Impact of GPS on National Mapping Organisations

Yola Georgiadou
Associate Professor
Division of Geoinformatics and Spatial Data Acquisition
International Institute of Aerospace Survey and Earth Sciences (ITC)
Hengelosestraat 99, POB 6, 7500 AA Enschede, The Netherlands
georgiadou@itc.nl

Summary

A National Mapping Organisation (NMO) is among other things the custodian of the National Spatial Reference System (NSRS). To fulfil their role as custodians of national spatial reference systems in a new technological and political environment, NMOs are increasingly moving away from traditional geodetic networks and implementing national spatial reference infrastructures by taking full advantage of GPS–based active control system technologies. In some cases, they leverage this investment by cooperating with other government departments and the local industry on a partial cost recovery or cost-sharing basis.

In developing countries, the proliferation of land record modernisation programmes funded by international lending organisations exercises an additional pressure on NMOs to modernise their national spatial reference infrastructure. The long term success of land record modernisation programmes depends to a large extent on the updating strategies of the underlying digital cadastral databases through coordinated cadastral surveys. Therefore, the success of the programmes depends largely on the ability of NMOs to provide the surveying community with efficient and effective access to a spatial reference infrastructure. Some NMOs in Latin America have made their choice regarding NSRS implementation, while others are still exploring their options in cooperation with local academia and the geomatics private sector. Sustainable change requires rethinking of the technical processes related to the delivery of the NSRS to the user community and an appreciation of the changing perspectives of the stakeholders.

Introduction

A National Spatial Reference System is a reference of the highest accuracy that allows the combination and interchange of diverse spatially related data. It forms the fundamental layer of a national spatial data infrastructure and provides for common referencing of geographic information in a country. One of the roles of a NMO is to maintain, improve and facilitate efficient user access to the NSRS. To facilitate user access to the NSRS and ensure consistency in reporting the accuracy of position information obtained during the collection of spatial data, NMOs should also provide spatial positioning accuracy standards (FGDC 1998). Until recently, national spatial reference systems have been materialised through geodetic control networks in support of survey and mapping activities.

In section 1 we summarise the new operating environment within which NMOs around the world must fulfil their mandate as custodians of the NSRS. We refer to specific strategies adopted by the National Geodetic Survey of the United States and the Geodetic Survey of Canada to exploit opportunities and counteract threats. In section 2 we discuss the importance for economic growth of land record modernisation programmes, funded by international lending organisations in developing countries. We review related developments in Latin America and argue that the success of the programmes depends largely on the ability of NMOs to provide the professional community with access to a modern spatial reference infrastructure.

1 The new operating environment for NMOs and related strategies

The impact of GPS technology on NMOs cannot be considered in isolation from other external forces. Only through consideration of all factors can we gain an understanding of the required new strategies to enable the transition from traditional geodetic control to globally consistent national spatial reference systems. These factors are GPS technology, the growing Active Control System (ACS) market, the changing political environment and the changing perspectives of the primary stakeholders of NMOs.

1.1 External forces

GPS technology. GPS can be utilised in different fashions (Lee 1993) for a growing variety of applications with varying accuracy requirements: (Table 1)

- As a real-world three-dimensional digitiser, where the GPS receiver is the digitiser cursor, while the earth is the digitising table. Point mode digitising is like static GPS positioning. Stream mode digitising is like kinematic GPS positioning,
- To aid data retrieval and analysis by answering questions such as: Who owns the piece of land I am standing on? What is the soil type at this point? What is the best crop to grow at this point?
- For tracking moving objects either when the GIS is moving with the object (electronic charts, electronic maps) or when the GIS is stationary (fleet management, vehicle dispatching),
- For ground control and truthing.

Accuracy	Geomatics	Land	Marine	Airborne
<20 cm	Geodetic control Fault monitoring Construction surveys Engineering Surveys Geodynamics	Earth moving Road grading Agriculture Mining	Dredging Pylon positioning	Cat II/III Flight instrument
0.2 – 1.5 m	Resource mapping ITS database GIS Utility mapping Highway surveys Legal surveys	Facility surveys Mapping/GIS Highway surveys AVLS trains Precision farming	Rig positioning Docking Charting Buoy Position Seismic surveys	Precision approach Cat I
1 – 5 m	GIS data collection One-call Photo control Navigation Site specific farming	AVLS Automobiles AVLS emergency AVLS public Transport AVLS tracking Farming	Channel navigation Cabling Research Ship trials Harbour entry	En route Oceanic Initial Approach Runway Incursion
10 – 20 m	Reconnaissance	ITS navigation Area navigation	Harbour approach Oceanic	En route

Table 1: GPS positioning accuracy and applications. After Beck (1996)

GPS technology for monitoring and maintaining the International Earth Rotation Service (IERS) International Terrestrial Reference Frame (ITRF) has continued to rapidly expand its scope and improve its accuracy (IERS 1996). The ITRF is now the de facto worldwide standard for GPS. The station coordinate set for the World Geodetic System 1984 (WGS–84) has been adjusted to be compatible with the ITRF at the few cm-level. The accuracies and global accessibility of the IGS products are sufficient to support establishment of globally consistent, continent-wide and homogeneous reference systems linked to the ITRF (Gurtner 1993). High accuracy coordinates referenced to a global reference frame help ensure that continent-wide reference systems are characterised by a seamless relationship for mapping within and between countries.

To realise the benefits of uniformity in continental reference systems accurately linked to the ITRF, users should ideally have access to services that are economical and technically adequate as well as traceable and sustainable well into the future. Governments are meeting this need by establishing permanently operated full-coverage and multi-functional GPS augmentation services. When properly implemented, unlimited number of users at the same time can access the service and thus, determine coordinates referenced to the standard of a continental and/or national spatial reference system.

GPS augmentation services are distinguished by their area of applicability, methodology, availability, the data communication link, user interface requirements and format for the real-time data. The availability of nationally coordinated real-time GPS augmentation services can help ensure that users determine coordinates accurately referenced to a common geodetic reference system.

Although access to national spatial reference systems via GPS data products is achieved today in post-processing mode, wide use and acceptance will occur once real-time access is widely and seamlessly available. Ideally the GPS augmentation information should be available over as wide an area as possible, in a universally applicable methodology and format to support a full range of positioning accuracies. Wireless communication is a key enabling technology to make this happen. Much development activity is currently taking place to make real-time augmentations accessible, seamless, reliable and affordable.

ACS market. Overall usage and application of GPS/DGPS technologies are increasing as equipment costs drop and measurement quality improves. The worldwide ACS market is projected to grow over 16% per annum as control networks are evolving from traditional physical monumentation-based to real-time, active control networks.

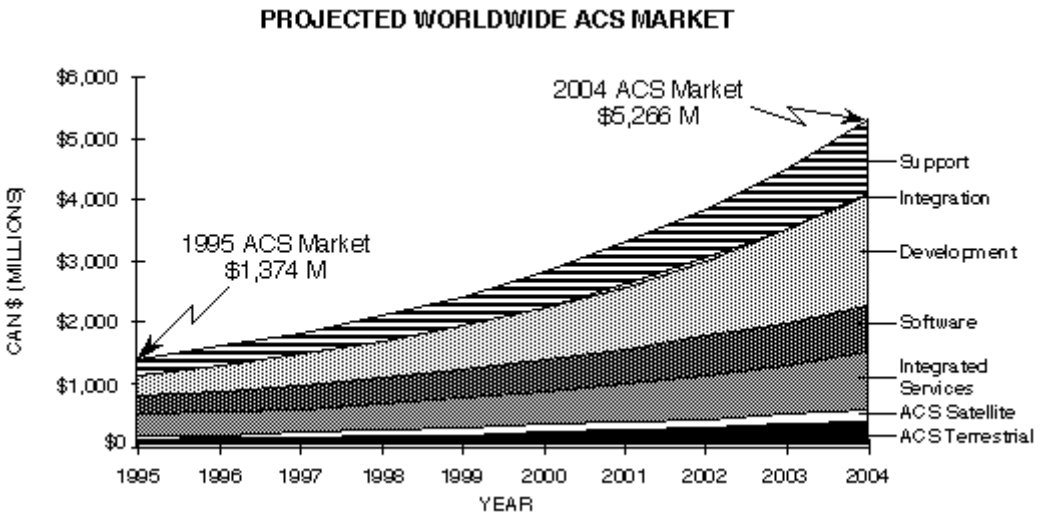

Figure 1: Projected worldwide Active Control System market. After Booz, Allen and Hamilton (1995)
Note: GPS product sales are not included

Accordingly, NMOs assume the role of developing ACS technology, in cooperation with academia, other government departments and transfer to the private sector for the implementation of applications (ibid.).

Political environment The pressure on governments around the world to halt the further growth of deficits and/or to decrease foreign financial aid compels NMOs to deliver their mandates with decreasing budgets (Groot 1998). Budget constraints require concentration on key, 'value-added' capabilities and more business-like operations (entrepreneurial government). Recovering some percentage of costs via sales of product and services is becoming increasingly popular. New regulatory frameworks, monitored by public relevancy tests, establish non-compete clauses with the private sector. Moreover they encourage the leveraging of technologies and expertise into the local industry.

Stakeholders Entrepreneurial government entails monitoring the relevance of NMOs products and services by polling the major clients and stakeholders. Table 2 summarises the replies of major stakeholders' groups in Canada to the question 'How integral are Geodetic Survey Division (GSD) activities to delivering your organisation's mission?'. The stakeholders include industry, academia, federal and provincial government departments, foreign governments and the managers of the Geodetic Survey Division. Table 2 is a representative example of the changing needs of the client/stakeholder community. The shift in the stakeholders' perspective towards space-based positioning and away from monumented networks is truly remarkable.

Geodetic Survey Division (GSD) Activity	Industry	Academia	Federal Gov't	Provincial ov't	Foreign Gov't	GSD Man'grs
Spatial Reference Frames	4	4	4	4	4	4
Geoid Modelling and Refinements	4	4	4	4	4	4
Active Control System	3	2	4	3	4	4
Traditional Control Network	1	0	1	1	0	0
Standards and Related Services	4	3	3	3	0	4
Geodetic Information System	3	2	2	2	0	1
Marketing Support to Industry	4	2	3	1	0	N/A
Consulting and Publications	0	1	3	1	1	1

Table 2: Responses of NMO primary stakeholders to the question 'How integral are Geodetic Survey's activities to delivering your organisation's mission?' from Booz, Allen and Hamilton (1995)
Note: Very important = 4, Not important = 0

1.2 Related strategies

To fulfil their role as custodians of the NSRS, NMOs in the developed world recognise that they must take full advantage of GPS-based active control and data communication technologies to implement GPS-based active control infrastructures. In some cases they opt to leverage this investment by cooperating with other government departments as well as the local industry on a partially cost recovering or cost sharing basis (Geodetic Survey Division 1998). In defining their new vision, NMOs in the developed world adopt a market and stakeholder driven approach that is achievable within practical investment constraints and measurable against goals in mandated and financial terms, as for example in:

> '…Increase the reliability, accessibility, availability and accuracy of the National Spatial Reference System (NSRS)…
> Evolve the National Spatial Reference System to respond to the changing environment and user needs…Expand [Continuously Operating Reference Station] CORS nation-wide….
> Optimise relationships [to customers and partners] to meet evolving needs and changing requirements…
> Achieve world class leadership in use and innovative techniques and application of geodetic science, remote sensing, and precise positioning…
> Enable NGS to be responsive to ever-changing environments and customer requirements….'
>
> Excerpt from the Strategic Plan of the National Geodetic Survey (NGS), USA (1998)

> '…Complete and implement the Canadian Active Control System, incorporating GSD's most advanced geodetic concepts
> Develop and implement a program to fully integrate spatial referencing and gravity activities into the Canadian ACS science mission
> Leverage the ACS and National Spatial Reference Infrastructure-related intellectual capital of the GSD in partnership with the Canadian Geomatics industry, provincial agencies and OGD's so that partial cost recovery or cost sharing is achieved
> Develop the geodetic information system….
> Develop and implement a strategy to make the transition away from traditional Geodetic control activities over a period of several years, and communicate GSD's plans to stakeholders for their inputs'
>
> Excerpt from the Strategic Plan of the Geodetic Survey of Canada, Geomatics Canada (1995)

The effectiveness of NMOs in achieving these goals ultimately lies with the quality of employees. Quality encompasses skills such as leadership, management and marketing skills and industry knowledge in addition to advanced geodetic skills. With the private sector frequently leading in technological GPS/DGPS innovation and offering attractive salaries, quality staff can be retained at NMOs only under the condition of appropriate remuneration.

2 Land record modernisation programmes and NMOs in developing countries

NMOs in developing countries are also operating in an environment characterised by increased fiscal responsibility, more entrepreneurial government, advances in GPS technologies and the emergence of a global geomatics marketplace. Moreover they are taking the lead or are cooperating with subnational authorities in the implementation of land record modernisation programmes funded by foreign government donors or international lending organisations. NMOs and other subnational authorities (for example, provincial cadastral organisations) are aware of the unique opportunity to develop and implement modern spatial reference systems as an underpinning to land record modernisation.

Land record modernisation programmes involve the development of computer-assisted information systems for the administration, analysis and distribution of land records created and used by government and members of the public. The systems provide integrated solutions for property assessment, land registry, cadastral mapping and land use within an information technology infrastructure that permits interoperability between systems (Mullin and McEvoy, 95). The importance of land record modernisation for economic growth was reiterated in a recent study (World Bank 1999). The reform agenda proposed by the World Bank for Latin American and Caribbean countries for the period 2000 – 2010 comprises five broad policy areas including the enhancement of protection of property rights.

> '…Recent theoretical and empirical work has established that property rights and adequate legal and regulatory systems are critically important for growth because they promote higher and more efficient investment. Available evidence indicates that both foreign and domestic investors perceive that in the protection of property rights, in the enforcement of contracts, and in the credibility of the legal and regulatory framework, the Latin American and Caribbean region lags substantially behind other regions, especially the East Asian and OECD countries…
> The reform agenda in this area includes enhancing the protections provided by property rights, expanding titling programs, developing efficient competition laws, and eliminating unnecessary or inefficient regulation of economic activity…'
>
> The World Bank Group, January 1999

Guaranteed mining property is considered the main trigger for the foreign investment of US$ 15 billion between 1990 – 1998 in Chile. The Economic Commission for Latin America and the Caribbean (ECLAC) of the United Nations explains the investment boom in Chile as:

> 'Institutional aspects were fundamental for foreign investors…. The mining concessions [in Chile] are protected by property rights, which means constitutionally the conformal to norms guaranteeing private property, with the right to sell, mortgage or bequeath…. Expropriation entails full compensation based on the market value of the mining concession…'
>
> Moguillansky, United Nations ECLAC (1998)

The World Bank and the Inter American Development bank (IADB) have financed land record modernisation programmes in several LAC countries in the 1990s. The programmes are geared towards land registration (legal cadastre), property assessment (fiscal cadastre) land use and mining cadastre (Gillone and Brunini 1998). Most programmes aspire to eventually integrate property assessment, land registry, land use and other themes within Digital Cadastral DataBases (DCDBs) that can be updated by coordinated cadastral surveys. In his review of the World Bank funded LRM programmes in Brazil, Nicaragua and Paraguay, McKenna (1996) singles out the maintenance of DCDBs as the key to the long-term success of the programmes.

> '…If we return to a cadastral project in ten years and the government cannot keep the information current, due to a lack of interest, a lack of budget or commitment we [the World Bank] have failed miserably. The replacement cost will be more expensive since the information would need to be completely updated and recompiled….'
>
> McKenna (1996)

Up-to-date DCDBs can do more than demonstrate the success of an LRM programme. Survey accurate DCDBs, that is, DCDBs updated by coordinated cadastral surveys, are marketable to local authorities, utility companies and other GIS administrators. Local authorities and utility companies demand coordinate accuracies of ±0.03m or better for their GIS applications. In Australia, some utilities and local authorities are considering establishing themselves survey accurate DCDBs by resurveying all land parcels in their area of responsibility, if they cannot obtain them elsewhere (Williamson 1996)

The marketability of survey accurate DCDBs is a unique opportunity for NMOs and subnational authorities (for example, provincial cadastre organisations) in developing countries. Revenues earned through the sale of digital products to value-adding clients (local authorities, utility companies, and so on) can generate funds sorely needed for the future maintenance of the DCDB, for salary improvement and training of staff.

However, survey accurate DCDBs are only possible if NMOs or subnational authorities either maintain dense survey control or establish permanently installed DGPS services or a combination of both. Either option must be accompanied by positioning standards and procedures to integrate local surveys into the spatial reference system. See for example the recommendations for integration of local surveys to the Canadian spatial reference system (Craymer 1998). The option of maintaining (and upgrading) dense survey control is being abandoned by NMOs and subnational authorities in developed countries primarily due to the high maintenance cost and the limitations of upgrading from a local geodetic datum to a ITRF compatible datum. The trend is towards gradually phasing out of the traditional dense survey control and establishing sparse GPS networks (Hamilton and Doig 1993) or province wide ACS type infrastructures (Geographic Data British Columbia 1998).

The findings of the Task Force on Control Surveys in the Maritime Provinces of Canada are illuminating in this respect (Hamilton and Doig 1993). The Task Force reviewed the status and the usefulness of the existing survey control framework by interviewing most direct and many indirect users of the control survey framework in the Maritime Provinces. It established beyond any doubt that the survey control framework of about 53 000 control points had been a sound investment for the provinces. Table 3 shows the average annual cost for maintaining mathematically and physically the survey control networks in the three Maritime Provinces: New Brunswick, Nova Scotia and Prince Edward Island.

	Area (km ^{2})	**Number of points of survey control network**	**Annual maintenance cost in CDN $ of 1993**
New Brunswick	76 800	24 968	$403 564
Nova Scotia	55 000	23 340	$237 966
Prince Edward Island	5 660	4 649	$76 615
Total	**137 460**	**52 957**	**$718 145**

Table 3: Survey control expenditures in the three maritime provinces of Canada. After Hamilton and Doig 1993

The need for transition to an ITRF compatible datum for the Maritime Provinces, the potential of GPS technology as well as cost efficiency considerations led the Task Force to adopt a scenario for the most effective conversion of the existing survey control to a spatial reference infrastructure of only 44 GPS control points. The Task Force urged the provincial authorities to jointly develop standards and guidelines for the use of GPS in property surveys as well as guidelines for managing GPS based spatial reference infrastructures (Geoplan and Gillis 1996).

Some pertinent questions are: 'Is it cost-effective for a NMO in Latin America with jurisdiction over an area of 137 000 km^2 to allocate $720 000 annually for the maintenance of a survey control network of 53000 points that is required to support coordinated cadastral surveys?'. If the answer is no, 'Which course should be followed?'. There are no ready answers to these questions. Moreover, the 'national spatial reference system' landscape in Latin America is far from gloomy. NMOs and cadastral authorities have established sparse GPS networks, including ACS type infrastructures in Mexico (Soler 1996) and Brazil (Fortes 1997) in several countries that are active in land record modernisation programmes. Recipes may not be available but there are strategies that may be valuable in promoting consensus among different stakeholders in spatial reference infrastructure.

One of these strategies is consensus-building workshops. A workshop of this nature, titled *The future of Geodetic Control Networks in South America and New Concepts in Cadastral Surveys* was held late in 1996 in Argentina under the auspices of the Professional Council of Surveyors of the Province of Buenos Aires (Georgiadou et al, 1997). The workshop was sponsored by the Commission 5 of the Federation International des Geometres, the Federal Council of Cadastre of Argentina, the Instituto Geografico Militar and the Argentine Federation of Surveyors. Among the participants were directors of cadastral authorities, leaders from the university community and private sector representatives from Chile, Brazil, Paraguay, Uruguay and most Argentine provinces as well as senior professionals from NMOs in Canada and the United States (Georgiadou and Falcon 1996).

Workshop discussions focused on the procedures for the delivery of the geodetic networks to users through densification and the consideration of alternatives. By the end of the workshop there was agreement among participants on the action needed to be taken involving the development of: procedures that will guarantee the management and delivery to users of the spatial reference systems, geospatial positioning standards to describe and classify the accuracy of points in the national spatial reference system and procedures for the integration of the national spatial reference systems to ITRF. Moirano et al (1997) and Costa et al (1999) document some of the progress made in the last couple of years on these issues in Argentina and Brazil respectively.

The transition to a new order of things is difficult to manage. Sustainable organisational and technological change should be based mostly on locally developed management and technical procedures and solutions, after consulting extensively with all stakeholders of spatial reference infrastructures. The maintenance of open channels of communication between NMOs with similar mandates can accelerate the process of change.

References

BECK N., 1996. *The new strategy of the Geodetic Survey Division of Canada*, presented in the Workshop *El futuro de las redes de control geodesico y los nuevos conceptos para los levantamientos catastrales*, 30 September to 4 October, 1996, Universidad Nacional de La Plata, La Plata, Argentina.

BOOZ, ALLEN & HAMILTON Ltd, 1995. *Vision and strategy for the Geodetic Survey Division*, Report prepared for the Geodetic Survey Division, Geomatics Canada, May 1995, 32 pages.

CRAYMER, M. R., 1998. *Integration of Local Surveys into the Canadian Spatial Reference System*, Presented at the Public Works and Government Services Canada (PWGSC) Survey, Contracting and CACS Seminar, Edmonton, Alberta, 24 February, 1998.

CONTRERAS, H., 1998. *GPS+GLONASS technology at the Chuquicamata Mine in Chile*, GEOCOM S.A., http://www.geocom.cl.

COSTA, M. A, PEREIRA, K. D. and BEATTIE, D. S., 1999. *La Integración de la Red Geodésica Brasilena a SIRGAS*, Geoconvergencia, March 1999, pp. 17–19.

FGDC, 1998. *Geospatial Positioning Accuracy Standards*, FGDC–STD–007–1998, parts 1, 2 and 3, http://fgdc.er.usgs.gov.html (or) ftp://fgdc.er.usgs.gov/pub/gdc/, 52 pages.

FORTES, L. P. S., 1997. *Operationalization of the Brazilian Network for Continuous Monitoring of GPS* (in Portuguese), Master Thesis, Instituto Militar de Engenharia.

GEODETIC SURVEY of CANADA, 1998 – Internet website address: http://www.geod.nrcan.gc.ca/html-public/GSDinfo/English/RealTimeAnnouncEnglish.html.

GEODETIC SURVEY DIVISION, 1996. *Accuracy Standards for Positioning*, Version 1.0, Geomatics Canada, Natural Resources Canada, pp. 1–28.

GEOGRAPHIC DATA BRITISH COLUMBIA, 1998 – Internet website address: http://www.env.gov.bc.ca/gdbc/acs.htm.

GEOPLAN CONSULTANTS INC. and GILLIS SURVEY SYSTEMS, 1996. *Guidelines for managing a GPS based control system for the Maritime Provinces*, prepared for the Maritime GPS Implementation Committee, under contract to the New Brunswick Geographic Information Corporation, New Brunswick, Canada, March 1996.

GEORGIADOU, Y and FALCON, E., 1996. *El futuro de las redes de control geodésico y los nuevos conceptos para los levantamientos catastrales*, Workshop report, 30 September to 4 October, 1996, Universidad Nacional de La Plata, La Plata, Argentina.

GEORGIADOU, Y, De MEYERE, J., ALVAREZ, M., KLEUSBERG, A., USANDIVARAS, J.C., 1997. *The Argentine Cadastre in Transition*, Geomatica, Vol. 51, No.2 pp. 143–151.

GILLONE, R. and BRUNINI, C., 1998. *Echar una red grande: El Proyecto de Asistencia al Sector Minero Argentino (PASMA)*, Geoconvergencia, Julio 1998, pp. 28–36.

GROOT, R., 1998. *What is the Role of National Mapping Agencies (NMAs) in the Development of National Spatial Data Infrastructures (NSDI)?*, Paper presented at the International Conference of Spatial Information Science and Technology, SIST' 98, Wuhan, China, 13–16 December, 1998.

GURTNER, W., 1993. *The Use of IGS Products for densification of Regional and Local Networks*, unpublished report, Symposium of the IAG Subcommission for the European Reference Frame (EUREF), Budapest, Hungary, 17–20 May.

HAMILTON, A. and DOIG, J., 1993. *Report of the Task Force on Control Surveys in the Maritime Provinces*, Contract Report prepared for the New Brunswick Geographic Information Corporation, March 1993.

IERS, (International Earth Rotation Service), 1996. *1995 IERS Annual Report*, Central Bureau of IERS, Observatoire de Paris, Paris, France, July.

LEE, Y. C., 1993. GIS and GPS, Lecture Notes, Department of Geodesy and Geomatics Engineering, Fredericton, New Brunswick, Canada.

MCKENNA, J. R., 1996. *Modernization of Cadastres and Land Registries in Latin America: the Experiences of Paraguay, Brazil and Nicaragua*, International Conference on Land Tenure and Administration, University of Florida, 12–14 November, 1996, pp. 5.

MOIRANO, J., BRUNINI ,C., DREWES H.and KANIUTH, K., 1997. *Methodology for the integration of the POSGAR network to the SIRGAS reference frame*. Proceedings of the IAG Scientific Assembly, Rio de Janeiro, Brazil, 1997.

MOGUILLANSKY G., 1998. *Chile: Las Inversiones en el Sector Minero 1980–2000*, United Nations Economic Commission for Latin America and the Caribbean, Serie Reformas Economicas 3, Santiago de Chile, 1998, pp. 61.
http://www.eclac.cl/espanol/noticias/comunicados/invmineras.htm.

MULLIN, R., McEvoy, J., 1995. *Management strategies for streamlining land records processes*, URISA 95, July 1995.

NATIONAL GEODETIC SURVEY, 1998. *Strategic Plan* of the National Geodetic Survey (NGS), National Oceanic and Atmospheric Administration (NOAA), USA.
http://www.ngs.noaa.gov/INFO/NGSStratPlan98.html.

WILLIAMSON, I., 1996. *Coordinated Cadastres – A key to building future GIS*, Proceedings of the Regional Conference on Managing Geographic Information Systems for Success, Melbourne, 3–4 July, pp.60–69 (1996).

WORLD BANK, 1999. *The Long March: A Reform Agenda for Latin America and the Caribbean in the Next Decade*, ISBN 0–8213–3985–0, The World Bank Group, January 1999.