A REPORT ON

THE GEODETIC INFRASTRUCTURE

OF

THE KINGDOM OF TONGA

Prepared by:

Viliami Folau
B.A. Land Use Planning & Real Estate, Dip. Geomatics (USP)

Surveyor
Surveying & Geodesy, GIS/Mapping and Division
Ministry of Lands, Environment, Climate Change and Natural Resources
P.O. Box 5, Nuku'alofa
Kingdom of Tonga.
viliami.folau@gmail.cm or vfolau@lands.gov.to

Tevita L. Malolo

M.Sc. Geodesy (Lond, UK); PGD Geodesy (UCL, UK); B.Tech.Surv. (PNGUT); Cert. Surv. (NZ); MASPNG; Former Surveyor General (Kingdom of Tonga).

Senior Lecturer in Surveying and Geodesy
University of Technology
PMB, Lae 411, Morobe Province
Papua New Guinea.

tmalolo@survey.unitech.ac.pg

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1. INTRODUCTION

1.1 NEW GEODETIC DATUM AND MAP GRID SYSTEM

The Kingdom of Tonga has in 2005 followed the international practice of moving away from **local ellipsoids** to adopt a **globally geocentric reference system** known as the **Tonga Geodetic Datum 2005** (TGD2005). Also, a new Map Grid System known as the **Tonga Map Grid** (TMG) was introduced as adopted for GIS mapping mainly while the daily practice of cadastral surveying and its applications to other cadastral survey systems are still using the old systems.

The establishment of the TGD2005 is fundamental to all the Kingdom's surveying and mapping requirements. The new datum is compatible with the most modern state of the art positioning systems, such as the latest Automated Total Station, Global Positioning System (GPS) and Global Navigation and Satellite System (GNSS).

Tonga's National Surveying and Mapping infrastructure; including a new geodetic datum, map grid and data formatting systems have been developed, *during the 2003 – 2007 implementation of the Component B: Land Hazards and Information under the World Bank project – Cyclone Emergency Recovery and Management Project*, in terms of common international standards that allow easy exchange of digital information and data.

The Surveying, Geodesy and GIS/Mapping Division at the time, and in particular the Geodesy Unit, of the Ministry of Lands, Survey and Natural Resources (MLSNR) was mandated with responsibilities for the overall control and maintenance of the National Surveying and Mapping infrastructure including the cadastral survey system of the Kingdom of Tonga.

1.2 REPORT PREVIEW

This paper attempts to provide a comprehensive report on the geodetic infrastructure of the Kingdom of Tonga.

Section 1 provides a very brief introduction to main thrust of the report. Section 2 deals with background information to the report by providing brief overview of each of the various survey works executed since the early years of 1900's and up to the introduction and adoption in 2005 of the existing geocentric datum and new map grid system, known as the TGD2005 and the TMG respectively. Section 3 focuses specifically on the definition and realisation of the TGD2005 and TMG and then very briefly summarises the Specifications for the TCD2005 and the main Characteristics of the TMG. Section 4 provides a brief account on the Surveying Capacity & Capability in-terms of Human and Physical Resources currently available in the

Surveying and Geodesy Division of the MLSNR. Section 5 looks at various Issues and the Way Forward in a way to ensure that the TGD2005 and the TMG are fully established and adopted at all levels of surveying and mapping practices in Tonga. Section 6 provides a duplication of the proposed upgrading of all previously established Geodetic Control Networks throughout the nation. And finally, Section 7 of the report provides a brief Conclusion and Recommendations.

2. BACKGROUND

2.1 SURVEYS PRIOR TO 1957

Old survey records indicated that surveying and mapping in Tonga began somewhere around in the early years of the 1900s onwards.

Up until 1927, at least three to four expatriate surveyors from Australia and New Zealand, assisted by only few locally trained field surveyors were consistently employed by the Tonga Government to carry out the required survey works. These included coastal traverses, road and engineering surveys, land boundary surveys for hereditary estates, townships and new individually granted allotments (town and tax allotments – at standard legal sizes) were carried out in most parts of the main islands of Tonga – at a steady rate of progress due to shortage of trained personnel. This was the situation during and after the 1st World War in 1918.

In 1927, it appeared that the size of the field survey forces and their annual outputs were nowhere came close to meet the demands from a rapidly increasing population for more subdivided lands - tax and town allotments.

However, during the period 1927 – 1957 a large amount of surveyed tax and town allotments were completed due to increasing number of Tongan overseas trained Surveyors (at technician level) returned and employed permanently by the Government of Tonga.

Although the bulk of the survey works, completed for the period 1900 – 1957, were of good standard theodolite traverses, various and different meridians were used as origin and occasionally a true meridian was used. Bearings of contiguous surveys in an area were usually in the same terms, but no system of regular coordinates was set up as a survey and mapping basis for the completed works.

This was the situation in Tonga prior to the introduction and adoption of the **Tonga Cadastral Survey Datum** (TCSD 57/61) and the **Tonga Cadastral Survey Grid** (TCSG 61) for the Cadastral Survey of the Kingdom of Tonga, 1957 - 1962.

2.2 TONGA CADASTRAL SURVEY OPERATIONS 1957 – 1962

The above Survey Operations were executed by Leach and Browne, Registered Surveyors, Milford in Auckland, New Zealand.

The Tonga Cadastral Survey Datum (TCSD 57/61) [and as well as the Tonga Cadastral Survey Grid (TCSG 61)] was established at four island groups, each with its own circuit origin and azimuth determination. The four circuits are: Tongatapu/'Eua, Nomuka, Ha'apai and Vava'u.

The **purpose** of the survey control network or circuit was to provide a homogenous framework from which to survey and subdivide land parcels into town and tax allotments of 8¼ acres each. The area of 8¼ acres is based on a land parcel having the nominal dimensions of (100 fathoms x 100 fathoms).

An instruction manual, titled "Instructions for the Cadastral Survey of the Kingdom of Tonga", was produced in 1958 by Leach and Browne, Reg. Surveyors, Milford in Auckland, NZ; which also established cadastral survey and office procedures for recording land registration information.

A report title "General Notes on the Primary Control for the Cadastral Survey of Tonga" was produced and signed by D. L. Leach himself.

2.2.1 Tonga Cadastral Survey Datum 1957 – 1961 (TCSD 57/61)

The **TCSD 57/61** is a local datum determined by astronomical observations at a single datum orientated station (point of origin for a regular coordinates system) for each of the four Survey Control Networks/Circuits established by conventional survey techniques in the main islands groups of Tonga, as follows:

- Tongatapu/'Eua Circuit by Triangulation 1957 – 1959
- Nomuka Circuit by Triangulation 1959
- Vava'u Circuit by Triangulation 1959 – 1960
- Ha'apai Circuit by Trilateration 1961

At each of the above circuits, a permanent and centrally located datum station was selected as the point of origin and its positions (latitude and longitude) were fixed by astronomical observations. An astronomical azimuth was also determined from the same point of origin to another control station within the same circuit. Height of the datum station was also fixed relative to MSL datum.

In all cases, the MSL datum for each island group circuit was determined from an analysis of 1 – 6 months tidal observations recorded from a tide gauge installed in each island group.

2.2.2 The Tonga Cadastral Survey Grid 1961 (TCSG 61)

Definition:

- **Map Grid System** – TCSG 61
- **Projection** – Transverse Mercator based on the UTM Projection Zone One
- **Ellipsoid** – International Spheroid 1924 or Hayford Figure 1910
  Parameters: a = 6,378.388 m; b = 6,356,912 m; f = 1/297
  Unit of Measurement: For UTM .. Metre (1m = 3.2808455 ft)
  For TCSG 61 .. Link (100 links to 1 chain or 66 ft)

- **True Origin** –
  The true origin of the UTM Zone One is the intersection of the Central Meridian (CM) of 177º West Longitude with the equator. The coordinates of this origin is 500,000 metres East and 10,000,000 metres North.

- **False Origin** –
  The origin of the TCSG 61 is a point on the 177º West Longitude which has a UTM Northing coordinate value of 7,500,000 metres North. There is therefore a direct relation between the UTM Zone One projection coordinates in metres and the TCSG 61 projection coordinates in links.

- **Scale Factor** –
  The Scale Factor at the CM is $k_o = 0.9996$ (a reduction of 1 = 2,500).

- **Convergence** –
  An approximate formula can be used for most applications but full formula can be obtained from geodetic text books.

  The Convergence (σ'') between the True Meridian and the Grid North can be computed by this approximate formula: $\sigma'' = \Delta\lambda'' \sin\phi$; where $\Delta\lambda''$ is the difference of longitude in seconds between the observer and the CM; ϕ is the latitude of the observer.

2.3 DIRECTORATE OF OVERSEAS SURVEYS (DOS) 1969 – 1972

Aim: To establish additional Primary Survey Controls in remote areas not covered in previous surveys to establish the TCSD 57/61 and TCSMG 61 for the Topographic Mapping of the Kingdom of Tonga.

Prior investigation revealed that Survey Controls in most areas were based on the TCSD & TCSMG, established previously during the Cadastral Survey Operations 1957 – 1962.

In remote and isolated islands or group of islands not covered during the Cadastral Survey Operations, DOS Surveyors established six more additional Survey Control Circuits and Datums (Horizontal and Vertical), where the Horizontal Datum in each case was either scaled from nautical chart or adopted from the Shoran Trilateration Survey. Where the positions (lat. & long.) of the horizontal datum were scaled from nautical chart, an astronomical azimuth was to be determined to another reference station within the circuit and, the height of the datum station (point of origin) was connected also to sea level so as to determine approximately the MSL height of the point of origin.

For the Topographic Mapping Series, a total of 10 Survey Control Circuits (4 from the Tonga Cadastral Survey Operations 1957 - 1962 and 6 from DOS Mapping Control 1970 - 1971) were used to provide the horizontal and vertical control requirements for the production of the first Topographic Mapping Series of the Kingdom of Tonga, excluding Telekitonga and Telekitokelau Islands in the Minerva Reefs. The 10 independent Control Survey Circuits are as follows:

- Niuafo'ou Circuit - Datum scaled from Nautical Chart No. 968
- Niuatoputapu Circuit - Datum scaled from Nautical Chart No. 968
- Fonualei/Toku Circuit - Datum based on Shell Shoran Trilateration 1970
- Vava'u Circuit - Datum based on TCSD & TCSG
- Late Circuit - Datum based on Shell Shoran Trilateration 1970
- Ha'apai Circuit - Datum based on TCSD & TCSG
- Nomuka Circuit - Datum based on TCSD & TCSG
- Hunga (Tonga & Hp) - Datum based on Shell Shoran Trilateration 1970
- TBU/'Eua Circuit - Datum based on TCSD & TCSG
- 'Ata Circuit - Datum scaled from Nautical Chart No. 2421.

2.4 SHELL SHORAN TRILATERATION 1970 – 1971

The survey operation was done by the Shell Internationale Petroleum Maatshappij N.V., the Hague, Netherlands in connection with the geophysical seismic surveys required before the hydrocarbon exploration conducted in Tonga during the seventies.

Purpose of the Survey:

To establish a fourth order basic Geodetic Network over three major islands groups (Tongatapu, Ha'apai and Vava'u) in order to obtain coordinates on a Common Datum for various base stations to be used for the positioning of pre-planned seismic surveys.

Investigation of Tonga's survey record revealed that a large number of geodetic and cadastral controls existed. These controls were grouped in circuits, almost identical with islands groups, with each having its own astronomically determined reference station. Thus, a survey for a wider geodetic was made to tie up these circuits together.

In spite of heavy seas and landing problems on some isolated islands, the two months field survey work was completed to acceptable standard and results at reasonable cost by trilateration using XR Shoran equipment.

A total of 27 baselines were measured, 5 of these being TCSD & TCSMG lines. The Trilateration network, based on a single datum (assumed to be of the TCSD 57/61), consists of 11 stations of which 3 were newly established and 8 were existing stations. Two of the existing stations were adopted for the datum and for orientation.

2.5 DOPPLER SATELLITE SURVEY OPERATION 1981 & 1984

Funded by the Australian Bi-lateral Aids to Smaller Pacific Island Nations, this comprehensive survey operations were undertaken by the Australian Army Survey Corps – the fieldwork was done in 1981 and part of 1984, and the final results were available in 1986.

Aim:

- To establish survey control using Doppler Satellite techniques to coordinate base points for the determination of Tonga's 200 nautical mile EEZ on an internationally accepted datum;
- To extract observational data of previous surveys in Tonga for rigorous mathematical adjustment.

Field Survey Operation:

5 AN/PRR 14 Geoceivers and 1 Wild RC 10 Aerial Camera were used during the field campaign.

Excluding the 6 stations in Minerva Reef (Telekitonga & Telekitokelau Islands), a total of 21 were occupied and coordinated in the Tonga region – 18 were extant control stations and 3 at sites where new stations were established.

At each site, an average of 29 satellite passes were observed to provide a positional accuracy of (+ or –) 1.5 metres in each component of latitude, longitude and height.

Reduction of Field Observation:

Reduction and processing of observed data were carried out using a mainframe computer. Raw data were processed using program SYSTEM and Satellite Datum values were computed using program GPP/DOP79. Transformation from NWL-9D values to WGS 72 was carried out using Seppeline Formula from which small corrections on the latitude,

longitude and height were derived. Adding of these corrections to NWL-9D coordinates yielded the final WGS72 coordinates.

Network Adjustment:

Observational Data, consisting of the 10 island groups networks established during the (1957 – 1962) Cadastral Survey Operations and the (1969 – 1972) DOS Mapping were extracted and forwarded to Australia for the final rigorous mathematical adjustment.

The adjustment was done using a least squares adjustment program.

The 10 Islands Groups Networks or Sections are as follows:

(i)	NIUATAF Section	(vi)	HA'APAI Section
(ii)	NIUAFOU Section	(vii)	HUNGA Section
(iii)	FONTOK Section	(viii)	TONEUA Section
(iv)	VAVAU Section	(ix)	ATA Section
(v)	LATE Section	(x)	MINERVA Section

All network assessments were generally assessed as third with some fourth order points.

Results: Final Results were given in geographical and UTM Grid coordinates relative to the WGS72 Reference Ellipsoid.

Conclusion:

The precise geodetic position of the Kingdom of Tonga, based on an internationally accepted datum has been determined. Results will contribute to the determination of the geoidal separations in the region. Acquired Doppler control points and subsequent network adjustments, combined with existing mapping and aerial photography will enable Tonga to accurately determine base point coordinates for the definition of its Exclusive Economic Zone (EEZ).

2.6 GPS PROJECTS IN TONGA SINCE 1990

The Geodesy Unit of the Surveying and Mapping Division, MLSNR was created in 1992 and mandated by HM Government in to be responsible to all geodetic surveys including GPS Projects and special mapping functions of the MLSNR.

The Geodesy Unit's foundation or pioneering staff in 1992 is as follows:

(i) **Tevita L. Malolo** - Principal Geodetic Surveyor Specialist (Head of Section), later became the Chief Geodetic Surveyor Specialist (Head of Surveying, Geodesy and Mapping Division) before becoming the MLSNR's CEO and Surveyor General in 2001. He was the first and the last person ever appointed to the position of Surveyor General in the long history of Surveying in Tonga.

(ii) **Francis Latu** – Graduate Geodetic Surveyor and later he became the Principal Surveyor (Geodesy) and Head of Geodesy Unit.

(iii) **Tevita 'A. So'otanga** - Graduate Cartographer, and later transferred to become the Chief Draughtsman in the General Drafting & Mapping Section of the MLSN.

The Principal Geodetic Surveyor Specialist and later the Head of the Geodesy Unit was the designated local counterpart of the following on-going GPS and Special Projects, since the creation of the Geodesy Unit in1992:

2.6.1 South West Pacific (SWP) GPS Project: since 1992

Initiated and implemented by an international consortium of Institutions and Government Agencies that were using GPS to monitor plate tectonic motion in the South West Pacific region.

This regional Project was first coordinated by Professor Michael Bevis formerly of North Carolina State University and the University of Hawaii and at present ? Recently, Dr John Bevan and his colleagues from the Institute of Nuclear Science (IGNS) in Wellington, NZ took over the project coordinating role.

The Kingdom of Tonga was included as part of this ongoing regional project with the MLSNR serving as the project's local counterpart since 1988. The Geodesy Unit took over the local counterpart role from the MLSNR's Geology Unit in 1992.

A regional geodetic network had been established within the South West Pacific Project area, with 4 geodetic stations being placed permanently in Tonga – one in Tongatapu, two in Vava'u (one of these is used as a Continuous GPS Base Station) and the fourth one is located further north in the island of Niuatoputapu.

In subsequent GPS campaigns related to this study, raw data are immediately downloaded from GPS receivers including the permanent tracker and forwarded to IGNS for verification and processing prior to distribution to other Institutions.

Results processed from raw data and analysed by research scientists can be obtained upon request. Reports and list of results – coordinates of GPS stations are now in digital format recorded in the Geodetic Database. The project began in 1988 and is supposed to be monitored annually.

2.6.2 South Pacific Sea Level and Climate Monitoring Project: since 1993

Funded by the Australian Government as a commitment to Small Island Countries of the Pacific, Tonga is included in this comprehensive and long-term regional project.

The project installation and implementation of the first two Phases of the Project was done by the National Tidal Facility of the Flinder's University of South Australia and

the Geodesy Unit of the MLSN has been the project's local counterpart since the start of the project.

A SEAFRAME station has been installed at Queen Salote Wharf (Nuku'alofa) on the main island of Tongatapu.

The SEAFRAME station is equipped with high precision automated instruments for real time measuring precisely and recording the required oceanographic and meteorological parameters and automatically transmitted electronically to Australia for verification and analysis.

A coastal and inland arrays of deep Bench Marks were also installed along the By-Pass Road in Ma'ofanga and connected back to the SEAFRAME station at Queen Salote Wharf for monitoring the stability of the SEAFRAME station relative to the vertical motion of land mass as indicated by the heights of the Bench Marks.

Precise differential levelling runs between the these arrays of deep Bench Marks and the SEAFRAME station have been undertaken for a number of years. Similarly, a number of precise static GPS surveys were undertaken between these arrays of deep BMs and the SEAFRAME station. Results and BMs' Station Description were provided to us by the NTF.

However, the implementation of Phase III of the project included the installation of a continuously operating GPS Base Station at 'Apifo'ou (St. John High School) in Nuku'alofa, Tongatapu.

Precise Levelling and GPS Results .. Reports and list of results; coordinates of GPS stations are in digital format. The surveys were based on WGS 84 – the Project started in 1993 and is monitored on annual basis. Precise levelling exercises are undertaken only on the arrays of deep bench marks and to the SEAFRAME station.

2.6.3 Surveys done by Geodesy Unit: since 1992

Prior to 2004, the Geodesy Unit Staff surveyors conducted also various surveys that contributed to the general maintenance of the national geodetic network, as follows:

- **Survey of Third Order Bench Marks - Tongatapu Island Circuit**

  A series of Third Order Bench Marks covering the entire island of Tongatapu were monumented and completely levelled for the monitoring of the underground water aquifer in the Tongatapu Island.

  Reduced levels for these Bench Marks are based on a MSL Datum derived from the analysis of a one year tidal observations taken in 1990 from a tide gauge installed at Vuna Wharf (Nuku'alofa).

The output is on station diagrams with heights above MSL, and they are now in digital format. The data is based on MSL measurements derived from a one year readings in 1990.

- **The Re-observation of 2nd Order Cadastral Survey Controls (Traverses):**

  The main traverse loops of the Central/Western District of Tongatapu were completely re-observed and coordinates were re-computed for all occupied stations before being plotted in black and white Survey Plans on films. For the Eastern District of Tongatapu, the re-observation of cadastral survey control traverses was partly completed.

  The report consists of sketches and data in digital format (Excel, DBF and MapInfo). The survey was based on the International Spheroid (Hayford 1910, UTM Zone 1).

- **Delimitation of the Kingdom of Tonga's Maritime Limits**

  The Geodesy Unit was mandated with the provision following geodetic tasks:

  - Advise Government through a Cabinet appointed Committee on technical aspects involved on the delimitation process of Kingdom's maritime boundary limits, particularly its 200 Nautical Miles Exclusive Economic Zone (EEZ) and the Extended Continental Shelf – south of Telekitonga and Telekitokelau Islands, relative to neighbouring states;

  - Assist International Consultant contracted in by the Tonga Government to prepare the Kingdom's EEZ and Extended Continental Shelf's claims;

  - Prepare Base Map of the Kingdom of Tonga and all it's Neighbouring States to show Potential Areas that Tonga could claim under the UNCLOS;

  - Document Base Points' coordinates based on the WGS84 or GRS80 reference ellipsoid; previous reports etc. on this important matter.

2.6.4 GPS Continuous Tracking Stations: since 1999

Tonga has accessed to two continuously operating GPS Base Stations since 1999.

The first CGPS Base Station was established in 1999 at Vava'u Airport, for the South West Pacific GPS Project, but the Station has been relocated to the District Survey Office in Neiafu, Vava'u.

The second CGPS Base Station was established in 2002 under the Phase III of the South Pacific Sea Level and Climate Monitoring Project. This station is located at 'Apifo'ou (St. John High School) in Nuku'alofa, Tongatapu.

3. TONGA GEODETIC DATUM 2005 AND TONGA MAP GRID

The **Tonga Geodetic Datum 2005** (TGD2005) is a **VISIONARY MISSION** that had been initiated and carried around by the Geodesy Unit of the MLSNR since 1992.

The dream was based on the fundamental concept of having a single unified **Modern Geodetic Reference System** and a new **Map Grid System** for the Kingdom of Tonga – to provide a rigid platform for the integration of all survey and mapping information. These had been collected and archived by the MLSNR since 1900.

Realising the importance of having a single unified reference system for Tonga, which would indeed promote the production of reliable, accurate and homogeneous geographical and land information for the whole country, this system is expected to assist the Government of Tonga in the overall planning and effective management of its limited resources.

The establishment of the **TGD2005** and **TMG** was an output of the World Bank Project: Cyclone Emergency Recovery and Management Project (CERMP) .. Component B2: Land Hazards and Information Management, which was implemented by a Consortium of International Consultants during the period 2003 – 2007. The Consortium comprises of Consultants from Landcare Research New Zealand Ltd in association with Beca International Consultations Ltd and International Geological and Nuclear Sciences (IGNS) NZ Ltd.

A local Project Team was appointed amongst the staff of the MLSNR under the leadership of the Surveyor General, assisted by the Heads of the Geodesy Unit and the GIS Unit.

3.1 TGD2005 – DEFINITION AND REALISATION

The TGD2005 is defined and realised by the geodetic coordinates of a set of zero-order (continuous tracker) and 1st order GPS sites (stations) distributed throughout the islands of the Kingdom of Tonga and referred to the GRS 80 ellipsoid determined within the International Earth Rotation Service Terrestrial Reference Frame 2000 (ITRF2000) at the epoch of 1st of January 2005.

> ***[Note:*** *"A 1st order GPS survey will be required to determine the coordinates of the 1st order sites. These coordinates will be made as consistent as possible with the ITRF2000 reference frame by including regional or global IGS stations, with known ITRF2000 coordinates and velocities, in the analysis of the 1st order survey. Since the surveys to generate the 1st order coordinates will occur at times different from 1st January 2005, a velocity model for Tonga will be needed to project the coordinates from the time of observation to the 1st January 2005 epoch.*
>
> *The velocity model can in the first instance be constructed from existing GPS data collected for scientific purposes.*

Subsequent surveys between 1st order and lower order stations will be needed to extend the TGD2005 coordinates from the 1st order stations to other geodetic marks. Provided all these surveys are done over relatively short baselines, there will be no need to use a velocity model in the processing of these data."]

3.1.1 TGD2005 - Descriptions and Specifications

- The TGD2005 is the official geodetic datum of the Kingdom of Tonga to meet the requirements of spatial referencing for all of the country's land information needs including, but not exclusive to, mapping and cadastral surveying;

- In line with recommendations of the International Association of Geodesy, the TGD2005 is based on, and aligned with, the International Terrestrial Reference System (ITRS);

- Also in line with recommendations of the International Association of Geodesy, the TGD2005 is referred to the Geodetic Reference System 1980 (GRS80) ellipsoid. The two main reference ellipsoids in use internationally are:

WGS84 Semi major axis	6378137 m	Flattening	1/298.257223563
GRS80	6378137 m		1/298.257222101

  Note: the WGS84 and GRS80 ellipsoids have a very small difference in the inverse flattening, but this difference is insignificant for most practical applications.

- **The TGD2005 is a Geocentric Datum**

  The TGD2005 is based on the ITRF2000 and referred to the GRS80 ellipsoid of revolution.

  With a geocentric system based on space geodesy, the station positions are naturally represented as distances X,Y,Z in metres from the centre of the Earth. The Z axis points north along Earth's rotation axis; the X axis points through the equator at the Greenwich meridian; the Y axis points through the equator at 90ºEast. Origin of Geocentric Datum (3D Cartesian Coordinates System) is at the centre of mass of the Earth's gravity.

  Hence, either of the WGS84 or GRS80 ellipsoids could be used for transforming coordinates between (X,Y,Z) and (ϕ,λ,h) and vice versa, using standard transformation formulae.

- **The TGD2005 is a Static Datum:**

The TGD2005 is adopted in such a way that the geodetic coordinates of those zero-order and 1st order GPS sites (stations) that defined the datum are consistent with ITRF2000 at epoch of 1st January 2005 and remained fixed at these values.

Similar approach has been adopted by Australia under the Geocentric Datum Australia 1994 (GDA94).
Static (Australia & Tonga) Datum option has the advantage over Semi-Dynamic (New Zealand) Datum and Dynamic (PNG) Datum in a way that a Static Datum is the simplest for the general public and for users outside the survey profession, eg. GIS users. Static Datum is immediately applicable to cadastral survey system. Dynamic Datum is rarely used and it can be best used for scientific investigation purposes.

- **Velocity Model for Tonga**:

The motion for Tonga has been determined by geodetic GPS observations at the four main island groups of Tongatapu, Ha'apai, Vava;u and Niuas. The whole country, with the exception of Niuafo'ou, appears to be rotating clockwise as a rigid block about a point near (26ºS, 176ºW). The velocity of the country relative to ITRF is about 80 mm/year at Tongatapu, increasing to 190 mm/year at Niuatoputapu. Niuafo'ou is moving more slowly, about 60 mm/year, relative to ITRF.

3.1.2 Summary – TGD2005 Specifications: Terminology and Definition

- **Datum –** Tonga Geodetic Datum 2005 (TGD2005: a Geocentric & Static Datum)
- **Geographical coordinate set (ϕ and λ)** – Tonga Geodetic Datum (TGD2005)
- **Grid coordinates (Universal Transverse Mercator, using GRS80 ellipsoid)** – Tonga Map Grid (TMG)
- **Reference Frame** – ITRF2000 (International Terrestrial Reference Frame 2000)
- **Epoch** – 2005.0
- **Reference Ellipsoid** – GRS80 (Geodetic Reference System 1980)
- **Semi-major axis (a)** – 6,378,137.0 metres
- **Inverse flattening (1/f)** – 298.257222101

3.2 TONGA MAP GRID (TMG)

Prior to introduction of the new TMG in 2005, the national practice of surveying and mapping in Tonga was based on a modified UTM Zone 1 and survey marks which were determined by various methods and accuracies over the years.

The positions of some island groups were based on astronomical fixes during 1960's and some scaled from nautical charts. This has resulted in huge discrepancies in absolute

coordinates of up to 2.5 km which are recorded for some island groups, particularly for Niuatoputapu/Tafahi Islands in the northern part of the Kingdom.

In conjunction with the revision of the national geodetic datum, upgrade of the geodetic networks and introduction of modern positioning systems and requirements, it was considered timely to investigate and revise the UTM map grid system (TCSMG61) adopted for national mapping and recording of land information. But this essential component was partly done during the implementation of CERMP Component B2: Hazards and Information Management World Bank Project?

However, with regard to the establishment of the **Tonga Map Grid** (TMG) in 2006 together with the TGD2005, the following recommendations were investigated (against the TCSMG adopted in 1961 for the Cadastral Survey of the Kingdom of Tonga and also for the DOS Topographic Mapping of 1971 – 1975). As a result of that investigation, the TGD2005 and TMG were finally adopted in 2006, as follows:

3.2.1 Projection

The Transverse Mercator (TM) projection was retained and adopted for the establishment of the 2005 TMG.

The TM is the recommended projection for the conformal mapping of regions that have a predominantly north-south extent. The TM projection formulae and equations have been built in to all GIS software.

3.2.2 Reference Ellipsoid or Spheroid

The Global Reference System 1980 (GRS80) was adopted and replaced the International Spheroid 1910 used by the Cadastral Survey of the Kingdom of Tonga (1957 – 1962) and the DOS Mapping (1971 – 1975). This was in line with the proposed TGD2005.

3.2.3 Unit of Measurement

The Metre was retained as the unit of measurement.

3.2.4 Meridian of Origin

The 177º W meridian of origin (Central Meridian) for UTM Zone 1 was retained and adopted for the establishment of the TMG.

Retaining of the values of the central meridian and scale factor ensures that the relationship between the existing UTM Mapping grid

3.2.5 Latitude of Origin

The Equator is the latitude of origin for UTM Zone 1 was retained.

3.2.6 Scale Factor

The scale factor for the value of the CM of 177ºW for UTM Zone 1 is o.9996. This was retained by the TMG.

As most of the island groups lie between 176ºW and 173.5ºW the scale factor ranges from 0.09998 to 1.0010 with the scale factor in Tongatapu being approximately 1.0000.

3.2.7 False Coordinates of Origin

The false coordinates of the origin point of the TMG have changed from the current values (UTM Zone 1)of 500,000 m East to 10,000,000 m North to **1,500,000 m East and 5,000,000 m North.**

The change is to ensure that the new coordinate values are not to be confused with the UTM values and that positive values exist for all land and oceanic areas of the Kingdom.

3.2.8 Datum

The **Tonga Geodetic Datum 2005** (TGD2005) is the new datum for all future surveying and GIS & LIS development in the Kingdom of Tonga.

3.2.9 Tonga Map Grid – Summary of Characteristics

- **Map Grid** – Tonga Map Grid (TMG)
- **Projection** – Transverse Mercator (TM)
- **Spheroid** – Global Reference System 1980 (GRS80)
- **Unit of Measurement** – Metre
- **Meridian of Origin** – 177º West of Greenwich
- **Latitude of Origin** – Zero degree (0º Equator)
- **Scale Factor at Origin** – 0.9996
- **False Coordinates of Origin** – 1,500,000 m East; 5,000,000 m North
- **Datum** – Tonga Geodetic Datum 2005 (TGD2005)

3.2.10 Further Work

It was recommended by the Study Report 2: GeoSource Tonga Part 2 that *"the TMG be adopted for natural mapping and land information purposes and the TCSG61 be upgraded to the TGD2005. The parameters of a possible new TCSG61 should be investigated further following field surveys and an analysis of the relationship of the TCSD 57/61."*

The above recommendation clearly indicates the reluctance of the consultants to get involved on the real issues that MLSNR has faced for many years in respect of its pressing need to

having a single unified reference system that would be used as a rigid platform for subsequent integration of the Kingdom's fragmented survey and information records.

May be this was why the consultants scheduled the procurement of the geodetic and GIS equipment to a later stage of the project implementation?

4 STATUS OF SURVEY CAPACITY AND CAPABILITY

This Section provides the resources (human and physical) currently available in the Surveying and Geodesy Division of the MLSNR for the implementation of geodetic surveys.

4.1 SURVEY CAPACITY: HUMAN RESOURCES AVAILABLE

Like other establishments within the MLSNR, the Surveying and Geodesy Division is still handicapped and understaffed since the introduction and implementation of the so called Government's voluntary redundancy program in 2006. It was a pity to see that Tonga's most qualified and experience surveyors were on redundancies or asked to retire due to non-renewal of employment contract.

As a result, the Geodesy Unit and its fundamental roles and functions to be provided for the betterment of surveying and mapping practice in Tonga and abroad has had to be closed due to shortage of field surveying staff to complete outstanding cadastral surveying assignments. A service believed to be best and cheaply provided by locally trained technician surveyors under strict professional supervision of well trained professional surveyors.

Today however, the practice of surveying in Tonga is far from being recognised by professional and well educated surveyors. Those currently assuming the supervisory roles may need to undergo further CPD by attending relevant training courses in professional practice.

Currently, there is no specialist geodetic surveyor employed by the MLSNR in Tonga. Therefore, there is pressing need for one of the young graduate surveyors, preferable the one graduated from the Otago University, be immediately offered a scholarship to undertake further studies in geodesy at postgraduate level.

However, the current surveying capacity with respect to their respective levels of experience in geodetic surveying is listed as follows:

- One (1) Deputy Secretary (Surveying & Geodesy) – a surveying degree holder with about 30+ years of field survey experience in cadastral surveying. He is not interested in geodetic surveying – lack the visionary mission to lead his followers;
- Three (3) senior surveyors in the level of Principal Surveyors – graduated surveyors with about 25+ years of experience in field surveying: mainly cadastral and engineering surveys. Have had practical training in using GPS and all have done

projects involving RTK, static GPS and DGPS observations, processing of GPS observed datasets, analysis and adjustment etc.

- Two (2) recently graduated surveyors – one graduated from the Otago University School of Survey in New Zealand with some 8+ years of experience in surveying: cadastral, engineering and geodetic surveying. The second one graduated from USP and has had more than 10+ years of field experience in cadastral, engineering and geodetic use of GPS equipment – for RTK, static and DGPS observations and data processing etc.

- Three (4) locally trained technician surveyors with many years of field experience in cadastral surveying. They are very experienced instrument men and be trained to become GPS operators. Most are capable of producing high quality works under supervision.

- Four (4) survey trainee surveyors recruited at Form Seven level of attainments in relevant subjects. They are capable of being used as GPS hardware and software operators if introduce to modern state of the art GPS/GNSS and automated total stations equipment.

4.2 PHYSICAL RESOURCES AVAILABLE

The MLSNR in 2005 was fortunate to procure its first ever full GIS and Geodetic Surveying equipment, the latest in the market, under the World Bank's CERM Project Component B: Land Hazards and Information Management. The procured equipment and full accessories are as follows:

- **GIS Equipment – Hardware and Software**

  5x new GIS Workstations; 2 x new Geodetic Workstation; 3 x PC Computers; 6 x HP 9500 Workstations; 1 x GIS TOSHIPA Laptop Computer; 1 x Wiring/Ducting of computer systems; 5 x Esri ArcView 9.0 softwares and licenses plus Training Manuals; 1 x Window 2003 Fileserver, 750GB RAID array; 1 x A0 Fast Inkjet colour HP 550 Plotter; 1 x Hawk-Eye Cx 36 wide A0 Scanner; 6 x Computer Desks; and 6 x Swivel and Wheel Chairs.

  The GIS Unit started using the GIS facility and equipment since April 2006 for its spatial data capture campaigns.

- **Geodetic Surveying Equipment – Hardware & Software**

  3x Topcon geodetic survey graded GPS Receivers with accessories; 3 x e-Trek Handheld GPS Receivers; 2 x Total Stations with accessories; Additional accessories (metal detectors, survey tripods, sighting targets and prisms); PC Computers and Laptop; GPS Processing Software – Trimble Geomatics Office; many other Surveying Software packages etc.

5 GEODETIC CONTROL NETWORK UPGRADE

It was clear from the very beginning of the project implementation (CERM Project Component B2: Land Hazards and Information Management) that there would be further geodetic works required for the general upgrading of all the 10 island groups networks, starting from the 1st Order Control stations (Primary marks), 2nd Order Control stations (Secondary marks) and 3rd Order Control stations (Tertiary marks).

Reference: *Study Report 2: GeoSource Tonga Part 2: Report on the Development of a Geodetic Datum and Map Grid for the Kingdom of Tonga, December 2004, pages 20 – 23.*

5.1 OBJECTIVE

> "The objective of upgrading the geodetic network is to provide a single accurate homogeneous survey control framework as a rigid base for all future topographic, hydrographic, engineering, cadastral (land boundary) and land information surveys".

This will enable geographic information to be captured in terms of a common reference frame so that GIS information can be accurately compared and analysed.

Other than for capturing new information, the upgraded survey control marks will form the basis for converting or transforming existing land information into the new system.

5.2 UPGRADE CRITERIA

1) **Establish one primary (1st order) on each of the principal inhabited island groups.**

Each principal island group should have a 1st order geodetic station connected directly to both the existing geodetic stations with coordinates in terms of ITRF and other 1st order stations.

2) **Use existing survey control stations.**

This will enable comparisons with existing coordinates and allow the conversion of existing coordinate values and assist in the development of transformation parameters.

3) **Upgrade survey mark at the required density.**

Upgrade survey marks according to density of population, land use and land value.

4) **Existing survey data.**

Existing survey control traverse data can be used to recalculate TGD2005 coordinates in terms of the new datum.

5.3 UPGRADE REQUIREMENTS

1) Networks to be upgraded

With the exception of 'Ata Island Network, which was recommended to be upgraded by Converting the WGS72 Doppler coordinates to WGS84 coordinates using published transformation parameters and a geophysical site velocity model, all the geodetic networks on the other nine island groups be upgraded by observation. See list below.

Listed below are the island groups' network and the method recommended for upgrading the survey control:

- Tongatapu/'Eua ... Observe primary survey marks
- Ha'apai ... Observe primary survey marks
- Vava'u ... Observe primary survey marks
- Niutoputapu ... Observe primary survey marks
- Niuafo'ou ... Observe primary survey marks
- Fonualei/Toku ... Observe primary survey marks
- Late ... Observe primary survey marks
- Hunga Tonga ... Observe primary survey marks
- 'Ata ... Convert primary survey marks
- Minerva Reef ... Observe primary survey marks

2) Existing 1st Order Stations – Primary Marks

Listed below are 1st Order Stations whose geodetic coordinates provide the Primary Survey Control Framework for the Kingdom of Tonga. These survey marks were sited and installed in such a way to ensure that they are free from any possible future disturbance. These stations are as follows:

• Tongatapu	TGPU	Blowholes
	TONG	Nuku'alofa CGPS Base Station
	Leach Mark	East Tongatapu
• Ha'apai	OIP II	Leach Mark
• Vava'u	Two Marks?	
• Niuas	NTPT	Falehau Village, NTT
	NFOA	Niuafo'ou Airport, NF

The coordinates and ellipsoidal heights of these marks were determined directly from **other Primary ITRF GPS stations using high level GPS processing software.** In addition, these marks included the international GPS campaign marks such as the Nuku'alofa CGPS Base Station at 'Apifo'ou and the marks sited at the Niuatoputapu and Niuafo'ou Airports.

3) Second Order Geodetic Stations – Secondary Marks

These stations will act as (i) reference stations for the development of the tertiary survey control on each island/island group and (ii) act as GPS base stations for static and RTK observations.

4) Third Order Geodetic Stations – Tertiary Marks

These marks will provide the main survey control network and will include the upgrade of the Doppler network and Leach primary control.

The upgrade of 21 Doppler stations to 2nd Order Standards will provide control to readjustment of observational data inputs to the Doppler survey – 6 circuits: Niuatoputapu, Niuafo'ou, Vava'u, Ha'apai, Nomuka and Tongatapu/'Eua. This upgrading work will also include the astronomical origins of the 6 principal circuits.

The 3rd Order Network should provide geodetic control for the cadastral survey control traverses – Leach and MLSN Control traverses for the daily survey operations. These points will also be used to control and adjust existing survey control traverses to update the TCSG61 coordinates to TGD2005 and TMG.

5.4 PROPOSED EXECUTION PROGRAMME

Refer to **GeoSource Tonga Study Report 2 Part 3: Geodetic Network Design and Survey** - for the Network Design and proposed survey programme.

6 ISSUES AND THE WAY FORWARD

6.1 HIGHLIGHTING THE MAIN THRUST OF THE REPORT

The TGD2005 and TMG have both been established and adopted since 2006, refer to Section 3: Tonga Geodetic Datum 2005 & Tonga Map Grid. Section 4 of this Report looks at the Current Status of Survey Capacity and Capability of the MLSNR's Surveying & Geodesy Division. Section 5 of the Report provides the proposed Geodetic Control Network Upgrade – as per consultants' *Study Report 2 Part 2: Development of a Geodetic Datum and Map Grid for the Kingdom of Tonga* and the *Study Report 2 Part 3: Geodetic Network Design and Survey.*

However, it was recommended by the consultants that the Tonga Map Grid (TMG) be adopted for natural resources mapping and for land information and; the Tonga Cadastral Survey Grid 1961 (TCSG61) be upgraded to the requirements specified for the Tonga Geodetic Datum 2005 (TGD2005). Further it was also stated that the parameters of a possible new TCSG61 should be investigated further following field surveys and analysis of the relationship of the Tonga Cadastral Survey Datum 1957/1961 (TCSD57/61). *Refer to above mentioned Study Report 2 Part 2.*

Immediately following the above statement of recommendation, the consultants provided a proposal for the overall upgrading work of the national geodetic control networks needed for the above stated investigation. This proposed upgrading work comprises all the 10 independent island groups' networks that were established during the Cadastral Survey of the Kingdom of Tonga (1957 – 1962) and the DOS, UK Mapping Control (1971 – 1972).

Reference: Study Report 2: GeoSource Tonga Part 2 - "Report on the Development of a Geodetic Datum and Map Grid for the Kingdom of Tonga, December 2004. This proposed work is duplicated in "Section 5 – Geodetic Control Network Upgrade" of this Report. Furthermore, the consultants also proposed survey programme to address the remaining geodetic control network upgrade and this is presented under *Study Report 2 Part 3: Geodetic Network Design and Survey.*

Other than the above, Section 4 of this Report presents the Status of Survey Capacity and Capability currently available within the Surveying and Geodesy Division of the MLSNR. In here we can say that in-terms of physical resources available, the Division has got all the necessary tools to enabling them to complete the remaining upgrading work mentioned above. But for the Survey Capacity in-terms of the human resources currently available, we believe not all available surveyors have the fundamental understanding and experience on the process and there are caps that need to be polished and closed up before tackling the proposed upgrading work – obviously we need professional and highly educated surveyors who are fully prepared to lead the remaining troop and fight a winning war.

Given the above and in respect of the current situation of the surveying capacity and financial requirements that are needed for full implementation of the above proposed work, the following "Issues and the Way Forward" have been identified and proposed.

6.2 ISSUES AND THE WAY FORWARD

6.2.1 Issue No. 1: Lack of Human Resources

The aftermath of the voluntary redundancy program introduced by Government in 2006 to downsize the number of the public service employees has nothing positive to contribute to development services expected of the surveying and geodesy arm of the MLSNR but left a big scar that will take at least another 2 decades to heal.

All dedicated and highly qualified surveyors with long years of professional experience were either made redundant or asked to retire by non-renewal of employment contract.

Those that were made redundant included 1 x Deputy Surveyor General, 1 x Chief Surveyor, 1 x Principal Surveyor (Tongatapu District Office) and 1 x Principal Surveyor (Geodesy Unit) and all the established staff of the Geodesy Unit. Also, the MLSNR's CEO and the Surveyor General was asked to retire effective from 31st of December 2006.

Hence, the **Lack of Human Resources** has become and will continue to become a major issue for the Surveying and Geodesy Division to face for another 20 years or so. As you can see from the list of those that had left the MLSNR in 2006 – all the top and middle management levels of surveying and geodesy services were completely wiped off in 2006. And similarly, the Office of the Geodesy Unit was closed and since then used as additional space for land titles cadastral surveyors who were comfortable with the application of modern surveying tools/systems.

The Way Forward:

To address the **Issue No. 1: Lack of Human Resource**, we propose that the Surveying and Geodesy Division must have a Master Training Program (Long, Medium and Short Term) for all levels of its staff which should be included under the overall staff development strategic plan of the MLSNR – and this Master Training Program MUST be prioritise and endorsed by the Minister of Lands.

The Division must liaise with major International Institutions and Donor Agencies, such as NZAID, AUSAID, CFTC, British Council, JICA etc. to prioritise and provide financial assistance for all levels of training and education required for the development of the current and future staff of the Division.

Government must give top priority to MLSNR's requirements and the number of scholarships awarded annually to Degree Studies in Surveying at under graduate level be increased – to say at least 3 scholarships per year for the next 5 years. At postgraduate level, two scholars – preferably one in the complex area of Geodesy and one for Post Graduate Diploma in Survey Practice (Licensed & Registered Professional Surveyor) are now urgently needed for the overall management and control of the surveying and geodesy services provided by the MLSNR.

6.2.2 Issue No. 2: Lack of Relevant Professional and Technical Skills:

Lack of highly educated and well trained professional surveyors has always been a major issue in Tonga. No one in the current staff of the Division holds any postgraduate or professional qualifications in any relevant areas of surveying and geodesy. Of the six graduated surveyors holding senior positions in the Division, none has not being given the opportunity to go for further studies at postgraduate level or attended to any professional attachment training to become a registered professional surveyor.

As a result, the level of understanding and skills of the existing staff, at professional and technical levels, is totally absent and missed out in all aspects of modern professional practice of surveying and mapping. Some have opted to hold fast to the kind of practice that they were brought up with of being expert field technician surveyors.

It must be realised that the MLSNR has no specialist geodetic surveyor to look after the functions and roles of the Geodesy Unit, since the voluntary redundancy program of 2006. It must be noted also that the established staff of the Unit all joined the redundancy program and since then the office has been closed down.

Consequently, the modern geodetic state of the art total stations and GPS/GNSS equipment procured during the implementation of the World Bank's CERM Project Component B2 together with the set geodetic tasks (provided under Section 5 of this Report) to be completed by the Geodesy Unit were all handed over to the current management of the Surveying and Geodesy Division.

The Way Forward:

The current management of the Surveying & Geodesy Division should be asked to retire immediately from the public service and the position be advertised abroad for an expatriate professional surveyor to occupy, preferably on contractual basis, for a period of say 5 years.

All professional and technical staff members of the Division must be encouraged to attend regular CPD Short Courses in order to keep up-to-date with new changes in the technology and practice. Also, professional surveyors are encouraged to attend major international and regional conferences, seminars, symposiums, workshops etc. so as to update their knowledge in the modern practice of surveying and geodesy.

Selected Staff members should be given opportunities to further their education at postgraduate level in surveying and geodesy.

Organize local in-house "on-the-job" short course training schemes in specific application areas of surveying and geodesy, such as automated surveying using total station in combination with auto-cad & civil-cad software; GPS/GNSS training short courses etc. - for all professional and technical staff of the Division to attend.

6.2.3 Issue No. 3: Lack of Finance

This is another major issue that has always been faced by small island nations of the Pacific including Tonga. The national infrastructure development of the Kingdom of Tonga cannot be fully achieved without the financial assistance of international donor agencies through bi-lateral aid programs etc.

The Recurrent Budget provided annually by the Government is mainly for salaries, stationery and maintenance with very small allocation given for the services to be provided to the public. Therefore, the recurrent budget allocation is not enough to be used for the upgrading of the national geodetic reference network – which is not a priority area in the economic and infrastructure development of the nation.

The Way Forward:

The only viable option here or the way forward is to seek an off-shore donor agency through formulating another Development Project Proposal based on the necessity for the MLSN to complete the remaining and outstanding surveys required for the general upgrading of the Kingdom of Tonga's National Geodetic Reference Frame to in-line with the recommendations of the international institutions in Surveying and Geodesy.

6.2.4 Issue No. 4: Lack of Professional Leadership Quality

Lack of Professional Leadership Quality has been evidently and vividly displayed by the current management of the all the services provided by the Division of Surveying and Geodesy. This is attributed to the enforcement of the 2006 redundancy program, which was introduced to rationalise the size of the public service. It is a pity to

record here that all the key top and middle level management positions of the Division were completely wiped out.

Since then, the top level management position was given to the most senior surveyor in the remaining survey force. His style of leadership is far from being seen as a professional leader for the Surveying and Geodesy Division. His knowledge of professional practice is far from being recognised at international level.

The Way Forward:

New blood should now be introduced to take over and replace the top level management position for the Division of Surveying and Geodesy.

The replacement of the top level management should be a highly qualified professional surveyor, preferably a registered surveyor, or a highly educated surveyor with postgraduate degree in geodesy or geodetic science with industrial experience.

7 CONCLUSION AND RECOMMENDATIONS

7.1 CONCLUSION

7.1.1 Project Achievements: World Bank CERMP Component B2 (2003 – 2007)

A new modern geocentric datum and map grid system, known as the TGD2005 and TMG respectively, have both been established and adopted in 2006 to replace the previously established local non-geocentric datum and map grid, known as the TCSD57/61 and TCSMG61: established independently within each island group by astronomical observations and adopted for the Cadastral Survey of the Kingdom of Tonga (1957 – 1962) and extended further by the DOS UK Mapping Control (1971 – 1972).

The TGD2005 is defined and realised by the geodetic coordinates of a set of zero-order (continuous tracker) and 1st order GPS sites (stations) distributed throughout the islands of the Kingdom of Tonga and referred to the GRS 80 ellipsoid determined within the International Earth Rotation Service Terrestrial Reference Frame 2000 (ITRF2000) at the epoch of 1st of January 2005.

The TGD2005 and the TMG were established during the period 2003 - 2007, under a World Bank Cyclone Emergency Recovery Management Project Component B2: Land Hazards and Information Management, by a consortium of international consultants formed by Landcare Research NZ Ltd in association with Beca International Consultations Ltd and Nuclear Sciences NZ Ltd.

The specifications of the TGD2005: Terminology and Definition are as follows:

- **Datum –** Tonga Geodetic Datum 2005 (TGD2005: a Geocentric & Static Datum)
- **Geographical coordinate set (ϕ and λ)** – Tonga Geodetic Datum (TGD2005)
- **Grid coordinates (Universal Transverse Mercator, using GRS80 ellipsoid)** – Tonga Map Grid (TMG)
- **Reference Frame** – ITRF2000 (International Terrestrial Reference Frame 2000)
- **Epoch** – 2005.0
- **Reference Ellipsoid** – GRS80 (Geodetic Reference System 1980)
- **Semi-major axis (a)** – 6,378,137.0 metres
- **Inverse flattening (1/f)** – 298.257222101

The Characteristics of the TMG are as follows:

- **Map Grid** – Tonga Map Grid (TMG)
- **Projection** – Transverse Mercator (TM)
- **Spheroid** – Global Reference System 1980 (GRS80)
- **Unit of Measurement** – Metre
- **Meridian of Origin** – 177º West of Greenwich
- **Latitude of Origin** – Zero degree (0º Equator)
- **Scale Factor at Origin** – 0.9996
- **False Coordinates of Origin** – 1,500,000 m East; 5,000,000 m North
- **Datum** – Tonga Geodetic Datum 2005 (TGD2005)

Note: *The consultants recommended that the Tonga Map Grid (TMG) be adopted for natural mapping (GIS) and land information purposes and that the Tonga Cadastral Grid (TCSG61) be upgraded to the Tonga Geodetic Datum 2005 (TCD2005). The parameters of a possible new Tonga Cadastral Grid should be investigated further following field surveys and an analysis of the relationship of the existing Tonga Cadastral Datum (TCSD57/61) with the new Tonga Geodetic Datum 2005 (TGD2005).*

7.1.2 Recommended Further Works

Refer to **Section 5: Geodetic Control Network Upgrade** for detail information on the objective, upgrade requirements and the proposed Survey Programme which are all presented under *Study Report 2 Part 3: "Geodetic Network Design and Survey"*. Section 5 was duplicated from *Study Report 2 Part 2:"Development of a Geodetic Datum and Map Grid for the Kingdom of Tonga by M. Archbold, G. Smith, December 2004."*

7.2 RECOMMENDATIONS

Given this comprehensive Report on the Geodetic Infrastructure of the Kingdom of Tonga the following recommendations are submitted for your further deliberation and consideration:

1. That the identified issues and the way forward briefly discussed in Section 6 of this report be further deliberated and noted by this forum;

2. That this forum considers viable solutions for the various problems currently faced by Surveying and Geodesy Division of the MLSNR as identified in Section 6 of this Report;

3. That Geoscience Australia considers its input, through the Government of Australia Bi-Lateral Assistance to Smaller Island Nations of the Pacific, in order to complete the following outstanding geodetic survey tasks in the Kingdom of Tonga:

    a. Assign a Geoscience Australia's Geodetic Surveyor to re-evaluate the work done by the Beca International Consultants Ltd in conjunction with the establishment of the TGD2005 and the TMG (as an integrated or unified single system for the Kingdom), under Component B2 of the World Bank CERM Project 2003 – 2007;

    b. Train and supervise MLSNR's surveyors executing the proposed survey programme under Section 7.1.2: Recommended Further Works, as specified precisely under Component B2 of the World Bank CERM Project's Study Report 2 Part 3: Geodetic Network Design and Survey;

    c. Train and supervise MLSNR's surveyors establishing a reliable MSL Datum in each of the major populated island group of Tonga;

    d. Investigate the possibility of preparing a precise geoid map, based on the TGD2005, of the Kingdom of Tonga from a combination of different methods, such as Stokes Integrals, Satellite Altimetry on oceanic areas, Combination of GPS heighting & Geodetic levelling on land areas and from the latest Global Geopotential Model such as the GEM2008;

    e. Supervise postgraduate scholars doing project works for Masters or PhD Degree in Geodesy or Geodetic Surveying in one of the Australian Universities;

    f. Act as regional coordinator, advisor and auditor for any large scale geodetic surveys undertaken in the region or in any smaller island nations of the Pacific,

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