Positioning Infrastructures for Sustainable Land Governance

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Key words: Geodetic Datums, Positioning Infrastructure, Land Governance, GPS, GNSS.

SUMMARY

This paper traces the evolution from the concepts of Geodetic Datums to Positioning Infrastructures and their relevance to the parallel evolution of the concept of Land Governance. A geodetic datum describes positions in three dimensions and underpins all of what we now call geo-spatial information. The concept of a Positioning Infrastructure is based on Global Navigation Satellite Systems such as GPS and extends to the ground infrastructure used to improve the accuracy and reliability of GNSS positioning for users. The paper outlines three broad roles for a modern Positioning Infrastructure, from the traditional function of supporting surveying and mapping processes, to enabling the monitoring of global process such as those associated with climate change and extending to real time precise positioning services employed in industries such as agriculture through precision farming. The paper concludes by outlining how Positioning Infrastructures will enable new approaches to Land Governance in the future and contribute to United Nations and World Bank goals such as reducing hunger and poverty, improving environmental sustainability, managing disasters and responding to climate change.

1. THE TRADITIONAL CONCEPT OF A GEODETIC DATUM

Historically, in fields such as surveying, cartography, cadastre and land administration, the term *Geodetic Datum* has been widely used. A geodetic datum enables accurate location of features anywhere on earth through a mathematical model that describes the origin, orientation and scale of coordinate systems. In its broadest sense, a geodetic datum describes positions in three dimensions as *latitude, longitude and height*. As such a geodetic datum underpins all of what we now call geo-spatial information.

In practice and again historically, most usage differentiates between the Horizontal Datum for latitude and longitude and the Vertical Datum, for heights. For many practical purposes, such as topographic maps and engineering projects, Vertical Datums need to depict heights above *mean sea level*.

From a user's perspective, the typical public face of a geodetic datum is a set of so-called *permanent survey marks* spread across the ground in the area of interest, along with a set of published latitudes, longitudes and heights for those marks.

It should also be noted that the scope of geodetic datums can vary from very local in nature to national and regional in nature. An increasingly important trend is to refine existing national and regional datums to be compatible with and/or even coincide with the global geodetic datum.

The widespread use of the Global Positioning System (GPS) has led to the geodetic reference frame used for GPS, known as WGS84, being seen by many as a proxy for the global geodetic datum. However, an approach based on a particular satellite system from a particular country has problems in a global context. Therefore, in modern geodetic best practice, a global geodetic datum is realized as closely as possible to the definition of the International Terrestrial Reference System (ITRS). A realization of the ITRS that is now widely recognized by the scientific community and an increasing number of national mapping organizations is the International Terrestrial Reference Frame (ITRF).

The characteristics of the typical approach to geodetic datums up until recently can be summarized as:

- Coverage was initially characterized by very local coordinate and height systems giving way over time to more national and continental coverage;
- Measurement processes historically involved ground based, labor intensive geodetic surveying techniques, giving way in recent decades to increased use of satellite positioning techniques, such as the USA's Global Positioning System (GPS) and its forerunners. The use of GPS has led to significant productivity increases in establishing and maintaining geodetic datums. It should be noted that GPS is now becoming part of a systems of systems under the umbrella term of Global Navigation Satellite Systems (GNSS). GNSS includes GPS but extends to Russia’s almost complete system, GLONASS and planned systems from Europe (Galileo) and Compass (China). For a recent description of GNSS developments see Rizos (2008);
- Outcome was typically focused on producing coordinates and heights on permanent survey marks in the ground with subsequent surveys using those marks to propagate coordinates. When GPS surveying came along it was simply applied as a measurement tool inside the existing approaches, focused on permanent survey marks as the outcome;
- Data capture and maintenance was initially done in a very analogue way. That has moved over time to be more in line with the concepts of Spatial Data Infrastructure (SDI), to include computerized data bases, access mechanisms, standards etc.

1.1 The Role of Geodetic Datums in General

Some typical traditional roles for a geodetic datum (excluding those in support of Land Administration) include:

- Mathematical control of local mapping projects and a broadening of scope over time to supply control for National topographic mapping on land and hydrographic charts in coastal waters and waterways;
- Control for other land surveys for cadastral, engineering and topographic applications extending to regional and national infrastructure projects requiring consistent heights and coordinates;
- Support to the emerging concept of Spatial Data Infrastructures and the need to underpin the many other geospatial data sets involved.

1.2 The Role of Geodetic Datums in Land Administration Systems To Date

The initial and still typical role for a Geodetic Datum in Land Administration was in support for Cadastral Surveying and Mapping. In cadastral surveying, for some jurisdictions the influence of the Geodetic Datum has been minimal, while in others it has been more integral through concepts such as the "coordinated cadastre".

In cadastral mapping, the typical scale of the mapping has been such that the demands on the Geodetic Datum have been more about achieving uniformity than about high levels of accuracy and reliability. This is now manifested in many parts of the globe where digital cadastral data bases (DCDBs) based on digitizing paper cadastral maps, do not have sufficient accuracy to be used for other purposes, such as the management of more accurate engineering and utility information.

As Land Administration evolved through the "multi-purpose cadastre" to include land planning and use and valuations, there were links to the concept of Spatial Data Infrastructure (SDI) and the role of the Geodetic Datum extended accordingly.

Recent trends of relevance to Land Administration have seen the emergence of more efficient and cost effective solutions for cadastral and other surveys that are often enabled by GPS and its ability to easily work directly in the Geodetic Datum.

2. FROM GEODETIC DATUMS TO POSITIONING INFRASTRUCTURES

The primary components of the Positioning Infrastructure are the GNSS satellite constellations themselves. In fact, GNSS could be considered as one of the only truly global infrastructures, in that the base level of quality and accessibility is constant across the globe.

Even so, a "single point position" using a standalone GNSS receiver has a typical accuracy of a few metres and under the wrong conditions, accuracy can be worse than 10m. Therefore, many GNSS users require improved accuracy or improved reliability and many require both. Improving accuracy and reliability requires so called "augmentation systems" using ground infrastructure such as Continuously Operating Reference Stations (CORS). Therefore, the term "Positioning Infrastructure" used in this paper includes both the fundamental satellite systems and the CORS Networks that augment those systems.

2.1 The Broad Role of Positioning Infrastructures

The concept of a modern Positioning Infrastructure still supports the activities traditionally associated with a geodetic datum but extends to much broader roles on the global stage. The roles of a modern Positioning Infrastructure can be grouped into three main categories:

a) Continuation of the traditional role of a Geodetic Datum in support of surveying and mapping activities;

b) Realization of the value of a stable geodetic reference frame for precise measurement and monitoring of global processes such as sea level rise and plate tectonics;
c) Extension to the concept of a true infrastructure that underpins the explosion in industrial and mass market use of positioning technology.

These three roles are now discussed in more detail.

2.1.1 Continuation of the traditional role of a Geodetic Datum

There is a still a need to support the traditional roles of a geodetic datum in surveying and mapping. However, the role is extending beyond the traditional professional domain of a surveyor or cartographer to the general public, who are becoming more and more spatially aware and more and more spatially enabled.

Traditionally, the geodetic datum has been realized through the placement of permanent survey marks and carrying out surveys to generate accurate latitudes, longitudes and heights for those marks. A global trend during the last decade has seen Continuously Operating Reference Stations (CORS), using Global Navigation Satellite Systems (GNSS) technology, complementing and/or replacing Permanent Survey Marks as a means of realizing and delivering the geodetic datum.

A significant issue for current and future geodetic datums is that traditional and new users of geospatial data seem to have a never ending hunger for better and better quality. That requirement for better geospatial data applies across several aspects including accuracy, reliability and access. The requirement for increased accuracy is especially important in the context of a geodetic datum, because the accuracies required of the data in many end-user applications are reaching the centimetre level. If users need centimetre accuracy then the underpinning geodetic datum needs to be defined, realized and maintained with millimetre accuracy.

Achieving such high levels of accuracy across broad coverage areas is a very challenging task but can be achieved using modern satellite positioning technology. It requires high quality networks of GNSS CORS, which enable very efficient establishment and maintenance of the geodetic datum at the millimeter level.

The ability of CORS networks to enable rapid establishment of a high quality geodetic datum is especially relevant for developing countries. Such networks enable a leap-frog approach similar to that seen in telecommunications where a developing country goes from having limited and unreliable telecommunications infrastructure based on land lines to a state of the art mobile phone infrastructure based on the latest digital wireless technologies.

2.1.2 Measurement and Monitoring of Global Processes

The growing use and propagation of CORS based on GNSS as a key component of a modern geodetic datum has also enabled a revolution in the ability to measure and monitor global processes. This aspect of a modern geodetic datum can be seen in the concept of Global

Geodetic Observing System (GGOS), which is being developed under the auspices of the International Association of Geodesy (a sister organization of FIG).

GGOS is enabling greatly improved measurement and monitoring of global processes such as:

- Changes in sea level due to global warming;
- Changes in various layers of the atmosphere over the short term (e.g. assisting weather prediction) and over the long term (e.g. greenhouse gas concentrations or ozone depletion);
- Changes in the planet's overall water storage, either as liquid in the oceans, as vapour in the atmosphere or as ice at the poles;
- Changes in ground cover through desertification or deforestation;
- Changes in the earth's crust as motion, uplift or deformation and including plate tectonics;
- Applying some or all of the above change detection capabilities to disaster monitoring and management, including earthquakes, tsunamis, floods, cyclones and hurricanes.

A key concept in better understanding the global processes outlined above is that a highly stable and accurate geodetic reference frame is required to ensure the quality of measurements at a given instant and the repeatability of measurements over the longer term.

A simple example of this concept is that it is difficult to be confident of millimeter quality measurements of sea level rise using a tide gauge, when the wharf on which the tide gauge is mounted could be subsiding; is it sea level rising or the wharf sinking? To address this problem, the state of the art approach to monitoring sea level rise is to use continuous GNSS measurements at the tide gauge to monitor its height relative to a reference frame that is highly stable over time. That long term stability is achieved by connecting the GNSS measurements at the tide gauge to the national and global CORS network.

2.1.3 Extension to the Concept of a Positioning Infrastructure

The third and most recent trend is to begin to see these networks of continuously operating GNSS reference stations as a Positioning Infrastructure. In coming years the Positioning Infrastructure will come to be seen as the fifth infrastructure after water, transport, energy, and telecommunications. Like those others, the Positioning Infrastructure will increasingly be seen as a critical infrastructure for society's triple bottom line.

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The transition from Geodetic Datum to Positioning Infrastructure can be traced through the stages described below.

The use of GNSS reference stations to enable real time precise surveying began in the mid 1990s and has become a well accepted technique for highly efficient and accurate surveying tasks. In its simplest form, real time GNSS surveying involves establishing a high quality GNSS receiver at a known location and “referring” all measurements to that “reference station”. The reference station calculates corrections to the orbits, ionosphere and troposphere and then broadcasts those corrections to another “roving receiver” that is measuring the points of interest for the survey. Such systems often use dedicated radios to broadcast the corrections from the reference station to the user’s receiver. Due to the mathematics required to derive the corrections, reliable centimetre accuracy from a single reference station is typically limited to users within a radius of 15 to 20km.

After the single reference station approach, the next logical step was to develop a network of CORS and calculate the corrections based on the multiple stations surrounding the users. In this approach data from all the reference stations are brought together in a central computer, which models the errors in the orbits, ionosphere and troposphere across the entire network area. The mathematics behind deriving those models with centimetre accuracy currently requires placing reference stations across the area of interest at a maximum spacing of 60 to 70km. Therefore the network approach can cover large areas of land with fewer reference stations compared to the 15 to 20km radius limit with the single station approach. Real time surveying using a CORS network has also been found to be more accurate and more reliable than using a single station.

It should be noted that while Positioning Infrastructure described here is designed to deliver centimetre accuracy to users, it can also deliver lower accuracies (e.g. decimetre to one metre), depending on the level of sophistication of the equipment employed by the user. This is analogous to one type of mobile phone allowing only voice and text messaging capability while another can do that plus other capabilities such as internet browsing but both phones connect to the same underlying telecommunications infrastructure.

The ideal way to transport the data required in modern real time precise positioning is to link the Positioning Infrastructure to a modern telecommunications infrastructure:

- Broadband internet, in the case of retrieving the reference station data to the central control and processing centre, and;
- Wireless mobile phone technologies based on Internet protocols in the case of delivering correction data to the users.

Therefore, the development of Positioning Infrastructure can be very synergistic to the development of telecommunications infrastructure.

An interesting by-product of having users of the Positioning Infrastructure directly connected to the Internet and reliably located is that it opens up the possibility for all sorts of data exchange in both directions. Such information could be tailored not only to the user’s application but also to their location.

Another important characteristic is that in many countries we see a mix of government and private sector involvement, such as a government deploying the reference stations and the private sector delivering value added services to users. Higgins (2008), outlines a model for understanding and agreeing the roles of various organizations from specifying and operating the Positioning Infrastructure through to delivering the services to users.

While the above description of the nature of Positioning Infrastructure and of its roots in surveying is useful background, the most important facet from now on is the rapidly growing market for precise positioning outside surveying.

Precise positioning is now enabling heavy machinery to be guided in a way that delivers significant productivity gains in key industries such as agriculture, construction and mining. Higgins (2007) gives details of some examples from Queensland, Australia, demonstrating the economic benefits that can accrue to those industries from precise positioning:

- 30% productivity increases in several key activities in the mining industry;
- Significant increases in yield and reductions in input costs through precision agriculture using GNSS enabled auto-steer and controlled track farming techniques. For example, recent studies in Australia are demonstrating fuel savings as high as 52% from controlled track farming;
- 30% time reduction in major civil engineering and construction projects, along with 10% reduction in traffic management costs and 40% reduction in lost time injuries.

Allen Consulting Group (2008), has found that in agriculture, construction and mining alone, productivity gains have the potential to generate a cumulative benefit to the Australian economy of between $73 billion and $134 billion over the next 20 years.

The study also found that a coordinated roll-out of a national network of GNSS reference stations across Australia (as opposed to leaving it solely to market forces) would increase the total uptake and the rate of uptake, providing additional cumulative benefits of between $32 billion and $58 billion (gross) to 2030.

The productivity gains possible in agriculture, construction and mining and enabled by a Positioning Infrastructure also contribute to significant environmental benefits. For example, in controlled track farming of wheat, fuel efficiencies have been estimated to reduce carbon footprint by 89kg of CO^2 equivalent gases per hectare. Significant amounts of carbon are also produced in the manufacture of fertilizers and pesticides. Therefore, reduced usage of fertilizers and pesticides along with unreleased carbon through less soil disturbance means that controlled track farming could reduce overall emissions of CO^2 equivalent by as much as 300kg/Ha (Tullberg, 2008). Besides carbon footprint, there are also significant additional environmental benefits through minimization of fertilizer and pesticide use.

3. CONCLUSION: THE ROLE OF POSITIONING INFRASTRUCTURES IN SUSTAINABLE LAND GOVERNANCE FOR THE FUTURE

Enemark (2008), summarizes the key challenges of the new millennium as climate change; food shortage; energy scarcity; urban growth; environmental degradation; and natural disasters. He points out that in the future these issues related to Land Governance and Management are going to be the core area for surveyors; the land professionals. In so doing, Enemark also states that this requires:

> *"high level geodesy to create the models that can predict future changes and modern surveying and mapping tools that can control implementation of new physical infrastructure and also provide the basis for the building of national spatial data infrastructures; and finally sustainable land administration systems that can manage the core functions of land tenure, land value, land use, and land development".*

A modern Positioning Infrastructure as outlined in this paper can and should underpin all of the issues Enemark has outlined. Some specific aspects of the role of Positioning Infrastructures in future Land Governance and in the context of developing countries include:

- A facilitation of much broader spatial enablement across society through trends such as the rapid uptake of GNSS capabilities in mobile phones. It is estimated that the global sales figures for GNSS capable mobile phones will reach 400 million by 2011. This trend is already particularly evident in countries such as India and China and will extend to many other developing economies in the coming decade;
- Real time communications being a requirement of a modern Positioning Infrastructure enables the possibility of real time processes in Land Governance. It is conceivable that within a decade mobile phone technology with embedded GNSS capability will allow decimetre accuracy positioning. That coupled with the mobile connection to the Internet will enable the positioning, adjudication and recording of property rights to be carried out in real time;
- Precision guidance of earth moving machinery, enabled by the Positioning Infrastructure, can greatly increase the efficiency of construction of hard infrastructures such as water, transport, energy and telecommunications. Positioning Infrastructure can also greatly enhance the efficiency of ongoing maintenance issues. This is especially true for large projects in rural and remote areas and significant for the World Bank, given that the development of rural infrastructure constitutes a substantial and growing component of Bank activities (World Bank, 2009).
- Practices like precision agriculture can greatly increase profits, and yield and decrease fuel, chemical and water use. Therefore, the Positioning Infrastructure can underpin and contribute to broader United Nations and World Bank goals such as reducing rural hunger and poverty, responding to climate change and improving environmental sustainability;
- Finally, an increased understanding of global change and disaster management issues enabled by the Positioning Infrastructure can now be factored into long term decision making on land use, planning and tenure security. Perhaps more importantly the

Positioning Infrastructure allows much more effective monitoring of and response to the impacts of those decisions into the future.

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BIOGRAPHICAL NOTES

Matt Higgins is Principal Survey Advisor with the Department of Natural Resources and Water in the Queensland Government, Australia. He holds Bachelor and Masters Degrees in Surveying. From 2007 to 2010, Matt is a Vice President of the International Federation of Surveyors (FIG). He is also the FIG representative on the UN mandated International Committee on GNSS where he Co-Chairs Working Group D on "Interaction with national and regional authorities and relevant international organizations". In 2008, Matt was elected President of the IGNSS Society. Matt is a past member of the Editorial Advisory Board of GPS World Magazine and a Fellow of both the Institution of Surveyors and the Spatial Sciences Institute in Australia. At the 2005 Asia-Pacific Spatial Excellence Awards, Matt received the award for "Professional Eminence and Excellence in the Spatial Sciences". The award is the SSI's highest form of recognition for professional eminence.

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