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Reducing Vulnerability of Pacific ACP States

# PAPUA NEW GUINEA TECHNICAL REPORT
# Assessment of Selected River Aggregate Deposits at Waramei and Wara Bili Rivers, South Vanimo

April 2009

*Waramei (upper photos) and Wara Bili (Lower photos) Aggregate Deposits, South Vanimo, Papua New Guinea.*

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# CONTENT

## LIST OF FIGURES



## LIST OF TABLES



## LIST OF APPENDICES

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## EXECUTIVE SUMMARY

The Vanimo aggregate assessment was carried out in March 2006 at the request of the West Sepik Provincial Administration. The main objectives of the survey were to determine the quality and quantity of river aggregate deposits that occur in the Waramei and Wara Bili Rivers to support infrastructure development; and to identify sources of good quality aggregate that can supply the local demand. This was also an opportunity for the SOPAC-EU Project to demonstrate community empowerment through appropriate technical advice pertaining to the development and management of their aggregate resources. In rural and semi-rural areas, the bulk of aggregate are consumed by the construction of new roads and the rehabilitation or upgrading of existing ones, which in turn, supports other economic initiatives such as logging, mineral exploration and agricultural activities.

The survey was carried out using appropriate geological, geotechnical and geophysical survey methods in order to ascertain the quality and volume of material that occur at each site. The survey involved the identification of different rock types, visual estimation of rock-type abundance, and mapping that includes measuring the size of each deposit. The abundance of rock fragments of about 1000 $cm^3$ in volume or greater were estimated and some were strength tested using a Schmidt hammer.

Mixed sand and gravel samples were collected and delivered to the materials laboratory of the Department of Works in Port Moresby for appropriate geo-technical tests. The following tests were conducted: Particle Size Distribution (PSD), Atterberg Limits, Compaction, and California Bearing Ratio. These tests were undertaken in accordance with AS 1289, “Method of testing Soils for Engineering purposes”. Additionally, seismic refraction survey was conducted on both sites using a six channel OYO 1198A seismograph system.

The survey results indicate that the Waramei aggregate deposit is predominantly composed of basic and acidic plutonic rock fragments with minor amounts of volcanic rocks and limestone. In contrast, the Bili aggregate deposit is predominantly composed of basic volcanic rock fragments with minor amounts of plutonic rocks and limestone. The Waramei deposit is about ten times bigger than the Wara Bili deposit with comparatively significant amount of oversize boulders. This is a significant advantage as a quarry operation will require larger volumes of bigger boulders to crush for road metals and building materials.

The geotechnical investigation reveals that the aggregate material at the Waramei River are suitable for various road and building construction applications while the Wara Bili deposit can be used for a limited number of applications. The seismic survey results indicate an average of 11 m of aggregate thickness at Waramei while the average sediment thickness at Wara Bili stands at 14 m.

The total available resource at Waramei is 2.2 million $m^3$ while there 0.28 million $m^3$ is available at Wara Bili. With an extractable resource of 0.6 million $m^3$ of aggregate at Waramei, it has the potential to support significant quarry operation. Typically, with any large and dynamic river catchments such as these two rivers, significant sediment replenishment is expected that replaces material that are removed through mining.

The characteristics of the Waramei deposit should generate interests among developers, especially for the construction of the Bewani-Amanab road and the maintenance and upgrading of the Vanimo-Bewani road; however, for any construction projects in Vanimo Town and nearby areas, the Waramei deposit is considered too distant and with the current poor road conditions, the viability of a quarry operation cannot be guaranteed.

## INTRODUCTION

Despite the abundance of quality aggregate resources in various parts of West Sepik Province (WSP), aggregate are sometimes imported from West Papua to meet the sand and gravel demand for construction purposes in Vanimo. This has prompted the West Sepik Provincial Government to seek the assistance of the SOPAC-EU Project in the identification of sources of good quality sand and gravel near Vanimo to support the local construction industry.

In the WSP, construction of new roads and the maintenance or upgrading of existing ones consume large quantities of aggregate material. Road construction supports other economic developments such as logging, mineral exploration and agricultural activities, hence the need to identify and assess selected river aggregate deposits near the Vanimo Township. This was also an opportunity for the SOPAC-EU Project to demonstrate community empowerment by offering appropriate technical advice pertaining to the development and management of their aggregate resources.

This aggregate survey was carried out in March 2006 in the Waramei and Wara Bili Rivers. It was necessary to conduct the survey using a number of geological, geotechnical and geophysical survey methods to determine the quality and quantity of material that occur at these two sites. Other factors such as resource accessibility, road conditions and the distance to market were also considered in this survey. This report highlights the findings of the survey and draws a conclusion together with recommendations.

### 1.1 Study Area

The study areas lie within the northwest corner of Papua New Guinea and to the south of Vanimo Town (Figure 1). The area is characterised by natural landforms such as mountain ranges, hills, gorges, basins, and meandering rivers. A prominent feature of the north western part of WSP is the Pual River (Figure 1), the western most major river that drains to the east coast of Vanimo and has its tributaries extending landward to the Bewani Mountains. The Bewani Mountains occur to the south of Vanimo (Figure 2) and to the west of the adjacent Torricelli Mountains. Both the Waramei and Wara Bili study sites are located in tributaries of the Pual River.

The Waramei study site can be accessed by the main road linking Vanimo and Ainbai Village whereas Wara Bili can be accessed through logging roads. This network of logging roads are regularly maintained by logging companies and in areas where logging has ceased the roads are, in most cases, inaccessible. One of the major challenges of these two sites is the maintenance of access roads. Four-wheel drive vehicles are highly recommended as the mode of transport to these two sites.

Villages and settlements are located in places around the study sites. Logging is the most visible human activity in these areas and is likely impacting the environment. The erosion and washing away of exposed top soil due to logging can contribute significantly to increased siltation of the waterways and it is possible that the elevated amount of silt and mud on the river aggregate deposits is a result of top soil erosion.

## 2. BACKGROUND

### 2.1 SOPAC-EU Project Intervention

The two SOPAC-EU Project Multi-Stakeholder Consultation Meetings for Papua New Guinea that were held in Port Moresby in 2003 (in June and October) had limited success in identifying aggregate-related tasks. This necessitated a fact-finding mission in February 2005 to the three

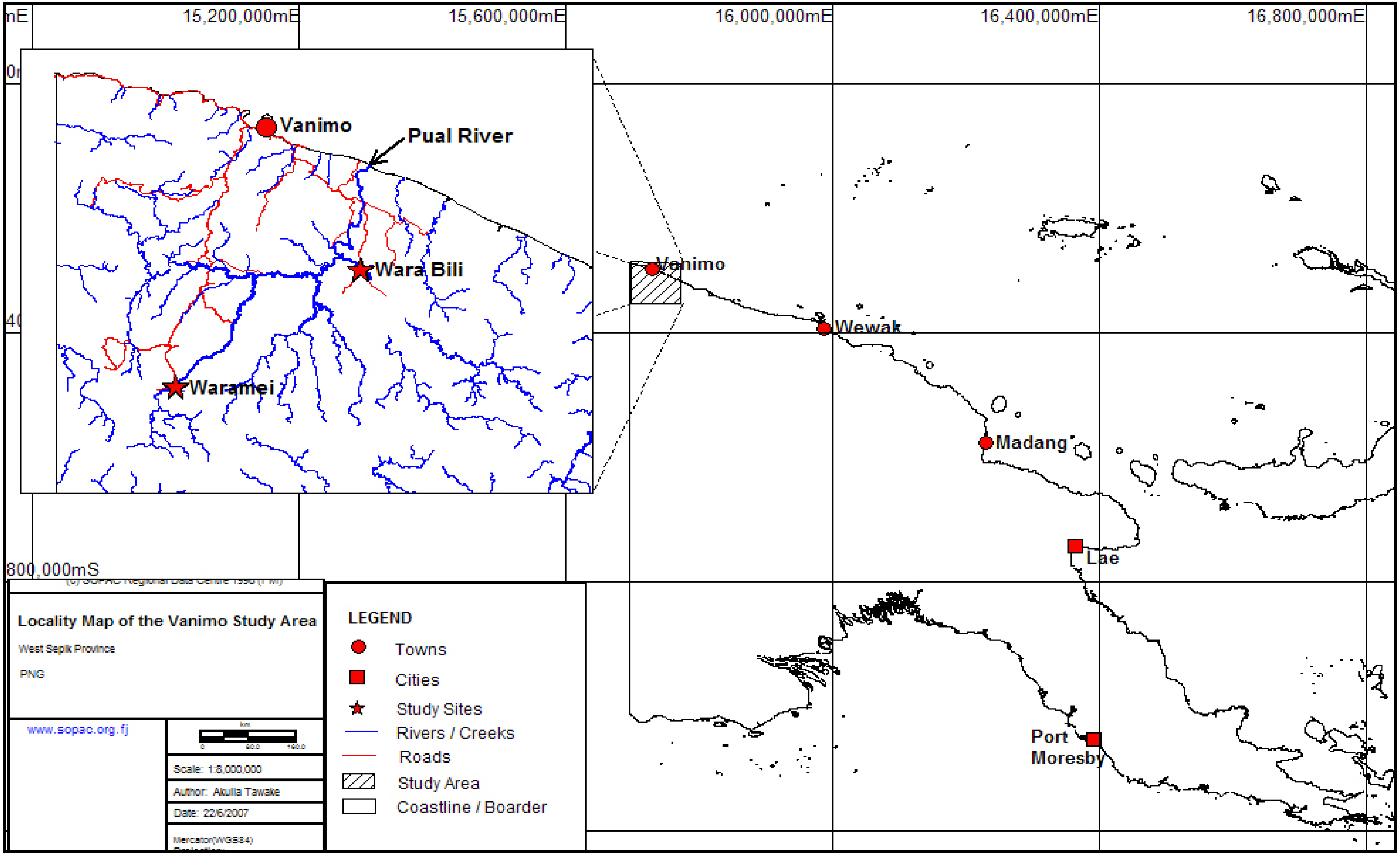


***Figure 1.** Locality map of the Waramei and Wara Bili study sites.*

northern coastal towns of the country (Madang, Wewak and Vanimo), the designated project intervention areas, to consult relevant stakeholders in identifying and subsequently refining the relevant tasks that were to be carried out. This expedition also presented an opportune time to visit potential resource areas near these three towns.

Following the February 2005 fact-finding mission, the SOPAC-EU Project then prioritised the tasks identified in consultation with the Papua New Guinea Geological Survey Division (GSD) and confirmed selected sites in Madang and Vanimo for detailed assessment. It was further agreed that the aggregate investigation in Madang could be carried out by GSD with full financial support of the Project while the Vanimo survey would be jointly conducted by the Project personnel and GSD.

During the site inspection in Vanimo, the Waramei and Wara Bili River aggregates deposits seemed to have attracted a lot of interest due to their accessibility through the extensive network of roads that exist in these areas. Additionally, these two sites were selected at the request by the West Sepik Provincial Government (WSPG) in its effort to support local communities' initiative to develop their resources. Further, the Waramei deposit is a prime site to extract road materials for the Vanimo – Bewani road upgrading and the construction of the Bewani – Amanab road, while the Wara Bili aggregate deposit can be used for the Vanimo – Aitape road upgrading and the maintenance of the surrounding network of logging roads.

## 2.2 Previous Study

A major road assessment project was carried out in West Sepik Province between 1991 and 1992 of all major coastal and inland roads in Vanimo and Aitape. The details of the study are covered in Engineering Geology (1992). Part of this project was the survey of the Pual River – Wutung and Ainbai Road Junction – Ainbai roads, prompting the assessment of potential, nearby accessible road material.

These roads were categorised as follows:

Category A: Long term gravel road
Category B: Scheduled for upgrading and sealing
Category C: Sealed road
Category D: Located in remote and inaccessible areas.

Category A received the highest level of study and investigation, since a prime objective of the Project was to enable the most cost effective use of road maintenance funds through rationalised utilisation of available road material resources along unsealed sections of the National Highway Network. Field investigations along Category A roads have therefore been directed towards identifying adequate resources of material suitable for use as gravel-wearing course in their pit-run conditions or with the minimum of processing.

The road material resource investigations were carried out in the WSP during March, April and September 1991. Over eighty existing and potential road material sources were located, evaluated and documented during field investigations. A further seventeen have been documented on the Category D roads.

This study also considered the engineering characteristics of the various material types, their suitability for use as gravel-wearing course and their potential for use in other construction applications. Fresh igneous rocks offer significant potential as sources of sealing chip, concrete aggregate and rip rap.

The closest studied road to the Wara Bili study site is the eastern end of the Pual River – Wutung Road, which is some significant distance away. Therefore the results of the Wara Bili survey cannot be compared to any previous results. In contrast, the locations of two gravel pits right at the end of the Ainbai Road Junction – Ainbai Road are close to the Waramei study site. The rocks in these two pits may have been derived from the same sources as the ones in the Waramei study site hence the test results are of significance in determining the engineering performance of the Waramei rocks. A study summary of these two sites is tabulated in Table 1.

*Table 1. Summary of the previous aggregate survey results in the Bewani Area.*

| | | Pit Name | |
|---|---|---|---|
| | | WOM | PUWANI |
| Local Area Name | | Bewani | Bewani |
| Longitude | | 03º 03.920’ | 03º 05.230’ |
| Latitude | | 141º 10.252’ | 141º 10.015’ |
| Material type | | River terrace gravel | River terrace gravel |
| Overburden depth | | Negligible | Nil |
| Material description | | Predominantly medium and coarse sand with subangular to subrounded fine – coarse gravel of microgranite, granite, microgranodiorite, granodiorite and microdiorite. | Slight silty fine – coarse sand and predominantly subrounded fine – coarse gravel of microgranite, basalt, microgranodiorite, dolesite, limestone and microdiorite. |
| Sample Type | | LA Block, Pit-run | LA Block, Pit run |
| Material Test Properties | | LA Abrasion, Particle Size Distribution | LA Abrasion, Particle Size Distribution |
| Variation in quality | | Unknown | Unknown |
| Geo-material Applications * | Sub-base | 2 | 2 |
| | Base coarse | 3 | 2 |
| | Sealing chip | 3 | 2 |
| | Gabion stone | 3 | 2 |
| | Rip rap | 4 | 3 |
| | Coarse Aggregates | 2 | 2 |
| | Fine Aggregates | 2 | 2 |
| Proposed method of Extraction | | Loader or backhoe excavator | Loader or backhoe excavator |
| Land Status | | Customary | Customary |
| Resource Estimate ($m^3$) | | 14,000 | 300,000 |
| Potential for Pit Extension | | Huge | |
| Processing Recommendations | | Screening and crushing | Screening and crushing |

** Suitability of the aggregate source is classified from 1 to 5: 1 is excellent and 5 unsuitable.*

## 2.3 Geology of the Study Area

This brief geology of the study area is extracted from Norvick and Hutchison (1980). Geologically, the area is dominated by narrow, east trending mountain ranges (Figure 2), the Bewani and Torricelli Mountains, which are composed of Cretaceous and Lower Tertiary volcanic, intrusive, and metamorphic rocks. The Torricelli Mountain range occurs immediately to the east of the Bewani Mountains and is considered as the eastern extension of the Bewani Mountains. These form the basement to an unconformity overlying Neogene and Quaternary succession of mainly immature clastic sediments.

The Bewani and Torricelli Mountains consist of a series of peaks, up to 1800 m high, separated by passes. Both these mountain ranges are flanked on both sides by a broad foothill zone which gradually drops in elevation from about 700 m to nearly sea level, and gives way to the alluvial plains along the north coast (Figure 2). Although not as high as many other mountainous areas in Papua New Guinea, the ranges are extremely rugged, and drained by numerous short, steep streams which are commonly obstructed by large boulders, gorges, and waterfalls. On leaving the mountains, the rivers develop wide, braided channels.

The Aitape Trough occurs to the north of the Bewani and Torricelli Mountains and extends right to the coast in most places between Vanimo and Aitape. This trough is characterised by thick sequence of poorly consolidated, predominantly immature clastic rocks, which contain a high proportion of volcanic, plutonic and metamorphic rock fragments probably derived from adjacent basement highs. Sedimentary structures indicate that deposition was at least partly by turbidity currents.

Along the southern margin of the trough, more than 3500 m of sediments are preserved in a zone of faulted and commonly overturned anticlines. Tectonism, uplift and erosion are thought to have proceeded at the same time as the deposition and the younger parts of the sequences were probably derived partly by the reworking of the older cover rocks. All different formations within the Aitape Trough decrease in thickness northwards, and some disappear over a discontinuous basement high.

## 3. METHODS

A number of basic geological, geotechnical and geophysical survey methods were used to assess the river gravel deposits at the Waramei and Wara Bili rivers. The survey involved the identification of different rock types that occur in each river gravel deposit and the visual estimation of the abundance of each rock type at each site whilst the measurement of the length and width of the sand and deposit was performed using a hip chain. Rock fragments of about 1000 $cm^3$ in volume or greater are considered oversize hence their relative abundance were estimated.

Additionally, a Schmidt hammer was used to test the strength of different rock types that occur at the Waramei deposit. Selected boulders of different rock types, about 10 x 10 x 10 cm in dimension or greater, were tested using the hammer being applied in a vertical downward position (Figure 3a). Depending on the size of the rocks being tested, the test was done on two or three boulders of the same rock type for each of the rock types. The average rebound reading for each rock type was calculated and used to estimate the actual strength of the rock with the aid of a diagram given in the instruction manual. This strength test was not possible at the Bili deposit due to the relatively smaller sizes of rock fragments at the site.

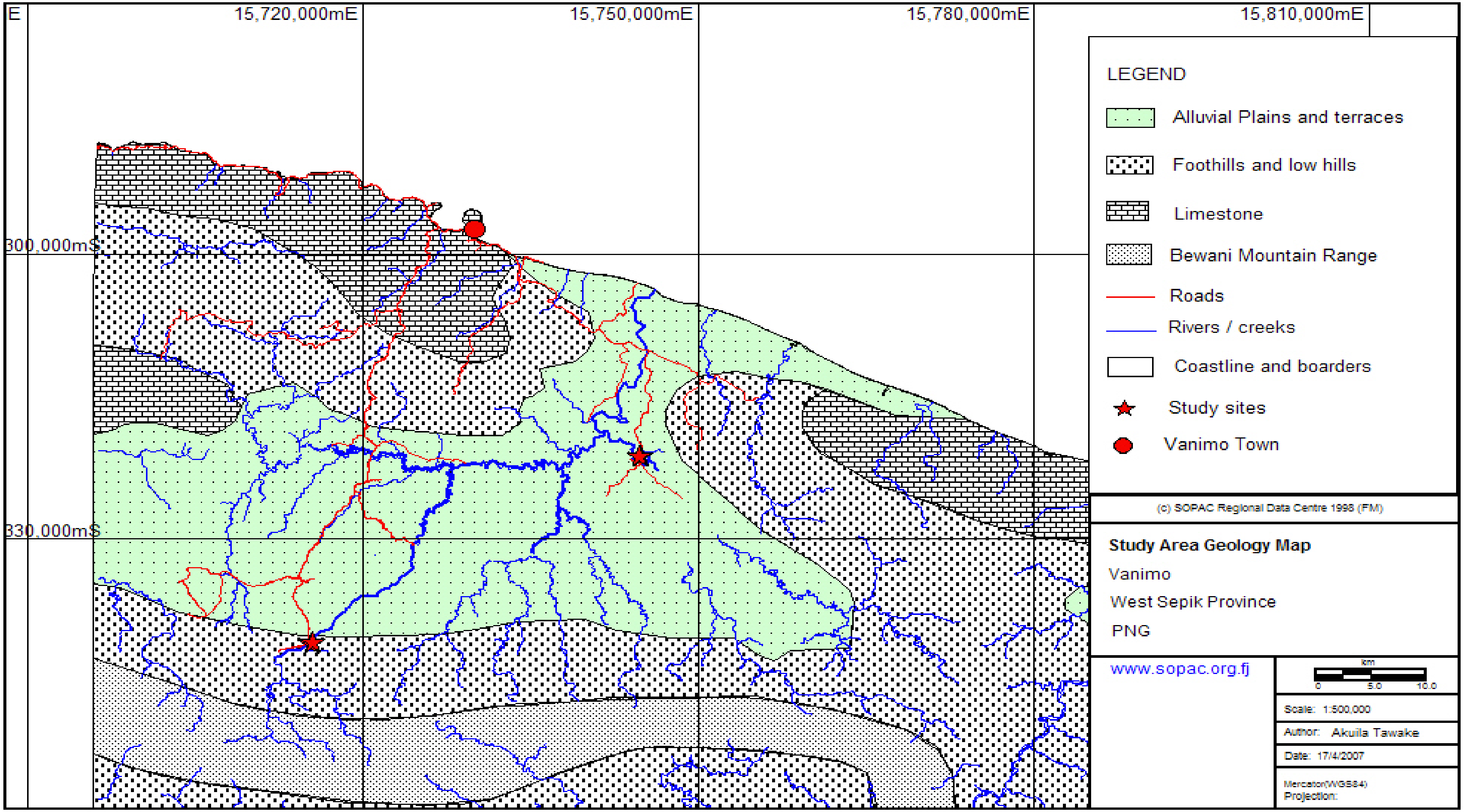


*Figure 2. The Geology map of the Study Area.*

Two bags of mixed sand and gravel samples were collected from separate sites within each deposit using a hand shovel (Figure 3b). Each bag contained approximately 50 kg of sediments. These samples were delivered to the material laboratory of the Department of Works in Port Moresby for appropriate geo-technical tests. The following tests were conducted: Particle Size Distribution (PSD), Atterberg Limits, Compaction, and California Bearing Ratio. These tests were undertaken in accordance with AS 1289, "Method of testing Soils for Engineering purposes". A brief explanation of the purposes of these tests and the reasons for conducting them are given in Appendix 1.

Due to the sandy gravel nature of the samples, the Liquid Limits (LL), Plastic Limits (PL) and the Plasticity Index (PI) of the Atterberg Limits test were not performed.


***Figure 3.*** *Various methods of aggregate assessment in Waramei and Wara Bili; a) Testing of rock boulder using the Schmidt Hammer. b) Collection of aggregate samples for geotechnical tests. c) The seismograph. d) The geophone clipped to the cable.*

Additionally, a seismic refraction survey was conducted at both the Waramei and Wara Bili aggregate deposits. The depth of sand and gravel deposit was estimated using a six-channel OYO 1198A seismograph system (Figure 3c) with inbuilt for data storage and a 5 m take-out geophone cable (Figure 3d). The respective positions of the profiles are shown in Figures 4 and 5. Profiles 1, 2 and 4 at Waramei were aligned almost parallel to trend of the river channel while profile 3 was at an oblique angle to it (Figure 4).

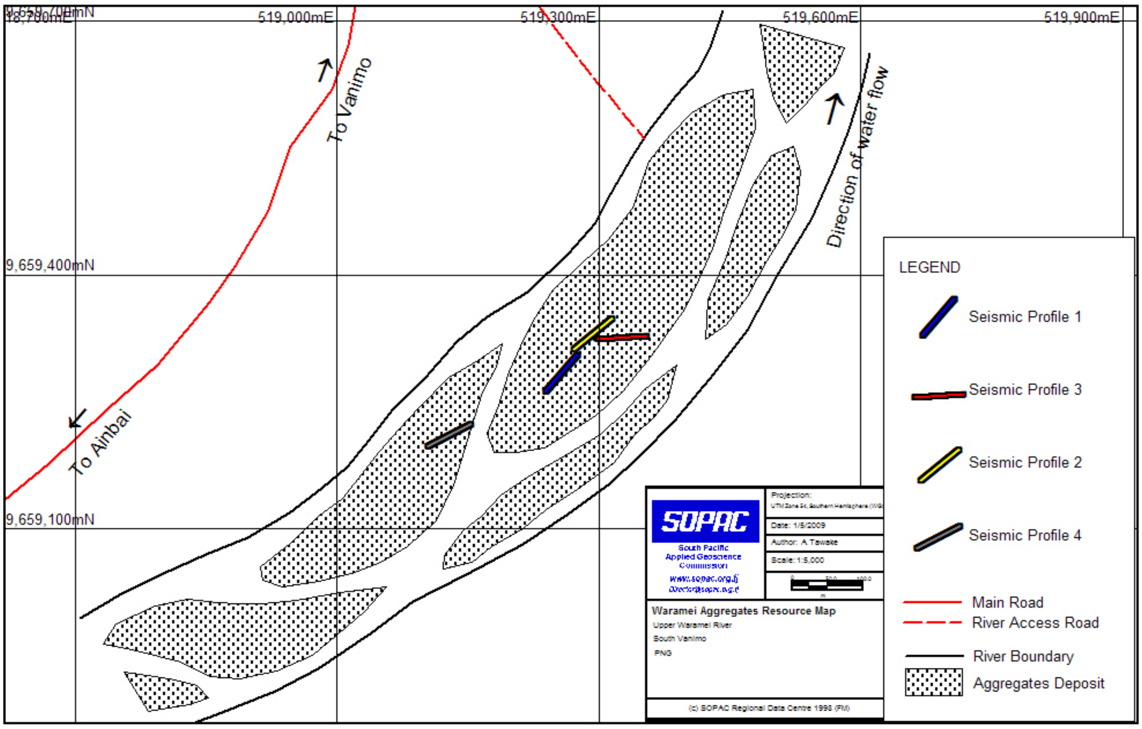


*Figure 4. Waramei aggregate resource map showing the location of the seismic profiles.*

The Waramei sand and gravel deposits were well exposed during the time of the survey and had been separated by very shallow running water channels. Profiles 1-3 are located within the same area, while Profile 4 is located at approximately 100 m upstream (Figure 4). At the Wara Bili deposit, the relatively small size of the deposit allowed for only one seismic profile to be conducted within the area (Figure 5). The geographic coordinates of each seismic profile, together with their respective directions are given in Appendix 2.

Arrival times were plotted against distance of receiving geophone from source of signal, which in this case was a hammer on a metal plate. In order to get the velocity of the layer, the gradient of the respective layers was calculated. Velocity values are obtained by inverting the gradient values.

Depth to the second layer refractor is calculated according to the equation (Kearey and Brooks, 1984):

$$Z = (X_c/2) * [(V_2-V_1)/(V_1+V_2)]^{1/2}$$

Where, $X_c$ is the cross-over distance between velocities of the top ($V_1$) and second ($V_2$) layers. All units are given in SI.

The refractor depth can also be calculated using this equation:

$$Z = ti/2*(V1*V2)/(V2^2-V1^2)^{1/2}$$

Where, ti is the intercept on the time axis of a travel-time plot or time-distance plot having a gradient of 1/V2.

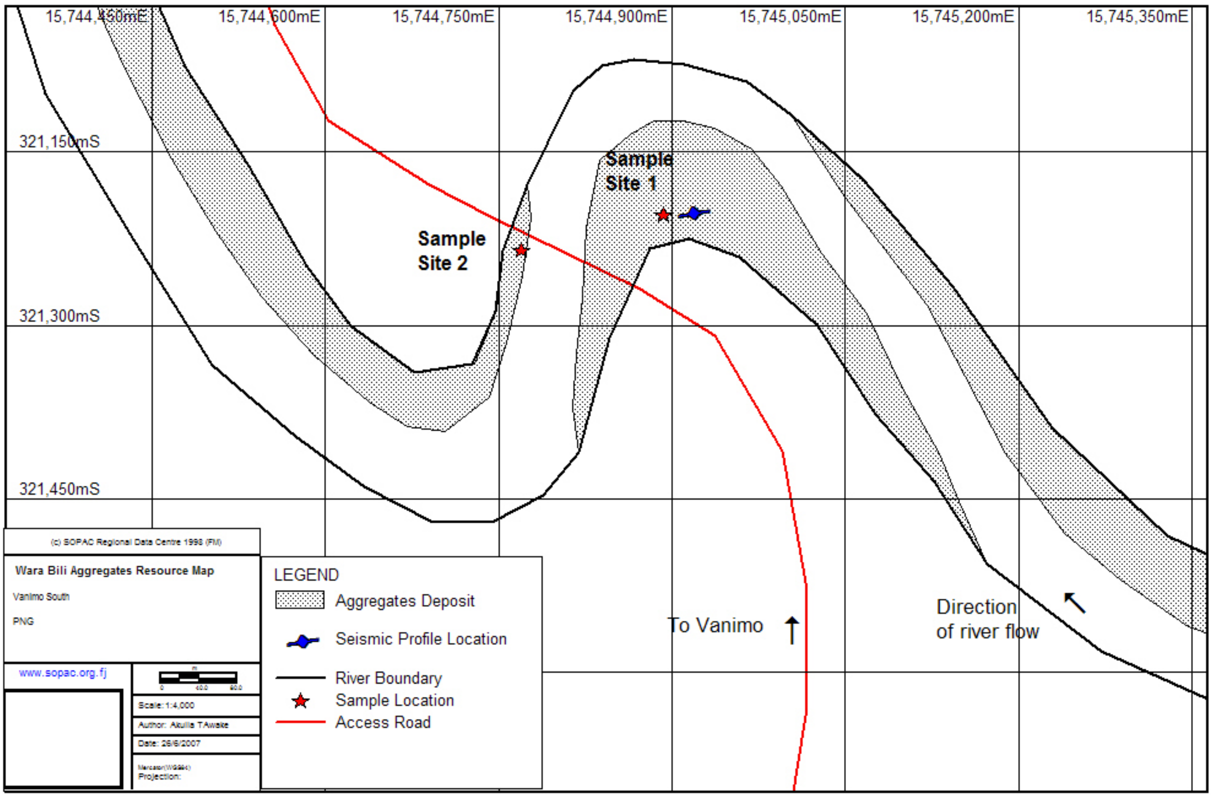


*Figure 5. Wara Bili aggregate resource map showing the location of the seismic profile and the sample sites.*

## 4. RESULTS

### 4.1 Rock Types and Abundance

The Waramei aggregate deposit is predominantly composed of intermediate and acidic plutonic rock fragments with minor amounts of volcanic rocks and limestone. Visual assessment of rock fragments onsite revealed the deposit consists of approximately 80 % plutonic rocks, 15 % volcanic rocks and 5 % limestone. Sedimentary rocks in the form of sandstones and siltstones are rare. Plutonic rocks mainly comprise fragments of granite, granodiorite, diorite, and microdiorite. Basalt fragments account for about 80 % of volcanic rocks while andesite makes up the other 20 %.

In contrast, the Wara Bili aggregate deposit is predominantly composed of basic volcanic rock fragments with minor amounts of plutonic rocks and limestone. The deposit consists of approximately 85 % volcanic rocks, 12 % plutonic rocks and 3 % limestone. The rock fragments are more sub-rounded and smaller in size. Volcanic rocks mainly consist of basalt, which contains 70 % of the volcanic rocks with minor amounts of andesite and dacite. Plutonic rock fragments are composed of granodiorite, diorite and gabbro.

There is a lot more gravel in the Waramei deposit, due to the significant amount of oversize rock fragments, compared to the relatively smaller rock fragment sizes at the Wara Bili deposit. On visual estimation the relative amount of sand and gravel at Wara Bili are about the same. Table 2 summarises the results of field investigations at both sites.

*Table 2. Field survey summary at Waramei and Wara Bili.*

| | Study Sites | |
|---|---|---|
| | Waramei | Wara Bili |
| Type of source | River gravel deposit | River gravel deposit |
| Length (m) | 1000 | 250 |
| Width (m) | 200 | 80 |
| Area ($m^2$) | 200,000 | 20,000 |
| Composition | 35 % sand : 65 % gravel | 50 % sand : 50 % gravel |
| Rock Origin | Mainly acidic to intermediate plutonic rocks with minor volcanic rocks | Mainly basic volcanic rocks with minor intermediate plutonic rocks |
| Rock Types | Granite, Granodiorite, Diorite, Basalt, Andesite | Basalt, Andesite, Dacite, Diorite, Gabbro |
| Oversize | 20 % | <1 % |
| Distance to main access road | Close | Close |
| Distance to Vanimo | Far | Far |
| Accessibility Problem | Moderate | Moderate |
| Extraction Method | Backhoe excavator or Loader | Backhoe excavator or loader |
| Processing Method | Screening and crushing | Screening |

## 4.2 Geotechnical Investigation

The results of the aggregate tests are given in Tables 3 and 4.

*Table 3. The results of the Schmidt Hammer strength test of rocks at Waramei.*

| Rock type | Average Rebound Value | Compressive Strength (MPa) |
|---|---|---|
| Granite | 60.20 | >80 |
| Granodiorite | 61.10 | >80 |
| Diorite | 53.36 | 71.20 |
| Microdiorite | 54.60 | 73.80 |
| Gabbro | 60.20 | >80 |
| Basalt | 48.80 | 61.60 |
| Andesite | 43.50 | 51.70 |
| Limestone | 25.70 | 22.00 |

*Table 4. Laboratory test results of the Waramei and Bili aggregate samples.*

| | | Waramei | Wara Bili |
|---|---|---|---|
| Material Description | | Sandy gravel with a trace of silt. | Sandy gravel with a trace of silt. |
| | | | |
| Particle Size Distribution (PSD) | Cl/Si (%) | 1 | 2 |
| | Sa (%) | 32 | 32 |
| | Gr (%) | 67 | 66 |
| | | | |
| Atterberg Limits | Nat (%) | 3.5 | 5.2 |
| | | | |
| Compaction | MDD (t/m$^3$) | 2.10 | 2.17 |
| | Opt (%) | 5 | 8 |
| | | | |
| In-situ California Bearing Ratio | CBR (%) | 80 | 16 |
| | DD (t/m$^3$) | 2.14 | 2.06 |
| | w (%) | 0.4 | 6.6 |

| **Key** |
|---|
| Cl/Si – Clay / Silt |
| Sa – Sand |
| Gr – Gravel |
| Nat – Natural water content |
| MDD – Maximum Dry Density |
| Opt w – Optimum Moisture Content |
| CBR – California Bearing Ratio |
| DD – Dry Density |
| w – Moisture |

The laboratory test result details are given in Appendix 3.

## 4.3 Seismic Profiling

### *4.3.1 Waramei Aggregate Deposit*

Table 5 shows the velocity-depth analysis for the Waramei River aggregate deposit. Corresponding travel time distance curves are given in the Appendix 4.

***Table 5.*** *Velocity-depth analysis results of the Waramei seismic refraction profiles.*

| Profile # | Shot Point | Layer | Gradient | Velocity (ms$^{-1}$) | Tint (s) | Xc (m) | Z (m) |
|---|---|---|---|---|---|---|---|
| 1 * | - 5 m | 1 | 0.00175 | 571.43 | 0.012 | 30 | 9.69 |
| | | 2 | 0.000733 | 1363.64 | | | |
| | 10 m | 1 | | | | | |
| | | 2 | | | | | |
| 2 | - 5 m | 1 | 0.0017 | 588.23 | 0.009 | 24 | 12 |
| | | 2 | 0.006 | 1666.67 | | | |
| | 10 m | 1 | 0.00105<br>0.0011 | 952.38<br>909.09 | | 19 | 9.50 |
| | | 2 | 0.0007 | 1428.57 | | | |
| 3 | - 5 m | 1 | 0.0011 | 909.10 | 0.003 | 34 | 17 |
| | | 2 | 0.00045 | 2222.22 | | | |
| | 10 m | 1 | 0.0012<br>0.0013 | 833.33<br>769.23 | | 25 | 12.5 |
| | | 2 | 0.00055 | | | | |
| 4 | - 5 m | 1 | 0.0009 | 111.11 | | 20 | 9.99 |
| | | 2 | 0.0005 | 2000.00 | | | |
| | 10 m | 1 | 0.00055 | 1818.18 | | 25 | 12.49 |
| | | 2 | 0.0003 | 1428.57 | | | |

* *Only the forward shot points are shown for the layer 1 velocities, due to significant error margin in the reverse shot point velocities for the same layer. Profile 1 only had 1 shot position at - 5 m*

The direct wave was not calculated as it was beyond the purpose of this survey. Analysis of the velocity curves shows there is some variation in the thickness of the layers, depending on the shot position. The top layer thickness ranging between 10 – 17 m for shot position – 5m, and a range of between 9.5 and 12.5 m for the 10 m shot position. The average depth of the deposit is about 11 m.

### *4.3.2 Wara Bili Aggregate Deposit*

The velocity-depth analysis of the Wara Bili seismic profile is given in Table 6. Two shot points were taken at - 5 m and 10 m positions. Analysis of the Wara Bili velocity seismic refraction curves produced higher velocities for the aggregate layer, and a depth range of between 12 and 17 m, to the second layer. The average depth of the deposit is about 14 m.

*Table 6. Velocity-depth analysis result for the Wara Bili seismic refraction profile.*

| Profile # | Shot Point | Layer | Gradient | Velocity (ms$^{-1}$) | Tint (s) | Xc (m) | Z (m) |
|---|---|---|---|---|---|---|---|
| 1 | 5 m | 1 | 0.00107 | 937.5 | | 35 | 17.5 |
| | | 2 | 0.0005 | 2000 | | | |
| | 10 m | 1 | 0.008 | 1250 | | 23 | 11.5 |
| | | 2 | 0.0005 | 2000 | | | |

The time-distance plot for the profile is given in Appendix 5.

## 4.4 Resource Estimation

Based on the calculated velocity-depth analysis, the volumes of the deposits are calculated as follows:

Waramei Deposit: V = Area x thickness
= 200,000 x 11
= 2,200,000 $m^3$

Bili Deposit: V = 20,000 x 14
= 280,000 $m^3$

These figures are the best estimates of the aggregate material available at the time of the survey. These do not take into account the sediment replenishment that normally occurs from time to time in dynamic river systems such as the Waramei and Wara Bili. The resource estimation figures are given in Table 7 below.

*Table 7. Resource estimation figures for the Waramei and Bili aggregate deposits.*

| | **Study Sites** | |
|---|---|---|
| | **Waramei** | **Bili** |
| Maximum Area ($m^2$) | 200,000 | 20,000 |
| Potential Area of Extraction ($m^2$) | 150,000 | 15,000 |
| Average depth (m) | 11 | 14 |
| Recommended maximum depth of extraction (m) | 4 | 3 |
| Total Resource ($m^3$) | 2,200,000 | 280,000 |
| Extractable Resource ($m^3$) | 600,000 | 45,000 |

# 5. DISCUSSION

## 5.1 Rock Types

The Waramei deposit is huge with the aggregate materials covering a total area of about 200,000 $m^3$. The deposit is composed predominantly of acidic to intermediate plutonic rocks with minor volcanic rocks and rare sedimentary types. About two thirds of the total rock material that occur at the Waramei deposit during the time of this investigation can be classified as gravel, of which approximately 30 % are considered oversize boulders. The Waramei deposit is about ten times bigger than the Wara Bili deposit. This is a significant advantage as a quarry operation will require a sizable volume of bigger boulders to crush for road metals and building material.

In comparison, the Wara Bili deposit is relatively small consisting predominantly of basalt rock fragments. Andesite, dacite and gabbro occur in minor amounts. By visual estimation, this aggregate deposit contains about equal amount of sand and gravel. The rock fragments are more rounded and smaller in size compared to those of the Waramei deposit. Oversize boulders are rare. These are typical characteristics of any river aggregate deposit that occurs at long distances from the rock sources. The mixed sand and gravel in Wara Bili are more suitable for the maintenance of gravel roads. The fresh, relatively bigger size gravels can be crushed and used for building and road construction.

## 5.2 Geotechnical Investigation

The PSD results indicate that the sediment samples collected from the Waramei and Wara Bili deposits are similar in terms of relative grain size. The results show both samples contain about 66 – 67 % gravel, 32 % sand, and a mere 1 – 2% silt and mud. While the visual estimation of the Waramei deposit is consistent with this grading result, there are some variations between the Wara Bili PSD results and the outcome of the visual estimation. This slight inconsistency is indicative of size variations within the aggregate deposit and can be attributed to the samples being collected from an area that may have contained more gravel than sand. In addition, the visual analysis is based on the estimate of what occurred on the entire surface of the aggregate deposit and down the walls of the sampling pits. Therefore the result of visual estimation is more representative of what actually occurred onsite at the time of the survey.

Due to the low content of silt and clay in the samples collected, the Natural Water Content (NWC) was the only parameter being measured in the Atterberg Limits test. The NWC of these samples are indicative of the water bearing capacity of each sample. The results show that the amount of water in each sample is generally low, however the Waramei sample contains significantly low amount of water compared to the Wara Bili sample.

The compaction test reveals that for the Waramei sample, it requires 5 % Optimum Moisture Content (OMC) to gain the Maximum Dry Density (MDD) of 2.1 $t/m^3$. For the Wara Bili sample a MDD of 2.17$t/m^3$ is achieved with 8 % of OMC. These results show that proper compaction can be achieved with low OMC for both samples. Additionally, the Waramei sample has higher dry density with very low moisture content, as opposed to the higher moisture content of the Wara Bili sample. This can be attributed to the presence of abundant, compact gravel fragments in the Waramei sample whereas the Wara Bili sample contains significant amount of sand and silt. The sand and silt can hold water for longer period hence increasing the moisture content of the sample.

There is significant difference in the CBR rating of the two samples. With a CBR of 80 %, the Waramei material can be classified as excellent for road sub-grades, which can be attributed to abundant gravely material in the sample. This indicates that the use of the Waramei material in road construction will require less material to achieve the optimum strength of the road. On the other hand, the Wara Bili sample with its 16 % CBR is regarded as moderately strong. This means that although the Wara Bili type materials can be used to strengthen the sub-grade, a huge volume of this material will be required to construct a suitably thicker road pavement to spread the loadings over a greater area. When the wheel loads are spread over a larger area of moderately strong sub-grade, the possibility of road deformation can potentially be avoided.

## 5.3 Seismic Profiling

Overall comparison of the results obtained from the analysis of the seismic profiles for the Waramei and the Wara Bili aggregate prospects show slight variations. Comparing the top layer, which is assumed here to be the aggregate layer, of both prospects, the Waramei River has a range of between 9.5 and 17 m, while the Wara Bili River has a slightly narrower range of between 11 and 17 m.

The aggregate layer, which is taken here to be the top layer, derives its seismic property from its bulk composition. The aggregate layer in both areas contains mostly sand, pebbles and cobbles. Since a higher percentage of the area is composed of sandy material, the velocity of the layer tends to indicate that of sandy material, which falls between 500 and 900 $m^{s-1}$. Most of the calculations tended to fall within this velocity. The Waramei River seismic Profile 3 and Profile 4, and the Wara Bili profile, however, yielded higher velocity values for the layers. The higher velocity values have been attributed to a slightly higher degree of compaction in both areas. This may be due to the presence of significant clay content.

There is some degree of variation in the depth and velocities for the Waramei aggregate prospects, probably as a result of the higher noise level within the area. This variation is not representative of the subsurface conditions. The high noise level is quite possible as the seismic profiles were conducted in patches of dry areas between the river pathways, hence the degree of uncertainty may be quite high.

In contrast, the seismic profiling of the Wara Bili aggregate deposit was conducted on one bank of the river hence the noise level was slightly lower. Further, the shot points were taken at least 50 m away from the river. Additionally, with data from only one seismic profile, the noise level at the Wara Bili Prospect cannot be ascertained thus the accuracy of the calculated results can possibly have a high error margin. Despite all these shortfalls, it is only possible to determine the volumes of the respective aggregate deposits based on the current data.

From observation, the Waramei aggregate deposit is within close proximity to, and runs parallel to the metamorphic Bewani mountain range. It is therefore possible that the aggregate layer may not be very thick. As determined from seismic refraction, this thickness could be anywhere between 9.5 and 17 m. Based on that observation, it is assumed that the aggregate layer increases in thickness away from the mountain range, which is downstream from the survey site.

The Wara Bili aggregate deposit seismic results suggest an average thickness of 14.5 m, which is thicker than the Waramei deposit. Although there is not enough seismic data to support this, it is anticipated that the weathered bedrock layer will be slightly deeper here since it occurs further down the tributaries of the Pual River trough.

## 5.4 Resource Estimation

The total volume of the respective aggregate deposits is calculated based on the measured area and the estimated thickness of the aggregate layer to the bedrock. It is the opinion of the authors that the total volume of each deposit could exceed the calculated volume, as the lateral extent of, for example the Waramei deposit, extends some distance from the survey area.

The rate of sediment replenishment is unknown and cannot be predicted to any degree of certainty; hence any additional river sediment recharge is not included in the resource figures given; however in a huge and dynamic river catchment system such as that of the Pual River, it is logical to expect significant sediment replenishment to occur at these two sites to replace those materials that are bound to be removed. This means that the available resource at each site only reveal the holding capacity of the river channel and does not necessarily indicate the total extractable resource.

The extractable resource for each deposit is calculated based on the potential area of extraction and the recommended maximum depth of extraction. The maximum depth of extraction at Wara Bili is reduced to 3 m due to the relatively narrow river channel and the close proximity of the access road and bridge to the proposed extraction site. Any intense aggregate extraction at the Wara Bili deposit needs to keep at least 30 m away from either side of the bridge. On the other hand, the Waramei River channel is wide hence a 4 m extraction depth is considered feasible.

## 6. CONCLUSION

The aggregate material at the Waramei River are suitable for a variety of road building applications. These include road base and sub-base materials as well as for pit run re-gravelling of roads. The material can be utilised for the building of road embankment and the strengthening of the road sub-grade. The bigger rock fragments can be crushed and used for manufacturing concrete and also used as sealing chips for tarsealed roads.

With a total resource of 2.2 million $m^3$, the Waramei site has excellent potential as the major source of sand and gravel for various construction applications. The characteristics of the Waramei deposit should generate interest among developers, especially for the construction of the Bewani-Amanab road and the maintenance or upgrading of the Vanimo-Bewani road; however, for any construction projects in Vanimo and nearby areas, the Waramei deposit is considered too far and with the current poor road conditions, the viability of a quarry operation cannot be guaranteed.

On the other hand, the Wara Bili aggregate deposit has significantly less resources and the geotechnical tests reveal that the aggregate material at Wara Bili are suitable for limited applications. The Wara Bili aggregate can be used as pit run re-gravelling of roads and as engineering fill for building of road embankment as well as for the strengthening of road sub-grade. Due to the low CBR value the Wara Bili material are considered less suitable for road base or sub-base of design road pavement; however, the Wara Bili River aggregate deposit is of sufficient quality to be used for the maintenance of the nearby existing roads including the mid-section of the Vanimo-Aitape road.

## 7. RECOMMENDATIONS

1) There appears little justification for the national and provincial government to import aggregate from outside Papua New Guinea (in Vanimo’s case from West Papua) since adequate local supply exist. In order to stimulate local aggregate resource development these deposits could be exploited.
2) The Waramei aggregate resource is strongly recommended to be used for the construction of the Bewani-Amanab road and the maintenance of the inland portion of the Vanimo-Bewani road.
3) Resource owners of these two sites, with the assistance of the West Sepik Provincial Government, must aspire to market and develop their aggregate resources. This can potentially become a significant income generating initiative.
4) A feasibility study of a quarry operation at Waramei to supply construction material to Vanimo may only be warranted if the condition of the Vanimo-Bewani road has greatly improved.
5) In the case of any quarry operation in one of these two sites, appropriate guidelines must be developed and enforced to ensure minimal environmental degradation occurs.

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Soil Compaction Handbook.

# APPENDIX 1

## Brief Description of Soil Test Methods

## 1. Atterberg Limits

The Atterberg limits are a basic measure of the nature of soils. Depending on the water content of the soil, it may appear in four states: solid, semi-solid, plastic and liquid. In each state the consistency and behaviour of a soil is different and thus so are its engineering properties. Thus, the boundary between each state can be defined based on a change in the soil's behaviour. The Atterberg limits can be used to distinguish between silt and clay, and it can distinguish between different types of silts and clays.

### 2. Soil Compaction

The compaction test is normally carried out on soil samples and can be defined as the method of mechanically increasing the density of soil. In construction, this is significant part of the building process. If performed improperly, settlement of the soil could occur and result in unnecessary maintenance cost or structure failure. Almost all types of building sites and construction projects utilise mechanical compaction technique (Soil Compaction Handbook).

The geotechnical properties (swell potential, compressive strength, CBR, permeability, compressibility, etc) of soil are dependent on the moisture and density at which the soil is compacted. Generally, a high level of compaction of soil enhances the geotechnical behaviour of the soil. In road construction, while the top layer of a road will provide the necessary traction and also some stability, the sub-base and the base below the road surface will need to be able to distribute the weight onto the sub-grade. Thus, the strength of the material bellow the surface layer is critical for the stability of the road.

### 3. California Bearing Ratio

The California Bearing Ratio (CBR) test is a simple strength test that compares the bearing capacity of a material with that of a well-graded crushed stone (thus, a high quality crushed stone material should have a CBR of 100 %). It is a penetration test for evaluation of the mechanical strength of road sub-grades. The CBR can also be used for measuring the load-bearing capacity of unimproved airstrips or for soils under paved airstrips. It can be explained in simple terms as, the harder the surface the higher the CBR rating.

Additionally, the CBR test is a way of putting a figure on the strength of sub-grade. The test is done in a standard manner so it is possible to compare the strengths of different sub-grade materials and using these figures as a means of designing the road pavement required for a particular strength of sub-grade. The stronger the sub-grade (the higher the CBR reading) the less thick it is necessary to design and construct the road pavement, this gives a considerable cost saving. Conversely if CBR testing indicates the sub-grade is weak (a low CBR reading) we must construct a suitable thicker road pavement to spread the wheel load over a greater area of the weak sub-grade in order that the weak sub-grade material is not deformed, causing the road pavement to fail.

The test is performed by measuring the pressure required to penetrate a soil sample with a plunger of standard area. The measured pressure is then divided by the pressure required to achieve an equal penetration on a standard crushed rock material. The test can be performed on laboratory-prepared samples or in the field. The CBR test is described in ASTM Standards D1883 and D4429, and American Association of State Highway and Transportation Officials (AASHTO) T193.

# APPENDIX 2

## The geographic coordinates and direction of the seismic profiles conducted within the selected study areas of Waramei and Wara Bili Rivers

| Study Site | Profile ID | Longitude | Latitude | Profile Direction (True North) |
|---|---|---|---|---|
| Waramei River | Waramei 1 | 141°10’19.7”E | 3°5’2.0”S | 040° |
| | Waramei 2 | 141°10’20.8”E | 3°5’0.4”S | 050° |
| | Waramei 3 | 141°10’21.9”E | 3°5’0.4”S | 086° |
| | Waramei 4 | 141°10’15.5”E | 3°5’5.3”S | 242° |
| Wara Bili River | Bili 1 | 141°26’16.5”E | 2°54’17.8”S | 260° |

# APPENDIX 3

## Results of the Waramei and Wara Bili Aggregates Laboratory Tests

DEPARTMENT OF WORKS
HEADQUARTERS
SCIENCE AND TECHNOLOGY BRANCH
MATERIALS TESTING LABORATORY
P. O. BOX 1108, BOROKO, NCD, PNG
TEL: (675) 324 1372 FAX: (675) 324 1373

Page No. 1 of 1

| | | | |
|---|---|---|---|
| Client: | SOPAC SECRETARIAT | Job No: | 2006-P-S02 |
| Project: | GENERAL INFORMATION | Report No: | |
| Location: | WEST SEPIK | Sampled By: | Client |
| Test Procedures: | AS 1289. 3.1.1, 3.1.2, 3.2.1, 3.3.1, 3.4.1 ,3.6.1 5.1.1 and 6.1.1 | Sampling Date: | Unknown |

**LABORATORY TEST RESULTS**

| Sample No. | Location Depth (m) | Material Description | Particle Size Distribution | | | Atterberg Limits | | | | | Compaction | | In-Situ California Bearing Ratio | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Cl/Si % | Sa % | Gr % | Nat % | LL % | PL % | PI % | LS % | MDD t/m3 | Opt w(%) | CBR % | DD t/m3 | w % |
| 2006 / 17 | Bili 1 & 2 | Sandy GRAVEL with a trace of Silt | 2 | 32 | 66 | 5.2 | not | applicable | | | 2.17 | 8 | 16 | 2.064 | 6.6 |
| 2006 / 18 | WAAMAE | Sandy GRAVEL with a trace of Silt | 1 | 32 | 67 | 3.5 | not | applicable | | | 2.095 | 5 | 80 | 2.136 | 0.4 |

Remarks:

PNGLAS

PNGLAS Accredited Laboratory
Number: 10

This laboratory is accredited by the Papua New Guinea Laboratory Accreditation Scheme. The tests reported herein have been performed in accordance with its scope of accreditation and PNGLAS requirements which include the requirements of ISO/IEC 17025. This document shall not be

18.4.2006.

(P. EVOA) Date
Laboratory Manager

PNGLAS.REG.0010/87/01/23
*Revised 28/01/05 wkg*

**KEY:**

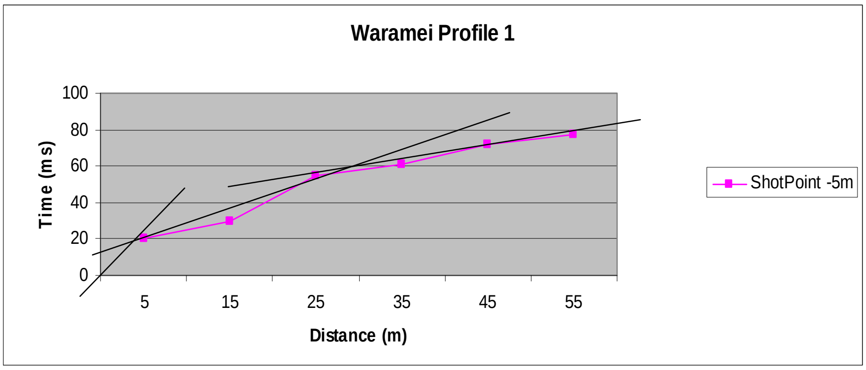
| | | | |
|---|---|---|---|
| Cl/Si | = Clay / Silt | LS | = Linear Shrinkages |
| Sa | = Sand | MDD | = Maximum Dry Density |
| LL | = Liquid Limits | OPT w(%) | = Optimum Moisture Content |
| PL | = Plastic Limits | CBR | = California Bearing Ratio |
| Gr | = Gravel | DD | = Dry Density |
| PI | = Plasticity Index | w | = Moisture |

# APPENDIX 4

## Seismic Profile Data for the Waramei Aggregate Deposit

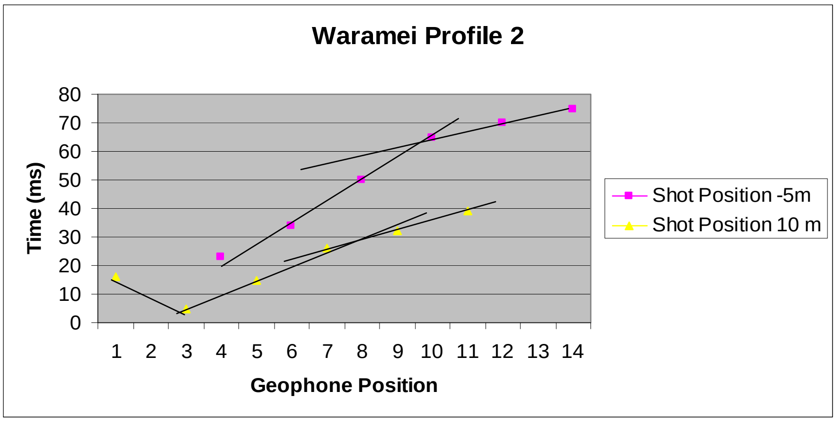
Profile 1 Waramei
Shot Position -5m

| Geophone # | Distance (m) | Time (ms) |
|---|---|---|
| 1 | 5 | 20 |
| 2 | 15 | 30 |
| 3 | 25 | 55 |
| 4 | 35 | 61 |
| 5 | 45 | 72 |
| 6 | 55 | 77 |



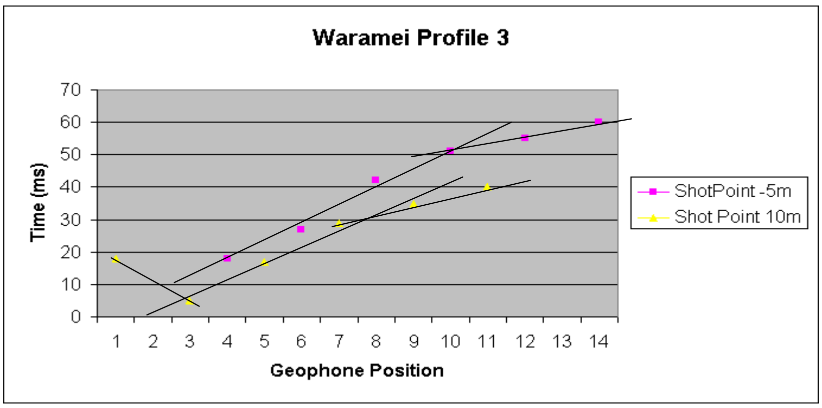

Profile 2 Waramei

| Geophone # | Distance (m) | Time (ms) |
|---|---|---|
| Shot position -5m | | 10m |
| -10 | | 16 |
| -5 | | |
| 0 | | 5 |
| 5 | 23 | |
| 10 | | 15 |
| 15 | 34 | |
| 20 | | 26 |
| 25 | 50 | |
| 30 | | 32 |
| 35 | 65 | |
| 40 | | 39 |
| 45 | 70 | |
| 50 | | |
| 55 | 75 | |

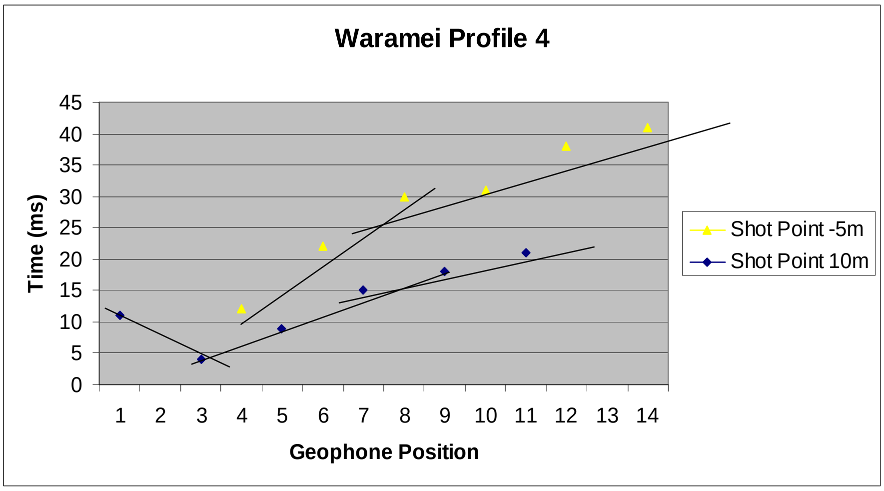



Profile 3 Waramei

| Geophone # | Distance (m) | Time (ms) |
|---|---|---|
| Shot position -5m | | 10m |
| -10 | | 18 |
| -5 | | |
| 0 | | 5 |
| 5 | 18 | |
| 10 | | 17 |
| 15 | 27 | |
| 20 | | 29 |
| 25 | 42 | |
| 30 | | 35 |
| 35 | 51 | |
| 40 | | 40 |
| 45 | 55 | |
| 50 | | |
| 55 | 60 | |



| Profile 4 | Waramei | |
|---|---|---|
| Geophone # | Distance (m) | Time (ms) |
| Shot position | -5m | 10m |
| -10 | | 11 |
| -5 | | |
| 0 | | 4 |
| 5 | 12 | |
| 10 | | 9 |
| 15 | 22 | |
| 20 | | 15 |
| 25 | 30 | |
| 30 | | 18 |
| 35 | 31 | |
| 40 | | 21 |
| 45 | 38 | |
| 50 | | |
| 55 | 41 | |



# APPENDIX 5

## Seismic Profile Data for the Wara Bili Aggregate Deposit

| Profile 1 | Wara Bili | |
|---|---|---|
| Geophone # | Distance (m) | Time (ms) |
| Shot position -5m | | 10m |
| -10 | | 14 |
| -5 | | |
| 0 | | 3 |
| 5 | 11 | |
| 10 | | 12 |
| 15 | 25 | |
| 20 | | 22 |
| 25 | 34 | |
| 30 | | 28 |
| 35 | 43 | |
| 40 | | 33 |
| 45 | 48 | |
| 50 | | |
| 55 | 53 | |