New Map Projections for Ireland

Consultation Paper

Making National Mapping Agency maps
compatible with GPS
whilst maintaining links to the existing
co-ordinate reference system

Ordnance Survey Ireland (OSi) and the Ordnance Survey of Northern Ireland (OSNI) are the mapping organisations responsible for the surveying and mapping of Ireland and Northern Ireland. They are jointly responsible for the development of a geodetic framework on which all mapping is based. Without this common co-ordinate reference system, mapping on the island would not "fit together".

This consultation paper follows 'A New Co-ordinate System for Ireland, Preliminary User Information', and is intended to provide additional details and technical data on the proposed change of map projection. The need for a new projection is discussed and new projection systems for Ireland proposed.

The Global Positioning System (GPS) enables precise positioning anywhere on earth with a precision of a few millimetres, if an appropriate reference frame and positioning infrastructure is in place. This framework and infrastructure in Ireland is known as IRENET95, and is a precise realisation of the European Terrestrial Reference System, ETRS89, resulting in European Terrestrial Reference Frame, ETRF89, co-ordinates.

Mapping in Ireland, however, as in many places around the world, is based on a different geodetic datum from that used by the GPS. Although transformation formulae and parameters are available between Irish Grid and ETRS89, it is beneficial, particularly for GPS users, to associate a map projection with ETRS89. A projection allows three-dimensional ETRS89 co-ordinates to be converted to a two-dimensional form that can be plotted on a map. This maintains the quality and precision of GPS for surveying and mapping purposes, and simplifies GPS positioning on all Ordnance Survey mapping products.

The objective of this consultation paper is therefore to propose new map projections for Ireland and to seek the views and valuable input from the user community on a range of issues associated with the subject.

Background and context

Irish Grid

The Irish Grid co-ordinate system, which is used by OSi and OSNI, is based on a rigorous adjustment of a carefully observed triangulation network, the origin of which dates back to the 19th century. The re-triangulation of Ireland and Northern Ireland in the 1950's and 1960's resulted in the Ireland 1965 datum from which latitude and longitude positions were computed in the Ireland 1975 (Mapping) Adjustment, on a modified Airy ellipsoid **[1]**. A Transverse Mercator projection was used to convert the latitudes and longitudes into 2-dimensional grid co-ordinates for mapping purposes.

The original parameters for the Irish Grid specified a scale factor of unity on the central meridian and applied to the Airy ellipsoid. Discovery of scale errors in the network resulted in the adoption of a scale factor of 1.000035 on the central meridian and introduction of the modified Airy ellipsoid to compensate. It is generally accepted that this scale factor is unusual (being greater than unity on the central meridian) and is partially due to shortcomings in measurement technology (including EDM equipment) at the time. Additional details and description of the datum and adjustment are contained in **[1]**.

ETRS89 and IRENET95

With the advent of satellite positioning systems in the 1960's, and specifically the US Department of Defense's Global Positioning System (GPS) in the 1980's, techniques for determination of precise global positions were developed. These techniques are capable of improving positioning by a factor of 10 compared to traditional methods, and can expose the limitations of existing control networks. This is the case in Ireland.

With almost global coverage available, it is now possible to establish precise continental co-ordinate reference systems. One such is the European Terrestrial Reference System (ETRS), established by the International Association of Geodesy (IAG). This is realised by a network of permanently recording GPS stations, and can determine, on a daily basis, solutions of the positions of the permanent sites, including movement in their relative positions due to tectonic plate activity. The resulting apparent movement has brought about the need to time-stamp positions. The adopted European System is therefore fixed at the start of 1989 (1989.00) and is known as ETRS89.

In 1994, OSi and OSNI jointly agreed to establish a new geodetic control network in Ireland based on ETRS89. The scheme was largely observed during 1995 and 1996, and the resulting network is known as IRENET95. This network complies with international standards and provides high precision, distortion free control for GPS surveys.

In order to establish compatibility between ETRS89 and the Irish Grid, OSi and OSNI commissioned the Institute of Engineering Survey and Space Geodesy (IESSG) at the University of Nottingham to determine the most appropriate mathematical transformation. As a result of this, and further research, transformation parameters between Irish Grid and ETRS89 have now been determined **[2]**.

The need for a new projection

Mathematical transformations cannot provide exact results; consequently they only partially realise compatibility between the Irish Grid and ETRS89. Applying a transformation to precisely surveyed positions results in distortion of the accurate GPS measurements to make them fit a less precise control network. It is more appropriate to maintain the accuracy of the survey by using mapping that is compatible with GPS, thus allowing surveys and mapping to be combined without the introduction of distortion. Therefore, to benefit fully from the accuracy achieved by IRENET95, both surveys and mapping should be based on this control network and datum.

Surveyors, engineers, navigators and a wide range of professional users, as well as the general public, increasingly use GPS. These users wish to be able to relate GPS positions to Ordnance Survey mapping unambiguously and quickly, without having to consider datum transformations, map projections, or the distortions inherent in the older mapping. It is therefore desirable that OSi and OSNI provide mapping that is compatible with GPS.

ETRS89 positions derived using IRENET95 control are three-dimensional, in the form of Cartesian or geographical co-ordinates. However, because ETRS89 relates to a different geodetic datum than Irish Grid, it follows that the ETRS89 latitude and longitude of any point differ from the Irish Grid values. To calculate grid co-ordinates from latitude and longitude requires that a map projection is associated with the new geodetic framework, thus providing two-dimensional grid co-ordinates that can be shown on a map. However, the grid co-ordinate obtained is dependent on the ellipsoid and projection parameters used.

ETRS89 relates to the GRS80 ellipsoid **[3]**, not the modified Airy ellipsoid used by the Irish Grid. By projecting onto different ellipsoids, different grid co-ordinates are obtained. However, the difference between the two sets of projected co-ordinates is only in the order of 55m. This is not large enough to identify which ellipsoid was used, and as a consequence introduces confusion. It is therefore desirable to alter the projection parameters sufficiently to differentiate between the co-ordinate systems used. Introducing changes to any of the projection parameters provides an opportunity to address additional ambiguities in the projection, such as the modified scale on the central meridian.

The problem of making maps compatible with GPS is not specific to OSi and OSNI. A number of European National Mapping Agencies (NMA's) including Denmark, France, Switzerland, and Sweden have already introduced, or are actively considering, new projections to associate with ETRS89.

The time is therefore ripe for the introduction of new map projections for Ireland to ensure full compatibility with GPS. This also provides an opportunity to address historic datum anomalies. The new projections need to be associated with the accepted global reference ellipsoid, GRS80, and associated co-ordinate system, ETRS89.

Intended properties of the new projections

The projections adopted by OSi and OSNI must fulfil several criteria. They are intended to be GPS compatible, and therefore must be associated with ETRS89 and the GRS80 ellipsoid. They must also be orthomorphic or conformal (that is, preserving local shape), and they must minimise mapping distortion throughout Ireland and Northern Ireland. The projections should also be based on formulae that are readily available. Additionally, they must allow compatibility with current mapping to be maintained.

New projection options

The Transverse Mercator projection has been identified as the most suitable type of map projection by OSi and OSNI, for the following reasons:

- It is suitable for mapping areas where the north-south dimension is greater than the east-west dimension.

- It is conformal (or orthomorphic), and therefore the relative local angles about a point on the map are shown correctly. Also, the local scale around any one point is constant, and the shape of small features is maintained. Conformal projections are standard for most NMA's in Europe.

Mapping distortions caused by the projection are dependent on, and can be minimised by, the choice of suitable parameters. Therefore, the following three forms of Transverse Mercator projection have been considered:

- the current projection, Irish Grid (IG);

- Universal Transverse Mercator (UTM);

- a newly derived projection, Irish Transverse Mercator (ITM).

The projection parameters for the IG, UTM and ITM are listed in **Table 1**.

		Current	Proposed	
		IG	**ITM**	**UTM**
Reference Ellipsoid		Airy (modified)	GRS80	GRS 80
Central Meridian		8° West	8° West	9° West
Scale on CM		1.000 035	0.999 820	0.999 600
True Origin	Latitude (ø) Longitude (λ)	53° 30' North 8° 00' West	53° 30' North 8° 00' West	0° 00' North 9° 00' West
False Origin (metres)		200 000 W 250 000 S	600 000 W 750 000 S	500 000 W 0 S

Table 1: Map Projection Parameters

Irish Grid (IG)
Originated as a classically derived Transverse Mercator projection, the IG was defined to meet the above criteria. The 1975 mapping adjustment resulted in alteration of the scale factor on the central meridian to 1.000035.

The parameters associated with IG are unsuitable for a proposed GPS mapping projection associated with the ETRS89 and the GRS80 ellipsoid. Applying these parameters, the difference between the projected ETRS89 and Irish Grid co-ordinate of a point is in the order of 55 metres. It is anticipated that this will introduce confusion regarding the co-ordinate system and projection used to derive any given point. Moreover, because of the adjusted scale factor on the central meridian, the effects of mapping distortions are not minimised.

UTM
UTM is an internationally recognised and widely available standard projection in mapping and GIS software. It was adopted in 1947 by the US Army, and used for military maps throughout the world. It divides the earth into sixty zones, between latitudes 84º North and 80º South. Each zone is 6º wide, with a scale factor of 0.9996 applied on the central meridian **[4]**.

Ireland is situated in UTM Zone 29, which has a central meridian 9º West of Greenwich, resulting in a small part of Counties Antrim and Down in the east of Northern Ireland extending outside the nominal zone width boundary of 6º West of Greenwich. However, the zone width may be altered to meet local circumstances and since the UTM grid has a standard zone overlap of 40 km on either side of a zone boundary, all of Ireland can be contained within Zone 29.

Since the central meridian lies along the West Coast of Ireland, mapping distortions are not distributed evenly. Applying UTM to Ireland results in co-ordinates that have a 7-digit northing and 6-digit easting, compared to the current IG reference system, which has 6 digits in each.

ITM

ITM is a newly derived projection that may be associated with the ETRS89 and the GRS80 ellipsoid. The true origin and central meridian defined in the Irish Grid are maintained, thus distributing the distortions due to the projection evenly.

Consideration was given to the introduction of a scale factor of unity on the central meridian. However, using a scale of 0.99982 (see **Appendix A**) results in two standard parallels, and the magnitude and effects of scale change are minimised.

The position of the false origin is moved to a point 600,000m west and 750,000m south of the true origin. This results in grid co-ordinates that are significantly different from IG, but does not introduce additional distortion or complexity. The magnitude of the shift ensures that IG co-ordinates plotted on the ITM projection do not fall on Ireland or Northern Ireland, and vice versa (see **Figure 1**).

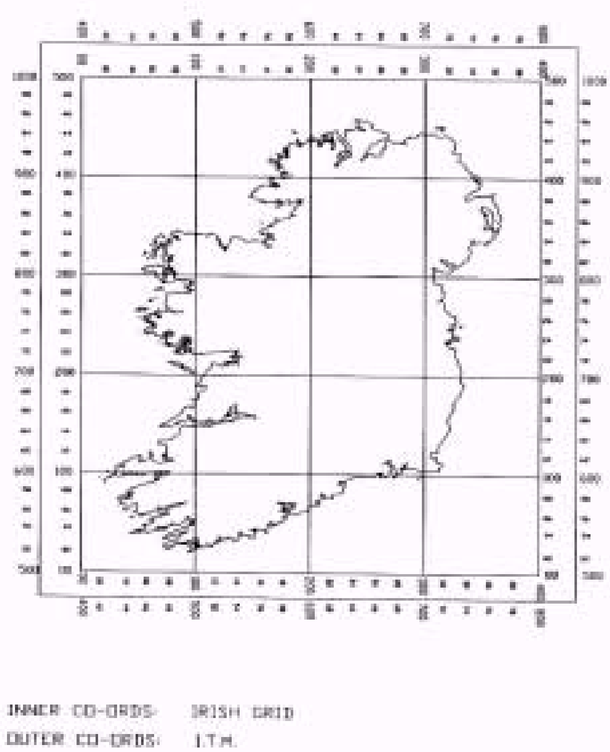

Figure 1: ITM and IG coordinates for Ireland
(This diagram is illustrative only – the relationship between IG and ITM is not constant and varies over Ireland.)

Comparison of the proposed projections

The effects of the three projections have been compared in relation to scale correction, area and convergence; figures are included in **Appendix B**.

Scale Correction
For Transverse Mercator projections, scale correction is a function of grid distance from the central meridian. It is therefore constant for any given easting, and is independent of the northing. The range of scale correction resulting from both IG and ITM is 355 ppm, whilst UTM has a range of 659 ppm. However, IG does not have a standard parallel (where scale is unity). Although UTM has one standard parallel, the location of the central meridian results in larger scale corrections on the West Coast. Since ITM is secant and centred on Ireland, it provides two standard parallels (see **Figure 2**).

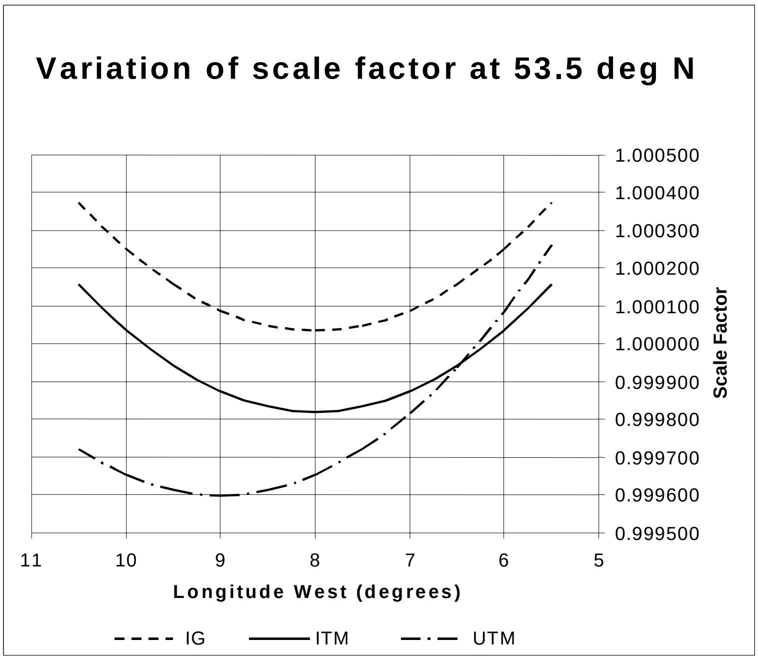

Figure 2: Variation of scale factor at 53° 30' N

Area
Currently all areas are computed by OSi and OSNI directly from the mapping (IG on the Airy modified ellipsoid), without applying scale corrections. Since all survey observations are reduced to the reference ellipsoid before being projected onto the mapping, changing the ellipsoid will introduce changes in the areas shown on maps.

To quantify the magnitude of the change, an area of one hectare (100m x 100m) on the current mapping was re-projected onto UTM and ITM. Applied to UTM, the largest change in area occurs on the central meridian at 9° West of Greenwich, and results in a decrease in area of 10.3m^2 (0.1%) Similarly, the worst-case for the proposed ITM mapping system occurs on the ITM central meridian at 8° West of Greenwich, and results in a decrease in area of 1.7m^2. Using the current IG projection parameters applied to the GRS80 ellipsoid results in an area increase of 2.4m^2.

When using a 1:1,000 scale map it is only possible to plot to an accuracy of 20cm, which results in a possible error in the area measurement of ±40 m^2. This is significantly greater then the area change resulting from a change in projection and therefore the effect on area measurements can be considered negligible.

Convergence
IG and ITM both use the same true origin and central meridian, and therefore using ITM projection parameters does not affect convergence. Furthermore, the change in the size of the ellipsoid from the modified Airy to GRS80 is not large enough to effect the calculated convergence.

Adopting UTM implies a central meridian at 9° West, which results in an increase in convergence of between 47' and 50'. At the extremes of the projection this increases convergence from 2° 03' 39" to 2° 53' 08".

Analysis of proposed projections and their implications

As described in previous sections, any new projections should minimise distortions within the new mapping system and realise ETRS89 co-ordinates that are substantially different from the existing corresponding Irish Grid co-ordinates (thus avoiding confusion). These criteria immediately rule out the possibility of maintaining the current projection parameters. However, both ITM and UTM will provide co-ordinates that are significantly different to IG.

With regard to scale correction, UTM produces the largest scale correction, of -400ppm or 40cm per km on the central meridian. This becomes significant when plotting measurements of greater than 500m. UTM also provides the largest range of correction (659 ppm). The location of the standard parallel requires that corrections of greater than 200ppm are applied to all observations west of a longitude of 7º west.

ITM, however, minimises and evenly distributes scale corrections, with a maximum scale correction of 180ppm on both the central meridian and the extremes of the projection. Positioning the central meridian in the centre of Ireland at 8º west also results in even distribution of convergence and t-T corrections.

The location of the UTM central meridian produces increases of 50’ in the convergence calculated along the East Coast. The adoption of either UTM or ITM map projections has no significant effect on area measurements.

This paper has described the complexities introduced when attempting to make GPS measurements fit onto existing mapping. The growing numbers of GPS users, most of whom have no interest in issues such as transformations and adjustments, will therefore be best served by a mapping system which is fully compatible with GPS.

There are, however, very many existing users of OSi and OSNI mapping. Many of these have associated their own data with the mapping data and therefore have significant databases using IG co-ordinates. There is substantial effort involved in converting these large databases into a different co-ordinate reference system. Any proposed change cannot ignore the needs of these users.

Whilst recognising that the majority of map data users in Ireland will not be concerned about the international compatibility of their work, there are important applications which will benefit significantly from such compatibility. Although UTM, for the reasons described, is not the ideal map projection when considering Ireland in isolation, it is an internationally recognised standard, and is likely to be adopted by the European Commission for its mapping needs.

Consequently, OSi and OSNI intend to adopt the following policy:

1. Adopt and offer a range of products and services using the ITM map projection with the above parameters to be associated with the ETRS89 co-ordinate reference system and the GRS80 reference ellipsoid.

2. Offer to their customers working in the international and European context the option to use data projected on UTM. This will provide a standardised international way in which grid co-ordinates can be expressed to ease integration and data exchange across Europe and beyond.

3. Continue to offer to their traditional map users the assured use and backward compatibility of IG products and services.

By using IRENET95 control, along with OSi and OSNI mapping projected in ITM or UTM, GPS surveys can be combined with national mapping while still maintaining survey accuracy and avoiding the current requirement to compute or apply transformations. It is further anticipated that the proposed new map projection, ITM, will simplify and encourage the use of GPS with OSi and OSNI products. Compatibility between the new projection and Irish Grid will be maintained using the derived transformations.

Use of ETRS89 requires that the GRS80 ellipsoid is used. Since the geoid in Ireland is not coincident with this ellipsoid, appropriate reductions must be applied when carrying out precise surveys. To further improve compatibility of OSi and OSNI products with GPS, methods are currently being investigated to allow the determination of orthometric height using GPS.

Following the introduction of new map projections for Ireland, all mapping must include the appropriate labelling to identify the projection used. Changes to the map detail depicted will not be significant enough to allow simple visual identification; the grid co-ordinates, however, will provide an easy method of distinguishing the projection and grid used. Adoption of new projections for Ireland may also have subsequent effects on the map cataloguing systems for users.

Consultation and implementation

Following the release of this technical consultation paper, a series of consultation seminars have been arranged throughout Ireland to discuss a range of issues connected with the proposed new projections for Ireland and other aspects of positioning. Once decisions have been made in light of the consultation, the new mapping projections and supply options can be implemented by OSi and OSNI.

It is anticipated that users will wish to raise a variety of issues associated with the proposed change of map projections, in advance of or at the consultation seminars. Particular issues which OSi and OSNI believe would provide valuable discussion and input are:

- The implications of the changes for different users;
- The time scale in which changes can be accommodated by users;
- The likely split between IG, UTM and ITM users;

- How the split of usage may develop over time;
- Areas where users would find support or further information valuable;
- What co-ordinate reference system should be used for small-scale maps such as the Discovery and Discoverer series;
- How product designs (particularly for paper mapping) can be developed to assist users in the easy identification of the co-ordinate reference system used for a particular map.

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Appendix A

Calculation of Scale Factor on the Central Meridian for ITM

Scale factor is a function of distance from the central meridian. Therefore, scale factor at a point is dependent on the ellipsoid chosen and the location of the central meridian. The longitudinal extent of Ireland is from approximately 5° 25' to 10° 30' west of Greenwich. Minimum distortion will be achieved if the central meridian bisects these, i.e. at 7° 57' 30" west of Greenwich. Obviously, it is desirable to simplify the parameters involved in the projection; therefore, this was rounded to 8° west of Greenwich.

To select the scale factor on the central meridian three options are available:

1. Maintain current scale factor of 1.000035
2. Use a scale factor of unity.
3. Use a scale factor of less than unity, i.e. secant projection

The third option produces two standard parallels and allows the magnitude of the scale corrections to be minimised throughout Ireland. Scale factor at a point is calculated from the formula:

$$F=F_o[1+P^2(((\cos^2\varphi)/2)(1+\eta^2))+P^4(\cos^4\varphi)/24)(5-4\tan^2\varphi+14\eta^2-28\tan^2\varphi\ \eta^2)]$$

Where:

F	is the scale factor at the point
F_o	is the scale factor on the central meridian
P	is the difference in longitude between the point and the true origin.
φ	is the latitude of the point
η	is the longitudinal component of the deviation of the vertical, and is derived from the formula:

$$\eta^2=(\nu/\rho)-1$$

Where:

ν is the radius of curvature of the ellipsoid perpendicular to the meridian, and is obtained from the formula:

$$\nu=a/(1-e^2\sin^2\varphi)^{1/2}$$

ρ is the radius of curvature of the ellipsoid along the meridian, and is obtained from the formula:

$$\rho=\nu(1-e^2)/(1-e^2\sin^2\varphi)$$

Where:

a	is the semi-major axis of the ellipsoid
e^2	is the eccentricity

Assuming a central meridian at 8° W, and a scale factor of unity on the central meridian, the maximum scale factor applying to Ireland was calculated as 1.000370 at approximately 10° 30' W, 51° 30' N, giving the range of required correction as 370 ppm.

Since the curve obtained from the above formula is symmetrical, the minimum magnitude of the required correction is obviously achieved by assuming a scale factor on the central meridian of 1-370ppm/2, i.e. 0.999815. This was rounded to 0.99982 to simplify the parameters involved in the projection. This has the added benefit of moving the position of the standard parallels towards the central meridian and, due to the geography of Ireland, increases the land area where scale is unity.

Factors and assumptions in the calculation:

- The calculation is based on a central meridian at 8° W.
- The central meridian does not correspond with the centre of the Island.
- The exact point having the maximum scale factor was not identified.
- The final figure was rounded to 5 decimals

Appendix B

Comparison of Projection Types:

- **Scale Correction**

	Current	*Proposed*	
	IG	**ITM**	**UTM**
Reference Ellipsoid	*Airy Modified*	*GRS80*	
Scale correction on west coast:	**1.000 390**	**1.000 175**	**0.999 723**
1. Over 100 m	+ 3.9 cm	+ 1.8 cm	- 2.8 cm
2. Over 1 km	+ 39.0 cm	+ 17.5 cm	- 27.7 cm
Plottable accuracy @ 1:1,000	20 cm	20 cm	20 cm
3. Max. Distance	**0.5 km**	**1.2 km**	**0.7 km**
Scale correction on Central Meridian:	**1.000 035**	**0.999 820**	**0.999 600**
4. Over 100 m	+ 0.4 cm	- 1.8 cm	- 4.0 cm
5. Over 1 km	+ 3.5 cm	- 18.0 cm	- 40.0 cm
Plottable accuracy @ 1:1,000	20 cm	20 cm	20 cm
6. Max. Distance	**5.7 km**	**1.1 km**	**0.5 km**
Scale correction on east coast:	**1.000 377**	**1.000 162**	**1.000 259**
1. Over 100 m	+ 3.8 cm	+ 1.6 cm	+ 2.6 cm
2. Over 1 km	+ 37.7 cm	+ 16.2 cm	+ 25.9 cm
Plottable accuracy @ 1:1,000	20 cm	20 cm	20 cm
3. Max. Distance	**0.5 km**	**1.2 km**	**0.8 km**
Range of scale correction:	355 ppm	355 ppm	659 ppm
Number of standard parallels in Ireland (where scale factor = zero):	0	2 721 269 E (ITM) 478 739 E (ITM)	1 680 550 E (UTM)

Table 2: Comparison of the effects of Scale Factor between the three projections

- **Area Correction**

Table 3 below shows a direct comparison between a current IG area measurement and the worst-case area differences in the ITM and UTM mapping systems:

	Current	*Proposed*	
	IG	**ITM**	**UTM**
Reference Ellipsoid	*Airy Modified*	*GRS80*	
Area (1 hectare):	10,000.0 m^2	9998.3 m^2	9989.7 m^2
Area difference from IG		- 1.7 m^2	- 10.3 m^2
Plottable accuracy @ 1:1,000	20 cm		
1. Best area measurement	9960.0 m^2		
2. Achievable accuracy	± 40.0 m^2		

Table 3: Area Comparisons