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ANUDEM VERSION 5.3

USER GUIDE

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ANUDEM calculates values on a regular grid of a discretised smooth surface fitted to large numbers of irregularly spaced elevation data points, contour lines, streamlines, sink points, lake boundaries and cliff lines. The program imposes a global drainage condition that automatically removes spurious sinks where possible.

The program is normally distributed as binary executable with a user interface built using Tcl/Tk for:

Sun Microsystems Solaris on SPARC hardware

Microsoft Windows on Intel hardware

Linux.

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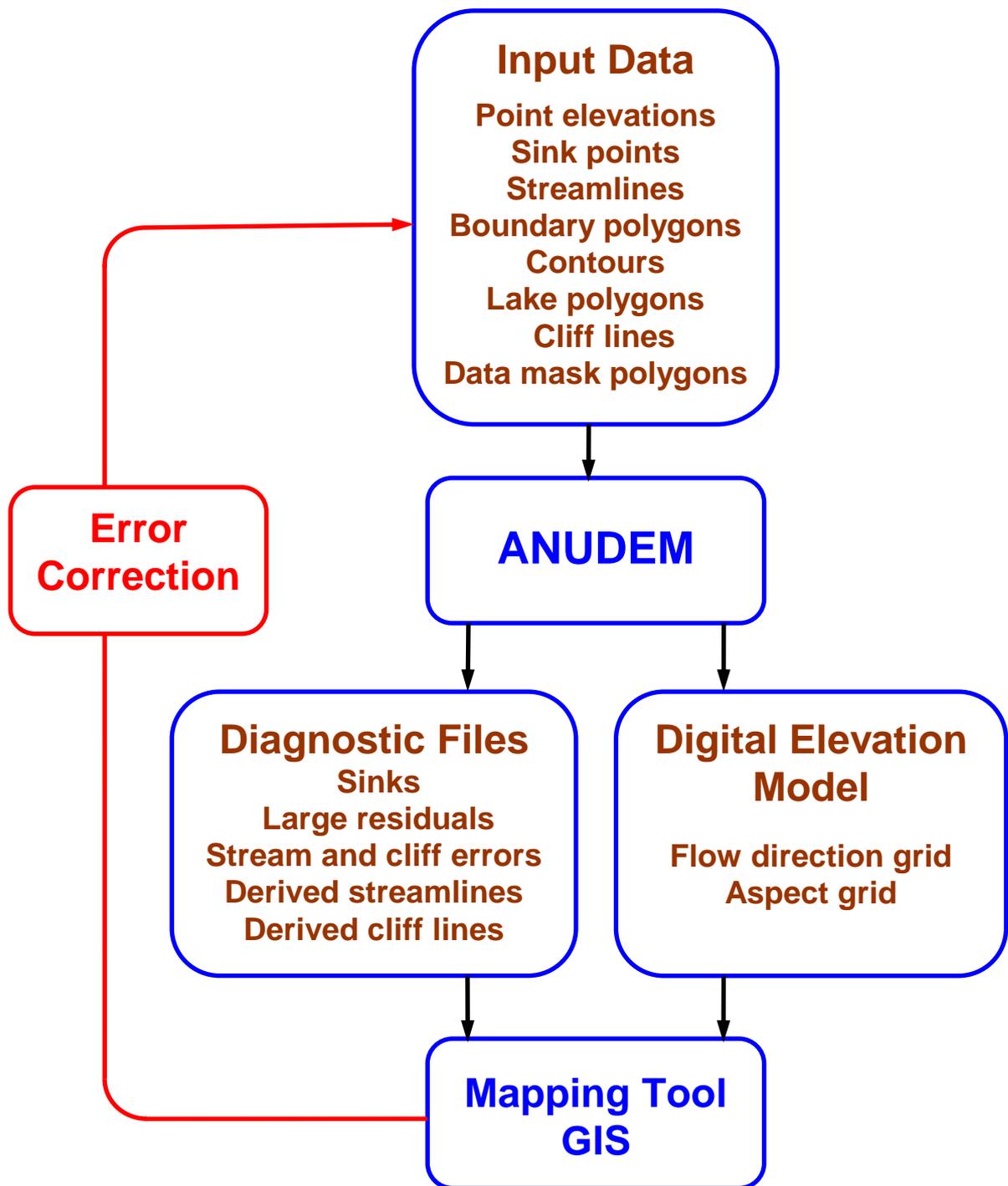


Figure 1. Main data flows through ANUDEM

1. INTRODUCTION

ANUDEM has been designed to produce regular grid digital elevation models (DEMs) with sensible shape and drainage structure from arbitrarily large topographic data sets. These DEMs underpin an extensive range of research and applications in natural resource analysis and assessment (Hutchinson 2008, Hutchinson and Gallant 1999, 2000). The program imposes a global drainage condition via a drainage enforcement algorithm that automatically removes spurious sinks. The input data may include point elevations, elevation contours, streamlines, sink data points, cliff lines, boundary polygons, lake boundaries and data mask polygons.

The program is normally distributed as a binary executable with a user interface built using Tcl/Tk for SUN-Solaris or Windows. Other platforms may be supported upon application.

This document reflects substantial revisions to ANUDEM. These revisions have substantially improved the performance of ANUDEM with very few alterations to the user interface to the program or the syntax of input and output files. The major revisions for Version 5.3 include:

- (a) Revision of the processing of elevation contour data to more faithfully represent the locations of the contour data.
- (b) Revision of the processing of lake boundary data, to more faithfully represent the location of lake boundaries, by now incorporating them as separators between grid points, and substantial upgrade of the method for aligning the estimated elevations of lake boundaries consistent with neighbouring elevation and streamline data.
- (c) Revision of the processing of streamline data to more faithfully represent the locations of input streamline data.
- (d) Revision of the automated drainage enforcement algorithm, with substantially improved performance on contour data.
- (e) Improved automatic delineation of ridges and streamlines from contour data.

These revisions build on the major enhancements released with ANUDEM 5.2, which included:

- (a) A capacity to model stream distributaries.
- (b) A lake boundary data type with lake boundaries incorporated into the interpolation process. Former versions used lake boundaries as masks after the interpolation process had been completed. The lake boundary algorithm has been upgraded to enable automatic determination of lake heights that are fully compatible with connecting streamlines and neighbouring elevation values.
- (c) A cliff line data type. This permits complete breaking of continuity of the fitted DEM across known cliff lines. The procedure incorporating cliff lines has been rewritten using an efficient cliff coding method that permits cliffs to be arbitrarily close to each other no matter what the grid spacing
- (d) A procedure to adjust the placement of streamlines and cliff lines to minimise spurious interactions between cliffs and stream lines as encoded onto a regular grid.

- (e) Improved representation of DEMs near coastlines, ensuring that grid points near the coast have non-negative elevations.
- (f) A polygonal data mask data type. This permits removal of elevation data from the interpolation process, typically used over dam walls and bridges, to enable interpolation of the underlying valley structure.
- (g) Enhanced point and line diagnostic outputs including sinks, large residuals, streamline errors, cliff errors and derived streamlines and cliff lines.
- (h) Output flow direction and aspect grids for hydrological applications. The output flow direction grid incorporates distributaries in streamline data.

The User Directives below contain comprehensive recommendations on use of ANUDEM, on assessing the accuracy of the fitted DEM, on how to optimise the grid resolution and on how to efficiently detect data errors.

The program interpolates topographic data onto a regular elevation grid by minimising a user specified roughness penalty on the fitted grid values and by simultaneously imposing constraints that ensure connected drainage structure and sensible representation of ridges and streams. The program can also produce a grid of flow directions and a grid of topographic aspect associated with the output DEM. These grids can be used directly in applications that require analysis of surface drainage and catchment structure.

The roughness penalty may be chosen to be a mixture of total curvature, potential and profile curvature. A mixture of total curvature and potential was found with the original version of the program to yield good results on scattered point data (Hutchinson 1989). The addition of the potential penalty reduces the overshoot that can arise with total curvature by permitting the grid to conform more closely to sharp changes in gradient. On the other hand, total curvature without potential has been found to yield good results on contour data provided that streams and ridge lines are simultaneously detected from the contour data (Hutchinson 1988).

A third roughness penalty, profile curvature, was introduced with Version 5.0 of ANUDEM. Unlike total curvature and potential, it is locally adaptive, since it is defined as the curvature of the fitted surface in the downslope direction, and it requires more computation. It is aimed at incorporating ridge and streamline structure directly into the roughness penalty. It can yield good results with good quality contour data (Hutchinson 1996, 2000) but its use is still regarded as experimental. Users should make their own assessment as to the applicability of this penalty to their data. The current default action of ANUDEM is to not use profile curvature.

The constraints imposed by the program ensure good shape and drainage structure in five main ways by:

1. Imposing a global drainage condition on the fitted grid values that automatically removes spurious sinks or pits.
2. Incorporating drainage constraints directly from input streamline data.
3. Representing ridges and streams, as deduced automatically from input contour line data. This is achieved by inserting curvilinear ridge and streamlines associated with corners of contour lines that indicate where these lines cross the elevation contours.

4. Breaking the continuity of the DEM over data cliff lines.

5. Ensuring compatibility of lake boundaries with the elevations of connecting streamlines and neighbouring DEM points.

The drainage enforcement algorithm is one of the principal innovations of ANUDEM. It can eliminate one of the main weaknesses of elevation grids produced by general purpose interpolation techniques that have limited their usefulness in hydrologic applications, particularly those that rely on the automatic calculation of catchment areas. The drainage condition can eliminate the need for detailed manual editing of the interpolated elevation grid to remove spurious drainage features. It can also aid in the efficient detection of data errors.

The imposed global drainage condition has also been found in practice to be a powerful condition that can significantly increase the accuracy, especially in terms of drainage properties, of digital elevation models interpolated from sparse sets of surface specific data. 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 drainage enforcement algorithm acts conservatively when attempting to remove sinks and does not impose drainage conditions that would plainly contradict the neighbouring 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 include at least the principal streamline network. This is particularly useful when processing very large data sets, and the program can optionally write a file with the locations of the remaining spurious sinks 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 streamline data and capable of producing generalised (coarse resolution) elevation models with appropriately generalised drainage properties.

ANUDEM has a comprehensive set of procedures for assessing the quality of the fitted DEM, for optimising DEM resolution and for detecting data errors. In addition to flagging remaining spurious sinks and circular data stream networks, the program can write a file of largest scaled residuals. The largest of these residuals indicate large elevation errors and locations where elevation data are inconsistent with streamline data. Where there are inconsistencies between elevation data and streamline data, these can be due to small but significant errors in input elevation data or errors in location or direction of input streamline data. Additional output diagnostic files are described in the User Directives.

2. DRAINAGE ENFORCEMENT ALGORITHM

Drainage enforcement is achieved by attempting to remove all sink points that have not been identified as such in input sink data files. 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 and enforcing a descending chain condition from the sink, via the intervening saddle, to the lower data point, sink or edge (Hutchinson 1989). This action is not executed if a conflicting elevation data point has been allocated to the saddle. The action of the drainage

enforcement algorithm is modified by the systematic application of two user supplied elevation tolerances. The program also enforces drainage by using streamline data.

Elevation tolerances

The first elevation tolerance allows the user 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 automated placement of drainage lines, particularly when the input data are limited in terms of accuracy or density. The action of the tolerance naturally become 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 those associated with significant errors in elevation data or streamline data or with areas where the input data are not of sufficient density to reliably resolve the drainage characteristics of the fitted grid.

The first tolerance should principally reflect the elevation accuracy of the input data points but it can also reflect the density of the input elevation data. Elevation differences between data points not exceeding the first tolerance are judged to be insignificant with respect to drainage. Thus data points that block drainage by no more than the first tolerance are removed. When data points are not sufficiently dense to accurately resolve drainage, the first tolerance may be increased somewhat to yield a more generalised drainage pattern at the expense of fidelity to the elevation data. This is especially useful when working at broader scales (coarser than say 1:100,000). When gridding contour data the first elevation tolerance should be set to half the data contour interval.

The first tolerance is also used when searching for possible clearances of remaining sinks to favour adjacent saddles that lead to destinations significantly lower in elevation than the remaining sink over saddles that lead to sinks at similar elevations to the remaining sink. This is particularly important in identifying connected drainage structure in areas with low elevation relief. This tolerance is also used to slightly favour saddle points that are not associated with elevation data points over saddle points that are associated with elevation data points. The tolerance is also used to slightly favour saddles associated with drainage constraints that are consistent with the intended drainage enforcement over saddles associated with drainage constraints that are inconsistent with the intended drainage enforcement. With ANUDEM Version 5.2 the drainage enforcement algorithm does not reverse constraints associated with input streamline data. The sinks that remain because of this are often good indicators of errors in the direction of input streamline data.

The second elevation tolerance is used to prevent drainage enforcement through unrealistically high barriers, whether or not supported by elevation data. Drainage is not enforced through saddle points that are more than this tolerance above the associated sink. This tolerance is rarely active and its size is not critical. The program provided default value is six times the first elevation tolerance. On rare occasions, when analysing difficult data sets with large variation in local relief, the user may increase this tolerance. The second elevation tolerance is likely to be inactive when source data are reasonably dense or mainly consist of elevation contours.

Streamline data

Drainage enforcement is particularly effective when used in conjunction with input streamline data. This is useful when more accurate placement of streams is required than what can be calculated automatically by the program. Input streamline data 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 if there are no errors in the input topographic data. Input streamlines must be directed in the direction of elevation descent. All downstream elevation data points that conflict with strict descent down each streamline are removed. The program removes closed loops from input streamlines and writes the locations of such loops to the output stream error file.

Version 5.3 permits modelling of stream distributaries by allowing each grid point to have up to two downstream directions. Elevations along all streams, including all distributaries, are initialised using a recursive procedure that uses all elevation data points that lie on streamlines. The output stream error file includes a flag for all distributary points to permit checking for possible streamline direction errors.

Side conditions are also set for each data streamline. These ensure that the streamline acts as a breakline for the interpolation conditions across the streamline so that each streamline lies at the bottom of its accompanying valley. Side conditions are not set for data points beside streams whose elevations are more than the second elevation tolerance below the height of the stream. Remaining sinks associated with such points are a good indicator of elevation errors and streamline direction errors.

3. NEW DATA TYPES

Three new data types were first introduced with earlier versions of ANUDEM to improve its locally adaptive capacity to model the shape and drainage structure of the landscape and to take advantage of existing source data. These data types are maintained in Version 5.3.

Cliff line data

A capacity to process cliff line data was first introduced in ANUDEM Version 5.0 to allow for broad scale breaks in elevation values in selected areas of the Australian continent (ANU Fenner School of Environment and Society and Geoscience Australia 2008). Cliff lines permit a complete break in continuity between neighbouring grid elevation values each side of the data cliff lines, as they are encoded into the grid. Further details of this algorithm will be described in a forthcoming publication. Cliff lines must be supplied to ANUDEM as directed lines, with the low side of each cliff line on the left and the high side of the cliff line on the right. This permits removal of elevation data points that lie on the wrong side of the cliffs, as they are encoded onto the grid, and better placement of cliffs in relation to streamlines.

The initial method for encoding cliffs permitted accurate breaking of continuity of the fitted DEM over data cliff lines, provided these lines were not within two grid cells of each other. This is unnecessarily restrictive since cliffs in general can be arbitrarily close to each other. The method was redesigned for Version 5.2 and later versions to completely remove this

restriction. The efficiency in coding of the revised method has permitted better processing of cliffs in terms of the quality of the output DEM and in terms of computational efficiency.

It has also been found that the minor shifts in position that are imposed on streams and cliffs as they are incorporated into the grid can lead to spurious interactions between these data. An automated method has therefore been developed to make small adjustments in the placement of both streams and cliff lines in the grid to minimise these spurious interactions. The magnitudes of these adjustments are normally less than the width of one grid cell but the adjustments can make a significant improvement in the quality of DEMs that depend on both stream and cliff line data. The maximum adjustments in cliffs and streamlines can be set by the user to reflect different positional accuracies of each data type.

Lake boundary data

Lake polygons were initially incorporated in ANUDEM as simple masks to set the elevation of each lake surface to the minimum elevation of all DEM values immediately neighbouring the gridded lake. This simple algorithm is not sufficient to accurately model landscapes with many lakes with interconnecting streams. The method for incorporating lakes has been completely revised to make full use of the information implicit in such lakes. The processing of lake boundaries has been substantially upgraded for Version 5.3 by now incorporating lake boundaries as separators between adjacent grid points rather than lying on grid points. This enables more accurate placement of lake boundaries within the DEM, in particular enabling more accurate incorporation of smaller lakes and closely neighbouring lakes. The revision has also led to a substantial revision of the method for estimating the elevation of lake boundaries.

The revised method also treats each lake boundary as a contour with unknown elevation and iteratively estimates the elevation of this contour from the grid points on the lake boundary. At the same time, the elevation of each lake boundary is made to conform with the elevations of any upstream and downstream lakes. The elevation of each lake boundary is also made to be consistent with the neighbouring DEM values. Grid points immediately outside the lake are made to lie above the elevation of the lake boundary and grid points on the interior of the lake made to lie below the elevation of the lake boundary. The method makes heavy use of efficient coding of the various conditions based on FORTRAN 90 bit operations on short integer grids. The method also flags errors in connecting stream line networks, including circular stream networks and lakes with multiple outflows.

Data mask polygon data

It is sometimes convenient to remove certain elevation data from the interpolation process without explicitly removing them from the elevation data files. This is particularly the case when there are many large data files. Data typically removed are those associated with features on the actual land surface that can interrupt accurate representation of shape and drainage structure of the true land surface. The underlying aim of ANUDEM is to represent the true ground surface. Unwanted data typically include dam walls and bridges over streams. They can also include ill-defined lake heights from remotely sensed elevation data sets, although in this case it may be preferable to remove the offending lake height data from the data files completely using standard GIS techniques. Data masks are enacted by digitising closed polygons around the unwanted features and submitting the polygons to ANUDEM as data mask polygons.

4. DEM QUALITY ASSESSMENT

The quality of a derived DEM can vary greatly depending on the data source and the interpolation technique. The desired quality depends on the application for which the DEM is to be used, but a DEM created for one application is often used for other purposes. Any DEM should therefore be created with care, using the best available data sources and processing techniques. Efficient detection of spurious features in DEMs can lead to improvements in DEM generation techniques, as well as detection of errors in source data as indicated above.

Since most applications of DEMs depend on representations of surface shape and drainage structure, absolute measures of elevation error do not provide a complete assessment of DEM quality (Hutchinson and Gallant 2000). A number of graphical techniques for assessing data quality have been developed. These are non-classical measures of data quality that offer means of confirmatory data analysis without the use of an accurate reference DEM. Assessment of DEMs in terms of their representation of surface aspect has been examined by Wise (1998).

Spurious sinks or local depressions in DEMs are frequently encountered and are a significant source of problems in hydrological applications. Sinks may be caused by incorrect or insufficient data, or by an interpolation technique that does not enforce surface drainage. They are easily detected by comparing elevations with surrounding neighbours. Hutchinson and Dowling (1991) noted the sensitivity of this method in detecting elevation errors as small as 20 metres in source data used to interpolate a continent wide DEM with a horizontal resolution of 2.5 kilometres. More subtle drainage artefacts in a DEM can be detected by performing a full drainage analysis to derive catchment boundaries and streamline networks, using the technique of Jensen and Domingue (1988).

Computing shaded relief allows a rapid visual inspection of the DEM for local anomalies that show up as bright or dark spots. It can indicate both random and systematic errors. It can also identify problems with insufficient vertical resolution, since low relief areas will show as highly visible steps between flat areas. It can also detect edge matching problems (Hunter and Goodchild 1995). Shaded relief is a graphical way of checking the representation of slopes and aspects in the DEM. These can also be checked by standard statistical analysis if there is an accurate reference DEM or accurately surveyed ground data (e.g. Sasowsky *et al.* 1994, Bolstad and Stowe 1994, Giles and Franklin 1996).

Contours derived from a DEM provide a sensitive check on terrain structure since their position, aspect and curvature depend directly on the elevation, aspect and plan curvature respectively of the DEM. Derived contours are a particularly useful diagnostic tool because of their sensitivity to elevation errors in source data. Subtle errors in labelling source data contours digitised from topographic maps are common, particularly for small contour isolations that may have no label in the printed map.

Other deficiencies in the quality of a DEM can be detected by examining frequency histograms of elevation and aspect. DEMs derived from contour data usually show an increased frequency of contour elevations in the elevation histogram. The severity of this bias depends on the interpolation algorithm. Work is in progress to reduce this bias in DEMs created by ANUDEM. The frequency histogram of aspect can be biased towards multiples of 45 and 90 degrees by

interpolation algorithms that restrict searching to a few specific directions between pairs of data points.

5. OUTLINE OF PROGRAM STRUCTURE

The program can process an arbitrary number of different input data files of arbitrary size, limited only by the memory and disk capacity of the host computer.

Each data file may be one of eight types:-

1. Point elevations
2. Sink points
3. Streamlines
4. Boundary polygons
5. Contour lines
6. Lake boundaries
7. Cliff lines
9. Data mask polygons

Detailed specifications of each type of data file are given below. The program first reads input data points or lines from each input data file, trims 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 at most 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 streamline data, removing unnecessary kinks. The selected data points are written to unformatted scratch files, one file for each data type, for quick retrieval during program execution.

The program then employs a simple multi-grid method that calculates grids at successively finer resolutions by successively halving the grid spacing, starting from an initial coarse grid until the final user specified grid spacing is obtained. The program simultaneously imposes sensible drainage conditions to remove sinks where possible according to the drainage enforcement algorithm described above and all data streamlines. It also breaks interpolation conditions across all data cliff lines and imposes natural constraints on grid values around and inside each lake polygon.

For each grid resolution, the accepted data points are read from the scratch files and values of all grid points are iteratively updated by Gauss-Seidel iteration with over relaxation (SOR method) subject to an appropriate roughness penalty and the ordered chain constraints described above to yield a root mean square residual from the elevation data in keeping with the natural discretisation error of the data (Hutchinson 2000). Iteration terminates when the user specified maximum number of iterations (normally 20) has been reached. Starting values for the first coarse grid resolution are calculated by setting the grid values to the average elevation of all input elevation data. Starting values for each successive finer grid are interpolated from the preceding coarser grid using biquadratic interpolation.

On completion of the multi-grid iterations, the program calculates all sink points remaining in the fitted grid and optionally writes a detailed summary to the log file. The locations of all remaining spurious sink points can also be written to an output spurious sink file for checking. The program calculates the root mean square residual from the fitted grid of the data points in their original positions. Streamline information, as incorporated onto the grid, can also be written to an output derived streamline file for checking.

6. SPECIFICATIONS OF INPUT DATA FILES

ASCII Data files in standard Arc/Info ungenerate or Idrisi vector format (Version 2) are read by ANUDEM without further specification and no FORTRAN format specifications are required. See Arc/Info and Idrisi documentation for further information on ungenerate and Idrisi file formats respectively. Otherwise, generic ASCII data file formats are as described below. The action of ANUDEM on each data file type, regardless of format, is also described. There is no limit on the number of input data files, nor on the size of any data file.

Elevation data points

Each file, in generic format, contains ordered X,Y,Z triples that denote the position and elevation of each data point, with at most one data point per record. The FORTRAN format of these triples must be supplied to the program. If in Arc/Info ungenerate format, then each record contains a Z, X, Y triple where the elevation precedes the position coordinates. 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.

Sink data points

Each file, in generic format, contains ordered X,Y,Z triples that denote the position and elevation of each sink point. The FORTRAN format of these triples must be supplied to the program. If in Arc/Info ungenerate format, then each record contains a Z,X,Y triple where the elevation precedes the position coordinates. 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 (eg. -999.0). Elevations provided with input sink data points tend not to be as visible as elevation data points when checking for data errors. It may be preferable to supply elevations at sink data points as separate elevation data points and provide all input sink data points with the elevation unspecified.

Streamlines

Each file contains strings of X,Y coordinate pairs, in order of DESCENDING elevation. If in generic format, each string must be preceded by a header that contains the number of coordinate pairs in the following string. In this case the FORTRAN formats of the header and of the coordinate pairs in the following string must be supplied to the program. 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** down each streamline.

Streamline data take **PRIORITY** over point elevation and contour line data. Thus elevation data points that conflict with descent down each streamline are ignored. ANUDEM optionally produces an output derived streamline diagnostic file that records the positions of all data streamlines as they have been incorporated into the grid, as well as all drainage enforcements made by the program to define drainage and ridge line structure. It also writes vectors to this file to flag large elevation data clearances associated with streamlines when the difference in elevation exceeds the second elevation tolerance.

Coastline polygons

Each boundary polygon file contains strings of X,Y coordinate pairs. If in generic format, each string must be preceded by a header that contains the number of coordinate pairs in the following string. In this case the FORTRAN formats of the header and of the coordinate pairs in the following string must be supplied to the program. 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 the log file 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, that 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 that is less than the user specified minimum height limit. This special value is written to the log file. If no polygon strings are read then no grid points are set to special values.

Contour lines

Each file contains strings of X,Y coordinate pairs. If in generic format, each string must be preceded by a header that contains the number of coordinate pairs in the following string and the elevation of the contour string. In this case the FORTRAN formats of the header and of the coordinate pairs in the following string must be supplied to the program. If in Arc/Info ungenerate or Idriasi vector format the height of the contour must be the label of the contour string. The heights of the points making up the contour line are incorporated into the grid. If the elevation of the contour line is missing, denoted by an elevation less than the user-specified minimum elevation, then ANUDEM estimates and iteratively updates the elevation of the contour line. This estimation procedure is also used to estimate the elevations of lake boundaries. Contours connecting to contours with different elevations are flagged in the contour error file.

Lake boundaries

Input data file formats are exactly as for boundary polygon files. Lake boundaries are initially treated as contours with missing elevation. ANUDEM estimates and iteratively updates the elevation of each lake boundary and incorporates the corresponding contour line into the interpolation process. It also ensures that the elevation of the lake boundary is consistent with elevations of connecting streamlines and neighbouring elevation data. Lake boundaries are

permitted to include islands within lakes, and lakes within islands. Lakes are automatically identified by ANUDEM as areas that lie within an odd number of lake polygon boundaries. Islands are automatically identified as areas that lie within a positive even number of lake polygon boundaries. All points of the DEM that lie inside lakes, as determined by lake boundary polygons, are set to the estimated height of the DEM on the boundary of the lake. Lake boundaries that are not closed polygons generate error messages in the same way that non-closed boundary polygons do, and the position of the endpoint of each non-connecting line string is written to the polygon error file when specified.

Cliff lines

Input data file formats are exactly as for streamline files. Cliff lines must be digitised in the DIRECTION so that the left-hand side of the line is on the low side of the cliff and the right-hand side is the high side of the cliff. This permits ANUDEM to remove elevation data points close to the cliff that are positioned on the wrong side of the cliff as the data points and cliffs are incorporated into the grid. ANUDEM optionally produces a derived breakline diagnostic file that records the positions of all cliff lines as they have been incorporated into the grid.

Data mask polygons

Input data file formats are exactly as for boundary polygon files. Data mask polygons permit removal of elevation data from the interpolation process. This is typically used to remove elevation data associated with dam walls and bridges. This enables interpolation of the underlying valley with connected drainage structure. Data mask polygons that are not closed polygons generate error messages in the same way that non-closed boundary polygons do, and the position of the endpoint of each non-connecting line string is written to the polygon error file when specified by the user.

7. SPECIFICATION OF OUTPUT DEM AND DIAGNOSTIC FILES

The program generates a log file and an output DEM, as well as five point diagnostic files, two line diagnostic files and three grid diagnostic files. These are all described below.

Log file

This text file contains a record of all input user directives and input data files and provides a comprehensive report on the operation of the program. It also concludes with summary statistics. This file should always be inspected to verify the correct operation of the program and to flag possible data and program errors. This file should be reported when seeking user assistance.

Output DEM file

This file may be written in grid or X,Y,Z format. ASCII and binary grid formats suitable for reading directly by Arc/Info and Idrisi are supported. ANUDEM supports grids as grids of cells, with the corresponding grid points at the centres of the cells, and grids as a point lattice. Both modes are used in applications. Interpreting DEMs as cells is consistent with the usual

interpretation of remotely sensed satellite imagery, while DEMs are commonly interpreted as point lattices in the earth sciences (see User Directives).

When data outside the area covered by the output DEM are available, use a positive grid margin of width at least 20 grid cells to minimise edge effects. When gridding very large areas that cannot be processed in one piece, then DEMs should be produced in separate pieces that overlap by a width of at least 20 grid cells. These DEMs can be smoothly spliced together using the Arc/Info GRID FUNCTION MOSAIC.

When an Arc/Info or Idrisi compatible output DEM format is specified, all output diagnostic files are written in formats compatible with Arc/Info or Idrisi respectively. Standard Idrisi documentation files are written for each output file in Idrisi format.

Spurious sink point file

This point file contains the locations of all remaining spurious sinks. It should be plotted together with the output derived streamline file to check for errors in all input topographic data.

Large residual point file

This point file contains the locations of all large elevation data residuals as scaled by the local discretisation error. The residuals are sorted in order of decreasing size. Scaled residuals larger than 10 should be plotted and inspected for possible errors in input elevation and streamline data. Large scaled residuals indicate conflicts between input elevation data and streamline data. These may also be associated with poor automatic drainage enforcements. These conflicts can be remedied by providing additional streamline and/or point elevation data after first checking and correcting errors in existing input data. This file also includes the unscaled residual values in the final column. When the large residual file is very large the user may wish to sort the file according to the magnitude of the unscaled residuals. Large unscaled residuals usually indicate input elevation errors.

Stream and cliff data error point file

This point file is an important indicator of streamline and cliff line data quality, particularly of stream direction errors and cliff direction errors. It should always be inspected. The codes of all points written to this file are provided in the user directives.

The file contains the locations of all closed cycles in input streamline data, as they are incorporated onto the grid. It also includes flags for streams that lead to closed cycles via connecting lakes. It flags lakes that have multiple outflows, as these are rare in nature and are likely to indicate stream direction errors. It also flags all stream distributaries as encoded onto the grid. These are more common in nature than lakes with multiple outflows, but can be a useful indicator of stream direction errors.

The file includes the positions of all waterfalls, as defined by streamlines crossing cliffs. The derived streamline file has specifically labelled streamline segments at the same locations. These can be useful in drainage analyses of the output DEM and can be a useful indicator of errors in the locations of data stream lines and cliffs. The file also flags grid points beside a cliff with an elevation that is inconsistent with the high or low side of the cliff, as determined by the direction of the data cliff line. This is a very useful indicator of errors in cliff line directions.

Polygon error point file

This point file contains the locations of points of non-closure of input polygons obtained from polygon boundary data, lake polygon data and data mask polygons. This file should be inspected and plotted when errors are indicated.

Contour error point file

This point file contains the locations of points on input contours with significantly biased residuals from the fitted DEM. These can indicate elevation errors in input contour data. This file also contains locations of points where contours with different elevations are connected, a sure indicator of a contour label error.

Derived streamline file

This line file contains all drainage constraints imposed by ANUDEM as determined from input streamline data, streamlines and ridge lines inferred from contour data and streamlines obtained by automatic drainage enforcement. These can be plotted to check for location errors in input streamlines and to verify appropriate concordance with constraints associated with input streamlines and automated drainage enforcements. Each type of derived streamline is given a different code. Streamlines that cross cliff lines are indicated by short stream lines of length one grid cell with a separate code.

This file also includes vectors flagging large source elevation data clearances via connecting streamlines and lakes that exceed the second elevation tolerance. These can be a useful indicator of source elevation data errors.

Derived cliff line file

This line file contains input cliff lines as they are represented on the DEM. These can be plotted to check for location errors in input cliff lines and to verify appropriate concordance with streamlines and drainage enforcements as represented in the derived streamline file. These can also be used to check that cliff lines have been directed so that the high side of each cliff line is on the right and low side is on the left.

Output grid code file

This output grid file is not normally used. It contains codes denoting those grid points that have an associated elevation data point and those grid points that are sink points.

Output flow direction grid

The output flow direction grid is commonly used in hydrological applications to infer streamlines and catchments associated with the output DEM. Since this grid incorporates ordered chain conditions associated with all input streamline data, it can lead to more reliable determination of catchments in low relief areas where elevation differences between neighbouring grid points can be very small. Values in this file are coded according to standard Arc/Info convention, with the cardinal directions indicated by successive powers of 2. Multiple directions representing data stream distributaries, are indicated by the sum of the corresponding powers of 2.

Output aspect grid

The output aspect grid consists of values of topographic aspect of the fitted DEM measured in degrees east of north.

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10. USER DIRECTIVES

User directive	Type	Description
Drainage option	0, 1 or 2	Level of drainage enforcement: 0 - no drainage enforcement; 1 - drainage enforcement where possible (normal option); 2 - drainage enforcement with voluminous sink diagnostics (not normally used).
Contour data option	0 or 1	0 - data consist mainly of spot heights; 1 - data consist mainly of elevation contours.
Discretisation error factor, vertical standard error, cliff position error, stream position error	Four non-negative real numbers (1.0, 0.0, 0.2, 0.2)	<p>The discretisation error is due to the method of incorporating elevation data onto the grid. It is scaled by the program depending on the local slope at each data point and the grid spacing. The discretisation standard error factor specified here should be set to 1.0, unless the data have significant random (non-systematic) horizontal errors. Set the discretisation standard error factor between 0.25 and 4.0 to adjust this component of the data smoothing, if necessary. A smaller value gives rise to less data smoothing, a larger value gives rise to greater data smoothing. The smaller value can permit the DEM to more closely match point data at peaks.</p> <p>The vertical standard error may be set to a small positive value if the data have significant random (non-systematic) vertical errors, with uniform variance. In this case, set the vertical standard error to the standard deviation of these errors. For most elevation data sets the vertical error should be set to zero. However the vertical standard error should be set to an appropriate positive value when gridding remotely sensed data that typically have significant vertical error. The vertical standard error may on occasion be set to a small positive value to stabilise convergence.</p> <p>The cliff position error is the maximum fraction of the grid cell width that data cliffs may be moved to avoid spurious intersection with data streamlines. Recommended default value is 0.2. Set to a larger value if data streamlines have significant positional error. It is inactive if set to zero or if there are no streams or no cliffs.</p> <p>The stream position error is the maximum fraction of the grid cell width that data streamlines may be moved to avoid spurious intersection with data cliffs. Recommended default value is 0.2. Set to a larger value if data cliff lines have significant positional error. It is inactive if set to zero or if there are no streams or no cliffs.</p> <p>The standard error recommendations are robust and have been tested with a wide variety of data sources. DO NOT change these parameters as a first option when confronted with poor results. These are almost always due to data errors.</p>

ALWAYS first check the log file and the data diagnostic files. In particular, always inspect the remaining sinks, the large scaled residuals and the locations of data stream errors in the output derived streamline file. The output sink file can be a very efficient way of detecting data errors. Monitoring the number of remaining sinks can be a simple and effective way of assessing the overall quality of the fitted DEM.

When gridding contour data, a **HIGHLY RECOMMENDED** way to check the quality of the result is to overlay the data contours with contours derived from the output DEM (using for example Arc/Info TIN COMMAND LATTICE CONTOUR).

The log file may be consulted for an estimate of the accuracy of the fitted DEM:-

The first (scaled) output RMS should be 1.00. This is a simple check that the program has smoothed the data correctly according to the specified data standard errors.

The second output RMS is unscaled and gives an indication of the standard error of the DEM, PROVIDED that the grid spacing has been chosen correctly. The grid spacing maybe optimised by choosing the grid spacing at which the root mean square slope of the DEM at the data points (SLOPE in the log file) stabilises. See Hutchinson (1996, 2000) for further information.

Two roughness penalties

Two non-negative real numbers

The first roughness penalty specifies the amount of potential to be added to the default total curvature penalty. Set to 0.0 for minimum curvature (for contour data). Set to 0.5 for mixture of minimum curvature and minimum potential (appropriate for spot heights). Values larger than 0.5 are not recommended.

The second roughness penalty is profile curvature. It is a locally adaptive penalty that can be use to partly replace total curvature. It can yield good results with high quality contour data but can lead to instability in convergence with poor data. Users should make their own assessment as to the worth of this penalty. One way to set this roughness penalty is by using the value that minimises the number of remaining sinks in the output DEM.

Set to 0.0 for no profile curvature (the default).
Set to 0.5 for moderate profile curvature.
Set to 0.8 for maximum profile curvature. Values larger than 0.8 are not recommended.

Elevation tolerances	Two non-negative real numbers	<p>These tolerances reflect accuracy of elevation data in relation to surface drainage. For point data set the first tolerance to the standard error of the data heights. For contour data set the first tolerance to half of the (average) contour interval. The program removes data points that obstruct surface drainage by less than this tolerance. The first tolerance is also used to prefer drainage enforcement via saddle points with elevation data points over saddle points that do not have an associated data point. When gridding contour data the automatically determined ridges and streamlines are limited in vertical relief to twice the first elevation tolerance.</p> <p>The second tolerance is used to prevent drainage clearance through unrealistically high barriers. This tolerance is rarely active and its value is not critical. The program provided default is six times the first elevation tolerance. Set to a larger value when gridding difficult data sets with large variations in local relief.</p> <p>Side conditions of streams are only set if they do not conflict with the data by more than the second elevation tolerance. See further information on the drainage enforcement algorithm and the action of the elevation tolerances in the notes above.</p> <p>A typical value of the first tolerance for point data at a scale of 1:100,000 is 5m.</p> <p>A typical value of the first tolerance for less dense point data at a scale of 1:500,000 is around 8-10m.</p>
Maximum number of iterations	20	Normally 20 iterations are adequate for both point and contour line data. Rarely, higher values (25-30) maybe useful to clear more sinks or to set more ridges and streams. Iteration ceases for each grid resolution when the maximum number of iterations has been reached.
Elevation units	1 or 2	1 - elevations in metres 2 - elevations in feet
Height limits	Two real numbers	Lower and upper height limits respectively. Data points outside these limits are ignored, and the fitted grid values are constrained to lie between these two limits.
Centring option	0 or 1	<p>0 – point lattice, 1 - cells (recommended).</p> <p>The main aim of this option is to simplify specification of the grid limits so that the user does not have to add or subtract half a grid spacing to match the specifications of a grid from another source.</p> <p>Most current pixel based systems (eg. Arc/Info, Grass, Idrisi) normally use option 1. Older vector based systems normally require option 0.</p> <p>See the notes on the grid spacing on how the number rows and columns of the DEM are calculated.</p>

		<p>N.B. The nomenclature for this option can be confused with the conventions for Arc/Info grid headers. If 0 is chosen (point lattice) then the output Arc/Info grid header will specify the position of a lower left centre of the corresponding grid cell. Conversely, if 1 is chosen (cells), the usually recommended value, the output Arc/Info grid header will specify a lower left corner of the corresponding grid cell.</p>
Position units	1 - 6	<p>1 - position units in metres 2 - position units in feet 3 - position units in kilometres 4 - position units in miles 5 - position units in degrees 6 - position units in radians</p>
X (longitude) limits	Two real numbers	Lower and upper X coordinate limits respectively. Data points outside these limits are ignored.
Y (latitude) limits	Two real numbers	Lower and upper Y coordinate limits respectively. Data points outside these limits are ignored.
Grid spacing	Non-negative real number	<p>The resolution of the final grid. The spacing should divide the X and Y ranges an integral number of times.</p> <p>When the centring option is 0 the number of grid points in the X direction is $(\text{upper X} - \text{lower X})/\text{spacing} + 1$ and the number of grid points in the Y direction is $(\text{upper Y} - \text{lower Y})/\text{spacing} + 1$.</p> <p>When the centring option is 1 the number of grid points in the X direction is $(\text{upper X} - \text{lower X})/\text{spacing}$ and the number of grid points in the Y direction is $(\text{upper Y} - \text{lower Y})/\text{spacing}$.</p>
Grid margin	Non-negative real number	<p>Specifies a working grid that includes the output grid by adding a non-negative margin to the output grid dimensions. If the margin is positive this should ensure better behaviour of the DEM near the edges of the output grid. Data points are accepted within the limits of the larger working grid.</p> <p>Normally set a margin equal to the width of at least 20 grid spacings.</p> <p>The size of the margin can alternatively be estimated by first fitting a grid with zero margin and see the extent of edge effects, particularly remaining sinks. Then set a margin corresponding to this extent, provided the margin area is supported by data.</p>
Number of data files	Positive integer	Number of data files, for each of which a name and type have to be supplied (see following options). There is no limit on the number of data files, nor on their size. Formats are only required for generic data files.
Data file name	255 characters	Name of input data file.

Type of data file	11-19	<p>11 - Generic elevation data file 12 - Generic sink data file 13 - Generic streamline data file 14 - Generic coastline polygon data file 15 - Generic contour line data file 16 - Generic lake boundary data file 17 - Generic cliff line data file 19 - Generic data mask polygon file</p>
	21-29	<p>21 - Arc/Info ungenerate point data file 22 - Arc/Info ungenerate sink data file 23 - Arc/Info ungenerate stream data file 24 - Arc/Info ungenerate coastline polygon data file 25 - Arc/Info ungenerate contour data file 26 - Arc/Info ungenerate lake boundary file 27 - Arc/Info ungenerate cliff line data file 29 - Arc/Info ungenerate data mask polygon file</p> <p>Arc/Info ungenerate only writes integer COVER-IDs. When using ungenerate to create contour data suitable for ANUDEM, first set COVER-ID = HEIGHT (e.g. with CALCULATE in tables), then IDEDIT before ungenerate to update the USER-IDs in the coverage coordinate files. Heights of contours are read by ANUDEM as real numbers, although Arc/Info only supports integer IDs.</p>
	31-39	<p>31 - Idrisi vector point data file 32 - Idrisi vector sink data file 33 - Idrisi vector stream data file 34 - Idrisi vector coastline polygon data file 35 - Idrisi vector contour data file 36 - Idrisi vector lake boundary file 37 - Idrisi vector cliff line data file 39 - Idrisi vector data mask polygon file</p> <p>Idrisi data files must be in standard Idrisi ASCII vector file format, e.g. as produced by the TOSCA digitising package. See Idrisi documentation for further details. Heights of contours are read from the FEATURE IDs as real numbers.</p>
Generic data file header format	255 characters	<p>Header format - required only for data file types 13 to 16: 13 - for reading no. of coordinate pairs eg. (10X, I10) 14 - for reading no. of coordinate pairs eg. (10X, I10) 15 - for reading no. of coordinate pairs and height of contour line, eg. (10X, I10, F10.3) 16 - for reading no. of coordinate pairs eg. (10X, I10) 17 - for reading no. of coordinate pairs eg. (10X, I10) 19 - for reading no. of coordinate pairs eg. (10X, I10)</p> <p>Header format not required for Arc/Info and Idrisi data types.</p>
Generic data file format	255 characters	<p>For types 11 and 12 - X,Y,Z format, at most one point per record, eg. (2F10.3, F10.3)</p> <p>For types 13 to 19 - X,Y format, more than one point per record allowed, eg. (8F10.3)</p>

		Data file format not required for Arc/Info and Idrisi data types.
Output grid file name	255 characters	Name of output grid file. The grid is written by rows. The .img extension is used for Idrisi format.
Mode of output grid	0, 1, 2 or 3	<p>0 - X,Y,Z format. This mode is generally not recommended, but can be useful when the DEM is to be imported into another GIS, such as GMT (Generic Mapping Tool). All subsequent output files are written in generic point, line and grid form.</p> <p>1 - Generic real grid values by rows from maximum Y to minimum Y. This mode is also generally not recommended. All subsequent output files are written in generic point, line and grid form.</p> <p>2 - Arc/Info grid format (rows from maximum Y to minimum Y). All subsequent output files are written in forms acceptable by Arc/Info. When a binary Arc/Info DEM is specified, an ASCII header file is also written, with name constructed by appending “.hdr” to the DEM file name, after removing any existing extension to the DEM file name. Thus, if the binary DEM file name was mygrid.dem the ASCII header file name would be mygrid.hdr. This is consistent with standard Arc/Info conventions.</p> <p>3 - Idrisi real grid values by rows from maximum Y to minimum Y, one value per record. All subsequent output files are written as standard Idrisi vector and image files, with standard .vec and .img name extensions. All output Idrisi files have standard associated documentation files with .dvc and .doc name extensions.</p>
Output grid format	255 characters	<p>Use blank to write the DEM as a binary file, for all of the above output modes. This is generally recommended as it saves computer time and disk space. It also avoids potential precision problems associated with numbers written in formatted ASCII format.</p> <p>An ASCII formatted DEM is recommended when the DEM is to be moved between DOS and Unix operating systems, except in Arc/Info mode, where the associated grid header records the byte order of the binary DEM file.</p> <p>For mode 0: The format, when specified, is for X,Y,Z values, e.g. (2F10.5,F8.2)</p> <p>For modes 1 and 2: The row format of the output grid, when specified, is recommended to be (10F8.2). When greater vertical precision is required, use (8F10.3).</p> <p>For mode 3: The format, when specified, MUST be for one real number per record. The general recommendation is (F8.2). When greater vertical precision is required use (F10.3).</p>

Sink point file	File name	<p>If non-blank, remaining sink points in the final grid are written to this file for later plotting. It is strongly recommended that this file be inspected or plotted, as a way of detecting errors and deficiencies in elevation and streamline data. The number of sinks remaining in the DEM that have not been specified in sink point data files is reported to the log file.</p> <p>The output sink point file is in Arc/Info ASCII ungenerate format if the DEM is in Arc/Info format. The file is in standard ASCII Idrisi vector format with accompanying vector documentation file if the DEM is in Idrisi format.</p>
Large scaled residual point file	File name	<p>If non-blank, point data that differ from the fitted grid by more than three times the local rms errors are written to this file for checking. The number of such residuals are reported to the log file whether or not they are written to this file. The labels in this file are the large residuals scaled by the local standard error estimate and the vertical standard error (see the standard error specs above). The unscaled residuals are also written to the final column. The labels may be plotted from this file, or the file may be inspected directly.</p> <p>A scaled residual larger than around 10 is a strong indication of an error in input elevation data or an error in the direction of an input streamline. It can also indicate a poor drainage enforcement deduced from limited input data. A large unscaled residual typically indicates an input elevation error. The file is in Arc/Info ASCII ungenerate format if the DEM is in Arc/Info format. The file is in standard ASCII Idrisi vector format with accompanying vector documentation file if the DEM is in Idrisi format.</p>
Stream and cliff error point file	File name	<p>If non-blank, positions in stream data that have closed loops are written to this file. Tributaries and streams over cliffs are also indicated. Cliffs with neighbouring grid points that are inconsistent with the high and low sides of the cliff are also indicated. This can be a good indicator of cliffs with incorrect direction. Points are coded as follows:</p> <ul style="list-style-type: none"> 1 – true circuit in data streamline network 2 – circuit in stream network as encoded on the grid 3 – circuit in stream network via connecting lakes 4 – tributary point 5 – data stream over cliff (waterfall) 6 – points indicating multiple stream outflows from lakes 8 – points beside cliffs with heights inconsistent with cliff direction <p>The file is in Arc/Info ASCII ungenerate format if the DEM is in Arc/Info format. The file is in standard ASCII Idrisi vector format with accompanying vector documentation file format if the DEM is in Idrisi format.</p>

Polygon error point file	File name	<p>If non-blank, then endpoints of non-connecting lines strings in non-closed polygon data are written to this file. Errors in polygons from all three input polygon data types (boundaries, lakes, data masks) are written to this file. The file is in standard ASCII Idrisi vector format with accompanying vector documentation file if the DEM is in Idrisi format. The file is in Arc/Info ASCII ungenerate format if the DEM is in Arc/Info format.</p> <p>N.B. If there are any non-closed polygons, it is strongly recommended that this file be inspected. If there are any non-closed boundary polygons then ALL boundary polygons will be ignored by the program.</p>
Contour error point file	File name	<p>If non-blank, then data contours with bias in height exceeding 5 times the standard deviation of the contour values as represented on the grid, are reported to this file. The points are sorted in order of decreasing magnitude of the scaled bias (with minimum magnitude of 5). The number of suspect data contour elevation errors is reported to the log file. The test is quite sensitive so it should be used with care.</p> <p>Contours that join other contours with a different elevation are flagged in this file by the code 1. This is a sure sign of a contour label error.</p> <p>The file is in Arc/Info ASCII ungenerate format if the DEM is in Arc/Info format. The file is in standard ASCII Idrisi vector format with accompanying vector documentation file if the DEM is in Idrisi format.</p>
Derived stream line file	File name	<p>If non-blank, streamlines and ordered chain conditions, as incorporated in the final grid, are written to this file for later plotting. This file is useful for detecting drainage problems in the fitted DEM. This file also includes vectors flagging large elevation data clearances via connecting streamlines. This can be a useful indicator of data error. Lines in this file have codes as follows:</p> <ul style="list-style-type: none"> 1 - data streamline not over cliff 2 - data streamline over cliff (waterfall) 3 - drainage enforcement clearing a spurious sink 4 - streamline determined from contour corner 5 - ridge line determined from contour corner 6 - drainage enforcement associated with lake boundary 7 - data streamline side conditions 9 - vector indicating large elevation data clearance <p>The file is in Arc/Info ASCII ungenerate format if the DEM is in Arc/Info format. The file is in standard ASCII Idrisi vector format with accompanying vector documentation file if the DEM is in Idrisi format.</p>
Derived cliff line file	File name	<p>If non-blank then all cliff lines, as represented in the DEM, are written to this file. All lines in this file have code 1.</p> <p>The file is in Arc/Info ASCII ungenerate format if the DEM is in Arc/Info format. The file is in standard ASCII Idrisi vector format with accompanying vector documentation file if the DEM is in Idrisi format.</p>

Grid point code file	File name	<p>If non-blank, then integer grid (ASCII for Arc/Info and Idrisi) denoting grid points that have been allocated a data point and the drainage status of each grid point as follows:</p> <ul style="list-style-type: none"> 0 - no data point, no sink 1 - elevation data point, no sink 2 - remaining sink point without elevation datum 3 - remaining sink point with elevation datum 4 - data sink point without elevation datum 5 - data sink point with elevation datum -1 - special value (outside any boundary polygons) <p>Blank if not required - not normally required</p>
Flow direction grid file	File name	<p>Integer grid denoting flow directions. Blank if not required - can be useful for better defining flow directions in relatively flat areas that would otherwise be determined from the relative grid point heights. It maintains flow directions towards data streamlines. It also encodes distributaries as obtained from streamline data. Some cycles may exist in this grid.</p> <p>For DEM modes 0 and 1:</p> <ul style="list-style-type: none"> 0 - sink point (no outflow direction) 1 -SW 5 - NE 2 - S 6 - N 3 -SE 7 - NW 4 - E 8 - W -9 - outside boundary polygons <p>For these modes distributaries are indicated by summing with a multiple of 10. Thus 23 would indicate flows to the south and southeast.</p> <p>For modes 2 and 3 (Arc/Info and Idrisi): Directions according to Arc/Info convention:</p> <ul style="list-style-type: none"> 0 - sink point (no outflow direction) 1 - E 2 - SE 4 - S 8 - SW 16 - W 32 - NW 64 - N 128 - NE -99 - outside boundary polygons <p>For these modes distributaries are simply indicated by addition. Thus 6 would indicate flows to the south and southeast.</p> <p>The file is in Arc/Info ASCII grid format if the DEM is in Arc/Info format. The file is in ASCII Idrisi image format if the DEM is in Idrisi format.</p>
Aspect grid file	File name	<p>Grid denoting DEM aspect in real degrees east of north. Blank if not required.</p> <p>The file is in Arc/Info grid format if the DEM is in Arc/Info format. The file is in Idrisi image format if the DEM is in Idrisi format. The file is an ASCII file if the output DEM is an ASCII file and a binary file if the output DEM is a binary file.</p>

