q) at each of the two sites in the vicinity of the pumping station. Recharge calculation follows the same formula but Q is replaced with **R**. The data for recharge was derived from measurements carried out during the return tide when there was noticeable upstream river flow.

$$Q = W \times D_m \times V_m$$

Where:

W = Width of river at the site profiled
D_m = mean cross-sectional depth.

4.3 Water Quality

4.3.1 Sampling methods

4.3.1.1 Water chemistry

Samples for water chemistry determinations were obtained from five sites along the Binaturi River at high tide, Mawata (mouth of river), Kunini (10 kilometres upstream), Boze (15 kilometres upstream), 50 metres below the pump and Ume No.2 (500 metres above the pump). Sampling at Mawata and Kunini were repeated at low tide. At each of these sites duplicate water samples were collected from 5 different depths: 25cm, 50cm, 100cm, 200cm and 300cm. One of the duplicate samples was acidified with nitric acid on arrival at the base camp.

A total of 70 water column samples were collected from the five sites. One surface sample each was collected from a tributary stream and the main river about 5km upstream of the pumping station. These sites were considered to be well above the tidal influence. Samples were also collected for analyses from shallow wells at Old Mawata, Masingara, Kunini and Boze. In addition, one tap water sample from Daru and another sample from a spring above Ume No. 2 were collected for analyses.

These water samples were brought back to Port Moresby and presented to the Analytical Laboratory of National Agricultural Research Institute (NARI) for the chemical analyses.

4.3.1.2 Conductivity, Temperature and pH

Conductivity is a measure of electrical conductance of water. The value of which reflects the amount of dissolved salts in the water. Conductivity measurements were made at 10 sites spaced between the river mouth and Ume No. 2 during the afternoon high tide and also at low tide the next morning. Portable meters were used for this exercise. Conductivity (mS/m), temperature in °C and pH were measured by collecting a bucket of surface water over the side of the boat and immediately dipping the electrodes into the water after the water was collected. This procedure was repeated for all the sites listed in Table 6. Readings were taken directly from the surface of the water at each site. The local name and the GPS position for each site were also noted. The GPS position was later used to determine the relative distance of each site from the mouth of the river.

5.0 RESULTS

Tables 1 - 5 show the hydrologic data for the cross sections. Data presented in Tables T.1 and T.2 were measured near the pumping station at low tide, 12th December. The data given in the "Projection" Table represent predicted flow conditions during the dry season based on data from table T.2. Data presented in Tables 3a and 3b were taken at Boze, and those presented in Tables 4 and 5 were measured at Kunini and Mawata (River Mouth) respectively.

Tables 1 and 2

T.1			T.2			PROJECTION		
30 m above intake			50 m below intake			50 m below intake		
Width: 23 m			Width: 27 m			Width 12 m		
			Wet season			Dry season		
Depth	Velo	Width	Depth	Velo	Width	Depth	Velo 1	Velo 2
1.1	0.817	1	1.0	1.801	1	-	-	-
2.0	1.018	3	2.5	2.695	3	1.5	2.695	1.276
2.5	1.018	5	3.0	2.025	5	2.0	2.025	0.959
2.8	1.354	7	2.9	2.312	7	1.9	2.312	1.095
3.0	1.476	9	2.8	2.312	9	1.8	2.312	1.095
3.0	1.476	11	2.5	2.025	11	1.5	2.025	0.959
3.0	1.801	13	1.5	1.354	13	0.5	1.354	0.641
2.8	1.801	15	0.8	1.085	15	-	-	-
2.0	1.801	17	0.7	1.085	17	-	-	-
1.5	1.801	19	0.7	1.476	19	-	-	-
1.0	1.250	21	0.6	1.476	21	-	-	-
0.6	0.472	23	0.5	1.622	23	-	-	-
2.11	1.340		0.3	1.476	25	-	-	-
			0.3	0.744	27	-	-	-
			1.436	1.678		1.53	2.121	1.004
**Q = 65.03			**Q = 65.06			**Q =	38.94	18.433
						Velocity	Same	Adjusted

The daily extraction of water from the Binaturi River for the Daru Town water supply was estimated to be in the vicinity of **800 - 1600 m^3 per 16 hour day** at a rate of **0.014 - 0.028** m^3 / sec (National Water Board staff, Daru, 2000, pers comm.).

This survey estimated the extraction rate, as a percentage of river discharge, to be **0.02** to **0.04** percent of **Q** = **65.06m^3/sec.** When adjustments are made for the projected dry season flow conditions, two possible scenarios are expected.

If one meter is removed from the present stage height without adjusting the velocity relative to reduced cross sectional area, the discharge **(Q)** will be **39.017 m^3/sec** and the percentage river extraction will be around **0.035 - 0.07%.**

On the other hand, *if we adjust the velocity relative to the proportion by which the cross sectional area is dropped*, discharge **(Q)** will be **18.433** and the extraction percentage will be **0.08 – 0.16%** of the river discharge at the pumping station.

Tables 3a and 3b showing cross sectional profile data collected at Boze on the 12th December, 2000.

Table 3a

Site: **Boze**
Tide: Low Time: 8.45 am

L/Bank	Depth	Velocity
m	M	m/sec
4	1.0	1.250
6	1.0	2.695
8	2.1	2.025
10	2.7	1.354
12	1.6	2.695
14	3.4	2.695
16	3.4	2.025
18	3.0	1.801
20	1.9	0.567
	2.233	**1.982**

Q = 88.52 m^3/sec

Table 3b

Site: **Boze**
Tide: **High**, Time 4.35 pm

R/Bank	Depth	Velocity
m	m	m/sec
2	1.5	1.250
4	2.0	1.801
6	2.5	1.801
8	3.3	1.476
10	4.3	0.959
12	3.0	1.162
14	4.5	1.162
16	3.5	0.859
18	2.5	0.294
	3.011	**1.196**

Q = 64.82 m^3/sec

Tables 4 and 5 show the cross sectional profile data for Kunini and Mawata (River mouth) measured on the 13th December, 2000.

Table 4

Site: Kunini
Tide: In coming (1.5 hr), high
Date 13/12/00

R/Bank	Depth	Velocity
m	M	m/sec
2	2.0	0.859
4	2.7	1.162
6	4.5	1.354
8	5.5	1.476
10	7.0	1.354
12	7.0	1.476
14	6.5	1.354
16	5.5	1.354
18	5.0	1.162
20	4.0	1.162
22	2.5	0.859
24	1.5	0.549
Mean	4.475	1.177

Q = 126.41 m^3/sec

Table 5

Site: River mouth
Tide: Incoming(1.5hr), high
Date: 13/12/00

R/Bank	Depth	Velocity
m	m	m/sec
2	1.1	0.587
7	1.1	2.025
10	1.9	1.354
14	3.0	1.622
17	4.0	1.622
22	4.5	1.476
27	4.5	1.476
32	4.5	2.025
37	4.6	1.801
42	4.5	1.801
47	4.5	1.801
52	4.5	1.801
57	4.5	1.801
62	4.5	2.025
67	4.5	2.025
72	4.5	2.025
77	4.5	1.622
82	3.4	1.250
83	3.0	1.162
Mean	3.768	1.647

Q = 515.09 m^3/sec

Table 6. The Electrical Conductance (EC), pH and temperature of surface waters between Mawata and the Ume pumping station at high tide and low tide on the 12th December, 2000.

Site name	GPS	Time	Tide	EC (mS/m)	Temp. °C	pH
River mouth	09 08 24 S / 142 57 21 E	3.30 pm	High	4140.0	28.0	8.02
River mouth		9.05 am	Low	4070.0	28.0	7.96
Masingara	09 07 46 S / 142 57 44 E	4.00 pm	High	3880.0	28.7	7.84
Masingara		9.00 am	Low	161.2	27.5	7.19
Baningiasi	09 06 32 S / 142 59 06 E	4.15 pm	High	2460.0	28.0	7.47
Baningiasi		8.54 am	Low	54.8	27.0	7.23
Elelaole	09 06 03 S / 142 59 38 E	4.20 pm	High	1430.0	27.7	7.36
Karakugagari	09 05 53 S / 142 59 53 E	4.30 pm	High	902.0	27.6	7.31
Karakugagari		8.50 am	Low	36.4	27.0	7.22
Kunini	09 05 16 S / 143 00 34 E	4.42 pm	High	60.2	27.4	7.35
Kunini		8.44 am	Low	35.0	26.7	7.27
Giringarande	09 04 54 S / 143 00 36 E	4.51 pm	High	41.5	27.4	7.30
Giringarande		8.40 am	Low	31.3	27.0	7.3
Boze	09 03 41 S / 143 02 18 E	5.24 pm	High	35.6	27.6	7.04
Boze		8.00 am	Low	30.0	26.8	7.16
Pump station	09 02 29 S / 143 04 46 E	5.40 pm	High	29.8	27.5	7.14
Ume No 2	09 01 16 S / 143 04 09 E	5.50 pm	High	30.3	27.6	7.14

5.1 Water Chemistry

5.1.1 Sodium

The levels at the mouth (mean = 9,364mg L^{-1}) are consistent with the 1994 survey (9,950 mgL^{-1}) although only slightly lower by about 6%. This is probably related to a higher river discharge. Ten kilometres upriver, at Kunini, the sodium level dropped significantly to 13.17 mgL^{-1}, 0.14% of the value recorded at the mouth of the river. At Boze the sodium level was 0.08% and about 0.09% at the pumping station and Ume No. 2. The two upper most sites showed lower readings from those measured in 1994 (20 mgL^{-1}).

5.1.2 Chloride

The situation was very similar with chloride levels between the mouth and the other sites. The chloride level at Mawata (river mouth), was 13960mgL^{-1} while at Kunini it was 41.6mgL^{-1} or about 0.3% of the level at the (Mawata). This dropped further to about 1.0% of the river mouth level at low tide. Boze recorded 7.5mgL^{-1} or approximately 0.005% and Ume No 2 approximately 0.006% of the river mouth level respectively.

5.1.3 Calcium, Potassium, Magnesium and Fluoride

These ions also showed very similar distributions patterns as displayed by sodium and chloride. A distinct drop was observed in the levels of these constituents at Kunini both at high and low tides. Above Kunini the levels remained consistently low.

5.1.4 Vertical profiles

Apart from pronounced differences between the sites in the ionic levels (Tables 7 - 12), the vertical water column distribution showed little variation. For the three major ions (Chloride, Sodium and Calcium), selected here to represent salinity, only chloride (Table7) showed some difference in its vertical distribution. At the mouth of the river chloride levels increased with depth but the situation was reversed at Kunini and for the other sites above Kunini. Upriver, the ionic concentrations, although extremely reduced compared to its level at the mouth, generally decreased with depth.

Tables 7 - 12 show the concentrations (mgL^{-1}) of Chloride, Sodium, Calcium, Potassium, Magnesium and Fluoride for different depths at various sites along the Binaturi River. S1A (river mouth, high tide), S1B (river mouth, low tide), S2A (Kunini, high tide), S2B (Kunini, low tide), S3 (Boze, high tide), S4 (pumping station, high tide) and S5 (Ume 2, high tide).

Table 7. Chloride

Depth (cm)	S1A	S1B	S2A	S2B	S3	S4	S5
25	13500	12500	58	18	10.0	7.50	10
50	13900	13000	40	17	7.9	6.75	9.2
100	13900	12000	37	15	7.1	6.75	8.3
200	14000	12000	3	13	6.4	6.40	7.5
300	14500	12500	35	11	6.1	6.40	7.1

Table 8. Sodium

Depth (cm)	S1A	S1B	S2A	S2B	S3	S4	S5
25	9540	9040	11.9	10.80	6.86	8.88	8.64
50	9460	9060	14.0	10.60	7.12	8.85	8.47
100	9340	9100	10.5	10.70	7.29	8.81	8.60
200	9260	9020	20.7	10.10	7.27	8.87	8.23
300	9220	9000	8.75	9.76	8.03	8.61	8.05

Table 9. Calcium

Depth (cm)	S1A	S1B	S2A	S2B	S3	S4	S5
25	405	485	13.4	15.1	9.28	13.1	11.2
50	499	509	15.3	15.2	9.55	13.2	11.1
100	529	543	15.8	16.2	9.74	13.3	11.2
200	552	755	16.3	15.2	9.82	13.5	11.3
300	510	1070	16.9	15.0	9.98	13.3	11.2

Table 10. Potassium

Depth (cm)	S1A	S1B	S2A	S2B	S3	S4	S5
25	494	580	3.15	1.27	0.87	1.17	1.14
50	656	610	2.84	1.28	1.16	1.07	0.78
100	599	626	2.45	1.44	1.05	1.03	1.09
200	626	766	2.52	1.26	1.16	1.09	0.99
300	638	934	2.57	1.30	0.95	0.80	0.84

Tabl 11. Magnesium

Depth (cm)	S1A	S1B	S2A	S2B	S3	S4	S5
25	1310	1600	8.71	7.69	4.57	6.09	5.19
50	1650	1620	9.90	7.83	4.66	6.07	5.22
100	1770	1830	10.10	8.78	4.81	6.11	5.19
200	1960	2600	10.50	8.24	4.70	6.26	5.38
300	1950	3710	11.20	8.23	4.58	6.20	5.21

Table 12. Fluoride

Depth (cm)	S1A	S1B	S2A	S2B	S3	S4	S5
25	1.33	1.40	0.22	0.22	0.15	0.14	0.16
50	1.23	1.40	0.24	0.21	0.13	0.13	0.12
100	1.23	1.45	0.27	0.21	0.13	0.14	0.14
200	1.23	1.45	0.23	0.19	0.12	0.13	0.09
300	1.26	1.40	0.23	0.18	0.13	0.15	0.09

6. 0 DISCUSSION

6.1 Hydrology

The main concern expressed by the residents along the Binaturi River system is that salt water is now moving further upstream, beyond traditionally known saltwater boundaries. The collection of hydrological data was considered an important component as it would help in determining the extent of this saline intrusion. The data would also serve to estimate how much of this intrusion is influenced by the current rates of water extraction for Daru Township. A concern generally experienced during the dry season flow conditions is that this extraction of water is the principle cause of the increased salination.

The 1994 survey showed a daily water extraction rate of 1,300 m^3/15hrs (0.024 m^3/sec). At the level of river discharge for that survey (17.99 m^3/sec), 30 metres downstream of the pump, the percentage extraction was 0.24 % (0.3%). The calculated discharge for the same site during this survey was 65.06 m^3/sec, which is about 3.6 times the 1994 discharge. Verbal communications with the National Water Board staff during this survey revealed a different figure for the amount of water extracted per operating day. Current extraction volume lies between 800 and 1600 m^3 per 16-hour day. This equates to an extraction rate of about 0.014 - 0.028m^3/sec or 0.02 - 0.04% of discharge. The level of water extraction from Binaturi River was eight times lower than that reported in 1994 (Levett) but the difference is due to a much higher discharge during this survey.

Working on information given by staff at the pumping station it was possible to manipulate the profile data for the intake site and project an estimate for dry season discharge at the pumping station. Subtracting one metre from the depth readings for the 30 metre downstream profile (Projection Tables 1 and 2) we came up with two possible discharge situations: In the first situation, when velocity was not adjusted for the drop in channel depth the predicted dry season discharge was 38.94 m^3/sec. On the other hand, when velocity adjustments proportional to the reduction in depth was considered, the discharge was 18.433 m^3/sec. It should be mentioned here that the dry season reduction in river level may be greater than one meter, that was used for the for our projections in this report.

Given the two discharge scenarios, one might ask what would be the impact if the *extraction of water continued at the current rate of 800 - 1600m^3/day? By percentage this* would represent 0.04 – 0.08% for the first condition when discharge (Q) = 38.94, and 0.08 – 0.16% in the second flow condition when Q = 18.43m^3/sec.

6.1.1 Net Outflow

Discharge and recharge measurements done at Boze showed a net outflow of 1,365,120 m^3/16hrs. The proportion 1,600 m^3/16 hrs translates to 0.117% which is about 4 times more than the calculated figure of 0.03% for the pumping station during the 1994 survey. Water extraction based on net outflow calculated for Boze is high because recharge relative to discharge is much closer therefore the net outflow would appear smaller. This then would show a higher proportion of water extracted. In the current survey the recharge flow rates were so reduced at the pumping station that measurement of the backflow was not possible. Only discharge was measured at that site. The net outflow at the pumping station therefore would be expected to be greater than the 27% that was calculated for Boze (Tables 3a and 3b).

6.2 Water Quality

6.2.1 Conductivity

Electrical Conductance (**EC**) was useful in that the data collected was immediately available for establishing the zone of active mixing between the incoming salt water with river water. Dissolved salt levels, as indicated by the EC values, were quite high (4140mS/m) at the mouth of the river and dropped to almost completely freshwater (60.2mS/m) at Kunini (Figure 2). There was no detectable saltiness, by taste; in the river water at Boze (EC: 35.6mS/m) and this was considered to be completely fresh water. The greatest change between the high tide EC and low tide EC was observed at the Masingara confluence (Figure 2). The difference between the high and low tide was 3,719mS/m, an enormous 96% drop in dissolved salts at low tide.

The zone of active mixing at high tide was located between Elelaole and Karakugagari. This was the site at which dilution factor, relative to the EC at the river mouth, seemed to be the highest. The loss of EC per unit upstream distance had a steep gradient. This reflected the high dilution factor imposed by the level of discharge. Almost complete loss of dissolved salts within was detectable 8 to 10km from the mouth of the Binaturi River. Karakugagari supplies the coastal village of Tureture with freshwater which was collected only at low tide. High tide water would have been quite saline as the EC was 902mS/m. During this survey there were no complaints of saltiness in the drinking water that was collected from Karakugagari. From the middle of the dry season and towards the end of the dry periods the water collection point is moved upstream towards Kunini (personal comm.) as the water becomes noticeably salty in taste during low tides. It is quite likely that relocation takes place at about the time when the EC level exceeds

60mS/m. Water having EC around 60mS/m will here be referred to as the saltwater front.

The river water at Kunini had a tinge of saltiness during high tide and water collection for drinking purposes was postponed until low tide. Low tide EC at Kunini was 35mS/m. The situation at Boze was different where people continued to collect water even during high tide. The EC at Boze remained close to 30mS/m for both high and low tides. Although there was a notable rise in the river water indicating high tides there was no significant change in the saltiness of the water. A distinct upstream flow of water was seen and measured at Boze. The lack of significant increase in the EC and saltiness of the water gave the impression that the river level rise was mostly an effect due to the backing up of fresh water discharge as it confronted the incoming high tide counter current. This effect seemed to diminish progressively upstream. The recharge current was too little to make meaningful measurements by the time it reached the pumping station where only discharge could be determined. Although the high tide EC was not measured at the water intake point it is assumed that there would not be much change as the high tide/low tide EC difference at Boze was not significant.

The flow conditions observed during this survey were high enough to hold back the high tide saltwater front at some point below Kunini but above the Karakugagari water sample collection point. The situation changes during low flow conditions in the drier months of the year. The saltwater front then migrates further upstream past Kunini and moves towards Boze, and possibly going beyond this point. Boze villagers indicated that they do not collect drinking water from the river at high tide during the dry season because the water tastes salty.

Figures 5 and 6: Both the line and the bar graphs show the distribution of surface water electrical conductance measured during high and low tides on the 12th of December 2000. The graphs highlight the rate of change in electrical conductance with upstream distance as well as the daily fluctuations in EC between high and low tides at a given location.

Figure 5

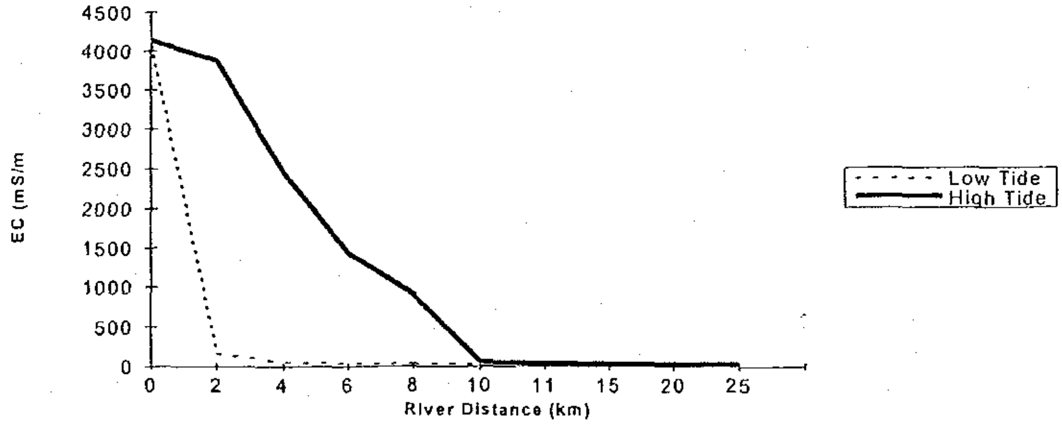
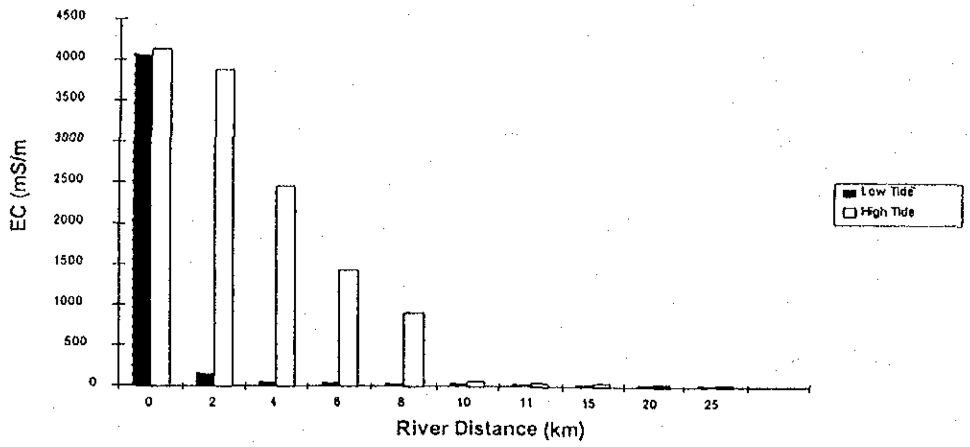


Figure.6



6.2.2 *Water Chemistry*

6.2.2.1 River water

The water chemistry data tied in very closely with surface water EC data. With the conditions of flow experienced during this survey the evidence presented by sodium and chloride concentrations suggested that the salinity front for that period was well below Kunini. In fact the EC data showed that the front, during low tide, was situated at a point below Karakugagari, which is about 7 kilometres from the mouth. High tide was then responsible for shifting the front past Karakugagari and the edge just reaching Kunini. One event witnessed during this survey was of the river water spilling over the banks and flowing freely through the drainage channels constructed in Kunini village. It was a case of the combined effects of extreme high tide and the high river stage height that resulted in the spill over. Discussions with the villagers revealed that it was quite a normal occurrence during that part of the year.

6.2.2.2 Well water

Channel overflow and its location relative to the coastline may explain the high sodium (1,107 mg/L) and chloride (1,895 mg/L) levels found in the well waters at Kunini. The EC was well above the level set (personal) for the saltwater front of around 100 mS/m. The well water did have a distinct saltiness to it when tasted. One would expect the wells to be less salty at that time of the year, seasonal rains, than was measured at Kunini. The salt content of the surrounding soils must be naturally high to produce the high ground water salt levels found in the wells. Sea spray and riverbank overflows during extreme high tides are probably the main sources of salt inputs to the soils at Kunini. Evaporative salt crystallisation may concentrate the salts in the surface soils, which may then be remobilised and incorporated into the ground water during the wet season. Construction of wells as alternative water source is not appropriate for Kunini as well as Tureture in view of the ground water salt levels.

6.2.3 Salinity Problem

The claims of increased salinity at and above Boze was not possible to verify due to the effect of the prevailing discharge conditions. There was no significant difference in the EC readings between the high tide and low tide measurements at those sites. However, it can be possible that during extensive dry periods, when discharge is much reduced, the 100ms/m saltwater front may move further upstream assisted by above normal high tides. It was pointed out to the villagers in Boze that the salinity front should be expected to move further upstream naturally in response to global warming and sea level rise. This explanation was generally agreed to by the villagers as events occurring along the coastline bear witness to this phenomena.

There was an apparent increase in water consumption between 1994 and the current study of December 2000, a rise from 1,300m^3/16hrs to 1,600m^3/16hrs. This showed an increase in consumption by about 23% from the 1994 figure. Although this figure was significant in terms of change in daily consumption between the two periods, this did not translate to a significant change in the percentage of water extracted from the river during this survey.

The question at that point was, could this increase in the extraction level have any influence on the position of the salinity front during the dry periods? The projected dry season discharge ($Q = 18.43$ m^3/sec) estimated for the pump site and the related 0.16% extraction rate for that flow condition should have very little direct influence on the migration of saline waters upstream, if the stream is a gaining stream. Whatever volume of water that is taken up by the pumps should be sufficiently replaced by lateral ground water inputs by the time it reached Boze. Gaining streams usually drain catchments with higher water tables relative to the river level during drier months of the year. The water table was quite high at Boze. This was evident in the water level at the village wells. They were about a meter above the low tide river level. Also, the gain in discharge at Boze over a distance of about 5 kilometres from the water intake point was 36%. A large proportion of this gain would have been from surface lateral inputs. A word of caution is due at this point against making a premature assumption that ground water will replace that which is removed by the pumps. The dry season flow conditions for Binaturi River is still hard to forecast because of the lack of dry weather hydrographic data.

The projected data is only a prediction based on adjustment made according to anecdotal evidence provided by a single person. The current velocities may differ greatly from that projected. Therefore, these projections should only be taken as a rough guide to a possible dry season flow condition for the Binaturi River at the pump site. Only actual dry season measurements can provide a more representative picture.

This survey was to have been the dry season component to the 1994 survey that tried to address the environmental issues still debated between Daru town authorities and the Binaturi River Issue Committee. Unfortunately the dry season was missed by about three weeks but we do have some projection of the possible flow conditions during the drier parts of the year. These projections should be taken on their face value only and that there is still a need to acquire data for the 'true' dry season flows. A quick hydrological survey at the pumping station and one at Boze during minimum flow conditions should sufficiently provide for that need.

7.0 VEGETATION OF THE BINATURI RIVER AND ITS SURROUNDING AREAS

7.1 The South Fly Area

The South Fly region of the Western Province generally has dry sub humid weather receiving less than 2000 mm of rainfall annually (McAlpine, 1982). Much of the rain falls during the northwest monsoons between November to March. The mostly flat to very slightly undulating terrain is associated with extensive low-lying areas of plains that are usually inundated during wet season. Very high seasonality causes severe and regular soil moisture storage depletion. Bleeker (1983) estimated that soil moisture storage in the South Fly zone is depleted to below 33% of capacity for more than 50% of every dry season.

7.2 Vegetation

The influence on vegetation due to seasonality of rainfall is most noticeable in this region. Inundation of low-lying areas for part of the year and dry for the rest of the year gives rise to a variety of vegetation complexes. The most prominent is the occurrence of large areas of savannah woodland and grasslands dominated by *Melaleuca* species. Areas of scrub vegetation also occur while forested areas are composed largely of dry evergreen forests (Hammermaster and Saunders, 1995). Vegetation along the Binaturi River and its surrounding areas display these general characteristics. Several, often over-lapping vegetation communities can be recognized.

7.3 Savannah woodland and grassland

This is the characteristic vegetation type occurring here and extends on both sides of the Binaturi River. *Melaleuca* is the dominant tree here and is often associated with *Acacia* and *Nauclea* species. Elephant grass, *Themeda australis* and kunai grass, *Imparata cylindrica* dominate the grasses of these savannah woodlands and grasslands.

7.4 Dry evergreen open forests on plains

Canopy forests are largely composed of dry lowland forests characteristically having a very open understory often with a thick layer of leaf litter on the forest floor. The forest east of the Giringarede River is one of the few relatively large areas of this forest type with a very mixed composition of tree species. *Intsia*, *Sysygium* and *Heritiera* trees attain large sizes here. The understory is fairly open with clumps of bamboos and the palm, *Livistona* sp. is often locally common.

The largest stand of the dry lowland forest occurs at the headwaters of the river, beginning around Egawal, approximately 2.5 kilometres upstream from Ume 2. Although not determined, it is possible that this forest extends over the whole catchment of the headwaters of the Binaturi River. The Upimbada spring water source occurs within this forested area. Composition of the forest here is slightly different from forest observed east of the Giringarede River. This forest appears to be relatively richer floristically. *Callophyllum* and *Sysygium* are common amongst other canopy trees. Noticeable also are the general absence of bamboos, *Heritiera* and the *Livistona* palm while Kavivi, *Areca novo-hibernica,* occurs as a common understory palm.

7.5 Mangroves

Mangroves extend from the river mouth to about 10 kilometres up river (Figure 7). Typical zonation is less prevalent. The largest band of mangroves occurs just behind the river mouth, extending along the short estuary and ending about 1 km below the Masingara confluence. Beyond this, it forms a narrow strip along the tidal banks of the river. Species associations vary slightly over the extent of the mangroves. Stands nearer to the river mouth are dominated by mature *Rhizophora/Bruguiera* trees reaching heights of about 20 to 25m or more. Of the three species of *Rhizophora* present, *R. apiculata* associates with *Brugueira gymnorhiza* and *B. paviflora* to form mature stands. Species of *R. stylosa* mostly occur as stunted trees around the mouth of the river. *Rhizophora mucronata* on the other hand prefers less saline conditions and occurs at the fore front of the mangrove fringe along the river banks. Two species of the cannon ball mangrove, *Xylocarpus granatum* and, a second species, occur throughout the stand but prefer the dryer banks of the river. Species of *Ceriops* line the banks of the estuary and discontinue some distance past the Masingara confluence. *Avicennia spp* occur less frequently and were observed around the river mouth. On sandy shores around the river mouth, *Thespesia populnea* and *Exocaria agallocha* are also common.

Camptostemon schultzii, the only Australasian representative of this genus, is predominant between the Masingara confluence and Karakugagari. Its distribution is restricted to regions of Northern Australia and Southern New Guinea, south of the Fly River and the Purari River Delta in the Gulf Province (Croft, 1981).

A gradual change in the composition of mangroves is evident as one follows the mangrove extension upstream. Occurrence of *Rhizophora* decreases around Elelaole

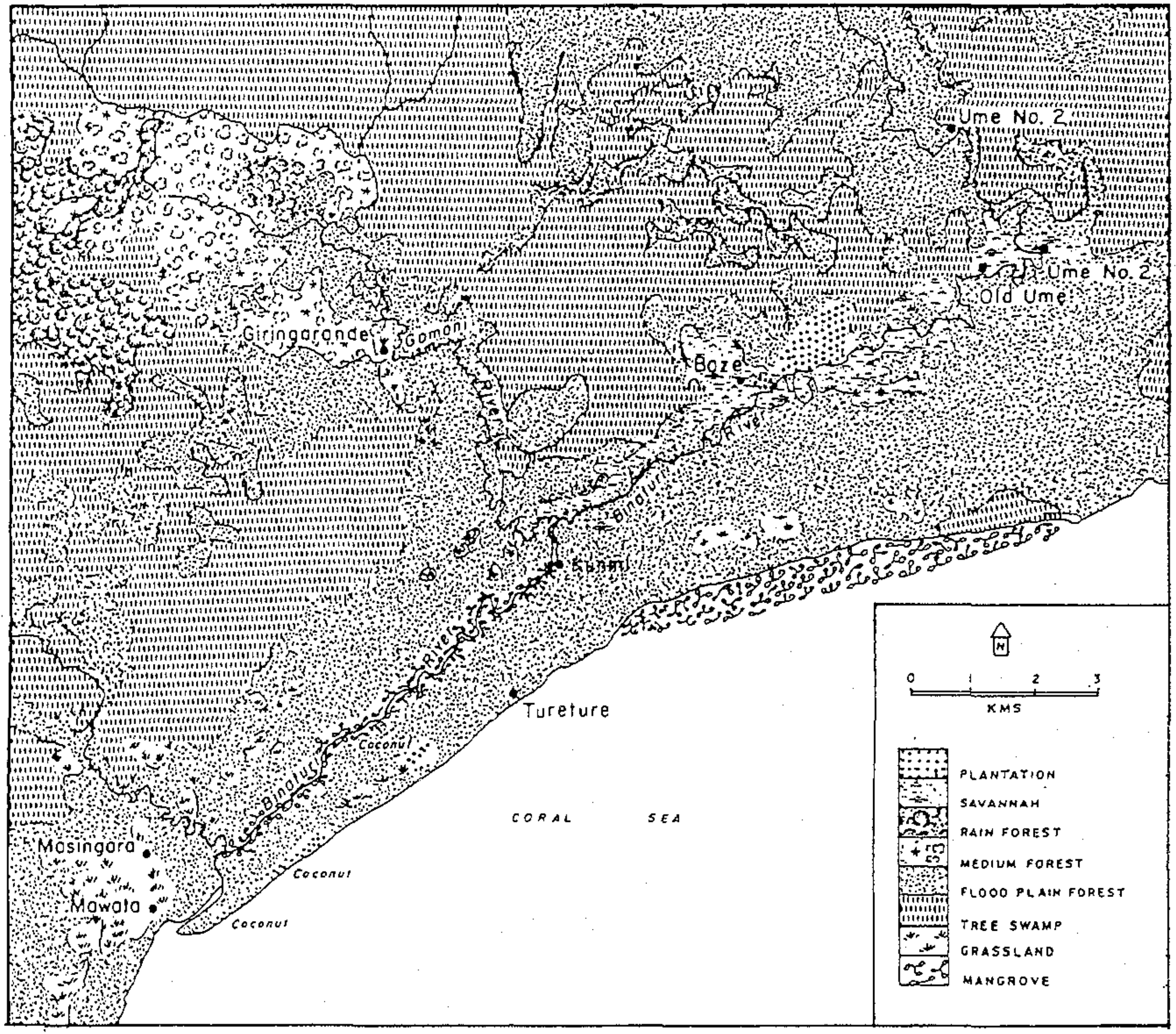


Figure 7: Vegetation map of the Binaturi River System

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where it is less muddy due to the raised riverbanks. This gives way to an increased occurrence of *Bruguiera* on higher ground co-occurring with *Camptostemon*, *Heritiera litoralis* and, to a lesser extent, *Xylocarpus* species. *Heritiera* is a transitional mangrove since it can occur in association with true mangroves and also grow equally well under lowland forest. *Dolichondrome spathacea*, which is rarely seen downstream, is very common here extending as far as the Giringarede confluence. *Barringtonia* species similarly becomes prevalent within this river section. There may be several species of *Barringtonia* occurring along the Binaturi extending well past Boze and Ume villages. Members of this genus are sometimes called freshwater mangrove due to their regular presence along waterways. *Barringtonia* maintains the widest range for any one species of plant along the Binaturi River becoming particularly abundant between Elelaole and the Giringarede confluence.

An increase in the abundance of vines and other climbers onto tree canopies was also noticed here, especially around Karakugagari. Such luxuriant vine growth was less evident beyond Kunini, and decreases in abundance further upstream. The nipa palm follows a similar trend. It is common from Elelaole going upstream but decreases in numbers beyond Kunini then eventually disappears before Boze village. *Sonneratia caseolaris* is the only mangrove species that extends as far up as Boze. Villages at Ume claim that *S. caseolaris* occurs there but no evidence of this was seen.

The true mangroves do not extend beyond Kunini village. The term "mangrove" is used loosely in Papua New Guinea. It collectively includes, true mangroves, which are habitually inter tidal, as well as, other closely associated, mostly terrestrial species. Decreasing incidence of true mangroves becomes obvious around Karakugagari a few kilometers downstream from Kunini, where Tureture villagers from the coast, fetch their fresh water from the Binaturi River. As their incidence decreases, true mangroves are gradually replaced by *Barringtonia*, *D. spathacea* and *H. tileasis*.

7.6 Vegetation along the Riverbanks

Vegetation beyond the mangrove fringe vary little, apart from some apparent differences in species composition when progressing upstream. Lower river banks between Kunini and the Giringarede confluence permits persistence of *Barringtonia*, *Dolichondrone*, *Hibiscus tiliaseus*, nipa palm and *S. caseolaris*. Roots of these trees are continually submerged due to swelling of the river as high tide intrudes. Beyond this, forests form only a narrow, often discontinuous fringe, along raised banks averaging no greater than 100m in width. There is often a marked distribution of particular species. Forests just above the Giringarede confluence are wetter, and relatively richer floristically. A very mixed composition of species occur on higher, well drained banks. *Dysoxylum*, *Vitex*, *Kibara*, *Alstonia spectabilis* and *Pongamia pinnata* are common constituents of forests here and appear to be little disturbed. Further upstream, the forest begins to open up. *Intsia*, *Alstonia scholaris*, *Terminalia*, *Sysygium* and *Bombax ceiba* stand out as large sized trees in this section of the fringe forest. Two terrestrial palms, *Gulubia costata* and

Caryota rumphiana, occasionally occur. There is frequent occurrence of large *Octomeles sumatrana* trees near Boze but it is not seen elsewhere along the river.

Clearing of forests for food gardens often extends right to the edge of the river banks This is evident particularly between Boze and Ume. Extensive areas of grasslands and secondary re-growth are maintained this way. The common occurrence of *Legastromia* sp in advanced re-growth indicate good forest recovery in certain sites but this is not consistent through out. Forests near river banks have also been cleared and planted with coconut trees and other fruit trees like the cultivated mango, *Mangifera indica* and several varieties of the Malay apple, *Sysygium moluccense.*

Anthocephalus chinensis becomes prevalent in disturbed areas upstream from the Ume pump station. This species is often associated with inundated areas and is less frequent elsewhere along the river. Open woodland savanna is visible from many sections along the river between Boze and Ume. Often savanna extends as far as the river banks. Forest above Ume are less disturbed and merges with the dry evergreen forest of the head waters. The rosewood, *Pterocarpus indicus* occurs frequently on raised banks of the river between Kunini and Egawal.

7.7 Occurrence of swamps

Other than the seasonal inundation of low-lying areas, there are no noticeable areas of permanent swamp. Certain areas are inundated as a result of back flow from swelling of the river. The incoming high tide causes the river to swell sometimes spilling over lower banks and inundate low-lying areas. Flooding due to heavy rains has a similar effect. These semi permanent swamps dry out during the dry season. No particular vegetation type is usually associated with these seasonally inundated areas. Often the presence of mixed sago woodland indicate occurrence of permanent swamps. Sago palms mainly occur along creek channels around the lower sections of the river and along the muddy banks of the main Binaturi River and its tributaries from Kunini upstream. They are less frequent from Ume and hardly seen past Egawal. Frequently inundated areas in wooded savanna areas often feature higher numbers of *Acacia* trees while a localized abundance of *Anthocephalus* trees generally occur in frequently inundated forest areas.

7.8 Fresh Water Plants

The highest density of floating fresh water plants occurred between Egawal and Upimbada. *Nymphoides* and *Pistia* commonly form small pockets of islands along the edges of the river often in association with masses of *Azolla, Urticularia spp* and *Ceratophyllum.* These two species occasionally occur between Ume and Boze, however, they are usually very small and few. Below Boze, these plants are very rarely seen. There is a general absence of Nymphaeaceae on the Binaturi River. Potentially fast growing *Ipomea aquatica* appears to be struggling to establish itself here even in the sections above Egawal. Fully submerged plants like *Aponogeton* and *Ottela* were collected near the Ume pump station. Local villagers see such plants upstream but do not recall seeing them below Boze village.

To a certain extent, the distribution of other partially submerged freshwater plants follow a similar trend. Certain grass species have a wider distribution. *Pragmites karka* and *Ischaemum sp* for instance also occur around Kunini. Two ferns, *Stenoclaena* and *Nepholepis,* are widely distributed but this is partly due to their semi terrestrial habit. Other plants, for instance, members of the Polygonaceae and Onagraceae are mostly seen around Boze extending upstream. Certain members of the Cyperaceae are also widely distributed but their abundance progressively decreases as they extend downstream.

7.9 Salinity and Distribution of Plants

Distribution of plants with respect to salinity gradients have mainly been studied using species of mangroves. Smith T.J (1992) analyses several studies on salinity levels and growth of mangroves and the apparently strong zonation typically seen in the distribution of mangrove species. He summarized that different mangrove species have evolved unique adaptations such that most have extremely wide tolerance to a number of physio-chemical factors including different salinity levels. Inter tidal mangroves can tolerate maximum salinity levels of 34% (*Xylocarpus granatum* to 100% (*Avicennia officianalis*) but they grow best under salinity levels of less than 30%.

The situation with the salinity levels up the Binaturi River is somewhat difficult to assess. Inter tidal mangrove species do not extend past Kunini which is situated approximately 10 km up from the river mouth. Kunini is thus the cut off point where salinity levels are adequate to maintain mangrove growth.

Beyond Kunini, the waters are supposedly fresh. However, the extension of *Nipa fruticans* and *S. caseolaris* beyond Kunini may suggest low levels of salt in the river. These two species are sometimes referred to as freshwater mangroves because they often associate with brackish water. It is probable that low levels of salt intrude as far as Boze during high tide, thus maintaining these two species. If certain freshwater plants are sensitive to salinity, the above observations may also explain the low incidences of many freshwater plants seen below Boze.

7.10 Conclusions

Based solely on the distribution of plants the following observations can be made. True mangroves do not extend past Kunini indicating this to be the high tide mark and also the maximum extent of salt intrusion. During high tide, seawater travels 10 km up the Binaturi River as far as Kunini. Heavy mixing of fresh water and seawater around Kunini results in the abundance of certain species like *Dolchondrome*, *Nipa*, *S. caseolaris*, *H. tiliaceus*, *Pandanus* spp, and *Barringtonia* species between Elelaole and the Giringarende confluence. The continued extension of *Nipa* and *S. caseolaris* upstream probably

9.0 SUMMARY

The 1,600 m^3 (max. pumping rate) extracted daily (16 hours) from Binaturi River did not contribute to salinity migrations beyond natural sites of salt influence. Even during drier parts of the year the projected figure for the percentage extraction peaking at 0.16% was considered to be not significant enough to move the salt front further than its natural boundary. However, this was considered a tentative conclusion given that the value was derived from anecdotal evidence.

From chemical and EC data, it was established that the salt front was positioned below Kunini and that it was suppressed at that point by the high discharge and flashy conditions brought about by the early stages of the monsoonal rains. The discharge conditions were greater in this survey than the period of the 1994 survey (Levett, 1994). This explained the findings that ionic levels at the topmost sites were much reduced than those of 1994. However, there is still some presence of these ions owing to its close proximity to the coast. Coastal influence through sea spray is contributing to the higher background salt levels as evidenced in the 1994 survey.

Further evidence of Kunini being the present boundary for salinity influence is seen in the mangrove distribution. Their distribution is terminated at Kunini and this is tied in very closely with the EC measurements. The ionic levels generally also reinforce this observation. However, there is evidence of sea level rise at the coastline and there is little doubt that there will be, if not already happening, subsequent upriver influence in terms of salinity migration.

It is only a small suspicion at this stage but nonetheless, the high salt levels in the well water at Kunini is indicative of this. Salt in the aerosols originating from the sea may be the major source but it can also be reflecting the relative salt levels in the high tide recharge waters.

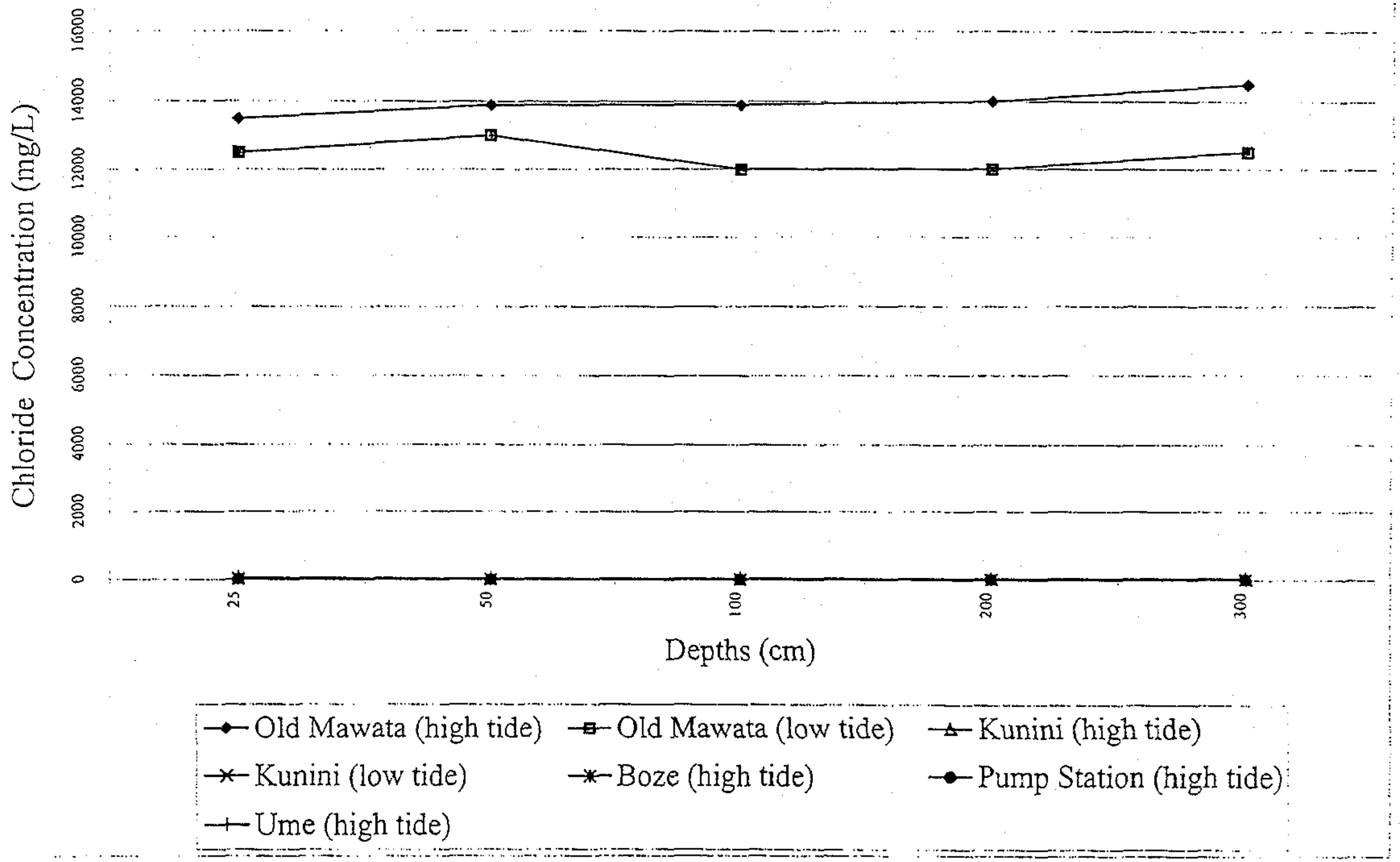
10.0 RECOMMENDATIONS

1. It was surprising to note that there was no river level measuring facility in place. We recommend that the Water Board of Daru immediately erect a gauge at the pumping station. The reading and recording of which should be delegated to the operator on site.

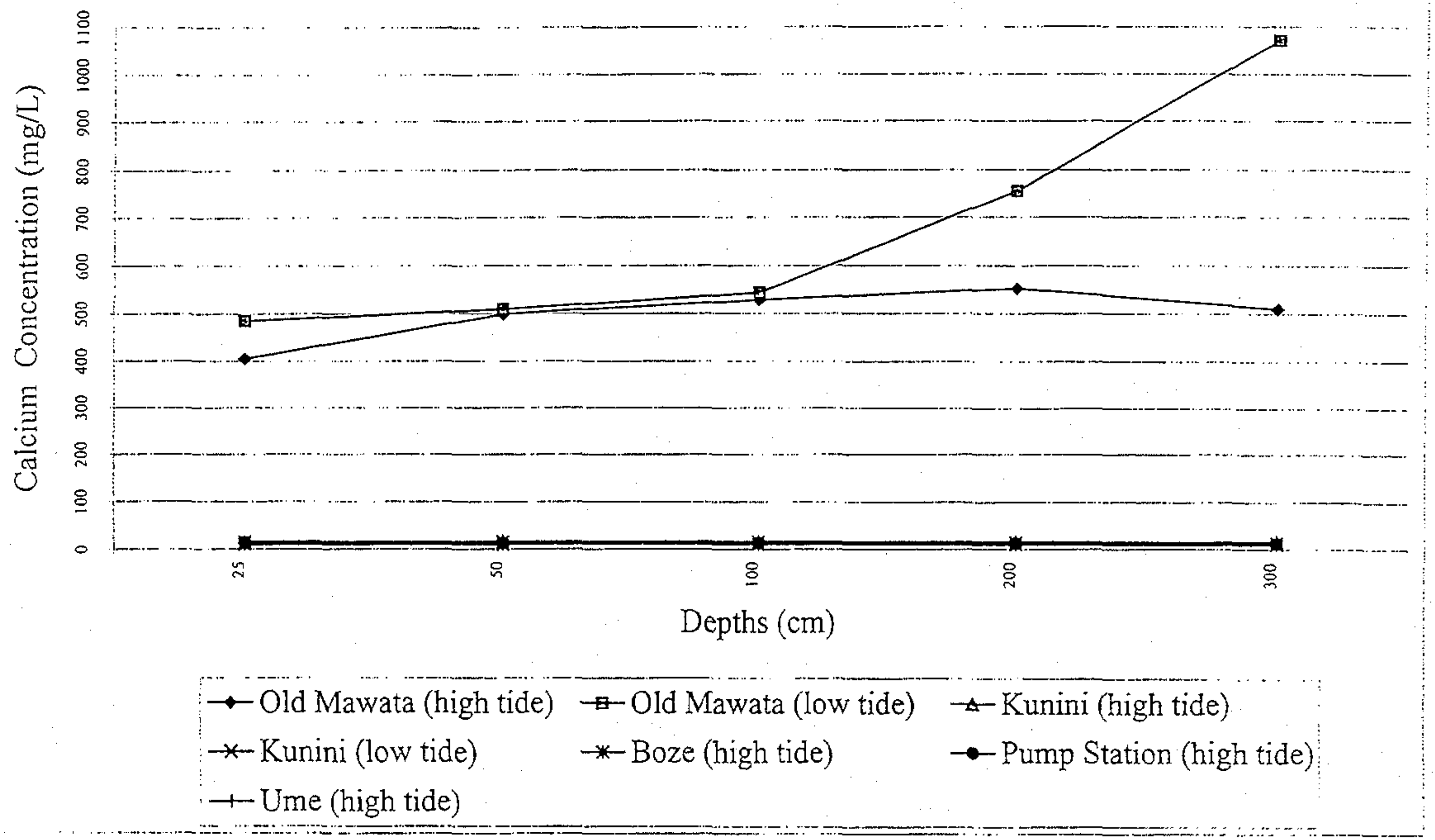
2. The problem of riverbed siltation is partially related to boat traffic on the river, particularly at narrow sections of the river. Speed regulation of boat traffic on the river would be one way of minimising the problems of siltation. The implementation and policing of such regulations would be the responsibility of the individual councillors concerned.

3. The dry season projections provided are assumptions based on wet season data. Hence, we recommend a proper dry season study to verify this assumption.

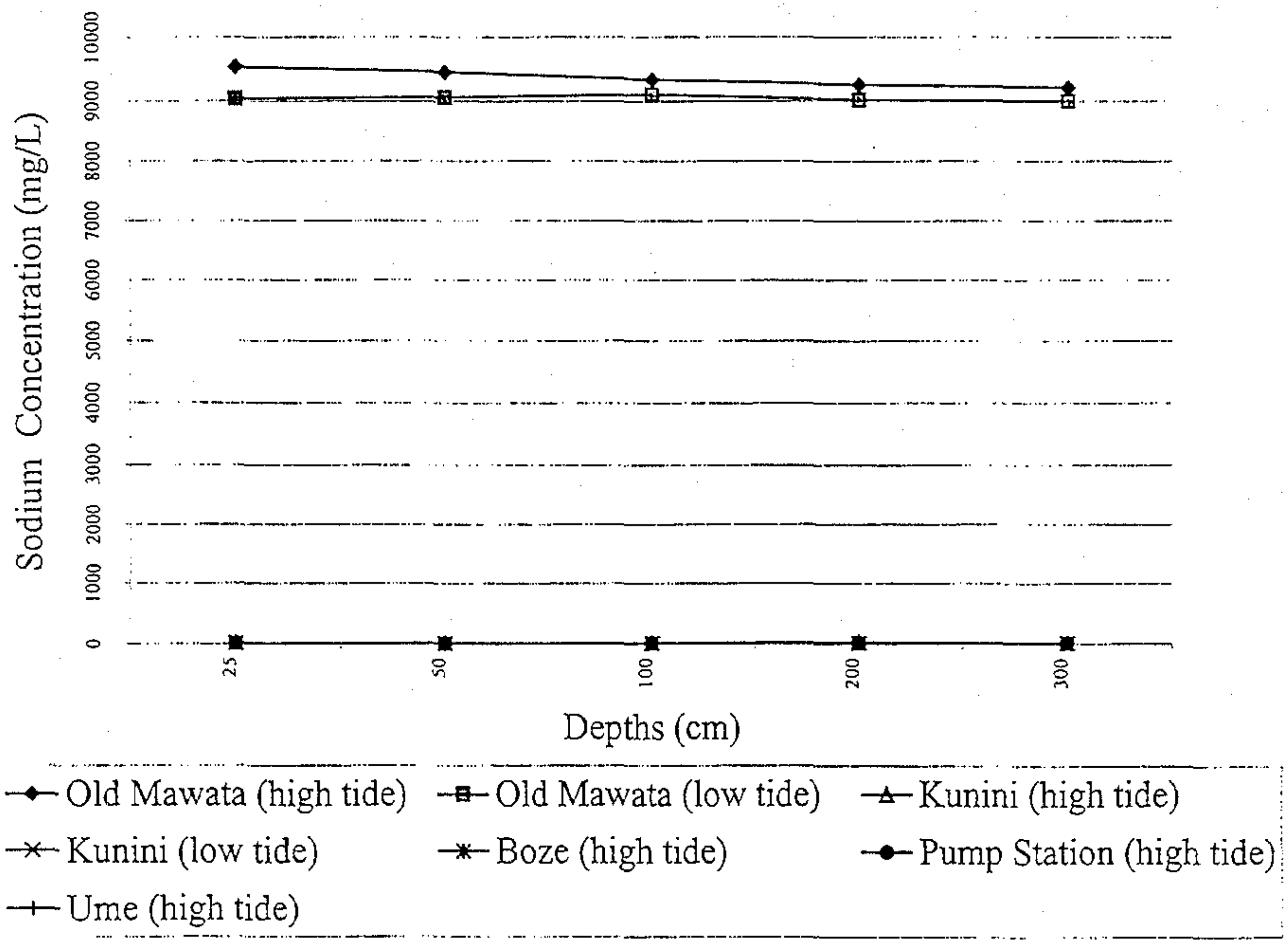
Graph 1: Chloride concentration (mg/L) at various depths in the five Survey Sites of the Binaturi River, Western Province.



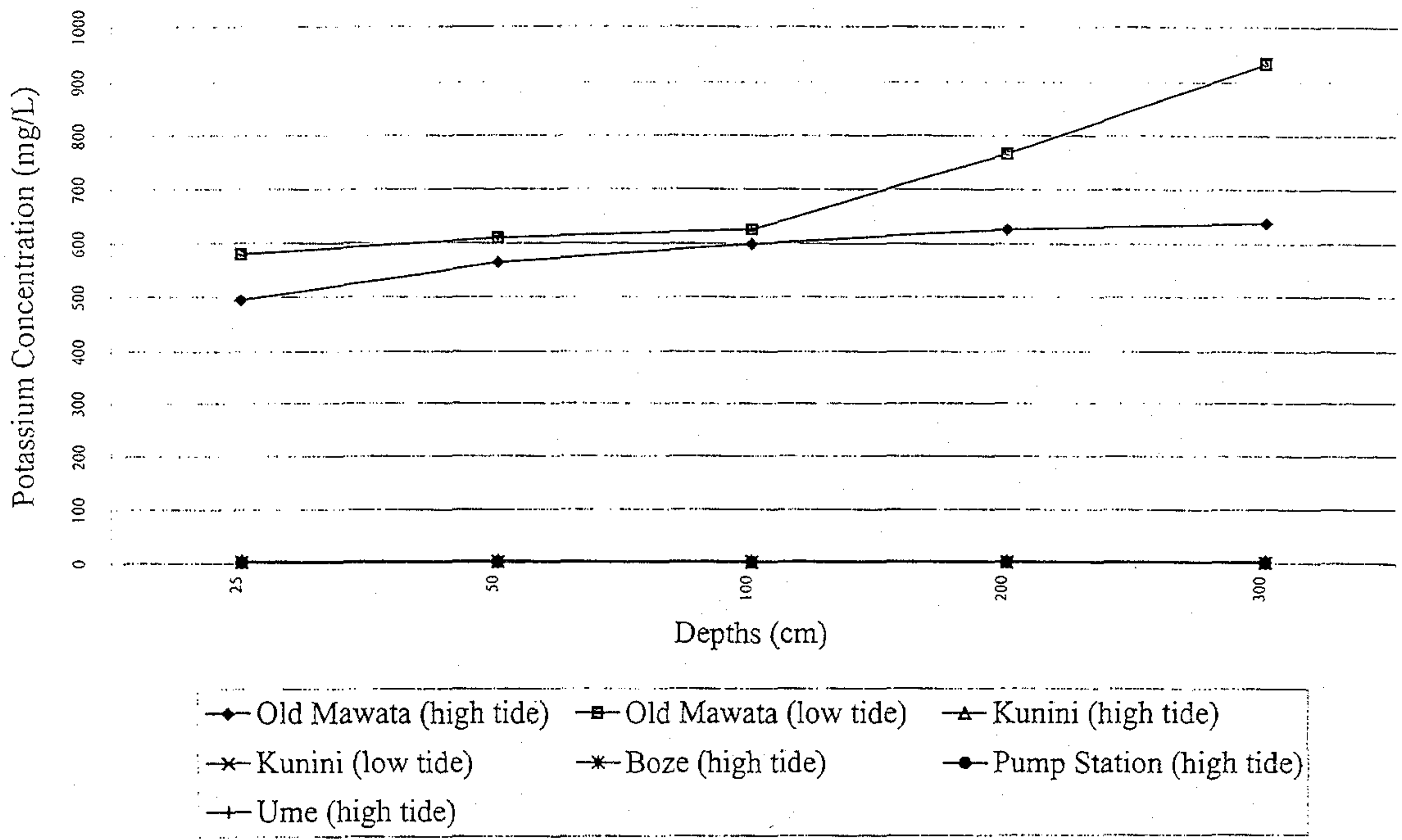
Graph 2: Calcium concentration (mg/L) at various depths in the five Survey Sites of the Binaturi River, Western Province.



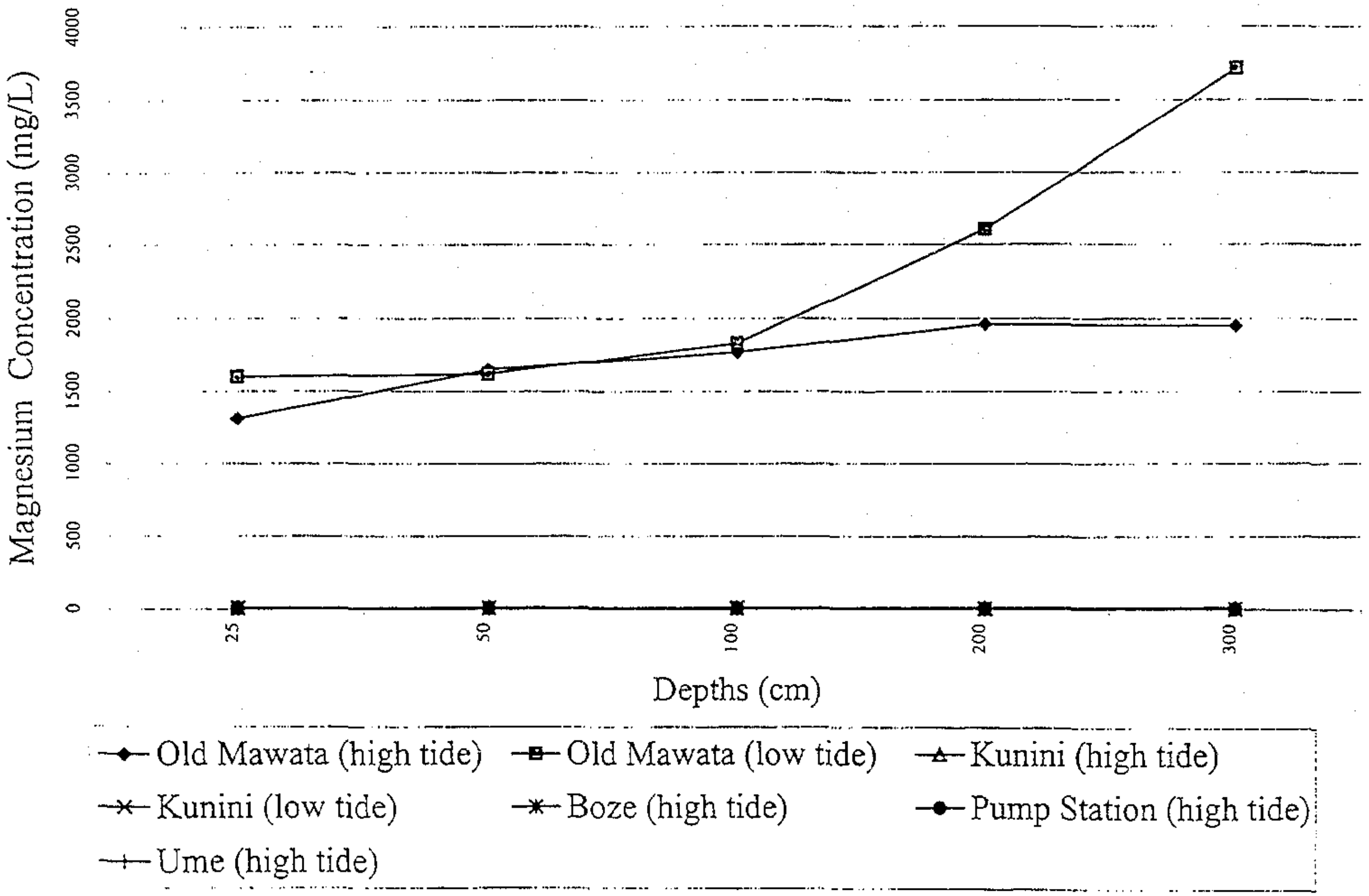
Graph 3: Sodium concentration (mg/L) at various depths in the five Survey Sites of the Binaturi River, Western Province.



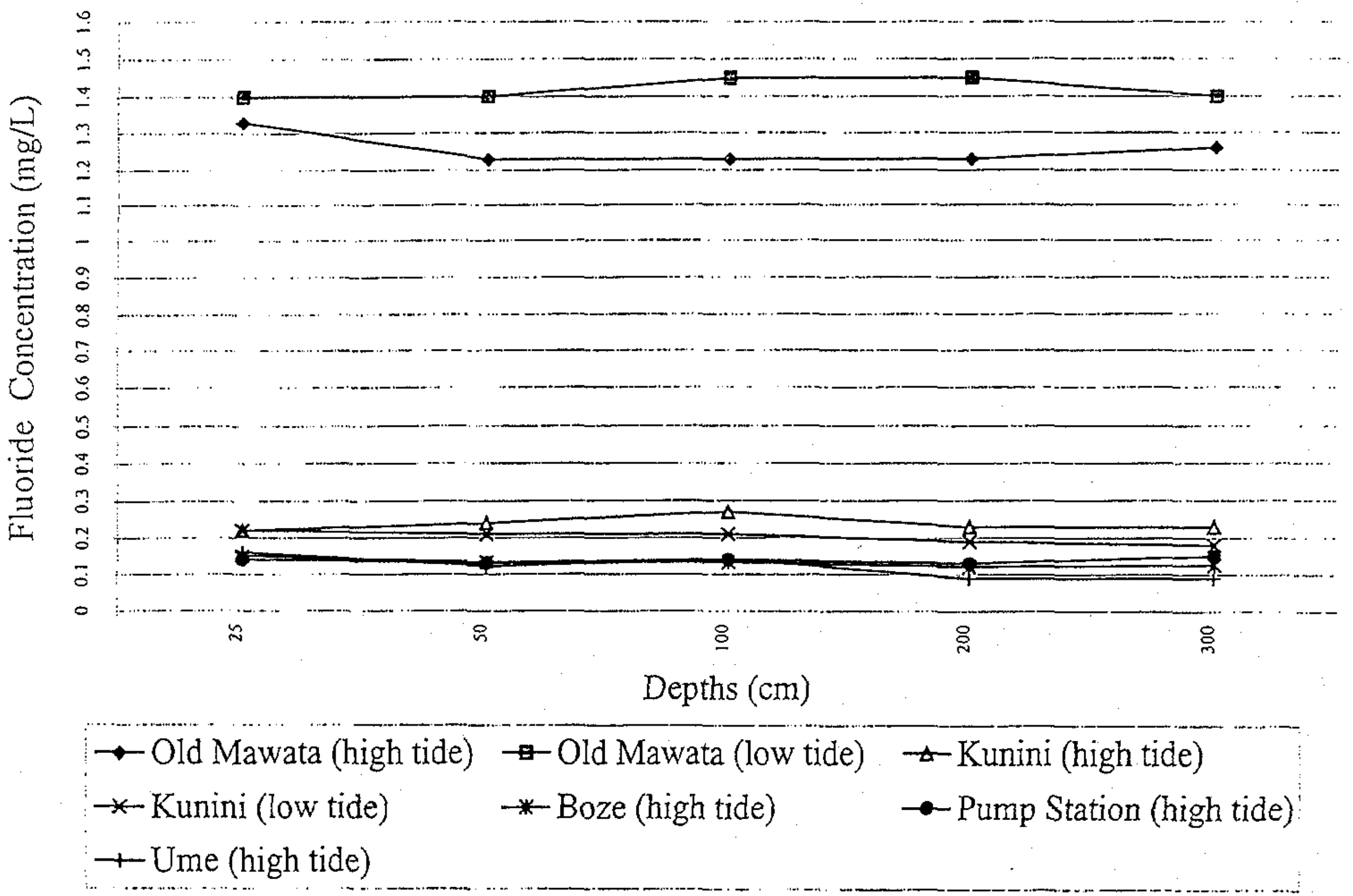
Graph 4: Potassium concentration (mg/L) at various depths in the five Survey Sites of the Binaturi River, Western Province.



Graph 5: Magnesium concentration (mg/L) at various depths in the five Survey Sites of the Binaturi River, Western Province.



Graph 6: Fluoride concentration (mg/L) at various depths in the five Survey Sites of the Binaturi River, Western Province.



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Ref: W200063

WATER ANALYSIS RESULTS

Binaturi River, Item A

Sample No	F	Cl	Ca	Na	K	Mg	t Acid	Alkaline	Hard (g/L)	TDS (g/L)
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	g/L	g/L
1A - 25cm	1.33	13500	405	9540	494	1310	14.8	115	6.406	15.074
- 50cm	1.23	13900	499	9460	565	1650	17.2	116	8.041	14.210
- 100cm	1.23	13900	529	9340	599	1770	14.1	114	8.609	12.095
- 200cm	1.23	14000	552	9260	626	1960	19.1	113	9.449	15.618
- 300cm	1.26	14500	510	9220	638	1950	15.5	114	9.303	16.087
1B - 25cm	1.40	12500	485	9040	580	1600	17.5	120	7.800	32.174
- 50cm	1.40	13000	509	9060	610	1620	17.0	114	7.860	31.076
- 100cm	1.45	12000	543	9100	626	1830	17.5	117	12.592	31.754
- 200cm	1.45	12000	755	9020	766	2600	19.0	115	17.950	37.030
- 300cm	1.40	12500	1070	9000	934	3710	19.3	115	0.069	11.364
2A - 25cm	0.22	58.0	13.4	11.9	3.2	8.7	9.0	58.8	0.079	0.462
- 50cm	0.24	40.3	15.3	14.0	2.8	9.9	7.0	58.8	0.081	0.460
- 100cm	0.27	36.5	15.8	10.5	2.5	10.1	8.3	57.5	0.084	0.252
- 200cm	0.23	38.0	16.3	20.7	2.5	10.5	9.5	59.3	0.088	0.146
- 300cm	0.23	34.5	16.9	8.8	2.6	11.2	9.3	57.5	0.069	0.266
2B - 25cm	0.22	18.5	15.1	10.8	1.3	7.7	14.8	52.5	0.070	0.268
- 50cm	0.21	17.0	15.2	10.6	1.3	7.8	10.0	56.3	0.076	0.262
- 100cm	0.21	15.3	16.2	10.7	1.4	8.8	11.3	56.3	0.072	0.23
- 200cm	0.19	13.0	15.2	10.1	1.3	8.2	9.5	55.0	0.071	0.110
- 300cm	0.18	11.3	15.0	9.8	1.3	8.2	9.1	56.3	0.042	0.122
3 - 25cm	0.15	9.7	9.3	6.9	0.9	4.6	13.5	40.3	0.043	0.188
- 50cm	0.13	7.9	9.6	7.1	1.2	4.7	13.3	39.8	0.044	0.094
- 100cm	0.13	7.1	9.7	7.3	1.1	4.8	12.5	38.0	0.044	0.136
- 200cm	0.12	6.4	9.8	7.3	1.2	4.7	12.8	40.0	0.044	0.274
- 300cm	0.13	6.1	10.0	8.0	1.0	4.6	11.5	38.8	0.044	0.132
4 - 25cm	0.14	7.5	13.1	8.9	1.2	6.1	12.3	48.0	0.058	0.800
- 50cm	0.13	6.8	13.2	8.9	1.1	6.1	12.0	47.5	0.058	0.380
- 100cm	0.14	6.8	13.3	8.8	1.0	6.1	12.2	48.8	0.058	0.236
- 200cm	0.13	6.4	13.5	8.9	1.1	6.3	10.5	47.8	0.060	0.240
- 300cm	0.15	6.4	13.3	8.6	0.8	6.2	11.6	47.8	0.059	0.246
5 - 25cm	0.16	10.0	11.2	8.6	1.1	5.2	10.0	39.3	0.049	0.204
- 50cm	0.12	9.2	11.1	8.5	0.8	5.2	10.0	38.3	0.049	0.166
- 100cm	0.14	8.3	11.2	8.6	1.1	5.2	9.6	38.2	0.049	0.214
- 200cm	0.09	7.5	11.3	8.2	1.0	5.4	11.3	39.4	0.050	0.122
- 300cm	0.09	7.1	11.2	8.1	0.8	5.2	10.5	38.0	0.049	0.200

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Lab Ref : **W200023**

WATER ANALYSIS RESULTS

Binaturi River, Item B

Procedure : **: APHA Methods**
Instrument : **ICP,Col,Titri, Grav, SIE, pH,AAS, HPLC**
PNGLAS Registration No.**0016**

Sample No.	Fe	Mn	As	B	F	Cd	Cr	Zn	Al	Ba	Cu	Ni	Mo	Pb	Hg	Sb	Se	Cl	Na
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
A Old Mawatta	0.16	0.19	<0.001	0.09	0.73	<0.001	0.005	0.032	0.074	0.008	0.02	<0.001	0.006	<0.001	<0.001	<0.001	<0.001	105	45.10
B Masingle	0.22	0.14	<0.001	<0.01	1.30	<0.001	0.018	0.028	0.049	0.014	0.02	<0.001	0.013	<0.001	<0.001	<0.001	<0.001	125	76.60
C Kunini	0.12	0.08	<0.001	<0.01	0.80	<0.001	0.035	0.157	0.100	0.023	0.02	<0.001	0.004	<0.001	<0.001	<0.001	<0.001	1895	1107
D Boze	0.04	0.10	<0.001	<0.01	0.37	<0.001	0.006	0.061	0.537	0.040	0.03	0.012	0.006	<0.001	<0.001	<0.001	<0.001	45	22.10
E Daru Tap	0.01	0.01	<0.001	<0.01	0.41	<0.001	0.010	0.198	0.109	0.020	0.07	<0.001	0.009	0.009	<0.001	<0.001	<0.001	70	17.00
F Upim.Spr	0.06	0.02	<0.001	<0.01	0.56	<0.001	0.009	0.014	0.027	0.010	0.01	<0.001	0.001	0.001	<0.001	<0.001	<0.001	58	14.40
G Binaturi R.	0.02	<0.01	<0.001	<0.01	0.30	0.002	0.002	0.015	0.108	0.009	0.05	<0.001	0.005	<0.001	<0.001	<0.001	<0.001	7	7.18

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Lab Ref.: **W200023**

WATER ANALYSIS RESULTS

Binaturi River, Item B

Procedure : **: APHA Methods**
Instrument : **I ICP,Col,Titri, Grav, SIE, pH,AAS, HPLC**
PNGLAS Registration No.0016

Sample No.	CN mg/L	NO2-N mg/L	NO3-N mg/L	SO_4 mg/L	TOC mg/L	TDS g/L
A Old Mawatta	0.003	0.008	0.01	4.05	2	0.222
B Masingle	0.002	0.106	0.18	2.80	3	0.404
C Kunini	0.002	0.007	1.03	76.5	2	4.220
D Boze	0.001	0.003	1.30	10.8	3	0.484
E Daru Tap	0.003	0.003	0.70	6.1	2	0.498
F Upim Spr	0.002	0.003	0.10	1.0	4	0.633
G Binaturi R.	0.001	0.002	1.00	0.3	4	0.526