Australian Government
Geoscience Australia

GEODATA 9 Second
DEM and D8

Digital Elevation Model **Version 3** and
Flow Direction Grid

Gridded Elevation and Drainage Data
Source Scale 1:250 000

User Guide

FENNER SCHOOL OF ENVIRONMENT AND SOCIETY, ANU and
GEOSCIENCE AUSTRALIA

THE AUSTRALIAN NATIONAL UNIVERSITY

A cooperative effort by Geoscience Australia and the
Fenner School of Environment and Society,
The Australian National University

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CHAPTER 1

Introduction

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Geoscience Australia

Within the portfolio of Resources, Energy and Tourism, Geoscience Australia plays a critical role by producing first-class geoscientific information and knowledge. This can enable the government and the community to make informed decisions about the exploration for resources, management of the environment, the safety of critical infrastructure and the resultant wellbeing of all Australians.

The Geospatial and Earth Monitoring Division (GEMD) of Geoscience Australia maps, monitors and models changes to the Earth and advises on how they affect Australian Society. GEMD works to improve the safety of communities and the protection of Australia's critical infrastructure.

GEMD combines its capabilities in geospatial information and knowledge management, research and mapping programs, earth observation capabilities and risk assessment, to bring together a comprehensive capability, able to respond flexibly to current and emerging government priorities.

The National Mapping and Information Group (NMIG) within the Geospatial and Earth Monitoring Division provides maps and fundamental spatial data sets for emergency managers, defence, other government departments and the public. It also coordinates the agency's national mapping activities and standards, through the Intergovernmental Committee for Surveying and Mapping (ICSM).

Digital topographic map data have been a major output of NMIG and it's predecessors for several decades. These have provided the basis for the *GEODATA 9 Second Digital Elevation Data Version 3 and Flow Direction Grid 2008*.

Further information about Geoscience Australia may be found at www.ga.gov.au.

The Fenner School of Environment and Society, ANU

The Fenner School of Environment and Society was established in 2007, incorporating the former Centre for Resource and Environmental Studies (CRES) of the Australian National University in Canberra. Its mission is to address resource and environmental issues of national and international importance through the development and application of interdisciplinary concepts, theories, frameworks and methods involving biophysical and socio-economic dimensions.

The Fenner School undertakes interdisciplinary research and conducts undergraduate and postgraduate training. The School has a strong commitment to collaborative solving of real-world problems and outreach to the public. The School conducts fundamental and commissioned research for industry and for all levels of government.

The principal research and education themes of the Fenner School are:

- Integrative theory, methods and applications
- Global change
- Landscapes, water and biodiversity
- People in environments

The Fenner School is an acknowledged international leader in developing digital elevation models and applying them to terrain dependent analyses of surface climate and natural resources. The ANUDEM elevation gridding program developed by Professor Michael Hutchinson at the Fenner School is used by research and resource management institutions around the world.

Further information about the Fenner School may be found at http://fennerschool.anu.edu.au.

Summary of the 9 Second DEM and Flow Direction Grid

The GEODATA 9 Second DEM (DEM-9S) Version 3 is a grid of ground level elevation points covering the whole of Australia, with a grid spacing of 9 seconds in longitude and latitude (approximately 250 metres) in the GDA94 coordinate system. The 9 Second Flow Direction Grid (D8-9S) is a corresponding grid describing the principal directions of surface drainage across the whole of Australia.

Version 3 of the DEM-9S was calculated by Version 5.2.2 of the ANUDEM procedure (Hutchinson 2007) from comprehensively revised and augmented national GEODATA TOPO-250K (TOPO-250K) topographic source data (AUSLIG 1992, Geoscience Australia 2003, Geoscience Australia 2006). The source data included revised versions of TOPO-250K elevation points, streamlines, cliff lines and waterbodies, trigonometric points from the National Geodetic Database and additional elevation, streamline and sink point data digitised by the Fenner School from 1:100K source material. Version 5.2.2 of the ANUDEM procedure incorporates major upgrades to the modelling of streamlines, lakes, cliff lines and the coastline.

The 9 Second Flow Direction Grid (D8-9S) has been released for the first time, with Version 3. This grid was calculated by the ANUDEM procedure as it calculated the DEM-9S. It incorporates the data streamline structure and describes the drainage structure continent-wide. It can be used to delineate streamlines and associated catchment boundaries for the DEM-9S. This is particularly useful in low relief areas where drainage structure is not reliably defined by the DEM elevations alone.

The comprehensive revisions and additions to the source data for the DEM-9S Version 3 were completed over a period of 3 years by the Fenner School and Geoscience Australia. This built on the substantial period of source data revision and algorithmic development by the Fenner School over the last 15 years. Comprehensive quality assurance of the DEM-9S and the D8-9S was performed jointly by the Fenner School and Geoscience Australia. The revised version of the ANUDEM elevation gridding procedure was developed and implemented by Professor Michael Hutchinson of the Fenner School.

The DEM-9S Version 3 is a model of the terrain in which each data point represents the approximate elevation at the centre of each 9 second by 9 second cell. The density and positional accuracy of the source point elevation data generalises the local terrain, resulting in limited representation of some high points. Version 3 incorporates the improvements made in Version 2 by including with the source data the national trigonometric points from the National Geodetic Data Base.

The representation of abrupt changes in landform has been comprehensively upgraded in Version 3 by incorporating, for the first time, the TOPO-250K national cliff line data and by upgrading the modelling of cliff lines by the ANUDEM procedure to minimise conflicts between streamlines and cliff lines. The upgraded procedure maximises the accuracy of the representation of surface shape within the limits imposed by the 9 second grid spacing.

Of central importance for the accurate representation of surface drainage structure is the upgrading of the modelling of streamlines by ANUDEM. This improves the positional accuracy of streamlines and explicitly incorporates, also for the first time, the extensive distributary streamline networks that occur in low relief areas of the Australian continent. ANUDEM has also been upgraded to improve the positional accuracy of the coastline and to ensure a smooth transition between land and seabed away from areas with coastal cliffs.

Elevation errors in the DEM-9S are closely related to terrain complexity. Tests of the DEM against 1:25 000 scale elevation data not used to produce Version 3 indicate that the standard error of the DEM is no more than 10 metres in lower relief areas making up around half of the continent. The standard error increases up to around 60 metres in highland areas with steep and complex terrain. In such areas there is significant variation in elevation across each 9 second grid cell. Maximum absolute errors are naturally larger than standard errors. These range from around 20-40 metres in the lower relief half of the continent up to around 200-300 metres in complex highland areas.

The rasterised drainage structure embodied in the D8-9S respects the positional accuracy of the corrected TOPO-250K streamline data, and their distributary connections, to within the limits of accuracy achievable at the 9 second scale. Thus the average positional error of the gridded streamlines is around 1/4 of one grid cell or 60 metres. Approximately 95% of the gridded streamlines lie within 125 metres of the mapped streamline network and virtually all are within 270 metres.

The density of source data points used to create the DEM, and its horizontal resolution, warrant that the DEM be considered to have a scale of approximately 1:250 000. This makes the DEM useful for national, statewide and regional applications, particularly those applications that depend on an accurate representation of surface drainage and catchment structure.

CHAPTER 2

The Development of the 9 Second DEM

- Early National Digital Elevation Models
- 9 Second DEM Version 1
- 9 Second DEM Version 2
- 9 Second DEM Version 3

This chapter recounts the development over the last three decades of national topographic data, and the associated development of the ANUDEM elevation gridding procedure, leading to the successive versions of the 9 Second DEM.

Early National Digital Elevation Models

The first coarse resolution national digital elevation model was developed by Moore and Simpson (1982) at the Bureau of Mineral Resources (now Geoscience Australia). This model was interpolated from point elevation data surveyed nationwide at spacings ranging from 3 minutes to 6 minutes of latitude and longitude. Interpolation was performed using the minimum curvature gridding procedure developed by Briggs (1974). This model did not explicitly incorporate any drainage structure and had a relatively coarse grid spacing of 6 minutes (approximately 10 km). Nevertheless it was of sufficient accuracy to detect significant lineaments in the Australian landscape (Harrington *et al*. 1982).

This model had a direct sequel, in terms of source data and methodology, in the 1.5 minute (approximately 2.5 km) national DEM developed by Hutchinson and Dowling (1991). This model used much of the same point elevation data used for the first national DEM but supplemented these with national trigonometric and benchmark data supplied by the Division of National Mapping (NATMAP). The elevation data were also supplemented with national streamline data digitised from 1:2.5M mapping. Moreover the elevation and streamline data were gridded using the then newly developed ANUDEM procedure (Hutchinson 1989). This procedure was based in part on the method of Briggs. The crucial innovations of ANUDEM were computational efficiency and a facility to enforce accurate surface drainage structure in the interpolated DEM. The latter was achieved by directly incorporating the drainage structure implicit in streamline data and by implementing an automatic drainage enforcement algorithm that ensured sensible drainage structure generally. The sensitivity to drainage structure of the ANUDEM procedure was such that it led to significant correction of all source elevation and streamline data sets. The resulting 1.5 minute (approximately 2.5 km) DEM was of sufficient quality to be released by the ANU Centre for Resource and Environmental Studies for general use. This DEM has supported a wide range of national resource modelling applications, particularly the spatial representation of surface climate (Hutchinson 1991), from the late 1980s.

9 Second DEM Version 1

Between the mid-1960s and 1988 the Australian Land and Information Group (AUSLIG) conducted a program to capture selected points from 20 metre contour data of 1:100K scale maps over the whole of Australia (Manning *et al.* 1989), with a view towards eventual production of a national digital elevation model. The ANUDEM elevation gridding program was also initially developed in the mid-1980s, with applications to such data a primary objective (Hutchinson 1989). These data formed the basis for the TOPO-250K relief theme that now underpins the 9 Second DEM. An early version of the ANUDEM program was applied to these point elevation data for use in telecommunication applications by the Department of Communications. AUSLIG also applied an early version of the ANUDEM program to the same elevation point data to produce an 18 second DEM for about one third of Australia. Production of the 18 second DEM was only done on user demand and was not of adequate resolution for many applications.

The GEODATA 9 Second DEM Version 1 project grew out of agreements between AUSLIG, the Australian Geological Survey Organisation (formerly BMR, AGSO and now Geoscience Australia), the Australian Heritage Commission (AHC) and the ANU Centre for Resource and Environmental Studies (CRES). AUSLIG and AGSO had agreed to undertake cooperative programs in geosciences, geodesy and geographic information and had developed preliminary specifications for a national DEM in early 1994. The AHC and CRES had developed similar specifications for a national DEM in early 1994 to support continent-wide assessment of the disturbance of rivers and catchments. It was agreed that the AHC and CRES would join with AUSLIG and AGSO in the production of the DEM. It was also agreed that Version 4.4 of the ANUDEM program would be used to calculate the DEM from the TOPO-250K relief theme and drainage layer. Version 1 of the 9 Second DEM was released in July 1996 (Carroll and Morse 1996). This DEM led to a major refinement in the modelling of surface processes by researchers and natural resource management agencies nationwide.

9 Second DEM Version 2

Further examination of the DEM and its supporting source data by CRES in their Wild Rivers Project for the AHC (Stein *et al.* 1998, 2002) made it clear that there were significant deficiencies in the 9 Second DEM Version 1. These related particularly to remaining errors in the directions of source stream line data, as well as disparities in the spatial density of the same data. There were also sporadic large errors remaining in the source point elevation data. These deficiencies led to significant errors in the representation of terrain shape and surface drainage structure. These included isolated large anomalies in terrain slope later found by Kirby and Featherstone (1999) in making terrain based corrections to gravity data.

It also became clear that Version 4.4 of the ANUDEM elevation gridding program could be upgraded to improve representation of peaks, to overcome problems caused by disparities in density of stream line data and to improve overall accuracy and connectivity of surface drainage. CRES therefore began independent revision of the ANUDEM program, as well as systematic revision of the source stream line and point elevation data.

In view of the wide potential applicability of a more accurate continental DEM, CRES approached AUSLIG in 1997 with a proposal to carry out a comprehensive revision of all source data and to produce an upgrade of the DEM for general distribution. The proposal was accepted, with AUSLIG agreeing to fund the source data revision and DEM upgrade work performed by CRES. CRES continued to support the revision of the ANUDEM elevation gridding program. Final quality assessment was completed by AUSLIG in consultation with CRES. The project had a scheduled completion date of mid 1999.

During the course of the project, the improved version of the ANUDEM program revealed a new generation of significant source data errors that had hitherto remained undetected. The errors were in both stream line data and point elevation data. CRES corrected 25,000 errors in point elevation data and 9,000 errors in stream line data. CRES also digitised an additional 87,000 spot heights and an additional 11,000 stream lines from 1:100K scale source material.

The improvements to the drainage enforcement algorithm within ANUDEM also made it feasible for the first time to apply the drainage enforcement algorithm to the low relief areas with ill-defined drainage structure that cover nearly half of the continent. This resulted in CRES digitising 21,000 sink data points to assist the definition of drainage structure in these areas.

These unscheduled additions significantly extended the duration of the project. Other unscheduled additions included the incorporation of trigonometric data points from the National Geodetic Data Base to improve the representation of high points in the DEM. These data also required significant editing and revision. Radar altimeter data for Lake Eyre were also added to the source data to replace existing TOPO-250K point data for Lake Eyre.

It was also recognised that cliffs inland from the Nullabor coast could only be modelled satisfactorily by implementing a new cliff data type in ANUDEM. This was successfully designed and implemented in July 2000. The success with which ANUDEM then modelled the Nullabor cliffs led to the incorporation of additional cliff line data for the Kimberley coast and for the Blue Mountains in New South Wales. Time precluded inclusion of all significant cliff lines around the continent, although such a task was seen as desirable in a future upgrade.

The extended project led to a very significant improvement over Version 1. Version 2 of the 9 Second DEM was computed by Version 5.0 of the ANUDEM program and released by AUSLIG in April 2001. It was immediately used in separate projects for the National Land and Water Resources Audit to model sediment transport across the continent (Gallant 2001) and to define a nested series of catchments across the continent for systematic reporting of land and water resources (Hutchinson *et al.* 2000).

9 Second DEM Version 3

Surface drainage based modelling applications of Version 2 demonstrated its much improved quality but also revealed shortcomings and potential for further improvement. Catchments derived from the DEM showed good, but not complete, agreement with the existing AWRC River Basins and Drainage Divisions (Hutchinson *et al.* 2000). These discrepancies revealed shortcomings in the AWRC drainage boundaries, particularly in the Western Division. But the discrepancies also revealed occasional deficiencies in the supporting DEM, where closer inspection revealed areas where there were insufficient source elevation data. The applications also revealed remaining errors in source elevation and stream line data.

It was concluded that a further (and final) revision of the 9 second DEM would be required to enable a comprehensive and accurate revision to accurately represent the drainage divisions across the continent. Moreover, major improvements had also been made in the representation of streams and lakes by the ANUDEM algorithm and Geoscience Australia had completed production of the TOPO-250K cliff theme for the continent. CRES therefore approached Geoscience Australia in 2004 with a proposal to carry out further revision of all source data and incorporate the new national cliff line data to produce an upgrade of the DEM for general distribution. The proposal was accepted, with Geoscience Australia contributing to the source data revision and collaborating with CRES (later to become the Fenner School) on comprehensive quality assurance of the DEM.

The project was anticipated to take less than one year, but during the course of the project the improved version of the ANUDEM program revealed yet again a new generation of significant source data errors that had remained undetected. The national cliff data set also presented new challenges for the ANUDEM program due to spurious interactions generated by closely separated cliff lines and streamlines. This led to the development of a completely revised cliff algorithm within ANUDEM to minimise these spurious interactions and maximise the accuracy of the representation of surface shape at the 9 second scale. The ANUDEM program was also revised to incorporate steam distributaries.

Corrections and revisions to source data continued until early 2008. Over this time the Fenner School corrected 12,000 errors in point elevation data and 7000 direction errors in stream line data. The Fenner School also digitised from 1:100K source material an additional 239,000 spot heights, 79,000 stream lines and 5,000 sink points in order to better delineate stream lines and catchment boundaries.

Quality assurance was completed jointly with Geoscience Australia from mid 2007 to mid 2008. The resulting DEM generally represents the shape and drainage structure of the Australian continent to within the limits achievable at 9 second resolution.

CHAPTER 3

About DEM’s and Flow Direction Grids

- What is a DEM?
- What is a Flow Direction Grid?

This chapter describes Digital Elevation Models, their associated Flow Direction Grid and the sort of applications for which these grids can be used.

What is a DEM?

A Digital Elevation Model (DEM) is a representation of the terrain using point elevation information. DEMs can be of two types - irregular or gridded.

An irregular spaced DEM is often interpreted as a Triangular Irregular Network (TIN). The terrain is simulated as a series of planar triangular facets produced by joining all the adjacent points. The assumption that the surfaces are planar is adequate if the points have been chosen at changes in grade in the terrain. The accuracy of the TIN model can be improved by the addition of break lines. These lines represent discontinuities in the terrain surface such as cliffs, ridges and streams and they indicate where interpolation between adjacent points is invalid. The main advantage of TIN models is economy of representation in visualisation applications. They are less well suited than regular grid DEMs for systematic spatial coverage in support of environmental analysis and modelling (Hutchinson 2008).

In a gridded DEM the elevation points are spaced at a regular interval to create a grid or lattice. These grids can be directly observed or, as in the case of the GEODATA 9 Second DEM Version 3, computed from topographic information including point elevation data, elevation contours, stream lines and cliff lines. By incorporating stream lines and cliff lines, a gridded DEM can represent all of the discontinuities that can be represented by a TIN and has the significant advantage of being directly compatible with remotely sensed sources of natural resource data in grid form. A regular grid DEM is also readily used by many grid-based applications.

Where the DEM is directly observed, say from aerial photogrammetry or field survey, the elevation value can be truly representative of the value that would be found on the ground at the location of that point, provided there is no significant measurement error. Significant measurement errors can arise due to ground cover by vegetation and buildings, especially when elevations are measured by aerial and spaceborne platforms. These measurements are also affected by complex terrain (Harding *et al.* 1994).

Where the gridded DEM has been derived from a primary data source then the direct relationship between the elevation value and the actual value on the ground at the respective location is dependent on the algorithm used to interpolate the grid and the resolution of the grid itself. The DEM is really a **model** of the terrain as the name suggests, and as with all models it can be specified to best suit the application for which the data are to be used.

For instance, the application of the DEM may require that all local high points (hills or mountains) in the source data be retained in the grid. This would be necessary if the DEM were to be used for aircraft flight planning where the minimum flying height of the aircraft is critical. This could also aid the siting of signal transmittters and receivers, although high points could then have errors in horizontal position by up to half of one grid interval.

Alternatively, the DEM can be used to map the locations of an endangered species whose habitat is altitude dependent, principally via its strong dependence on surface climate. Here the resultant value for each grid cell may be either the elevation of the centre point of the grid cell or the average height of the area coved by the grid cell. In areas away from peaks these values are approximately the same.

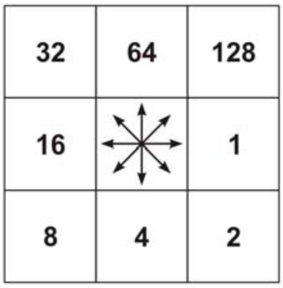
Many applications depend on the shape represented by the DEM rather than the absolute elevation values. These include hydrological applications, for which an accurate representation of surface drainage structure is critical (Hutchinson and Gallant 2000; Hutchinson 2008). Computation of terrain corrections to observed gravity data and remotely sensed data are other important applications that depend primarily on the representation of terrain shape. The measures of shape most commonly used are slope and aspect in the downslope direction.

The 9 Second DEM Version 3 attempts to maximise its utility for all of these applications by having each grid point represent the approximate elevation of the centre of the corresponding 9 second grid cell. If more precise elevation information is needed around peaks, then higher order interpolation across the grid cell may be used, but the limited density and spatial accuracy of the source elevation data for the 9 Second DEM Version 3 limits the additional accuracy that this can provide.

See Chapter 5 for a systematic assessment of the accuracy of the 9 Second DEM Version 3.

What is a Flow Direction Grid?

A flow direction grid is a regular grid of surface flow directions accompanying a regular grid DEM. It normally ascribes to each DEM point one of eight cardinal directions (N, NE, E, SE, S, SW, W, NW) denoting the direction of surface flow from the grid point to one of its immediate neighbours. If there is no downstream neighbour and the point is not on the edge of the DEM, it is usually given a value denoting a sink. The 9 Second Flow Direction Grid is produced in standard ESRI grid format to permit standard hydrological applications. The ESRI Flow Direction Grid (D8) is an integer raster where values, indicated in Figure 1, represent flow direction from the centre. The main applications of flow direction grids are automated delineations of streamlines and catchment boundaries. Flow direction grids are well suited to the calculation of convergent flow for various hydrological modelling applications associated with streamflow.



Value	Direction of flow from centre
1	East
2	South East
4	South
8	South West
16	West
32	North West
64	North
128	North East
0	**Indicates a sink**

Figure 1. Raster values represent flow direction from the centre.

Flow direction grids can be derived by computing the aspect of the downslope direction at each DEM grid point from the relative heights of the neighbouring grid points. However, in low relief areas, which abound in large parts of Australia, the downslope direction is not always accurately defined by relative elevations of neighbouring DEM points. This can lead to significant errors in delineating streamlines and catchment boundaries. The flow direction grid associated with the production of the DEM by the ANUDEM program always adheres to the flow directions implicit in the supporting streamline data, no matter how flat the local relief. The Flow Direction Grid is therefore being released with the 9 Second DEM to ensure that streamlines and associated catchments can be accurately delineated everywhere.

Flow direction grids are less well suited to the calculation of flow in divergent areas, unless the single flow directions are suitably augmented by additional flow directions. Methods for modelling stream and catchment behaviour based on flow direction grids with multiple directions are currently under development. The ANUDEM procedure incorporated multiple flow directions associated with distributaries in the TOPO-250K streamline data, but such multi-flow grids are not amenable to analysis by standard GIS packages. The flow direction grid distributed with the 9 Second DEM has therefore been derived from the multi-flow direction grid produced by ANUDEM by choosing the principal stream direction at each multi-flow grid point, as defined primarily by the hierarchy field for the TOPO-250K streamlines (Geoscience Australia 2006), and secondarily according to stream name.

See Chapter 5 for a systematic assessment of the accuracy of the 9 Second Flow Direction Grid.

CHAPTER 4

Product Information

- Coordinate Systems and Grid Properties
- DVD Contents
- Formats
    - ESRI ASCII Grid (ASC)
    - ER Mapper Grid (ERS)
    - ESRI Grid (Folder)
    - ERDAS Imagine Grid (IMG)
    - XYZ ASCII Grid (XYZ)

The 9 second DEM and Flow Direction Grid data is supplied on a single layer DVD-ROM. Data is provided in five formats that are compressed into ZIP files.

Coordinate Systems and Grid Properties

All data uses the Geocentric Datum of Australia (GDA94) for its horizontal datum, with units in decimal degrees, and the Australian Height Datum (AHD71) for its vertical datum in units of metres.

Note: If coordinate information is not present when loaded into any application, users will need to force or define (different for each application, please consult with individual application support) coordinate information as GDA94 and AHD71.

The DEM-9S is a 32 Bit continuous, floating point grid and the D8-9S is a 16 Bit continuous signed integer grid. Both have a NoData value of -9999.

DVD Contents

Volume is GEODATA_9secDEMandD8

D8-9S	Folder containing the Flow Direction Grid in five formats
D8-9S_ASC.zip	Compressed ESRI ASCII Grid
D8-9S_ERS.zip	Compressed ER Mapper Grid
D8-9S_ESRI.zip	Compressed ESRI Grid
D8-9S_IMG.zip	Compressed ERDAS Imagine Grid
D8-9S_XYZ.zip	Compressed XYZ ASCII Grid
DEM-9S	Folder containing the Digital Elevation Model in five formats
DEM-9S_ASC.zip	Compressed ESRI ASCII Grid
DEM-9S_ERS.zip	Compressed ER Mapper Grid
DEM-9S_ESRI.zip	Compressed ESRI Grid
DEM-9S_IMG.zip	Compressed ERDAS Imagine Grid
DEM-9S_XYZ.zip	Compressed XYZ ASCII Grid
adobe.txt	Information about reading PDF formats
availability.txt	Standard Geoscience Australia availability statement
copyright.txt	Standard Geoscience Australia copyright statement
GDA9494.prj	ESRI projection file for Geocentric Datum of Australia 1994
UserGuide.pdf	Comprehensive Report
licence.pdf	Licence Agreement
ANZCW0703011541.txt	Plain text ANZLIC metadata record for DEM-9S
ANZCW0703011541.xml	XML ISO19115/19139 metadata record for DEM-9S
ANZCW0703012015.txt	lain text ANZLIC metadata record for D8-9S
ANZCW0703012015.xml	XML ISO19115/19139 metadata record for D8-9S
publication.txt	Standard Geoscience Australia publication statement
quality.txt	Standard Geoscience Australia quality statement
readme.txt	Standard Geoscience Australia disc content statement

Formats

For correct spatial referencing, data should be used in the formats native application. For example, use the ESRI GRID in ArcGIS and the ERS file in ER Mapper. Although many of the common GIS applications allow viewing of alternative formats, some do not register the raster dataset correctly according to the position of the top left pixel. Some applications reference the dataset around the centre of that pixel and some from the top left corner of that pixel. Check that the top left neat edge starts at easting 112.0 and northing -9. Each pixel is 0.0025 square and the dataset contains 13897 rows and 16440 columns.

ESRI ASCII Grid (ASC)

ArcGIS by ESRI was used to create the final data. One of its output formats is GRIDASCII. As inferred by the name this is an ASCII file format and it is therefore easy to read across a large number of platforms. This format consists of header information containing a set of parameters, which can be used to geocode the data. Although the header includes the coordinates of the lower left corner of the area covered by the grid the elevation data are given as strings of elevations, in row by row, starting from the upper left point on the grid. The file format is:

```
NCOLS 16440                 (number of columns)
NROWS 14297                 (number of rows)
XLLCORNER 112.9             (longitude of the lower left corner)
YLLCORNER -43.7425          (latitude of the lower left corner)
CELLSIZE 0.0025
NODATA_VALUE -9999
row 1                       (space delimited string of elevations)
row 2                              |
.                                  |
.                                  v
row n
```

ER Mapper Grid (ERS)

A proprietary raster format produced using the ER Mapper image processing software. It is made up of two files. The dataset header file has the same base name as the data file it is describing, with the extension ".ers" added. So, "DEM-9S.ers " is a valid raster dataset header file name for the raster data file "DEM-9S".

The ER Mapper dataset header file is an ASCII file describing the raster data in the data file. The ER Mapper raster data file contains the data itself, the data is stored in a binary, Band-Interleaved-by-Line (BIL) format. The pixels' data type is defined in the accompanying header file.

The entire header file holds information about the data source and is contained in the DatasetHeader block. There are two compulsory sub-blocks, the CoordinateSpace block (to define the coordinate space and location) and the RasterInfo block (to define the characteristics of the data in the accompanying data file). The RasterInfo block may contain a number of optional sub-blocks.

ESRI Grid

A proprietary raster format by ESRI, produced using ArcGIS or ArcInfo. An ESRI Grid is made up of various files stored in two directories. One directory named per the dataset name and a second directory called info. These datasets are best viewed and managed using ArcGIS or ArcInfo, else linkages between folders can be broken and the dataset corrupted.

Both the DEM-9S and D8-9S were produced in this format and all other provided formats are derived from it.

ERDAS Imagine Grid (IMG)

ERDAS Imagine's proprietary raster format, that uses their hierarchal file format (HFA) structure. Data in this format was produced using ArcGIS 9.2. A single file, with the IMG file extension, holds the data and coordinate system information. This files can be read directly in ArcGIS, ER Mapper and ERDAS Imagine

XYZ ASCII Grid (XYZ)

This is an ASCII format which holds the data in an X, Y, Z or Longitude, Latitude, Elevation format.

The values for the longitude and latitude are in decimal degrees to six decimal places and the elevations are in metres to six decimal places. The fields are space delimited.

There is an X,Y,Z triplet for each point in the grid. Each triplet is a separate record in the file. The data begins at the centre of the cell at the upper left corner of the grid and then proceeds row by row of the grid. The last point in the data is the centre of the cell at the lower right corner of the grid.

The file format is;

```
(X)        (Y)       (Z)       (Note, this line does NOT appear)
142.165000 -9.230000 0.027774
142.167500 -9.230000 0.046402
142.170000 -9.230000 0.060375
142.172500 -9.230000 0.071334
etc.
```

CHAPTER 5

Essential Characteristics of the DEM

- Physical Configuration of the DEM
- Source Data Summary
- Map Sheet Effects
- The ANUDEM Gridding Algorithm
- Accuracy Estimates

It is anticipated that the GEODATA 9 Second DEM Version 3 and its associated 9 Second Flow Direction Grid, will be used for a large range of applications.

The user, should therefore, be aware of and understand the data sources used, the capabilities of the ANUDEM gridding algorithm and how these were used, and of course, the accuracy of the results.

The following pages detail the characteristics of the GEODATA 9 Second DEM and the 9 Second Flow Direction Grid that are essential for their proper use and understanding.

Physical Configuration of the DEM

This section contains information about the way in which the GEODATA 9 Second DEM Version 3 is supplied and what each elevation point represents.

Coverage

The GEODATA 9 Second DEM is a digital elevation model of the Australian continent, Tasmania and the near islands. The data do not cover Heard Island, Norfolk Island, Lord Howe Island, Cocos Island, Christmas Island and the Australian Antarctic Territory. The spatial coverage of the DEM is contained between latitudes 9 °S and 44 °S and between longitudes 112 °E and 154 °E.

Grid Spacing

The elevation points in this product are at a spacing of 9 seconds of longitude by 9 seconds of latitude. Tests using various cell sizes indicated that the cell size of 9 seconds is the optimum across Australia for the available source data. The DEM generalises the terrain by smoothing complexities in relief within each grid cell.

The grid spacing is uniform in terms of geodetic coordinates. This was decided on due to the national nature of this product. An outcome of this however is that the spacing of points on the earth's surface varies across Australia. The spacing in a north-south direction remains relatively consistent at about 270 metres. In the east-west direction spacing varies from 265 metres at the top of Cape York to 194 metres in southern Tasmania.

Coordinate System

The data for the DEM-9S and D8-9S are held in the Geocentric Datum of Australia 1994 (GDA94) coordinate system in decimal degrees. This supersedes the Australian Geodetic Datum 1966 (AGD66) coordinate system used for Version 1. The elevations are based on the Australian Height Datum (AHD71) and are in metres.

The supply of elevations to the nearest micrometre does not imply that the accuracy of the data is to 1 micrometre. A precision of 1 micrometre is used to preserve drainage structure in low relief areas and in particular to avoid the appearance of terracing in the data that can occur in very flat areas of Australia.

No-Data Points

A value of -9999 has been used to signify that the relevant elevation point has no realistic value. This value has been set for points that the ANUDEM gridding algorithm has interpreted as falling in the sea.

Grid Point Locations

Each elevation point in the data file represents the approximate elevation of the centre of the 9 second by 9 second area covered by the corresponding grid cell. The locations of each z value with respect to the extents of the grid are shown in Figure 2.

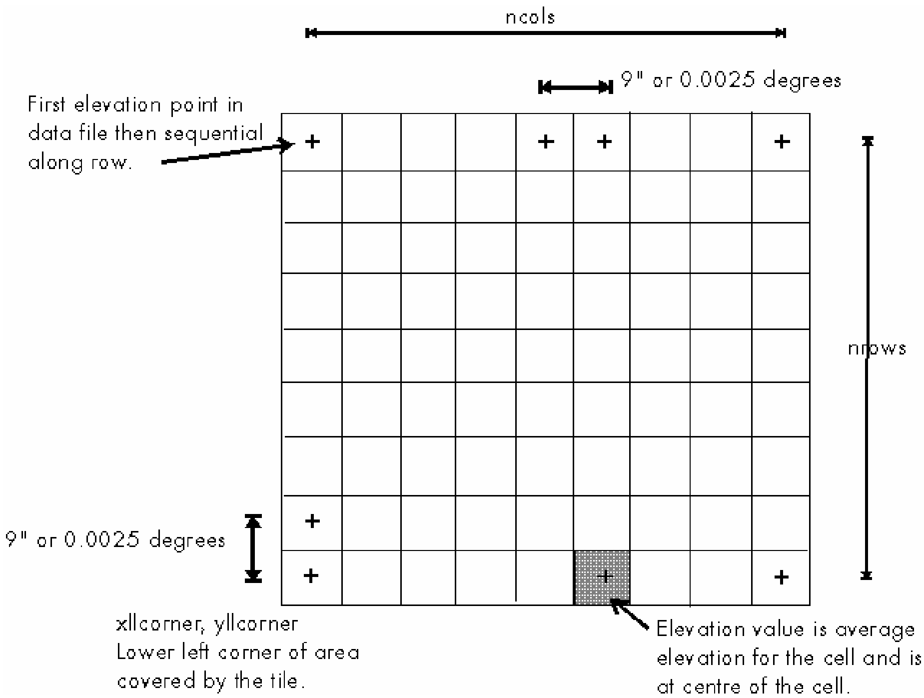


Figure 2. Grid geometry and structure.

Source Data Summary

The source data sets used to create the GEODATA 9 Second DEM Version 3 are listed below. A full description of the source data and the source data revisions is given in Chapter 6.

Six of the source data sets listed below came from the TOPO–250K digital product from Geoscience Australia. All were comprehensively checked and revised by the Fenner School during the DEM production process. More information on the TOPO-250K data and its origins can be found in the *GEODATA TOPO−250K User Guide* (Geoscience Australia 2006).

1. Revised spot heights from TOPO–250K Relief theme, Version 1;
2. Revised watercourse features from the Drainage layer of TOPO–250K, Version 1;
3. Revised cliff lines from the morphology layer of TOPO-250K Relief theme, Version 2;
4. Revised trigonometric data points from the National Geodetic Data Base;
5. Revised coastline of Australia from GEODATA COAST-100K data and coastal inlets from the TOPO–250K Framework layer;
6. Lakes from the waterbody layer of TOPO-250K Hydrography theme, Version 1;
7. Reservoirs from the waterbody layer of TOPO-250K Hydrography theme, Version 1 for Tasmania and Version 2 for the mainland;
8. Radar altimeter point elevation data supplied by Geoscience Australia for Lake Eyre;
9. Additional spot height data digitised by the Fenner School from digital 1:100K scale mapping;
10. Additional stream line data digitised by the Fenner School from digital 1:100K scale mapping;
11. Additional sink point data digitised by the Fenner School from digital 1:100K scale mapping;
12. Coastline cliffs selected from GEODATA COAST-100K data;
13. Selected contour lines and cliff lines digitised by the Fenner School from 1:100K scale topographic mapping.

The cliff lines from TOPO-250K Relief theme were used in the production of the 9 Second DEM for the first time with Version 3. This depended on the new availability of these data and new functionality in the ANUDEM program to process cliff lines in a way that minimised spurious interactions between streamlines and with closely neighbouring cliff lines.

The lakes and reservoirs from the TOPO-250K Hydrography theme were also used for the first time in the production of the 9 Second DEM Version 3. This depended on new functionality in the ANUDEM program to automatically estimate the elevations of the boundaries of all closed lakes.

Map Sheet Effects

The original elevation data were captured from 1:100K scale map information. These maps were created between 1965 and 1988 by different authorities, including the Division of National Mapping and the Royal Australian Survey Corps, and using a variety of mapping and surveying procedures. This has resulted in some variation in density and accuracy of elevation source data that can be evident in changes of texture in images of the data.

The stream line data were captured from 1:250K scale map information. These maps were also digitised with some variation in density and accuracy. Variations in density of digitised stream line data are particularly evident in some coastal areas.

In both Version 2 and Version 3 of the DEM, map sheet effects resulting from spatially varying source data density were largely overcome by the improvements in the ANUDEM elevation gridding program and by systematically calculating the DEM in 43 overlapping tiles that corresponded approximately to standard 1:1M Maps as shown in Figure 3.

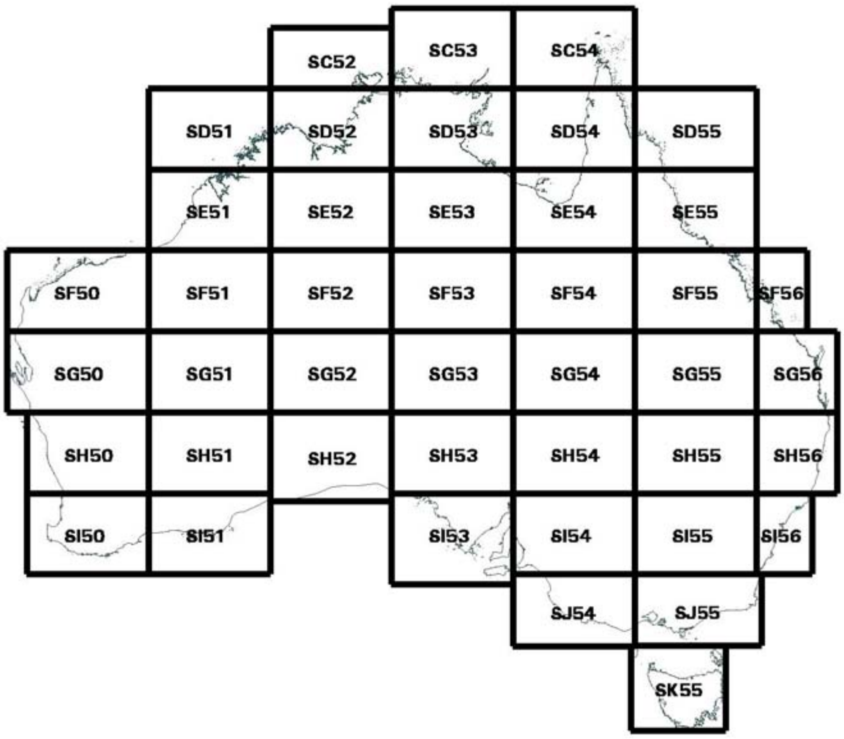


Figure 3. Index of the production tiles for the 9 Second DEM.

The coordinate limits of these tiles are listed in Appendix C. The index above indicates the coverage of each tile and the tile number. Where a standard 6 degree x 4 degree tile would contain large areas of sea the tile extents have been reduced. Tiles with very small areas of land have been joined to larger neighbouring tiles.

Each tile was gridded with a margin of 0.1 degrees (approximately 10 km) so that the grids for all tiles could be joined with minimal edge effects. The final DEM was compiled by smoothly blending together the overlapping edges of the tiles.

Drainage enforcement was applied to all tiles. This included inland low relief areas with diffuse drainage structure. This was made possible by systematically identifying all sinks associated with inland lakes and removing sand ridge data whose fine scale structure precluded adequate representation at the 9 second resolution.

The ANUDEM Gridding Algorithm

The ANUDEM program was revised to Version 5.2.2 to create elevation grids from the source data listed above. This program has been designed to produce accurate digital elevation models with sensible drainage properties from data sets including spot heights, contour lines, stream lines, lakes and cliff lines. ANUDEM is capable of using drainage network information to enforce drainage where this is compatible with the elevation data and user specified elevation tolerances. The ANUDEM program is described in more detail in Chapter 7.

The revised version of ANUDEM included a number of significant enhancements as follows:

- Improved automated drainage enforcement algorithm.
- Improved representation of streamlines and cliffs. This included improved location of streamlines and minimisation of spurious interactions of modelled cliff lines with intersecting streamlines and with closely neighbouring cliff lines.
- Improved location and representation of coastlines, permitting a smooth transition to the sea floor in the absence of coastal cliffs.
- Improved representation of lakes that permitted automated estimation of the elevation of closed lake boundaries.

The program was also revised to provide additional diagnostics to detect errors in all source data. This greatly facilitated efficient detection of errors in the very large data sets used to produce the 9 Second DEM. The principal diagnostics used in Version 3 were, as was for Version 2, the identification of remaining spurious sinks and large residuals from source elevation data in the fitted DEM for each tile. Spurious sinks were the most sensitive indicator of deficiencies in the representation of shape and drainage structure. These commonly arose from errors in point elevation data and direction errors in streamline data. The revised algorithms incorporating streamlines and cliffs were also partially designed and tuned by minimising the number of remaining spurious sinks.

Accuracy Estimates

This section describes the elevation accuracy of the 9 Second DEM and the accuracy of its representation of surface drainage structure via the 9 Second Flow Direction Grid.

Elevation Accuracy

The elevation error at a single point in a DEM depends on the grid spacing (cell size) of the DEM and the roughness of the surface that is being modelled. Thus elevation error is least in relatively flat terrain and largest in complex mountainous terrain. The error also tends to be smaller with smaller grid cell size, provided there are sufficiently dense source data to identify the finer scale variation in elevation. The ANUDEM program monitors the root mean square slope of the DEM as the grid cell size is refined to finer resolution (Hutchinson 1996). This stabilised with a cell size of around 9 seconds, indicating that 9 seconds is the optimum grid cell size for extracting all information from the available TOPO-250K source data.

A suitable measure of surface roughness for estimating elevation error is the local relief around each DEM cell. This can be simply defined as the range of elevation covered by the cell and its eight closest neighbours. Two approximate error models were constructed for the 9 Second DEM as functions of local relief. The error models are defined by:

$$SE = 7 + 53(1 - \exp(-R/75)); \text{ and}$$

$$MAE = 25+175(1 - \exp(-R/45));$$

where SE is the standard elevation error, MAE is the maximum absolute elevation error and R is the local relief as defined above. These error estimates can be readily calculated directly at any point on the DEM. The coefficients in these models were estimated by fitting the models to the residuals from the DEM of point elevation data selected from 1:25 000 scale contour data across all of New South Wales and Victoria. These data were not used to construct the DEM and cover the full range in terrain complexity from the flat plains of western New South Wales to the most complex landforms associated with the Great Dividing Range. These error models were coupled with the 9 Second DEM to calculate the maximum standard elevation error and maximum absolute elevation error as a function of cumulative percentage area of the Australian continent and plotted in Figure 4.

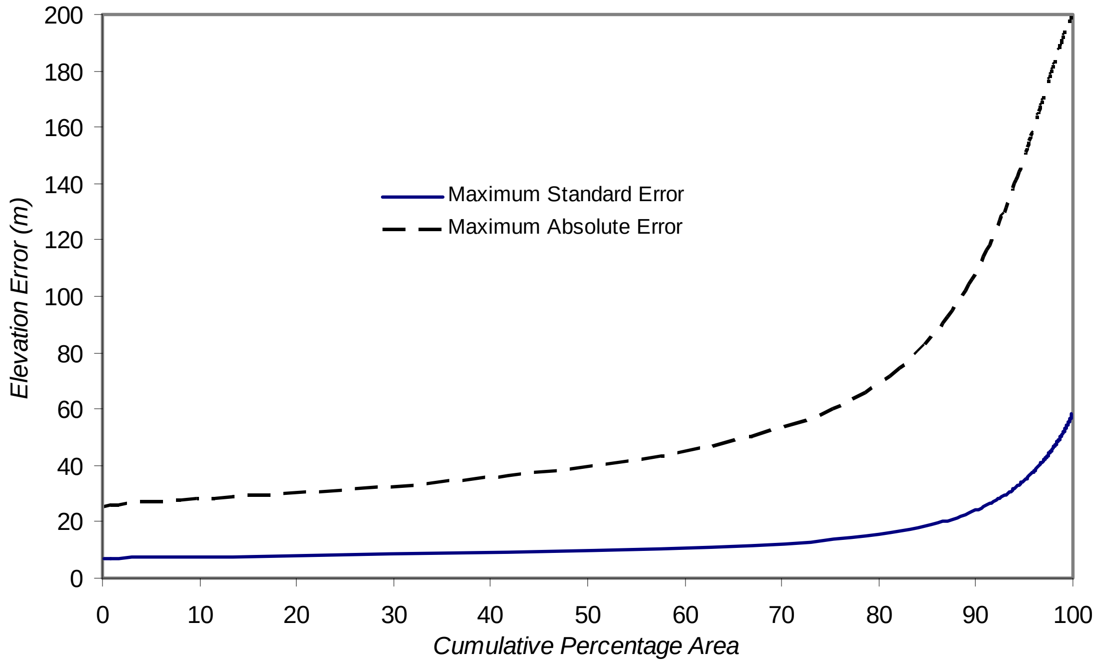


Figure 4. Maximum standard elevation error and maximum absolute elevation error of the 9 Second DEM as functions of cumulative percentage area of the Australian continent.

The curves in Figure 4 are directly related to local relief across the continent, as summarised in Table 1. From the table and Figure 3 it can be seen that for 50% of the continent the 9 Second DEM has local relief not exceeding 4 metres and standard elevation error not exceeding around 10 metres. This standard error is only twice the stated 5 metre error for the TOPO-250K point elevation source data (Geoscience Australia 2006). As the local relief of the DEM increases the elevation errors increase. Thus a further 30% of the DEM has standard error not exceeding around 15 metres, a further 15% has standard error not exceeding around 35 metres, a further 4% of the DEM has standard error not exceeding around 50 metres and the remaining 1% of the DEM has standard error not exceeding around 60 metres. The maximum absolute errors across the DEM cells are naturally larger than the standard errors. These range from 20-40 metres for the lower relief 50% of the continent up to around 200 metres for high relief areas. There are isolated instances of errors as large as 300 metres in complex highland areas.

Maximum Local Relief (m)	Cumulative Area (%)	Maximum Standard Elevation Error (m)	Maximum Absolute Elevation Error (m)
4	50	10	40
13	80	15	70
56	95	35	150
140	99	50	190
250	99.9	60	200

Table 1. Maximum standard and maximum absolute elevation errors of the 9 Second DEM as a function of maximum local relief and cumulative land area.

The mean standard elevation errors are also plotted by 1:250K map sheet in Figure 5.

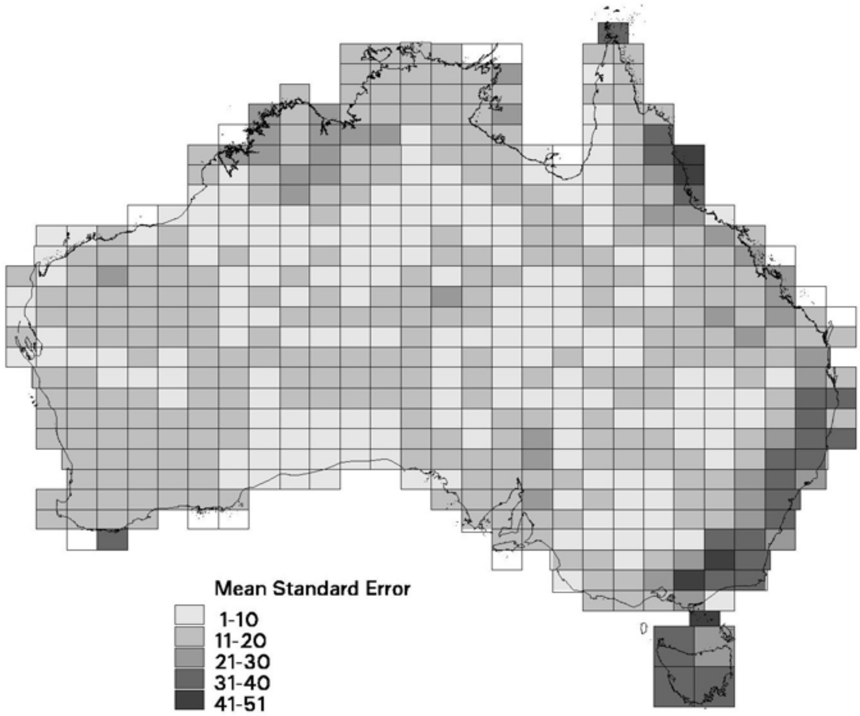


Figure 5. Mean standard elevation error by 1:250K map sheet across Australia.

Accuracy of Representation of Peaks

The inclusion of accurately located trigonometric data from the National Geodetic Data Base and closer fitting of peaks by the ANUDEM gridding algorithm has greatly improved the representation of peaks. Table 2 compares the residuals from all three Versions of the 9 Second DEM of the 19,000 points obtained from the National Geodetic Data Base. The residuals make due allowance for the different coordinate systems used for Version 1 and the later Versions of the DEM.

The mean bias and the root mean square residuals have both been significantly reduced in Version 3. The bias represents the mean difference between the 19,000 data points and the DEM, indicating that Version 3 of the DEM underestimates the elevations of peaks by an average of just 5 metres.

DEM	Mean Elevation Bias (m)	Root Mean Square Residual (m)	Maximum Residual (m)
Version 1	26	45	750
Version 2	11	20	225
Version 3	5	12	190

Table 2. Statistics of elevation residuals of 19,000 points from the National Geodetic Data Base.

It should be noted that not all significant peaks shown on 1:100K scale map sheets have been included in the source data for the DEM. The DEM should therefore be used with care in line of sight calculations that depend critically on the accuracy of representation of peaks.

Flow Direction Accuracy

For many applications, accurate representation of terrain shape is more important than absolute elevation accuracy. Measures of accuracy of overall shape and drainage structure, as principally determined by slope and aspect, are more difficult to quantify than standard elevation errors. This is because measures of slope and aspect are scale or resolution dependent and also because independent measures of these quantities are not generally available.

An independent assessment of the accuracy of the drainage structure represented by Version 2 of the DEM found there was close agreement between the boundaries of the national river basins (AUSLIG 1997) and the catchment boundaries calculated by Hutchinson et al. (2000) from the flow direction grid associated with the DEM. The DEM and these derived catchments have been used to successfully support continent-wide sediment transport modelling (Prosser et al. 2001, Gallant 2001) and systematic reporting of analyses for the National Land and Water Resources Audit (Hutchinson et al. 2000).

Version 3 of the DEM has improved the representation of streamlines and catchment boundaries by upgrading the ANUDEM algorithms and by adding significant numbers of additional data points in areas where the catchment boundaries had been less accurately defined. Comparisons of the rasterised streamlines defined by the 9 Second Flow Direction Grid with corrected TOPO-250K streamline data indicate that the rasterised streams respect these streamlines to within the limits of accuracy achievable at the 9 second scale. The average positional error of the gridded streamlines is around 1/4 of one grid cell or 60 metres. Approximately 95% of the gridded streamlines lie within 125 metres of the mapped streamline network and virtually all are within 270 metres.

CHAPTER 6

Building the DEM-9S Version 3 and D8-9S

- The Revised Source Data
- The Digital Elevation Model Production Process
- The Flow Direction Grid Production Process
- Quality Assurance

This chapter describes in detail the revisions to the source data and the production process used to create Version 3 of the 9 Second DEM and its associated Flow Direction Grid. It also summarises the total number of revisions and additions to the source data for both Version 2 and Version 3 of the 9 Second DEM. This information should help potential users to assess the appropriateness of the data in their applications. This chapter also describes the extensive quality assurance procedures performed for the DEM and Flow Direction Grid.

The Revised Source Data

The revised source data used to create the GEODATA 9 Second DEM Version 3 are described below. The source data came mainly from the TOPO–250K digital map product from Geoscience Australia. More information on this data set and its origins can be found in the *GEODATA TOPO–250K User Guide* (Geoscience Australia 2006).

The source TOPO-250K data were comprehensively revised by the Fenner School. Additional spot heights, stream lines, sink data points, contour lines and cliff lines were also digitised by the Fenner School as required to improve the accuracy of the DEM.

Revised Spot heights from GEODATA TOPO–250K Relief

These data are composed of elevation points derived from Geoscience Australia's national coverage of 1:100K scale map production material and are held in tiles which equate to standard 1:250K scale map areas. There are 5.2 Million spot heights in the Relief theme of TOPO-250K Version 1. The standard elevation error for these points is around 5 metres (Geoscience Australia 2006).

The density of these elevation points varies considerably across Australia. Figure 6 depicts the number of spot heights in each 1:250K tile as provided below.

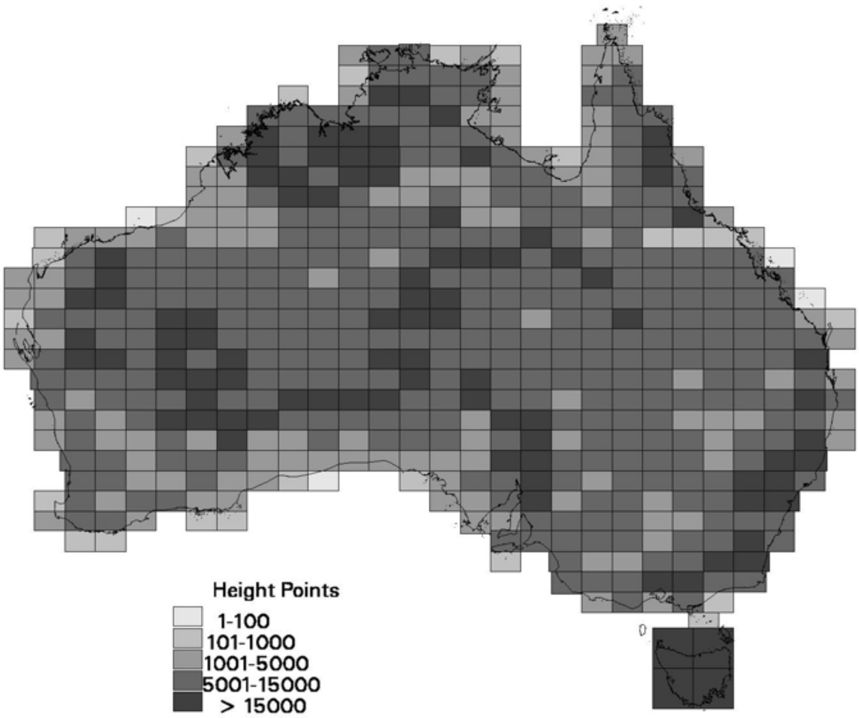


Figure 6. Number of spot heights by 1:250K map sheet.

Figure 7 indicates the total number of corrections and deletions made by the Fenner School to the spot heights in TOPO-250K Version 1. There were 25,000 revisions for Version 2 of the 9 Second DEM and a further 12,000 revisions for Version 3. A further 135,000 spot heights were deleted but are not included in this figure. These consisted of 79,000 coastal zero heights, 55,000 sandridge points and 1,500 spot heights in Lake Eyre.

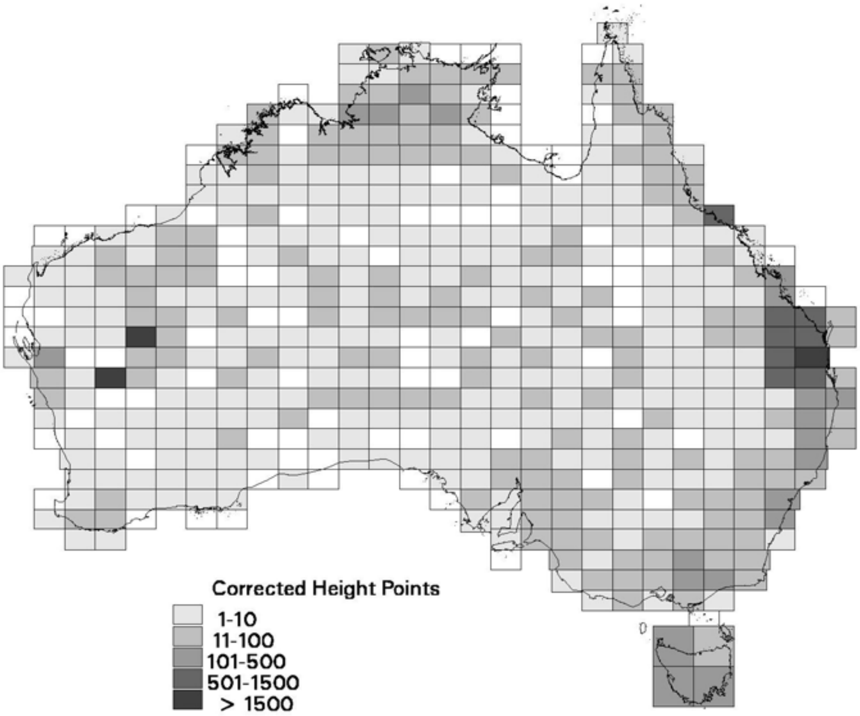


Figure 7. Number of corrected or deleted heights by 1:250K map sheet.

No points in the source data were attributed as being on a sandridge, although it was clear from initial analyses for Version 2 of the 9 Second DEM that there were large numbers of points on the tops of sandridges in some map sheets. The initial grids for these map sheets had a corrugated appearance that had no relationship to true relief, since the point data were not dense enough to resolve the sandridge structure. Where such effects were found, the sandridge elevations were identified and deleted. The number of deletions is indicated by 1:250K map sheet in Figure 8. A total of 41,000 sandridge points were deleted from the point elevation data for Version 2 of the 9 Second DEM. A further 14,000 additional sandridge points were identified and deleted for Version 3.

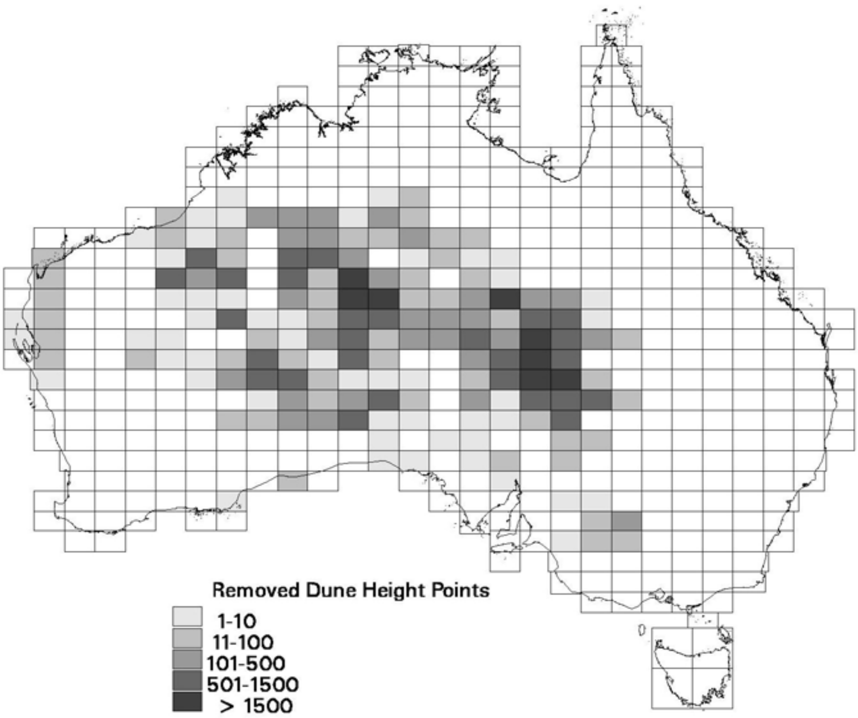


Figure 8. Number of sandridge points removed by 1:250K map sheet.

Revised Stream Line Data from GEODATA TOPO-250K Hydrography

This information was derived from stream information in the TOPO–250K Hydrography theme Version 1. The Drainage layer in this theme is composed of watercourses depicted on the 1:250K scale topographic maps as lines, connector features across waterbodies, as well as drains and canals. Figure 9 shows number of streamlines by 1:250K map sheet before revision.

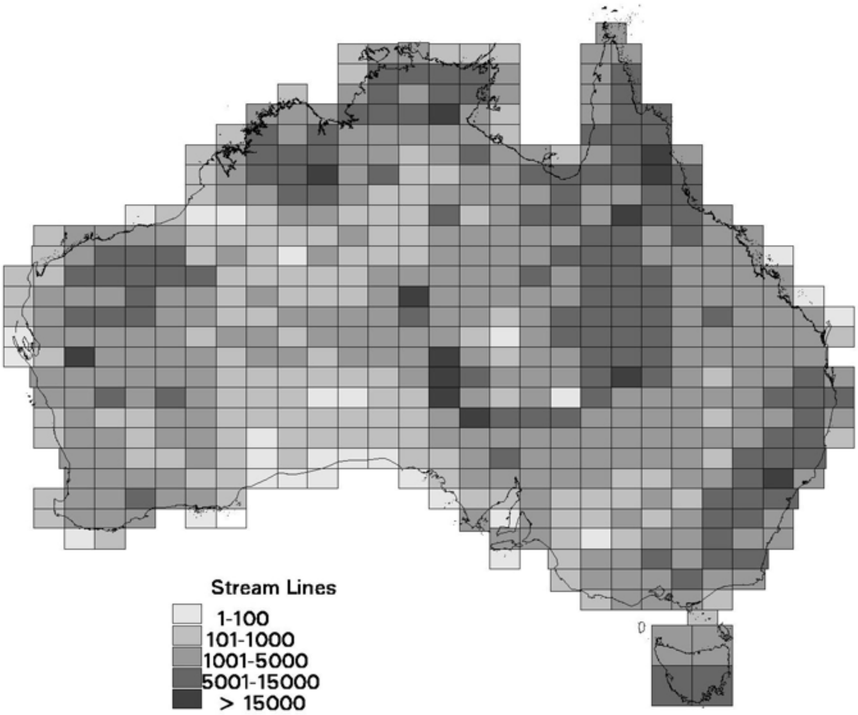


Figure 9. Number of streamlines by 1:250K map sheet.

The stream line data were edited where necessary so that the sequence of points in each stream arc was oriented in the direction of flow. This included breaking some stream arcs that had been joined through stream junctions to traverse both downstream and upstream directions. This was a necessary pre-requisite for optimal results from the use of the ANUDEM algorithm.

Canals were considered as artificial drainage lines. They often flowed along elevation contours and sometimes even crossed catchment divides and so did not generally represent the natural drainage structure of the landscape. Canals were deleted from the source data except in some low relief areas where they helped the DEM to represent the natural drainage structure.

Revisions to the stream line data set by the Fenner School are shown by 1:250K map sheet in Figure 10. There were 9,000 revisions for Version 2 of the 9 Second DEM and a further 7,000 revisions for Version 3.

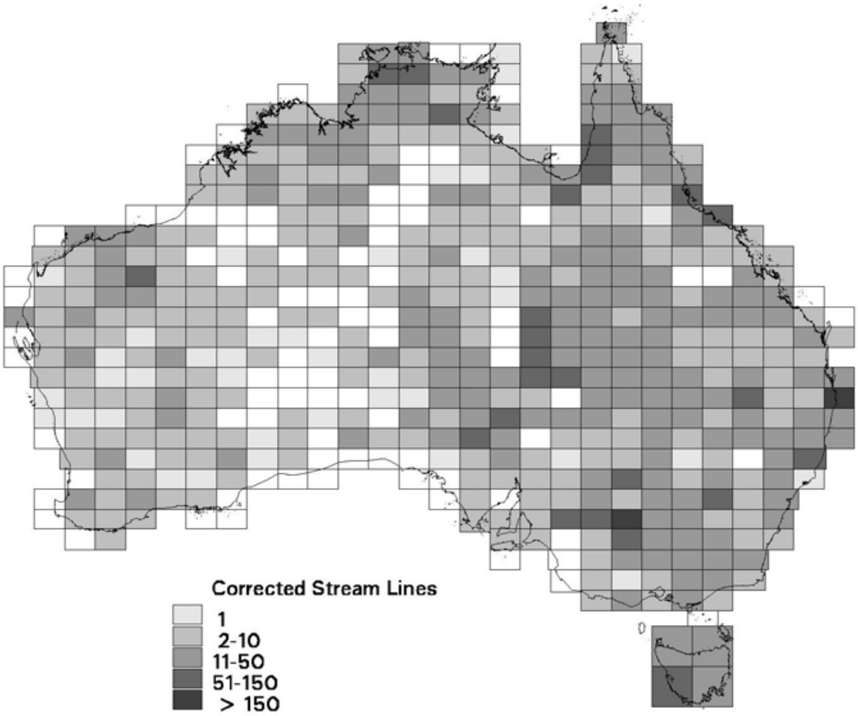


Figure 10. Number of corrected streamlines by 1:250K map sheet.

Stream distributaries were explicitly modelled in 9 Second DEM Version 3. The number of multi-flow grid cells due to stream distributaries are shown by 1:250K map sheet in Figure 11.

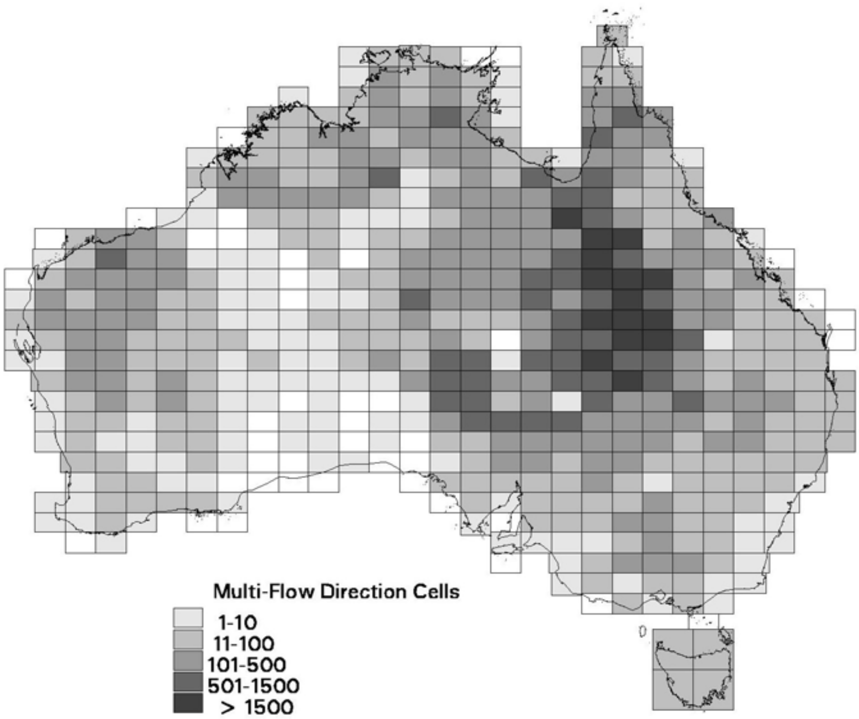


Figure 11. Number of stream distributaries by 1:250K map sheet.

Revised Cliff line from GEODATA TOPO-250K Relief

For the Version 2 of the DEM selected cliff lines were digitised by the Fenner School from rectified digital 1:100K scale map images and used as a new data type in the ANUDEM program to better define cliffs on the Nullabor coast, the Kimberley coast and in the Blue Mountains in New South Wales. For Version 3 of the DEM these cliff line data have been complemented by the continent-wide cliff line coverage now provided by the Relief theme of TOPO-250K Version 3. A total number of 26,000 cliff lines were used and are summarised by 1:250K map sheet in Figure 12.

Cliff lines are normally digitised in the direction so that the high side of the cliff is on the righthand side and the low side of the cliff is on the lefthand side. This information is used by the ANUDEM program to improve the representation of cliffs. ANUDEM consequently requires the directions of the cliff lines to be correct and provides diagnostics for cliffs with likely incorrect directions. A relatively small number, about 100 of the cliff lines in TOPO-250K Version 3, were found to have incorrect directions. All such direction errors were corrected.

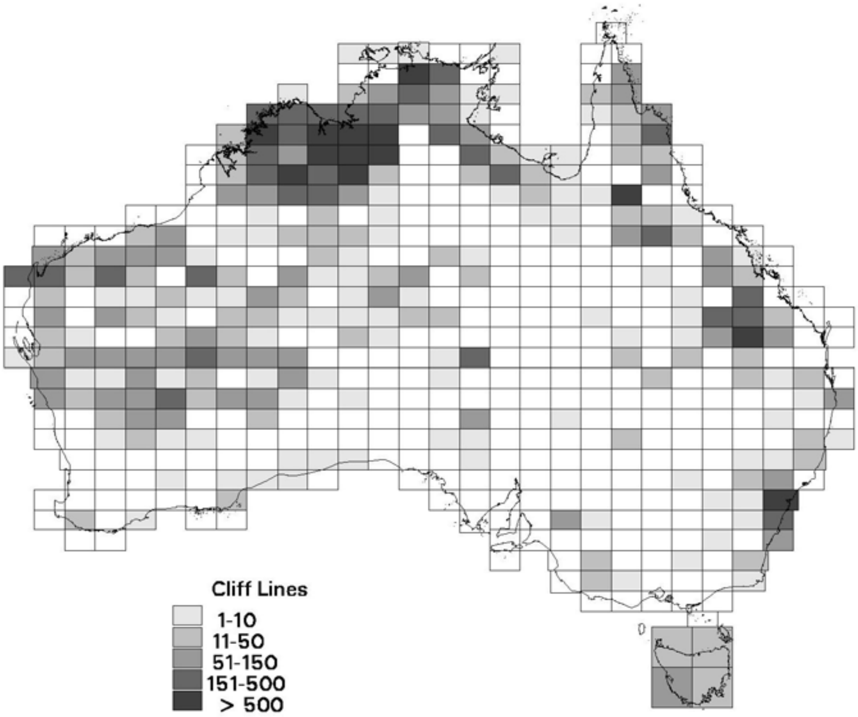


Figure 12. Number of corrected cliff lines by 1:250K map sheet.

Revised Coastline from GEODATA COAST-100K and TOPO-250K Framework

The coastline of Australia and its islands was derived from the GEODATA COAST-100K coastline data and lines describing coastal inlets from the TOPO–250K Framework Layer. The data were used to create bounding polygons within which the land points of the DEM were contained. DEM values outside the coastline were given a no-data value of -9999.

The coastline was also used as a contour line of zero elevation in places where there was a relatively smooth gradient to the coast. These zero values were not used in places where the coastline was formed by a cliff or steep slopes. The selected zero elevation data points replaced the 79,000 zero elevations deleted from the TOPO-250K Relief Theme Version 1.

National Trigonometric Point Data

A total of 37,000 trigonometric data points were supplied from the National Geodetic Data Base. These were used in both Version 2 and Version 3 of the DEM. These data assisted the modelling of high points across the continent. The data were revised to remove duplicates and the many trigonometric points measured from the tops of towers and other structures. Points were also converted to the GDA94 coordinate system where necessary. This left 19,000 corrected trigonometric points for use in the DEM. The positional and vertical errors of these points are generally less than 1 metre. The numbers of trigonometric data points are displayed by 1:250K map sheet in Figure 13.

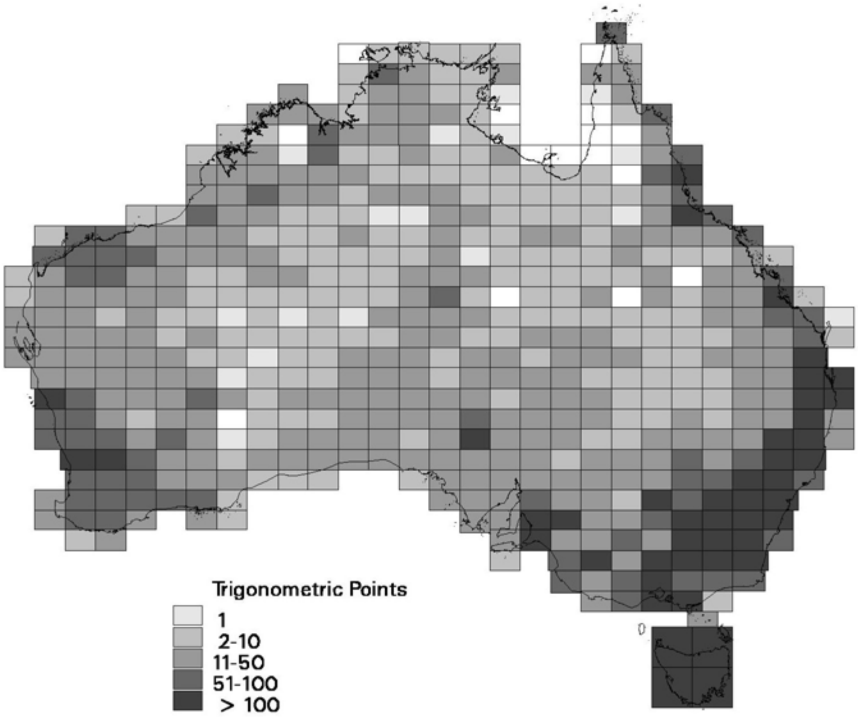


Figure 13. Number of trigonometric data points by 1:250K map sheet.

RADAR Altimeter Point Data for Lake Eyre

For Version 2 of the DEM, 300 elevation data points across Lake Eyre were supplied by AUSLIG to better define the elevation at the lowest part of the continent. The Fenner School then removed the corresponding 1,500 erroneous point data for Lake Eyre from the TOPO-250K Relief Theme Version 1. For Version 3 of the DEM the same 300 elevation data points were used for Lake Eyre as for Version 2.

Spot Height Data Digitised by the Fenner School

A total number of 87,000 additional spot heights were digitised by the Fenner School from rectified digital 1:100K scale map images for Version 2 of the DEM. A further 239,000 spot heights were digitised from the same source for Version 3. The total numbers of additional spot heights for Version 2 and 3 are summarised by 1:250K map sheet in Figure 14.

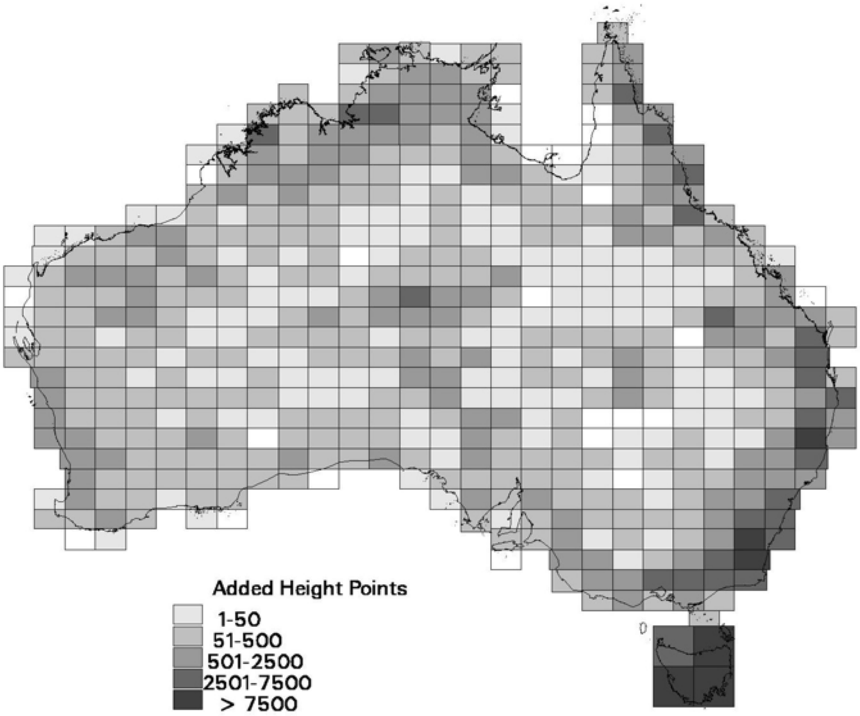


Figure 14. Numbers of additional spot heights digitised by the Fenner School by 1:250K map sheet.

Stream Line Data Digitised by the Fenner School

A total number of 11,000 additional stream lines were digitised by the Fenner School from rectified digital 1:100K scale map images for Version 2 of the DEM. A further 79,000 stream lines were digitised from the same source for Version 3. The total numbers of additional stream lines for Version 2 and 3 are summarised by 1:250K map sheet in Figure 15.

Figure 15. Numbers of additional stream lines digitised by the Fenner School by 1:250K map sheet.

Sink Point Data Digitised by the Fenner School

A total number of 21,000 sink data points were identified and digitised by the Fenner School from rectified digital 1:100K scale map images for Version 2 of the DEM. These improved the definition of drainage structure in low relief areas near the coast and in inland areas. A further 4,000 sink data points were digitised from the same source for Version 3. The total numbers of additional sink data points for Version 2 and 3 are summarised by 1:250K map sheet in Figure 16.

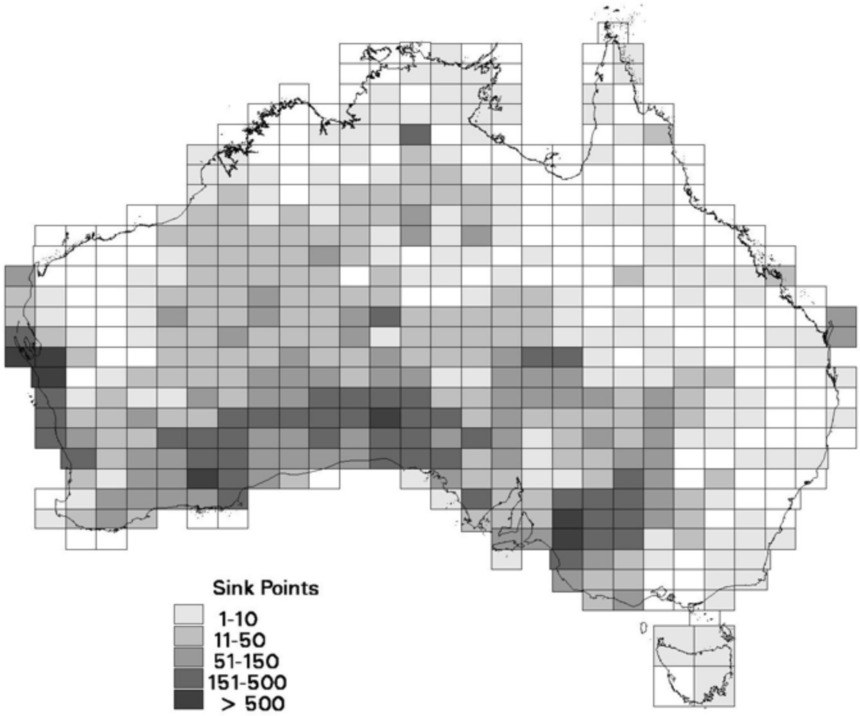


Figure 16. Numbers of sink data points digitised by the Fenner School by 1:250K map sheet.

The Digital Elevation Model Production Process

The following steps were used to derive Version 3 of the DEM. The Fenner School carried out all source data revision and digitised all source data additions except the national trigonometric data. The Fenner School also performed all preliminary and final gridding using the ANUDEM program, as the program was progressively upgraded to Version 5.2.2. The quality of the final DEM owes much to the close interaction between the upgrade of the ANUDEM program and the revision of the source data. Geoscience Australia provided final quality assessment by comparing each tile of the output DEM with the corresponding tile from Version 2 of the DEM and with 1:100K scale topographic mapping, as described in the following section.

1. The drainage network was corrected for:

   a) Natural drainage - an attempt was made to delete all arcs defining canals from the coverage. Canals were not removed in some low relief areas where drainage was not being defined effectively.

   b) Consistent drainage – extensive editing was undertaken to orient data stream lines in the direction of flow. Arcs were split where it was found that watercourses had been incorrectly joined over ridges as a result of the digitising process.

      This process was aided by:

      (i) Stream error diagnostics and spurious sink diagnostics output by the ANUDEM program.

      (ii) Knowledge of the convergence of stream flow in patterns characteristic of moderate-high relief terrains.

   (iii) Use of spot height coverages and 1:100K scale topographic map images to determine slope.
   (iv) Use of 3 second Shuttle (SRTM) elevation data to further determine slope and stream direction in low relief areas free from vegetation cover.

2. The coastline for Australia was obtained from the GEODATA COAST-100K data and coastal inlets were extracted and built from the TOPO–250K Framework Layer. All grid cells outside the assembled polygons were given a no-data value by the ANUDEM program.
3. The coastline was also converted to a contour with zero elevation. This was not valid for lengths of coastline formed by cliffs or steep slopes. These lengths were identified by reference to 1:100K scale topographic maps and the corresponding arcs were deleted from the zero elevation contour file.
4. Stream, elevation, coastline, contour, cliff and sink point data files were formatted to a form suitable for input to the ANUDEM program. This was done by converting the data files to Arc/Info ungenerate ASCII point and line format.
5. Trigonometric data were supplied for Version 2 of the DEM by AUSLIG from the National Geodetic Data Base and processed by CRES as follows:
   a) Points were projected where necessary to the GDA94 coordinate system and duplicates were removed.
   b) Trigonometric data points with elevations not on the ground surface were removed. These were points that had been measured from the tops of towers and other structures.
6. Accurate radar altimetric point data across Lake Eyre were also supplied for Version 2 of the DEM by AUSLIG to replace inaccurate point data from TOPO-250K relief theme.
7. Gridded images of the 1:100K scale topographic maps were also supplied by AUSLIG for Version 2 to assist checking and correction of source data. CRES projected and registered these images to the GDA94 coordinate system.
8. Grids were calculated for each 1:1 Million map sheet with an adjoining margin of 0.1 degree (approx. 10 km). Errors in point and streamline data were mainly detected by examining diagnostics from ANUDEM. These consisted of stream network errors, remaining sinks and large residuals from point data in the preliminary grids. Preliminary grids were produced using ANUDEM Version 5.0. Later grids were produced using progressively upgraded versions of ANUDEM. All final grids were produced using ANUDEM Version 5.2.2. All detected source data errors were corrected. Sink points and additional data points and streamlines were also digitised where necessary from the rectified 1:100K scale map images.
9. The grids were submitted to Geoscience Australia for checking and approval. As described below, this revealed further minor errors in spot heights and stream directions, as well as a lack of point data in some cliff areas. All data errors were corrected and additional point data were digitised. The final grids were submitted to Geoscience Australia to confirm that all detected shortcomings in the DEM had been addressed.
10. The final overlapping 1:1 Million grid tiles were smoothly blended together over the overlap regions using the Arc/Info command *grid>mosaic*. The tiles were first blended together horizontally by rows. The blended rows were then blended vertically to form an overall lattice.

The Flow Direction Grid Production Process

The flow direction grid, with at most one flow direction for each grid cell, was derived from the multi-flow direction grids produced by ANUDEM at the time of fitting the DEM. The multi-flow direction grid accounts for the multiple flow directions that occur at distributary nodes in the channel system but multi-flow direction grids are not currently amenable to analysis by standard GIS packages. The following describes the processing of the multiple flow direction grid tiles to produce a grid with national coverage. This includes the correction of minor shortcomings and finally, conversion of the grid to a single flow direction (D8) grid compatible with standard GIS packages.

1. The multi-flow direction grids produced by ANUDEM for each of the mapsheet tiles were clipped to non-overlapping tile boundaries and merged with the Arc/Info GRID MERGE function. Occasional loops formed in the flow paths along mapsheet borders were manually corrected either by altering the flow direction of one cell to flow out of the loop or by setting the flow direction to zero (i.e. denoting a sink).
2. Very infrequently spurious sinks (i.e. those not corresponding with a data sink) remained in the flow direction grid despite extensive revision of source data. These were normally in low relief areas with ill-defined drainage structure. These sinks were automatically cleared wherever possible by altering the flow direction of the sink cell to a neighbouring stream cell (i.e. one through which a map stream passed) or otherwise to the lowest neighbouring cell that was not within the catchment of the sink. Neighbouring cells are adjacent cells in any of the eight directions. Remaining spurious sinks that were within 300m of a mapped stream were cleared by manually altering the flow direction codes of grid cells in the vicinity of the sinks, guided by the 1:100K scale topographic maps. The DEM values were not altered.
3. Crossing flow paths, arising where the inter-cardinal flow directions of adjacent grid cells differ by 90 degrees (e.g. 45º and 315º or 135º and 225º), were occasionally formed along the tile borders where tiles were joined. These were also corrected by altering the flow direction of one of the grid cells, preferentially one not overlying a stream line.
4. Alterations were also made to the flow directions of some grid cells coded with multiple flow directions, principally to remove one of the flow directions where there was no evidence of a bifurcation in the mapped (data stream) channel network. A rectangular neighbourhood of 5 by 5 cells around the multiple flow direction cell was searched for bifurcations in the mapped channel system. Bifurcations were identified from the arc – node topology of the mapped streamline vectors as nodes that occurred as the from (start) node for more than one arc. In erosional landscapes, as indicated by the flatness index of Gallant and Dowling (2003), the flow direction draining to the grid cell of the stream draining from the highest source was retained.
5. Finally, a single flow direction, D8 compatible, version of the flow direction grid was derived by choosing the flow direction of the major stream at distributary points, primarily according to the value of the hierarchy field of the TOPO-250K Version 3 streamlines (Geoscience Australia 2006), and secondarily according to stream name. Thus the direction to the stream labelled as a ‘major’ stream was chosen in preference to that labelled as a ‘minor’ stream. Similarly, the direction of flow to a ‘river’ was preferred to that of a ‘creek’ or an unnamed stream where the hierarchy of the streams in each of the flow directions was equal. Hierarchy values and stream names were assigned according to the value of the mapped (data) streamline that overlaid the majority of the grid cells of the stream link in the DEM derived stream network.

Quality Assurance

Quality assurance of the final DEM and associated flow direction grid built on the extensive quality assurance performed over the three year DEM production period. During that time the Fenner School performed comprehensive checking and correction of all source data. It also digitised extensive point elevation data and streamline data to ensure accurate representation of streamlines and catchment boundaries. These data revisions were closely coordinated with the major upgrades to the ANUDEM gridding procedure described above. The increasing efficiency in detecting subtle source data errors gave increasing confidence in both the veracity of the methods and the quality of the final DEM.

Final quality assurance was performed jointly with Geoscience Australia on both the 9 Second DEM and the Flow Direction Grid.

The Digital Elevation Model

Quality assessment of the DEM was conducted on each production 1:1M tile. The method adopted was to inspect the most significant differences between Version 2 and Version 3 of the DEM. Geoscience Australia reported on the improvement or otherwise, of Version 3 by comparing the DEMs at each place where there were significant differences with 1:100K scale mapping. The comparisons were done in two modes. The first compared absolute elevations. This was intended to check for significant errors in source data. The second mode compared elevations that had been scaled by the local relief of the 3 x 3 cell neighbourhood of each grid cell. This was intended to detect significant errors in shape and drainage structure.

The detection of the locations of the most significant differences was largely automated using appropriate GIS procedures. For each 1:1M tile, scaled and unscaled difference grids were calculated between the two DEMs. For each difference grid, the differences between the two DEMs were then ranked from largest to smallest after placing a 10 km wide buffer around each grid point. The buffer ensured that the differences selected for inspection were suitably spread across each tile. Differences were then inspected in order from largest to smallest. Places where Version 3 was apparently inferior to Version 2 were reported to the Fenner School for resolution. The overwhelming majority of large differences revealed that Version 3 was indeed a distinct improvement on Version 2. Occasional deficiencies in Version 3 corresponded to remaining source data errors and difficulties in modelling elevations around the new cliff lines in data sparse areas. The Fenner School corrected the remaining data errors and digitised additional point elevation data to overcome the deficiencies around cliffs, as confirmed by inspection of the revised DEM by Geoscience Australia.

The Flow Direction Grid

Quality assessment of the Flow Direction Grid was based on its ability to correctly delineate the major river systems. In particular, Geoscience Australia checked that the D8 defined flow paths followed the major channel in distributary drainage systems. The D8 flow paths were traced downstream from the source grid cells of the TOPO-250K streams to a terminal point, either a coastal outlet or an inland sink cell. The stream network so delineated was compared with the mapped streamlines by visual inspection focusing on the major rivers that were tracked downstream from source to outlet. Distributary points where the derived stream network diverted from a major stream to a minor anabranch were reported to the Fenner School. These points were corrected by selecting the alternative of the flow directions from the multiple flow direction grid. The corrections were verified by checking the stream network delineated from the revised D8 flow direction grid.

CHAPTER 7

ANUDEM

- Introduction to ANUDEM
- Drainage Enforcement Algorithm
- Outline of Program Structure
- Specifications of input data files

The ANUDEM Version 5.2.2 elevation specific gridding program, developed and implemented by Professor Michael Hutchinson at the Fenner School of the ANU, was used to derive the DEM from the source data. The program has been designed to produce accurate digital elevation models with sensible drainage properties from data sets of arbitrary size, ideally including well chosen point elevation, stream line, contour line, sink point, lake and cliff line data sets (Hutchinson 1989, 2007).

The program has been upgraded to address the specific requirements for Version 3 of the 9 Second DEM. The following sections have been derived from the user information provided with ANUDEM.

Further enquiries should be directed to the author at
http://fennerschool.anu.edu.au/people/academics/hutchinsonm.php

The information was correct on 30 June 2008.

Introduction to ANUDEM

ANUDEM has been designed to produce accurate digital elevation models with sensible drainage properties from point elevations, stream lines, contour lines and cliff lines (Hutchinson 1989, 2007). It was first applied to the generation of a national DEM, at the relatively coarse grid resolution of 1.5 minutes of latitude and longitude, by Hutchinson and Dowling (1991). The algorithm implemented by the program interpolates the elevation data onto a regular grid by minimising a suitably weak roughness penalty on the fitted grid values and by simultaneously imposing constraints that:

1. Ensure connected drainage structure by imposing a global drainage condition on the fitted grid values that automatically removes spurious sinks or pits and by calculating drainage constraints directly from input stream line data (Hutchinson 1989). These actions make up one of the principal innovations of the program. They eliminate one of the main weaknesses of elevation grids produced by general purpose interpolation techniques that has limited their usefulness in hydrologic applications, particularly those that rely on the automatic calculation of surface drainage and catchment areas.
2. Ensure proper representation of ridges and streams as deduced automatically from input contour line data. This is achieved by automatically inserting ridge and stream lines deduced from corners of contour lines that indicate where these lines cross the elevation contours, as described in Hutchinson (1988).

The program also includes capabilities to:

3. Smooth point elevation data according to the natural discretisation error associated with the incorporation of point data onto a regular grid (Hutchinson 1996).
4. Break continuity of the fitted DEM across cliff lines as specified by input cliff line data.
5. Automatically estimate the elevation of lake boundaries.
6. Provide extensive data diagnostics to facilitate efficient detection and correction of source data errors.

The imposed global drainage condition has been found in practice to be a powerful condition that can significantly increase the accuracy, especially in terms of their drainage properties, of digital elevation models interpolated from sparse sets of surface specific data (Hutchinson 1989). The size of such data sets can be at least an order of magnitude smaller than the number of points normally required to adequately describe elevation using digitised contours. This can minimise the expense of obtaining reliable digital elevation models in terms of the capture, correction and storage of primary elevation data. The global drainage condition also virtually eliminates the need for detailed manual editing of interpolated elevation grids to remove spurious drainage features.

The program acts conservatively when attempting to remove sinks and does not impose drainage conditions that would plainly contradict the elevation data. A consequence of this is that errors in both elevation and position of input elevation data can often be indicated by sinks in the final fitted grid, especially when the input data includes at least the principal stream line networks. This is highly useful when processing very large data sets, and the program can optionally write out diagnostic information for each sink to assist in the correction of data errors. The number of such sinks is usually quite small. The conservative nature of the program imposed drainage conditions also makes the program quite robust to moderate errors in the positions of input stream line data and gives it the capability of producing generalised (coarse resolution) elevation models with appropriately generalised drainage properties.

Drainage Enforcement Algorithm

The global drainage condition is imposed by an algorithm that attempts to remove all sink points that have not been identified as such in input sink data. The drainage enforcement algorithm has been significantly upgraded for Version 5.2.2 of ANUDEM, to improve the detection of errors in source data and to improve connectivity of surface drainage where this is appropriate.

The essence of the drainage enforcement algorithm is to find for each sink point the lowest adjacent saddle point that leads to a lower data point, sink or edge. Provided a conflicting elevation data point has not been allocated to the saddle, the algorithm then enforces a descending chain condition from the sink via the intervening saddle to the lower data point, sink or edge. This action is in fact modified by the systematic application of a user supplied elevation tolerance. This tolerance allows the user of ANUDEM to adjust the strength of drainage enforcement in relation to both the accuracy and density of the input elevation data.

The detailed action of this tolerance has undergone considerable development and testing with data sets of varying densities and accuracies at a variety of scales. The aim has been to achieve the strongest possible drainage enforcement without making serious errors in the placement of drainage lines, particularly when input data are limited in terms of accuracy or density. The action of the tolerance naturally becomes less critical as the accuracy and density of the input data improves. When the tolerance has been set appropriately, the sink points not cleared by the program are normally those associated either with significant elevation errors in input data or with areas where the input data are not of sufficient density to reliably resolve the drainage characteristics of the fitted grid.

The user supplied tolerance should principally reflect the elevation accuracy of the input data points but can also reflect the density of the input elevation data. Elevation differences between data points not exceeding this tolerance are judged to be insignificant with respect to drainage. Thus data points that block drainage by no more than this tolerance are removed. When data points are not sufficiently dense to accurately resolve drainage, this tolerance may be increased somewhat and will yield a slightly generalised drainage pattern at the expense of fidelity to the elevation data. This is especially useful when working at coarser scales (coarser than say 1:100K). The tolerance is also used when searching for possible sinks clearances, to slightly favour those saddle points which are not associated with data points, over those saddle points which are associated with data points.

Drainage enforcement can also be obtained by incorporating stream line data. This is useful when more accurate placement of streams is required than can be calculated automatically by the program. It can also be used to remove sinks that would not otherwise be removed by the automatic drainage enforcement algorithm. This is in fact the recommended way to correct drainage anomalies in elevation grids calculated by the program. All elevation data points that conflict with strict descent down each stream line are removed. The program checks for closed loops in data stream lines. Such closed loops are prevented by the program and a report is written to an output diagnostic file on those data stream lines which attempt to form closed loops.

Side conditions are also set for each stream line. These ensure that the stream line acts as a breakline for the interpolation conditions and simultaneously ensures that each stream line lies at the bottom of its accompanying valley.

Outline of Program Structure

The ANUDEM program can process arbitrarily many different input data files, each of arbitrary size. The only size limit imposed by the program is the size of the fitted DEM. This needs to be stored in the memory of the computer running ANUDEM. Each data file may be one of seven types:-

1. Point elevation data
2. Sink point data
3. Stream line data
4. Boundary polygon data
5. Contour line data
6. Lake boundary data
7. Cliff line data

The program first reads input data points from each input data file, windows the data to the user specified map limits and then generalises the data to the user specified grid resolution. Point data are generalised by accepting up to 100 data points per grid cell and discarding any remaining points. Line data are generalised by accepting at most one line data point per grid cell, and, in the case of stream line and contour line data, removing unnecessary kinks.

The ANUDEM program then employs a simple multi-grid method which calculates grids at successively finer resolutions, starting from an initial coarse grid, until the final, user specified grid resolution. The program simultaneously imposes sensible drainage conditions to remove sinks where possible according to the algorithm described above. For each grid resolution, the accepted data points are allocated to the grid and the grid values are calculated by Gauss-Seidel iteration with overrelaxation (SOR method) subject to an appropriate roughness penalty, ordered chain constraints, cliff line conditions and data smoothing according to the estimated discretisation error.

The ordered chain constraints are obtained from user supplied stream line data, sink point data and contour line data and by automatic drainage enforcement as calculated by the program. All drainage lines are broken across cliff lines. Iteration terminates when the user specified maximum number of iterations (normally 20) has been reached. Starting values for the first coarse grid resolution are set to the average elevation of all elevation data points, including those on contour lines. Starting values for each successive finer grid are interpolated from the preceding coarser grid.

On completion of the iterations, the program calculates all sink points remaining in the fitted grid and optionally writes a detailed summary to output. These sink points are also optionally written to a user specified diagnostic file for plotting. The program calculates the root mean square residual from the fitted grid of all point data files. Stream line information, as incorporated onto the grid, can also be written to a file in a format suitable for plotting.

Specifications of input data files

Data files in standard ARC/INFO ungenerate format or IDRISI vector format are read by ANUDEM without further specification. Otherwise, data file formats are as described below. The action of ANUDEM on each data file type, regardless of format, is also described.

Elevation data points

Each file contains ordered X,Y,Z triples that denote the position and elevation of each data point, with one data point per record. For each grid resolution, elevation data points are allocated to the nearest grid point. If more than one data point is allocated to the same grid point, then the average value is taken, with no more than 100 data points being considered for each grid point. There is no limit on the number of input elevation data points read from the user supplied data files. Elevation points that conflict with neighbouring cliff line conditions are removed.

Sink data points

Each file contains ordered X,Y,Z triples that denote the position and elevation of each sink data point. The program does not attempt to remove sinks at such points. The height of a sink point can be left unspecified by setting the Z value to a value lying outside the user specified height limits (e.g. -999.0). Sink points that lie on data stream lines are removed.

Stream lines

Each file contains strings of X,Y coordinate pairs, in order of descending elevation. The coordinate pairs in each streamline must be ordered from highest point to the lowest point, since the values in the grid are constrained to descend linearly down each stream line. Stream line data take priority over point elevation and contour line data. Thus elevation data points which conflict with descent down each stream line are ignored. The locations of streamlines can be automatically adjusted, to within a small user supplied tolerance, to minimise conflicts with closely neighbouring cliff lines.

Boundary polygons

Each file contains strings of X,Y coordinate pairs. Each string or consecutive group of strings must close within a program calculated tolerance to form a closed polygon. Polygons that do not close generate error messages to output and the position of the endpoint of each non-connecting line string is written to the polygon error file (when specified). Non-connecting boundary polygons can lead to (possibly very large) areas of the DEM, which should have been enclosed by the polygon, being set to the special value. Polygons with an area less than a small fraction of the area of one grid cell are ignored. Points in the final output grid that lie outside the polygons specified by these line strings are set to a program determined special value which is less than the user specified minimum height limit. This special value is written to output. If no polygon strings are read then no grid points are set to special values. Boundary polygons are normally interpreted as coastlines. In this case the program ensures that land points adjacent to the coastline have non-negative elevations. It also ensures that, in the absence of coastline cliffs, there is a smooth transition across the coastline to the (normally unknown) negative elevations of the neighbouring seabed.

Contour lines

Each file contains strings of X,Y coordinate pairs, with an elevation value for each string. The height of the points making up each contour string is incorporated into the grid. The program automatically identifies ridge line points and stream line points from the corners in the data contour lines.

Lake boundaries

Input data file formats are exactly as for polygonal boundary files. Lake boundaries are permitted to include islands within lakes, and such islands may in turn contain lakes. All points of the DEM that lie in lakes, as determined by lake boundary polygons, are set to the minimum height of all DEM points outside and adjacent to the boundary of the lake.

Cliff Lines

Cliff lines have the same format as stream lines with a nominated direction. Each file contains strings of X,Y coordinate pairs. Each cliff line must be oriented in the direction so that the high side of the cliff is on the right-hand side and the low side of the cliff is on the left-hand side. The locations of cliff lines can be automatically adjusted, to within a small user supplied tolerance, to minimise conflicts between cliffs and closely neighbouring stream lines.

APPENDIX A

Acknowledgments

	Fenner School, ANU	Geoscience Australia
Project Management	Prof Michael Hutchinson	Hamish Anderson Phil Tickle
Production	John Stein Janet Stein Prof Michael Hutchinson	
Quality Assurance	John Stein Janet Stein	David Campbell Andrew Clive Janine Luckman Michael Holzapfel

APPENDIX B

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APPENDIX C

9 second DEM Production Tile Coordinates

TILE NUMBER	TILE NAME	LOWER LEFT CORNER		UPPER RIGHT CORNER	
		Longitude	Latitude	Longitude	Latitude
SC52	MELVILLE ISLAND	126	-12	132	-9
SC53	CAPE WESSEL	132	-12	138	-8
SC54	TORRES STRAIT	138	-12	144.5	-8
SD51	BRUNSWICK BAY	120	-16	126	-12
SD52	DARWIN	126	-16	132	-12
SD53	ROPER RIVER	132	-16	138	-12
SD54	MITCHELL RIVER	138	-16	144	-12
SD55	COOKTOWN	144	-16	150	-12
SE51	BROOME	120	-20	126	-16
SE52	HALLS CREEK	126	-20	132	-16
SE53	NEWCASTLE WATERS	132	-20	138	-16
SE54	NORMANTON	138	-20	144	-16
SE55	TOWNSVILLE	144	-20	150	-16
SF50	HAMERSLEY RANGE	113	-24	120	-20
SF51	OAKRIVER	120	-24	126	-20
SF52	LAKE MACKAY	126	-24	132	-20
SF53	ALICE SPRINGS	132	-24	138	-20
SF54	CLONCURRY	138	-24	144	-20
SF55	CLERMONT	144	-24	150	-20
SF56	ROCKHAMPTON	150	-24	152.5	-20
SG50	MEEKATHARRA	113	-28	120	-24
SG51	WILUNA	120	-28	126	-24
SG52	PETERMANN RANGES	126	-28	132	-24
SG53	OODNADATTA	132	-28	138	-24
SG54	COOPER CREEK	138	-28	144	-24
SG55	CHARLEVILLE	144	-28	150	-24
SG56	BRISBANE	150	-28	154	-24
SH50	PERTH	114	-32	120	-28
SH51	KALGOORLIE	120	-32	126	-28
SH52	NULLABOR PLAIN	126	-32.4	132	-28
SH53	TARCOOLA	132	-32	138	-28
SH54	BROKEN HILL	138	-32	144	-28
SH55	BOURKE	144	-32	150	-28
SH56	ARMIDALE	150	-32	154	-28
SI50	ALBANY	114	-36	120	-32
SI51	ESPERANCE	120	-36	126	-32
SI53	PORT AUGUSTA	132	-36.5	138	-32
SI54	ADELAIDE	138	-36	144	-32
SI55	CANBERRA	144	-36	150	-32
SI56	SYDNEY	150	-36	152.75	-32
SJ54	HAMILTON	138	-35.97	144	-36
SJ55	MELBOURNE	144	39.5275	150.25	-36
SK55	TASMANIA	143.8175	43.7425	148.4975	-39.5275