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NATURAL ENVIRONMENT RESEARCH COUNCIL

BGS STANDARDS
for the acquisition and management of
SPATIAL COORDINATE DATA

Information Management Programme

Internal Report IR/03/126

BRITISH GEOLOGICAL SURVEY

INTERNAL REPORT IR/03/126

BGS STANDARDS
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SPATIAL COORDINATE DATA

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Foreword

This report was instigated under the BGS-geoIDS project that was established to investigate and recommend standards for data management to be applied throughout the British Geological Survey (BGS). Advanced drafts were prepared in the year 2000, when the author John Hallam left BGS but final approval was not reached. In the interim, major developments have occurred in the way that the Ordnance Survey (and other authorities) recommend that spatial positioning is done. Changes resulting from these advances have been incorporated and these revisions to the report are the responsibility of Ian Smith, who undertook to have it completed.

Acknowledgements

Dr Richard Bingley, Prof Terry Moore and Prof Alan Dodson of the University of Nottingham's Institute of Engineering Surveying and Space Geodesy have provided valuable comments on the text and clarification of some of the complex matters discussed in this document. This has resulted in a much-improved report and has been much appreciated.

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Summary

This report sets out the standards that are recommended for use by BGS in recording spatial coordinates for the positioning of points, both in digital databases and elsewhere in other forms of documentation. The recommended standards conform to internationally accepted criteria using the latest state of knowledge of the shape of the earth. The report is arranged in two main sections: one that contains the standards definitions and another that provides background information on the issues that have been considered in arriving at the recommendations and points to further reading.

1 INTRODUCTION

At its inaugural meeting, the BGS-geoIDS Data Standards Subproject identified the need for greater consistency and the use of documented standards in the recording of spatial locations. Amongst the issues raised were:

- the inconsistent use of our National Grid; with positions being recorded as coordinates or references, in various numeric and character formats
- the poor definition of fields and dictionaries for spatial location data in many tables, with little or no technical metadata
- the need for a clear understanding of the principles and complexities involved in the conversion and transformation of positions between different coordinate systems, and of the limitations of most transformation algorithms
- the increasing integration of diverse datasets, both in GIS and the DGSM, requires consistency in the spatial coordinates
- the most recent BGS guidance [34]did not satisfy current or future requirements.

A working group was convened, under the Data Standards Subproject, to review these and other pertinent issues, and to recommend appropriate standards for adoption by BGS. The following have been members of this group or have provided valuable comments on the draft versions of this document: J Hallam (convenor), K Adlam, K Becken, S Coats, C Graham, R Lawley, J Mankelow, A McKenzie, R Musson, J Rowley, I Smith, D Tragheim and J Walsby.

These standards for using spatial coordinate data in BGS databases are being introduced in order to enhance the quality of this key data. Geodetic surveying and positioning is a highly specialised topic that has given rise to considerable confusion in the hands of non-specialists. With the advent of satellite positioning systems, such as the Global Positioning System (GPS), many positioning issues have been resolved, so that improved and rigorous solutions are available. The standards presented here focus on establishing what we know of the coordinate data, however much that may be, so that users may assess its potential value and limitations.

Section 2 of this report recommends appropriate standards for using coordinate data in BGS and a means of implementing and maintaining those recommendations. It gives the specific standards, with the attributes and format that are required in acquiring and entering coordinate data, and procedures for its subsequent management. It discusses the implications for data users and managers, with such training as is needed to implement the standards.

Section 3 of the report comprises a review of the issues that were considered in formulating the standards, particularly the significance of GPS and global coordinate systems, and the potential problems in relating GPS-based data to existing spatial coordinate data. It may help to inform the user of some of the complex issues involved.

References to the list of source documents and software in section 3 are denoted by numbers in square brackets, e.g. [31].

A glossary of acronyms and terms is included for those who are less familiar with the subject. Readers are particularly recommended to consult the Ordnance Survey's excellent Guide to coordinate systems in Great Britain [19], which provides an in-depth treatment of the subject, but without presuming much prior knowledge.

2 RECORDING AND MANAGEMENT OF COORDINATE DATA

2.1 PURPOSE AND SCOPE OF THE STANDARDS

The purpose of these standards is to provide consistent procedures for recording all relevant information relating to spatial coordinate data, including their source, errors and coordinate system, and for their subsequent management. They are concerned principally with horizontal coordinates for spatial point data in corporate databanks. In most respects they are also relevant to other data types such as lines and polygons, and to more ephemeral project datasets. The issue of height and Vertical Datum is briefly covered but all these aspects should be more fully addressed in the future.

2.2 DATA ACQUISITION AND ENTRY

2.2.1 Coordinate positions from maps

Whereas plans depict the true size and position of topographic features, maps represent at least some of this detail in a symbolic form, at an exaggerated size, and/or displaced in position, particularly at smaller scales. For example, the minimum size of features that are shown in true plan on 0S 1:10 000 maps ranges from 5m for buildings to 12 m for named roads.

The coordinates with respect to the grid, or graticule are required for accurate positioning. To obtain these from a map, care must be taken to interpret the true position of detail (usually the estimated centre of a small or narrow feature rather than its boundaries as shown).

Where source documents provide both tabulated coordinates and plotted map positions, the tabulated values must be used unless the plotted positions are known to be more accurate.

2.2.2 Coordinate positions from GPS

Where new data is spatially located by means of GPS, the WGS84 geographical coordinates (or, in the case of any differential techniques, the ETRS89 geographical coordinates) should, by preference, be recorded as the master values for corporate data. Where the user selects an alternative representation, to satisfy their immediate requirement in the field, the relevant transformation parameters that are applied by the receiver or software should be recorded in the appropriate metadata. Wherever possible, receivers or software should be used that apply standard transformations, as identified in section 2.5 of this report.

2.2.3 Coordinate reference

The coordinate reference must be identified in a specific field in the dataset, except where the whole dataset is coordinated in a single system, in which case the field name will specifically identify the system through a standard coded format. For geographical coordinates, the TRF must be identified. For grid coordinates, the grid system must be identified, together with the TRF where this is not implicit in the grid system. (see section 2.4.5). The coordinate reference identifiers will be maintained in a standard BGS dictionary, which will be related to the current version of the EPSG database of geodesy parameters [2].

2.2.4 Elevation

Elevation data in Great Britain should normally be referred to Ordnance Datum Newlyn (ODN). On offshore islands and in Northern Ireland, local datums should be observed. The datum must be identified in the name of the data. Depths in boreholes should be given as positive values below the datum, which might be a locally identified index such as Rotary Table or Casing Collar. The datum will be referenced as a standard from the dictionary table shown in Table 1.

Table 1 Code Dictionary for vertical datums

Code	Vertical Datum
ODN	Ordnance Datum Newlyn
ODNI	Ordnance Datum for Northern Ireland
GL	Ground Level
RT	Rotary table
CC	Casing collar
KB	Kelly bushing

2.2.5 Accuracy

The accuracy of the coordinates is to be recorded as a code (Table 2) that denotes approximately the error in the method used for deriving the position. Whenever practicable this error should be obtained by means of a realistic error budget.

Table 2 Accuracy codes

a Code dictionary for accuracy of horizontal position data

	Error of coordinate values			
	Rectangular	geographical		
Code	**metres**	**degrees**	**minutes**	**seconds**
0	>1000	>0.01	>0.5	>30
1	>300	>0.003	>0.15	>10
2	>100	>0.001	>0.05	>3
3	>30	>0.000 3	>0.015	>1
4	>10	>0.000 1	>0.005	>0.3
5	>3	>0.000 03	>0.001 5	>0.1
6	>1	>0.000 01	>0.000 5	>0.03
7	>0.3	>0.000 003	>0.000 15	>0.01
8	>0.1	>0.000 001	>0.000 05	>0.003
9	<0.1	<0.000 001	<0.000 05	<0.003
U	Not known			
. (decimal)	Not entered			

b Code dictionary for accuracy of height

Code	Error (metres)
0	>100
1	>30
2	>10
3	>3
4	>1
5	>0.3

6	>0.1
7	>0.03
8	>0.01
9	<0.01
U	Not known
. (decimal)	Not entered

2.2.6 Resolution

Coordinates are to be recorded to a resolution sufficient to locate the point centrally within the area of uncertainty, i.e. at the most probable position. The resolution should at least three times 'better' than the accuracy (e.g. for an accuracy of ± 6 metres, the resolution is to be 2 metres or better), but where the coordinates are read from a map or plan, the resolution is not required to better than 0.2 mm on the paper (for example, 5 metres at 1:25 000 scale).

Where coordinate data are taken from existing documents, or from survey instrumentation and/or computation, the values should never be truncated. Furthermore, coordinates are not to be rounded if the resulting resolution would be less than one order 'better' than the accuracy.

2.2.7 Source or derivation of position

Coordinate data can become available in a number of ways that will influence their validity and accuracy. They may be measured in the field, taken off maps or other records or estimated from other information. In so far as it is known, the source of the data is to be recorded by means of a standard code (Table 3).

Table 3 Code dictionary for source or derivation of position

Code	Method of derivation of position
MAP	measured from map graticule
AP	measured on air-photograph
REC	copied from form or other record
EST	estimated from known point
DR	deduced (dead) reckoning
TRI	determined by triangulation
TPS	determined by a total station using polar tacheometry or radials
GPS	determined by GPS

2.3 DATA FORMAT

2.3.1 General format

Coordinates are to be held as real numbers in double precision. Single fields are to be used for each coordinate. No field may be used for both geographical and grid coordinates. Data should be displayed to the user with an appropriate number of significant figures for the data quality and application.

2.3.2 Geographical Coordinates

Geographical coordinates are to be held in decimal degrees, by default to six decimal places. Latitude to be positive north of the equator, and negative to the south. Longitude to be in the range 0 to 180, positive to the east of the Zero Meridian (0º of longitude) and negative to the west. Conversion sub-routines are to be used for data entry or viewing in decimal minutes or decimals seconds, if required. To aid in viewing, where the software is capable, decimal digits to be *displayed* in groups of two or three, with spaces between.

Where it is necessary to retain the original data in various sexagesimal formats (degrees, minutes, seconds), as in the legal definition of offshore boundaries, such data is to be held as text fields, with a third field to record the specific text format. To facilitate subsequent parsing and conversion, the format is to be space delimited, starting with the hemisphere.

Example:

TREAT	**TP**	**TXT_ FORMAT**	**LAT_ TXT**	**LONG_ TXT**	**TRF**	**LAT**	**LONG**
NOR_1	8	H dd mm ss	N 61 44 12	E 01 33 36	ED50	61.736 667	1.560 000
NOR_2	9	H dd mm ss.ss	N 61 44 12.00	E 01 33 13.44	ED50	61.736 667	1.553 733
FRO_1	B	H dd mm.mmm	N 63 40.649	W 00 47.736	EF89	63.677 483	-0.795 600

2.3.3 Grid coordinates

Grid coordinates are to be held numerically in the fundamental unit of the grid system concerned, by default to one decimal place. In the great majority of cases this unit is the metre, although very occasionally an Imperial measure. To aid in reading, the integer part of the coordinates should be displayed in groups of three digits, with spaces between.

*NB: The format of grid references, including our National Grid References, is explicitly defined by the Ordnance Survey and other authoritative agencies. This format comprises a **single** alphanumeric string (for example SK 1234 5678), commencing with two characters for other than local usage, and thence an equal number of digits for easting and northing, commensurate with the resolution. This format is designed for use with specific map scales and is also appropriate for text documents such as memoirs. For digital datasets, grid coordinates, not grid references, should be used.*

2.4 DATA MANAGEMENT

2.4.1 Original data

The original coordinates as determined by, or supplied to, BGS must be entered and retained with the dataset. If these subsequently need to be converted and/or transformed to another coordinate system, it may then be appropriate to relegate the values in the original coordinate system to an archive, but they must never be deleted.

2.4.2 Master coordinate reference system and TRF

ETRS89 will be adopted as the standard coordinate reference and a scheduled programme will be developed for the progressive transformation of datasets to the associated ETRS89. Positions will be held as geographical coordinates (latitude/longitude).

NB: The spatial data will continue to be available to users in the original or other coordinate systems, as required

2.4.3 Standard projections

For maps at scales of 1: 500 000 and larger, covering both onshore and offshore areas, UTM is the preferred projection and grid coordinate system, unless there are overriding reasons to the contrary. The standard TRF for this projection should be ETRS89. The UTM grids must be restricted to their relevant zones of 6° of longitude, on the appropriate Central Meridian. For the UK and surrounding areas, these are Zone 29, Central Meridian 3°E; Zone 30, Central Meridian 3°W and Zone 31, Central Meridian 9°W. Two or more such grids may be portrayed on a single map sheet.

A Transverse Mercator projection, centred on an appropriate meridian and with a geographic graticule, should normally be used for scales of 1: lM and smaller.

2.4.4 Transformations

For any dataset in which any of the spatial coordinates have been transformed from a different TRF, a field is to be included to record a standard dictionary code for the transformation method. These codes will be maintained in a Transformation Table, which will either include the relevant transformation parameters or link to a defined source. This table will be linked to the EPSG database [2].

Coordinate transformation for datasets that could potentially be used at 1:250 000 scale or larger should, wherever possible, be undertaken by specific validated software outside a GIS environment. Great care is needed in the use of GIS software for this purpose, at least until more rigorous and better documented versions become available.

Data management will maintain external links so as to be aware of current transformation algorithms from official sources such as the Ordnance Survey and EUREF, or otherwise from the current version of the EPSG database [2], and will maintain appropriate software for their implementation.

All conversions, transformations, and other mathematical operations on spatial coordinate data will be carried out in double precision arithmetic.

2.4.5 Field names for spatial coordinate data

Fields for spatial coordinate data are to be named in accordance with the following conventions, where 'XXXX' and 'CCCC' are standard dictionary codes identifying, respectively, the TRF (Table 4) and grid system (Table 5):

Geographical coordinates:

	Field name	**description**
general case:	LAT	latitude
	LONG	longitude
	TRF_code	standard TRF code 'XXXX'
all data on single TRF:	LAT_XXXX	latitude
	LONG_XXXX	longitude

(for example LAT_ED50, LONG_ED50)

Grid coordinates:

	Field name	**description**
general case:	CCCC_E	easting
	CCCC_N	northing

	TRF_CODE	standard TRF code 'XXXX'
TRF implicit in grid system:	CCCC_E CCCC_N	easting northing
(for example: BNG_E, BNG_N)		
TRF not implicit in grid system:	CCCC_XXXX_E	easting
	CCCC_XXXX_N	northing
(for example: U31N_ED50_E, U31N_ED50_N)		

Table 4 Code dictionary for Terrestrial Reference Frames (TRFs)

TRF_ CODE	ACRONYM	EPSG_ CODE	ELLIPSOID	DESCRIPTION
GB36	OSGB36	6277	Airy 1830	Ordnance Survey Great Britain 1936
ED50	ED50	6230	International 1924	European Datum 1950
ES89	ETRS89	6258	GRS80	European Terrestrial Reference System 1989
WG84	WGS84	6326	WGS84	World Geodetic System 1984
IR75		6300	Airy 1830 modified	Ireland 1975

Table 5 Code dictionary for grid coordinate systems

GCS_CODE	EPSG_ CODE	TRF_ CODE	DESCRIPTION
BNG	27700	GB36	(British) National Grid
IRG	29900	IR75	Irish Grid
U##N_XXXX			UTM Grid, Zone ## (01-60), northern hemisphere, TRF code XXXX
U##S_XXXX			UTM Grid, Zone ## (01-60), southern hemisphere, TRF code XXXX

2.4.6 Other external developments

Data Management staff will maintain a current awareness of the status of ETRS89, EUVN and EVRS with respect to the UK, and in particular to the national topographic mapping and coordinate reference systems, by regular monitoring of the relevant web sites, including those of the Ordnance Survey and European agencies such as CERCO, EUREF and MEGRIN.

2.5 STANDARD COORDINATE TRANSFORMATIONS

The following transformations are to be used with coordinate data for the British Isles and surrounding shelf areas. The transformations will be implemented within a range of applications, which should be checked to ensure that their output is accurate. BGS have several applications that meet the standards, including Blue Marble's Geographic Calculator and GeoCalc, Grid Inquest from Quest Geodetic Solutions Software Ltd, and Concept Systems Inca software.

They should be reviewed regularly, and further standard transformations added when appropriate. As a result, some transformations that have become invalid since March 2000 have been removed to Annexe A.

(Note: Many geodetic entities have been assigned an unique code by EPSG. Where available, the code is given here to aid and clarify the identity of the transformation.)

2.5.1 ETRS89 to OSGB36

2.5.1.1 OSTN02 (0.1M)

Authority: Ordnance Survey.

Accuracy: ~ ± 0.1 m for primary and secondary stations in OSGB36.

EPSG code: None as yet.

Status: Current at Aug 2003

Extent: Great Britain (based on OSTN02 that covers all the British Isles)

Applicability: Standard BGS transformation procedure where the coordinate data is accessible.

Method: 'Rubber sheet' transformation, using bi-linear interpolation to obtain easting and northing shifts from a transformation grid of one kilometre resolution. The method transforms and converts between ETRS89 geographical coordinates and (projected) National Grid coordinates.

Availability: Grid Inquest is available at http://www.qgsl.com/software/gridiq.shtml (this is a free download; there is also a .dll application available for including in programs). This is only applicable to onshore UK.

2.5.1.2 OSTN02 (5M)

Authority: Ordnance Survey.

Accuracy: ~ ± 5 m for primary and secondary stations in OSGB36.

EPSG code: None as yet.

Status: Current at Aug 2003

Extent: Great Britain, to 20 km offshore (as for OSGB36).

Applicability: Widely applicable lower accuracy transformation and conversion procedure for Transverse Mercator and other projections

Method: Helmert 7 parameter transformation by position vector

Availability: http://www.gps.gov.uk/additionalInfo/gpsSpreadsheet.asp

2.5.1.3 'OSGB PETROLEUM TRANSFORMATION'

(Not formally named, this is its recognised offshore title)

Authority: Ordnance Survey [19], DTI / UKOOA [27].

Accuracy: ± 5 m or better.

EPSG code: 1314

Status: Current as of August 2003

Extent: Great Britain, to 20 km offshore (as for OSGB36).

Applicability: GPS receivers, and GIS packages which are unable to implement OSTN02.

Method: Helmert 7 parameter transformation by position vector (Bursa-Wolf) method between the 3-D Cartesian coordinates.

Approximate transformation parameters from ETRS89 (WGS84) to OSGB36						
dX (m)	dY (m)	dZ (m)	Rot X"	Rot Y"	Rot Z"	Scale (ppm)
-445.448	+125.157	-542.060	-0.1502	-0.2470	-0.8421	+20.4894

Test point:	Latitude	Longitude	Ellipsoid height
ETRS89	53.000 000°	1.000 000°	50.00 m
	(53° 00' 00.000"N)	(1° 00' 00.000"E)	
OSGB36	52.999 644°	1.001 803°	3.99 m
	(52° 59' 58.719"N)	(1°00' 04.490"E)	

2.5.2 ETRS89 (WGS84) to ED50

"Common Offshore" transformation

Authority: DTI / UKOOA [27].

Accuracy: ~ ± 2 m for North Sea, decreasing to the west.

EPSG code: 1311

Status: Current as at August 2003. This transformation has effectively become the legal definition of ED50 for the UK continental shelf (UKCS) to the east of 60° longitude.

Extent: Great Britain, Ireland, North Sea and English Channel. ED50 has little meaning to the west of 90° W longitude.

Method: Helmert 7 parameter transformation by position vector (Bursa-Wolf) method between the 3-D Cartesian coordinates.

"Common offshore" transformation parameters from ETRS89 (WGS84) to ED50						
dX (m)	dY(m)	DZ (m)	Rot X"	Rot Y"	Rot Z"	Scale (ppm)
+89.5	+93.8	+123.1	0	0	+0.156	-1.200

Test point:	Latitude	Longitude	Ellipsoid height
ETRS89	53.000 000°	1.000 000°	50.00m
	(53° 00' 00.000"N)	(1° 00' 00.000"E)	
ED50	53.000 802°	1.001 417°	2.72m
	(53° 00' 02.887"N)	(1° 00' 05.101"E)	

2.6 IMPLEMENTATION

2.6.1 Responsibilities for implementing the standards

Geoscience Resources & Facilities Directorate	**Geoscience Data & Information Management**
• Basic training for staff working with spatial coordinates • Ensure compliance of any GPS receivers and GIS software to corporate standards, particularly the transformation parameters	• Identify relevant databanks and managers • Ensure core expertise amongst the key managers • Amend data fields and tables in databanks to corporate standards • Obtain and install standard software utilities for conversions and transformations • Trial implementations of standards for range of datasets • Extension of standards to complex data types • Generate 'master' coordinates in ETRS89 or equivalent for corporate datasets, using the definitive OS transformation for National Grid coordinates

2.6.2 Implications for data users

The underlying purpose of the corporate standards is to enhance the quality of the spatial coordinate data held in BGS datasets. A clearer framework, which records the accuracy of the coordinates, the source from which they have been derived, as well as the TRF or grid system and its associated TRF, will enable the reliability of such data to be taken into account.

The implication of these standards for most users is that they will need a short training course, as outlined in the following section, to ensure that the standards are understood and can be applied consistently across the organisation.

2.6.3 Implications for data management

For data management, the major implications derive from the implementation schedule outlined in the above table. Some databanks may contain little coordinate data, if any.

The mapping of existing data into new or amended fields, or possibly tables, is likely to be a significant issue in some cases. One could foresee problems with the attribute data rather than the numeric coordinates. For many of the existing records, the data relating to the accuracy and source of the coordinates, and in some cases even the coordinate reference, is patchy at best. Care will be needed if the new standards are not to be degraded by populating the attribute fields with data that cannot be mapped across with reasonable confidence. The existing fields should be retained until they are no longer of potential value.

The Ordnance Survey has defined OSTN02 that allows ETRS89 and National Grid coordinates to be inter-converted [19]. National Grid coordinates will remain unchanged, but are defined with respect to ETRS89 and OSTN02, rather than OSGB36. The vast majority of the familiar, and often almost inaccessible, triangulation pillars are now redundant. In their place, the Ordnance Survey has established about a thousand ground stations as the realisation of ETRS89, which are much more conveniently located and appropriate for GPS. Within this network, there are currently approximately 30 active stations whose data can be obtained free-of-charge via the WWW. This major change is of significance only to surveyors, not to map users.

The OS are considering the introduction of a 'new mapping grid', i.e. a new projection based directly on ETRS89. Mapping on this grid would then be compatible with a seamless and highly accurate coordinate system, onshore and offshore, across the whole of Europe, and effectively the world. Until this is implemented (which could be many years in the future), there is no pressing need to transform our National Grid coordinate data, provided that this data is used solely onshore. However, there will be an increasing need to transform data from different coordinate systems to a common reference frame, as for example for the DGSM, and in these cases this must be ETRS89. For compatibility with other existing datasets and mapping, National Grid coordinates would still be needed for the foreseeable future.

Well-documented standard software utilities will be needed for both coordinate conversions and coordinate transformations of large corporate datasets. These should preferably be generic utilities that can, for example, implement any Transverse Mercator projection, or any Helmert transformation and may need to be implemented as Oracle and as Access/Excel functions. A free spreadsheet application is currently available from the Ordnance Survey [23a], and from Quest [24], which includes a Dynamic Linked Library (DLL) for incorporating into software.

These are essentially issues for data management. It is envisaged that data users will be provided with views or working versions of the underlying tables, so that they see locational data only in their required coordinate system.

Current GIS software packages do not always retain the relevant TRF with the datasets, or handle transformations dependably. The introduction of ESRI's 'Spatial Database Engine' or equivalent may alleviate this problem, by making the spatial coordinate data accessible for data management.

2.7 TRAINING AND EXPERTISE

It is envisaged that the management of corporate datasets will be undertaken by, or at least be under the close control of, Information Services and Management. This directorate will need to develop and maintain a depth of expertise in the issues that are addressed in this document. These issues are likely to be increasingly significant for a period of many years, and possibly some decades. To maintain the integrity and quality of the spatial coordinate data, the various coordinate systems must be known and understood, as must the data itself and any processing that is applied after acquisition.

To ensure that the standards are understood and applied consistently, there is a perceived need for some form of basic education or training for all those who generate or subsequently use spatial coordinate data An outline for a short training course is included with the standards.

2.7.1 Basic training course

Audience:	Staff who generate, enter or work with spatial coordinate data
Duration:	One day, with presentations and practical
Purpose:	To provide a working level knowledge of the standards and their application to various data types and disciplines
Major topics:	Recognition of spatial data in differing coordinate systems
	Correct application of the standards with respect to coordinate accuracy, source and/or derivation, and other attributes where relevant
Awareness of:	Global coordinate reference systems and their potential significance
	Significance of TRFs and transformations
	Ellipsoidal and orthometric heights

Projections and their properties

Correct use of grid references

Capabilities and limitations of various GPS receiver equipment

Capability and/or limitations of current GIS packages in handling data in different TRFs.

Practical: Outdoor exercise on site to provide practical examples of various techniques for obtaining positional coordinates and assessing their accuracy

2.7.2 Core expertise within data management

The data management programme will need to develop and maintain a core of expertise in the issues that are addressed in this standards document, probably at two levels. All data managers with responsibility for any significant amount of spatial coordinate data will need a sound working knowledge of the standards, at least in so far as these are relevant to the datasets in question. Beyond that, they should have a basic awareness of the full range of topics raised in this document and the possible relevance to their data.

At a second level, which might entail perhaps two or three members of staff would be the responsibility for:

- ensuring that the standards are maintained consistently across the corporate datasets
- the validation and installation of standard software utilities for conversions and/or transformations
- carrying out any transformations on corporate datasets
- maintaining an awareness of external factors, including any relevant policy developments by the Ordnance Survey and other authoritative agencies
- updating and developing this standards document

3 ISSUES AFFECTING THE STANDARDS

3.1 TERRESTRIAL COORDINATE SYSTEMS

This section provides a discussion of coordinate systems, for the benefit of data managers and others working with a diversity of spatial coordinate systems. Such readers are advised to consult the Ordnance Survey's Guide to coordinate systems in Great Britain [19] for an excellent introduction to the these topics. Terrestrial coordinates (those for describing positions on the surface of the Earth) may be one of three types: 3-D Cartesian coordinates, grid (projected) coordinates and geographical coordinates.

3.1.1 3-D Cartesian Coordinates.

3-D Cartesian coordinate reference systems comprise three perpendicular axes, X, Y and Z, with a common origin at the Earth's centre. The Earth's axis of rotation is taken as the Z axis, the positive side passing through the North Pole. Normal to this axis and passing through the origin, the X and Y axes are contained in the equatorial plane. The positive X axis passes through the Prime Meridian (0 degrees longitude).

3D Cartesian coordinates are the most fundamental and flexible type of coordinates, though of little value to the practical user, as they do not relate position directly to the surface of the Earth. With an increasing recognition that this surface is not static, but dynamic, horizontally and vertically, in a wide range of timescales, it has become more desirable to take the Earth's centre as the origin of a truly global coordinate reference system. As an origin, the Earth's centre has become accessible only since the advent of artificial satellites, as it inherently constitutes one of the two foci of every satellite's elliptical orbit.

The U.S. Department of Defense's World Geodetic System 1984 (WGS84) is the predominant 3-D Cartesian coordinate reference system in use today and for the foreseeable future. (The date refers to the alignment of the X axis at time 1984.0). Coordinates in this system are obtained through the satellites of the Global Positioning System (GPS), which are positioned through the WGS84 coordinates of its 5 permanent tracking stations [7]. The coordinates for one of these stations (X = 3981776.718 m, Y = -89239.153 m and Z = 4965284.609m) for example, would not readily indicate to many users that it is located close to the M4 motorway in Berkshire!

3.1.2 Grid Coordinates

For most practical applications, whether on paper maps or on GIS displays, spatial locations are required on a plane surface, ie in 2-D. Map projections provide the means for representing a 3-D ellipsoid on the plane surface, though at the inevitable cost of some distortion, in shape and/or scale, which increases markedly with the area of ground coverage. The projections now used for most national topographic mapping, Transverse Mercator and Lambert Conical Orthomorphic, are designed to maintain shape (orthomorphism) at least locally, at the expense of scale. Ground coverage of an individual projection, such as a UTM zone, is usually limited so that scale distortion does not exceed 0.1%.

The 2-D coordinates are more commonly referred to as grid coordinates, map coordinates, plane (rectangular) coordinates, or as eastings and northings. Map projections comprise a set of defined formulae and specified constants to convert precisely between geographical and grid coordinates. The only common parameters are those defining the size and shape of the ellipsoid, which must be the same for both of the coordinate systems.

Some projections, such as Universal Transverse Mercator (UTM), are for general application, in that they may be used with any consistent set of geographical coordinates. With such projections, therefore, it is essential to state the TRF that has been used. Other projections, such as the

Ordnance Survey's National Grid, have a single specific application, and define both the geographical coordinate system and all the projection constants.

3.1.3 Geographical Coordinates

Latitude and longitude comprise the most common coordinate type for stating position on the near-spherical surface of the globe. They are 'spherical' coordinates, in that they define a position by **angles** with respect to the surface of the rotating globe. The latitude of a point is the angle between the equatorial plane and the line perpendicular to the surface at that point, whilst longitude is the angle about the rotational (polar) axis between the same perpendicular line and an arbitrary zero longitude. North-south lines of constant longitude are known as meridians, and east-west lines of constant latitude as parallels. Latitude and longitude are often regarded in a sense as horizontal coordinates, complemented by the vertical direction of gravity, for which we have a strong natural sense of direction.

To define these coordinates more precisely, it is first necessary to identify the global surface in question. In spatial location one can recognise three different surfaces:

1. the Earth's topographic surface, comprising the topography of the ocean bottom as well as the exposed landmasses. This surface is highly irregular, and in places even vertical
2. the surface that we would intuitively take as flat and consistent, the surface of the oceans, averaged for tidal variation. This surface is everywhere perpendicular to the direction of gravity (an equipotential surface) and is termed the 'geoid'. Its shape is close to that of an ellipsoid, that is an ellipse rotated about its short (semi-minor) axis
3. the regular geometric or mathematical form of the ellipsoid is important as a reference for positioning. There have been many attempts to determine the size and shape of the ellipsoid that best averages the geoid.

To put these various surfaces into perspective, the maximum separation between the geoid and best current ellipsoid is little more than 100 metres. The difference between the Earth's polar and equatorial radii is about 21.4 km (0.3%), only slightly more than the 19.9 km range of the topographic surface.

There are two principal types of latitude and longitude, astronomic and geographic (or geodetic). Astronomic positions are observed individually, as the angles between the local *vertical* and the relevant reference planes, which are determined from the Earth's rotation with respect to the stellar background. Not only are they difficult to measure and compute with any accuracy, but they are coordinates on the *geoid* surface.

Geographical or geodetic coordinates provide consistent and accurate positioning, using the regular form of an ellipsoidal reference surface. However, an ellipsoid is merely a mathematical concept which attempts to provide the best average fit to the somewhat irregular shape of the geoid. Since an ellipsoid has no physical reality, one cannot observe or measure the perpendicular to its surface at any point. Latitude and longitude as geographic coordinates must either be assumed or calculated.

Historically, the geodetic control points that underpin topographic mapping have been coordinated by chains or networks of triangulation, and more recently trilateration. Typically it has been necessary to assume that the geoid and the chosen ellipsoid are coincident and parallel at one origin point, where the geodetic coordinates and orientation are thus taken as identical to the observed astronomic values at that point. The defined size and shape of the ellipsoid then enables latitudes and longitudes of the other control points to be calculated, again by assuming that the triangulation is laid over the ellipsoid surface.

Many ellipsoids and datum points have been used in the past for topographic mapping on a national basis. Each combination constitutes an independent latitude and longitude coordinate system. Given the raft of underlying assumptions and the errors inherent in network observation and adjustment, a given ground point could have many different geographic coordinates. Such coordinates will be uncertain or ambiguous unless the relevant TRF is specified.

3.2 TERRESTRIAL REFERENCE FRAMES (TRFS): REALISATION AND CONSISTENCY

To be of any practical value, all ground stations and points must be located with respect to the physical Earth. Historically, the necessary parameters to achieve this have been described as a 'geodetic datum' or just 'datum'. These terms have been much abused, and the underlying concepts are readily misunderstood. With particular reference to the classical networks of triangulated control stations, authorities such as Bomford [28] have defined a geodetic datum as 'an ellipsoid + an origin', the 'origin' being the geodetic coordinates and orientation at an initial control station, which have usually to be determined by astronomic observation. In other words, an ellipsoid of given size and shape is fixed to the Earth in position and orientation at just one initial point. Coordinates for the other control stations are then calculated and fixed, on the assumptions that the initial values were 'correct', the triangulated network (observed by the best methods available and adjusted by least squares) is error-free and that the observations were made over the ellipsoid surface. Such assumptions will have been unavoidable, but are most unlikely to be true. Their effects will rarely be discernible to those using the topographic mapping for which the control network was established. Problems are only apparent where two networks overlap. Not only will the latitude and longitude values for the common points be different in the two networks, but such differences are unlikely to follow any consistent pattern.

The great majority of current topographic maps are necessarily located with reference to these historical networks of national or regional triangulation. Since the time of their survey, two significant issues have emerged that offer, on the one hand, much improved positioning methods and accuracies, but on the other, problems that were not previously recognised or could not be addressed. Both issues require that 'datums' are considered with greater clarity and precision.

The first issue is the advent of satellite positioning, which can now provide coordinates in a single global coordinate reference system, to an accuracy of a few centimetres. Second is the recognition that the Earth's surface is not static, but is continuously in motion both horizontally and vertically, on a variety of timescales. Whilst the accuracy of satellite positioning now enables these movements to be measured, at least on the shorter timescales, this requires a reference system that is essentially independent of such movements, i.e. a system that is referenced to the globe as a whole rather than any single ground point. The classical concept of geodetic datums is now replaced by two entities: *Terrestrial Reference System (TRS)* and *Terrestrial Reference Frame (TRF).* A TRS sets out the principles by which a given coordinate reference system is located with respect to the Earth, whereas a TRF *realises* the system by providing *consistent* coordinates for a set of actual ground stations. *'Realisation'* and '*consistency'* are both essential concepts in understanding either modern reference frames or classical 'datums'.

As an example of a TRS, just four criteria and four numeric parameters are needed to define the WGS84 global 3-D Cartesian coordinate system and its accompanying ellipsoid [7]. It is geocentric, in that its origin is the centre of mass of the Earth including the oceans and atmosphere. The orientation of its axes at time 1984.0 correspond (within 0.005") to the Reference Pole and Zero Meridian as determined by the Bureau International de l'Heure. Its orientation with time creates no residual rotation with respect to the Earth's crust (i.e. it is static in relation to the averaged tectonic motion of the various plates).

"……an important distinction is needed between the definition of a coordinate system and the practical realization of a reference frame. To achieve a practical realization of a global geodetic reference frame, a set of station coordinates must be established. A consistent set of station coordinates infers the location of an origin, the orientation of an orthogonal set of Cartesian axes, and a scale. In modern terms, a globally distributed set of consistent station coordinates represents a realization of a Terrestrial Reference Frame."

(National Imagery and Mapping Agency, 1997)

This quotation from the defining manual for WGS84 clearly expresses the significance of TRFs. Coordinate reference *systems,* which include any designation of a specific ellipsoid, are merely abstract concepts, and of no practical use, either to a geodesist or a layman. The spatial location and orientation with respect to the Earth of any coordinate reference system, viewed either as an ellipsoid or a set of 3-D Cartesian axes, can only be inferred from the coordinates that are given to actual ground stations. The 3-D coordinates for just three control stations will imply both the location and orientation of the Cartesian axes. For the whole set of control stations coordinates in a TRF to be consistent, the coordinates for any and every subset of three control stations must infer the *same* location and orientation of the axes. For GPS, such consistency is continuously monitored and fundamental to its operation.

A further benefit of satellite positioning is that it can now provide highly accurate global coordinates for the ground stations in the older national and regional networks, such as the Ordnance Survey's OSGB36. This was observed purely as a triangulation network, without any measured distances or astronomic data, and adjusted by least squares to provide a consistent geometric figure [14]. Its purpose was to provide a control network for the National Grid mapping. So far as this mapping is concerned, the coordinates for the many thousands of trig pillars and other control points are all inferred to be consistent and error-free. This pragmatic approach is essential for any topographic mapping. The global coordinates for the OSGB36 stations now confirm that the triangulation network lacked consistency, in that the scale and orientation (and also the location and orientation of its Airy ellipsoid), as inferred by its original coordinates, vary throughout the network [8, 9]. This lack of consistency (which is similarly found in other national and regional TRFs such as ED50 (European Datum 1950) reflects both the inevitable errors in observation, computation and adjustment, and the raft of simplifying assumptions that are inherent in the underlying TRSs.

3.3 COORDINATE REFERENCE SYSTEMS AND FRAMES

Within the last decade the GPS satellite positioning system has, for the first time, provided economic and practical access to a global coordinate reference system, with a potential accuracy at the centimetric scale. At this accuracy level, and on a global scale, the physical ground surface is sensitive to the motion of the continental plates, and for global consistency is held static relative to the crust as a whole. Such motions are included as station velocities in the scientific International Terrestrial Reference Frame (ITRF).

Topographic mapping, particularly at larger scales, is not practical if the stations are considered to be moving over time. This impasse is resolved by establishing a coordinate reference frame for the whole or part of an individual plate, which takes the coordinate positions at a specific date and thereafter holds these values fixed. In Europe the agreed date was 1989.0: the resulting coordinate reference system is known as the *European Terrestrial Reference System 1989* (ETRS89).

3.3.1 Horizontal Reference Systems

In the U.K. context, ETRS89 has been adopted as the fundamental coordinate reference system by both the Ordnance Survey (OS) and the Hydrographic Office (HO). The OS has redefined the National Grid in terms of ETRS89 and the HO plans to transfer all its charts for British waters to this system [20, 33]. At the European level, the EC is expected to adopt the system for its own data (and potentially stipulate such a requirement in contract documents) and to promote its use in all member states [3].

In recognition of these developments, the standards identify ETRS89 geographical coordinates as the 'master' coordinates for adoption by BGS. It is envisaged that there will be a progressive transformation of corporate data to this system. The process should be largely transparent to those working with spatial coordinates, as they will need coordinate data to be compatible with the topographic mapping that is current at the time. In the UK, there is likely to be a lead time of some years before the OS adopts ETRS89 as the basis for the published mapping.

3.3.2 Vertical reference system

The heights that are provided directly by GPS receivers are of no direct value, in that they are referred to an ellipsoid, rather than orthometric heights relating to the geoid or other gravity-related reference frame, and are of insufficient accuracy for many purposes. For the time being, height data in the UK should continue to be referred to Ordnance Datum Newlyn (ODN). For GPS data this is achieved by using OSGM02 to convert ellipsoidal heights above the GRS80 ellipsoid to heights above ODN. To complement ETRS89, it is anticipated that a new European Vertical Reference System (EVRS) may be adopted in the future [3]. The relationship or transformation(s) between this reference frame and ODN have yet to be determined. The potential significance of this issue to corporate data will need to be reviewed at a later date.

3.4 TRANSFORMATION OF SPATIAL COORDINATE DATA

Conversion and transformation of coordinates can be a confusing subject, especially when poorly documented software, including many GIS packages, appear to offer this between almost any TRFs, but without clearly identifying methods or accuracies. One needs first to make a distinction between conversions and transformations.

"Conversion, within the same TRF, from one type of map projection to another, or to latitude and longitude, is a simple matter of applying the predefined mathematical formulas, and can be as accurate as one desires. However, transformation from one TRF to another is always an approximation, and is based on empirical formulas and algorithms, deduced from measurements. Typical accuracies vary from 10 centimetres to 100 metres." (MEGRIN, 2000)

Conversions change the same spatial location data from one coordinate *type* to another, that is from 3-D Cartesian to geographical, or, by means of a projection, from geographical to grid (or the reverse in either case). These are pure geometrical conversions, where the TRF remains unchanged. Conversion is one-to-one between 3-D Cartesian and geographical coordinates, whereas different projections will convert the same geographical coordinates to different grid coordinates. In every case, these conversions require the parameters for a constant and specified ellipsoid.

The function of a *transformation* is to take the coordinates of a point on one TRF and return the coordinates of the same point on a second TRF. Unless the second TRF is itself defined as a transformation from the first, the relationship between the two can only be established from an analysis of the coordinates of common points, as observed on each TRF, since neither will be consistent in terms of the other. These transformations, therefore, can never be exact, and are liable to change and improve with time as further common points are coordinated in both TRFs.

WGS84 or derivatives such as ETRS89 are now almost invariably taken as the common base frame for these transformations. A pattern is becoming evident, in which the first algorithms, as derived from the initial data, are simple 3-parameter Cartesian shifts of the notional ellipsoid origin. Further data subsequently permit more accurate 7-parameter algorithms to be established. At the third stage, with plentiful data, 'rubber-sheet' matrix transformations can accommodate the inevitable inconsistencies in the local or regional TRFs. At the fourth and final stage the whole of the original TRF is re-observed and coordinated in ETRS89 or equivalent. As the latter is inherently more accurate and accessible, the original TRF can then be *redefined* as a specific transformation from the WGS84- based TRF. Until the final stage is achieved, transformation algorithms need to be regarded as transitory, and periodically subject to improvement. For the National Grid, the Ordnance Survey have published the definitive version, described at [22a]. On the UK continental shelf the 7-parameter "Common offshore" transformation is now gaining legal status [27] and here it effectively redefines ED5O.

The magnitude of transformation shifts ranges from less than 200 metres (vector) in the British Isles to several kilometres in the case of some isolated older TRFs, whilst the accuracy of transformation algorithms varies from around ±100 metres for some of the 3-parameter shifts to about ±10 cms in the case of final definitive transforms (as good as the uncertainties in the original TRFs). The potential inaccuracy of the simpler transforms should not be permitted to constitute a significant element in the error budget of derived ETRS89 coordinates, if more accurate transformations are available.

Table 6 attempts to illustrate these relationships, as a matrix with conversions vertically (exact) and transformations horizontally (approximate). It shows coordinates on TRF 'M' as an intermediate stage in transforming from values on TRF 'A' to those on TRF 'B'. Here the 'M' signifies 'Master', as the global coordinates on WGS84 or preferably its more precise realisation on the relevant tectonic plate, such as ETRS89 for the UK and environs. This stage is significant, firstly because the best available transformation parameters are almost always those to/from ETRS89 or WGS84. Secondly, because these values, held as geographical coordinates (and thus independent of any projection), should progressively become the master coordinates held in BGS corporate datasets. They can subsequently be projected to grid values, or transformed onto another TRF using the best parameters then available. Every time that data are transformed, the method and parameters need to be recorded. The routine for changing coordinates should always be in the order:

conversion > transformation > conversion.

Thus grid values are first converted to geographical and secondly, to 3-D Cartesian, on the same TRF. The transformation is then applied and the resulting 3D Cartesian coordinates are converted to geographical and then grid coordinates on the new TRF.

Table 6 Conversions and transformations

↓ single ellipsoid ↓	Terrestrial Reference Frames				
Type	National		global		regional
Example	*(OSGB36)*		*(ETRS89)*		*(ED50)*
3-D Cartesian coordinates (X / Y / Z) metres	X_A, Y_A, Z_A	◄≈►	X_M, Y_M, Z_M	◄≈►	X_B, Y_B, Z_B
Standard formulae	↨		↨		↨
Geographical coordinates (latitude / longitude)	φ_A, λ_A degrees		φ_M, λ_M degrees		φ_B,λ_B degrees
Projections	↨		↨		↨
Grid coordinates (eastings / northings)	E_A, N_A metres (National Grid)	//	E_M, N_M (OSGRS80)		E_B, N_B metres (UTM)

↨ exact conversion

◄≈► approximate 3 or 7 parameter (Helmert) transformation

// 'rubber sheet' transformation (e.g. OSTN97 and OSTN02)The OS spreadsheet program at [23a] implements conversions for any Transverse Mercator projection and should be used to validate any software written in-house. Currently, Helmert transformations may offer the only means of changing between many TRFs. These operate on 3-D Cartesian coordinates, using seven parameters to shift and rotate the three axes and change scale.

The WGS84 manual includes transformation parameters for virtually every TRF, together with an estimate of their uncertainties, which range from ± 2 metres at best, to a default worst of ± 25 metres.

Such transformations are subject to periodic refinement, as new observations continue to reveal and map out the inconsistencies in the national and regional TRFs. As this work progresses, at some point it becomes more accurate, economic and practical to abandon the original TRF and substitute a definitive transformation from the global coordinates. As an important example, onshore in the UK, the National Grid has been redefined as a transformation of ETRS89 coordinates with an accuracy of ± 0.1 metres. Offshore, the European Datum 1950 (ED50) had been extrapolated, somewhat tenuously, for the North Sea and other areas of the continental shelf: for petroleum exploration and production (i.e. to an accuracy sufficient for these purposes), ED50 is now taken as a defined Helmert transformation from ETRS89 [27].

The standards identify the transformations that are currently to be used for corporate data.

Liaison with the relevant agencies will be necessary, to ensure that any future authoritative transformations are incorporated in the standards. Care needs to taken that any in-house transformation routines utilise current best algorithms and parameters, and not older versions, or even tabular transformations, that may still be held [29, 34, 35, 36].

3.5 QUALITY OF SPATIAL COORDINATE DATA

The coordinate values for spatial data need to be accompanied by standard metadata that records their source or derivation, and their quality. For corporate datasets this is a difficult area, in that for much of the existing data the information is missing, obscure or noted in diverse and inconsistent formats, which may be of little real value.

A single coded dictionary to record the source and/or derivation of the coordinates is valuable as an indicator of reliability and quality, although there will often be a close correlation with accuracy. The dictionary needs to cater for all sources of coordinate data, from the unknown to the precisely documented.

Accuracy, precision and resolution are related but distinct terms that must not be confused. Accuracy is a combination of random error (precision) and systematic error (bias).

A length may be recorded as: 384.27 ± 0.12 metres

in which case '± 0.12 metres' is a statement of the accuracy and the resolution is 0.01 m.

For spatial coordinates, the accuracy is to be stated with respect to the local realisation of the relevant TRF (e.g. for National Grid coordinates, the accuracy relative to the local trig pillars and other control stations that define OSGB36). In recording the coordinates for a spatial location, the objective should be to record the most probable values, without any rounding or truncation, together with a realistic assessment of the positional accuracy. As a general guide, the resolution with which the coordinates are recorded should be an order greater than the accuracy, as above.

It is notable that the accuracy field (if any) in existing datasets is almost invariably ill-defined, and populated simply in decades of metres, whether as codes or numeric quantities. No meaningful assessment of accuracy can be made without applying at least some simple statistics for the various factors in the coordination procedure, or in other words deriving an error budget. A set of accuracy codes denoting error in bands between the decades and half-decades would encourage the use of such budgets, and be readily transportable between geographical and grid coordinates. A lot of our coordinate data, for example, is located with respect to the topographic detail shown on OS 1:10 000 sheets. Here, the initial component in the error budget will be the inherent accuracy of this detail relative to the National Grid, which is approximately ± 4 metres (equivalent to ± 8.8 metres at 99% confidence level) [18].

3.6 GIS SOFTWARE

The checks that have been undertaken to date (on Bentley's Microstation and ArcView 3.2, and to a lesser extent on MapInfo 5) indicate that conversions, that is the use of projection formulae between geographic and grid coordinates, are undertaken at or near geodetic accuracy of ± 0.001 m or better. It should follow that the mathematical implementation of the simpler 3- and 7-parameter type transformations can be achieved with more than sufficient accuracy. The problem, however, is that despite the inclusion of a plethora of such parameters, mostly relevant only to the U.S., the few of potential interest are often not the currently accepted versions. Most seem to be taken from the WGS84 manual [7], and hence are likely to be several years old. There is a need to be able to customise such software with current transformations and the relatively few specific coordinate systems that BGS requires, and preferably to delete (or at least relegate to a reference file) the vast remainder. Another problematic issue is the somewhat tenuous manner in which data is tied to a specific TRF, if at all.

For the British Isles, where the relevant TRFs differ by less than 200 m, these issues are not significant for output at around 1:l M scale and smaller, but very relevant at 1:50000 or larger.

4 GLOSSARY

accuracy: A measure of the closeness to the true value of a parameter.

Cartesian coordinates: A system of uniquely marking the position of a point on a plane {or in 3-dimensional space} by 2 {3} numbers (its "cartesian coordinates") giving its distances from 2 {3} mutually perpendicular lines ("cartesian axes"). The distances and the axes to which they are parallel are usually marked (x,y) in a plane and (x,y,z) in space; the "origin" is the point at which the axes intersect.

Coordinate conversion: The application of standard predefined parameters and formulae to express the same spatial location in a different coordinate type. Thus conversions are made either between 3-D Cartesian coordinates and geographical coordinates, or between geographical coordinates and grid coordinates. In the latter case, the conversion is known as a projection. Conversions may be regarded as exact, provided the appropriate formulae are used. Conversions assume that the TRF remains constant, but require an ellipsoid to be specified.

coordinate (reference) system: A geometric framework with respect to which points can be given unique coordinates. Every coordinate system, of whatever type, must be related to a specific TRF for the coordinates to be unique. Sometimes abbreviated to CRS.

datum: (also 'geodetic datum'). A simplistic and rather abused term for the means by which a coordinate system is located with respect to the physical surface of the Earth. Definitions have varied, depending on the current state of geodetic knowledge and understanding. ‘Terrestrial Reference System’ and ‘Terrestrial Reference Frame’ (TRS and TRF) are more satisfactory terms for modern usage.

ED50: European Datum (1950 Adjustment). The horizontal TRF resulting from an adjustment by the U.S. Army Map Service in 1945-50 of existing triangulation data for much of mainland Europe (including France and southern Norway). Computed on the International 1924 ellipsoid. Restricted for military use until mid-1960s. Declassified for civilian use in the North Sea, although the TRF could not be definitively extended to the UK. Also the geographical coordinate system based on this TRF, which is increasingly ambiguous when extrapolated to the west and north across the British Isles. [10, 16, 27, 36, 39, 40].

Ellipsoid (oblate or semi-minor): The solid geometric shape obtained by revolving an ellipse about its short (semi-minor) axis. Used as a simple model of the shape of the Earth, and thence as the reference surface on which geographical coordinates are calculated. Ellipsoids are variously defined by two parameters for size and shape, most commonly a semi-major axis ‘a’ (equatorial radius) and the inverse flattening ‘1/f’ (‘a’ divided by the difference between semi-major and semi-minor axes). Many ellipsoids have been derived in the last 200 years to approximate the shape of the Earth. Most of the coordinate systems for current topographic mapping are based on old ellipsoids, such as that by Hayford (International 1924).

EPSG: European Petroleum Survey Group. This group of surveyors from European Oil Companies maintains a comprehensive database of geodetic parameters as a contribution to POSC. The database is frequently updated and freely available on the web, although it is not a totally authoritative source [2].

ETRFyy: European Terrestrial Reference Frame yy. The realisation of ETRS89 as the European subset of stations for an ITRFyy expressed in ETRS89 at epoch 1989.0, the first realisation being ETRF89 and the latest being ETRF2000. Note: the only reference stations that have ETRFyy coordinates are those that were part of the realisation of the associated ITRFyy, eg Herstmonceaux SLR and GPS in the UK.

ETRS89: European Terrestrial Reference System 89. The TRS adopted by EUREF, the IAG Subcommission for the European Reference Frame, which is coincident with the ITRS at the epoch 1989.0 and fixed to the stable part of the Eurasian Plate. Note: this acronym is also used (somewhat confusingly) to define the TRF realised from a network of active stations, whose coordinates are first computed in the ITRFyy at the epoch of observation (through a connection to stations that are part of the ITRFyy realisation) and then transformed into ETRS89 at epoch 1989.0, eg the EUREF GB 2001 solution that was used to define the current coordinates of the active stations in Great Britain.

EUVN: EUropean Vertical reference Network. A new European vertical TRF for gravity-related heights. Its relationship and status with respect to ODN are not yet known [3].

geoid: The equipotential surface that coincides with the average surface of the world's oceans. The desired reference surface for gravity-related (orthometric) heights

geographical coordinates: Angular ('spherical') coordinates of (geodetic) latitude and longitude on an ellipsoid reference surface.

GPS: Global Positioning System. The principal satellite positioning system, operated by the U.S. Department of Defense. With a single receiver, of whatever quality, users can obtain their position to a real time accuracy of about ± 50 m. By utilising two receivers, a wide range of differential techniques are available, enabling accuracies from ± 10 m to ± 10mm or better to be obtained. The system operates in WGS84.

graticule: The lattice formed by intersecting lines of latitude (parallels) and longitude (meridians).

grid coordinates: spatial locations represented as 2-D cartesian coordinates on a plane surface

GCS: Grid Coordinate System. A 2-D coordinate reference system based on a specific TRF and an associated map projection.

GRS80: Global Reference System 1980. The ellipsoid used for many of the precise global coordinate systems that are fixed to specific continental plates, such as ETRS89. For all practical purposes, its defining parameters are identical to those for WGS84. [37].

Helmert transformation: A standard method for transforming 3-D Cartesian coordinates between two TRFs, one of which is almost invariably WGS84 or, in Europe, ETRS89. The method utilises up to seven parameters (shifts and rotations of the axes and a scale change). Typical accuracies are ± 1 m to ± 10 m, depending on the degree of distortion inherent in the TRFs and the area over which the transformation is applied.

Ireland 1975: The horizontal TRF that defines the Irish Grid on the ground, comprising explicitly the primary stations of the 1975 adjustment, and implicitly all lower order control stations that have subsequently been added, adjusted and given fixed coordinates. Computed on the Airy 1830 ellipsoid, modified by a reduction in size of 35 ppm. The geographical coordinate system based on this TRF. [25, 26].

Irish Grid: The grid coordinate system for Ireland (Irish Republic and Northern Ireland). Uses the Transverse Mercator projection and specific projection parameters, with Ireland 1975 as the TRF. Irish Grid coordinates are unambiguous. *NB: use of the term Irish 'National' Grid is incorrect* [25].

ITRFyy: International Terrestrial Reference Frame yy. The realisation of the ITRS in a certain year (yy), based on multiple space geodetic techniques, notably GPS, Satellite Laser Ranging (SLR) and Very Long Baseline Interferometry (VLBI). To date, the ITRF has been realised on nine occasions, the first being ITRF89 and the latest being ITRF2000. Such realisations result in a set of coordinates and their time variations (or velocities) for a global network of stations that are included in the computation.

ITRS: International Terrestrial Reference System. A highly accurate global TRS used for geodesy, which forms the basis of the ITRF. The associated ellipsoid of the ITRS is GRS80.

(British) National Grid: The grid coordinate system for Great Britain (England, Wales and Scotland). Uses the Transverse Mercator projection and specific projection parameters, with OSGB36 as the TRF. British National Grid coordinates are unambiguous. See [22a]

National Grid Reference (NGR): A single alphanumeric string (e.g. SK 1234 5678) used to relate position to National Grid maps. The number of digits relates directly to the scale of mapping and the precision/accuracy of location. These references are used in text documents, not in digital datasets. See [22a]

ODN: Ordnance Datum Newlyn. The vertical TRF for gravity-related heights on the mainland of Great Britain, comprising around 500,000 Ordnance Survey bench marks. The vertical coordinate system for heights related to this TRF, defined as positive upwards. Hence heights are expressed as '123.45 m ODN' or '-6.78 m ODN', not as 'above' or 'below' ODN.

OSGB36: Ordnance Survey Great Britain 1936. The horizontal TRF that defines the National Grid on the ground, comprising explicitly the 326 primary stations of the 'Retriangulation' (1936-1957), and implicitly all lower order control stations that have subsequently been added, adjusted and given fixed coordinates. Computed on the Airy 1830 ellipsoid. The geographical coordinate system based on this TRF. [8, 9, 14].

OSGM02: Ordnance Survey Geoid Model 2002, constructed using dense gravity and height data and fitted to available GPS datums. It has ar.m.s. error of 3.2 cm across the UK. It has replaced OSGM91. A vertical transformation between ETRS89 ellipsoid height and orthometric height is also available from Ordnance Survey. This transformation is based on a gravimetric geoid model aligned with the respective vertical datums for Great Britain, Northern Ireland and Ireland. It has replaced OSGM91.

OSTN02: Ordnance Survey Transformation 2002. The OS conversion/ transformation between ETRS89 geographical coordinates and National Grid coordinates for Great Britain. It provides a precision of ~±0.1m. It has replaced OSTN97.

POSC: Petrotechnical Open Software Corporation. A not-for-profit organisation established by the hydrocarbons exploration industry to establish standards in data and software.

precision: A statistical measure indicating the spread of a series of repeated measurements. An indication of repeatability.

projection: A procedure for converting geographical coordinates (angular coordinates on a specific ellipsoid) to or from 2-D Cartesian (grid) coordinates on a plane surface. The Transverse Mercator projection is the most widely used for topographic mapping.

resolution: The smallest amount of a quantity that can be discriminated and/or displayed.

spheroid: An alternative term for the 'ellipsoid' model of the Earth, more commonly used in older literature. Emphasises the fact that the shape of the Earth is close to that of a sphere.

(Coordinate) Transformation: The procedure by which coordinates in a system based on one TRF are equated to those in a system based on a second TRF. The accuracy of transformations ranges from about ±10 cm to perhaps ± 100 metres, depending on the amount of observational comparison between the TRFs, the degree to which they lack true consistency, and on the transformation method that is used.

TRF: Terrestrial Reference Frame. A set of reference ground stations and their coordinates, observed and computed on a specific ellipsoid, and adjusted for mutual consistency. These coordinates are thereafter held fixed and implicitly taken as the error-free framework for subsequent topographic mapping. A coordinate system based on this framework will be valid when positions are interpolated within the area of the reference points, but increasingly ambiguous if they are extrapolated beyond this area. As a result of the inevitable errors in observation and adjustment, TRFs can never be truly consistent or error-free.

The TRF is the entity that connects the perfect but conceptual geometry of ellipsoids and projections to the real ground surface, on which observations and computations can never be free of error. Spatial coordinates are always uncertain unless the TRF is known.

TRS: Terrestrial Reference System. Comprises the principles by which a given TRF is located with respect to the Earth. These will explicitly include a specific ellipsoid.

triangulation: the measurement of the elements necessary to determine the network of triangles into which any part of the earth's surface is divided in surveying; *broadly* **:** any similar trigonometric operation for finding a position or location by means of bearings from two fixed points a known distance apart.

trilateration: a technique used in surveying and mapmaking, measuring the sides of a network of triangles.

UKCS: United Kingdom Continental Shelf. For UK mineral purposes, this is the offshore area beyond territorial waters, out to the median line boundaries as delimited by various international treaties. Most of the UKCS is covered by DTI 'designation' orders for potential petroleum exploration and production.

UKOOA: UK Offshore Operators Association. An association representing the petroleum exploration and production industry operating on the UKCS.

UTM: Universal Transverse Mercator. A standard projection and grid coordinate system, enabling global coverage (excepting the polar regions) in 60 zones, each of 6° extent in longitude, with uniform projection parameters. Requires an ellipsoid and TRF to be specified, and thus a ground point could have several sets of UTM coordinates. [5].

WGS84: World Geodetic System 1984. The global TRS associated with the control/space segment of GPS and used for navigation. It includes an ellipsoid of the same name which is practically identical to the GRS80 ellipsoid. Note: there is no equivalent WGF84, ie there is no TRF realised from WGS84 and, strictly speaking, the only stations that have WGS84 coordinates are those of the GPS control segment [7].

5 REFERENCES, BIBLIOGRAPHY, SOURCES AND SOFTWARE

Information sources are assigned codes:

L BGS library.

M miscellaneous documents.

S software held by BGS.

W web publications.(NB some Websites are for privileged users only, may be unavailable or be out of date. Some publications may be in pdf form)

Items of major current significance are shown in **bold.**

European Petroleum Survey Group (EPSG)

Provides practical geodetic expertise, although not always regarded as authoritative.

web site: http://www.epsg.org/

[1]W EPSG, 1999. Guidance Note 7. POSC literature pertaining to Geographic and Projected Coordinate System Transformations.

[2]W EPSG, 1999. EPSG geodesy parameters. MS Access database. (Check for latest version)

European Reference Frame (EUREF)

Tasked to promulgate the official transformations between ETRS89 and national European TRFs.

web site: http://lareg.ensg.ign.fr/EUREF/

Multipurpose European Ground Related Information Network (MEGRIN)

MEGRIN was established by CERCO (Comité Européen des Responsables de la Cartographie Officielle) which comprises the heads of 37 European National Mapping Agencies.

web site: http://www.megrin.org/

[3]W MEGRIN, 2000. Short proceedings, conclusions and recommendations. Spatial Reference Workshop, Marne-la-Vallée, 29-30 November 1999.

National Imagery and Mapping Agency (NIMA)

Agency of the U.S. Department of Defense. Successor to Defense Mapping Agency (DMA) and U.S. Army Map Service.

web site: http://164.214.2.59/GandG/

[4]W Defense Mapping Agency (DMA), 1983. Geodesy for the layman. DMA Technical Manual 80-003.

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[6]W Defense Mapping Agency, 1990. Datums, Ellipsoids, Grids, and Grid Reference Systems. DMA Technical Manual 8358.1.

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Ordnance Survey:

Web site: http://www.ordsvy.gov.uk

http://www.gps.gov.uk/index.asp

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[18a]W Ordnance Survey 2000. Positional accuracy of mapping of 1:2500 scale. Information paper 4/2000

[19]W Ordnance Survey, 2000. A guide to coordinate systems in Great Britain**.**

Ordnance Survey technical data web publication.

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[22a]W Ordnance Survey, 2000. The National Grid map reference system

Software:

[23]S Ordnance Survey, 1999. 0STN97 and OSGM91 [National Grid Transformation and National geoid Model]. Data and user guide on CD-ROM. Version 1. (now outdated)

[23a] Ordnance Survey, 2002. Transformation & Conversion spreadsheet. http://www.gps.gov.uk/additionalInfo/images/ProjectionandTransformationCalculations_v32.xls (free download)

[24]S Quest [Quality Engineering & Survey Technology Ltd] 1999. Grid Inquest [Ensure that you have latest version] MS Windows software utilising OSTN02 and OSGM02 to convert between ETRS89 and National Grid.

Ordnance Survey Ireland

Web site: http://www.osi.ie/

and

Ordnance Survey Northern Ireland

Web site: http://www.osni.gov.uk/

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UKOOA (UK Offshore Operators Association)

Web site: http://www.ukooa.co.uk

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[39]M Weightman, J A, 1975. Doppler ties to European Datum and the European geoid. Commonwealth Survey Officers Conference 1975. Paper No. B4. Geodetic Office, Mapping and Charting Establishment (RE).

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ANNEXE A

This Annexe includes transformations that are no longer valid having been superceded. They are included so that any reference to them can be understood in context.

OSTN97

Authority: Ordnance Survey.

Accuracy: ~ ± 0.2 m for primary and secondary stations in OSGB36.

EPSG code: None as yet.

Status: superceded.

Extent: Great Britain, to 20 km offshore (as for OSGB36).

Application: Standard BGS transformation procedure where the coordinate data is accessible.

Method: 'Rubber sheet' transformation, using bi-linear interpolation to obtain easting and northing shifts from a transformation grid of one kilometre resolution. The method transforms and converts between ETRS89 geographical coordinates and (projected) National Grid coordinates.

ETRS89 to Ireland 1975

Level 2 Transformation

Authority: Ordnance Survey Ireland / Ordnance Survey Northern Ireland [26].

Accuracy: ~± 0.5 m.

EPSG code: None as yet.

Status: Superceded.

Extent: Ireland, to ~20km offshore (as for Ireland 75).

Method: Helmert 7 parameter transformation by position vector (Bursa-Wolf) method between the 3-D (NB: ref [26] gives rotations of opposite sign)

Level 2 Transformation parameters from ETRS89 to Ireland 75						
dX (m)	dY (m)	dZ (m)	Rot X"	Rot Y"	Rot Z"	Scale (ppm)
-482.530	+130.596	-564.557	+1.042	+0.214	+0.631	-8.150

Test point:	Latitude	Longitude	[Ellipsoid height]
ETRS89	53.000 000 °	-7.000 000 °	50.00m
	(53° 00' 00.0000"N)	(7° 00' 00.0000"W)	
Ireland 1975	52.999 723 °	-6.999 139 °	-4.7