

# **Development of the Kingdom of Tonga Cyclone Emergency Recovery and Management System using Geospatial Tools**

**Malcolm ARCHBOLD, New Zealand and Sione Nailasikau (Naila) HALATUITUIA, Tonga.**

**Key words:** Tonga, Pacific, GPS, GIS, LIS, Cyclone, Disaster Management.

## **SUMMARY**

As a result of Cyclone Waka's estimated damage of USD 48m in December 2001 the World Bank IDA funded the Tongan Cyclone Emergency Management and Recovery Project (CERMP). One of the project components, Land Hazards and Information Management was established to improve the land information resources for preparedness and emergency response capability for the Government of Tonga.

Between 2004 and 2007 the Ministry of Lands, Survey and Natural Resources developed a geographic information system (GIS) to support cyclone emergency planning and disaster management. In addition to developing the GIS infrastructure the Ministry produced new 1:50,000 topographical maps and orthophotos using satellite imagery based on a new national integrated geodetic datum and map projection. The production of the topographical maps was undertaken by the Ministry staff in order to build capacity and resources.

In addition modern "state of the art" GIS software, computers and surveying equipment was procured followed by training and capacity building so that the Ministry staff could undertake a programme of data capture, editing and production of the topographical maps, resurveying principle survey stations in all of the island groups to define the new datum and map projection.

Since the completion of the project the Ministry has further developed the functionality of the GIS system by embarking on a programme to capture cadastral parcel boundaries to support land parcel information records and census processes. The intention is to further develop the GIS system so that it becomes the basis of a national land information system.

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## **1. INTRODUCTION**

The Kingdom of Tonga covers approximately 700,000 km<sup>2</sup> of ocean and comprises 171 islands of which approximately 40 are inhabited. The southwest Pacific region is highly prone to natural disasters, especially cyclones, volcanic eruptions and earthquakes. Tropical cyclone Waka struck the northern islands of Tonga in December 2001 and affected over 26,000 inhabitants. The government damage assessment estimated losses of USD 48m.

The Cyclone Emergency Recovery and Management Project (CERMP) funded under the World Bank IDA credit developed in the aftermath of Tropical Cyclone Waka. In March 2004 the Project Team were awarded the Emergency and Risk Management Capacity Building Component B.2. Land Hazards and Information Management. The client was the Ministry of Land, Survey and Natural Resources, Government of Tonga and the project was completed in June 2007.

In order to produce a modern land information system a new geodetic datum and map projection had to be designed using international standards and specifications. This would form the basis on which to build the spatial data and information such as digital topographical maps and geo-referenced (spatially correct location) satellite imagery. Prior to the project the Kingdom of Tonga did not have an integrated national geodetic datum. Existing maps, survey networks and land boundaries were developed using separate island survey networks based on independent datums at different times. Tonga's most recent national mapping was completed by the British Directorate of Overseas Surveys (DOS) in the 1960's. Twenty three map sheets were produced at a scale of 1:25,000 with each of the thirteen island groups being based on separate datums. Each datum origin control point varied greatly in positional accuracy from the modern GPS position by several hundred metres in most cases but over 4km at one island. This could have caused considerable risk if used in modern navigation systems.

The map projection used for the DOS mapping was the Universal Transverse Mercator (UTM) projection on the International (Hayford 1910) spheroid. Although the 23 topographical maps were excellent for the time and used innovative mapping techniques, they were outdated and in a format not suitable for digital reproduction. In addition, they were not spatially accurate in terms of the world reference system.

The mapping system to support the Cyclone Emergency Recovery and Management System proposed for the Ministry involved the development of Geographic Information System (GIS)

infrastructure, procurement of imagery and production of new topographical mapping. In order to base the GIS data on a modern reference system Tonga needed a new datum and map projection specific to its location and geographical extent. It also had to be developed in terms of the global mapping systems already use by other countries. The project also needed to build the knowledge and capacity of the Ministry staff, assist in the procurement of new equipment and survey procedures to replace the existing 1960's survey equipment and techniques, and establish robust systems and procedures that ensured knowledge transfer and capacity building would continue after the completion of the project.

## 2. DEVELOPING A GEODETIC DATUM

With the increasing use and benefits of positioning and surveying tools such as GPS, a modern geodetic datum on which to base a nation's spatial data infrastructure is fundamental. National land information structure such as a geodetic datum, map projection and standards are developed in terms of international specifications to allow the use of independent positioning techniques such as GPS by government, private and community users and the exchange of spatially correct information and data.

To meet modern survey standards and international best practice, Tonga has adopted a geocentric datum (origin at the centre of the Earth) based on the International Terrestrial Reference System (ITRS) defined by the International Earth Rotation and Reference System Service (IERS). The datum options available for Tonga were:

- To adopt a "dynamic" datum where the geodetic stations have coordinates that change with time. This approach has not been adopted anywhere in the world to our knowledge, except for scientific purposes.
- To adopt a datum where the coordinates at stations in Tonga are consistent with ITRF2000 at a particular epoch, say 01 January 2005, and remain fixed at these values. (A "static" datum.) This approach has been adopted by Australia, where the whole country moves uniformly with respect to the ITRF, but there is no significant internal deformation of the country.
- To adopt a datum where the coordinates of stations in Tonga are consistent at a particular epoch, say 01 January 2005, and remain fixed at these values from the point of view of the general public. However, survey professionals would use the known or modelled ITRF2000 velocities of geodetic stations in order to correct survey data collected at times before or after 01 January 2005 to that date. (A "semi-dynamic" datum.)

This approach has been adopted by New Zealand, because as well as motion relative to the ITRF there is complex internal deformation of the country. In order to recommend the most suitable option consideration of the tectonic plate movements was necessary. The motion of the island groups within the SW Pacific relative to the ITRF are relatively well known from scientific GPS surveys over the past decade. Tonga's tectonic movement has been determined by geodetic GPS observations and the whole country appears to be rotating clockwise as a rigid block about a point approximately 500km south of the southernmost island group. As the

velocity of the country varies in location from 80mm to 190mm/yr and there is little internal deformation, unlike New Zealand, there is less need to adopt a semi dynamic datum. Therefore it was recommended that Tonga adopt a static datum, based on ITRF2000 coordinates at 1 January 2005. The datum is defined by seven geodetic survey stations located on each of the five island groups. These seven stations were surveyed over a two year period by Ministry Survey staff using equipment procured during the project and training by the Consultant Team. The new geodetic datum has been officially named the Tonga Geodetic Datum 2005.

### **3. DEVELOPING A MAP PROJECTION**

In order to produce a scaled map in either hard copy or digital form, the spherically shaped Earth must be projected onto a plane surface (map projection). There have been many map projections produced internationally to best meet individual countries mapping requirements. Prior to the project Tonga had two map projections in use. These were the Universal Transverse Mercator (UTM) projection for topographical mapping and the Tonga Cadastral Grid for legal boundaries and land title surveys. The UTM projection was adopted by the US Army in 1947 for describing rectangular coordinates on large scale maps of the entire World. After consideration the Transverse Mercator projection was retained as this is the recommended projection for the conformal mapping of regions that have a predominately north-south extent (like Tonga) and uses standard equations that are supported by all GIS, survey and mapping software platforms. The existing UTM Zone 1 South projection could have been retained however confusion would have reined between modern and historical coordinates of similar values. Therefore it was recommended that new false coordinates of the origin point be adopted so that they are not confused with the UTM values and that there are positive values for all of Tonga's land and sea areas. The following are the parameters for the new datum and national mapping system:

Name: Tonga Map Grid; Projection: Transverse Mercator; Central Meridian: 177° West of Greenwich; Reference Spheriod: GRS80; Datum: Tonga Geodetic Datum 2005; Latitude of Origin: The Equator; Central Meridian Scale Factor: 0.9996; False Coordinates: 1,500,000 metres East and 5,000,000 metres North.

### **4. TOPOGRAPHICAL MAPPING**

To support the land information needs of a Cyclone Emergency Recovery and Management System the Ministry of Lands, Survey and Natural Resources developed a vision whereby the Ministry became a core government GIS service provider. This vision was:

*“GeoSource Tonga is the geographic information service of the Ministry of Lands, Survey, Natural Resources and Environment. It lies at the centre of a network of providers in the Kingdom of Tonga. It is the centre of excellence for core topographic, land resource, and cadastral data and GIS services, utilising up-to-date technology and skilled staff focused on the sustainable development and management of land (especially crown lands, parks, and*

*reserves), minerals, and energy, and the facilitation of spatial technologies throughout the Kingdom”*

Consultation with key stakeholders early in the project highlighted the need to establish GIS infrastructure within the Land Information Unit and production of key fundamental datasets. The key datasets identified were imaging (aerial photos/orthophotos) and topographical layers both of which were to be based on the new geodetic datum and map projection. It was decided that the national mapping be produced at a scale of 1:50,000.

Production of the national orthophoto imagery and topographical mapping involved the procurement of unrectified satellite imagery, photo identification of satellite imagery points for georeferencing, satellite image ortho-rectification, data capture from existing 1:25,000 topographical maps and digitising of topographical information from orthophotos. In a separate, but related workstream, geodetic GPS survey equipment was procured, surveyor training undertaken and a new national geodetic control network established.



Photo: Ministry GIS staff producing national topographical mapping data using GIS tools.

Rather than outsource the entire data capture and production of the 1:50 000 topographical mapping the decision was made that most of the Ministry staff would use the GIS tools and infrastructure developed to produce the mapping data. Despite it being a higher-risk alternative, the driving motive behind undertaking this work in-house was to maximise the learning by Ministry staff, to engender a sense of ownership in the result, and to build capacity in the Ministry to undertake such work in the future. This aim was substantially

achieved. The Consultant assisted in the "one off" complex tasks such as rectification of the satellite imagery and creation of the national 20m DEM based on the original 1:25 000 DOS topographical mapping.

The map-making process uses the cartographic tools of ArcGIS with the maps composed as ArcView (.mxd) workspaces. Data appearing on the maps are directly referenced back to the GeoSource Tonga database so that the two are synchronised and the maps being as current as the underlying data. Maps ready for printing are exported to .PDF format for ease of handling and speed of printing. At the conclusion of the project, eleven topographic map sheets were completed for the Tongatapu, Niua, Ha'apai and Vava'u Island Groups covering the entire country.



Sample of the 1:50,000 national topographical mapping produced by the Land Information Unit using Geospatial tools.

## 5. GEOSOURCE TONGA DEVELOPMENT

In addition to the topographical mapping a land information needs analysis based on a 5-year vision was completed, primarily of the Ministry of Lands Survey Natural Resources and Environment but including the National Disaster Management Office, Department of Environment and four other government agencies. The study identified a considerable breadth of stakeholder interest in the GeoSource Tonga facility and the possibility of utilising these data and the analytical capabilities of the system in a range of applications.

Four applications, of sub-project size (Land Parcel Database, Utilities Databases, Rural Water Database, and Coastal Erosion) were identified as being relevant to the Cyclone Emergency Recovery and Management Project. Due to the resource and funding constraints of the project these sub projects were to be consider for latter inclusion in the Ministry's Strategic Plan.

Since the completion of the project the Ministry has further developed the functionality of the GIS system by embarking on a programme to capture cadastral parcel boundaries to support land parcel information records and census processes. The intention is to further develop the GIS system so that it becomes the basis of a national land information system. This direction supports Pacific regional initiatives such as the Land Management and Conflict Minimisation Project and the Pacific Urban Agenda.

GeoSource Tonga has developed the GIS infrastructure, a national topographic mapping and imagery for the Kingdom of Tonga and created the fundamental base spatial datasets upon which to further progress national planning objectives to support future economic and social development.

## REFERENCES

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## BIOGRAPHICAL NOTES

**Malcolm Archbold** is the General Manager, Geospatial, Beca, Auckland New Zealand. Malcolm graduated from the University of Otago and has lived and worked in Papua New Guinea, New Caledonia and New Zealand. He has also worked in Antarctica and was part of the UN Survey Team involved in demarcating the border between Iraq and Kuwait in 1991. Malcolm is a Licensed Cadastral Surveyor, Registered Professional Surveyor and an Executive Committee Member of the NZ Spatial Industry Business Association (SIBA). He is also on the Executive Committee of the NZ Pacific Business Council.

**Dr Sione Nailasikau (Naila) Halatuituia** is the Secretary for Lands, Survey, Natural Resources & Environment, Kingdom of Tonga. Naila completed his PhD Thesis titled Tonga's Contemporary Land Tenure System: Reality and Rhetoric School of Geosciences, University of Sydney, 2002. He is the SPC Consultant for the Pacific Land Initiative (Pacific Urban Agenda & Land Management & Conflict Minimisation), National Representative for SOPAC, and Commissioner, Tongan Royal Constituency Boundary Commission 2010-2014.

## CONTACTS

### **Malcolm Archbold**

Beca  
P.O. Box 6345  
Auckland 1141  
NEW ZEALAND  
Tel. +64 9 300 9247  
Fax + 64 9 300 9300  
Email: malcolm.archbold@beca.com  
Web site: www.beca.com

### **Sione Nailasikau (Naila) Halatuituia**

Ministry of Lands, Survey and Natural Resources,  
P.O.Box 5  
Nuku'alofa  
TONGA  
Tel: +676 23210  
Fax: +676 23216  
Email: [halatuituia@gmail.com](mailto:halatuituia@gmail.com)  
Web site: www.lands.gov.to