University of Natural Resources and Life Sciences, Vienna

Department of Water, Atmosphere and Environment

Institute of Hydraulics and Rural Water Management

„Evaluation of agricultural Conditions of three ungauged Watersheds in Vanuatu“

Master's Thesis

Submitted by:	Mag. Schabschneider, Helmut
Enrolment Number:	h0226835
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Supervisors:	Univ.Prof.Dipl.-Ing.Dr.nat.techn. Willibald Loiskandl
	Dipl.-Ing. Dr. nat. techn. Dominik Ruffeis

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Abstract

Within the project “Generation and adaptation of improved agricultural technologies to mitigate climate change-imposed risks to food production within vulnerable smallholder farming communities in Western Pacific countries“, the work at hand examined the agricultural conditions at three target-communities in Vanuatu, with special focus on water-related problems under consideration of new risks attributed to climate change. During a stay in Vanuatu over several months, existing problems have been assessed on site and primary and secondary data on meteorology, hydrology, pedology, geology, topography, agriculture, water- and land use has been collected in order to define the agricultural conditions and the relation of the reported problems to climate change. Furthermore, informal interviews were conducted with the farmers to complete the picture.

The gathered data has then been processed to give a comprehensive picture of the conditions and water-related problems at the study sites, and Vanuatu in general. The material is presented in the form of maps, soil descriptions, descriptions of the agricultural system, descriptions of areas prone to water deficit respectively flooding/water logging, meteorological specifications, but it also includes information on Vanuatu's historical agricultural systems and existing policies concerning climate change and water.

Based on these findings, suitable strategies, technologies and interventions that can increase the resilience of Vanuatu's small-scale farmers are proposed.

Zusammenfassung

Mit der vorliegenden Arbeit wurden im Rahmen des Projekts "Generation and adaptation of improved agricultural technologies to mitigate climate change-imposed risks to food production within vulnerable smallholder farming communities in Western Pacific countries" die landwirtschaftlichen Bedingungen in drei Untersuchungsgebieten in Vanuatu erhoben. Spezieller Fokus lag hierbei auf Probleme in Relation zu Wasser, unter Berücksichtigung neuer, dem Klimawandel zugeschriebener Risiken. Während eines mehrmonatigen Aufenthalts in Vanuatu wurden die Probleme vor Ort untersucht, und Primär- und Sekundärdaten bezüglich Meteorologie, Hydrologie, Pedologie, Geologie, Topographie, Landwirtschaft, Wasser- und Landnutzung wurden gesammelt um die landwirtschaftlichen Bedingungen zu definieren und in Bezug zum Klimawandel zu setzen. Außerdem wurden informelle Interviews mit den Bauern geführt um das Bild abzurunden.

Die Weiterverarbeitung der gewonnenen Daten erfolgte mit dem Ziel, ein umfassendes Bild der Bedingungen und wasserbezogenen Probleme in den Untersuchungsgebieten, aber auch in Vanuatu im Allgemeinen, zu schaffen. Die so erhaltenen Materialien werden in Form von Übersichtskarten, Bodenbeschreibungen, Beschreibungen des landwirtschaftlichen Systems, Beschreibung von Gebieten mit Tendenz zu Trockenheit beziehungsweise Staunässe/Überflutung, und meteorologischen Kenndaten dargestellt, sie beinhalten darüber hinaus aber auch Informationen zu Vanuatus traditioneller Landwirtschaft und existierender Strategien bezüglich Klimawandel und Wasser.

Basierend auf diese Ergebnisse werden abschließend Strategien, Technologien und Interventionen vorgeschlagen, die die Resilienz von Vanuatus Kleinbauern erhöhen können.

Danksagung

Dass ich mit der vorliegenden Arbeit mein Studium der Kulturtechnik und Wasserwirtschaft abschließen kann ist mitunter durchaus überraschend. Nicht nur, weil ich dazu selten den direkten Weg gegangen bin und es meist nicht offensichtlich war, dass ich dem Abschluss des Studiums tatsächlich nicht abgeneigt bin. Zu guter Letzt hätte vor allem meine Familie wohl nicht immer auf meine Wiederkehr von der anderen Seite der Welt gewettet. Deshalb gebührt ihr mein besonderer Dank, denn obwohl mein Schaffen oft für mein Umfeld mindestens ebenso undurchsichtig war wie für mich, hat mich meine Familie von Anbeginn und auch im Laufe meines Studiums immer bedingungslos unterstützt und meine Pläne verständnisvoll akzeptiert.

Ähnliches gilt für meinen Betreuer Herrn Univ.Prof. Dipl.-Ing. Dr.nat.techn. Willibald Loiskandl, der mich im Laufe meines Studiums immer wieder unterstützt und sich für mich engagiert hat, was inzwischen eine langjährige angenehme Zusammenarbeit zur Folge hat. Mein Zweitbetreuer Dipl.-Ing. Dr. nat. techn. Dominik Ruffeis stand mir ebenso schon bei vorangegangenen Projekten zur Seite, und hat mich auch in Melanesien dabei unterstützt, mich in dieser neuen Umgebung zurechtzufinden und meine Arbeit zu einem guten Ende zu bringen.

Zu guter Letzt möchte ich mich noch bei meinen Freunden und Mitbewohnern bedanken, die in schweren Zeiten immer wieder für mich da waren und mich auch regelmäßig mit der einen oder anderen netten Aufmerksamkeit ermuntert haben!

Special thanks also go out to the NARI- staff, who gave me the possibility to be part of this project, especially Dr. Workneh Ayalew, who helped me with initial guidance when I arrived in Vanuatu.

Antap long hem mi wantem telem tankyu tumas long ol man Vanuatu we ol i bin saportem mi long kantri blong olgeta, mekem se mi bin harem olsem mi stap long kantri blong mi nomo! Ol memba blong DARD i bin olsem famili blong mi, olgeta i bin helpem mi taem mi bin nidim wan samting, mo olgeta i no bin kros tumas taem mi konfus!

Finalement, je veux exprimer ma gratitude au personnel du VARTC, à Tagabe autant qu'à Saraoutou, pour avoir mis votre infrastructure à ma disposition et m'avoir aidé avec du data et même avec des conseils personnaux!

Pledge of Integrity

I hereby certify that the work presented in this thesis is my own, that all work performed by others is appropriately declared and cited, and that no sources other than those listed were used.

Place:

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Content

1 Introduction

1.1 Motivation

In the course of the EU- funded project "Generation and adaptation of improved agricultural technologies to mitigate climate change-imposed risks to food production within vulnerable smallholder farming communities in Western Pacific countries ", an in-depth assessment of water related problems with regard to farming in Vanuatu had to be carried out. The overall objective of this project is to mitigate climate change associated risks to food security and livelihoods for vulnerable smallholder farming communities, with special focus on improving the food production capacity of smallholder farming areas vulnerable to suffer from climate change induced phenomena.

The project focuses on three climate change- induced scenarios:

- soil moisture deficit (dry conditions)
- excessive soil moisture (wet conditions)
- worsening soil salinity conditions

In Vanuatu, three sites were chosen earlier in this project to study these scenarios, the respective communities are Malafau and Siviri on Efate island, and Middle Bush on Tanna island. According to Rapid Assessments and Focus Group Discussions that had been carried out prior to this work, involving stakeholders from these communities, farmers experience the following problems there:

- Malafau: excess soil moisture (stress) and water logging on cropping plots
- Siviri: soil moisture deficit (stress), and other soil water constraints
- Middle Bush: seasonal excessive soil moisture and water logging (stress) as well as soil moisture deficit during the peak dry season.

During a stay in Vanuatu over several months, these problems had been assessed on site and the hydrological and agricultural conditions on those three sites had been examined.

1.2 Research Goal & Objectives

Research Goal:

The research goal is to specify how farmers are suffering from water related problems in an agricultural context, and to identify and define the parameters that lead to these issues and relate them to climate change. Finally, strategies and techniques for dealing with these problems are to be suggested.

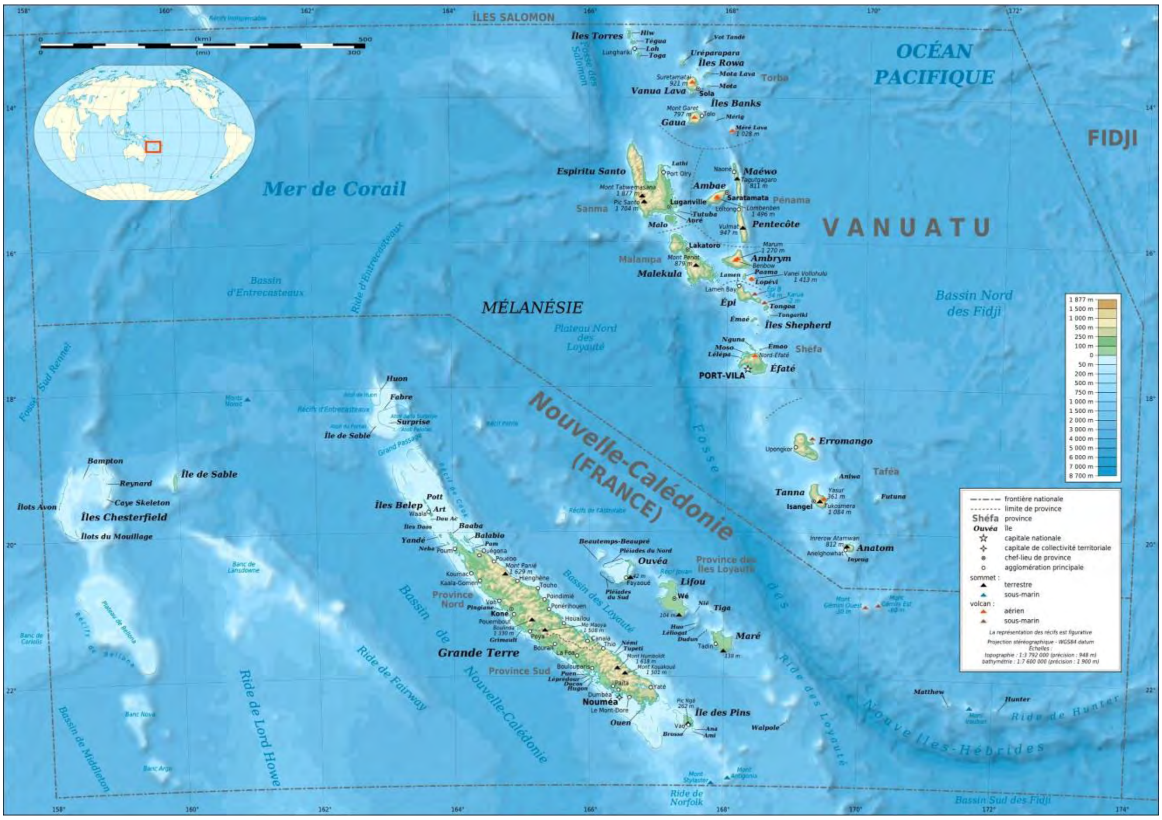
Objectives:

- To study evidences for, and potential risks related to climate change in Vanuatu.
- To assess the environmental conditions with respect to water, soil, land use at the selected study sites
- To map land use, soil types, water sources (used and potential ones) at the sites, including locations vulnerable to draught, flooding and water logging.
- To establish a database on soil and water
- develop recommendations that address known problems which farmers are experiencing with regard to the specific scenarios.

2 Background

2.1 Geographical Location of Vanuatu

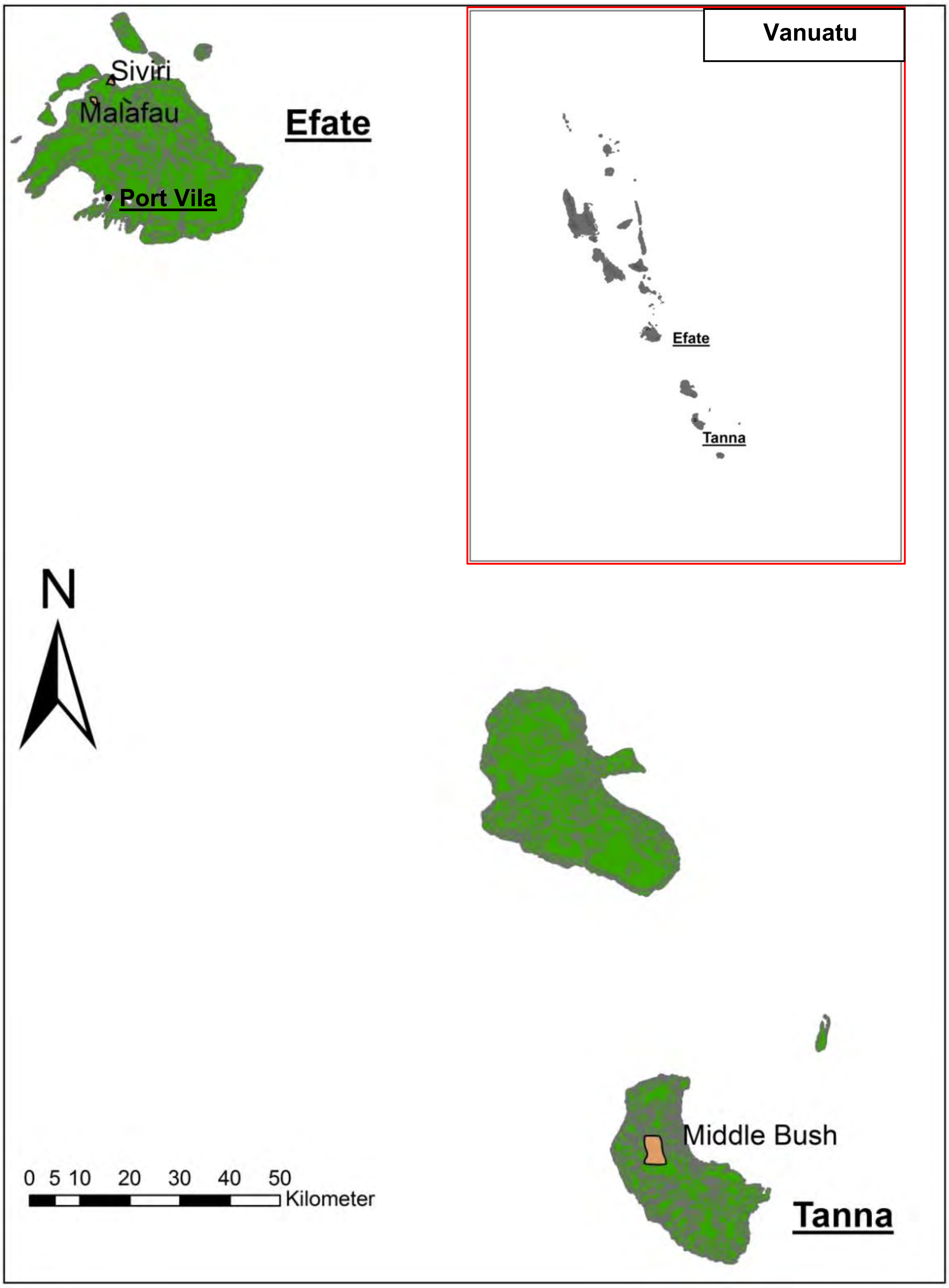
Vanuatu is a country in Melanesia, located around 168° east and 16° south (Picture 1). The archipelago consists of around 80 islands that stretch out over 1200 km primarily from north to south in an approximate Y- shape.



Picture 1: Bathymetric and topographic map of New Caledonia and Vanuatu, Oceania (Gaba, 2009) *Note that there is an on-going dispute between New Caledonia and Vanuatu concerning Matthew island and Hunter island.*

2.2 Study Sites

Of the three study sites two (Siviri and Malafau) are located on Efate island, which is a central island on which also the capital Port Vila is situated. The third site is located on central Tanna, an island about 200 km south of Efate (Picture 29):



Picture 2: Location of the study sites within Vanuatu

2.2.1 Siviri

Siviri is a small village in the north of Efate, at Undine Bay (Picture 2). This site as it is defined in the project consists of four villages: Siviri, Paunagisu, Emau and Sama.

The village Siviri itself is situated on the first limestone terrace of the island (around 5 m above sea level, at 17°31'S/168°19'E).

2.2.2 Malafau

Malafau is a small and new village in northern Efate (Picture 2), the area became populated around 2005 after an exodus of a part of the villagers of Siviri due to a church conflict. The study site itself comprises of four villages: Moso (on Moso island), Malafau, Tanoliu and Meten.

2.2.3 Middle Bush

Middle Bush is a rather densely populated region in the centre of the island of Tanna (Picture 2). Located more than 210 km south of the other two study sites, it is situated on a high plane at more than 300 m above sea level and comprises the following villages, located around 19°27'S/169°18'E:

Lamak, Launapheuw, Loulipang, Launamilo, Loupikas, Lauaru, Lenemita, Lowehau, Louwaula, Loujiaru, Euel, Lenaken, Lamak, Jupik (Epuk), Lounaukiam Apen, Loumiai, Laul, Lounauru, Launalou, Lounauru, Latuan, Lowiaru, Ilimanga, Lamnatu, Lamneau, Lounuwao Tuan, Kaunamelkin, Lanupu Pin Nipin (spelling of the villages in RED not sure).

2.3 Climate Change and its likely Manifestations in Melanesia

Climate Change can have as many effects as reasons, and as stated by BARNETT (2001), the prediction of its effects is characterized by high uncertainties. Apart from the prediction of the overall change of the world's climate, its local characteristics are highly disputed. In the south-west Pacific, the anticipated effects of climate change include:

- Increased temperature
- Increased atmospheric CO_2
- Insufficient soil moisture/precipitation
- Excess moisture/precipitation
- Sea level rise
- Increased cyclone/storm intensity and frequency

In Vanuatu, the main issues of climate change are ENSO-(El Niño/Southern Oscillation) related problems with insufficient precipitation in years with intensified El Niño- phases and excess moisture in wet years with intensified La Niña phases respectively. Also, the intensity of cyclones is reported to have increased and sea level rise may also cause problems on some islands, although Vanuatu mainly consists of elevated islands.

ENSO is a phenomenon associated with El Niño and La Niña, two terms that describe natural phases of unusually high water temperatures (El Niño) or unusually low water temperatures (La Niña) that occasionally occur along the Pacific coast of Middle- and South America (Figure 1, Figure 2).

These temperature distributions are influencing wind, pressure, and rainfall patterns. During El Niño conditions, the balance point of rainfall over the pacific moves east, during La Niña the western Pacific receives more rainfall than usual. Typically, 3 to 7 years lie between two El Niño/ La Niña- Events, and they last for about a year. "Southern Oscillation" refers to local differences in sea level pressure that occur between the Eastern and western tropical Pacific due to El Niño/ La Niña ("IRI Home Overview of the ENSO System," n.d.)

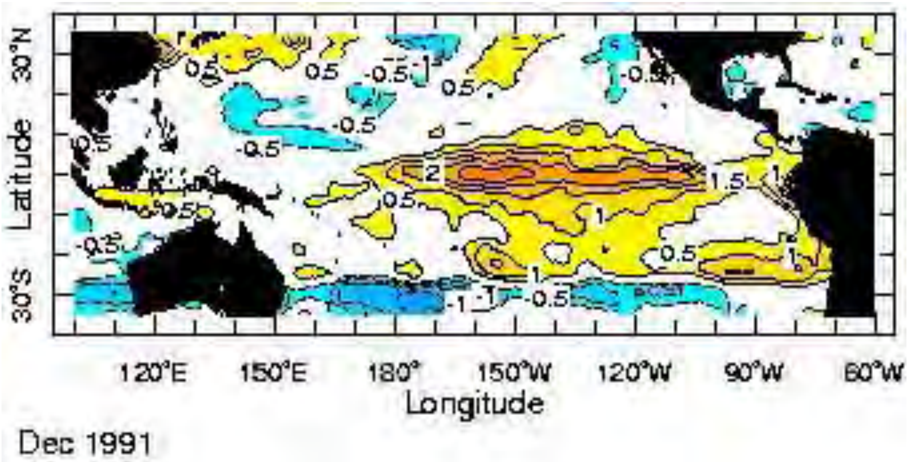


Figure 1: Surface water temperature deviation from average during a typical El Niño-phase (picture obtained from the International Research Institute for Climate and Society ("IRI Home Overview of the ENSO System," n.d.))

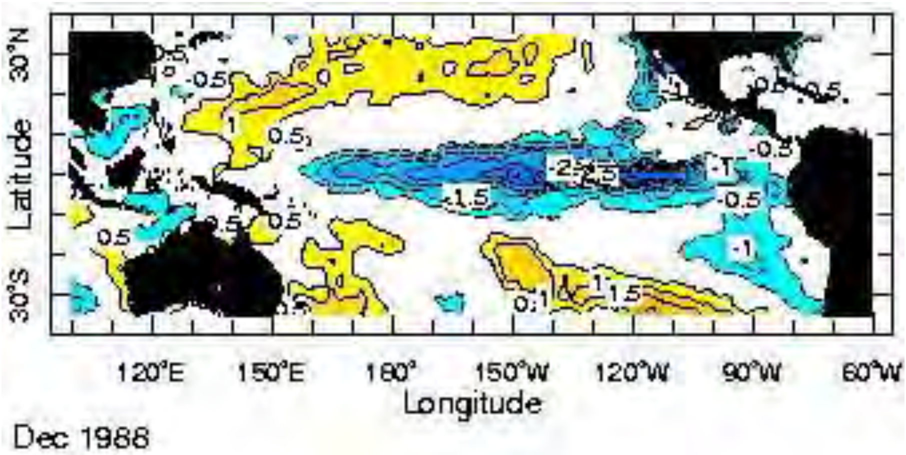


Figure 2: : Surface water temperature deviation from average during a typical La Niña-phase (picture obtained from the International Research Institute for Climate and Society ("IRI Home Overview of the ENSO System," n.d.))

PCCSP Climate Futures is a free web-based tool that provides access to climate change projections for 14 pacific countries and East Timor, including Vanuatu (Whetton P, Hennessy K, Clarke J, McInnes K, 2012). These projections are based on global climate models. Out of 24 models published in the IPCC 4th Assessment Report: Climate Change 2007, 18 have been judged by the authors to be reliable in this region. On the PCCSP Climate Futures- webpage (http://www.pacificclimatefutures.net), the projections for each of these countries are provided. It allows users to explore the likelihood of future changes in temperature, rainfall, wind, sunshine, humidity and evaporation based on 20-year time periods around 2030, 2055 and 2090 for three different underlying greenhouse gas emission scenarios (low (B1), medium (A1B) and high (A2)). These scenarios are three representative scenarios out of the future greenhouse gas emission scenarios described in the "IPCC Special Report on Emissions Scenarios" (IPCC, 2000).

The average over the 18 model-outputs on temperature and rainfall can be formed, and for Vanuatu the projections can be seen in Figure 3. Over the next 80 years, depending on the emission scenario, the mean temperature is expected to rise between 1.4 and 2.6 degrees. Regarding rainfall, the models give a more heterogeneous picture: for the low-emission and the moderate-emission scenario, the rainfall is projected to go down or up by 0.5 % respectively. Only for the high-emission scenario the amount of rainfall is expected to increase considerably, namely by over 5 %. Given the fact that the scenarios B1 and A1B lead to significant temperature increases, but the precipitation might even go down, water stress for plants might increase over the next decades. Also excess water can become a more serious issue, but the detailed effects of the changes will depend on the temporal distribution of the temperature and precipitation changes (hence the forming of the seasons).

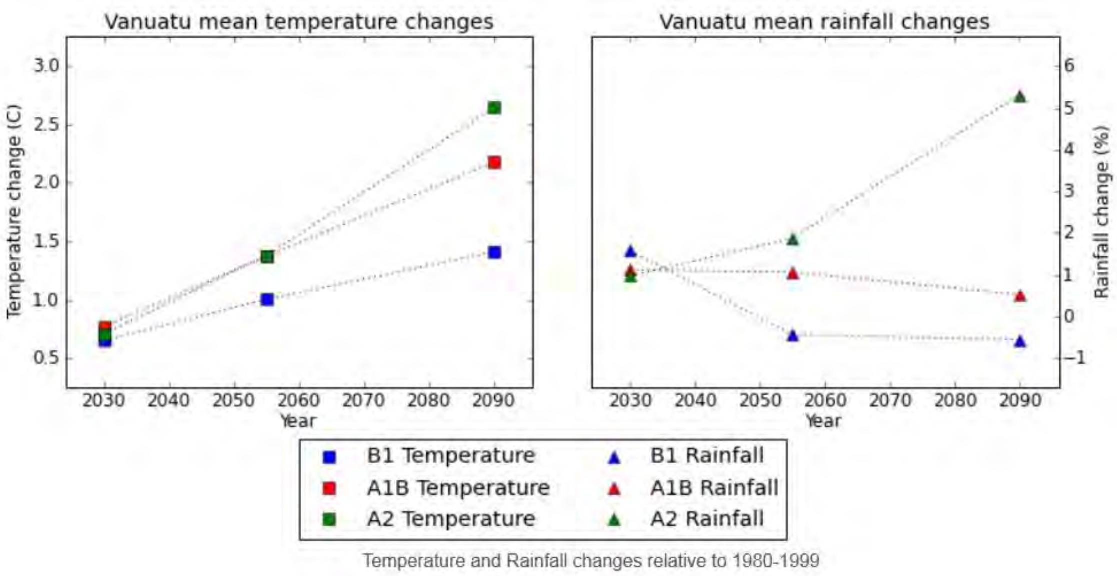


Figure 3: Vanuatu mean projected temperature and rainfall changes (after PCCSP Climate Futures(http://www.pacificclimatefutures.net))

2.4 Traditional Agriculture in Vanuatu

The following section is based on the probably most comprehensive book about agriculture in Vanuatu, BARRY WEIGHTMAN's "Agriculture in Vanuatu" (Weightman, 1989).

2.4.1 History

Vanuatu became populated about four to five thousand years ago, and men settled about two thousand years later. The first European who reportedly set foot on the archipelago was the Portuguese de Quiros, who landed in Big Bay on the island he named Espiritu Santo, believing that he had discovered the big southern continent Terra Australis Incognita. But it was not until 1825, when sandalwood was discovered on Erromango, that foreigners became interested in Vanuatu. Hence, written history, apart from a few observations while sailing by (by James Cook and Bougainville in the 60's and 70's of the 18th century, and a few other navigators later on), begins only by that time, when white settlers and missionaries wrote down their impressions.

By that time, the population of Vanuatu might have been around a quarter of a million (just like today), but also numbers as high as one million have been published (compare Siméoni & Lebot, 2012). The availability of vast good agricultural land permitted fallowing cycles with only one season of agricultural use and many years of fallowing, a system that provided great stability and resistance to plant pests, diseases and soil erosion. Even though this form of agriculture might seem extensive, without any tillage and little irrigation being practiced, large surpluses used to be produced. These surpluses were used in case hurricanes, droughts or other disasters destroyed the food gardens, or, to regionally varying but always high extents, for customary purposes, guaranteeing peace with the spirits and the neighbouring groups.

The arrival of white settlers then brought huge changes to Vanuatu, most of them affecting the agricultural system too. Maybe the most dramatic change was the population decline until the 1930's: Data from the Vanuatu National Census of Population and Housing, which was carried out for the fifth time in 2009, suggests that the population of Vanuatu was well below 40.000 (when extrapolating the exponential growth since then even below 35.000) around 1930 (see Figure 4).

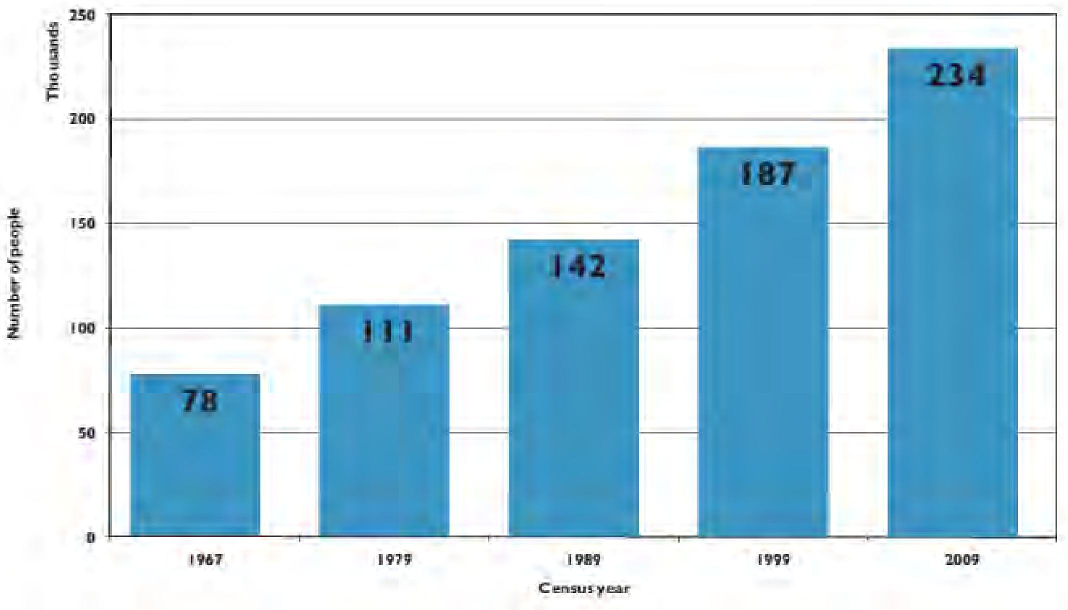


Figure 4: Population of Vanuatu (from Vanuatu National Statistics Office, 2009)

This population decline had two main reasons: Firstly, the introduction of new diseases by the new arrivals, and secondly the so- called "Blackbirding", the partly voluntary and partly forced or at least through trickery accomplished exodus of Ni- Vanuatu workers to plantations in Australia and Fidji.

The resulting small population density had various consequences for Vanuatu's agriculture. For the plantations (introduced around 1870, firstly producing copra and cotton, later also maize, cocoa and coffee) it meant a shortage of labour, and because the majority of the population was independent of wage labour, most of the plantations could not recruit enough workers to persist. For the smallholder farmers all this resulted in the availability of enough land to abandon some farming techniques that used to be helpful in times of denser population, like terraced farming plots and irrigation channels.

Another related phenomenon that still remains in Vanuatu is the resettlement of "man bush", i.e. clans living in the centre of the islands (in contrast to "man solwota", the coastal inhabitants), to coastal areas. Enforced by missionaries, whole villages were made to move from central areas to the seashore. This, together with the blackening of old habits by some churches and the simple loss of people that used to carry customary knowledge, led to a loss of established farming techniques that is hard to quantify. In 1882, Reverend JOHN INGLIS wrote (Inglis, 1882): "On Aneithum there is a large system of irrigation, but of an ancient date; long channels cut as scientifically as if levels and inclines had been laid down by the surveyor with the aid of his theodolite. If you ask the natives who made this old channels for irrigation, they tell you they do not know; they suppose that they were made by the *natmases*, that this, the gods, in other words, the spirits of their forefathers, which, of course, means their forefathers themselves". There exist many reports by the early arrivals which praise the sophisticated irrigation structures in Vanuatu, but as this report already indicates, the practice of these techniques began to vanish already in the 19th century. Nowadays only a few irrigated taro plots are left, mainly in south and central Santo and Maewo.

What definitely has to be included in all considerations about agriculture or generally life in Vanuatu is *kastom* (i.e. traditional culture), including magic. Planting seasons, weather phenomena, the arrangements of plants in the garden, everything has a kastom- explanation. There are special villagers responsible for the dwelling of the most sacred tuber (yam), the yam-master, there are taro- masters, *bungee jumping* originates from a kastom in Pentecost which is an initiation ceremony that also guarantees a good yam harvest. On some islands, women are not allowed to enter the food garden during their period or else the roots of the plants would rot (Calandra, 2013), and on Tanna kava must not be prepared by males who have already touched a woman sexually, just to give a few examples.

2.4.2 Food Crops and Animal Husbandry

The ownership of land in Vanuatu is an important issue (beyond agriculture), the usage rights for gardening and conditions for entering land were and still are strictly regulated by kastom. Traditional agriculture in Vanuatu is best described by being horticultural. Usually, a family owns a piece of land, on which the family members would clear lots of varying size (one to several ares) by burning and cutting with the bush knife, or where available with axes or chain saws. The most common form of usage is the annual multi- crop food garden, on which mainly different root crops are planted in locally varying patterns, mainly following kastom guidelines. Some areas might be tilled, that is dug with a stick, to permit certain tubers to grow extraordinarily large in order to use it for kastom purposes. After a few seasons, depending primarily on the population pressure, the land would be left to lie fallow, but it can partly be used further on when banana or manioc are still thriving while being overgrown progressively (see Picture 3).

Picture 3: Example of a multi-crop garden that is left fallow but partly still used

The early arrivals brought, amongst other food crops, yam, taro, bananas, sugar cane, island cabbage, edible nuts and breadfruit to Vanuatu. Also pigs, poultry and possibly kava were introduced in pre- historic times. Varieties of banana and coconut are most probably indigenous, sweet potato and manioc were introduced later (before 1850), together with more sweet varieties of banana. White settlers also brought maize and cocoa and coffee in order to cultivate it for export on plantations, but outside the few remaining plantations only maize is used in moderate amounts by the locals, on some islands cocoa and coffee is still used as a cash crop but there is no tradition of processing it for private use.

Cattle were introduced to Vanuatu already in 1845, but it has hardly been accepted by the locals. Mainly it was introduced to produce milk for the new settlers, but it became also a popular mean to control undergrowth of the coconut plantations.

Pigs came with the first settlers in ancient times, and they have always been of great importance to the ni- Vanuatu. Pigs are highly valued as source of meat, but above all they are important for ceremonial killings at feasts, at grade taking ceremonies or as status symbol of a chief. Not for nothing Vanuatu's flag also features an icon of a pig tusk. The pigs are usually kept in small wooden cages (sometimes elevated) close to the houses but they are frequently allowed to move freely (the former was presumably not the case before the arrival of the missionaries, who reportedly put great effort into keeping away the pigs from churches and bedrooms). This demanded the construction of remarkable fences around the food gardens in former times, and it is still an issue for present day agriculture. Nowadays the pigs are interbred with European races.

Poultry is also very common in Vanuatu, and the bush fowl is also known to inhabit Vanuatu since ancient times. The village fowl is also a result of interbreeding with the breeds brought by Europeans, and they commonly accompany most houses in Vanuatu. They are almost exclusively used as source of meat, as eggs use to be lost to dogs, rats or other faster consumers.

Additionally, goats and sheep were introduced to Vanuatu in the 19th century with moderate sustainable success. Here and there a village still features one or two goats or far less frequently sheep. Horses were introduced as means of transport, and they are still used on Santo and above all Tanna, where wild herds still thrive.

2.5 Recent Challenges for Vanuatu's Agriculture

2.5.1 Socio- economic Issues

The most recent dramatic change in Vanuatu's society is most probably the growing participation of ni- Vanuatu in cash- economy. Since primary school is free in Vanuatu, until recently there weren't many needs people in the rural areas couldn't still without money. Even more, there were, in many areas still are, hardly any options to spend money. One factor that does now enforce the growing dependency on cash is the introduction of mobile phones to Vanuatu. The network is still expanding, and there are obvious effects on people's handling of cash: First, a mobile phone and all the necessary accessories (like a solar power station to charge it) are a considerable investment. And then, this mean of communication gives you many more opportunities to take part in the cash economy, which are also promoted consequently by the providers.

This is amongst the reasons why there is a growing tendency for mainly youngsters to move to the cities. Also the little influence of kastom on the city life is a reason, on the islands the traditional regulations can be very strict, and many youngsters seek to escape it. But generally, most inhabitants of Vila would still mention an outer island when being asked where they came from, and many youngsters would tell that they are only here for a while, in order to make money, but that they are planning to return. But in fact, chances for making quick big money in the cities are rare (there is hardly any industry), and so people tend to stay longer without registration, hence the number of people living in the cities is growing faster than the census data on urban population might suggest (the Vanuatu National Census of 2009 gives a urban to rural drift (Vanuatu National Statistics Office, 2009)).

The high number of people in the cities who cannot produce their own food and the higher need for cash in the rural areas is one reason for the high portion of cash crops being grown. In case of a loss of parts of the yield this means that there is less staple food available for backup. Also, decreasing availability of labour due to migration to Port Vila is reported on Efate.

But even in the rural areas increasing population pressure can be observed. Due to the on-going church-driven practice of resettling "man bush" to the seaside, traditional farming systems are left behind and many people have to do farming on sites they are not used to, competing with their neighbours for land they have no kastom ownership of. Also, in some villages, rival churches cause a division of the inhabitants, and in some cases a part of the villagers is made to move to a probably less suitable agricultural land.

Also, in former times large surpluses used to be produced for kastom purposes. These surpluses were available as backup in case of yield losses, but kastom, while still being a driving force in Vanuatu, is losing importance and feasting is becoming less intense.

2.5.2 Claimed negative Effects of Climate Change on Smallholder Agriculture in Vanuatu

There are intensified natural disasters reported that may be a result of climate change. Local farmers report unanimously an equalisation of the seasons and that they find it hard to set the right times for planting and harvesting. This is especially true for recently introduced crops: one farmer reported to me that they had to plant tomato seedlings three times on a plot since the first two attempts failed because the seedlings dried out. But also the planting of the traditional crops is reported to be more suspect to failure, mainly because of prolonged drought. Another big issue is the rotting of the tubers due to prolonged submergence or other exposure to water. These phenomena are suspected to be caused by intensified La Niña and El Niño periods. Also the cyclones are reported to be more frequent and more severe than in the earlier days. In regions with shallow soil, also soil erosion is becoming a problem. Generally, the farmers do report a decline of the yields, while neither crops nor farming techniques generally do change.

Vanuatu's National Advisory Comittee on Climate Change (NACCC) made the following statements about climate change and agriculture in Vanuatu (National Advisory Comittee on Climate Change (NACCC), 2005):

"

- Climate-related disasters have had huge impacts on the economic growth and national development. Tropical cyclones Uma, Anne and Bola that hit Vanuatu during 1987 – 88, were the cause of significant economic and social costs. Approximately 50 deaths were reported, a number of inter-island coastal trading vessels were lost, and massive damages sustained by the agriculture and tourism industries. The total destruction of property was valued at over US$152 million In 1999, heavy rain associated with tropical cyclone Dani caused serious damage, estimated at US$8m to infrastructure.
- The results of the climate scenario models and historical/observational trends point to warmer and drier conditions in much of Vanuatu. The magnitude of the expected change is likely to increase away from the equator. However, it is likely that some parts of the country may receive increased rainfall, due largely to the frequent tropical depressions and storms that are likely to develop around Vanuatu waters .It is also likely that the cyclones will become more intense and more frequent. The HADCM2 model indicates

there may be more frequent El Nino type conditions associated with prolonged dry seasons.

- Soil degradation is an important issue affecting agriculture. The traditional practice of shifting cultivation that allowed the soil to go through a process of regeneration by being left idle for extended periods ranging from 5-10 years is no longer possible. With the increasing population, the fallow periods are being shortened, adding to the soil degradation. Climate variability and extreme events such as droughts and floods will exacerbate the impact on the land, and in turn on the agricultural productivity. Agro-forestry and improved farming systems are being promoted as means to reduce soil degradation. "

Another source of concern is drinking water. In Vanuatu there is no tradition of digging wells, and most of the drinking water comes from rainwater tanks. This is due to the high porosity of the rock, which causes rainwater to springs run dry in the dry season and clearly because of the good availability of rain water. But in dry seasons in some areas the rainwater tanks run dry, and villagers have to seek for water in sometimes distant creeks, a problem that is more drastic under El Niño conditions.

3 Methodology

3.1 Preparatory Work

First, institutions that might have needed data for the project had to be identified. This data includes:

- Topographic data,
- Meteorological data, including rainfall, temperature, if easily available also humidity and radiation
- Land use/ land cover data
- Pedological data
- Hydrological data
- Geological data
- Data on water use
- Official policies concerning water/agriculture

Preferred data format for geospatial data was common GIS- format. Also aerial photographs were desirable.

The local institutions in question that might provide such data are

- Vanuatu Meteorology and Geohazards Department (Associate to the project)
- Department of Geology, Mines and Water Resources (Associate to the project)
- Vanuatu Agricultural Research and Technical Centre (VARTC, Associate to the project)
- World Vision Development Group (Associate to the project)
- The GIZ
- Vanuatu Ministry of Agriculture, Quarantine, Forestry and Fisheries

Also the availability of laboratories for soil and water analysis had to be investigated. At the same time the necessary equipment had to be bought and/or constructed. For a detailed list of this equipment see Annex IV: List of Equipment . Some equipment, like chemicals for soil testing or augers for sampling, could not be obtained due to import restrictions or infrequent service of the freight ships from overseas.

Following a gap analysis under consideration of the data that was found, the data acquisition at the field sites had been started. The following topics were meant to be covered in more detail:

- Experienced problems related to water
- Land use
- Crops
- Location of frequently waterlogged/flooded/dry cultivated plots
- Precipitation
- Soil characteristics
- Water sources

3.2 Secondary Data Collection

Several institutions were contacted in order to retrieve secondary data and policy reports concerning climate change, including:

- Ministry of Lands
- Department of Geology, Mines and Water Resources
- VARTC offices on Santo and Efate
- National Statistics Office
- Vanuatu Meteorology and Geohazards Department
- The publishing house Geo Consulte

Much GIS- data (ArcGIS- format) of varying accuracy covering different fields could be collected at the Lands department, meteorological data, including rain, temperature, humidity, pressure, sunshine, cloud cover and wind data of Bauerfield and White Grass Airport was handed over by the Vanuatu Meteorology and Geohazards Department. The collected rain data is partly incomplete but can to a limited extent serve as a data source to determine trends. Existing daily rain data for Siviri, Port Havannah (close to Malafau) and Middle Bush had not been delivered until the end of this work package. For an overview on rain gauges that are operated or were operated in the past all over Vanuatu please refer to Annex III: Vanuatu rain gauges.

Two very comprehensive books about soils and the agriculture of Vanuatu could be found in the libraries of the VARTC- offices on Santo and Efate: One is the Soil atlas SOLS DE L'ARCHIPEL VOLCANIQUE DES NOUVELLES HEBRIDES (VANUATU) by PAUL QUANTIN and the other one is a synopsis of the history and the current practices of Vanuatu's agriculture, AGRICULTURE IN VANUATU by BARRY WEIGHTMAN. General information and information on the spatial distribution of precipitation in Vanuatu could be extracted from the ATLAS DU VANOUATOU (VANUATU) by PATRICIA SIMéONI.

3.3 Primary Data Collection

Through preliminary informal interviews farmers gave information about their issues relating to water, which was merged with data gained from transect walks. During the first stay at the project sites also basic rain gauges (simple ombrometer made out of plastic bottles and accumulative rain gauges made out of canisters) were installed.

After gaining an overview on land use and soil, sites for profile pits, infiltration tests and soil sampling were chosen after consultation with the partners, and soil samples were taken and analysed in the laboratory.

3.3.1 Fieldwork

3.3.1.1 Mapping

The first survey at the study site gave information about land use, water related issues and the kind of farming that is carried out at the study sites. Therefore, prolonged stays at the study sites were used to do informal interviews with the chiefs and the farmers about the situation of agriculture in their village, and to do transect walks in order to capture the topography, settlement structure and land use. Basic mapping using the "Magellan eXplorist 310"- GPS device was carried out.

On the two sites on Efate, Siviri respectively Malafau were chosen as representative villages amongst all the villages within the study sites. Most of the farming plots at both villages on Efate plus at the villages of Middle Bush were visited, waypoints and tracks were stored on the GPS and hand notes were taken, including data on water related problems, infrastructure, land use and vegetation. Additionally photos of selected spots were taken. The usual procedure was to store the tracks walked continuously, and set waypoints at prominent points like crossroads, waterways or corners of farming plots.

In Siviri, all the plots used by the villagers were visited and mapped. But due to the smallness of the farming plots and the low accuracy of the GPS- device this method was dismissed.

In Malafau the farming areas, above all the ones used for growing bananas, are vast, so that not all of them (especially those close to the ring road) could be mapped in detail.

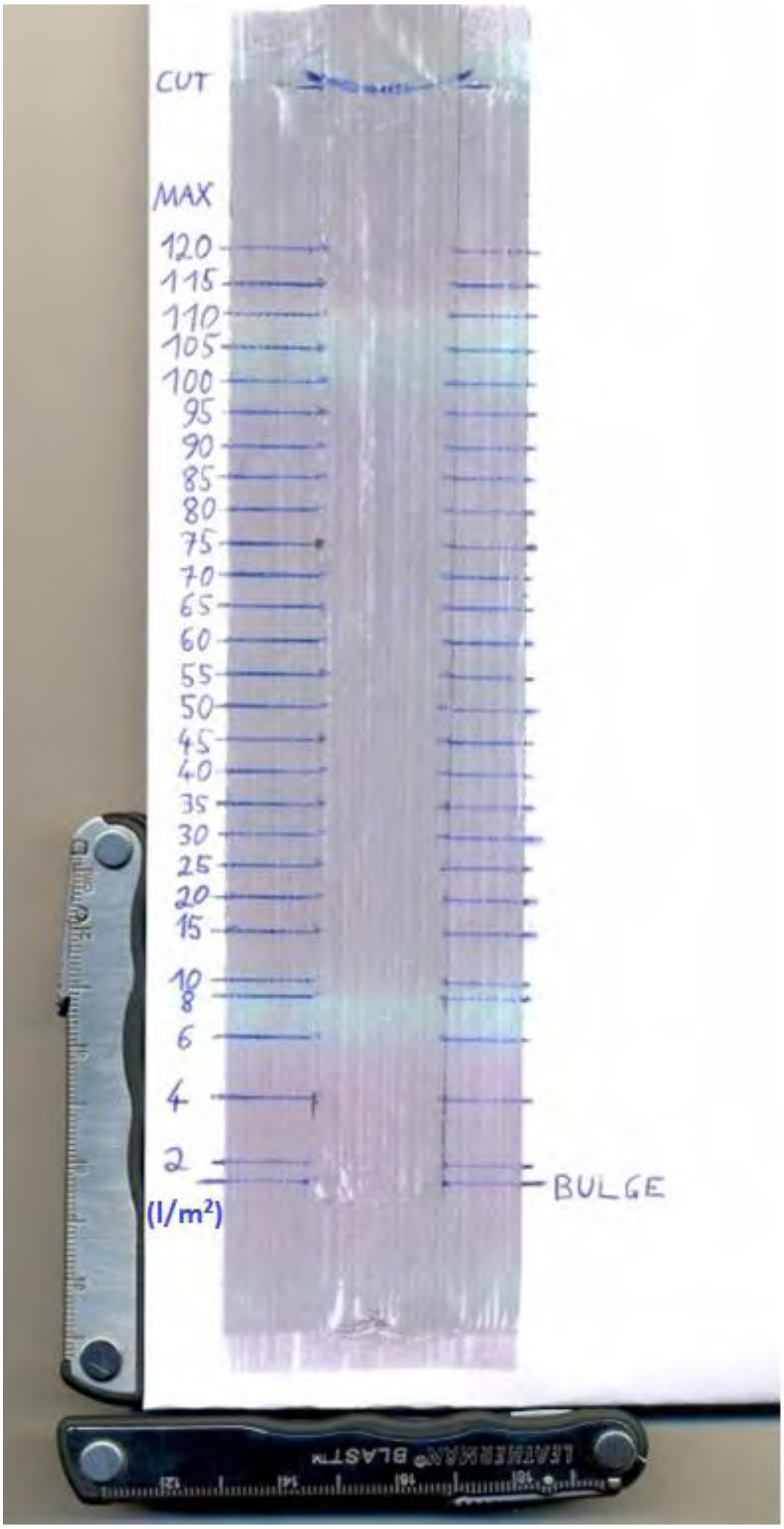
In Middle Bush, the whole area was covered, according to the wish of most chiefs to map all the areas affected by flooding respectively water logging. This made the methodology differ from the one used at the other sites, since the focus was now on mapping all areas affected by these problems within the whole study site rather than mapping all farming plots used by one village. Farming plots of the following villages had to be covered by the mapping:

Lamak, Launapheuw, Loulipang, Launamilo, Loupikas, Lauaru, Lenemita, Lowehau, Louwaula, Loujiaru, Euel, Lenaken, Lamak, Jupik (Epuk), Lounaukiam Apen, Loumiai, Laul, Lounauru, Launalou, Lounauru, Latuan, Lowiaru, Ilimanga, Lamnatu, Lamneau. Lounuwao Tuan, Kaunamelkin, Lanupu Pin Nipin (the spelling of the villages in RED is not sure).

3.3.1.2 Rain Gauges

In order to collect precipitation data , rain gauges had to be set up. All over Vanuatu, there is no single operating automatic weather station (state of 2012). Since it is expected that there will be weather stations available later on in the project, a cheap and easy way to determine precipitation had to be found to allow preliminary rain data assessment.

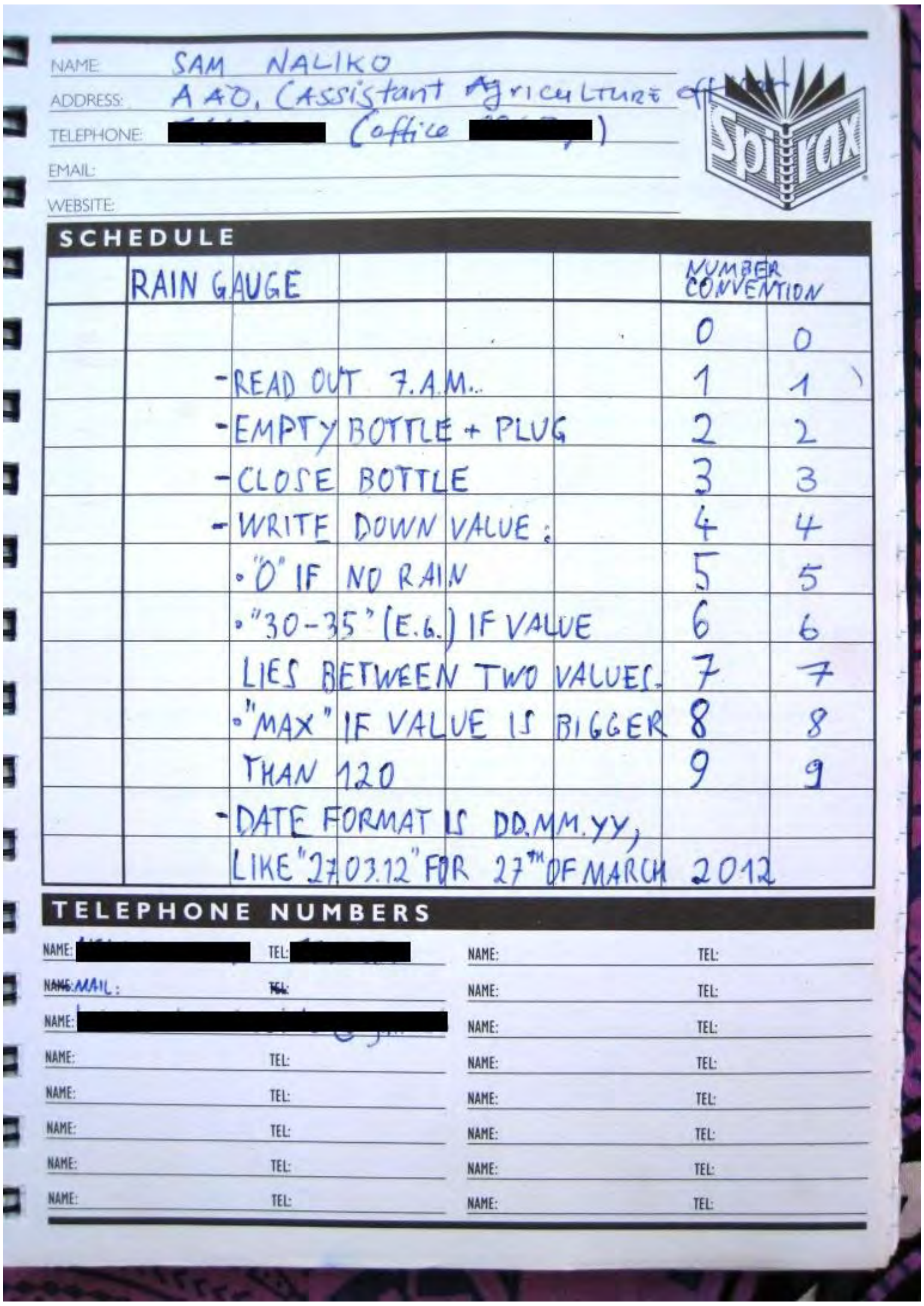
To meet this goal it was decided that the best way would be to just calibrate a plastic bottle of a beverage that is available throughout Vanuatu (VANUATU WATER, 600 ml), cut its bottom and install it upside down on a wooden stick at one metre height (see Picture 5 for an image of the gauge installed at Malafau). Once a special accuracy scale was purchased, a bottle of this type had been calibrated, using defined water amounts and the cross section of the open bottom, and the marks were transferred to a non- elastic duct tape. With this tape a master sheet was created, with which these marks can always be transferred to a tape and then be transferred back to a bottle of the same kind again (Picture 4). Since good rain gauges are not easily available in Vanuatu, the extension officers at DARD also received an instruction manual on constructing, installing and reading a gauge like that for future use (see Annex II: Manual for constructing a daily rain gauge out of a Vanuatu Water 600ml- bottle).



Picture 4: Calibration sheet for the daily rain gauge, including a two-dimensional scale in order to allow correct print- out

Picture 5: Rain gauge for daily reading made of a water bottle, as constructed for the study sites

Using good quality permanent markers a rain gauge like this can last for several months, if the marks are retraced several years. Once the daily gauges were installed, the person in charge of the reading received instructions, one written version on the first page of the notebook, and one training with the gauge accompanied by explanatory notes in Bislama.



Picture 6: Example of the instructions for the reading of the rain gauge that came with the notebook for the people in charge

Then gauges designed for monthly reading were built in order to have a backup and a different source of rain data. These gauges consist of a 10 l jerry can and a funnel (Picture 7) with known cross-section of the inlet (Picture 8). The edge of the funnel was sharpened (resulting in the edge being on the outside of the ring, see Picture 8) and the area of the inlet was determined by measuring its circumference on the outside. The reading can be done using any calibrated eprouvette for measuring the amount of a liquid, and with the known cross- section of the funnel (0.01462 m^2) the amount can be converted to $mm.m^{-2}$. 100 ml of vegetable oil are added after the emptying of the jerry can to lower evaporation from inside the jerry can once there is water inside. This amount of oil has to be considered at the next reading of the rain gauge of course. Additionally, the gauge was covered up with a piece of cloth in order to protect it from the direct sunlight.

Picture 7: Preperation of the funnel for the monthly gauge

In Malafau two rain gauges were set up, one for daily readings and one for monthly reading. Chief Louis Manapanga agreed to read the small Ombrometer daily at 7am. A notebook for the recording was provided. The big gauge is to be read on the first of each month by staff members/field officers of DARD.

In Siviri only the big gauge for monthly reading was set up, since there are two high- quality Ombrometers already set up in the area and read daily (since 2011), one close to the football field (hence, close to most farming plots) and one close to the Undine Bay coconut plantation. These were set up by the Vanuatu Meteorology and Geohazards Department, which is an associate of the NARI- project. The data has not been handed over until the end of this work package.

In Middle Bush both gages for daily and monthly reading were set up besides the church of Lamnatu, and Sam Naliko, the local Assistant Agriculture Officer, agreed to do the reading of the daily gauge.

Picture 8: Rain gauge for monthly reading made of a water bottle, as constructed for the study sites. After installation, the gauge was sheltered from the sun with a piece of cloth

All the gauges were set up following common rules for the selection of sites for measuring rain (see for example "Guide to Meteorological Instruments and Methods of Observation" (WMO, 2010)): The gauges are set at forest clearings or gardens with scattered trees, from the opening of the gauges there are no obstacles above an angle of 45° from the horizontal, and there are no obstacles higher than the gauge in the near surrounding. Mostly, the obstacles are further away

than twice their height. The daily gauge was set up at one metre height, the big gauge on the other hand could not easily be mounted that high, it has just been fixed to the ground, resulting in the opening of the funnel being situated about 0.5 m above ground.
Since it was not possible to do the monthly reading on the first of the month on each site, corrections were used to calculate the monthly precipitation. At Malafau, where one small and one big gauge were set up, the amount read at the big gauge was corrected by the amount of rain that was measured with the daily gauge outside the month in question (e.g., if the reading one month was done on the third, and the last month on the second, the amount read at the big gauge was lowered by the daily readings of the current month (2^{nd} and 3^{rd}), and the reading of the 1^{st} of last month was added).

At the other sites there is no daily data available until now, so the data was corrected by the daily mean calculated from the data of the big gauge, multiplied by the number of days the measurement was set- off, following the methodology described in the previous paragraph.

3.3.1.3 Soil Survey

3.3.1.3.1 Infiltration

In order to determine the influence of the soil on water problems of farmers, infiltration tests were carried out. Therefore, at each study site three characteristical spots were chosen to conduct infiltration tests at. According to recent tendencies to question the additional value of double-ring infiltrometer tests, the tests were done using a single ring infiltrometer as described in the FAO- "Guidelines for designing and evaluating surface irrigation systems" (Walker, 1989).

The procedure suggested there is the following:

- Examine and select possible sites carefully for signs of unusual surface disturbance, animal burrows, stones that might damage the cylinder, etc.
- Then a metal cylinder with a diameter of 30 cm or more and a height of about 40 cm is set in place and pressed firmly into the soil, after which a driving plate is placed over the cylinder and tampered with the driving hammer until the cylinder is driven to a depth of about 15 cm.
- Fix a gauge of almost any type to the inner wall so that the water level changes that occur can be measured.

- Pure water into the cylinder, and when the water surface is quieted, take an initial reading.
- Additional measurements should be recorded at periodic intervals, 5 to 10 minutes at the start of the tests, expanding to 30 to 60 minute intervals after 3 or 4 readings, but the observation frequencies should be adjusted to infiltration rates.
- When the water level has dropped about one-half of the depth of the cylinder, water should be added to return the surface to its approximate initial elevation.
- The depth should be maintained in the cylinder between 6 and 10 cm throughout the test.
- To evaluate the infiltration function, readings near the later part of the test shall be selected and the slope there is the basic intake rate.

Other sources suggest to pre- wet the soil and determine the infiltration rate by keeping the water level constant and measure the water volume that has to be added in order to do so. Unfortunately, doing the infiltration tests completely in accordance with some standard procedure proved to be difficult, due to several reasons:

- Since it was not possible to purchase a metal cylinder that could have been used for infiltration tests and also a PVC pipe of a diameter somewhat close to the FAO-suggestion (> 30 cm) was not available, a custom made plastic pipe with a diameter of about 32 cm was used. The problem with it was that it was not possible to hammer it into the ground since the material was too brittle. One side of the pipe was sharpened to make it go down into the ground more easily. But also with this improvement it was never possible to hammer the pipe more than 3-5 cm into the ground, so the desired depth of 15 cm could not be reached.
- The availability of water was very limited at most sites, the water always had to be carried in jerry cans over long distances, and it was difficult to assure that at every test there was some assistance for carrying water to the test site. This lead to the decision not to do stationary infiltration tests, since not everywhere it could be assured that enough water would be available to do hold the water level constant, but the results of the individual sites should be comparable.
- The water level had to be read at shorter intervals due to the high infiltration, and the reading could not be done over several hours, because the water consumption was too high. In most cases, a stationary rate was reached during the measurement though.

- The water level has not been kept in the suggested range, because errors caused by the necessary frequent refills (due to the unknown amount of water draining away during the filling and the disturbance of the water surface) were considered to be more problematic than the falling hydrostatic pressure.

Under these limitations, instationary tests were carried out according to the following scheme:

- Choose a spot with uniform, flat, preferably unvegetated soil.
- Clear the spot from superficial roots.
- Level the spot.
- Drive the pipe as deep as possible into the ground.
- Attach a meter inside the pipe and cover the ground inside the cylinder with a piece of cloth (in order to not disturb the soil when pouring the water into the cylinder, see Picture 9).
- Before starting the test, pre- wet the soil for 20 min.
- After that, fill up the cylinder until the initial level with water again, remove the piece of cloth.
- Read the water level every minute, reduce that interval according to the speed of the percolation and the accuracy of the meter (1 mm in this case)
- Record the water level until all the water has vanished.
- The determined infiltration rate is the rate at which the water level in the pipe decreased shortly before all the water had drained away. Usually, that rate was reached asymptotically before that point.

Due to the methodical restrictions the infiltration rates are rather to be used for relative comparison of the sites only.

Picture 9: Infiltration test setup

3.3.1.3.2 Profile Pits

At all the sites where infiltration tests were carried out also profile pits were dug, apart from one site at Malafau, where delayed harvest of the yam that is grown at this site made it impossible to interfere with the soil there due to the high status of yam in Vanuatu's culture.

The survey was carried out on profile pits that were dug down to at least 1.2 m depth or to the parent rock where the soil was shallower than that. Following the FAO "Guidelines for Soil Description" (Jahn, Blume, Asio, Spaargaren, & Schad, 2006), the following properties were described:

a) Recent meteorological conditions

b) Land use (Table 1):

A	= Crop agriculture (cropping)	
AA	= Annual field cropping	
	AA1	= Shifting cultivation
	AA2	= Fallow system cultivation
	AA3	= Ley system cultivation
	AA4	= Rainfed arable cultivation
	AA5	= Wet rice cultivation
	AA6	= Irrigated cultivation
AP	= Perennial field cropping	
	AP1	= Non-irrigated cultivation
	AP2	= Irrigated cultivation
AT	= Tree and shrub cropping	
	AT1	= Non-irrigated tree crop cultivation
	AT2	= Irrigated tree crop cultivation
	AT3	= Non-irrigated shrub crop cultivation
	AT4	= Irrigated shrub crop cultivation
Additional codes may be used to further specify the land-use type. For example:		
	AA4	= Rainfed arable cultivation
	AA4T	= Traditional
	AA4I	= Improved traditional
	AA4M	= Mechanized traditional
	AA4C	= Commercial
	AA4U	= Unspecified

Table 1: Land-use classification (Jahn et al., 2006)

c) Vegetation:

Listing of the dominant crops

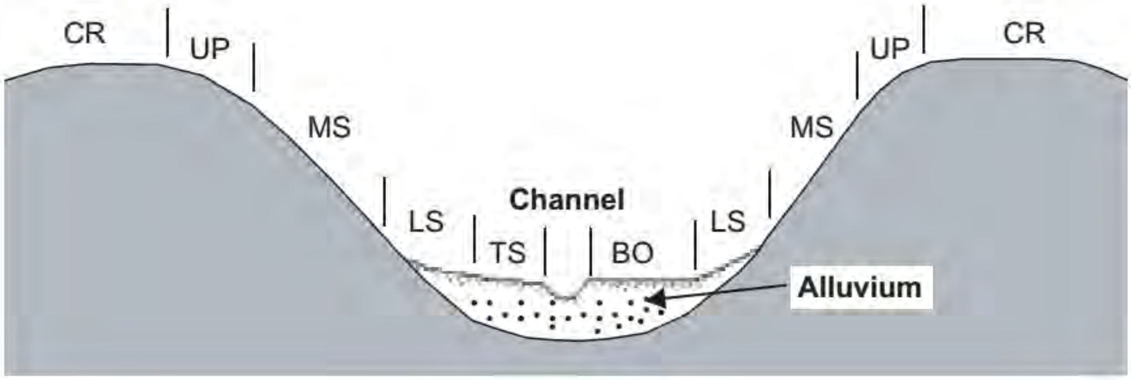
d) Landform and topography:

- the major landform, refering to the morphology of the whole landscape (Table 2):

1st level	2nd level	Gradient (%)	Relief intensity (m km^{-1})	Potential drainage density
L level land	LP plain	< 10	< 50	0–25
	LL plateau	< 10	< 50	0–25
	LD depression	< 10	< 50	16–25
	LV valley floor	< 10	< 50	6–15
S sloping land	SE medium-gradient escarpment zone	10–30	50–100	< 6
	SH medium-gradient hill	10–30	100–150	0–15
	SM medium-gradient mountain	15–30	150–300	0–15
	SP dissected plain	10–30	50–100	0–15
	SV medium-gradient valley	10–30	100–150	6–15
T steep land	TE high-gradient escarpment zone	> 30	150–300	< 6
	TH high-gradient hill	> 30	150–300	0–15
	TM high-gradient mountain	> 30	> 300	0–15
	TV high-gradient valley	> 30	> 150	6–15

Table 2: Physiographic Position: Hierarchy of major landforms (Jahn et al., 2006)

- the position of the site within the landscape (Picture 10):



Picture 10: Slope positions in undulating and mountainous terrain (Jahn et al., 2006)

- the slope angle (Table 3):

Class	Description	%
01	Flat	0–0.2
02	Level	0.2–0.5
03	Nearly level	0.5–1.0
04	Very gently sloping	1.0–2.0
05	Gently sloping	2–5
06	Sloping	5–10
07	Strongly sloping	10–15
08	Moderately steep	15–30
09	Steep	30–60
10	Very steep	> 60

Table 3: Slope gradient classes (Jahn et al., 2006)

e) Stone cover and rock outcrops:

The abundance of exposed bedrock and coarse surface fragments was described in terms of surface percentage (Table 4):

	Surface cover	(%)
N	None	0
V	Very few	0–2
F	Few	2–5
C	Common	5–15
M	Many	15–40
A	Abundant	40–80
D	Dominant	> 80

Table 4: Classification of rocky surface share (Jahn et al., 2006)

f) Distribution and thickness of layers:

The layer boundaries were recorded, diffuse transition zones between the layers are indicated by noting ranges, e.g. "11-15" cm.

g) Erosion:

If erosion was visible, its type was described (Table 5):

N	No evidence of erosion		
W	Water erosion or deposition	A	Wind (aeolian) erosion or deposition
	WS Sheet erosion		AD Wind deposition
	WR Rill erosion		AM Wind erosion and deposition
	WG Gully erosion		AS Shifting sands
	WT Tunnel erosion		AZ Salt deposition
	WD Deposition by water		
WA	Water and wind erosion		
M	Mass movement (landslides and similar phenomena)		
NK	Not known		

Table 5: Classification of Erosion (Jahn et al., 2006)

h) Abundance of roots :

For each layer the abundance of roots was checked

i) Soil texture:

A field estimation of the soil texture was conducted using following the key in the FAO-guidelines (Table 6).

				~% clay
1	Not possible to roll a wire of about 7 mm in diameter (about the diameter of a pencil)			
1.1	not dirty, not floury, no fine material in the finger rills:	sand	S	< 5
	• if grain sizes are mixed:	unsorted sand	US	< 5
	• if most grains are very coarse (> 0.6 mm):	very coarse and coarse sand	CS	< 5
	• if most grains are of medium size (0.2–0.6 mm):	medium sand	MS	< 5
	• if most grains are of fine size (< 0.2 mm) but still grainy:	fine sand	FS	< 5
	• if most grains are of very fine size (< 0.12 mm), tending to be floury:	very fine sand	VFS	< 5
1.2	not floury, grainy, scarcely fine material in the finger rills, weakly shapeable, adheres slightly to the fingers:	loamy sand	LS	< 12
1.3	similar to 1.2 but moderately floury:	sandy loam	SL (clay-poor)	< 10
2	Possible to roll a wire of about 3–7 mm in diameter (about half the diameter of a pencil) but breaks when trying to form the wire to a ring of about 2–3 cm in diameter, moderately cohesive, adheres to the fingers			
2.1	very floury and not cohesive			
	• some grains to feel:	silt loam	SiL (clay-poor)	< 10
	• no grains to feel:	silt	Si	< 12
2.2	moderately cohesive, adheres to the fingers, has a rough and ripped surface after squeezing between fingers and			
	• very grainy and not sticky:	sandy loam	SL (clay-rich)	10–25
	• moderate sand grains:	loam	L	8–27
	• not grainy but distinctly floury and somewhat sticky:	silt loam	SiL (clay-rich)	10–27
2.3	rough and moderate shiny surface after squeezing between fingers and is sticky and grainy to very grainy:	sandy clay loam	SCL	20–35
3	Possible to roll a wire of about 3 mm in diameter (less than half the diameter of a pencil) and to form the wire to a ring of about 2–3 cm in diameter, cohesive, sticky, gnashes between teeth, has a moderately shiny to shiny surface after squeezing between fingers			
3.1	very grainy:	sandy clay	SC	35–55
3.2	some grains to see and to feel, gnashes between teeth			
	• moderate plasticity, moderately shiny surfaces:	clay loam	CL	25–40
	• high plasticity, shiny surfaces:	clay	C	40–60
3.3	no grains to see and to feel, does not gnash between teeth			
	• low plasticity:	silty clay loam	SiCL	25–40
	• high plasticity, moderately shiny surfaces:	silty clay	SiC	40–60
	• high plasticity, shiny surfaces:	heavy clay	HC	> 60

Table 6: Key to the soil texture classes (Jahn et al., 2006)

j) Soil colour:

The colour of each layer was determined using Munsell Soil Color Charts.

k) Aggregate stability:

Where aggregates were abundant, their stability was checked according to a method described in "BODENKUNDLICHES PRAKTIKUM" (Schlichting & Blume, 1995). Here, some aggregates are put into a bowl filled with water, and after swinging round the bowl the stability is determined by classifying the decay of the aggregates from AS1 (no decay) to AS6 (complete decay and dissolution).

l) Parent rock/Lithology:

The parent rock, if it could be reached, was described in terms of stability and structure (i.e. "weathered" or "soft") and lithologicaly (Table 7).

Major class		Group		Type	
I	igneous rock	IA	acid igneous	IA1	diorite
				IA2	grano-diorite
				IA3	quartz-diorite
				IA4	rhyolite
		II	intermediate igneous	II1	andesite, trachyte, phonolite
				II2	diorite-syenite
		IB	basic igneous	IB1	gabbro
				IB2	basalt
				IB3	dolerite
		IU	ultrabasic igneous	IU1	peridotite
				IU2	pyroxenite
				IU3	ilmenite, magnetite, ironstone, serpentine
		IP	pyroclastic	IP1	tuff, tuffite
				IP2	volcanic scoria/breccia
				IP3	volcanic ash
				IP4	ignimbrite
M	metamorphic rock	MA	acid metamorphic	MA1	quartzite
				MA2	gneiss, migmatite
				MA3	slate, phyllite (pelitic rocks)
				MA4	schist
		MB	basic metamorphic	MB1	slate, phyllite (pelitic rocks)
				MB2	(green)schist
				MB3	gneiss rich in Fe–Mg minerals
				MB4	metamorphic limestone (marble)
				MB5	amphibolite
				MB6	eclogite
		MU	ultrabasic metamorphic	MU1	serpentinite, greenstone
S	sedimentary rock (consolidated)	SC	clastic sediments	SC1	conglomerate, breccia
				SC2	sandstone, greywacke, arkose
				SC3	silt-, mud-, claystone
				SC4	shale
				SC5	ironstone
		SO	carbonatic, organic	SO1	limestone, other carbonate rock
				SO2	marl and other mixtures
				SO3	coals, bitumen and related rocks
		SE	evaporites	SE1	anhydrite, gypsum
				SE2	halite
U	sedimentary rock (unconsolidated)	UR	weathered residuum	UR1	bauxite, laterite
		UF	fluvial	UF1	sand and gravel
				UF2	clay, silt and loam
		UL	lacustrine	UL1	sand
				UL2	silt and clay
		UM	marine, estuarine	UM1	sand
				UM2	clay and silt
		UC	colluvial	UC1	slope deposits
				UC2	lahar
		UE	eolian	UE1	loess
				UE2	sand
		UG	glacial	UG1	moraine
				UG2	glacio-fluvial sand
				UG3	glacio-fluvial gravel
		UK	* kryogenic	UK1	periglacial rock debris
				UK2	periglacial solifluction layer

Table 7: Lithological classification (Jahn et al., 2006)

m) Carbonates:

The presence of carbonates in the parent rock was determined by adding some drops of 12-percent HCl to the soil (note: the recommendation of the FAO is 10 %- HCl, but this was not available in Vanuatu).

	%		
N	0	Non-calcareous	No detectable visible or audible effervescence.
SL	≈ 0–2	Slightly calcareous	Audible effervescence but not visible.
MO	≈ 2–10	Moderately calcareous	Visible effervescence.
ST	≈ 10–25	Strongly calcareous	Strong visible effervescence. Bubbles form a low foam.
EX	≈ > 25	Extremely calcareous	Extremely strong reaction. Thick foam forms quickly.

Table 8: Classification of carbonate reaction (Jahn et al., 2006)

n) Magnitude, period of inundation:

Inundation periods were estimated by interviewing local farmers and classified being frequent, infrequent, rare or very rare.

o) Depth to groundwater table:

The groundwater table was recorded where groundwater was reached.

3.3.1.3.3 Sampling

At the sites of the profile pits, several soil samples (three per layer) were taken and transferred to the Food Technology Development Centre & Analytical Unit at Tagabe, Port Vila to do further analysis (pH and bulk density) and the disturbed samples of each layer have been stored at DARD for subsequent further analysis at NARI.

On each site two undisturbed samples of $200cm^2$ using sampling cylinder, plus one disturbed sample using a spade (approximately 800-900 g (wet)) were taken from each layer down to 120 cm depth. As only three sampling cylinders have been brought to Vanuatu by me it was not possible to transfer each probe in the cylinder to the laboratory and do further tests on the undisturbed sample (like hydraulic conductivity tests).

3.3.2 Laboratory Work

The Food Technology Development Centre & Analytical Unit's laboratory at Port Vila, Tagabe was used to do pH- testing of the soil samples as well as to dry soil samples in order to determine the bulk density. Any further analysis of the soil could not be carried out, due to lack of equipment and the necessary chemicals.

3.3.2.1 Bulk Density

The bulk density is the density of dry, undisturbed soil. Together with the usually only moderately varying density of the soil constituents it is a measure for the porosity of the soil. It is usually determined by drying a known volume of soil at 105 degrees and weight the dry mass (compare the FAO- guidelines for soil description (Jahn et al., 2006)).

The procedure was to take the samples in the field using the sampling cylinders. The cylinders were then emptied into plastic bags and samples were stored and brought to the laboratory, where the samples were dried in a drying oven at slightly above 100 degrees Celsius for at least 24 hours. Since the temperature was not exactly adjustable, it was controlled from time to time using a mercury thermometer and temperature and time was adjusted accordingly. The two samples of each layer were dried and weighted separately and the mean of the two densities was attributed to the soil layer. The reference volume was the sampling cylinder volume, so possible effects of shrinking of the soil during the drying process were not taken into account.

3.3.2.2 Soil pH

Soil pH can affect the availability of mineral nutrients to plants as well as many other soil processes, which influences the yield. Before doing the pH- test the pH- meter of the Food Technology Development Centre & Analytical Unit had to be calibrated. The necessary buffer solutions to do that could not be purchased in Vanuatu, and due to the infrequent service of freight ships from Australia and strict quarantine rules it was not feasible to order any chemicals like this from overseas. Therefore, a cooperation with the soil laboratory at USP (University of South Pacific) was established, and the calibration plus the first tests were carried out there. Again, the procedure used for measuring the pH followed the FAO- guidelines for soil description (Jahn et al., 2006): a soil suspension with 1 part (wet) soil and 2.5 parts 1 M KCl solution was left for 15 minutes and then the pH had been determined using an electronic pH-meter.

4 Results

4.1 Existing Data relating to Climate Change in Vanuatu

4.1.1 Evidence for Climate Change in Vanuatu

4.1.1.1 Meteorological Data

Well-founded meteorological evidence for climate change is hard to find in Vanuatu. In 2012, there were only two meteorological stations that provided long-term data until recently, many long-term measurements were abandoned in the 1990's or earlier. Out of the two automatic stations that have been operated a long time at the international airports on Efate (Bauerfield Airport) and Tanna (Whitegrass Airport), none is currently (2012) operating, and furthermore the station on Tanna was moved with the airport in 1998 and there are gaps in the data.

Therefore, only few records are available for long-term trend analysis, in Figure 5, the available long-time series for rain- and temperature that were handed over by the Vanuatu Meteorology and Geohazards Department after clearing them from incomplete years is displayed:

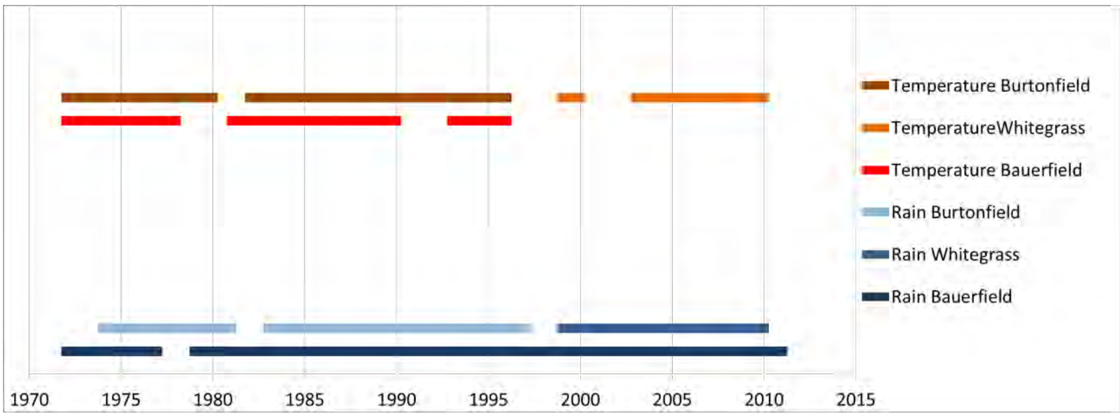


Figure 5: Available long-term weather data

The longest time- series is the monthly rain data collected at Bauerfield Airport in Port Vila, Efate, covering 39 years, with data points in 1978 only missing. Temperature- and rain data from Tanna (Burtonfield and Whitegrass) covers almost this time span too, but since the station was moved from Burtonfield to Whitegrass and the old and the current location differ both in altitude and topography, the data should not be treated as one series. Hence, rain- and temperature data can be statistically analysed only for the three locations separately.

For an overview of the obtained data of these stations please refer to Figure 6, in Figure 7 the annual rainfall of the longest series (between 1972 and 2011) at Bauerfield Airport (17.42S/168.18E, 21 m above sea level) is displayed.

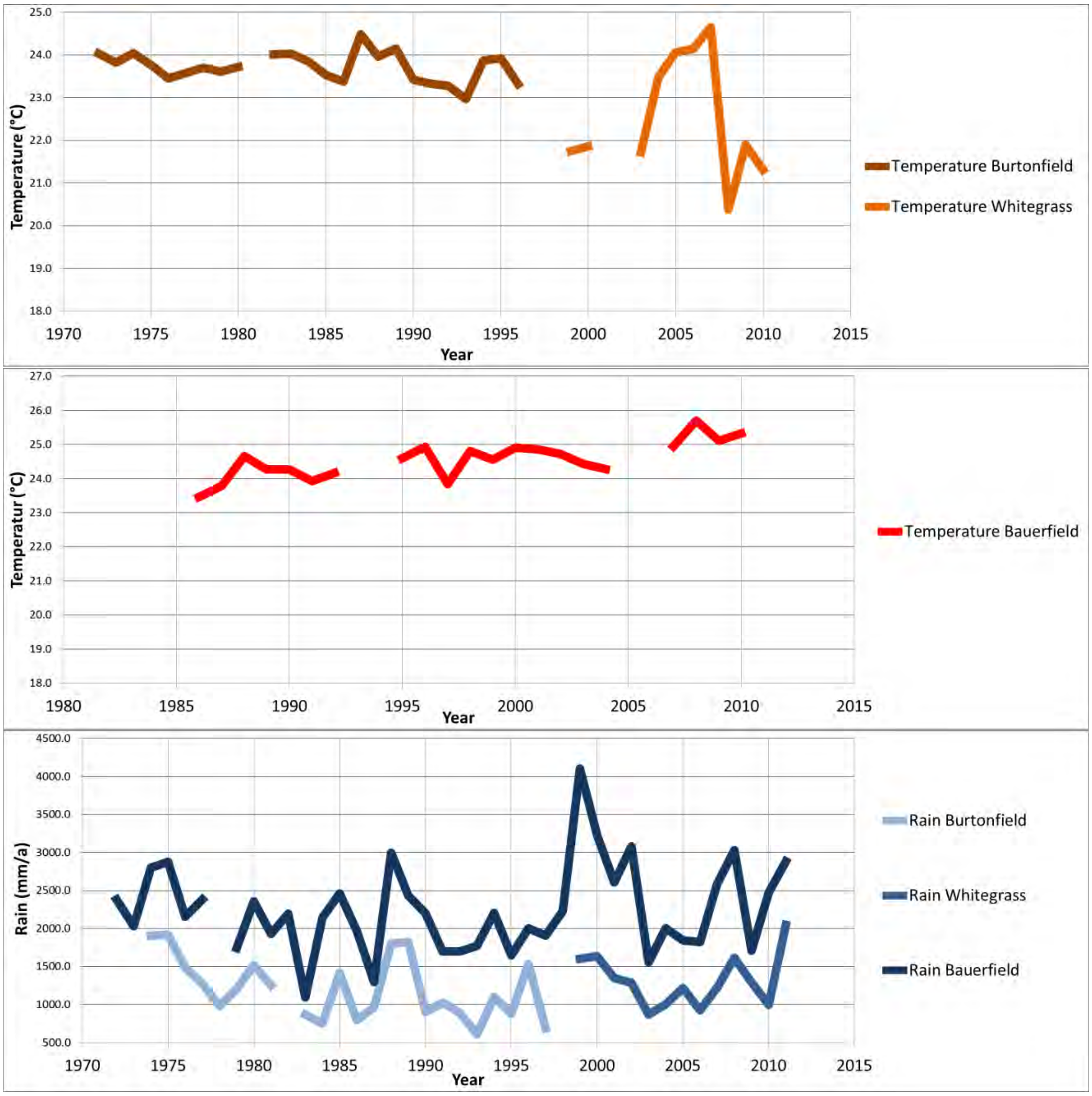


Figure 6: Temperature and precipitation progressions

The mean annual rainfall of the two stations (the mean of 30 years, 1971-2000 on Tanna (Burtonfield) and 1972-2001 on Efate (Bauerfield)) is 1277.6 mm/a on Tanna and on Efate 2245.6 mm/a, whereby the Tanna series also includes two years of data from records belonging to the previous station at Isangel and two years from the currently operated station at Whitegrass airport (compare Annex III: Vanuatu rain gauges, Table 25 and Table 26).

When analysing the records of each station for a linear trend, one finds the following slopes and correlation coefficients (Table 9):

	Unit	Bauerfield	Burtonfield	Whitegrass
Rain				
Slope	mm/(10*a)	64.18	-263.15	9.10
R^2	-	0.02	0.22	0.00
Temperature				
Slope	K/(10*a)	0.54	-0.13	-0.04
R^2	-	0.57	0.08	0.00

Table 9: Trends (change per decade) and corresponding correlation coefficients in temperature and rain data

It can be seen that there are trends in the data, but they are partly contradictory. Temperature progression on Tanna for example is slightly negative from 1973 until 1997, and the new station gives a positive trend since 1999, but it is almost zero. Since both R^2 are very close to zero too, it is can be concluded that there is no temperature trend on Tanna. On Efate, temperature data shows an increase of the mean temperature by 0.5 K per decade.

Rain seems to increase on Efate. On Tanna, the two rain data series show contradictory trends again, before the station was moved a strong negative trend was observed, but at the new location at Whitegrass airport a small positive trend is observed.

But all this data is characterised by a very low R^2. This can be due to a non- linear trend, or to no analytical trend at all. When having a closer look at the graphs (Figure 6), one can easily see the linear trend for the temperature at Bauerfield. This data series is the longest and shows a positive temperature trend which is supported by the highest R^2. But all the other devolutions suggest that there is no underlying trend of linear or non- linear form, hence no trend at all. But all this must be seen under the fact that the time series are short, rather too short to allow profound analysis of the climate.

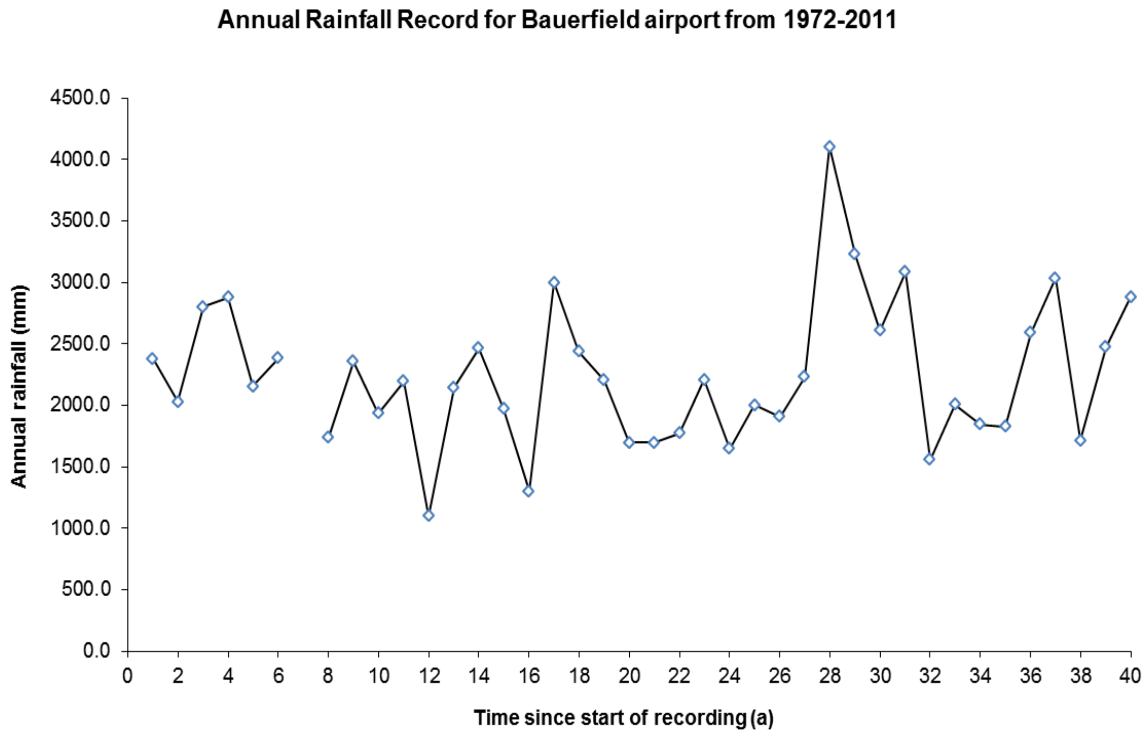


Figure 7: Annual rainfall Bauerfield airport

Since it is both reported that seasonal extremes are more pronounced and that the seasons are getting more and more indistinguishable, some statistical analysis was undertaken on the rain data from Bauerfield Airport station, which provides the longest time series.

At first glance, the recorded mean annual rainfall shows a quite unsteady progression (Figure 7). Therefore, those fluctuations were investigated. The first analysis is based on the fact that there are only two different seasons in Vanuatu, hence one season lasts about 6 months, and on the assumption that there is a linear trend in the precipitation. The first step was to form a moving average over 5 months along the forty years of monthly data (1972-2011, Figure 8) and to fit a linear slope to the time series. Then the deviation of this average (absolute value) from the linear fit was calculated to represent de-trended absolute derivation of the 5- month periods from "normal". Also, the absolute deviations of the moving averages from the long-time mean were calculated (Figure 9, here the trend has not been taken into account). In both cases values whose calculation included missing data points were dismissed. The results can be seen in Figure 8 and Figure 9.

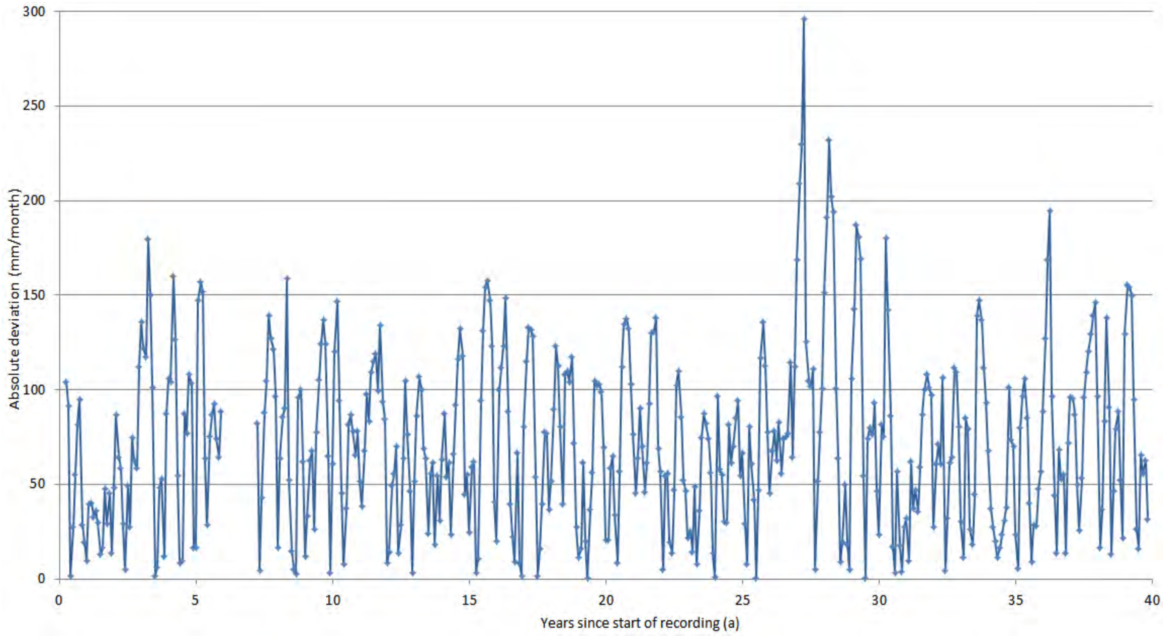


Figure 8: Deviation of the 5-month moving average from the long-term linear trend (Bauerfield Airport)

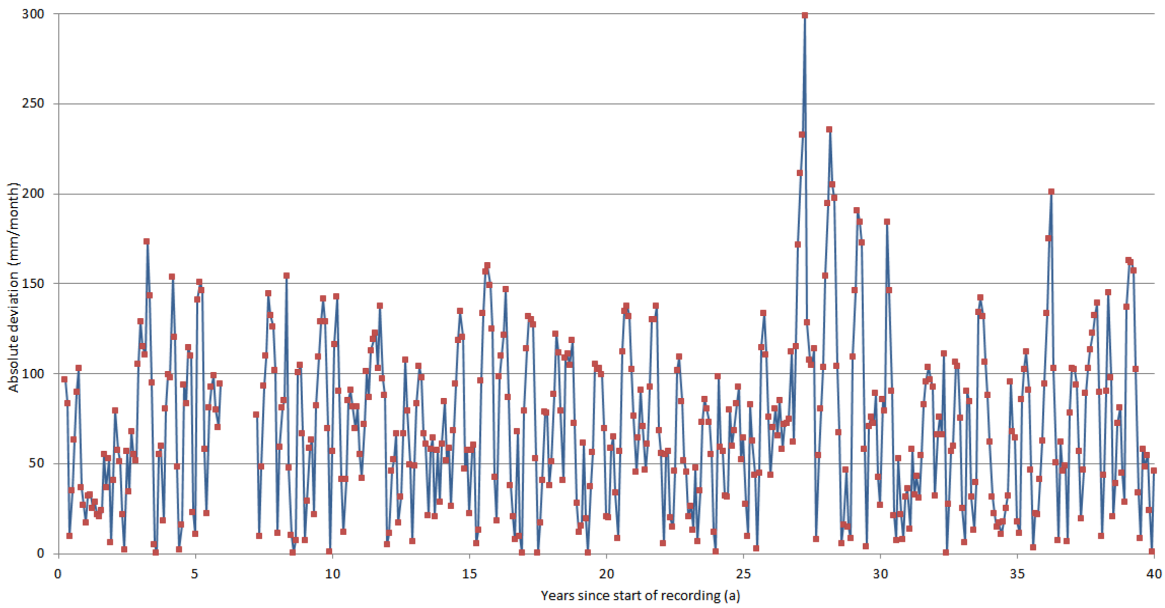


Figure 9: Deviation of the 5-month moving average from the long-term average (Bauerfield Airport)

Of course, as there are two seasons, there is an underlying oscillation period of the absolute deviations of 6 months at average. The progressions of the two deviations differ little. There was a very pronounced deviation of the seasons between the years 27 and 31 of the recording (1999 and 2003 respectively), which strengthens the impression that an incline of "abnormal" years can be seen. This impression is supported by calculating the linear slope of the deviation. The annual slope turns out to be 0.246 mm/a based on the long-term average and 0.231 mm/a based on the de-trended series, which means that on average every year the mean deviation of 5-month means from "normal" is increasing by approximately 0.24 mm, a trend that is moderate though considering the high absolute precipitation values.

A second way the data was dealt with was to look at the progressions of the mean precipitation of the individual months separately. Consequently, the mean precipitation of each month in the 40 years of recording was calculated, and then every year the month was compared with its long-term mean in terms of its deviation in mm/month. These deviations were investigated for a trend (Table 10).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Slope (mm/year)	1.3	1.0	-1.6	0.7	0.0	0.2	0.0	-0.3	-0.2	-0.9	1.4	0.0
Mean (mm/month)	294.3	330.4	319.5	233.5	185.3	180.8	86.0	83.1	85.5	117.0	150.9	175.5

Table 10: Trends of the mean precipitation of each month (Bauerfield Airport)

This table gives a rather heterogeneous picture: The months of the seasons (dry, cold season in orange, hot, rainy season in brown) do not develop homogenously, and three months of the dry season are getting more rain and the other three less, in the wet season precipitation shows a slight overall increase.

All those results have to be treated with caution anyway, since a 40- year data set is a pretty short series when dealing with El Niño and La Niña oscillations that have a characteristic period length of two to seven years.

4.1.1.2 Other Data

Concerning the severity of cyclones, in 2005 the National Advisory Committee on Climate Change of Vanuatu published a National Adaptation Programme of Action (National Advisory Comittee on Climate Change (NACCC), 2005) in which it is stated that "There has been a significant increase in the frequency of tropical cyclones in the country as a whole over the record period. A total of 124 tropical cyclones had affected Vanuatu since 1939. Forty-five (36%) of these were categorized as having hurricane force winds (>64 knots), twenty-six (21%) were of storm force winds (48 - 63 Knots) and twenty-five (20%) were of gale force winds (34 - 47 knots). An additional 28 tropical cyclones were not categorized."

Another source for indications for climate change is its effects as reported by farmers. This approach has the advantage that the integrated effect of climate change on agriculture can be captured, but the disadvantage that some phenomena cannot clearly be attributed to changing climate. They might as well have other reasons, as for example a recent change of the land use regime, and there is a tendency observable that climate change is a too popular justification for inconvenient events that arise recently in agriculture in Vanuatu. Additionally it is not easy to number yield losses since there is no practice of yield ascertainment in Vanuatu.

Rising sea level is reported to be an issue on some northern islands, above all in the Torres group, where for example on Loh villagers report significant land losses in the past decade, but no agricultural land has been affected yet, because gardening is almost exclusively practiced on higher parts of the island. Since Vanuatu's islands are generally "high" and very terraced, the effect of sea level rise is small, and it may even be the case that the uplift of the land predominates over the sea level rise in some areas, as for example on Tanna, that has a very active volcano.

1.1.1 Policies concerning Climate Change Adaptions in Vanuatu

Several working groups have been formed in order to establish policies concerning climate change, for example the National Advisory Committee on Climate Change (NACCC) in 2005, some held workshops, as the National Water Safety Plan Training & Planning Workshop in 2006 ("NATIONAL PLAN DRAFT," 2006), which also deals with the underlying international guidelines.

In 2002, the "VANUATU WATER RESOURCES MANAGEMENT ACT NO.9 OF 2002" has been assented, regulating the protection, management and use of water resources in Vanuatu (*Vanuatu Water Resources Management Act*, 2002). It mainly describes the administrative and legislative authorities in charge.

The NACCC published the following ranked list of adaptation strategies (National Advisory Comittee on Climate Change (NACCC), 2005):

1) Agriculture & food security (preservation/processing/marketing, modern & traditional practices, bartering)
2) More resilient crop species including traditional varieties
3) Land use planning and management (modern & traditional agricultural practices, early warning including traditional systems)
4) Water management policies/programmes (including rainwater harvesting)
5) Sustainable forestry management

6) Community based marine resource management programmes (modern & traditional/aqua-culture)
7) Mainstream climate change considerations into infrastructure design and planning (modern & traditional, EIA)
8) Sustainable Livestock farming and management
9) Develop Integrated Coastal ZoneManagement (ICZM) programmes, including mangroves & coastal flora management plan.
10) Sustainable tourism
11) Vector & water borne disease activities (modern & traditional)

In the WATER SAFETY PLAN PROGRAMME draft, the actions for implementation of water safety plans are defined ("NATIONAL PLAN DRAFT," 2006):

"AWARENESS & COMMUNITY PARTICIPATION

For safe quality drinking water, communities need to understand the linkages between water quality and health and know the contributions they can make to ensure safe drinking water.

1. Strengthen collaboration among local communities (and between local communities and relevant government agencies) to access local knowledge on water resource management

2. Establish a mechanism for awareness and education of outer island communities taking into consideration the relative remoteness of some of these communities

3. Develop community education and awareness programmes

- Strengthen collaboration between agencies to share resources and develop awareness programmes and materials;
- Establish a working group for community awareness & education that would be responsible for developing IEC materials for awareness raising on drinking water quality and health issues;
- The Awareness Working Group should engage in public consultations to identify issues and concerns of the public in relation to drinking water and

health.

- Translate relevant IEC materials into local languages (e.g. Bislama)

4. Conduct workshops to empower communities to take more ownership and responsibility of their drinking water

- Promote the linkages between drinking water quality and health issues through community workshops;
- Empower communities to maintain safe quality water by training them on simple water quality tests and sanitary surveys e.g. H2S test kits and WHO sanitary survey forms;
- Empower communities (landowners) to engage in public awareness programmes

WATER RESOURCE MANAGEMENT

For safe quality drinking water we need to ensure adequate supply of good quality of source water for public water supplies.

5. Enforce legislation (regulations) for effective management of water resources in Vanuatu.

- Enforce the Water Resource Management Act (2002)
- Enforce other legislation and /or regulations (of other agencies) that regulate water supply management, water quality management, health surveillance etc;
- Build the capacity (mainly human resources) of relevant agencies to enforce these legislations.

6. Strengthen Catchment Management of major water supplies in Vanuatu

- Implement Catchment Management Plans developed by the Water Resource Management Committee;
- Conduct a review of existing laws for Catchment Protection and Management;
- Awareness programme for tourists and members of public;
- Place signage warning tourists and members of the consequences of tampering with the catchment, intakes, or accidental or deliberate contamination of water sources;

• Introduce community policing of catchments by landowner groups or Water Resource Management Committee.

7. Establish formal agreements with land owners for access to their land to establish water supplies (intake, storage, distribution)

• Since most water supplies are on land owned by local communities it is essential to have some formal agreement with landowners for access to their land and water resources for the purpose of water supply development

8. Develop land-use plans for catchment areas of major water supplies in Vanuatu

9. Encourage more constructive dialogue among stakeholders (via the Water Resource Management Committee)

10. Strengthen monitoring of drinking water quality

• Strengthen surveillance and monitoring of drinking water supplies (including urban and rural supplies);

• Establish strategy for sharing of data among relevant agencies;

• Prepare annual reports on drinking water quality status and share among key stakeholders.

11. Explore alternative water sources

INSITUTIONAL ARRANGEMENTS

For safe quality drinking water we need effective cooperation among key stakeholders at all levels of operational policy, regulatory framework and information sharing.

12. Establish and strengthen the National Steering Committee (made up of representatives of different agencies and community groups)

• The board should include the following:

- A representative from DGMNR, MoH, Environment Unit, Meteorology Service, Ministry of Finance,

- Agricultural, Commercial and Tourism sectors
- Provincial Government Reps (e.g. SHEFA and SANMA)
- Community reps (e.g. the Tagabe River Management Committee),NGOs
- Local Municipalities (Port Vila and Luganville)

• Clearly identify the missions, roles and responsibilities of each agency with respect to water supply management;

• Develop a structure for collaborative work

o Build trust between each agency

o Share good and bad examples and lessons learnt

13. Capacity Building for agencies in developing and implementing WSPs

• An ongoing Capacity Building and Training programme needs to be established to ensure local expertise is available to assist with WSP development & implementation.

• Conduct training workshops to train staff from other agencies on development and implementation of WSPs.;

• A strategy for maintaining expertise within agencies needs to be developed (e.g. staff passing on their knowledge to successors).

14. Improve sharing of information among agencies

• Establish a working group that would collate data and prepare annual reports on the following:

i. Drinking water quality of various supplies (urban, rural and outerisland) in Vanuatu

ii. Water-borne disease statistics

• Inter & intra governmental relationships and networks should be strengthened to improve information sharing;

• Establish a network between other PICs that have or are in the process of developing and implementing WSPs to share lessons learnt.

15. Enforce existing legislation or draft new legislation to address national water supply concerns

• Conduct a legislative review of various acts and regulations that regulate water resource, water supply or water quality management.

• Make amendments to existing legislation to address key issues in water resource, water supply and water quality management.

FINANCING

For safe quality drinking water we need appropriate financial arrangements and support to invest in needed improvements in water resources management, appropriate technology, institutional arrangements and community awareness and participation.

16. Secure high level Government Commitment for development and implementation of Water Safety Plans in Vanuatu

17. Increase self reliance by completing the Water Safety Plan to identify needed capital improvements and directing limited resources (from National Budget) to these improvement

18. Establish strategic planning for water supply development (using Water Safety Plans as a tool)

19. Identify funding sources
- Agencies need to identify sources (national budget and donor aid) for funding WSP implementation;
- Review current and projected budgets to identify funding for needed capital or institutional improvements for implementation of WSPs;
- Establish proper evaluation/review process for donor funded projects to avoid mis-management of funds

20. Allocate funding for needed improvements (capital works or institutional arrangements) or capacity building
- Complete Water Safety Plans for water supplies to use as justification for funding or donor support for needed improvements;
- Prepare an Improvement Schedule to identify (prioritize) those improvements that can be made with existing funding and those that will need additional funding from Government or donor support.

APPROPRIATE TECHNOLOGY

For safe quality drinking water we need to consider appropriate technology including reliability, practicality, energy needs, easy access to consumables, easy access to technical 'know how' and repairs/maintenance.

21. Identify appropriate technology, infrastructure and equipment (including consumables) for rural water supply keeping in mind the needs, capability and resources of local communities

- Ensure that the technology is feasible, appropriate and takes into consideration the unique geographical, geological, hydrological and socioeconomic situations;
- The technology should take into consideration frequent natural disaster events e.g. volcanoes, earthquakes, droughts and cyclones.

22. Build the capacity of local communities for the operation and management of rural water supplies

ISLAND VULNERABILITY

For safe quality drinking water we need relevant information and resources (including climatic data) on effects of climate change, natural disasters etc. to enable preparations for sustainability of water supplies and quick recovery after events such as natural disasters (flooding, drought, cyclones etc).

23. Improve preparedness for natural disaster events that could have significant impact on water resources and water supply

- Review and implement the National Disaster Management Plan;
- Increase local awareness of the Disaster Management Plan;
- Establish early warning systems for natural disasters such as earthquakes, cyclones, tsunamis and drought;
- Engage local communities (elders) to access local knowledge of predicting weather patterns and natural disasters;
- Promote emergency storage of water (through local media) before, during and after natural disasters such as flood, drought, cyclones and earthquakes;
- Ensure there are sufficient funds allocated for response to natural disasters.

24. Improve access to relevant regional and national climatic data

- Encourage sharing of information on climate change and weather patterns in Vanuatu;
- Strengthen the capacity for monitoring effects of Climate Change on water resources;
- Establish networks with regional meteorological centres for information sharing on climate change and regional weather patterns.

4.2 Desired Improvements for Smallholder Agriculture in Vanuatu

In the focus group discussions conducted during the beginning of this project the main wishes of the interviewed farmers were:

- Protecting water resources to have safe and secure access for household use
- Improving production of meat and eggs from chicken and ducks
- Adding value to the staple crops through processing into food and feed
- Integrating livestock and crop production to improve yield from livestock and crops
- Keeping chicken, ducks and pigs for higher cash income. It is the farmer's view that the current supply of meat to local markets is less than the demand.
- Introduction of other / new crops or crop varieties into the farming system
- More training and materials to improve breeding stock and knowledge of farming livestock
- Introduction of cyclone resistant dwarf varieties of banana and manioc
- Information on processing the starch of taro to preserve it for own consumption over time and rest the land for fallow over a longer period
- Introduction of early maturing bananas, disease resistance varieties and "moon shaped" bananas ("White Man Banana") for the market

Also the hope that a lift of EU's ban on kava would open a big market for Vanuatu's kava-export and hence generate good income for smallholder farmers is expressed all over Vanuatu.

4.3 Individual Sites

4.3.1 Siviri

4.3.1.1 General Information

Each village at this study site has different issues relating to soil and water. The villages are not experiencing the same water constraints, but the whole area was selected as a representative dry area, whereby preliminary investigations indicated that the village of Siviri is affected by draught the most. For the work at hand, only the conditions for the farming plots of Siviri were investigated. Most of Siviri's farming plots are located up the cliffs south of the village, around 50 m above sea level.

4.3.1.2 Land Use

As generally in Vanuatu, the arable land around Siviri is mainly used for crop farming, additionally agroforestry plays a role. Small-scale animal husbandry for domestic use is common, in pre-independence times big areas up the hill have been used for grazing cattle.

The regular farming system is the annual multi-crop garden on plots that were cleared from bush in advance by burning (Picture 11). The plots are left fallow every few years, for differing periods of time, but some crops will continue to be harvested during the fallow periods (e.g. banana). The gardens lie mainly on the upper terraces (Figure 11), which is primarily due to the domestic (and reportedly a few remaining wild) pigs that damage the plants regularly after entering the gardens that are too close to the village. The remaining plots close to the village are therefore fenced. Some plots are located as far as two kilometres away from the village. Even up at the water source, more than eight kilometres from the village by foot, some villagers have gardens (see Figure 12). The plots are scattered in the bush in a rather irregular manner, and most are only a few ares of size (see Figure 11). The main crops are manioc, taro, yam, papaya, coconuts, banana, island cabbage, sweet potato and grapefruit, all of which are part of the regular diet of the farmers, but also serve as cash crops. In addition to those common plants to Vanuatu, also more unusual crops like garlic, onion, chilli and lemon are present. To a minor extent, coffee and kava are grown (close to the main water source).

Picture 11: Typical food garden of Siviri

Practiced agroforestry includes the production of sandalwood and "whitewood" (Endospermum medullosum) for the wood market, together with some charcoal production.

Animal husbandry is only of minor importance, poultry and pigs are the base of small scale meat production, whereby pork serves more ceremonial purposes.

Siviri has drinking water supply by a water pipe that was installed by the government with foreign aid. The pipe transports water from a spring tapping (see Figure 12, "Main well" and Picture 12) on the other side of Undine Bay to Siviri and surrounding villages. Two high-level tanks are located on the cliffs above Siviri to allow constant supply (see Figure 12). Additionally, there is a pumping well close to the ring road for local supply.

Picture 12: Spring tapping for Siviri's drinking water supply

4.3.1.3 Farmer's Reports on Water Issues

At Siviri the farming plots on the terraces above the village are subject to dry conditions during the hot season, and crops are reported to dry up. This is especially true for the vast "white grass"- areas along the ring road on the way to Vila, which have been used as grazing land for cattle in pre-independence times. Also, soil erosion is a problem during the wet season. At some of the bigger farming plots, rill erosion can be observed.

Even though there would be some potential farming areas closer to the village and on the same level (above all close to the ring road), this potential is hardly being used. This is mainly due to the problem of domestic pigs entering the farming plots and eating and destroying the root crops. Therefore the plots are continuously moved further from the houses, but due to population growth also new houses tend to be built further up the hill, which is also displacing the problem.

The water pipe offers permanent and easy supply of all the adjacent villages, but it is frequently subject to manipulation and intentional damage. Also, since the new houses are built further and further up the hill, the water pressure there is too small to guarantee constant supply.

4.3.1.4 Thematic maps

Three thematic maps of Siviri were created (Figure 10 - Figure 12), showing the results of the survey on land use, soil and water issues. The locations of the profile pits (respectively infiltration tests) are also displayed.

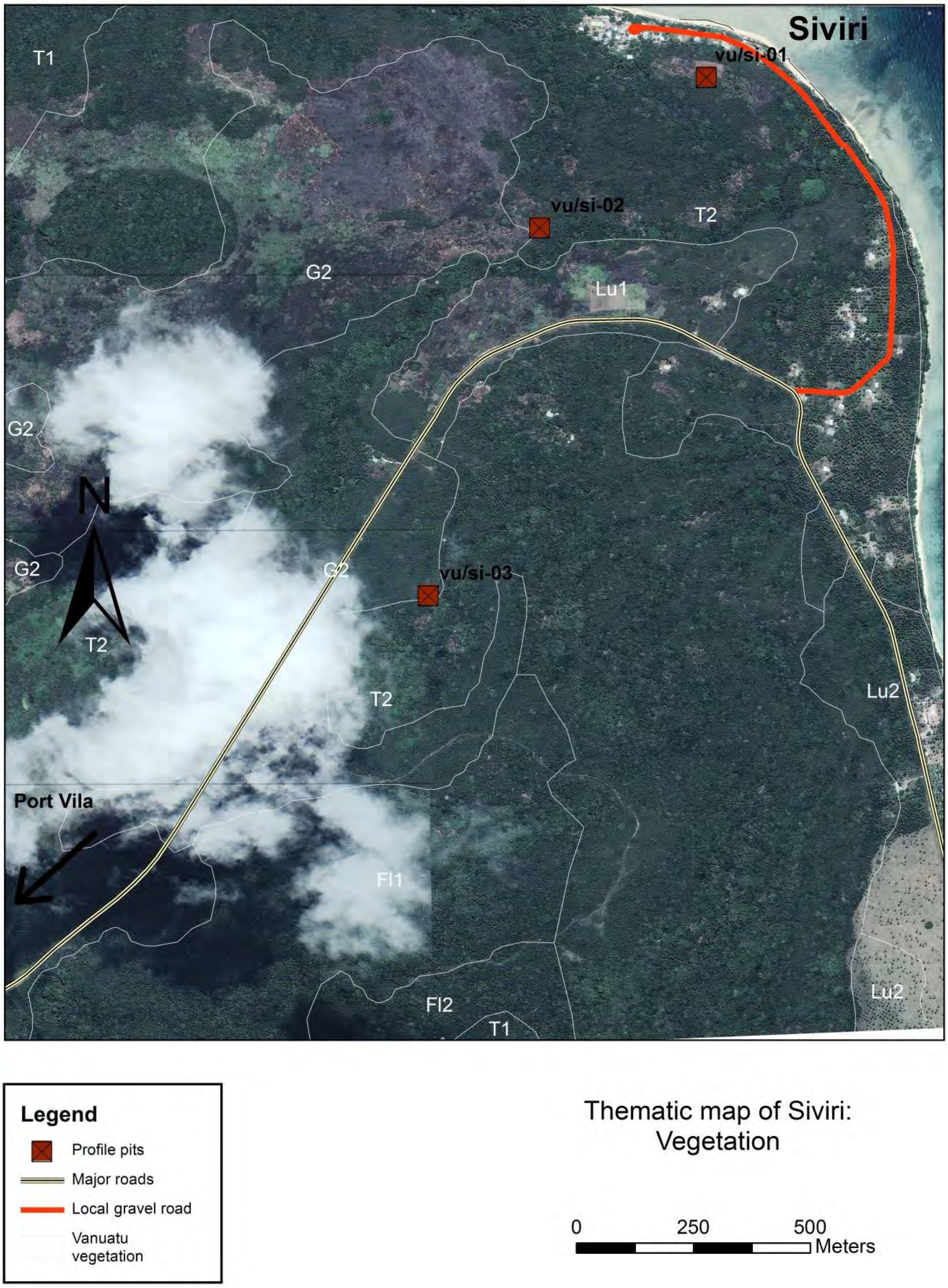


Figure 10: Thematic map of Siviri: Vegatation (based on land cover data retrieved from retrieved from the Ministry of Lands and Google Earth images)

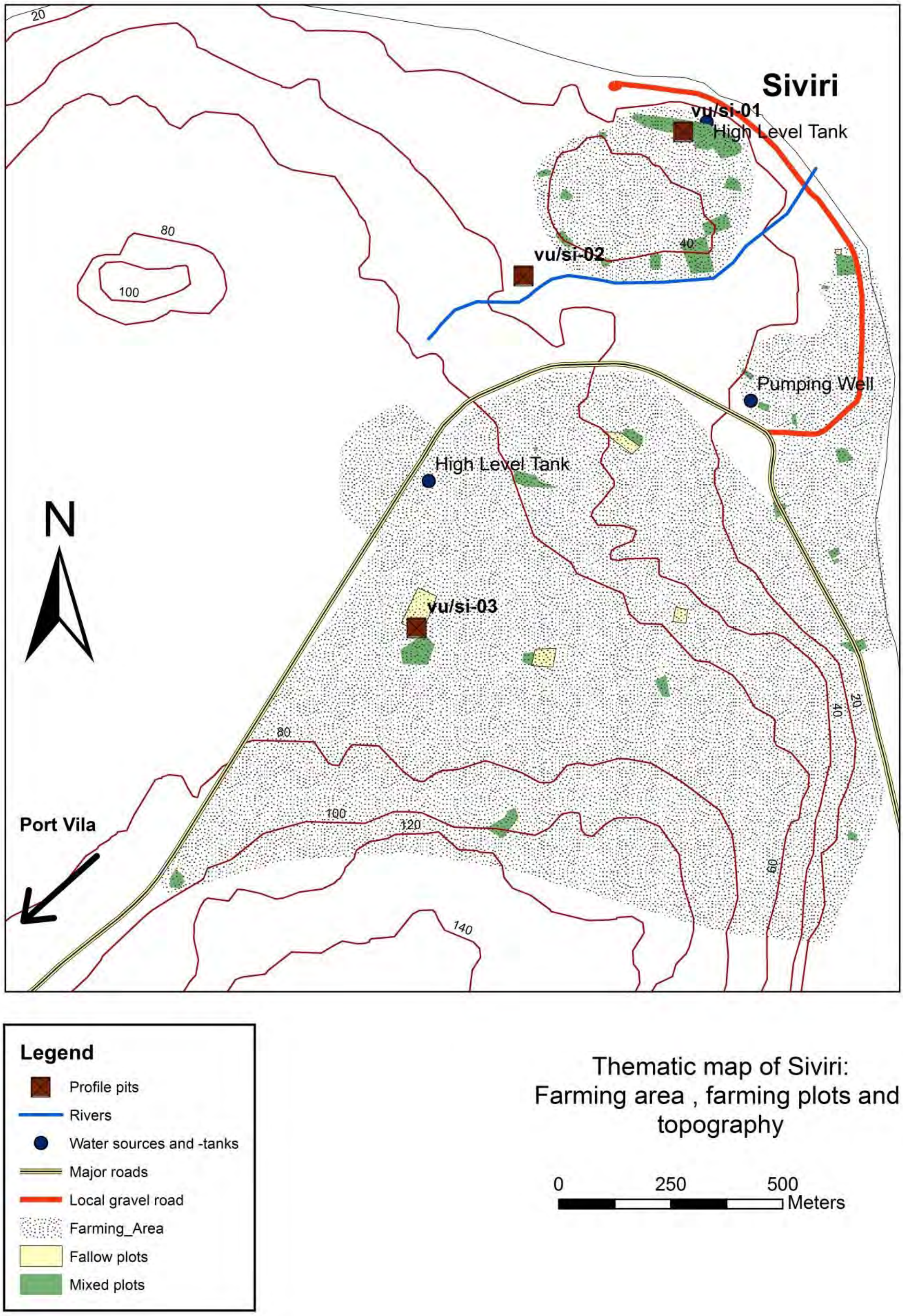


Figure 11: Thematic map of Siviri: farming area, land use (based on contour data retrieved from retrieved from the Ministry of Lands)

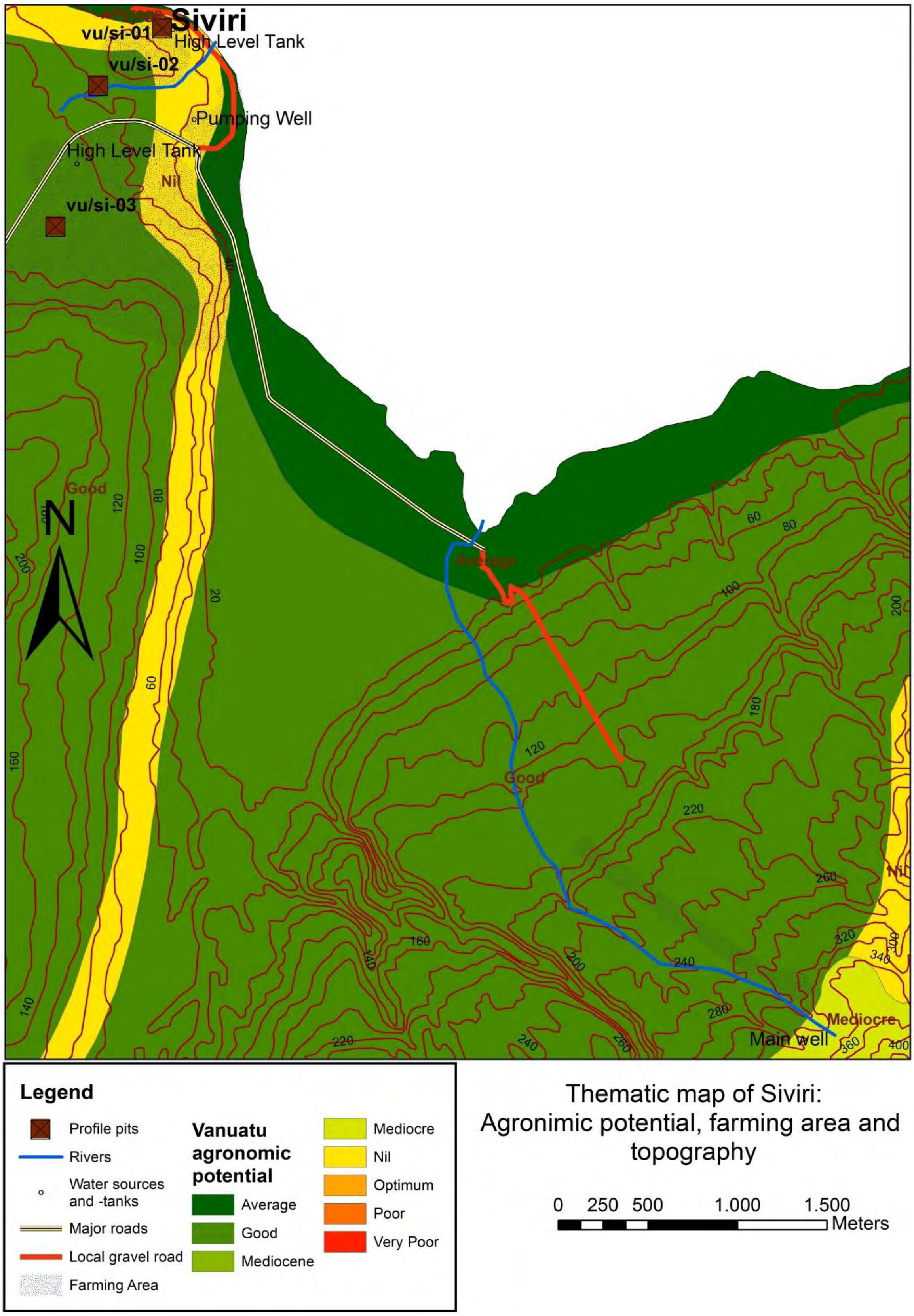


Figure 12: Thematic map of Siviri: Agronomic potential (based on contour data and agronomic potential data retrieved from retrieved from the Ministry of Lands)

The displayed agronomic potential and contour lines is GIS- data retrieved from the Ministry of Lands which again is based on data from Paul Quantin (Quantin, 1998). Also the vegetation codes were received from the Ministry of Lands, for the legend and a full-scale version of the maps please refer to Annex I: Thematic maps.

Note the vast "white grass"- areas (G2) in Figure 10. The dotted "farming area" is the land the small farming plots are scattered on.

The pumping well displayed in Figure 11 and Figure 12 is a single well that is not connected to the main water supply network, which is a rather linear network of pipes supplied by the main well south-east of Siviri (Figure 12). The nil-potential area includes the very steep limestone-step from the first to the second terrace, but right above and below that cliff, still in the yellow area, farming plots offering good conditions for farming can be found, which indicates that the zoning of the agronomic potential is maybe too coarse.

4.3.1.5 Precipitation

4.3.1.5.1 Secondary Data

Long-term rain data for Efate is provided by the weather station at Bauerfield airport, and since this automatic weather station is located at the west coast of the island, the mean annual rainfall of the station, which is 2245.6 mm/a (see 4.1.1), could be attributed to Siviri. But Siviri lies 20 km north of the airport, with several small mountain ranges with peaks of up to over 600 m lying in between, so the actual precipitation in Siviri can be significantly different, due to the predominant macro weather situation (south- eastern trade winds) most probably lower. SIMEONI (Simeoni, 2009) estimates the precipitation in the area in north-west- Efate to be between 1000 and 2000 mm/a (see Figure 13).

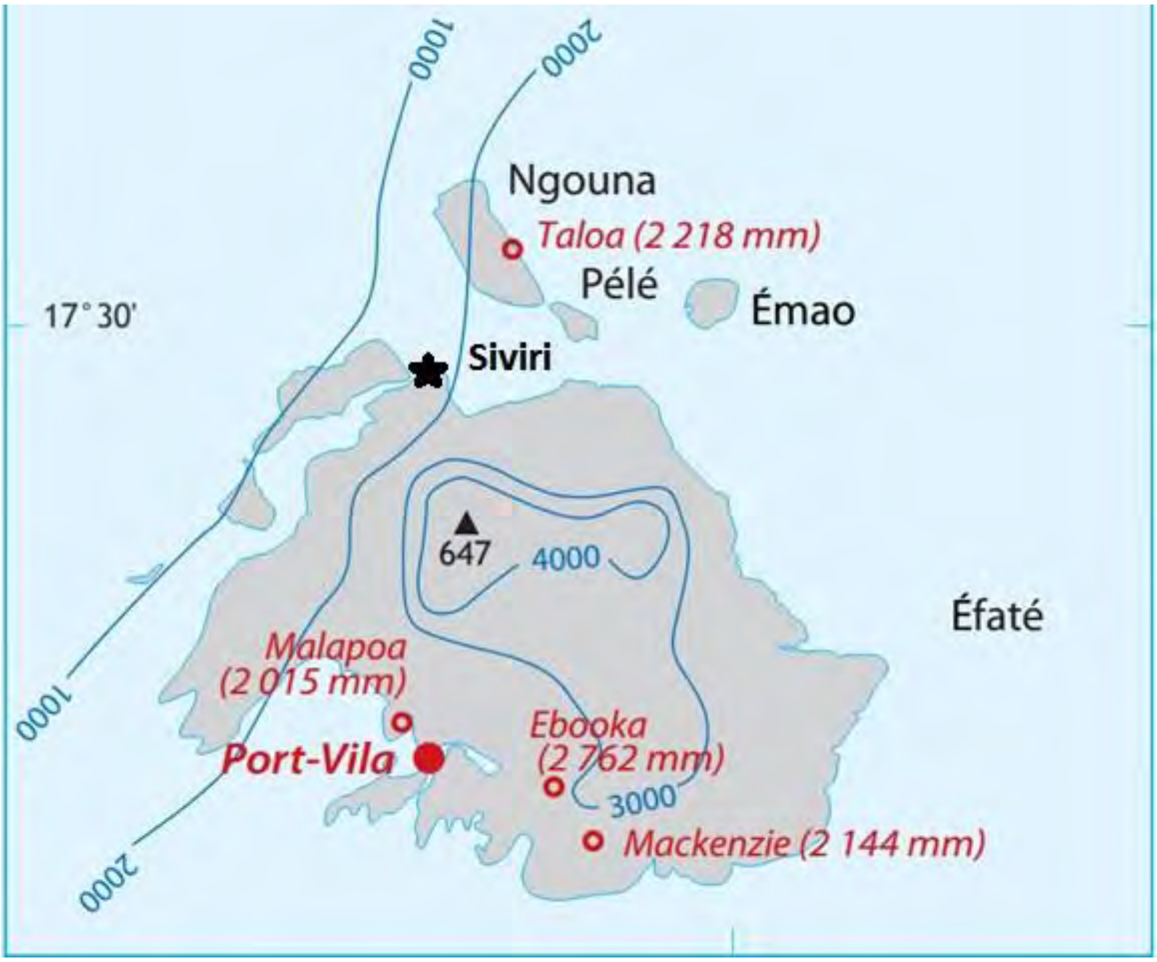


Figure 13: Isohyet zones on Efate (Simeoni, 2009)

4.3.1.5.2 Primary Data

Since the daily precipitation data of Siviri was not handed over by the Vanuatu Meteorology and Geohazards Department, and the automatic weather stations assigned for the project haven't been installed at the sites until now, the available precipitation data is very limited (compare Table 11). At Siviri, the monthly gauge could be installed during February. Therefore, two full months could be recorded there until the end of the work package. The value for February, which has only partly been recorded (orange in Table 11) was extrapolated using the mean precipitation during the days of the measurement. Continuative reading and collection of the data from the site has been assured by DARD- members.

Date	Rainfall Siviri (mm/month)	
Gauge type	Small	Big
24.02.-29.02.	-	121
01.02.-29.02.	-	501
01.03.-31.03.	-	235
01.04.-30.04.	-	409

Table 11: Rainfall Siviri, recorded 2012

The precipitation in this period is significantly higher than the long-time mean precipitation of these three months recorded at Bauerfield airport, which is 330, 320 and 234 mm/month (compare Table 10).

4.3.1.6 Geology and Pedology

4.3.1.6.1 Secondary data

Geological and pedological data of North- Efate was obtained from SOLS DE L'ARCHIPEL VOLCANIQUE DES NOUVELLES HEBRIDES (VANUATU) by Paul Quantin (Quantin, 1998). The following section is based on the geological maps provided in this book.

Siviri and its farming areas entirely lie on calcareous rock formations. The first terrace, down at the coast, on which only a minor share of the farming areas lie, is described as *"formations calcaires littorals recentes, récifs et plages de sables"*. The translation would be "recent calcareous coastal formations, riffs and sandy beaches". All the higher areas lie on "*formations calcaires anciennes, plateaux et gradins surélevés*", "ancient calcareous formations, elevated plateaus and terraces".

In Siviri, conditioned by the geology, two main types of soil are found. In the coastal areas, Quantin describes the soil as *"sols peu évolués d'apport des formations marines recifales recemment emerges - Régosoliques (sur sables)"*, meaning "little developed soils originating from marine, recently elevated riffs – regosolic (on sand). In the more elevated areas the characterisation is *"sols á sesquioxydes de fer, sols fersiallitiques á reserve calcique (peu désaturés á charactéres vertiques)"*, which is "soils containing iron- sesquioxides, iron-bearing soils with calcareous buffer (little unsaturated, vertic character)".

Quantin also examined two soil profiles in the area of Siviri (encoded 319 and QD in the soil atlas, see Figure 14). He describes the soil in the area as homogeneous and little developed, in principle varying only in colour (dark brown to black at the surface, dark red-brown to dark brown in the downs).

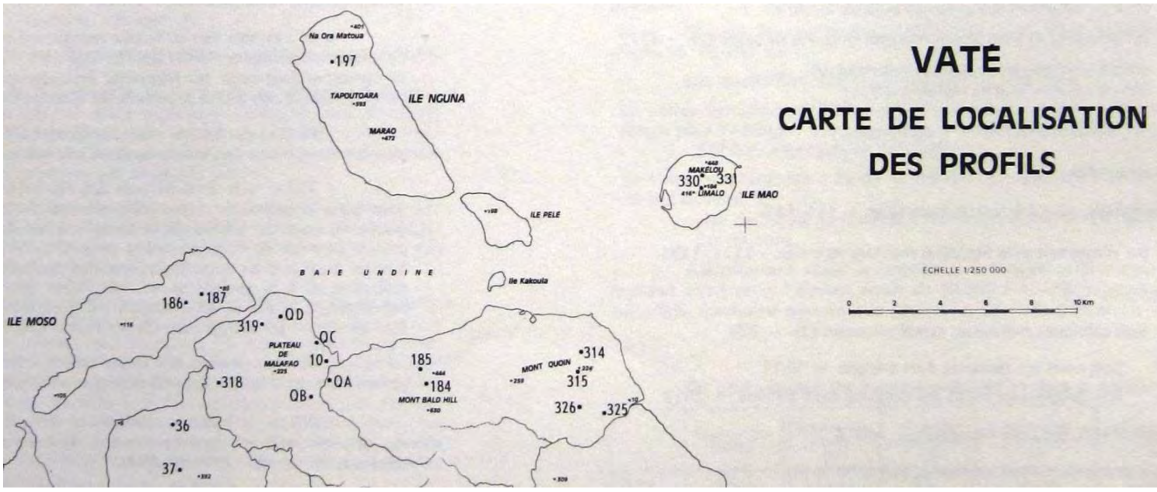


Figure 14: Localisation of the profile pits, Efate (Quantin, 1998)

In the profiles, a calcareous and clayish A- horizon rich in humus down to 10-20 cm, featuring well- defined aggregates, strong cohesion and strong permeability, lies on a transition horizon which extends down to 10-30 cm. The B- horizon is similar to the A- horizon in structure and cohesion, but it shows a much reduced permeability. The transition to the parent rock is little developed and clearly localised (see Annex V: Soil Data, Table 28).

The physical properties of Siviri's soil can be found in Table 12, the chemical properties in Table 13. The physical properties that are described are the granulometry, the structural stability, the water retention capacity and the density. The chemical properties that are described are

- the organic matter
- pH
- Base exchange
- Assimilable phosohor
- Total elemental constitution.

Depth of soil		≥ 40 cm		≤ 40 cm	
Horizon		A1	(B)	A1	(B) - A
Depth	cm	0/10 - 15	40/50	0/10 - 15	15/30
Granulometry	%				
Organic matter		9.0 - 12.3	1.8 - 3.3	13.0 - 8.3	4.3
Clay		49.9 - 51.1	90.3 - 80.8	65.9 - 46.7	91.1
Silt		15.3 - 28.1	4.3 - 6.5	12.7 - 29.0	3.7
Silt + clay		65.2 - 79.2	94.5 - 87.3	78.6 - 75.7	94.8
Fine sand		18.2 - 8.6	0.2 - 7.6	4.8 - 13.0	0.1
Coarse sand		7.1 - 3.2	1.9 - 3.3	3.5 - 3.0	0.7
Structural stability	%				
Dispersion coefficient (A + L)		2.5 -	1.7 -	1.4 -	1.2
Aggregation coefficient		93.0 -	90.9 -	92.5 -	91.6
Water retention capacity	%				
Hygroscopicity		10.1 - 13.9	10.7 - 16.6	11.2 - 16.0	12.1
Hunidity of fresh soil		42.4 - 60.1	51.6 - 56.2	43.1 - 39.0	49.1
pF, 2		-	-65.9	-	-
pF, 3		52.3 - 55.7	62.6 - 59.3	52.6 - 49.6	55.8
pF, 4.2		44.3 - 40.6	49.3 - 45.9	44.2 - 45.1	49.3
Density - Porosity	g/cmı				
Bulk density			0.81 x		
Solid density			2.54 x		
Total porosity	%		68.11 x		
Microporosity	%		48.06 x		
Macroporosity	%		20.05 x		
NB - The analyses have been undertaken on fresh soil and expressed in relation to the same soil, dryed at 105° C					
x Density determined between 40 and 50 cm					

Table 12: Physical soil properties Siviri (Quantin, 1998, translated for this work by the author)

Depth of soil	cm	≥ 40		≤ 40	
Horizon		A1	(B)	A1	(B) - A
Depth		0/10 - 15	40/50	0/10 - 15	15/30
Organic matter	‰				
Carbon		45.6 - 62.7	17.2 - 8.8	68.1 - 41.7	22.5
Nitrogen		3.44 - 4.62	1.65 - 0.75	6.71 - 2.93	2.49
C/N		11.5 - 13.6	10.4 - 11.7	10.7 - 14.2	9
pH (water)	-	5.8 - 6.0	5.7 - 5.0	6.1 - 6.6	6.2
Base exchange	%				
Ca		37.0 - 43.7	29.5 - 29.4	65.9 - 56.6	48.5
Mg		7.2 - 12.3	3.5 - 3.9	8.5 - 15.8	4.6
K		0.19 - 0.31	0.05 - 0.06	2.25 - 0.15	0.13
Na		0.25 - -	0.32	-	-
Sum		44.5 - 56.6	33.0 - 33.7	76.6 - 72.5	53.3
Exchange capacity (pH =7)		52.0 - 59.6	38.5 - 38.1	78.2 - 71.6	55.3
Saturation rate		85.3 - 95.0	85.9 - 88.4	98.3 - 100	96.3
Assimilable phosohor	p.p.m.				
P_2O_5		4.0 - 12.0	0.0 - 0.0	8.0 - 3.0	0
Total elements	%				
Burn-up		30.2 - 31.2	26.5 - 26.8	-31.9	
Residue		2.0 - 3.2	0.57 - 0.51	-2.6	
SiO_2		29.2 - 30.9	34.00 - 33.7	-32.6	
Al_2O_3		20.6 - 14.6	25.3 - 19.6	-15.8	
Fe_2O_3		15.8 - 15.4	14.4 - 15.4	-12.7	
SiO_2/Al_2O_3		2.4 - 3.6	2.3 - 2.9	.3.5	
$SiO_2/(Al_2O_3+ Fe_2O_3)$		1.6 - 2.2	1.7 - 1.9	-2.3	
TiO_2	‰	1.21 - 1.11	1.16 - 1.47	-0.89	
MnO_2	‰	-1.64	-0.81	-	
P_2O_5	‰	1.27 - 1.38	0.49 - 0.81	1.03 - 0.33	0.7
CaO	‰	14.4 - 13.1	9.5 - 8.1	25.4 - 20.4	15.9
MgO	‰	5.4 - 6.7	3.3 - 4.8	4.7 - 11.3	3.8
K_2O	‰	0.7 - 0.3	0.2 - 0.3	1.72 - 0.26	0.5
Na_2O	‰	-0.5	-0.4	-	-
NB - The analyses have been undertaken on air-dry sieved soil (2 mm) and expressed in relation to the same air-dry soil					

Table 13: Chemical soil properties Siviri (Quantin, 1998, translated for this work by the author)

4.3.1.6.2 Primary Data

In Siviri, only the soil of the main farming plots was investigated, which are all located on the first limestone terrace or further up. These are also the areas that might be more important in the future (compare section 2.2.1). The first profile lies within one of the main farming plots close to Siviri, right above the first cliff, the second one is located further up the hill, within the "White Grass"- area (former cattle grazing land), and the third pit was dug on a fallow plot on the other side of the ring road (see Figure 10 and Figure 11). For a detailed description of the profile pits please refer to Annex V: Soil Data

The soil in Siviri appeared in the field as uniformly clayish and characterised by its shallowness, the parent rock usually lies only 20 to 60 cm below the soil surface. At the sites of the three profile pits, the soil is made up of two main layers, sometimes a third can be observed, but it is not very distinct and rather a mix of the B- horizon with decomposed parent rock (see Picture 13). The parent rock is uniformly weathered coral limestone, and the stone can be found in the form of outcrops or lose stone cover, covering 0-40 % of the surface. The soil itself is consists of distinct, quite stable aggregates, the porosity is high, and also due to remains of the frequent fire clearance (burnt wood), the soil is very soft and light, having a bulk density of less than 1 g cm^{-3}.

Picture 13: Typical soil profile Siviri

At every site (see Figure 10 and Figure 11), infiltration tests were carried out. The infiltration rates were generally high, at vu/si-03 so high that the 30 l of water that were usually available for one test were not enough for a constant lowering rate to arise (see Figure 15). Because of this unusually high rate, the test there was repeated, but the phenomenon was confirmed. The asymptotical infiltration rates are 60 mm/h at vu/si-01 and vu/si-02, and 510 mm/h at vu/si-01, whereby this result has to be treated with caution.

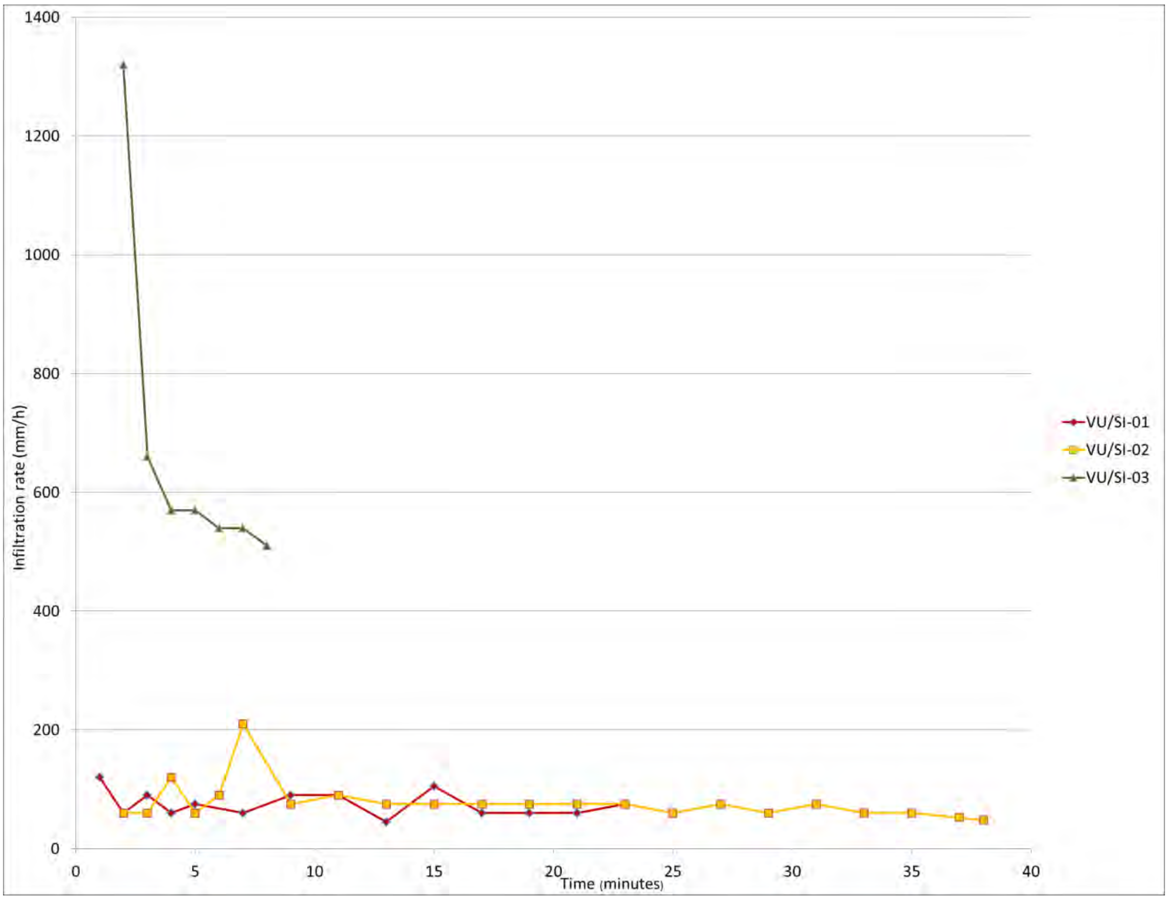


Figure 15: Infiltration tests Siviri

The pH of the soil in Siviri ranges from 4.49 to 6.4. The bulk density is generally very low, it usually lies below 1 g cm^{-1}, whereby the mean density is 0.84 g cm^{-1}).

	Site	VU/SI-01	VU/SI-02	VU/SI-03
	Infiltration (cm/h)	6	6	51
Horizon	Bulk density (g/cm³)			
#0		0.64	0.84	0.84
#1		0.92	0.87	0.95
#2				
#3				
	pH (-)			
#0		5.28	6.40	5.57
#1		4.49	6.25	4.92
#2				
#3				

Table 14: Overview on physical and chemical soil properties, Siviri

A more detailed display of the soil properties can also be found in the Soil Data Sheets (see Annex V: Soil Data).

4.3.1.7 Summary of Investigations at Siviri

The field survey showed that Siviri's farming areas are characterized by terraced land with clayish, highly aggregated soil that is shallow and underlying coral limestone that is highly permeable. The pH- measurements both show a slightly acidic soil. This and the measured moderate water permeability and porosity (which is inversely proportional to the bulk density) confirmed the data found in QUANTIN's soil atlas. The cation exchange capacity is high, above all in the very shallow soils (compare Table 13), and the total saturation rate is very high.

Precipitation data is insufficient to make profound statements, but the available data suggests that it lies between 1000 and 2000 mm/a, most probably above 1500 mm/a.

Farming is practiced mainly on the upper limestone terraces of the island, in a traditional manner, on small clearings in the forest. The available farming area is limited by the coast, the cliffs and supposedly the dry "white grass"- areas. Only a remarkably small portion of the available farming land is currently in use (compare the small "mixed plots" within the dotted "Farming area" in Figure 11).

4.3.2 Malafau

4.3.2.1 General Information

All of the villages at this site experience wet conditions. For the work at hand, Malafau was chosen as representative village. It is situated on the bottom of a broad valley at 17°34'S/168°17' E, 20 m above sea level, in between two rivers. All of the plots are located around the village or on the way from the village to the ring road, so they are all situated within the valley (compare Figure 17). Being separated from Siviri only by 6.5 km horizontal distance, and a small range of hills that do not exceed 140 m, the farming conditions are different nonetheless. At Malafau, soil moisture deficit is also a problem during the dry season, but excess soil moisture (stress) and flooding of cropping plots are the main restrictions for farming there.

4.3.2.2 Land Use

In Malafau, the land is mainly used for crop farming, additionally agroforestry and small-scale animal husbandry play a role. The whole village and its surrounding plots are arranged in a quite regular, rectangular pattern, since it has been created more or less on the drawing board when the villagers moved there from Siviri and had to cut the bush first.

The annual multi-crop garden is the dominant farming system (see Picture 14), whereby also single-crop plots are cultivated (mainly banana). Usually, plots are cultivated for three years, and then left fallow for two years. Most gardens lie close to the village, surrounding it in all directions, but plots used mainly for banana production for the market stretch out to the ring road (about 1.5 km from the village). Fencing of the gardens is not common, but practiced at some places. The main crops are manioc, taro, yam, island cabbage, papaya, coconuts, banana, grape fruit, sugar cane and sweet potato, all of which are staple crops, but also serve as cash crops. Banana is the major income source in Malafau. In addition to those more common plants, also tomato, corn, garlic and onion are grown.

Agroforestry is mainly practiced in the form of charcoal production, but also whitewood (Endospermum medullosum) is cultivated as a cash crop. A minor protection area north-east of the village restricts farming there.

Picture 14: Typical food garden of Malafau

4.3.2.3 Farmer's Reports on Water Issues

Generally, conditions in Malafau are reported to be wet with occasional water logging. On the other hand, first assessments showed though that farmers experience both problems with excess water and drought.

The soil in the valley is described by the villagers as relatively uniform, and so are the conditions for farming. The only significant place where the conditions are different is close to the ring road, where there are some plots nearby a swamp. The valley is very flat (compare Figure 17) and the river frequently floods big portions of the farming plots. The water is reported to drain away quickly though (within about one day after the rain fall stops), but the ground water level can stay high for a longer period, so that some depressions can experience prolonged water logging.

On the other hand, farmers feel restricted by the availability of water during the dry season, for example, in the farming season 2012 some farmers needed 3 attempts to finally successfully plant tomato seedlings without the seedlings drying up.

4.3.2.4 Thematic maps

Three thematic maps of Malafau were created (Figure 16 - Figure 18), showing the results of the land survey on land use, soil and water issues. The locations of the profile pits (respectively infiltration tests) are also displayed.

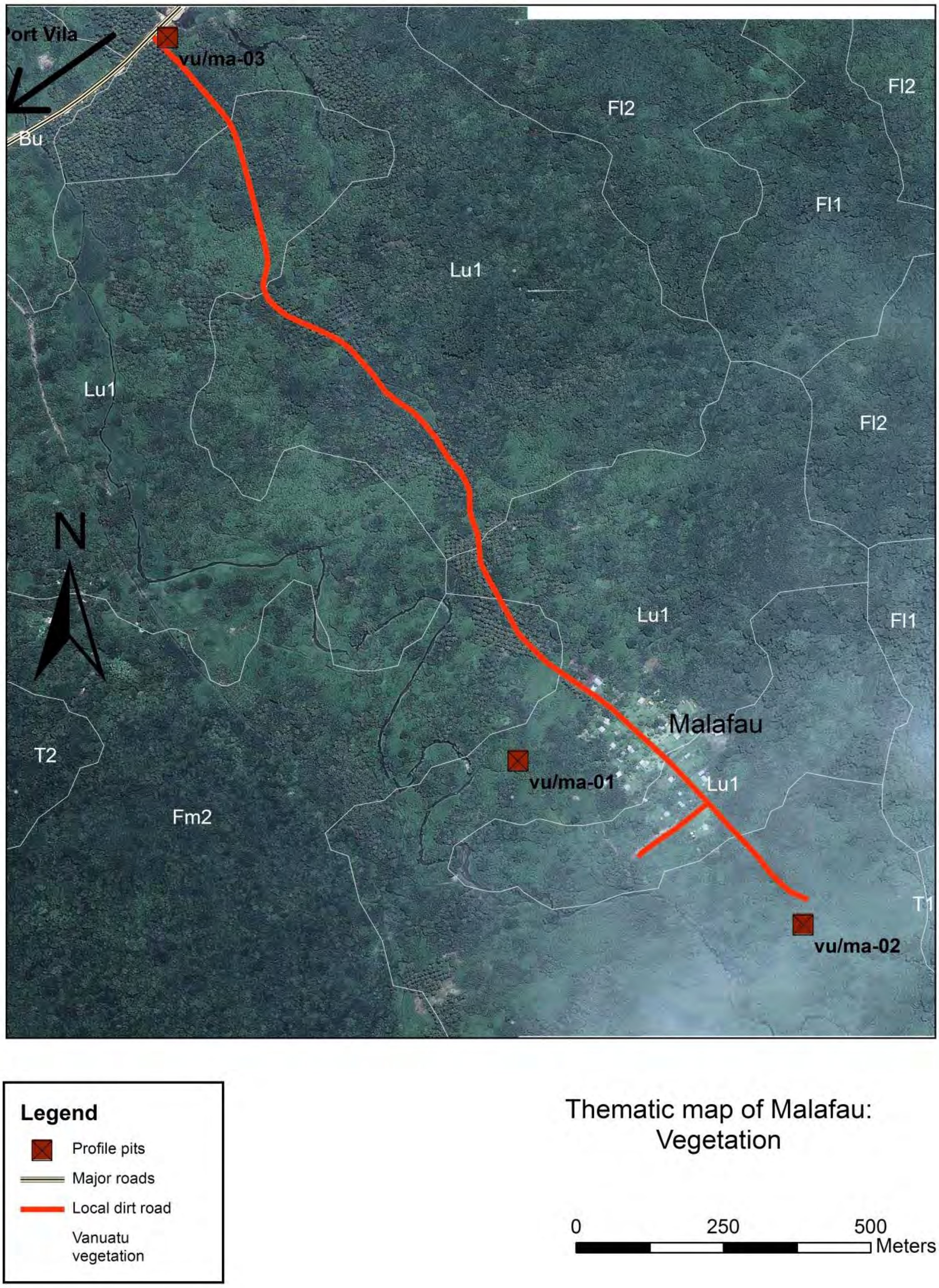


Figure 16: Thematic map of Malafau: Vegatation (based on land cover data retrieved from retrieved from the Ministry of Lands and Google Earth images)

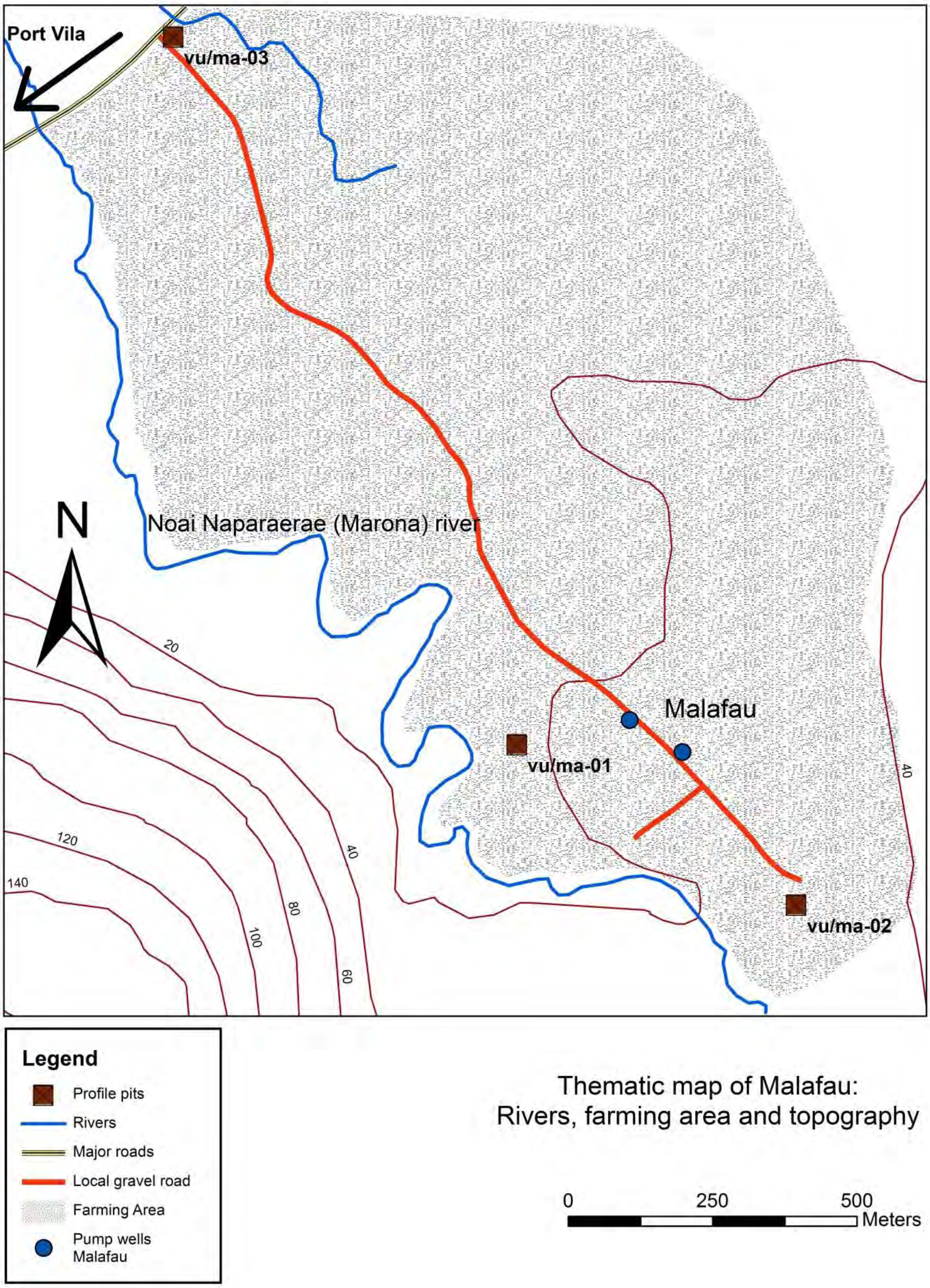


Figure 17: Thematic map of Malafau: farming area, land use (based on contour data retrieved from retrieved from the Ministry of Lands)

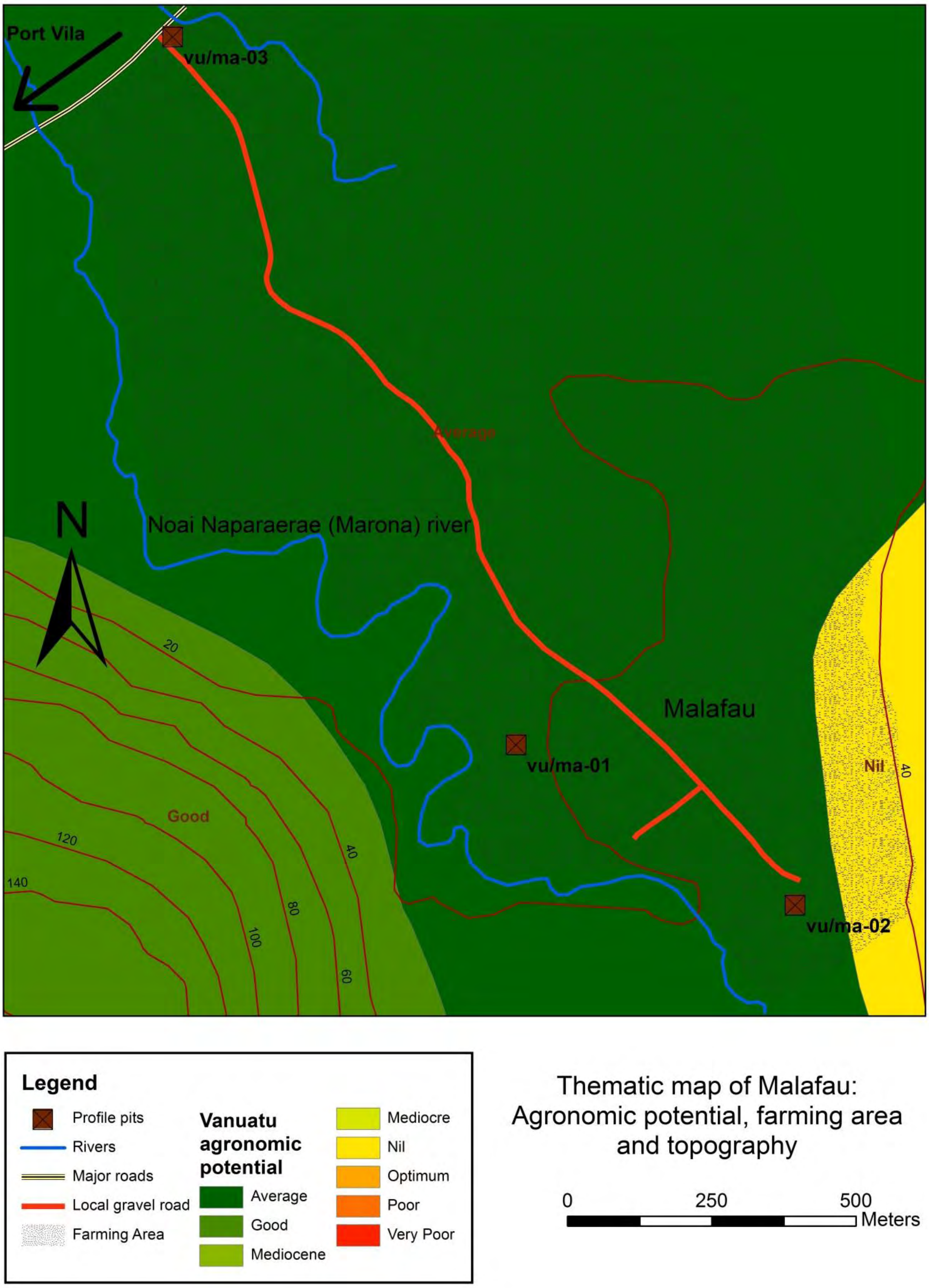


Figure 18: Thematic map of Malafau: Agronomic potential (based on contour data and agronomic potential data retrieved from retrieved from the Ministry of Lands)

The displayed agronomic potential and contour lines is GIS- data retrieved from the Ministry of Lands which again is based on data from Paul Quantin (Quantin, 1998). Also the vegetation codes were received from the Ministry of Lands. For the legend and a full-scale version of the maps please refer to Annex I: Thematic maps.

Malafau's farming area is quite uniform, and the plots are densely spread within it along the gravel road that leads to the village, further away from it they become less dense and regular, being scattered in the bush in a similar manner as in Siviri. Many plots lie close to the river, where the land is flat and high water levels in the river result in flooding of big parts of the area (compare Figure 17).

4.3.2.5 Precipitation

4.3.2.5.1 Secondary Data

The weather station at Bauerfield Airport is again the closest source for long-term rain data and since this automatic weather station is located at the west coast of the island, the mean annual rainfall of the station, which is 2245.6 mm/a (see 4.1.1), could also attributed to Malafau. But Malafau lies 15 km north of the airport, with a small mountain range with of up to over 400 m lying in between, so the actual precipitation in Malafau can be significantly different. SIMEONI (Simeoni, 2009) estimates the precipitation in the area (north-west- Efate) to be between 1000 and 2000 mm/a (see Figure 19).

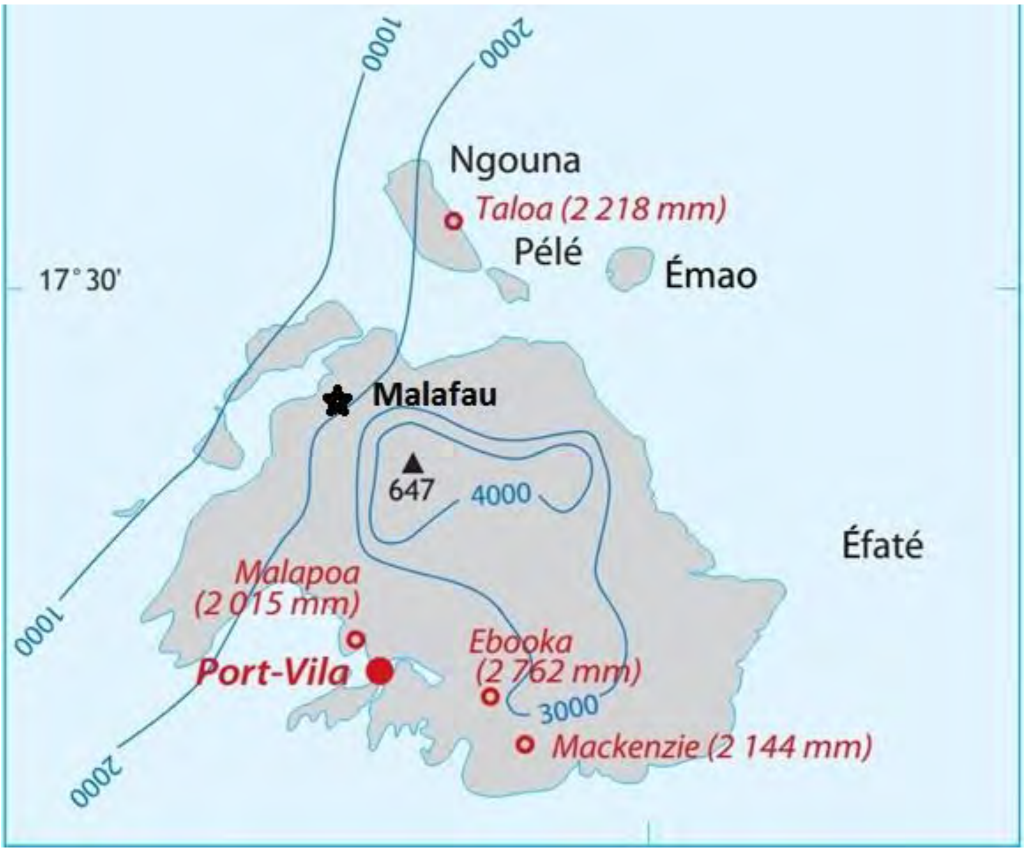


Figure 19: Isohyet zones on Efate (Simeoni, 2009)

4.3.2.5.2 Primary Data

Since the daily precipitation data of Port Havannah, which is recorded by the Vanuatu Meteorology and Geohazards Department, was not handed over, and the automatic weather station assigned for the project has not been installed at the site until now, the available precipitation data is very limited (compare Table 11). At Malafau, the gauges could be installed during February. Therefore, two full months could be recorded there until the end of the work package. The value for February, which has only partly been recorded (orange in Table 15) was extrapolated using the mean precipitation during the days of the measurement. Continuative reading and collection of the data from the site has been assured by DARD- members.

Date	Rainfall Malafau (mm/month)	
Gauge type	Small	Big
17.02.-29.02.	110	105
01.02.-29.02.	266	253
01.03.-31.03.	230	297
01.04.-30.04.	433	422

Table 15: Rainfall Malafau, recorded 2012

The precipitation of February and March is lower than the long-time mean precipitation of these three months recorded at Bauerfield airport, for April it is significantly higher (compare Table 10).

4.3.2.6 Geology and Pedology

4.3.2.6.1 Secondary data

Geological and pedological data of North- Efate was obtained from SOLS DE L'ARCHIPEL VOLCANIQUE DES NOUVELLES HEBRIDES (VANUATU) by Paul Quantin (Quantin, 1998). The following section is based on the geological maps provided in this book.

The farming areas of Malafau lie on young fluvial land. Paul Quantin described it as *"Alluvions fluviatiles récentes, sableuses, des plaines d'effondrement récentes, en majeure partie provenant des tufs volcaniques"*, which is "recent sandy fluvial alluvium, recently collapsed plains, mainly developed from volcanic tuffs".

The soil is described as *"sols peu évolués d'apport alluvial modaux"*, "little developed soils from modal alluvium".

In the valley of Malafau, Quantin described one soil profile (encoded 318 in the soil atlas, see Figure 14). He describes a deep soil with thick A to D- horizons, the A- Horizon being brown-grey to brown, containing humus and being of lumpy, sandy-clayish to sandy structure. The cohesion is medium and the permeability high. The C to D horizons are brown-grey with a reddish complexion, the structure more sandy and the permeability as well as the cohesion and the rooting are decreasing down to the parent material, which can be found below 80 cm and is of a grey-brown colour. It is also noted that sometime a hydromorphic layer with strongly reduced permeability can be found below the topsoil (see Annex V: Soil Data, Table 29).

The physical properties can be found in Table 16, the chemical properties in Table 17. The physical properties that are described are the granulometry, the structural stability, the water retention capacity and the density. The chemical properties that are described are

- the organic matter
- pH
- Base exchange
- Assimilable phosohor
- Total elemental constitution.

Depth	cm	0/20	60/80
Granulometry	%		
Organic matter		5.76	0.38
Clay		22.14	11.22
Silt		17.79	12.83
Silt + clay		39.93	24.05
Fine sand		33.78	40.36
Coarse sand		20.61	35.2
Water retention capacity	%		
Hygroscopicity		5.76	4.36
Hunidity of fresh soil		31.8	35.07
pF, 3		34.7	36.8
pF, 4.2		21.4	
NB - The analyses have been undertaken on fresh soil and expressed in relation to the same soil, dryed at 105° C			

Table 16: Physical soil properties Malafau (Marona); (Quantin, 1998, translated for this work by the author)

Horizon		A1	(B)
Depth		0/20	60/80
Organic matter	‰		
Carbon		31.1	2.13
Nitrogen		3.26	0.27
C/N		9.5	8
pH (water)	-	7	7.1
Base exchange	%		
Ca		22.88	9.36
Mg		4.02	3.8
K		1.54	2.17
Na		0.16	0.14
Sum		28.6	15.47
Exchange capacity (pH =7)		30.12	16.66
Saturation rate		94.9	92.9
Assimilable phosohor	p.p.m.		
P_2O_5		-	1.06
NB - The analyses have been undertaken on air-dry sieved soil (2 mm) and expressed in relation to the same air-dry soil			

Table 17: Chemical soil properties Malafau (Marona); (Quantin, 1998, translated for this work by the author)

4.3.2.6.2 Primary Data

The sites for the soil profiles in Malafau (see Figure 16 and Figure 17) were chosen in such a way that profile one and two represent the main farming areas close to the village. Profile three lies down at the ring road to Port Vila, where plots are used by the villagers, but the usage is limited due to a swamp. Unfortunately, at the intended site for the second profile pit the infiltration test was carried out, but the pit could eventually not be dug because the yam has not been harvested yet. In Vanuatu culture, yam is nothing to interfere with.

In the field, the soil in the valley of Malafau appeared very little developed. The clayish A-horizon only has a depth of 15-30 cm, shows medium- sized aggregates and lies on several layers of fluvial, sandy sediments. These sediments, most probably consisting of fluvial tuff, contain very little carbonates (0-2%), and roots are abundant until at least one metre depth. Generally, the soil is very lose, it is sandy and shows little cohesion. Also, the density is very low (< 1 g cm^{-3}). The profile close to the village showed a clayish intermediate layer, probably an ancient A- horizon, now buried underneath more recent fluvial sediments. A succession of different layers of sandy and clayish character could be observed down until the bottom of the pit (>130 cm, see Picture 15), the same is true for the profile close to the ring road, where the observation was limited by the high groundwater table (at 85 cm). There, the B- horizon features red and greyish spots indicating an undulating groundwater table.

For a detailed description of the profile pits please refer to Annex V: Soil Data.

Picture 15: Typical soil profile Malafau

At every site, infiltration tests were carried out. The infiltration rates were generally very high (180 to 240 mm/h), at vu/ma-03 the infiltration rate even increased towards the end of the experiment (Figure 20). The last few data points have not been included in the analysis because the rise of the rate was accompanied by high visible activity of earthworms in the cylinder (most probably escaping earthworms dug tunnels that increased the infiltration rate).

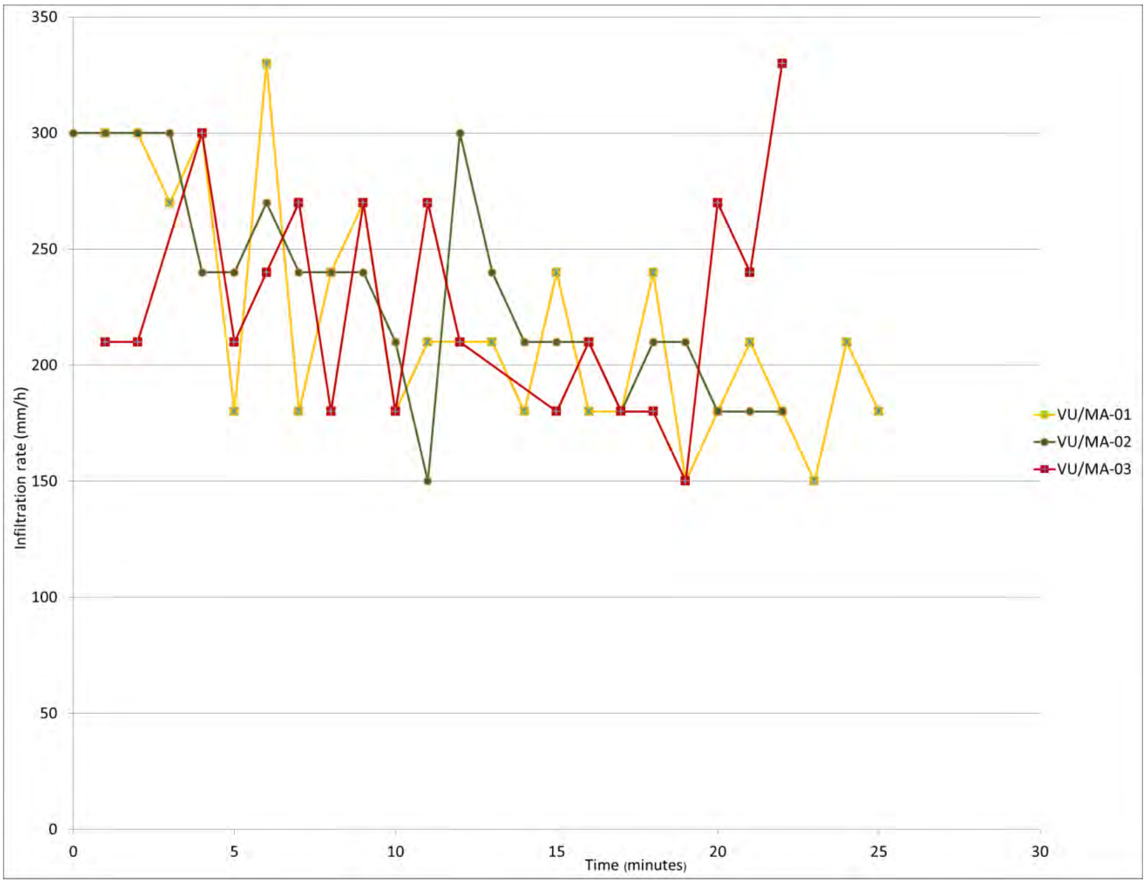


Figure 20: Infiltration tests Malafau

The pH of the soil in Malafau lies in the narrow range of 6.21 to 6.68. The bulk density is generally very low, it lies below 1 g cm^{-3} throughout, whereby the mean density is 0.74 g cm^{-3}.

	Site	VU/MA-01	VU/MA-02	VU/MA-03
	Infiltration (cm/h)	24	18	18
Horizon	Bulk density (g/cm³)			
#0		0.77	-	0.80
#1		0.69	-	0.72
#2		0.65	-	0.79
#3		0.74	-	
	pH (-)			
#0		6.64		6.31
#1		6.62		6.28
#2		6.68		6.21
#3		6.60		

Table 18: Overview on physical and chemical soil properties, Malafau

A more detailed display of the soil properties can also be found in the Soil Data Sheets (see Annex V: Soil Data).

4.3.2.7 Summary of Investigations at Malafau

Malafau's agricultural land is characterised by the field survey as levelled land in a valley-bottom (see Figure 17) with little developed, deep multy-layer sandy soil with a shallow, more clayish topsoil layer. It lies on fluvial sandy sediments and shows little cohesion and roots are abundant. The bulk density is very low, the hydraulic conductivity very high. All this confirms QUANTIN's observations in this valley, who also found a very low water retention capacity. Only the soil pH measured for the work at hand is not neutral, as QUANTIN determined it, but it is moderately acid, which can be a result of the differing measuring techniques (water vs. 1 M KCl solution). The cation exchange capacity is low, whereas the total saturation is high.

Precipitation data is insufficient to make profound statements, but the available data suggests that it lies between 1000 and 2000 mm/a, most probably above 1500 mm/a.

Farming is mainly restricted by frequent flooding of the plots by the river and water logging due to high groundwater tables. During the dry season, a low groundwater table and the high hydraulic conductivity of the soil are resulting in water stress.

4.3.3 Middle Bush

4.3.3.1 General Information

The study site Middle Bush is situated around 19°27'32'S/ 169°18'20'E on a high plane about 350 m above sea level. On Tanna, there is an active volcano (Mt. Yasur), about 15 to 20 km from the study site. Alone due to the elevation and the fact that the soil genesis is different, the conditions for farming there are very different from the ones at the other two study sites, whereby the villages in the area all experience the same problems. Generally the soil in the area is deep and clayish.

In Middle Bush, water is a big issue. Conditions are wet and the area relatively flat, which makes the area prone to flooding and water logging due to heavy rain in the area (compare Figure 22). Flooding and subsequent excess soil moisture represents a major threat to the yields of the farmers, but some areas are also subject to drought during the dry season.

4.3.3.2 Land Use

The arable land of Middle Bush is mainly used for crop farming, additionally agroforestry plays a role. Small-scale animal husbandry for domestic use is common, cattle breeding is also practiced.

The regular farming system is the annual multi-crop garden, whereby the different crops within one plot are mostly arranged in a specific way according to *kastom* (e.g. taro around maniok). The plots are scattered around the villages (compare Figure 22), sometimes arranged in a regular, rectangular way with dams in between them. Fencing is not common. The main crops are manioc, taro (including some water taro), yam, papaya, peanuts, coconuts, banana, island cabbage, sweet potato, grapefruit, coffee and kava. Additionally, rice is grown to a varying extent. Coffee and kava are grown extensively, coffee serves as cash crop only, also kava is sold at the market to a big extent.

Practiced agroforestry includes the production of sandalwood and "whitewood" (Endospermum medullosum) for the wood market, together with some charcoal production.

Poultry and pigs are the base of small scale meat production for subsistence, whereby pork serves more ceremonial purposes. Cattle is almost exclusively bred for the market (mainly at Lenakel).

Picture 16: Typical food garden of Middle Bush

4.3.3.3 Farmer's Reports on Water Issues

Since just recently, in 2011, big areas of the land have been flooded, the awareness of the problem is high. But flooding occurs frequently, and the farmers have concepts to deal with it: once a plot is flooded, they would usually dig a channel through the small dams that usually separate the plots, and then the water is released to the next plot. Doing that, the water would eventually reach the creek (compare Figure 22). Recently, many farmers have abandoned good farmland because they fear to lose their crops due to anew flooding.

Another big issue is drinking water: there are not as many rain water tanks in Middle Bush as in other areas of Vanuatu, so not everyone has access to rain water for drinking, cooking, washing clothes or personal hygiene. The villagers then usually have to get water from the creeks, which involves a walk that takes one to two hours return.

4.3.3.4 Thematic maps

Three thematic maps of Middle Bush were created (Figure 16 - Figure 18), showing the results of the land survey on land use, soil and water issues. The locations of the profile pits (respectively infiltration tests) are also displayed.

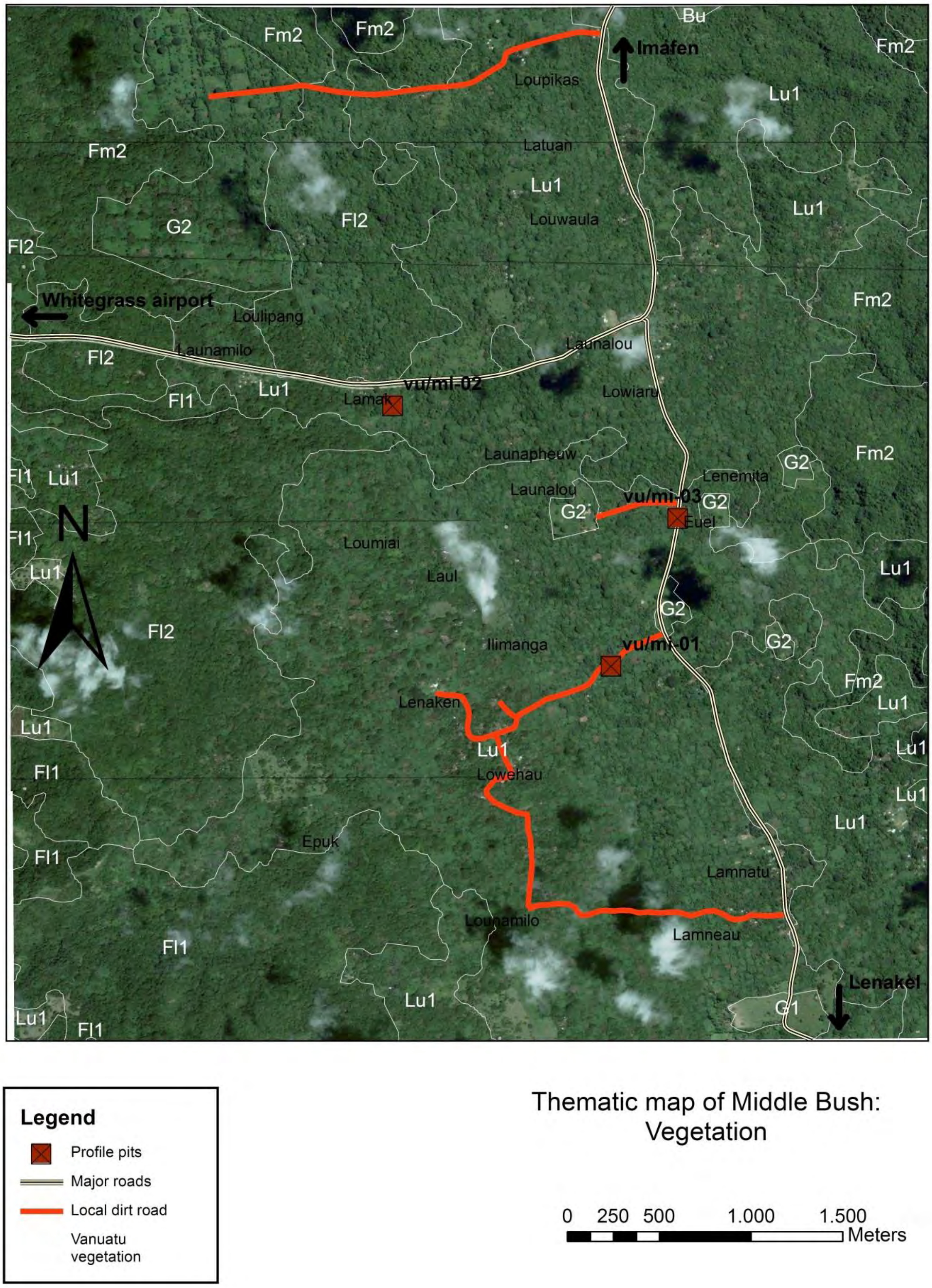


Figure 21: Thematic map of Middle Bush: Vegatation (based on land cover data retrieved from retrieved from the Ministry of Lands and Google Earth images)

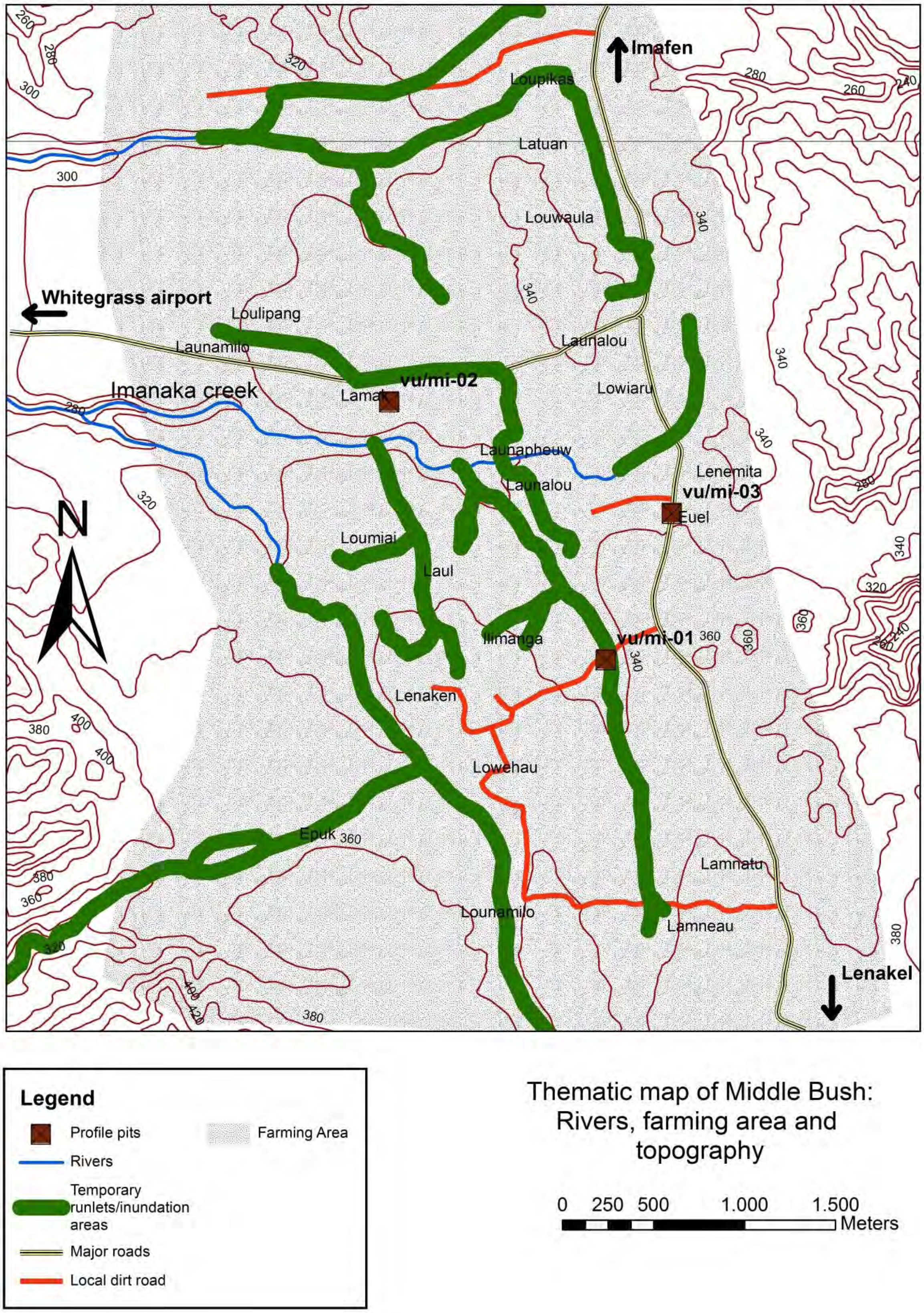


Figure 22: Thematic map of Middle Bush: farming area, inundation areas (based on contour data retrieved from retrieved from the Ministry of Lands)

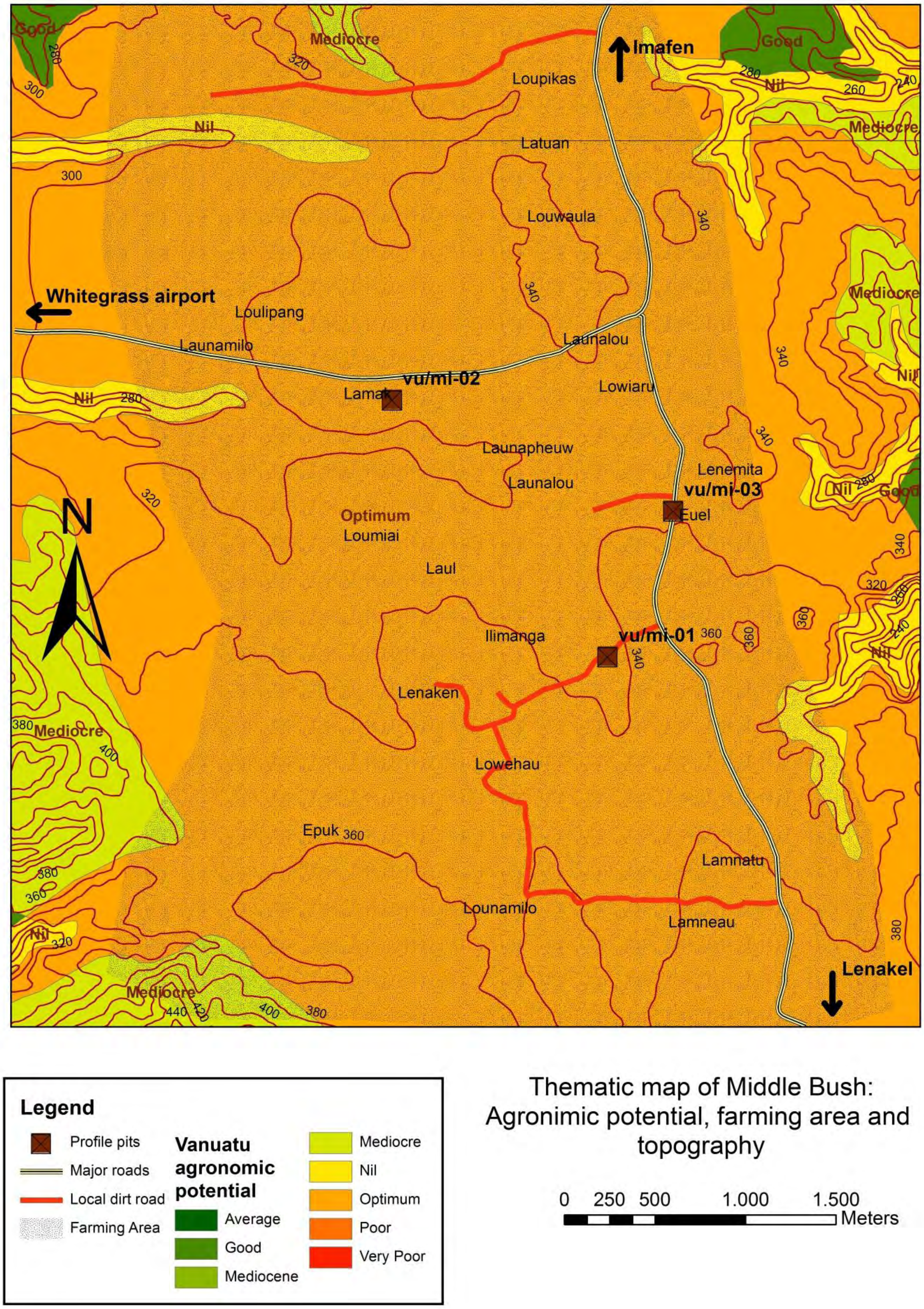


Figure 23: Thematic map of Middle Bush: Agronomic potential (based on contour data and agronomic potential data retrieved from retrieved from the Ministry of Lands)

The displayed agronomic potential and contour lines is GIS- data retrieved from the Ministry of Lands which again is based on data from Paul Quantin (Quantin, 1998). Also the vegetation codes were received from the Ministry of Lands, for the legend and a full-scale version of the maps please refer to Annex I: Thematic maps.

In Figure 21 to Figure 23, the main characteristics of Middle Bush's farming area can be seen. It is a big, quite densely populated, only slightly undulating area, where, in case of heavy rain, big potions of the land are flooded by temporary runlets and pools. The runlets marked in Figure 22 can swell to big rivers and feed pools that persist for months and therefore destroy the harvest. That is why, all along those runlets, abandoned farming plots can be found.

4.3.3.5 Precipitation

4.3.3.5.1 Secondary Data

Since the automatic weather station at Whitegrass airport is located at the west coast of the island, almost at sea level, the recordings of this station (1277.6 mm/a), cannot be attributed to the area of Middle Bush. Tanna has a more prominent central massive than Efate, and as Middle Bush lies on this ridge it will receive more rain than what results from Burtonfield and Whitegrass indicate. SIMEONI (Simeoni, 2009) estimates the precipitation in Middle Bush ("Centre Brousse") to be around 2500 mm/a (see Figure 24).

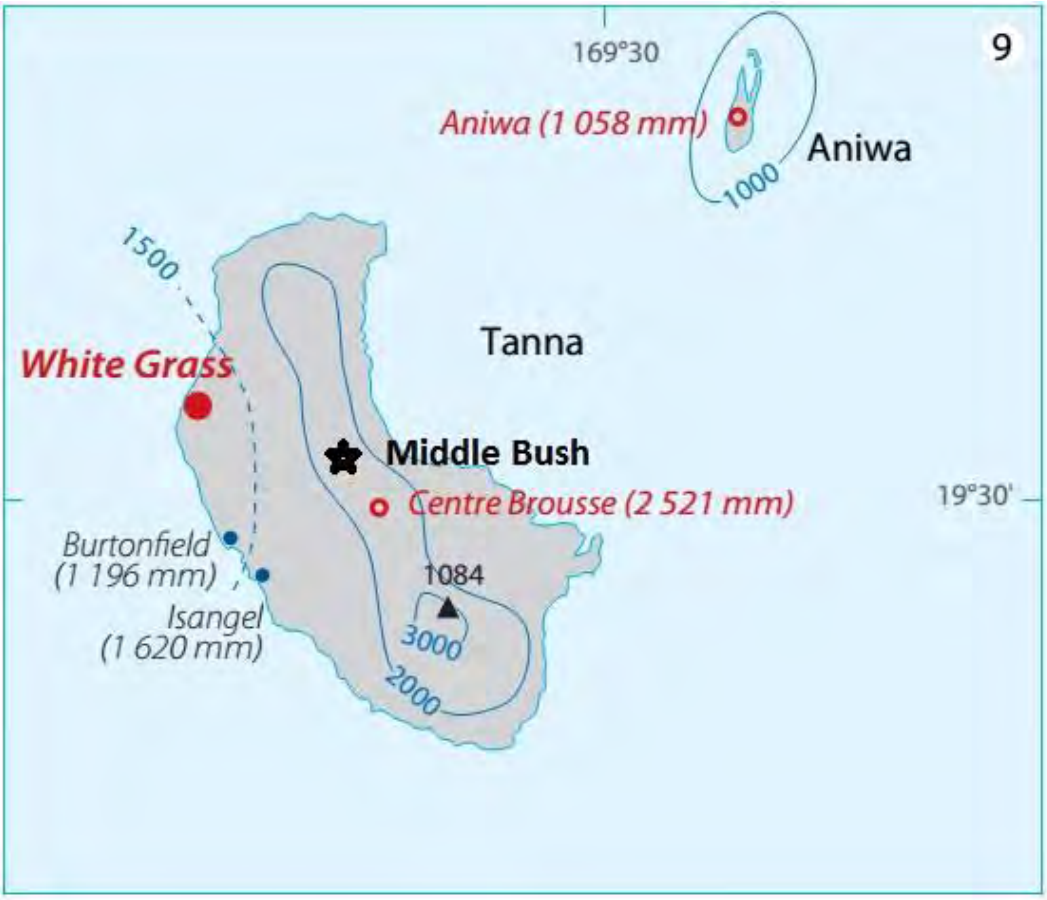


Figure 24: Isohyet zones Tanna (modified after Simeoni, 2009)

4.3.3.5.2 Primary Data

Since no automatic weather station will be installed at Middle Bush for this project, and the daily precipitation data was not handed over by the Vanuatu Meteorology and Geohazards Department, the available precipitation data is very limited (compare Table 19). At Middle Bush, the gauges could be installed by the beginning of April only. Therefore, only one full month could be recorded there until the end of the work package. Continuative reading and collection of the data from the site has been assured by DARD- members.

Date	Rainfall Middle Bush (mm/month)	
Gauge type	Small	Big
01.04.-30.04.	204	244

Table 19: Rainfall Middle Bush, recorded 2012

The precipitation in this period is significantly higher (almost twice the value) than the long-time mean precipitation of this month recorded at Burtonfield airport (compare Annex III: Vanuatu rain gauges, Table 26).

4.3.3.6 Geology and Pedology

4.3.3.6.1 Secondary data

Geological and pedological data of North- Efate was obtained from SOLS DE L'ARCHIPEL VOLCANIQUE DES NOUVELLES HEBRIDES (VANUATU) by Paul Quantin (Quantin, 1998). The following section is based on the geological maps provided in this book.

The centre of Tanna, and therefore the whole area of Middle Bush, has tuff as parent rock. Quantin categorises it as *"formations volcaniques intermédiaires (Pléistocène): plateau de tufs basaltiques",* "intermediate volcanic formations (Pleistocene): basaltic tuff plateau".

According to Quantin, Middle Bush's soils are *"andosols á profil differencie, saturés, chromiques, complexes, cendres andésitiques récentes sur roches basaltiques pléistocènes, Andosol saturé modal. Épais de 1 á 2 m, et paléosol brun sur tufs basaltiques"*, which can be translated as "Andosols with differenciated profile, saturated, chrome- containing, complex, andesitic recent ashes on basaltic pleistocenic basaltic rock. Saturated andosol, between 1 and 2 metres thick, and brown paleosol on basaltic tuffs".

Quantin examined several soil profiles in Middle Bush, here profiles nr. 515 and 107 are described (série centre-Brousse and série de Lonamilo, see Annex V: Soil Data, Table 30 and Table 31). Nr. 515 lies in central Middle Bush, 107 on the northern edge of the project site.

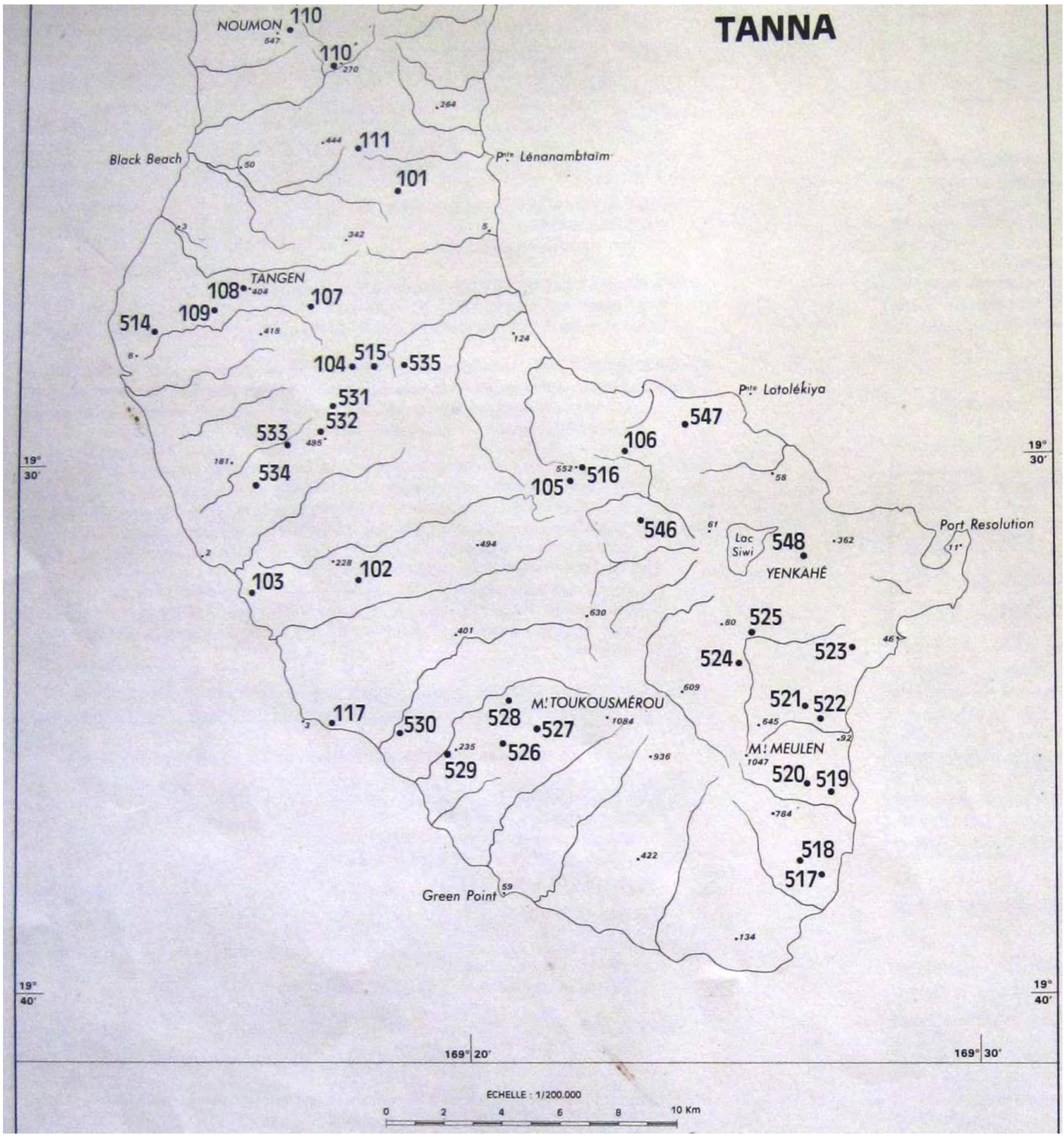


Figure 25: Locations of the profile pits, Tanna (Quantin, 1998)

Quantin describes very deep soil, which is rich in primary minerals, whereby the upper horizons are rich in unaltered plagioclases and magnetite, and the fraction below 2 µ mainly consists of amorphous substances and traces of clay. The portion of clay increases in deeper layers, which transcend to brown earth. In northern region (profile 107) the upper layers are similar, but the layers deeper than 60 cm constitute of a high portion of clay (Table 30 and Table 31).

In Table 20, the physical properties, in Table 21 the chemical properties can be found. The physical properties that are described are the granulometry, the structural stability, the water retention capacity, the density and the specific surface. The chemical properties that are described are

- the organic matter
- pH
- Base exchange
- Assimilable phosohor
- Total elemental constitution

Profile N°		515				107		
Horizon		A11	A12 (B)	(B)-C	II (B)-C	A11	A12 (B)	II (B)
Depth	cm	0-20	80-100	150-170	210-230	0-20	20-45	100
Granulometry (<2mm)	%							
Gravel		0	0	0	0	0	0.2	0
Organic matter		6.05	2.49	1.25	0.56	6.49	3.39	0.67
Clay		6.67	18.57	20.08	15.69	20.89	27.68	65.18
Silt		6.16	12.55	14.14	16.34	12.09	21.41	30.16
Silt + clay		12.83	31.12	34.22	32.03	32.98	49.09	95.34
Fine sand		77.78	63	61.56	39.12	59.61	46.3	3.81
Coarse sand		3.34	3.39	2.97	28.29	0.92	1.22	0.18
Structural stability	%							
Dispersion coefficient (A + L)		28.8	19.5	35.1	-	4.6	4.5	3
Aggregation coefficient		50.6	39.4	40.7	-	74.4	67.5	86.6
Water retention capacity	%							
Hygroscopicity		3.96	7.05	11.73	14.56	5.83	9.77	23.11
Hunidity of fresh soil		45.28	46	62.3	61.26	42.22	35.67	77.43
pF, 3		47.11	50.52	65.35	61.75	41.17	37.67	78.68
pF, 4.2		21.32	27.23	40.09	30.38	29.64	25.78	66.09
Density - Porosity								
Bulk density	g/cm^3	0.93	0.77	0.64	0.52	-	-	-
Total porosity	%	61.6	66.5	74.7	79.5	-	-	-
Specific surface	m^2/g	5	38	117	32	-	-	-
Specific surface <2µ		176	175	-	132	-	-	-
NB - The analyses have been undertaken on fresh soil and expressed in relation to the same soil, dryed at 105° C								

Table 20: Physical soil properties Middle Bush (Quantin, 1998, translated for this work by the author)

Profile N°		515				107		
Horizon		A11	A12 (B)	(B)-C	II (B)-C	A11	A12 (B)	II (B)
Depth	cm	0-20	80-100	150-170	210-230	0-20	20-45	100
Organic matter	‰							
Carbon		33.9	13.65	6.66	2.88	35.55	17.93	3.14
Nitrogen		3.4	1.43	0.58	0.19	3.76	1.56	0.3
C/N		10	9.5	11.5	15.4	9.5	11.5	10.5
pH (water)		5.9	6.5	6.5	6.5	6.3	6.6	5.5
Base exchange	%							
Ca		14.06	8.76	10.33	15.77	17.13	13.38	4.95
Mg		2.1	1.56	2.72	5.99	2.6	3.46	2.86
K		0.46	1.59	2.86	4.68	1.22	1.82	4.44
Na		0.37	0.31	0.59	0.8			
Sum		16.99	12.22	16.5	27.24	20.95	18.66	12.25
Exchange capacity (pH =7)		21.64	18.34	21.96	32.52	22.4	21.53	24.47
Saturation rate	%	78.5	66.6	75.1	83.8	93.5	86.7	50.1
Assimilable phosohor	p.p.m. (Troug)							
P_2O_5		300	28	110	70	50	100	23
Total elements	%							
Burn-up		13.51	14.2	16.26	20.52	15.45	10.41	27.38
Residue		64.23	50.27	42.08	23.12	58.36	44.46	2.27
SiO_2		12.33	18.35	19.89	27.62	14.49	17.91	30.77
Al_2O_3		3.95	7.72	10.04	14.56	5.02	12.8	23.88
Fe_2O_3		3.64	6.58	8.05	10.73	4.58	10.25	13.92
SiO_2/Al_2O_3		5.31	4.04	3.37	3.23	4.91	2.23	2.19
$SiO_2/(Al_2O_3+Fe_2O_3)$		3.34	2.62	2.23	2.2	3.1	1.53	1.6
TiO_2	‰	0.24	0.48	0.63	0.85	0.39	0.92	1.13
MnO_2	‰	0.07	0.16	0.21	0.26	-	0.29	0.3
P_2O_5	‰	3.7	4.6	3.4	3.6	2.33	3.83	3.04
Ca	me/100 g	25.32	22.82	37.8	34.23	22.32	38.16	5.78
Mg	me/100 g	16.37	31.25	51.09	40.67	14.19	29.26	10.07
K_2O	me/100 g	1.91	2.76	4.88	6.58	1.7	7.43	4.95
Na_2O	me/100 g	7.74	6.77	11.61	5.16	-	16.13	-
Hygroscopicity	%, dry soil (105 °C)	3.56	5.77	8.73	12.73	5.83	5.58	23.11
NB - The analyses have been undertaken on air-dry sieved soil (2 mm) and expressed in relation to the same air-dry soil								

Table 21: Chemical soil properties Middle Bush (Quantin, 1998, translated for this work by the author)

4.3.3.6.2 Primary Data

The profile pit sites in Middle Bush are spread all over the area (see Figure 16 and Figure 17), aiming to include sites with different characteristics. All sites lie within agricultural land, whereby the location of pit one itself is locally covered with wild cane, pit two lies within grassland that is sometimes grazed by cattle, pit three lies on a plot that is currently in use. All the three sites are close to areas that are subject to flooding and water logging. Profile one and two were dug at side-cuts of roads, both are next to areas that become waterways when the region gets flooded, but they are rarely affected because of the local topography (their positions close to sloping territory). Pit three is also on terraced land, but nevertheless it is reportedly subject to flooding.

The A- horizon is loamy or clayish, and almost uniformly about 70 cm deep, the B-horizon stretches down to one metre or more and consists of sandy clay loam, both horizons show reddish colours (see Picture 17). Down to 1.5 m no parent rock whatsoever could be reached, and at side-cuts of roads or at heavily eroding creeks it becomes evident that the soil is several metres deep, which is also supported by stories of the locals. However, roots have hardly been observed below ~70 cm. Aggregates are observable but they are smaller than on Efate and range from stable to unstable, the bulk density is comparable to the one at Siviri and lies around 1 g cm^{-3}. The carbonate test could not be conducted on Tanna because the hydrochloride acid could not be made available there.

For a detailed description of the profile pits please refer to Annex V: Soil Data.

Picture 17: Typical soil profile Middle Bush

At every site (see Figure 21 and Figure 22) infiltration tests were carried out. The infiltration rates were generally low (2 to 7 mm/h). At vu/mi-01 the infiltration rate increased at towards the end of the experiment, whereby the last few data points have not been included in the analysis because the rise of the rate was accompanied by high visible activity of earthworms in the cylinder (Figure 26; most probably escaping earthworms dug tunnels that increased the infiltration rate). The more regular fluctuations are a result of the lower initial infiltration rates and the precision of the water level measurement (+/- 0.5 mm).

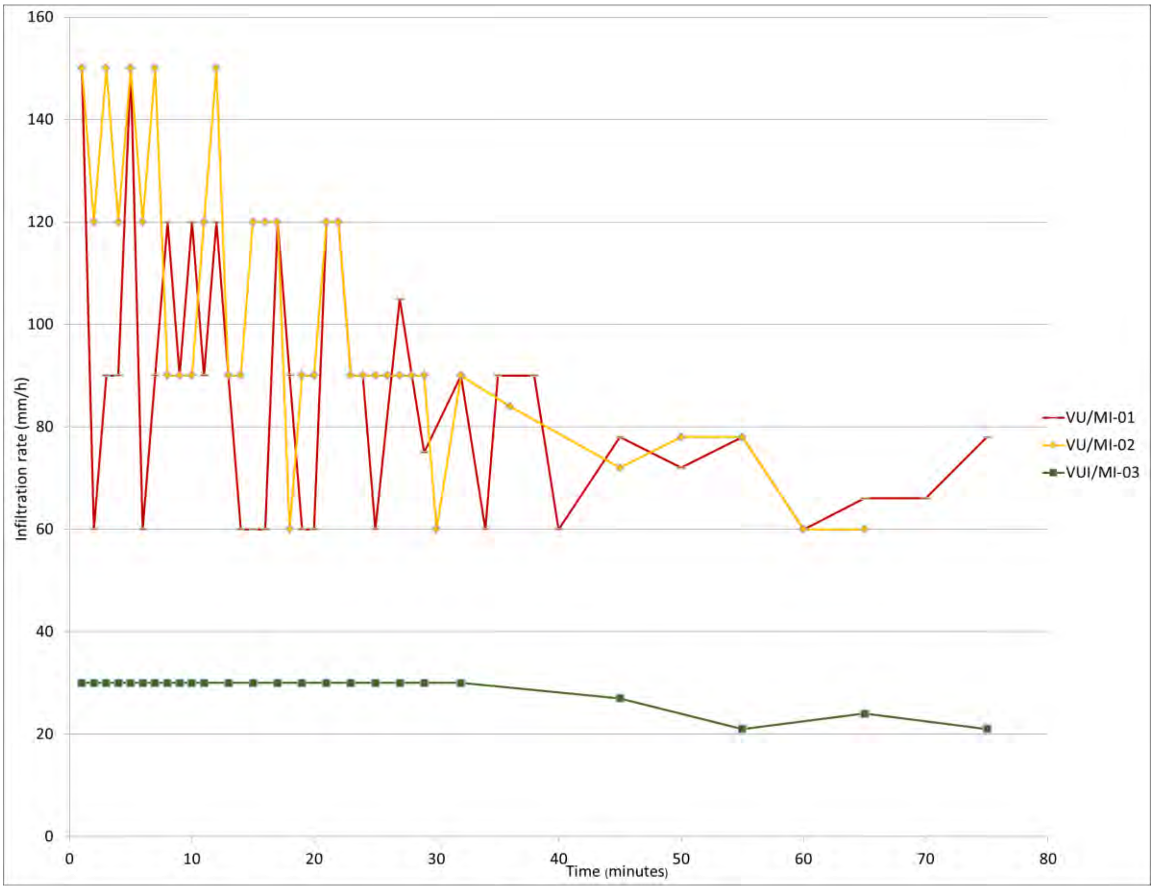


Figure 26: Infiltration tests Middle Bush

The pH of the soil in Middle Bush lies in a narrow, acidic range from 5.16 to 5.60. The bulk density is generally very low, it usually lies below 1 g cm^{-1}, whereby the mean density is 0.84 g cm^{-3}.

	Site	VU/MI-01	VU/MI-02	VUI/MI-03
	Infiltration (cm/h)	7	6	2
Horizon				
#0	Bulk density (g/cm³)	1.03	1.03	0.92
#1		0.65	0.76	0.74
#2				
#3				
#0	pH (-)	5.16	5.30	5.41
#1		5.60	5.27	5.43
#2			5.28	
#3				

Table 22: Overview on physical and chemical soil properties, Middle Bush

A more detailed display of the soil properties can also be found in the Soil Data Sheets (see Annex V: Soil Data).

4.3.3.7 Summary of Investigations at Middle Bush

The area of Middle Bush was characterised by the field survey as levelled land (compare Figure 22) with several metres deep, loamy or clayish, rather light and moderately aggregated soil with a thick topsoil, which is in accordance with QUANTIN's results. An almost neutral pH like QUANTIN determined it could not be confirmed, the results here show a more acid soil, which can be a result of the differing measuring techniques (water vs. 1 M KCl solution). The hydraulic conductivity is partly very low, the cation exchange capacity is moderate, the percent base saturation is rather high.

Precipitation data is insufficient to make profound statements, but the available data suggests that it is around 2000 mm/a, most probably more than that.

In Middle Bush, the main restriction for farming in are the frequent floodings by temporary runlets and pools that form after heavy rain (compare Figure 22) and can persist for months due to the low hydraulic conductivity of the soil. As a result, also good agricultural land is not in use along those frequently flooded areas.

5 Interpretation

5.1 General

When looking for evidence for climate change using the available meteorological data, no significant linear trend can be found, except in the temperature recorded at Bauerfield. This data series is the longest and shows a positive temperature trend that is supported by the highest R^2 (see Table 9). Concerning deviations of the seasons from "normal", the increase of the deviation of 5-month-means by approximately 0.24 mm/a looks moderate. The progressions of the mean precipitation for each month separately on the other hand (Table 10) can support the farmer's impressions that both the transition between the seasons become less defined and that the seasons become more intense: The trend of April, usually signifying the end of the rainy season, shows a trend to receive more rain, as well as the next three months (still far less pronounced), and the second half of the dry season shows to receive less and less rain. Taking climate change into account, the risk of the likely scenarios that lead to water deficit, excess water, temperature stress or any other worsening of farming conditions, is to be regarded as high, since the vulnerability of the current agricultural system is high.

Another issue that has to be dealt with when talking about threats to Vanuatu's agriculture are the numerous invasive species, like the *Leucaena leucocephala* (kasis) tree, that was introduced to Vanuatu as cattle feed and for nitrogen fixation, or even more dominant the creeping vine *Merremia peltata* (big lif rop) that has reportedly been introduced to the islands during World War II by the American army for camouflage purposes. As well as *Mikania micrantha* (amerikan rop), which is spreading fast on the islands the Americans ran military bases at, like Efate and Santo, shutting off light from the trees they climb and strangling them (see Picture 18).

The effects of changes in the land use regime (caused by the formation of agglomerations and the consequent intensification of agriculture, or the cultivation of less suitable areas due to resettlements of villages) also deserve close attention, as well as the raising involvement of Vanuatu's rural population in cash- economy.

Picture 18: Invasive vines shutting off sunlight from the crops

What can be deduced from the little rain date data that has been collected with the self-made rain gauges is that the data of the two types of gauges fits quite well together. Given the fact that commercial gauges may have an error of up to 50%, the relative error of the gauges, being 29% the most (relative aberration of the accumulated monthly rain from the daily gauge from the monthly gauge), seems to be acceptable. Note that the absolute errors, above all of the values for February, might be big though, since these values are only deduced from a few days of measurement. Else, it is hard to deduce legitimate statements from this pool of data. In the recorded period of time, precipitation in Siviri seems to have been higher than in Malafau, and Middle Bush was a lot dryer in April than at the other two sites.

Generally, data acquisition in Vanuatu proved to provide a variety of challenges. The time it takes items to be shipped to Vanuatu on the infrequent freight ships often easily exceeds the length of a research stay, and chemicals or other restricted substances (like soil) are hard to get through custom. Some basic instruments, like a gauge auger, soil sampling cylinders or a metal cylinder for infiltration tests could simply not be made available with reasonable effort, and the available instruments were often of insufficient quality (like the GPS- device, that did not allow the determination of the area of small plots or of the elevation of tracking points in sufficient accuracy). After some initial problems with the acquisition of instruments, also the secondary data acquisition was characterised by long official channels and unanticipated obstacles.

Due to problems with the GPS- device (low accuracy plus some undesired but hard to avoid function when setting the waypoints), a big part of the collected topographic data (above all from Siviri) had to be dismissed but could partly be collected again. Doing the mapping alone also raised some problems, due to lack of information about the locations of the plots and due to the many items that need to be used/carried (GPS, camera, bush knife, notebook), but it was hard to get assistance at every field survey.

5.2 Siviri

On the limestone terraces of Siviri conditions are dry, sometimes to the extent that it is endangering the staple crops of the community. These dry conditions are basically the consequence of three factors:

1) Small thickness of the soil
2) High hydraulic conductivity of the soil and underlying rock
3) Low precipitation

ad 1:

At the spot of the soil test sites the thickness of the soil is only around 20- 60 cm, and everywhere there is parent rock breaking through the surface. The soil itself is rather clayish, but also there are many macro pores due to the abundance of stable, round aggregates arranged in a light soil matrix. In times of low precipitation, once the water in the macro pores has drained away, the accessible water for plants is limited.

ad 2:

The highest infiltration rate was measured in Siviri, also the mean infiltration rate is high. Quantin also found that the hydraulic permeability of the upper layer is very high. This high drainage capacity of the soil results from the high porosity.

Furthermore, the underlying parent rock in this area is weathered coral limestone. Coral limestone has a high porosity due to its origin, and additionally, as it is very calcareous, it is very weathered and soft. The depth to the groundwater table on the terraces is presumably in the order of at least several meters, thus, the accessible water to plants is limited in times of infrequent precipitation.

ad 3:

The precipitation in Vanuatu is generally high, in this area (north Efate) it is expected to be slightly below 2000 mm/y. Though, at the site of the village and on the slopes where the farming plots are located, the inhabitants of the area have the subjective impression that the precipitation is relatively low compared to other areas on Efate and that precipitation is getting less, especially during dry season. That Siviri receives less precipitation than Malafau could not be confirmed by the rain measurements that have been undertaken during this research stay, but the high uncertainty that arises from the short data series that could be obtained of this data needs to be considered.

On the long run, soil erosion and leaching could become a major threat to agriculture in Siviri. The erosion that can be observed after heavy rain does not heavily affect farming yet, but has to be paid attention to, especially under consideration of the shallowness of the soil and the potentially growing population. The soil is already covered by stones to a big extent, and rock outcrops are abundant, especially close to the first cliff. Also, an eye should be kept on soil acidity. The soil at Siviri's farming plots is generally acid, whereby the most intensively used plot that was tested (VU/SI-01) shows the lowest pH, which can be a result of high leaching due to intensive farming and high hydraulic conductivity. Quantin's results (compare Table 13), that do not indicate that leaching is a problem, are several decades old and maybe are not valid any more.

A growing population could also lead to insufficient drinking water supply during the dry season, since the water source is reported to occasionally run dry that time of the year, and the water storage tanks for the houses on the upper terraces don't work in a satisfactory manner already.

5.3 Malafau

After the first investigations it seems that the problems related to excess water are rather problems caused by flooding than water logging. The valley is very flat (0-2% estimated) and the river close to the village is frequently escaping its river bed. As reported by the locals, some farming plots would then be up to one meter and more under water. But all interviewed farmers agreed that the water would be gone within a few hours once the rain is gone. The obtained primary and secondary data also shows that, on average, the infiltration rates in Malafau are high, higher than in Siviri (the 51 cm h^{-1} at VU/SI-03 have to be regarded as an outlier).

However, around the houses (in local depressions) it was witnessed that after heavy rain the water would sometimes stay for several days, and also at the farming plots crops happen to be damaged. During the investigated time period (mid February until the end of April), the measured precipitation was 20% less than in Siviri though. The soil layers are basically sandy and non- calcific on fluvial parent rock, and they show a high hydraulic conductivity, so once there is excess water it is easily drained from the farming plots. This is not true for a few sinks that lie close to the groundwater table, and for areas that show a buried topsoil layer. But these areas are hardly used for farming now, and if, only banana is grown on them currently.

The topsoil itself is thin and little developed, which implies a low fertility and a small water retention capacity. Therefore, the farmers experience water deficit and stress for the plants during the dry season.

5.4 Middle Bush

The infiltration rates at all the three examined sites were much lower than the ones on Efate, and precipitation is presumably in the same range or even higher. Hence, water logging is likely, confirming the local farmer's reports. Still, when mapping the area it became evident that in many areas farmers are rather experiencing problems due to plants being drowned for long periods of time. This is due to big areas being flooded in case of heavy rain, and the water accumulating in pools. Middle Bush is, apart from a few creeks, relatively flat. Once flooding occurs, farmers dig channels through the small dams that separate farming plots, so that the water would flow to the next plot and so on, but there are not many ways to drain areas safely without affecting the next plot downstream. A big flooding, which heavily affected most of the plots, just occurred 2011. This is why the awareness of the problem is high now, and so is the fear of such an event destroying the harvest again. Many farmers are avoiding farming on areas that were flooded in 2011 and potentially good plots are left abandoned now. As a locally varying but always significant farming area is reserved for growing coffee or kava for the market, this can lead to a shortage of available farmland for growing staple crops, which lead to frequent aid shipments of rice for the local farmers in the past.

Apart from water related problems for farming it is evident that water for drinking and personal hygiene has limited availability, mainly due to the dependence of the villagers on only a few rainwater tanks, forcing the villagers to sometimes walk down to the creek for getting drinking water or for washing and personal hygiene.

6 Outlook

6.1 Siviri

At the workshop in January 2012, the community stated that there is interest in setting up an irrigation system. Due to the fact that there is already a water pipe supplying the village and the surrounding houses with potable water, this option seems feasible at first. In order to estimate the potential of such a system, the water source which is currently in use was visited. The source is located about 6.5 km direct distance from the village, on the other side of Undine Bay, up a mountain (see Figure 12). In order to bring the water to the village, a pipe system (including several small pools for pressure reduction and two high- level tanks) has been laid all the way, mainly above ground. But after the first surveys the option to just lay another pipe for irrigation does not appear to be a big help for the community. This is due to the size and the discharge regime of the water source: not having any hydrological data of the region, villagers having farming plots close to the well were interviewed, and they all stated that the river fed by the water source uses to run dry during the dry season. So, at this stage the most feasible option to help the farmers dealing with drought seems to introduce mulching to slow down evaporation from the soil. Also, erosion can be reduced that way, and lost soil can slowly be built up again.

It may also be fruitful to take a look at the possibility of intensifying the use of the land close to the seashore for crop farming. Even though the soil there is younger, it is good farming land, and there should be ways to deal with straying pigs. Other restrictions for growing staple crops there (apart from the limited space) might be customary land-ownerships and an again increasing importance of the coconut palm plantations there due to a coconut oil factory that is planned to be built at Undine Bay.

In order to mitigate possible drinking water shortages, a relocation of one of the two high-level tanks should be undertaken. Currently this tank, that has been set up as water storage for the upper part of the village, does not operate due to the poor design of the pipe system that does not provide enough pressure.

An option to increase the income of the farmers would be to rehabilitate the old cattle breeding areas that had been in use before independence. Those are located in vast areas on the plateau between Siviri and Malafau ("Malafao- plateau"). These plots are currently not in use for crop production, since the conditions there are very dry, but on test plots possible usages could be examined.

6.2 Malafau

To relief the excess water stress in Malafau, the possibility to establish a network of drainage channels should be investigated. Also the promotion of Water Taro (as traditionally planted for example on Espiritu Santo) might offer a solution, but this would imply a complete change of the farming system, since this would require a network of irrigation channels that supply the taro constantly with fresh water. Both measures would require fixed constructions (water in-/outlets) at the river banks, which can be a challenge since the banks are not very stable and the construction would require some maintenance.

At some depressed plots, more emphasis can be put on water tolerant crops like water taro or raised-bed techniques. Adaption to excess water has been executed already in the swampy areas close to the ring road, where the only planted crop is banana, which is at least more tolerant to high ground water tables.

The implementation of mulching and techniques to apply compost from domestic waste to the plots can enforce the build-up of the topsoil and relief the water stress from the plants during the dry season.

6.3 Middle Bush

In Middle Bush, it should be looked at the possibility of promoting Water Taro varieties on plots at areas which are likely to being flooded anyway. There is current research on Water Taro and more than 300 Taro varieties at VARTC on Espiritu Santo, where Water Taro is traditionally grown too. It should be tried to get information about adequate taro varieties that do not need constant freshwater supply but can survive prolonged submerging. At some shallow basins, raised-bed farming can offer a relief.

There is also the wish amongst some farmers there to introduce "wan tri blong drink wota", a tree that consumes the water once the area is flooded. Some farmers suspect that this could be bamboo, but since the main problem in the area is heavy flooding involving high water amounts it is unlikely that this is a way to resolve that issue.

A possible solution, being a big and technical intervention though, would be to construct a widespread network of trenches that connect to the creeks. These channels might be several (1-4) kilometres long, but it should be sufficient to just dig those channels in the bare, deep, little conductive soil. The banks could be protected by reed grass (or possibly the locally growing wild cane) and once constructed, the effort for maintenance should be low if the vegetation is cut frequently and the channel is kept free from trees.

Setting up more rain water tanks and rainwater harvesting systems (simple corrugated iron roofs) seems to be a feasible solution to drinking water shortage, there are also water sources (one close to Lamnatu) which could guarantee good water supply for some villages once they are caught properly.

6.4 General

With this thesis, limitations on farming that were reported by farmers could be connected to specific characteristics of the farming areas at the study sites. Some of the problems might result from changed land use patterns, some from the increasing use of little suitable farming land, some from climate change. The former tendencies are basically a result of resettlements, city agglomeration, population growth and the growing importance of cash income. A connection of the underlying phenomena to climate change could not be clearly shown though, the available data does not permit any profound statement concerning that. In any case, the vulnerability of small-scale farmers in Vanuatu to changes of the agricultural conditions is high, so the risk associated with climate change is high and has to be taken seriously.

Evidently, some problems farmers are facing nowadays are not completely new to Vanuatu, concepts for dealing with the recent challenges of farming can also be found in historic indigenous knowledge. As mentioned in section 2.4.1, farming techniques like raised bed farming, terraced farming and gravitational irrigation systems have been in use in Vanuatu or are still common in certain areas. Adverse tendencies could be mitigated by the re-implementation of those traditional techniques that have widely been abandoned in the last 150 years. There is proof that Vanuatu's population was much higher (up to 4 times the current value) some centuries ago, so the land is capable of producing more food than nowadays, if soil degradation can be mitigated. Still, an unbalanced distribution of densely populated areas and available farming land creates shortages.

For securing drinking water supply, simple methods like harvesting rainwater by equipping houses with roofs of corrugated iron and rainwater tanks can be a solution.

At all densely populated areas of Vanuatu, one reason for yield declines is the decreasing length of the fallow periods (Weightman, 1989). In order to mitigate depletion of the soil, concepts of composting could be introduced. Currently residual waste is either fed to pigs or burnt. Proper training would be essential, also in order to end practices like the burning of batteries. Mulching can be a feasible concept for improving the availability of water, too. Furthermore, in order to increase food security, methods of storing staple crops should be investigated and promoted.

But all this would require a bigger service capability of the extension service. Similar is true for the dissemination of varieties of the common staple crops, like water taro or drought resistant varieties of yam. But the policy of the 1980's regarding agricultural extension was to reduce governmental extension service and count on a takeover of this field by private companies, but this commercialisation did not take place to a sufficient extent (Weightman, 1989). Hence, the remaining governmental institutions with the reduced staff cannot satisfy all the needs for knowledge dissemination and related services all over Vanuatu. This problem is even intensified by the fact that the staff of the extension service is frequently occupied by training workshops overseas, gaining knowledge that does not necessarily apply well to Vanuatu. And the question that remains is if Vanuatu could provide more personal at all, given the fact that there is no agricultural university programme currently being offered in Vanuatu.

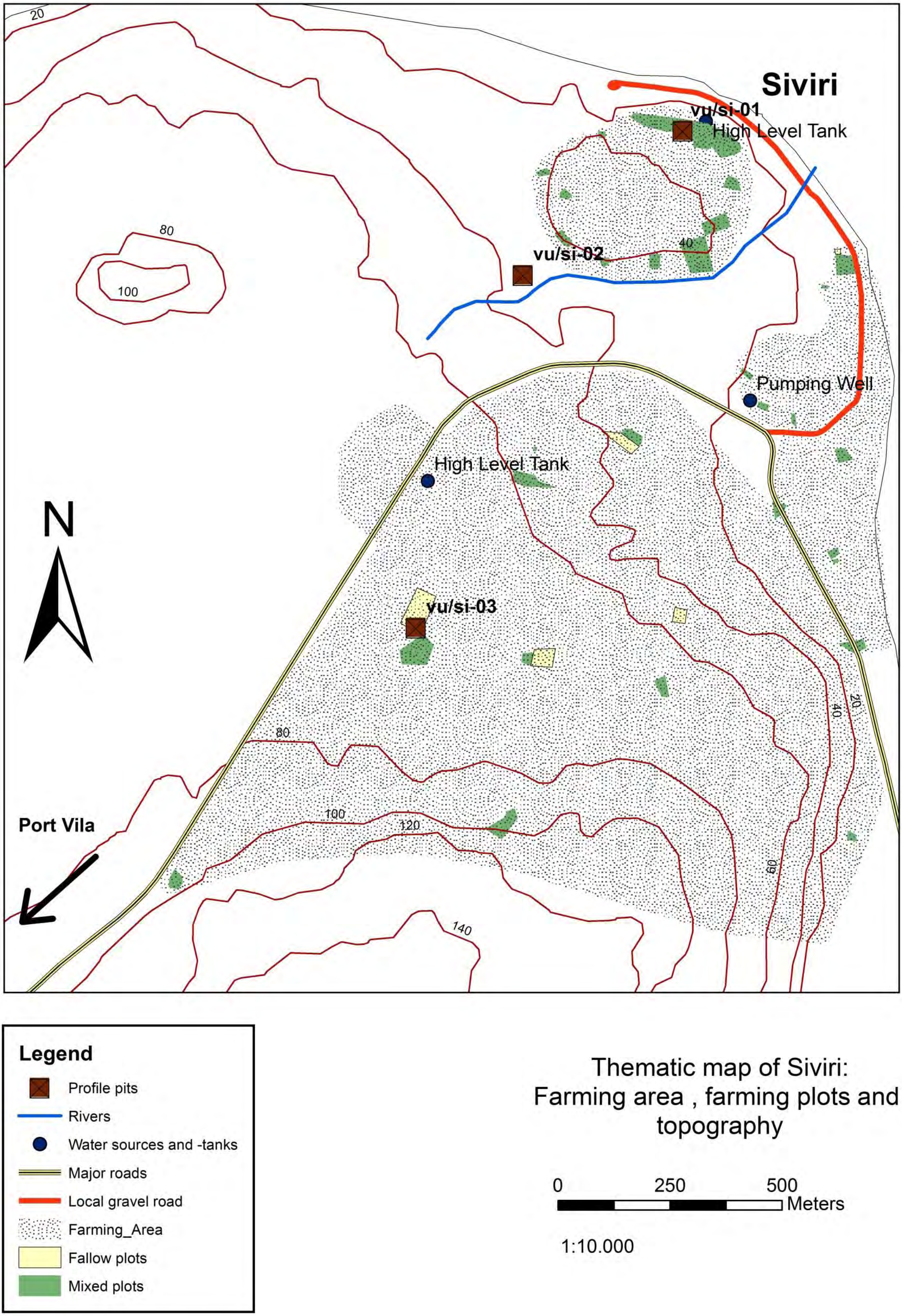
In any case, a change of the farming system needs to be accompanied by intensive training, reliable information transfer and monitoring. Because sometimes, the most well-intended strategies, based on the most sophisticated expertises, fail to have a sustainable impact, if their benefits are not made obvious to the farmers. Or, as Barry Weightman, maybe the most profound expert on Vanuatu's agriculture, put it: "*This is what takes time to explain to newcomers and visitors who, gazing wide-eyed around, almost invariably ask in some amazement,* "*But why on EARTH don't they grow.....?" As I have said, the earth is not the problem."*

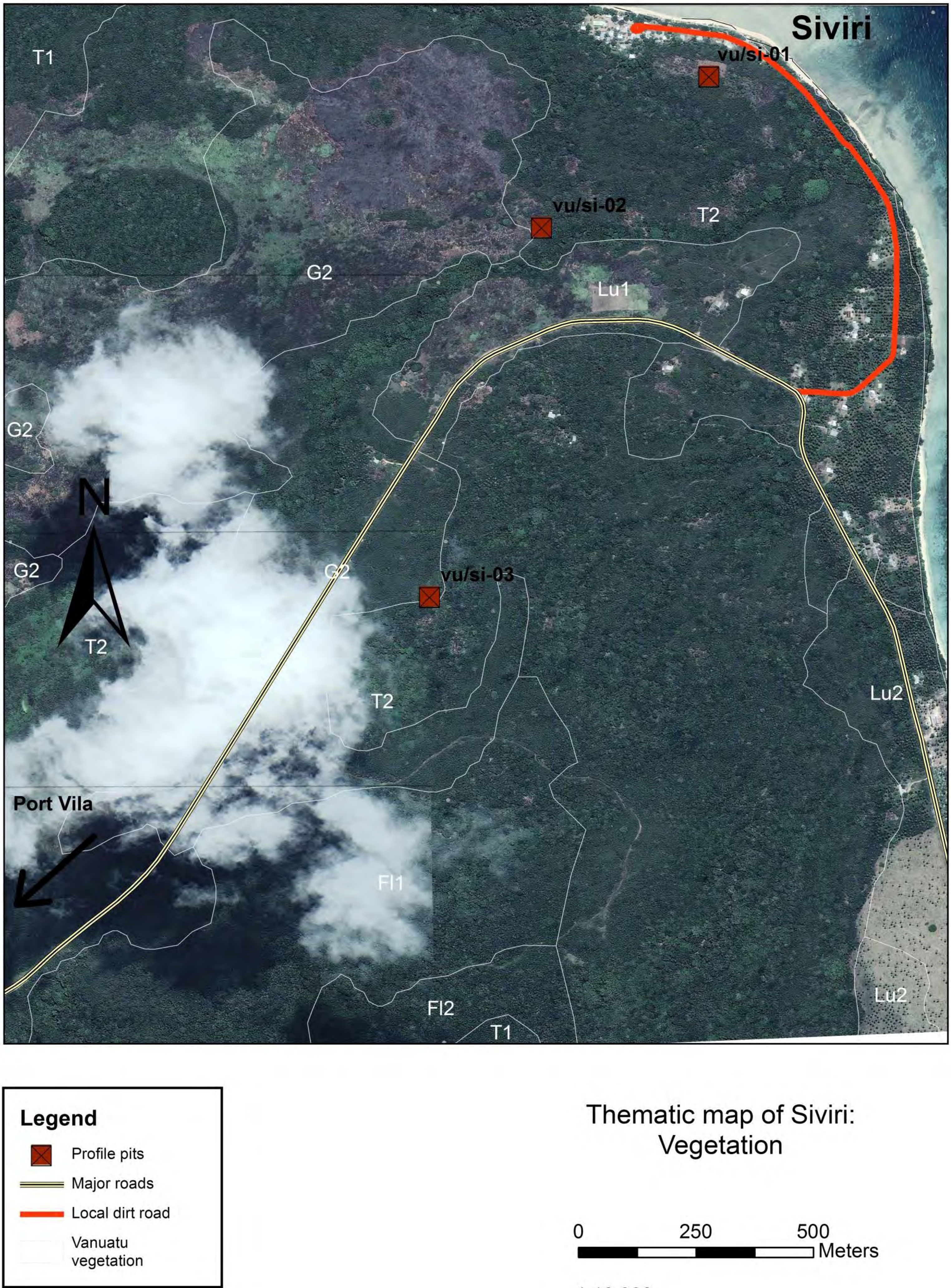
7 Annex

Annex I: Thematic maps

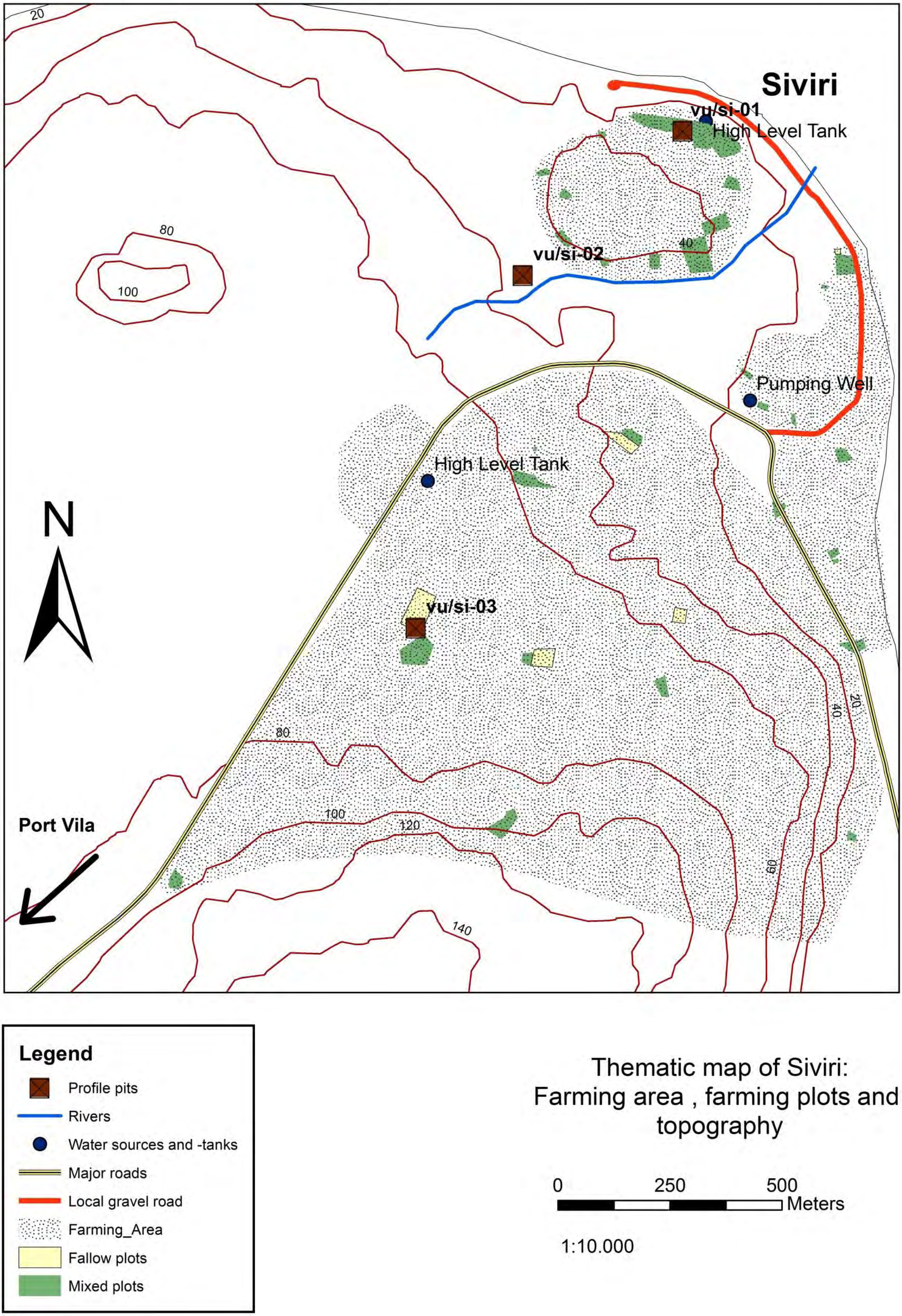
Code	Type	Description	VANRIS codes
1	Fm1	Medium height forest (> 20m), mostly closed canopy	Fme*, Fmm*
2	Fm2	Medium height forest (> 20m), open canopy, degraded or logged over	Fmo*, Fms, FmW
3	Fl1	Low forest (< 20m), mostly closed canopy	Fl*
4	Fl2	Low forest (< 20m), open canopy, degraded or logged over	Flo*, Fls*
5	Fp	Forest plantation	N/A
6	T1	Thickets (3-8m), dense structure	T*
7	T2	Thickets (3-8m), open structure	T*
8	S	Scrubs (< 3m)	S*
9	M	Mangroves and marshes	M
10	G1	Grassland, no trees (including cattle farms)	G*
11	G2	Grassland, with scattered trees and woody shrubs	G*
12	Lu1	Cultivated area, mosaic of annual crops, gardening and fallows	N/A
13	Lu2	Cultivated area, plantations, i.e. coconut plantations or crop area dominated by coconut	N/A
14	Bs	Bare soil, rocky outcrops, other naturally unvegetated area (volcanic areas)	N/A
15	Bu	Built-up and settlement area, villages and infrastructure (i.e. airstrips)	N/A
16	Sw	Swamps	Sw*
17	Wb	Waterbodies	N/A
18			
19			
20	nil	no informatio, shadow area (inside volcano craters)	N/A

Table 23:Agronomic potential legend


Siviri
vu/si-01
High Level Tank
vu/si-02
Pumping Well
High Level Tank
vu/si-03
N
Port Vila
20
40
60
80
100
120
140
Legend
Profile pits
Rivers
Water sources and -tanks
Major roads
Local gravel road
Farming_Area
Fallow plots
Mixed plots
Thematic map of Siviri: Farming area , farming plots and topography
0
250
500
Meters
1:10.000



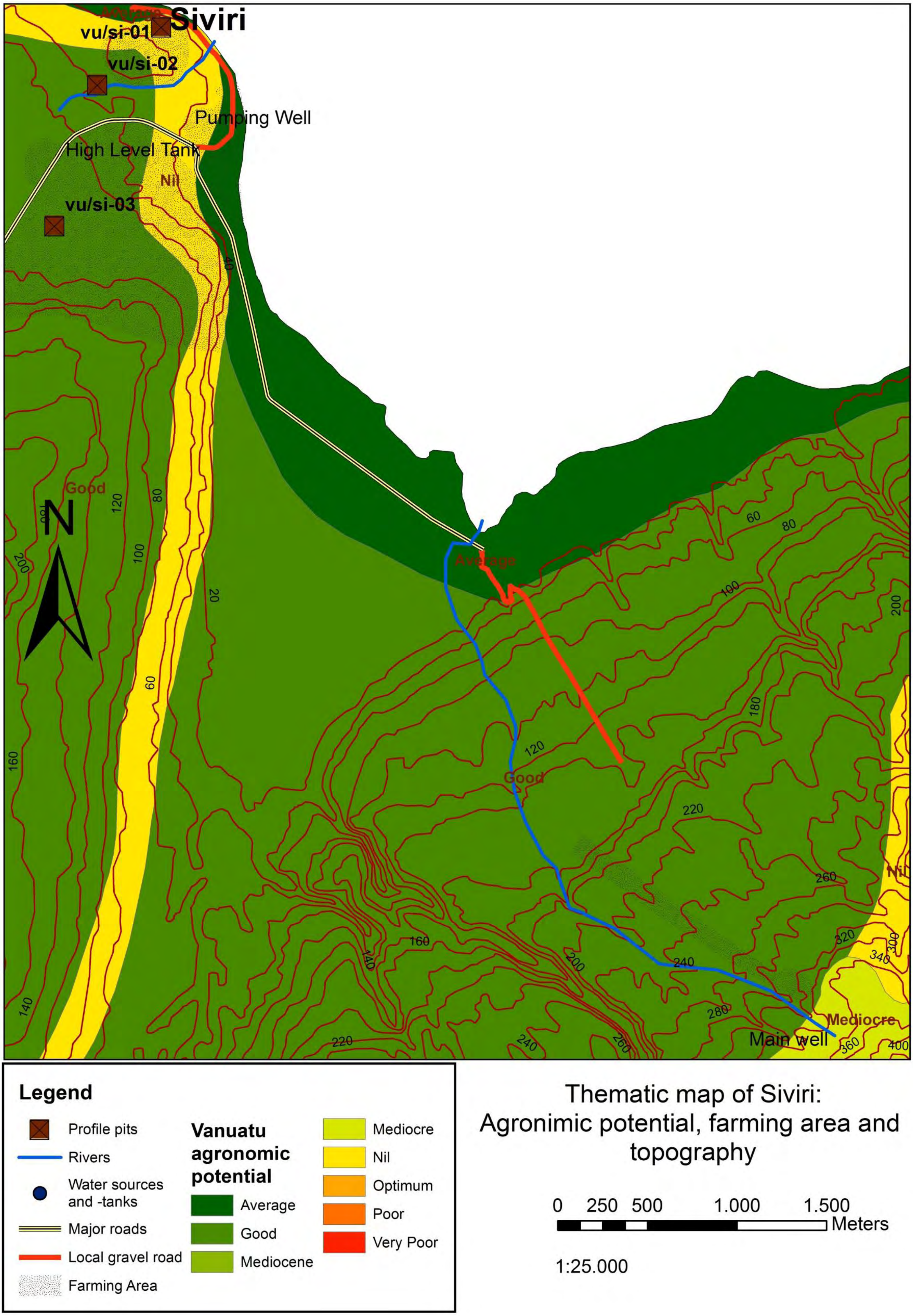
Thematic map of Siviri: Vegetation

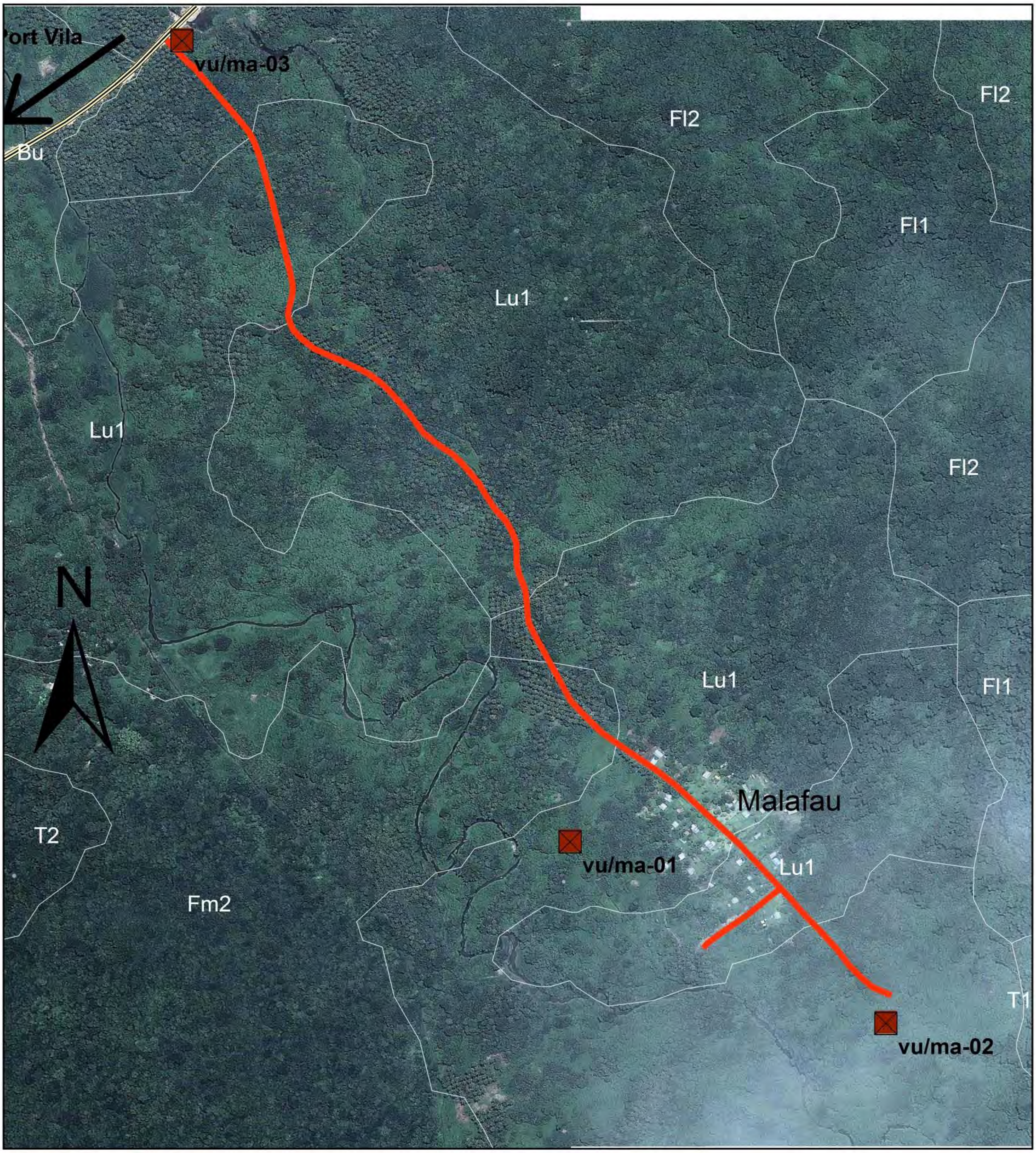


Thematic map of Siviri: Farming area , farming plots and topography

0 250 500 Meters

1:10.000


Siviri
Average
vu/si-01
vu/si-02
vu/si-03
Pumping Well
High Level Tank
Nil
Good
Average
Good
Nil
Mediocre
Main well
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
400
Legend
Profile pits
Rivers
Water sources and -tanks
Major roads
Local gravel road
Farming Area
Vanuatu agronomic potential
Average
Good
Mediocene
Mediocre
Nil
Optimum
Poor
Very Poor
Thematic map of Siviri: Agronimic potential, farming area and topography
0 250 500 1.000 1.500
Meters
1:25.000



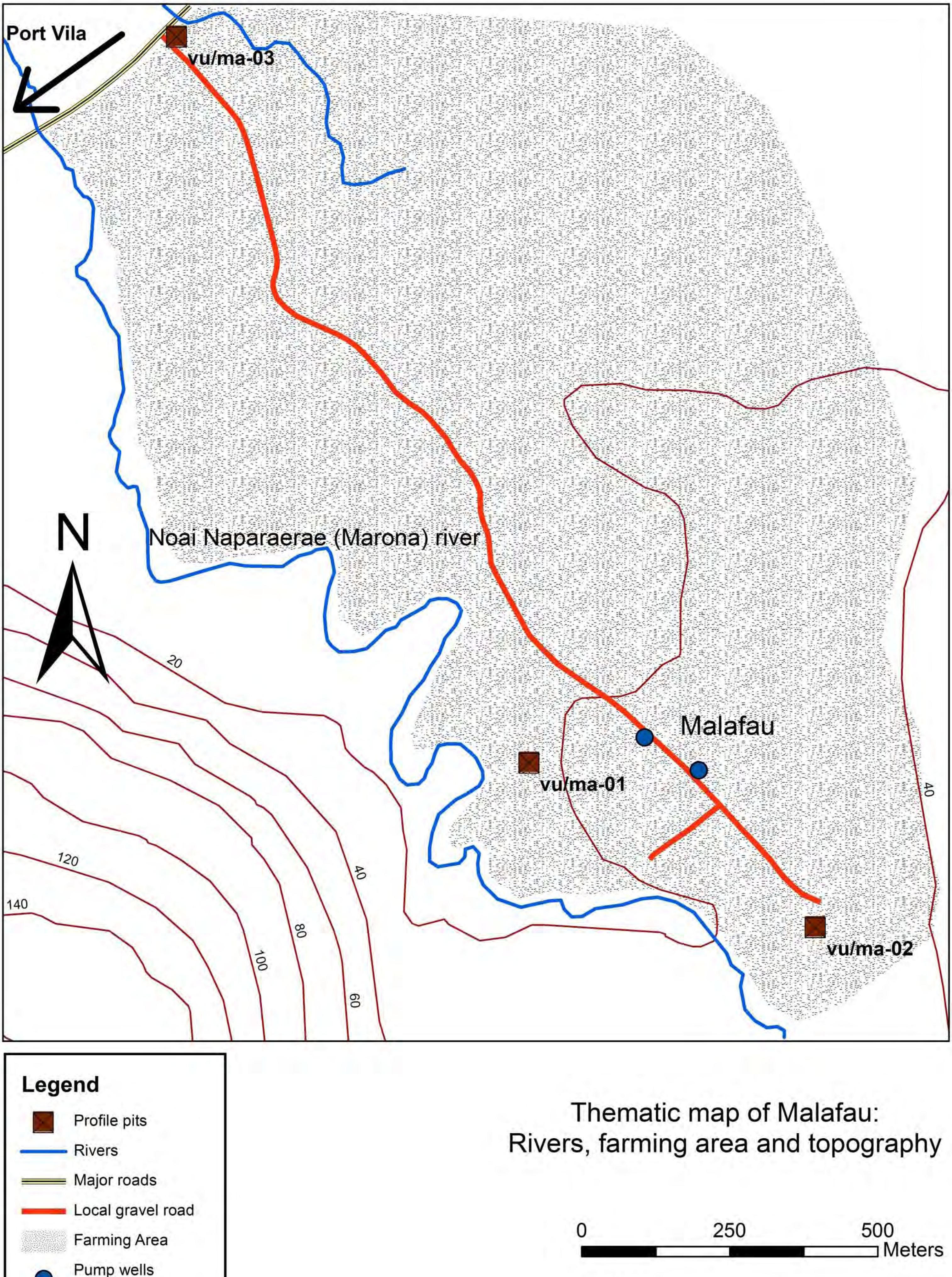
Legend

- Profile pits
- Major roads
- Local dirt road
- Vanuatu vegetation

Thematic map of Malafau:
Vegetation

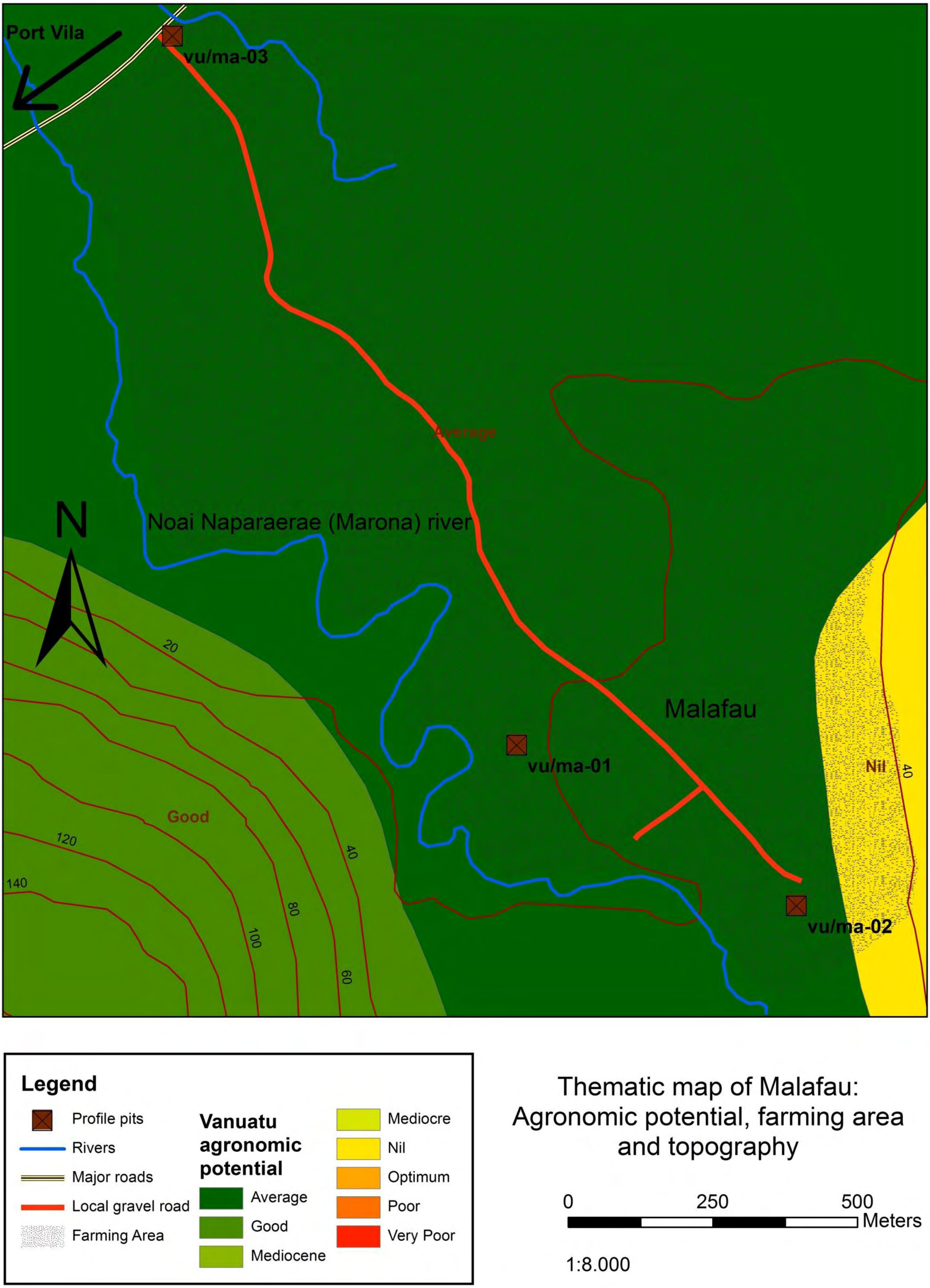
0 250 500 Meters

1:8.000

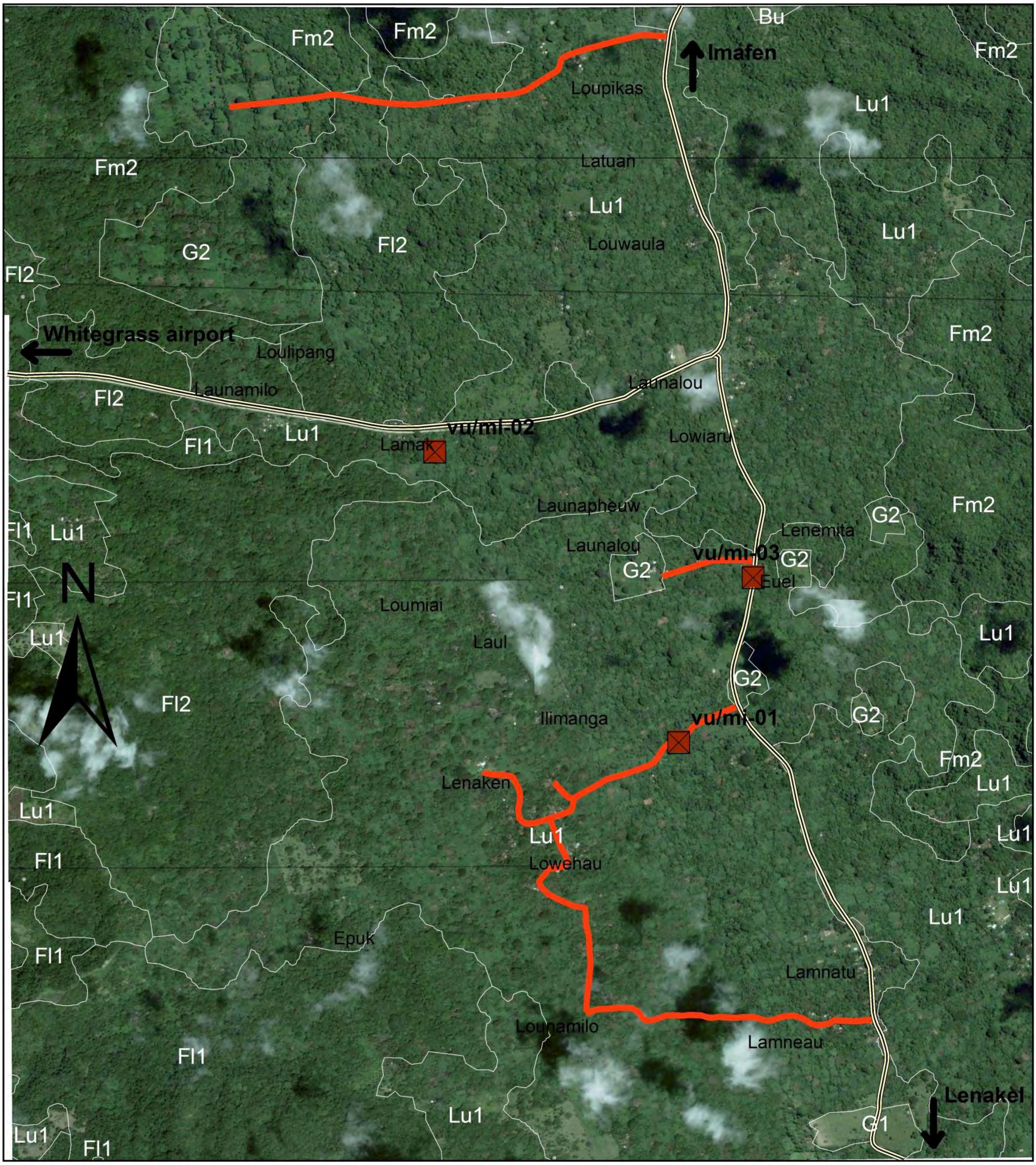


Thematic map of Malafau:
Rivers, farming area and topography

1:8.000



Thematic map of Malafau: Agronomic potential, farming area and topography



Legend

Profile pits

Major roads

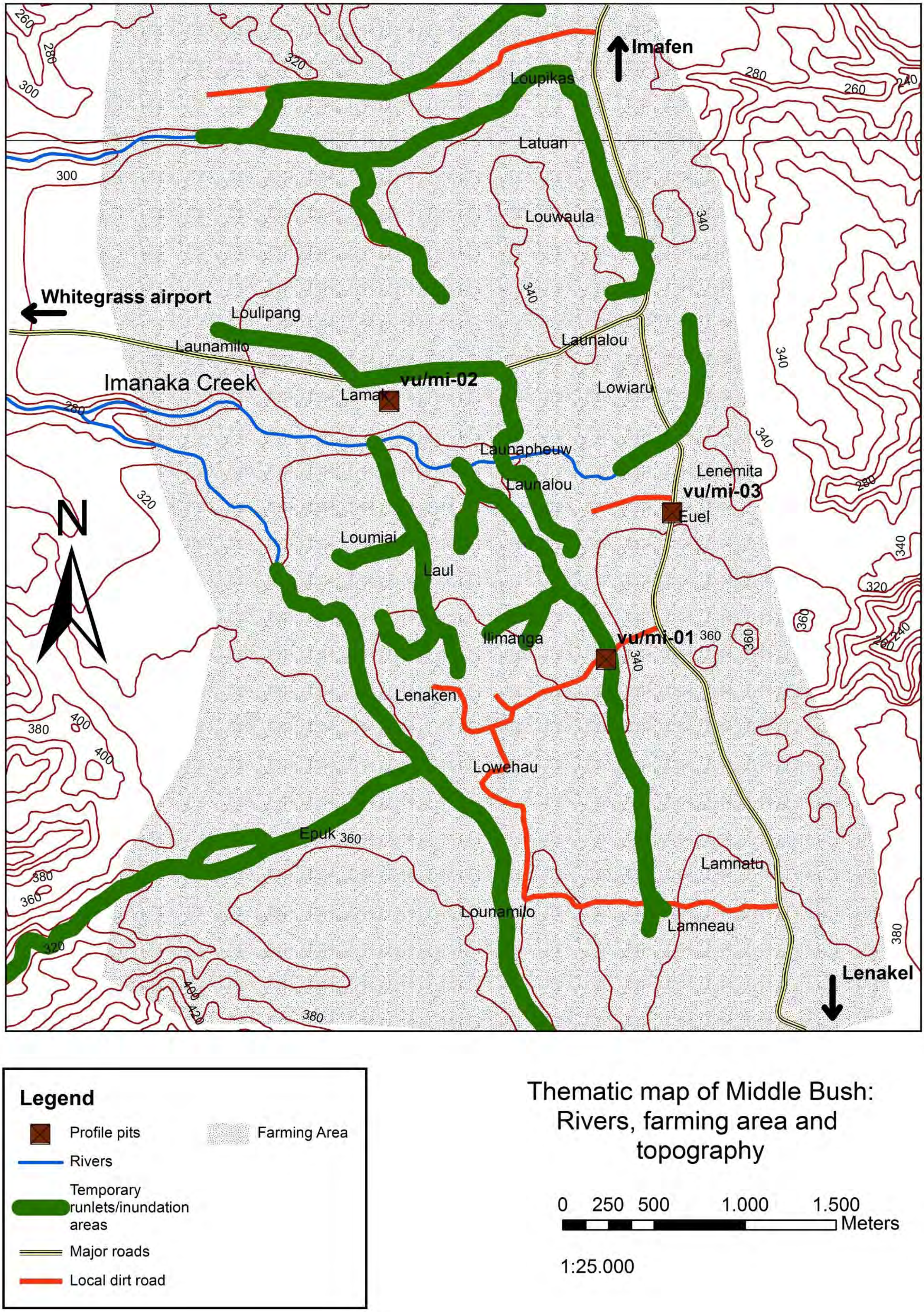
Local dirt road

Vanuatu vegetation

Thematic map of Middle Bush: Vegetation

0 250 500 1.000 1.500 Meters

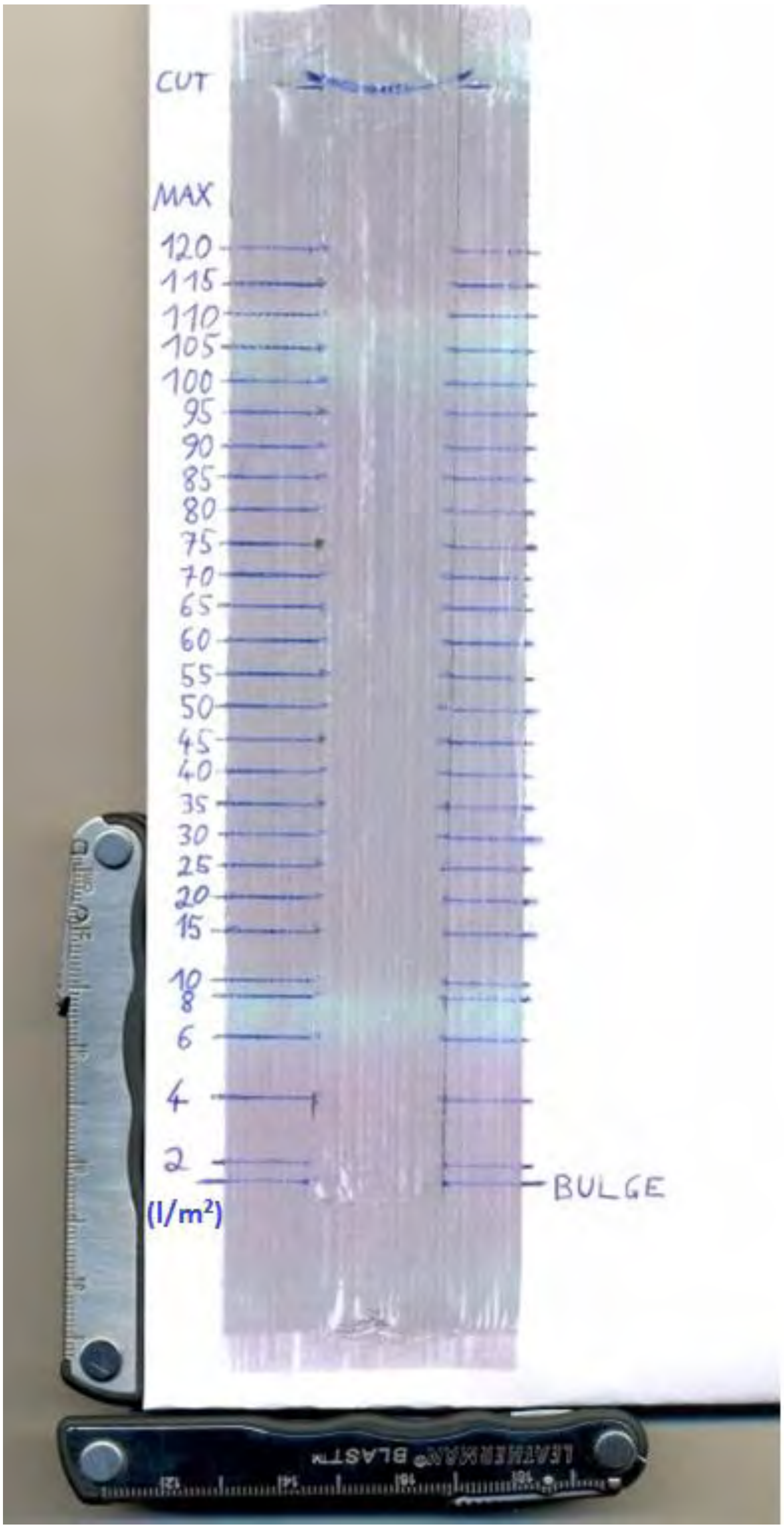
1:25.000



Thematic map of Middle Bush: Rivers, farming area and topography

Das Bildelement mit der Beziehungs-ID r3d96 wurde in der Datei nicht gefunden.

Annex II: Manual for constructing a daily rain gauge out of a Vanuatu Water 600ml- bottle



Picture 19: Edit format for the gauge marks as handed over to the DARD- staff

Das Bildelement mit der Beziehungs-ID rId96 wurde in der Datei nicht gefunden.

Picture 20: Instructions on installing and reading the daily gauge (as handed over to the DARD-staff)

Annex III: Vanuatu rain gauges

Das Bildelement mit der Beziehungs-ID rId96 wurde in der Datei nicht gefunden.

Table 24: Rain gauges operated by the Vanuatu Meteorology and Geohazards Department

Das Bildelement mit der Beziehungs-ID rId96 wurde in der Datei nicht gefunden.

Table 25: Bauerfield average monthly rainfall (obtained from the Vanuatu Meteorology and Geohazards Department)

Das Bildelement mit der Beziehungs-ID rId96 wurde in der Datei nicht gefunden.

Table 26: Burtonfield average monthly rainfall (obtained from the Vanuatu Meteorology and Geohazards Department)

Annex IV: List of Equipment

Distilled Water
Spade
Pickaxe
Stop watch
Sampling knife
Munsill - Colour Charts
d = 32cm plastic pipe
Soil sampling cylinders (undisturbed soil sample)
pH buffer solutions (potassium hydrogen phthalate/potassium dihydrogen orthophosphate/sodium tetraborate)
pH- meter

0.5 l plastic bottles
20 l jerrycan
2 x 10 l jerrycan
Funnels
Wooden sticks and nails

GPS- device
Balance
Brush
Plastic Bags
Pens, Permanent marker
Ruler
Tape measure
2 x plastic canvas cover (3x3m)
Ropes
Notebooks
Water level
Portable solar power station
Labels

Annex V: Soil Data

(Named by a code that describes the location, the country code is “vu”, then “si” for Siviri, and, 01-03 for the three sites of the soil survey, so a possible code is “vu/si-03”)

Das Bildelement mit der Beziehungs-ID rId96 wurde in der Datei nicht gefunden.

Table 27: Physical and chemical properties of the soil samples. The first number of the sample code refers to the layer, the second number is the sample number. The infiltration tests with the results marked in red were dismissed.

Das Bildelement mit der Beziehungs-ID rId95 wurde in der Datei nicht gefunden.

Table 28: Soil morphology Siviri (Quantin, 1998)

Das Bildelement mit der Beziehungs-ID rId96 wurde in der Datei nicht gefunden.

Table 29: Soil morphology Malafau (Quantin, 1998)

Das Bildelement mit der Beziehungs-ID rId96 wurde in der Datei nicht gefunden.

Table 30: Soil morphology Middle Bush (Quantin, 1998)

Table 31: Soil morphology Middle Bush (Quantin, 1998)

Table of Content

1. Field Sheets Siviri

Das Bildelement mit der Beziehungs-ID rId96 wurde in der Datei nicht gefunden.

Figure 27: Location of the soil survey sites

1.1 vu/si-01

Date:03.05.2012 Name: Helmut Schabschneider

Scheme name: vu/si-01 City, District: Siviri, Efate

Crop type: Farming plot, in use

Content:

Survey map: includes:

- soil sampling plots
- place(s) of single-ring infiltrometer experiment(s)
- location of profile pit

Remarks:

No significant rain since 3 weeks, few showers on the 3th.

Coordinates: 17°31.474'S/ 168°19.519'E Elevation: 45 m

Das Bildelement mit der Beziehungs-ID rId96 wurde in der Datei nicht gefunden.

Picture 21: Soil profile vu/si-01

- *Soil and Site Description*

Village/Scheme Name	Vu/si-01			
Physiographic Position	LL			
Vegetation	Papaya, Cassis, Is. cabbag			
Slope				
Slope Characteristics	~3% (estimated)			
Erosion	W (water erosion)			
Area of Block [ha]				
Predominant Soil in Block				
Area of Predominant Soil [ha, %]				
Depth to Drainage Barrier [cm]	50cm (coral limastone)			
Depth to Groundwater Table [cm]	?			
External Drainage (Flood Hazard)				
Surface Flooding (river, rainfall)				
Magnitude, Period of Inundation	frequent	infrequent	rare	very rare
Profile Reference	Routine profile description			

Further notes and annotations:

Lithology: SO1

Rock outcrops: ~5%

Stone cover: 40%

Surface cracks: 1-10mm

Parent rock carbonates: N (no audible reaction with HCl): ST

- *Soil Samples*

Undisturbed soil samples → core sampler (ring)

No of Cyl.	Sampling Spot (GPS)	Depth, Horizon	Density (gcm^{-3})	Comments, Descriptions,…
#01	vu/si-01	1cm, 1st	0,69	
#02	vu/ si-01	1cm, 1st	0,58	
#11	vu/ si-01	30cm, 2nd	0,86	
#12	vu/ si-01	30cm, 2nd	0,97	
				3rd layer to shallow to take core samples

Disturbed soil samples:

No	Sampling Spot (GPS)	Depth, Horizon	pH	Further remarks (segregations, abundance of roots,…), description of spot, comments,…
#0	vu/ si-01	1cm, 1st	5.28	
#1	vu/ si-01	30cm, 2nd	4.49	

- *Profile pit*

Soil Description in Profile Pit:

Depth [cm]	Sample no	Colour Colour Mottling	Texture & Texture Unit	Consistence	Aggregate-stability	Segregations	Abundance of roots	Further accommodation
0 : 19-22 cm	#0, #01, #02	7.5YR 2.5/1	Clay/ heavy clay	Dry, crums	AS1 (d~2-4mm)		Plenty	Parent rock : weathered stone (EX)
1 : 38-42cm	#1, #11, #12	10YR 5/4	Heavy clay/clay		AS3 (d~0,2-1mm)		Few	
2 : 42-57cm	#2	7.5YR 4/6	Sandy clay loam		only rocks stay		Few	

- *Single Ring Infiltrometer*

Date: 11.04.2012

Weather: No rain since two days

Starting time of measurement: 11:50am

Infiltration rate: ~ 6 cmh^{-1}

Comments: most probably a leak affected the measurement (soil aside the pipe became wet during measurement) plus the plastic pipe used as infiltration cylinder has not been sharpened at the end yet, therefore the pipe could only be pushed somewhat like 3cm into the ground (FAO- guideline: 15cm).

1.2 vu/si-02

Date:03.05.2012 | Name: Helmut Schabschneider

Scheme name: vu/si-02 | City, District: Siviri,Efate

Crop type: “white grass”

Content:

Survey map: includes:

- soil sampling plots
- place(s) of single-ring infiltrometer experiment(s)
- location of profile pit

Remarks:

No significant rain since 3 weeks, few showers on the 03.

Coordinates: 17°31’38.87’’S/ 168°19’19.57’’E   Elevation: 56m

Das Bildelement mit der Beziehungs-ID rId96 wurde in der Datei nicht gefunden.

Picture 22: Soil profile vu/si-02

- *Soil and Site Description*

Village/Scheme Name	vu/si-02			
Physiographic Position	LL			
Vegetation	Former cattle farm (before independence), burning of grass every year			
Slope	0-2%			
Slope Characteristics	MS			
Erosion	N			
Area of Block [ha]				
Predominant Soil in Block				
Area of Predominant Soil [ha, %]				
Depth to Drainage Barrier [cm]	20cm (weathered coral limestone)			
Depth to Groundwater Table [cm]	?			
External Drainage (Flood Hazard)				
Surface Flooding (river, rainfall)				
Magnitude, Period of Inundation	frequent	infrequent	rare	very rare
Profile Reference	Routine profile description			

Further notes and annotations:

Lithology: SO1

No surface cracks

Rock outcrops (~1%)

Rock artefacts: V

Parent rock carbonates: ST

- *Soil Samples*

Undisturbed soil samples → core sampler (ring)

No of Cyl.	Sampling Spot (GPS)	Depth (cm), Horizon	Density (gcm^{-3})	Comments, Descriptions,…
#01	vu/si-02	1cm, 1st	0.85	
#02	vu/si-/02	1cm, 1st	0.83	
#11	vu/ si-/02	10cm, 2nd	0.86	
#12	vu/ si-/02	10cm, 2nd	0.88	

Disturbed soil samples:

No	Sampling Spot (GPS)	Depth, Horizon	pH	Texture	Further remarks (segregations, abundance of roots,…), description of spot, comments,…
#0	vu/ si-02	1cm, 1st	6.40		
#1	vu/ si-02	10cm, 2nd	6.25		

- *Profile Pit*

Soil Description in Profile Pit:

Depth [cm]	Sample no	Colour Colour Mottling	Texture & Texture Unit	Consistence	Aggregate-stability	pH	Segregations	Abundance of roots	Further accommodation
0 : 7cm	#0, #01, #02	2.5YR 2.5/2	Clay		AS2	6.40		~1/cm^2	Parent rock : weathered stone (EX)
1 : 20	#1, #11, #12	7.5YR 3/3	Clay loam		AS3	6.25		~0.3/cm^2	
2 :									
3 :									

- *Single Ring Infiltrometer*

Date: 12.04.2012

Weather: Heavy rain all evening on the 12th plus during the night.

Starting time of measurement: 11:34

Infiltration rate: ~ 6 cmh^{-1}

Comments: No water track visible (ground too wet because of rain)

1.3 vu/si-03

Date:04.05.2012 Name: Helmut Schabschneider

Scheme name: vu/si-03 City, District: Siviri/Efate

Usage: Fallow plot

Content:

Survey map: includes:

- soil sampling plots
- place(s) of single-ring infiltrometer experiment(s)
- location of profile pit

Remarks:

No significant rain since 3 weeks, few showers in the morning of the 4th.

Coordinates: 17°32'4.37'S/ 168°19'11.82'E Elevation: 85m

Picture 23: Soil profile vu/si-03

- *Soil and Site Description*

Village/Scheme Name	vu/si-03			
Physiographic Position	LL			
Vegetation	vine (“American rope”, small leafed)			
Slope	~2%			
Slope Characteristics	MS			
Erosion	N			
Area of Block [ha]				
Predominant Soil in Block				
Area of Predominant Soil [ha, %]				
Depth to Drainage Barrier [cm]	?			
Depth to Groundwater Table [cm]				
External Drainage (Flood Hazard)				
Surface Flooding (river, rainfall)				
Magnitude, Period of Inundation	frequent	infrequent	rare	very rare
Profile Reference	Routine profile description			

Further notes and annotations:

Lithology: SO1

Parent rock carbonates: ST

- *Soil Samples*

Undisturbed soil samples → core sampler (ring)

No of Cyl.	Sampling Spot (GPS)	Depth (cm), Horizon	Density (gcm^{-3})	Comments, Descriptions,…
#01	vu/si-03	1cm, 1st	0,85	
#02	vu/ si-03	1cm, 1st	0,83	
#11	vu/ si-03	20cm, 2nd	0,93	
#12	vu/ si-03	20cm, 2nd	0,98	

Disturbed soil samples:

No	Sampling Spot (GPS)	Depth, Horizon	pH	Texture	Further remarks (segregations, abundance of roots,…), description of spot, comments,…
#0	vu/ si-03	1cm, 1st	5.57		
#1	vu/ si-03	20cm, 2nd	4.92		

- ***Profile Pit***

Soil Description in Profile Pit:

Depth [cm]	Sample no	Colour Colour Mottling	Texture & Texture Unit	Consistence	Aggregate-stability	Segregations	Abundance of roots	Further accommodation
0 : 14cm	#0, #01, #02	7.5YR 2.5/1	Clay		AS2 (d~1-10mm)		Roots	
1 : 30cm	#1, #11, #12	.5YR 4/4	Heavy clay		AS3		Roots	

- Single Ring Infiltrometer

Date: 12. & 13.04.2012

Weather: Rain in the morning

Starting time of measurement: 04:00pm/00:02pm

Infiltration rate: ~51 cmh^{-1}

Comments: Test was carried out two times, since the rates were so high that an error was suspected. The first test showed an asymptotic rate of ~96cm/h, the second ~50cm/h. Both values are so high that it is very likely that the equilibrium hasn't been reached until all the water was gone, but due to very limited availability of water and time constraints no further tests could be carried out.

2. Field Sheets Malafau

Das Bildelement mit der Beziehungs-ID rId96 wurde in der Datei nicht gefunden.

Figure 28: Location of the soil survey sites

2.1 vu/ma-01

Date:01.05..2012 Name: Helmut Schabschneider

Scheme name: vu/ma-01 City, District: Malafau, Efate

Usage: Mixed Plot, AA2

Content:

Survey map: includes:

- soil sampling plots
- place(s) of single-ring infiltrometer experiment(s)
- location of profile pit

Remarks:

-

Coordinates: 17°34’26.38'S/ 168°17’34.75'E Elevation: 22 m

Picture 24: Soil profile vu/ma-01

- *Soil and Site Description*

Village/Scheme Name	vu/ma-01			
Physiographic Position	LV			
Vegetation	Yam, Pineapple, Island Cabbage, Banana			
Slope	02			
Slope Characteristics	BO			
Erosion	N			
Area of Block [ha]				
Predominant Soil in Block				
Area of Predominant Soil [ha, %]				
Depth to Drainage Barrier [cm]	? >130cm			
Depth to Groundwater Table [cm]	? >130cm			
External Drainage (Flood Hazard)				
Surface Flooding (river, rainfall)				
Magnitude, Period of Inundation	**frequent**	infrequent	rare	very rare
Profile Reference	Routine profile description			

Further notes and annotations:

Lithology: UF1: sedimentary: fluvial sand and gravel

Coarse source fragments: VF (<2% fine gravel)

Parent rock carbonates: N (no audible reaction with HCl)

Rock fragments: V (very few)

- *Soil Samples*

Undisturbed soil samples → core sampler (ring)

No of Cyl.	Sampling Spot (GPS)	Depth (cm), Horizon	Density (gcm^{-3})	Comments, Descriptions,…
#01	vu/ma-01	1cm, 1st	0.80	
#02	vu/ ma-01	1cm, 1st	0.75	
#11	vu/ ma-01	20cm, 2nd	0.64	
#12	vu/ ma-01	20cm, 2nd	0.74	
#21	vu/ ma-01	50cm, 3rd	0.64	
#22	vu/ ma-01	50cm, 3rd	0.66	
#31	vu/ ma-01	80cm, 4th	0.71	
#32	vu/ ma-01	80cm, 4th	0.76	

Disturbed soil samples:

No	Sampling Spot (GPS)	Depth, Horizon	pH	Further remarks (segregations, abundance of roots,…), description of spot, comments,…
#0	vu/ ma-01	1cm, 1st	6.64	Spade sample
#1	vu/ ma-01	20cm, 2nd	6.62	Spade sample
#2	vu/ ma-01	50cm, 3rd	6.68	Spade sample
#3	vu/ ma-01	80cm, 4th	6.60	Spade sample

- *Profile Pit*

Soil Description in Profile Pit:

Depth [cm]	Sample no	Colour Colour Mottling	Texture & Texture Unit	Consistence	Aggregate-stability	Segregations	Abundance of roots	Further accommodation
0 : 11-15	#0, #01, #02	7.5YR 2.5/1	Loam		D~2-15mm AS1		Roots	Surface covered with dead roots
1 : 43	#1, #11, #12	10YR 3/2	Fine sand				Roots	
2 : 77	#2, #21, #22		Coarse sand				Roots	
3 :99	#3, #31, #32		Clay loam					
4			Loam					

- ***Single Ring Infiltrometer***

Date: 18. & 19.04.2012

Weather: Heavy (30 mm) rain in the afternoon of the 18.

Starting time of measurement: 04:52pm/09:10am

Infiltration rate: ~ $18 cmh^{-1}$

Comments: test was carried out twice due to suspected leak when doing the test on the 18. The result of the first test (~$24 cmh^{-1}$) was dismissed.

2.2 vu/ma-02

Date:19.04.2012 Name: Helmut Schabschneider

Scheme name: vu/ma-02 City, District: Malafau, Efate

Usage: Mixed garden

Content:

Survey map: includes:

- soil sampling plots
- place(s) of single-ring infiltrometer experiment(s)
- location of profile pit

Remarks:

Remarks: only infiltration test was carried out at this site, since by time when the profile pit had to be dug the yam on the plot has not been harvested yet (contrary to a previous agreement). Therefore there was not enough space to dig a pit, but a quick estimation plus information from the farmers indicated that the soil at vu/ma-02 shows very similar behaviour to the soil at vu/ma-01.

Coordinates: 17°34'35.41'S/ 168°17'35.541'E Elevation: 33 m

Das Bildelement mit der Beziehungs-ID rId96 wurde in der Datei nicht gefunden.

Picture 25: Soil profile vu/ma-02

- *Soil and Site Description*

Village/Scheme Name	vu/ma-02			
Physiographic Position	LV			
Vegetation	Yam, Island Cabbage			
Slope	02			
Slope Characteristics	TS			
Erosion	N			
Area of Block [ha]				
Predominant Soil in Block				
Area of Predominant Soil [ha, %]				
Depth to Drainage Barrier [cm]				
Depth to Groundwater Table [cm]				
External Drainage (Flood Hazard)				
Surface Flooding (river, rainfall)				
Magnitude, Period of Inundation	**frequent**	infrequent	rare	very rare
Profile Reference				

Further notes and annotations:

- *Soil Samples*

Undisturbed soil samples → core sampler (ring)

No of Cyl.	Sampling Spot (GPS)	Depth (cm), Horizon	Density (gcm^{-3})	Comments, Descriptions,…
#01	vu/	, st		
#02	vu/	, st		
#11	vu/	, nd		
#12	vu/	, nd		
#21	vu/	, rd		
#22	vu/	, rd		
#31	vu/	, th		
#32	vu/	, th		

Disturbed soil samples:

No	Sampling Spot (GPS)	Depth, Horizon	pH	Further remarks (segregations, abundance of roots,…), description of spot, comments,…
#0	vu/			Spade sample
#1	vu/			Spade sample
#2	vu/			Spade sample
#3	vu/			Spade sample

- *Profile Pit*

Soil Description in Profile Pit:

Depth [cm]	Sample no	Colour Colour Mottling	Texture & Texture Unit	Consistence	Aggregate-stability	Segregations	Abundance of roots	Further accommodation
0 :	#0, #01, #02							
1 :	#1, #11, #12							
2 :	#2, #21, #22							
3 :	#3, #31, #32							

- ## *Single Ring Infiltrometer*

Date: 19.04.2012

Weather: 30mm rain in the afternoon of the 18th.

Starting time of measurement: 02:15pm

Infiltration rate: ~ 18cmh^{-1}

Comments:

2.3 vu/ma-03

Date: 01.05.2012	Name: Helmut Schabschneider
Scheme name: vu/ma-03	City, District: Malafau, Efate
Usage: Banana plot	

Content:

Survey map: includes:

- soil sampling plots
- place(s) of single-ring infiltrometer experiment(s)
- location of profile pit
- places of in-field measurements

Remarks:

-

Coordinates: 17°33’46.62'S/ 168°17’15.49'E Elevation: 20 m

Das Bildelement mit der Beziehungs-ID rId96 wurde in der Datei nicht gefunden.

Picture 26: Soil profile vu/ma-03

- *Soil and Site Description*

Village/Scheme Name	vu/ma-03			
Physiographic Position	LV			
Vegetation	FrBa (Banana), old Maniok roots			
Slope	01			
Slope Characteristics	BO			
Erosion	N			
Area of Block [ha]				
Predominant Soil in Block				
Area of Predominant Soil [ha, %]				
Depth to Drainage Barrier [cm]	?			
Depth to Groundwater Table [cm]	85			
External Drainage (Flood Hazard)				
Surface Flooding (river, rainfall)				
Magnitude, Period of Inundation	**frequent**	infrequent	rare	very rare
Profile Reference	Routine profile description			

Further notes and annotations:

Land Use: AA2 (3?)

Lithology: UF2: sedimentary: fluvial clay, silt and loam

Carbonates: SL (~0-2%)

No rock artefacts

- ***Soil Samples***

Undisturbed soil samples → core sampler (ring)

No of Cyl.	Sampling Spot (GPS)	Depth (cm), Horizon	Density (gcm^{-3})	Comments, Descriptions,…
#01	vu/ma-03	1cm, 1st	0.82	
#02	vu/ ma-03	1cm, 1st	0.79	
#11	vu/ ma-03	40cm, 2nd	0.66	
#12	vu/ ma-03	40cm, 2nd	0.78	
#21	vu/ ma-03	80cm, 3rd	0.74	
#22	vu/ ma-03	80cm, 3rd	0.85	

Disturbed soil samples:

No	Sampling Spot (GPS)	Depth, Horizon	pH	Further remarks (segregations, abundance of roots,…), description of spot, comments,…
#0	vu/ma-03	1cm, 1st	6.31	Spade sample
#1	vu/ma-03	40cm, 2nd	6.28	Spade sample
#2	vu/ma-03	80cm, 3rd	6.21	Spade sample

- *Profile Pit*

Soil Description in Profile Pit:

Depth [cm]	Sample no	Colour Colour Mottling	Texture & Texture Unit	Consistence	Aggregate-stability	Segregations	Abundance of roots	Further accommodation
0 : 30	#0, #01, #02		Loam- clay loam			Few		
1 :~45	#1, #11, #12	Red and greyish spots (~10cm^2)	Usorted sand			almost none		
2 :	#2, #21, #22		Loam- sandy loam					

- *Single Ring Infiltrometer*

Date: 19.04.2012

Weather: Few showers in the afternoon

Starting time of measurement: 16:55pm

Infiltration rate: ~ 18cmh^{-1}

Comments: after 15 min an equilibrium of ~ 18 cmh^{-1} had been reached, but then the rate showed an increase again. In the following 6 minutes it went up to 33 cmh^{-1} again. Many earthworms were observed trying to flee from the water, so a possible explanation of the increase in the rate the water went down could be that an earthworm dug a passage for the water.

3. Field Sheets Middle Bush

Das Bildelement mit der Beziehungs-ID rId96 wurde in der Datei nicht gefunden.

Figure 29: Location of the soil survey sites at Middle Bush

3.1 vu/mi-01

Date:10.05.2012 Name: Helmut Schabschneider

Scheme name: vu/mi-01 City, District: Middle Bush, Tanna

Usage: wild cane (nearby old road cut) Soil type:

Content:

Survey map: includes:

- soil sampling plots
- place(s) of single-ring infiltrometer experiment(s)
- location of profile pit

Remarks:

-

Coordinates: 19°27’32.24'S/ 169°18’20.63'E Elevation: 337 m

Das Bildelement mit der Beziehungs-ID rId96 wurde in der Datei nicht gefunden.

Picture 27: Soil profile vu/mi-01

- *Soil and Site Description*

Village/Scheme Name	vu/mi-01			
Physiographic Position	SE			
Vegetation	Fallow			
Slope	6%			
Slope Characteristics	UP, SS			
Erosion	N			
Area of Block [ha]				
Predominant Soil in Block				
Area of Predominant Soil [ha, %]				
Depth to Drainage Barrier [cm]				
Depth to Groundwater Table [cm]				
External Drainage (Flood Hazard)				
Surface Flooding (river, rainfall)				
Magnitude, Period of Inundation	frequent	**infrequent**	rare	very rare
Profile Reference	Routine profile description			

Further notes and annotations:

No rock artefacts

- *Soil Samples*

Undisturbed soil samples → core sampler (ring)

No of Cyl.	Sampling Spot (GPS)	Depth (cm), Horizon	Density (gcm^{-3})	Comments, Descriptions,…
#01	vu/mi-01	2cm, 1st	0,99	Many earthworms
#02	vu/mi-01	2cm, 1st	1,08	
#11	vu/mi-01	90cm, 2nd	0,65	
#12	vu/mi-01	90cm, 2nd	0,64	

Disturbed soil samples:

No	Sampling Spot (GPS)	Depth, Horizon	pH	Further remarks (segregations, abundance of roots,…), description of spot, comments,…
#0	vu/mi-01	2cm, 1st	5.16	Spade sample
#1	vu/mi-01	90cm, 2nd	5.60	Spade sample

- *Profile Pit*

Soil Description in Profile Pit:

Depth [cm]	0 : 40-70 1 : 140 2 :
Sample no	#0, #01, #02 #1, #11, #12
Colour Colour Mottling	10YR 2/1 7.5YR 2.5/3 2.5YR 4/6 (higher share of « range » than it could be found in the Munsell- soil- charts) Rusty- orange mottles (abundance : C (common),Size : M (6-20mm))
Texture & Texture Unit	Loam Sandy clay loam Loamy sand
Consistence	
Aggregate-stability	
Segregations	Grains >2mm (~5%)
Abundance of roots	Small roots
Further accommodation	Layers not easily destinguishable, D (boundaries diffuse)

- *Single Ring Infiltrometer*

Date: 09.05.2012

Weather: Heavy rain (20mm) on the night to the 08.

Starting time of measurement: 11:20am

Infiltration rate: ~ 6.6cmh^{-1}

Comments: The water wetted a cone with an angle of 40 degrees to the surface.

3.2 vu/mi-02

Date:10.05.2012 Name: Helmut Schabschneider

Scheme name: vu/mi-02 City, District: Middle Bush, Tanna

Usage: Mixed plot

Content:

Survey map: includes:

- soil sampling plots
- place(s) of single-ring infiltrometer experiment(s)
- location of profile pit

Remarks:

-

Coordinates: 19°26’46.30'S/ 169°17’42.04'E Elevation: 339m


Picture 28: Soil profile vu/mi-02

- *Soil and Site Description*

Village/Scheme Name	vu/mi-02			
Physiographic Position	LL			
Vegetation	Maniok, Taro, Banana, Lemon			
Slope	3-4%			
Slope Characteristics	UP,SS			
Erosion	N			
Area of Block [ha]				
Predominant Soil in Block				
Area of Predominant Soil [ha, %]				
Depth to Drainage Barrier [cm]				
Depth to Groundwater Table [cm]				
External Drainage (Flood Hazard)				
Surface Flooding (river, rainfall)				
Magnitude, Period of Inundation	**frequent**	infrequent	rare	very rare
Profile Reference	Routine profile description			

Further notes and annotations:

No rock artefacts

- *Soil Samples*

Undisturbed soil samples → core sampler (ring)

No of Cyl.	Sampling Spot (GPS)	Depth (cm), Horizon	Density (gcm^{-3})	Comments, Descriptions,…
#01	vu/mi-02	2cm, 1st	1.00	
#02	vu/ mi-02	2cm, 1st	1.05	
#11	vu/ mi-02	80cm, 2nd	0.74	
#12	vu/ mi-02	80cm, 2nd	0.77	

Disturbed soil samples:

No	Sampling Spot (GPS)	Depth, Horizon	pH	Further remarks (segregations, abundance of roots,…), description of spot, comments,…
#0	vu/ mi-02	2cm, 1st	5.30	Spade sample
#1	vu/ mi-02	80cm, 2nd	5.27	Spade sample
#2	vu/ mi-02	110cm, 2nd	5.28	Spade sample

- *Profile Pit*

Soil Description in Profile Pit:

Depth [cm]	Sample no	Colour Colour Mottling	Texture & Texture Unit	Consistence	Aggregate-stability	Segregations	Abundance of roots	Further accommodation
: 70	#0, #01, #02	7.5YR 2.5/1	Sandy clay		AS1		Few	
1 : 100	#1, #11, #12	7.5YR 3/2	Clay loam – Clay				Very few	
2 :?	#2	7.5YR 3/4	Clay				No	

- *Single Ring Infiltrometer*

Date: 10.05.2012

Weather: Heavy rain (20mm) on the night to the 08.

Starting time of measurement: 10:00

Infiltration rate: ~ 6.0 cmh^{-1}

Comments: The water wetted a cone with an angle of 45 degrees to the surface.

3.3 vu/mi-03

Date:11.05.2012 Name: Helmut Schabschneider

Scheme name: vu/mi-03 City, District: Middle Bush, Tanna

Usage: New road cut (<1YR): Grassland

Content:

Survey map: includes:

- soil sampling plots
- place(s) of single-ring infiltrometer experiment(s)
- location of profile pit

Remarks:

-

Coordinates: 19°27’32.24'S/ 169°18’20.63'E Elevation: 353 m

Das Bildelement mit der Beziehungs-ID rId96 wurde in der Datei nicht gefunden.

Picture 29: Soil profile vu/mi-03

- *Soil and Site Description*

Village/Scheme Name	vu/mi-03			
Physiographic Position				
Vegetation	Grass, Palm Trees			
Slope	3%			
Slope Characteristics	MS			
Erosion	N			
Area of Block [ha]				
Predominant Soil in Block				
Area of Predominant Soil [ha, %]				
Depth to Drainage Barrier [cm]				
Depth to Groundwater Table [cm]				
External Drainage (Flood Hazard)				
Surface Flooding (river, rainfall)				
Magnitude, Period of Inundation	**frequent**	infrequent	rare	very rare
Profile Reference	Routine profile description			

Further notes and annotations:

Coral stone artefacts from road construction

- *Soil Samples*

Undisturbed soil samples → core sampler (ring)

No of Cyl.	Sampling Spot (GPS)	Depth (cm), Horizon	Density (gcm^{-3})	Comments, Descriptions,…
#01	vu/mi-03	2cm, 1st	0.97	
#02	vu/mi-03	2cm, 1st	0.86	
#11	vu/mi-03	85cm, 2nd	0.76	
#12	vu/mi-03	85cm, 2nd	0.71	

Disturbed soil samples:

No	Sampling Spot (GPS)	Depth, Horizon	pH	Further remarks (segregations, abundance of roots,…), description of spot, comments,…
#0	vu/	2cm, 1st	5.41	Spade sample
#1	vu/	85cm, 2nd	5.43	Spade sample

- *Profile Pit*

Soil Description in Profile Pit:

Depth [cm]	Sample no	Colour Colour Mottling	Texture & Texture Unit	Consistence	Aggregate-stability	Segregations	Abundance of roots	Further accommodation
0 : ~70	#0, #01, #02	2.5YR 2/1	Silt loam		AS4			Diffuse layer boundaries : D
1 :	#1, #11, #12	5YR 3/2	Sandy clay loam					

- *Single Ring Infiltrometer*

Date: 11.05.2012

Weather: Heavy rain (20mm) on the night to the 08.

Starting time of measurement: 11:30am

Infiltration rate: ~ 2.1 cmh^{-1}

Comments:

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Abbreviations/ Explanatory Notes

ENSO	El Niño/Southern Oscillation
IRI	International Research Institute for Climate and Society
PCCSP	Pacific Climate Change Science Program
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (German Society for International Cooperation)
NACC	National Advisory Comittee on Climate Change
VARTC	Vanuatu Agricultural Research and Technical Centre
NARI	PNG National Agricultural Research Institute
DARD	Vanuatu Department of Agriculture and Rural Development
Kastom	Traditional culture of Vanuatu
ni- Vanuatu	Native citizen of Vanuatu

Curriculum Vitae

Personal Data

Name:	Mag. rer. nat. Bakk. techn. Helmut Schabschneider
Born:	30. December 1982 in Lilienfeld.
Principal residence:	Köchling 27, 3371 Neumarkt an der Ybbs

Education

2011-Present	Studying Kulturtechnik und Wasserwirtschaft (Environmental Engineering and Water Management, Master)
2013	Obtaining Magister Rerum Naturalis (Master) degree in Physik (Physics)
2011	Obtaining Bakkalaureus Technikus (Bachelor) degree in Kulturtechnik und Wasserwirtschaft (Environmental Engineering and Water Management)
2002-2003	Studying Technical Physics
2001-2002	Military Service
2001	Graduation with distinction
1993-2001	BG/BRG Wieselburg: Secondary School with focus on natural sciences and mathematics.
1989-1993	Music-Primary School Neumarkt/Ybbs

Language Skills

German (mother tongue)
English (fluent)
Bislama
French
Spanish (basic)