Ireland's Surveying Infrastructure for the 21st Century

William Patrick PRENDERGAST, Ireland

Key words: GPS networks, geoid model, co-ordinate reference systems, co-ordinate transformations, network RTK.

SUMMARY

This paper presents the results of a research project which examined the suitability of Ireland's modern surveying infrastructure to meet the needs of the planning, development and surveying sectors for precise surveying, and resulted in the publication of "Best Practice Guidelines for precise surveying in Ireland"

The accuracy needs of the development and surveying sectors are presented and the examination investigates the potential of the surveying infrastructure in meeting those needs. The Passive and Active GPS Networks, the geoid model, the old and new co-ordinate reference frames and co-ordinate transformations are all examined to develop a set of preferred methodologies for precise surveying. Although Ordnance Survey Ireland and Ordnance Survey of Northern Ireland have collaborated to provide the an infrastructure suitable for the 21st Century the next challenge is to get surveyors and their clients to adopt it.

Ireland's Surveying Infrastructure for the 21st Century

William Patrick Prendergast, Ireland

1. INTRODUCTION

The Ordnance Survey of Great Britain and Ireland established it's base in Ireland in 1824 and three separate surveying infrastructures have been implemented in Ireland during the 180 years since then. The first infrastructure was a British Isles wide infrastructure for plan and Ireland had a separate infrastructure for height based on the vertical datum at Poolbeg lighthouse in Dublin. All the large scale Ordnance Survey mapping of the 19th century at 6 inches and 25 inches to 1 mile was based on this original infrastructure.

When Ireland gained its' independence in 1922 the Ordnance Survey was split into three; Ordnance Survey of Great Britain (OSGB) with responsibility for England, Wales and Scotland, Ordnance Survey of Northern Ireland (OSNI) with responsibility for the 6 counties of Northern Ireland, and Ordnance Survey Ireland (OSI) for the remaining 26 counties of Ireland. The original infrastructure eventually became obsolete by the middle of the 20th century, and Ordnance Survey Ireland and Ordnance Survey of Northern Ireland jointly designed and implemented the second surveying infrastructure for the whole island of Ireland between 1952 and 1975. The supply of this second infrastructure was hugely beneficial in providing an homogeneous system for surveyors, engineers, architects, planners and developers during the latter part of the 20th century.

2. REVIEW OF IRELAND'S NEW SURVEYING INFRASTRUCTURE

Advances in satellite positioning systems and improved adjustment methods provided an opportunity to implement a third surveying infrastructure for the 21st century during the last decade (Table 1).

Table 1: Milestones in the supply of Ireland's third surveying infrastructure

SUPPLY DATE	INFRASTRUCTURE IMPLEMENTED
1996	Zero Order GPS network
1996	Passive GPS network
1999	Official seven-parameter transformation between ETRS89 and IG75
2002	Active GPS network
2002	New Co-ordinate Reference System – Irish Transverse Mercator
2002	Geoid Model (OSGM02)
2002	Polynomial Transformation between ETRS89 and IG75
2004	Network RTK system from Active GPS network

2.1 Zero Order GPS Network

The IRENET95 campaign during 1995 realised ETRS89 co-ordinates for 12 stations of a zero-order 3D GPS network (8 in Ireland, 3 in Northern Ireland and 1 in the Isle of Man). Descriptions and co-ordinates for these zero-order GPS stations are not available for general use in order to minimise damage to these stations and to restrict their use for scientific purposes only. This first level network of stations is called a zero-order network because the accuracy of its co-ordinates is considered to be an order of magnitude (10 times) better than the accuracy of co-ordinates of the previous primary horizontal control network, and as such can expose the limitations of the existing control networks. This improved accuracy is mainly due to the GPS technology and improved adjustment methods for computations.

2.2 Passive GPS Network

A second level of the 3D GPS network consists of the 173 densification stations of the Passive GPS network, numbered D001 to D173 (Figure 1). Three co-ordinates (ETRS89, IG75 (Irish Grid 1975 (mapping adjustment)) and ITM) are published for these stations, and OSI and OSNI quote an accuracy equivalent to ± 20 mm in Latitude, Longitude and ellipsoidal height for the ETRS89 co-ordinates (OSI and OSNI, 1999). Results achieved by private surveying firms to date seem to confirm this level of reliability. This Passive GPS network complies with international standards and provides a high precision three-dimensional control network which has been independently quality assured by EUREF.

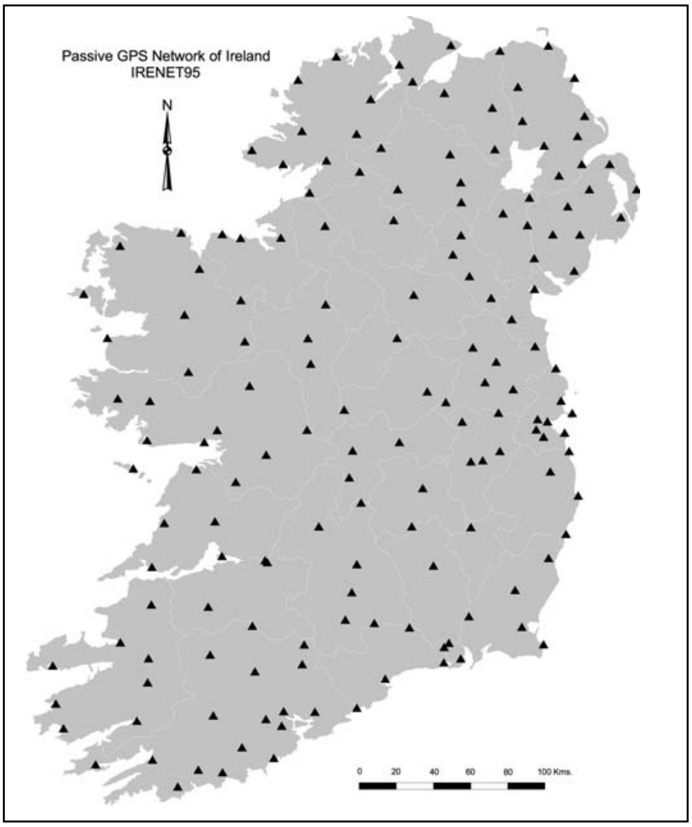

Figure 1: Ireland's Passive GPS Network (Cory *et al*, 2004)

2.3 Official Seven-Parameter Transformation

Surveyors who used this Passive GPS network prior to 1999 had to calculate local seven-parameter transformations for projects in order to transform surveyed ETRS89 co-ordinates onto the IG75 co-ordinate reference frame. This practice gave rise to many different versions of IG75 co-ordinates, which were both unofficial, and in many cases undocumented. OSI and OSNI subsequently published a set of official variables for the seven-parameter transformation, and survey practice should have changed at that stage to adopt the new official values (Table 2). Whereas it is impossible to precisely relate co-ordinates in one system to those in a different, unconnected system, the use of the official values for the seven-parameter transformation provides a connection between the two systems to a consistent accuracy tolerance. However, the adoption of the new official values by practitioners was not as widespread as one would have wished for.

Table 2: Official variables for a seven-parameter transformation between the ETRS89 and IG75 co-ordinate reference frames (OSI & OSNI, 1999)

Translations		**Rotations**		**Scale Factor**
Δx	+ 482.530 m	θx	+ 1.042"	+ 8.150 ppm
Δy	- 130.596 m	θy	+ 0.214"	
Δz	+ 564.557 m	θz	+ 0.631"	

Although these official variables for a seven parameter transformation permitted the computation of Eastings and Northings on the IG75 co-ordinate reference frame from the 3D ETRS89 co-ordinates, no official geoid model was available to convert computed heights on the Airy modified ellipsoid into orthometric heights.

2.4 Active GPS Network

The Active GPS network was established in 2002 by the IRENET02 observation campaign and consists of 16 stations (OSI - 10 stations, OSNI - 3 stations, and the Commissioners of Irish Lights (CIL) - 3 stations). The positions of the Active GPS stations were determined to the same standards as the zero-order network, and consequently their accuracy is likely to be equivalent to ± 10 mm for latitude, longitude and ellipsoidal height for the ETRS89 co-ordinates. EUREF is expected to confirm this accuracy in the near future. Two additional stations were recently established at Cavan and New Ross to expand this network (Figure 2).

This network of permanently recording GPS stations enables positioning when using only a single receiver, a significant saving for surveyors. The intention is for users to combine data collected at the Active GPS station(s) nearest to the users' location with data observed by the user on site either during post-processing off-site or for real-time processing on-site using the telecommunications network.

Data collected at the Active GPS stations can be accessed in two ways:

- The user accesses the geodetic website (http://www.osi.ie/gps/index.asp) and chooses the Active GPS station(s) and the observation period they require. This data is provided in separate RINEX files for each hour of observation and supplied over the internet in a ZIP file to speed up download to the users' PC.
- A Real Time Kinematic (RTK) service is available for the four Active GPS stations located in Dublin (Belfield, Phoenix Park, Swords and Tallaght) where a differential correction is available in real-time via GSM mobile communications.

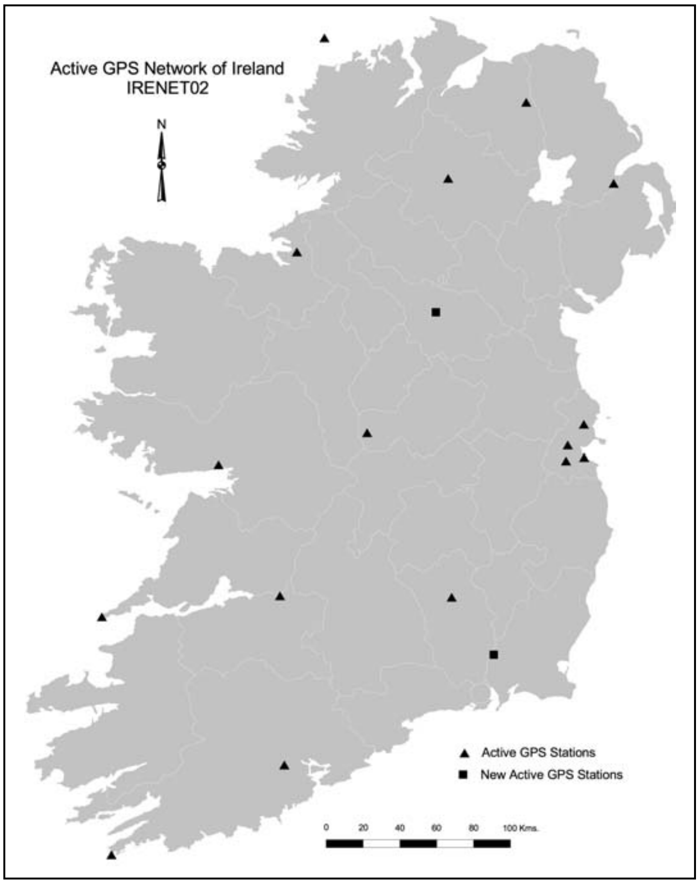

Figure 2: Ireland's Active GPS Network (Cory *et al*, 2003)

2.5 Ireland's New Co-ordinate Reference System - Irish Transverse Mercator

The Irish Transverse Mercator (ITM) co-ordinate reference system (Table 3) was jointly designed by OSI and OSNI in 2000 as part of a GPS compatible co-ordinate reference system for Ireland. Improvements from the previous Irish Grid co-ordinate reference system include:

- Adoption of GRS80 instead of the Airy modified ellipsoid, to ensure the co-ordinates are GPS compatible.
- Adoption of a sub unity scale factor for the central meridian of the projection to ensure projection distortions are as close as possible to unity and are symmetrical across Ireland.

- Adoption of a different false origin from the Irish Grid co-ordinate reference system to ensure co-ordinates in both IG75 and ITM co-ordinate reference frames are easily distinguishable.

Table 3: Defining parameters for the Irish Grid and Irish Transverse Mercator co-ordinate reference systems (OSI and OSNI, 2001)

	IG	ITM
Map Projection	Transverse Mercator	Transverse Mercator
True Origin	8^0 00' 00" West 53^0 30' 00" North	8^0 00' 00" West 53^0 30' 00" North
False Origin	200 000 m West 250 000 m South	600 000 m West 750 000 m South
Ellipsoid	Airy Modified	GRS80
Scale Factor of Central Meridian	1.000035	0.999820
Measurement Unit	International Metre	International Metre
Vertical Datum	Malin Head	Malin Head

The ITM co-ordinate reference system was officially realised in 2002 when ITM co-ordinates were published on the OSI geodetic website. The Irish Institution of Surveyors (IIS) considers that ITM has equal status to the IG75 co-ordinate reference frame. Although OSI and OSNI have stated that they intend to continue to provide spatial data in IG75, the Irish Institution of Surveyors has recommended that ITM be adopted as soon as possible as the preferred official co-ordinate reference frame for Ireland.

2.6 Geoid Model (OSGM02)

Both the Passive and Active GPS networks are three-dimensional such that GPS observations connected to either network will yield ETRS89 co-ordinates (latitude and longitude and ellipsoidal (GRS80) height). A geoid model (OSGM02) of the separation between the GRS80 ellipsoid and the geoid was jointly developed by OSI, OSNI and OSGB for the whole British Isles and was published in 2002. Consequently, it has since been possible to use these GPS networks to their fullest potential as 3D control networks.

The Quest software, which is available as freeware on the OSI website (http://www.osi.ie/gps/secure/converter/download.asp) has the geoid model (OSGM02) embedded in it, so it can be used to convert ellipsoidal heights into orthometric heights as well as for co-ordinate transformations. The contractor who computed this geoid model also assessed its accuracy at 0.048 m for Ireland and 0.038 m for Northern Ireland (Table 4) at a 95% confidence level (2σ).

Table 4: Accuracy assessment (1σ) of OSGM02 (Forsberg *et al*, 2002)

	Ireland	**Northern Ireland**
Maximum	0.050	0.041
Minimum	- 0.064	- 0.035
Mean	- 0.003	0.002
Standard Deviation	0.024	0.019

2.7 Polynomial Transformation

A new polynomial transformation was provided within the Quest software to supply improved 2D transformation results, and this improved accuracy was confirmed in a test performed by the Irish Institution of Surveyors (Table 5).

Table 5: Residuals between published IG75 co-ordinates and IG75 co-ordinates computed from ETRS89 co-ordinates using the polynomial and seven-parameter transformations (using official variables)

	POLYNOMIAL		**SEVEN PARAMETER**			
	Quest Software		Trimble Total Control Software		GeoGenius Software	
	ΔE	ΔN	ΔE	ΔN	ΔE	ΔN
Max	0.383	0.381	0.496	0.586	0.496	0.589
Min	- 0.284	- 0.350	- 0.576	- 0.466	- 0.575	- 0.463
Mean	0.014	0.017	0.064	- 0.034	0.065	- 0.031
St Dev	0.133	0.132	0.253	0.181	0.253	0.181
Vector (2σ)	**0.375**		**0.622**		**0.622**	

2.8 Network RTK

The RTK service in the Dublin area is currently being further developed to include a network RTK system using GNSMART from Geo++ for all areas of the island of Ireland where GSM phone signals are available (further extension of the system to more remote areas will follow the GSM rollout). This service is expected to be publically available via a single access number by late spring / early summer 2004, once internal testing has been completed, and should provide accurate positioning in real time with a single GPS receiver for most areas. However, it will be a chargeable service to fund the maintenance and future development of the system (Greenway, 2003).

3. TESTING THE NEW SURVEYING INFRASTRUCTURE'S POTENTIAL

3.1 Ireland National Development Plan

Ireland's National Development Plan committed an investment of €52 Billion between 2000 and 2006, and a significant portion of this investment was allocated to public transport infrastructure. Many of the transport infrastructure projects require precise surveys to supply data for project design and to monitor construction progress to ensure increasingly tighter specifications are achieved. An investigation was conducted by an Irish Institution of Surveyors (IIS) Task Force to identify the accuracy tolerances being demanded for precise surveying contracts and to examine the control networks supplied by OSI and OSNI in order to determine what is practically possible.

3.2 Accuracy Specification of Survey Contracts

An email survey of private surveying firms conducted in 2003 (Prendergast, 2004) indicated that relative accuracy tolerances specified in survey contracts for major construction projects in Ireland are becoming increasingly tighter (Table 6).

Table 6: Most common relative accuracy @ 1σ (68% confidence) requested for precise surveying projects in Ireland

	Eastings	Northings	Height
Max	0.030	0.030	0.025
Min	0.002	0.002	0.003
Mean	0.011	0.011	0.010

3.3 Accuracy Estimations of IG75 and ITM Co-ordinates

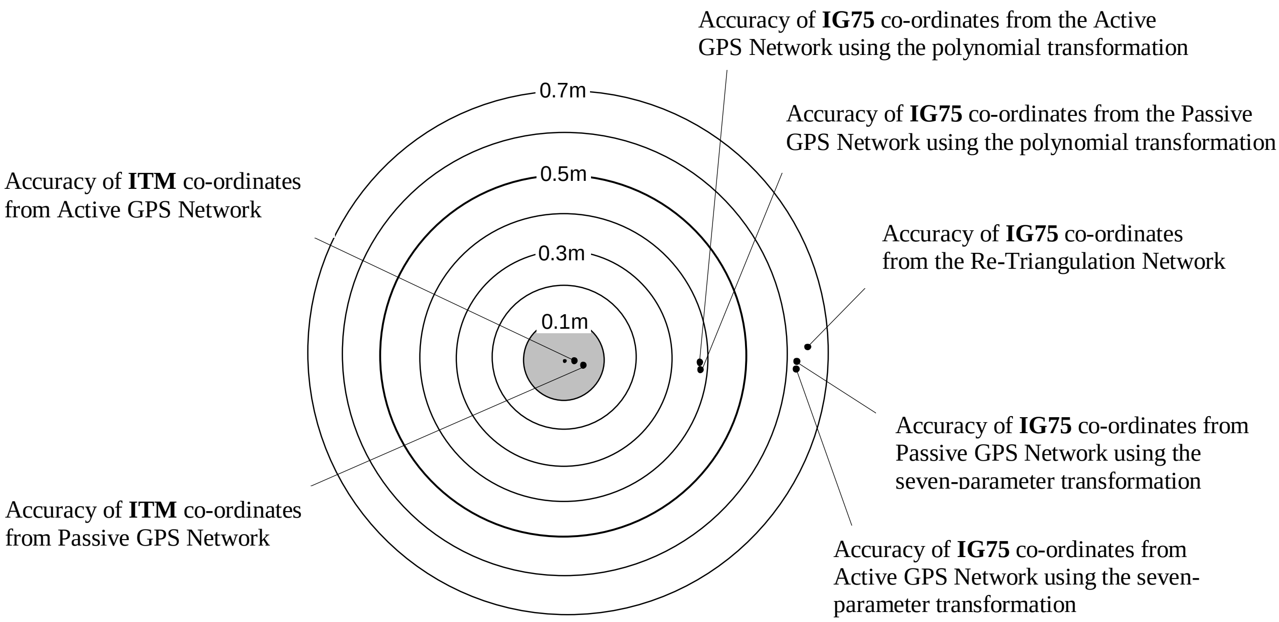

Figure 4: Estimated absolute and relative accuracies (2σ) of IG75 and ITM co-ordinates surveyed at a range of 5 km using GPS in static mode (Prendergast, 2004)

Estimations of relative and absolute accuracies @ 2σ (95% confidence) are graphically depicted for IG75 and ITM co-ordinates surveyed using GPS in static mode from the different control networks at a range of 5 km (Figure 4). The small black circles indicate the size of the relative accuracy for each computation, and the distance of the centre of the black circles from the bull's eye indicates the absolute accuracy of the measurements relative to a co-ordinate reference frame. The smaller the black circle the better the relative accuracy and the closer to the bull's eye the better the absolute accuracy.

It is obvious that the relative accuracy of each set of observations is similar since GPS in static mode was used for each measurement. The relative accuracy from the Active GPS Network is slightly better at 14.7 mm compared to 15.2 mm from the Passive GPS Network, because there is no centring error at the Active GPS Network station. However, it is interesting to note the improvement in absolute accuracy by using the polynomial transformation for IG75 co-ordinates, and the significant improvement by using the ITM co-ordinate reference frame, which does not need a transformation.

3.4 Potential Accuracy of ITM Co-ordinates From the Passive GPS Network

These results indicate that the absolute accuracy of survey data can be improved from 0.65 m to 0.05 m if ITM is adopted instead of the IG75 co-ordinate reference frame, a significant improvement indeed. However, the Passive GPS network would not provide very much coverage at ranges of 5 kms, but would provide approximately 95% coverage of Ireland, using ranges of 20 kms (Figure 5).

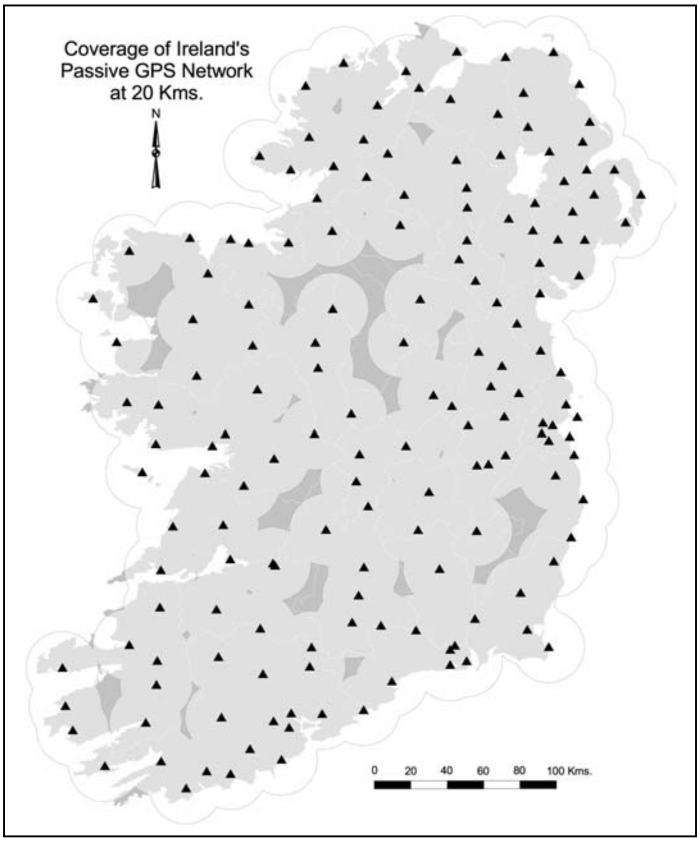

Figure 5: 95% coverage of Ireland's Passive GPS Network at a range of 20 Kms

3.5 Accuracy Standard for Precise Surveying

If the accuracy of the ITM co-ordinates is then re-computed using a range of 20 kms values of 28.9 mm and 20.8 mm @ 1σ are achieved for the absolute and relative accuracies from the Passive GPS network. Consequently, it should be possible to supply data with an absolute accuracy of 57.8 mm at a 95% confidence level for 95% of the island of Ireland. Therefore, Irish Institution of Surveyors proposed the adoption of an accuracy standard of < 60 mm (2σ) in absolute accuracy for ITM co-ordinates for the control for precise surveying projects. The provision of control for precise surveying projects will in future require GPS equipment to connect to the GPS network in order to achieve this accuracy standard.

3.6 Potential Accuracy of ITM Co-ordinates From the Active GPS Network

Absolute accuracy from the Active GPS Network should be better than absolute accuracy from the Passive GPS Network in similar conditions because:

- The accuracy of the network is better; Active GPS network is considered to be the equivalent of ± 10 mm in x, y & z, (yet to be confirmed by EUREF), whereas the Passive GPS network is confirmed as equivalent to ± 20 mm in x, y & z.
- There will be no centring error at the network end of the baseline from the Active GPS network, whereas there will be from the Passive GPS network.

Figure 6: 85% coverage of Ireland's Active GPS Network at a range of 65 Kms

This suggests that it may be possible to achieve the proposed accuracy standard of < 60 mm (2σ) at distances greater than 20 kms from the Active GPS stations. The Irish Institution of Surveyors conducted a range of tests using short, medium and long baselines from the active GPS Network and the results indicate that it may be possible to achieve the proposed accuracy standard at distances of 50 kms from Active GPS stations. Additionally, if computations use baselines from at least three Active stations this distance can be extended slightly further to 65 kms (test was indicative rather than conclusive).

However, ranges of 65 kms from the existing Active GPS Network only provide a coverage of ~ 85% of the island because the three CIL stations along the western seaboard are net yet fully operational, and it now seems likely that they might never be. This coverage was recently increased to ~ 90% (Figure 6) by the addition of two new stations at New Ross and Cavan, established in late 2003. The Irish Institution of Surveyors has proposed that an additional station is also necessary in the vicinity of Newport, Co. Mayo, and although the three CIL stations provide most of their coverage out into the ocean, significant areas of north Donegal and virtually the whole county of Kerry are not provided for if these stations do not become fully operational. However, this examination is likely to be superceeded by the arrival of the network RTK system in late spring / early summer 2004, which needs to be tested to determine it's coverage to meet the proposed accuracy standard of < 60 mm (2σ).

3.7 Accuracy Estimations of Height Co-ordinates

Although the contractor who computed the geoid model (OSGM02) assessed its accuracy at 0.048 m for Ireland and 0.038 m for Northern Ireland (Table 4) at a 95% confidence level (2σ), this accuracy needs to be independently confirmed to encourage private practitioners to adopt this new technique. OSI and OSNI have agreed to fund a research project in this regard.

Orthometric heights surveyed from the GPS Networks at a 5 km range have substantially better absolute accuracy than orthometric heights surveyed from the Levelling Network at the same range (51.6 mm to 68.8 mm compared to 203.8 mm). Additionally, the relative accuracy achieved (28.6 to 30.5 mm) with these two heighting techniques is similar at this range of 5 km. However, the relative accuracy of a digital level (or equivalent) is superior over shorter distances at 6.4 mm for levelling compared to 20.5 mm (Active GPS network) and 20.9 mm (Passive GPS network) at a range of 500 m. It should be noted that this accuracy estimation for height does not take account of Ocean Tide Loading (OTL) for the GPS methods described.

If the accuracy of the orthometric heights are then recomputed using a range of 20 kms values of 51.8 mm and 47.8 mm @ 1σ are achieved for the absolute and relative accuracies from the Passive GPS network. Consequently, it should be possible to supply height data with an absolute accuracy of 103.6 mm at a 95% confidence level for 95% for the island of Ireland. Again, there was no allowance for OTL in this accuracy estimation.

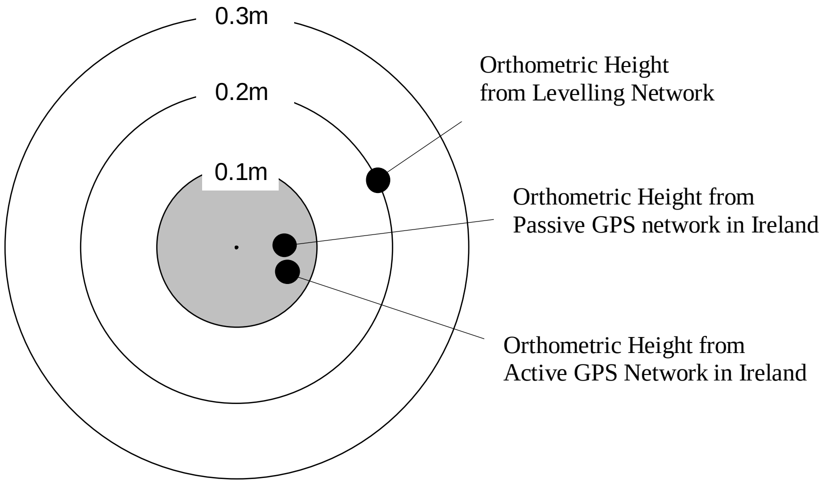

Figure 7: Estimations of absolute and relative accuracy of orthometric heights calculated from the GPS and Levelling Networks

Although the promise of GPS heighting is millimetre-level accuracy over hundreds of kilometres, the reality is often more like centimetre-level accuracy over tens of kilometres and current indications suggests that medium baselines may not provide the accuracy currently being demanded for height data. Testing the new network RTK system during the next few months is essential to determine what level of accuracy is possible using this technique.

4. ISSUES YET TO BE RESOLVED

It has been already shown that it may be necesary to establish an additional station in the Active GPS network in the Newport area in County Mayo, and more additional stations will also be necessary if the existing CIL stations to not quickly become fully operational.

The network RTK system due to be released in Ireland in late spring / early summer 2004 needs to be urgently tested to:

- Determine it's coverage in meeting the proposed plan accuracy standard of < 60 mm (2σ);
- Determine it's ability to provide absolute accuracies better than 103.6 mm for height data;
- Determine the coverage of these improved accuracy levels.
- Assess the accuracy of the models for Ocean Tide Loading (OTL) and tropospheric effects used by the network RTK system.

OSI and OSNI have agreed to fund a research project to independently determine the accuracy of the geoid model (OSGM02) in order to encourage private practitioners to adopt this new heighting technique. A solution also needs to be developed for using this technique on adjacent sites since it has the potential to produce relativity problems. Finally, the investigation to determine the accuracy of the geoid model should also attempt to identify information deficiencies when the geoid model was computed, which might include:

- Insufficient gravity data in some areas

- Improving the quality of orthometric heights of fundamental benchmarks and the Passive GPS network
- Improving the quality of DEM data

5. CONCLUSIONS

In the past, during the design and implementation of Ireland's second surveying infrastructure in the 1950s, 1960s and 1970s, decisions were taken by OSI and OSNI to support their national mapping programmes instead of the foundation of a national surveying infrastructure. The 1975 realization of the Irish Grid co-ordinate reference system (IG75) was adopted because:

- It included a number of stations in Northern Ireland to maintain a link with new mapping produced in the north between 1952 and 1975;
- It included a number of stations in the south of Ireland to maintain a link with new mapping produced in the south between 1965 and 1975;
- It included a number of stations of Ireland's first surveying infrastructure of the 19th century to provide a link to the co-ordinate frame on which the existing mapping was based, even though this first infrastructure contained a 35ppm scale error.

During the last decade, improved decisions were taken by OSI and OSNI when designing and implementing Ireland's third surveying infrastructure. A high quality infrastructure was established which has exposed the limitations of the national mapping, but perhaps its design still had a focus for the provision of new national mapping rather than as a multi-purpose surveying infrastructure. The density of stations in the Active GPS network is possibly less than what it should have been, and it will be some time yet before the network RTK system can be sufficiently tested to assess if it can deliver a solution suitable for most applications. Decisions to cease maintenance of the old trigonometric and leveling networks of Ireland's second surveying infrastructure and of the new Passive GPS network seem to have been taken from an economic perspective alone, and may yet turn out to be rash decisions in hindsight.

The trend towards cost recovery in OSI and OSNI, and their recent establishment as agencies outside the civil service in both countries is forcing them to think and operate more and more as commercial enterprises. This has the potential to introduce commercial bias into their decisions on the design, implementation and operation of the new surveying infrastructure. They contend that the provision of this surveying infrastructure is not commercially viable, and should be funded from public funds since it constitutes a service to the state. I support this position, insofar as the infrastructure should then be designed as a multi-purpose infrastructure to suit the needs of many sectors rather than just supporting their national mapping programmes. It is also important that the needs of these other sectors are adequately addressed in a participatory fashion rather than using consultation exercises to disseminate information on decisions already taken.

REFERENCES

Cory, M.J., Greenway, I.C., and Hill, C.J., 2003, GPS Compatible Positioning in Ireland (Part 1), Survey Review Vol. 37 No. 290, pp 294-307, Bristol, CASLE.

Cory, M.J., Greenway, I.C., and Hill, C.J., 2004, GPS Compatible Positioning in Ireland (Part 2), Survey Review Vol. 37 No. 291, pp 377-395, Bristol, CASLE.

Forsberg, R., Strykowski, G., Illife, J.C., Ziebart, M., Cross, P.A., Tscherning, C.C., Cruddace, P., Stewart, K., Bray C., and Finch, O., 2002, OSGM02: A new geoid model of the British Isles, Proceedings of the 3rd meeting of the International Gravity and Geoid Commission (ed. Tziavos, I.N.), pp. 132-137, Thessaloniki, International Gravity and Geoid Comission.

Greenway, I.C., 2003 Developing Ireland's National Mapping – A Progress Report, pp 1-7, Dublin, OSI.

Ordnance Survey Ireland and Ordnance Survey of Northern Ireland, 1999, Making Maps compatible with GPS - Transformations between the Irish Grid and the GPS Co-ordinate Reference Frame WGS84 / ETRF89, pp 1-31, Dublin, OSI and OSNI.

Ordnance Survey Ireland, Ordnance Survey of Northern Ireland, 2001, New Map Projections for Ireland – Consultation Paper, pp 1-11, Dublin, OSI and OSNI.

Prendergast, W. P., (Ed.), 2004, Best Practice Guidelines for Precise Surveying in Ireland, pp 1-75, Dublin, The Irish Institution of Surveyors.

Snow, R., 2003, GNSS Receiver Networking in the 21st Century, Geo Informatics Volume 6 – June, pp 14-17, Emmeloord, Cmedia Productions BV.

BIOGRAPHICAL NOTES

W. P. Prendergast served as an officer in The Irish Army for over 20 years, 15 of which were spent in Ordnance Survey Ireland as the Officer Commanding the Survey Company. He was involved in the initial implementation of the Ordnance Survey digital mapping programme and was also a member of the Ordnance Survey senior management team throughout the 1980's and early 1990's. Since 1996, on retiring from the Army, he has lectured in the Department of Geomatics in the Dublin Institute of Technology where his specialist subjects are digital cartographic systems, spatial data modelling and land administration systems.

He has been an active member on the council of the Irish Institution of Surveyors (IIS) since its establishment in 1989, and served as the IIS President from 2000 to 2002. He has also served as the President of the Irish Society for Surveying, Photogrammetry and Remore Sensing from 1987 to 1988, and as President of CLGE (Comité de Liaison des Géomètres Européens), the European umbrella organisation for national associations of professional surveyors in Europe, from 1997 to 2001.

CONTACTS

William Patrick Prendergast
Department of Geomatics,
School of Environmental Planning and Management,
Faculty of the Built Environment
Dublin Institute of Technology,
Bolton Street,
Dublin 1
IRELAND
Tel. + 353 1 402 3838
Fax + 353 1 402 3999
Email: paddy.prendergast@dit.ie
Web site: http://www.dit.ie/geomatics