Survey Review

A process to graphically demonstrate distance errors associated with local ground-based coordinate systems

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A process to graphically demonstrate distance errors associated with local ground-based coordinate systems

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Abstract

This paper describes an empirical process for graphically illustrating, on any project, and using any particular distance accuracy specification, boundaries where significant errors could be introduced in derived ground distances as a result of using local ground-based coordinate systems. The process involves selecting three-dimensional points across the project site, replacing their heights with combined scale factor corrections, and creating contours to represent potential distance errors. The resultant contour map shows potential distance errors in parts per million, which, for comparison with accuracy specifications and practical deliberations, are considered millimetres per kilometre. The effectiveness will depend on the spacing of the selected points and the topography of the project site, but on most projects today closely spaced three dimensional points are readily available. The benefits were demonstrated on an example site, with the conclusion that the process is robust and effective, and will have applications on many large scale civil construction sites, residential estate developments, and other surveys where local ground-based coordinate systems may be used.

Keywords: GNSS, Local Ground-Based Coordinates, Map Projections, Scale Factors.

Word Count: 4,322.

1 Introduction and problem statement

Surveyors are routinely using Global Navigation Satellite Systems (GNSS) to carry out their professional work. Real time kinematic (RTK) techniques are recognized as particularly useful for traditional functions such as mapping, bulk earthworks, and basic engineering construction. RTK is also being used for cadastral surveying, though care is needed in these special cases to be sure distance and other accuracy specifications are met (Gibbings 2014; Surveyors Board of Queensland 2012).

A prime concern is that distances derived from GNSS point positions, due to the coordinate systems used, are generally different from distances a surveyor would measure with traditional methods such as with electronic distance measuring equipment (EDME) found in total stations. This is because distances derived from two points measured with GNSS will normally be ellipsoidal distances (or grid distances if a map projection is used) and there is, in general, a scale factor correction (this is actually a combination of two scale factors) needed to convert these distances to the equivalent horizontal distance at ground height. This problem was referred to as the grid-to-ground problem by Limp and Barnes (2014) and has recently been the subject of some discussion in Australia, particularly in the cadastral surveying context (Gibbings 2014; Surveyors Board of Queensland 2012).

Evidence of a similar problem being encountered in the international context is the recent discussion by Cina, Manzino & Manzino (2016) of linking RTK GNSS coordinates measured in a Gauss projection based on the WGS84 ellipsoid with dimensions on original maps of the Italian Land Cadastre. Countries that have a digital cadastre based on a national coordinate reference system that is compatible with GNSS-based techniques such as Turkey (O. Demir &

Çete 2008) have the reverse problem of making conventional total station measurements consistent with GNSS-based techniques. In this case, total station measurements taken on cadastral surveys are constrained by at least two points in that national coordinate reference system (Erenoglu 2016) and this presumably is sufficient to account for the scale factor variations. Though full details of the process were outside the scope of the paper, the process described by Erenoglu (2016) was considered sufficiently rigorous to allow direct comparison of coordinates derived from total stations and GNSS techniques. Nevertheless, the discussion in this paper is confined to situations that are encountered in Australia where distances derived from two points measured with GNSS need to be converted to the equivalent horizontal distance at ground, or mean terrain, height.

On larger projects such as mines, residential estates, and civil construction sites, local ground-based coordinates may be used to avoid the need to deal with scale factors (for details in the Australian context refer to Pickford & Gibbings 2009). These local ground-based coordinates (LGBC) systems, or 'local area-specific low distortion projections' as they are termed by Limp and Barnes (2014, p. 141), are used over small areas (usually a few kilometres) to provide coordinates and derived distances at ground level. This overcomes the scale problem between distances derived from recognised map projections, for example the commonly used Universal Transverse Mercator (UTM), and distances measured on the ground.

There are several ways to establish LGBC systems. In their simplest form, a point is selected central to the project site and a combined scale factor (combination of projection point scale factor and height or datum scale factor) is used in some underlying map projection (such as Plane or Transverse Mercator) to equate gird distance to ground distance at that point. Two such processes were described by Pickford and Gibbings (2009): one based on a tangent plane map projection; and the other based on a modified Transverse Mercator projection. In both cases a new local projection is formed as an elevated reference surface and modified central scale factor such that the grid distance and ground distance (ground distance is usually taken as horizontal distance at mean terrain height) are equal at a point near the centre of the project.

Though these LGBC can be achieved in many ways, none of them is a comprehensive solution, and the process requires assumptions to be made with respect to how much the scale factor will change throughout the project site. For example, the point scale factor at the central point will change as activity moves away from that point, and the amount of change will depend on the underlying map projection chosen. Similarly, as the height changes above or below the central point of the projection, the height or datum scale factor will change and this will equate to a distance error of about 1 ppm for each 6.5 metre change in height (Department of Natural Resources and Mines 2015, p. 100 (Section 8.6.2)). In each case the assumption is made that the errors introduced by moving away from the central point, or by changing height, will not be significant for the task at hand. The problem is that, possibly because the construction of the LGBC systems is not well understood by all users on a project, practitioners may not have a good understanding of what 'significant' means on different sites. Pickford and Gibbings (2009) provided an analysis of this problem, and established some guidelines for maintaining errors to levels less than normal survey measurement accuracies. But the relevance of their guidelines all depends on the projection chosen, the undulation of the site, and other assumptions made – ideally the errors would be individually calculated for each project site.

The research question is: if using a LGBC system, how can a practitioner calculate, on their own specific project sites, how far they can go from the central point, and how much can the height change, before significant errors could be introduced in their derived distances? Note that these potential errors associated with LGBC are in addition to the normal errors associated with the survey measurements.

The aim of this article is to answer this question by developing and validating an empirical system to determine potential distance errors associated with the use of LGBC systems on project sites.

2 Accuracy standards

The Surveyors Board of Queensland's Guideline on RTK GNSS for Cadastral Surveys mentions LGBC systems in Section F.2, with a qualifier that '*great care must be taken if using this method*' (Surveyors Board of Queensland 2012, p. 5), particularly when working some distance from the central point (a suggestion was to take particular care over 2 km).

The assumption is that the scale factor will not change significantly over the project site, however, there is a limit to how far this assumption can be extended, both in a vertical and horizontal sense. The limit will depend on the base projection used, and what magnitude of error is considered acceptable (or significant) for the project. Pickford and Gibbings (2009) evaluation was based on a two distance accuracies: 3 mm + 2 ppm since this was similar to measuring accuracy of commonly used total stations; and 10 mm + 1 ppm based on GPS baseline accuracy at that time. They concluded that height variations of around 20 m and 40 m respectively would lead to these accuracy specifications being exceeded (allowing for a couple of metres difference depending on whether or not the projection was based on the UTM or tangent plane method), and this is consistent with 1 ppm for each 6.5 m mentioned earlier. For the tangent plane method, the total station accuracy was exceeded approximately 22.8 km from the central point.

The first question is whether or not 3 mm + 2 ppm (equates to 5 mm in one kilometre) is still a reasonable accuracy specification for the derived distances. An examination of manufacturer's web sites reveals that total stations commonly used on cadastral and engineering surveys quote accuracies in the order of 2 mm + 2 ppm. For practical purposes, we would need to add some site-specific errors to this, as well as setup errors at the instrument and prism, so 5 mm would seem a reasonable compromise in that respect. Of course, there are situations where the prism is mounted on a pole rather than a set of legs, and so 10 mm might also be useful to demonstrate the process being described in this paper.

The Queensland Cadastral Survey Requirements v7.0 (Department of Natural Resources and Mines 2015, p. 14 Section 3.4.2) specifies that all surveyed lines must have a vector accuracy of 10 mm + 50 ppm at 95% relative uncertainty in accordance with the recognised standard for control surveys in Australia, Special Publication 1 (SP1) (Inter-Governmental Committee on Surveying and Mapping (ICSM) 2012). This would equate to 60 mm per kilometre and, because this is substantially larger than the measuring accuracy of total stations, has been ignored as an accuracy specification for the purposes of this investigation. An accuracy specification of 10 mm would comply with the Queensland Cadastral Survey Requirements for all distances, though, and this reinforces the contention that 10 mm would seem a reasonable accuracy specification for the purposes of this paper.

It is also worth noting that the Guideline for Conventional Traverse Surveys, which is a supporting document for SP1 (Inter-Governmental Committee on Surveying and Mapping

(ICSM) 2012) recommends a measuring accuracy of 3 mm + 3 ppm to achieve a Survey Uncertainty of less than 10 mm.

The distance specifications discussed contain both a constant (mm-term) and a further component that varies with distance (ppm-term). However, since the errors under investigation in this paper only have a ppm-term, for the purposes of comparison, distance specifications have been equated to a single ppm-term at one kilometre. For the purposes of this research then, 5 ppm and 10 ppm (essentially 5 mm and 10 mm per kilometre) will be adopted as accuracy specifications since these are similar to the accuracy standards that might commonly be achieved for various types of surveys. This paper is largely concerned with the process - practitioners can use the same process with any accuracy specification they want when undertaking their own project-specific investigations.

3 Method and results

The process is described by demonstrating its use on a specific example site in a region that has practical significance. The site was selected between the cities of Toowoomba and Warwick on the Eastern edge of the Darling Downs, Queensland, Australia. The general topography in the area is evident from Figure 1.

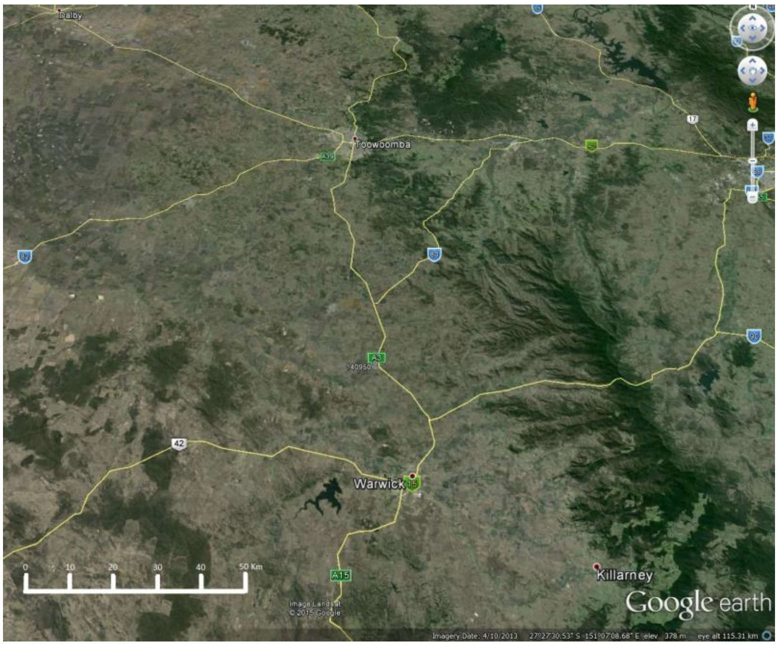

Figure 1 - Site Location (Google Earth Inc. 2013)

The area is generally along the Great Dividing Range, and contains some substantial variations in height that will be useful to highlight advantages and limitations of the process being described (refer to digital elevation model in Figure 2 and site contours in Figure 3). It was chosen because data was readily available, and there are currently substantial development and infrastructure projects planned in similar topography in that general area, so there is a practical relevance to the site.

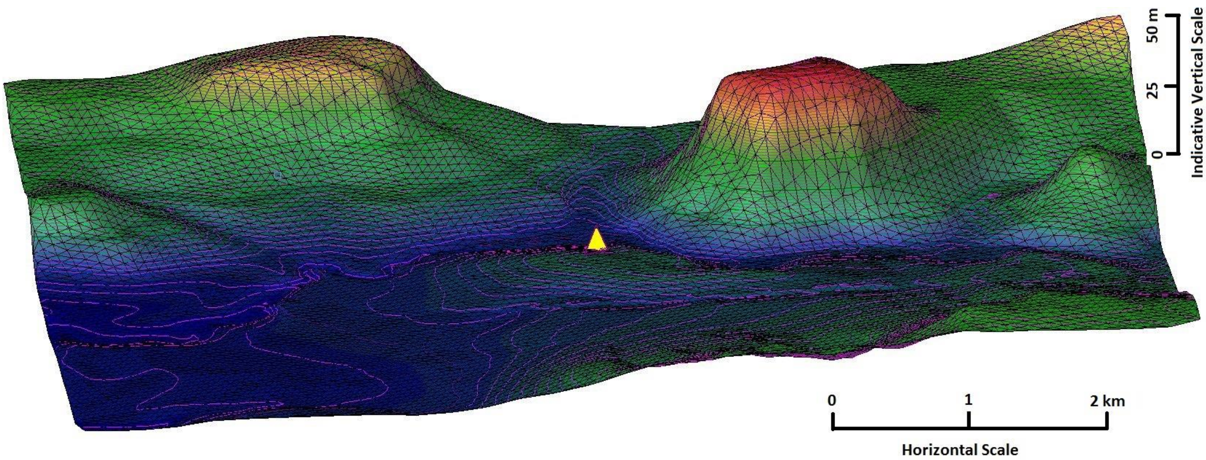

Figure 2 - Site Digital Elevation Model

The triangle in the centre of Figure 2 and Figure 3 represents the centre of our example project site. Ultimately this will become the centre point for the LGBC system utilised later in the project.

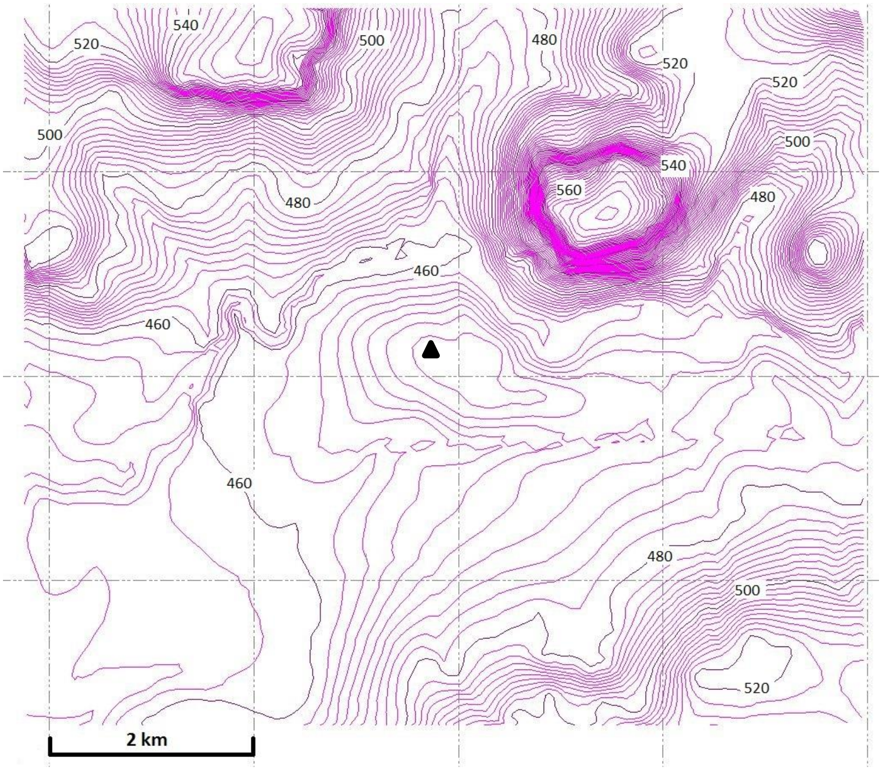

Figure 3 - Site Contours

The process requires a series of points across the project site and each point is required to have known horizontal position and elevation (reduced level (RL) in this example case). On many projects three-dimensional positions (commonly to metre level accuracy or better) are readily available across the site since this information is often needed early in the project for planning and approval purposes. For example, Digital Elevation Models (DEM) may be available over which a regular grid can be superimposed and data extracted for the nodal points. In some cases, on existing large scale construction sites, simply using the existing survey control point network is sufficient. The density of the points will influence the precision of the outcomes, but in most cases points separated by several hundred of metres, or even kilometres could be sufficient. In general, as will become clear as the process unfolds, abruptly undulating terrain will require a denser point cloud (points closer together).

For this example case the information was obtained from a Lidar survey across the area. The points were available in a .csv format and were spaced at approximately 25 m intervals. These were filtered to approximately 80 m spacing to reduce processing time. This was achieved by manipulation in a spreadsheet to only use every tenth point. A dense point spacing was used in this case to highlight the process: a much less dense pattern would also suffice, particularly on the flat areas of the site. These points were imported into a computer aided drafting (CAD) package that was capable of producing contours. In this case Trimble Business Centre (TBC) (Trimble Navigation Limited 2005-2014) was used since it also had the ability to produce point scale factors on the UTM map projection – this was convenient, but not essential because the point scale factors can be obtained separately and added manually, particularly if the points are sparse. To calculate point scale factors manually readers are referred to Schofield and Breach (2007, p. 305 Eq. 8.46a).

As discussed earlier, two scale factors need to be considered: the projection point scale factor; and a height or datum scale factor. The next step in the process is to map the effect of these two scale factors together, but in the interests of clarity and for understanding the process, each scale factor is dealt with in isolation first, and then brought together and considered as a combined scale factor later in the paper.

The first scale factor under consideration is the map projection point scale factor. In this example a UTM projection was used for the easting and northing coordinates. The point scale factor is defined as the ratio of an infinitesimal distance at that point on the map grid to the corresponding distance on the ellipsoid. This scale factor occurs because the map grid is flat (or at least it is flattened out after projecting features onto it) and the ellipsoid is curved. The RLs in the .csv point list were replaced with UTM point scale factors (quoted in ppm) and then import into the CAD package (refer Table 1).

	A	B	C	D
1	ID	Easting	Northing	RL
2	10	395980.162	6901586.618	522.9781
3	20	396230.162	6901586.618	522.2817
4	30	396480.162	6901586.618	522.2242
5	40	396730.162	6901586.618	525.1375
6	50	396980.162	6901586.618	531.2442
7	60	397230.162	6901586.618	537.8336
8	70	397480.162	6901586.618	542.114
9	80	397730.162	6901586.618	546.709
10	90	397980.162	6901586.618	550.08

	A	B	C	D	E	F
1	ID	Easting	Northing	Projection Scale Factor (ppm)		
2	10	395980.162	6901586.618	90.9478		
3	20	396230.162	6901586.618	90.3063		
4	30	396480.162	6901586.618	89.6664		
5	40	396730.162	6901586.618	89.028		
6	50	396980.162	6901586.618	88.3912		
7	60	397230.162	6901586.618	87.7559		
8	70	397480.162	6901586.618	87.1221		
9	80	397730.162	6901586.618	86.4899		
10	90	397980.162	6901586.618	85.8593		

Table 1 - CSV with RLs replaced by Point Scale Factors

These points were then contoured to produce a map where the contours represent potential distance errors in ppm (refer Figure 4). In this image the minor contours in green represent 1 ppm and the major contours in black represent 5 ppm. The line scale at the bottom is two kilometres. As expected, due to the construction of the UTM projection, the ‘contours’ are very close to straight lines in the north-south direction. They are not exactly straight lines due to the flattening of the ellipsoid, but at this scale and at this latitude, it’s difficult to perceive any difference.

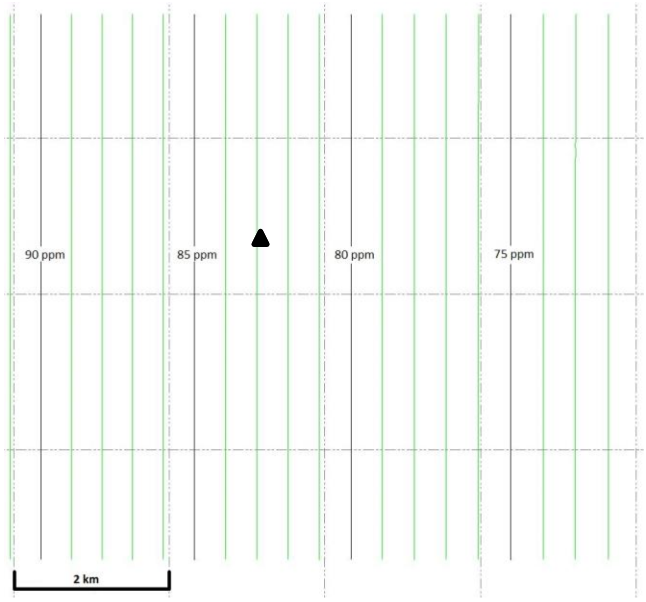

Figure 4 - Contours of UTM Point Scale Factors

The second scale factor to be considered is the height or datum scale factor. This occurs because the terrain is not coincident with the map grid. A similar process was carried out to the point scale factor earlier, with the RLs in the .csv point list replaced with height scale factors (quoted in ppm). This height scale factor is produced automatically in TBC (and other CAD packages) and is the ratio of the ellipsoidal height at the point and the mean radius of curvature of the earth at that point plus the ellipsoidal height. More details on height scale factor including a convenient formula can be sourced from Schofield and Breach (2007, p. 310) who refer to this as the altitude correction. These edited points were then import these into the CAD package and contoured as before (refer Figure 5).

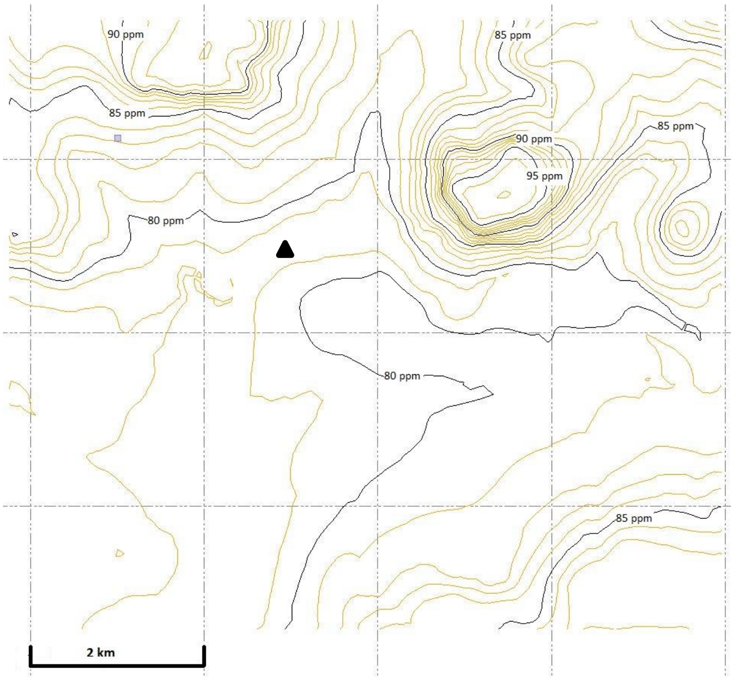

Figure 5 - Contours of Height Scale Factors

In this image the minor contours in orange represent 1 ppm and the major contours in black represent 5 ppm. As before, the line scale at the bottom is two kilometres. As expected the 'contours' follow a somewhat similar pattern to the topography in Figure 2.

We now move back to the general process by bringing these two scale factors together and considering them as a combined scale factor. The normal practice would be to begin at this part of the process since the treatment of the two scale factors individually was only to help understand the process. As before, the RLs in the .csv point list are now replaced with combined scale factors (quoted in ppm). The combined scale factor can either be produced automatically from the CAD package or by multiplication in the .csv file through spread sheeting. The combined scale factor at the centre point is subtracted from the combined scale factors of all the other points so the ppm corrections are related to zero at the centre point. An alternative is to first apply a LGBC system based on the centre point and then output combined scale factors (these would then be related to zero at the centre point). These amended points were then import into the CAD package and contoured as described earlier (refer Figure 6).

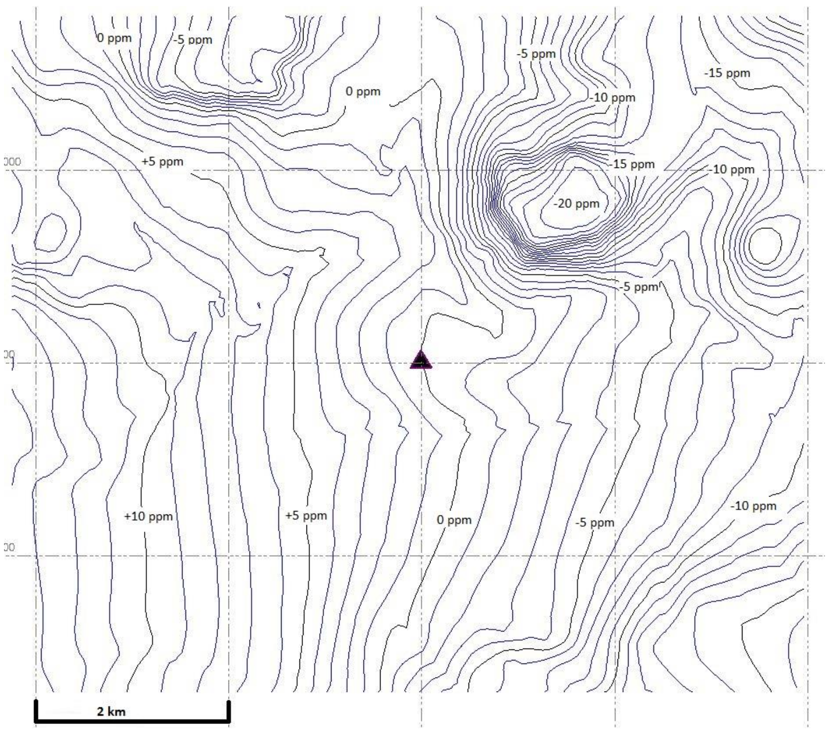

Figure 6 - Contours of Combined Scale Factors

In this image the minor contours in blue represent 1 ppm and the major contours in black represent 5 ppm. The triangle in the centre of the image represents the centre of our example project. This 'contour' plan now provides an immediate indication of what errors may be introduced due to the LGBC system as activities move away from the project centre. Clearly the project could expand several kilometres in most directions, except to the north-east. Moving any more than about 1.5 km in the north-east direction will potentially result in the local ground-based map projection introducing errors greater than 10 ppm on survey lines.

To highlight this for the purposes of this paper, polygons have been created representing +/- 5 ppm and +/-10 ppm, but it may be easier on a project to simply create bold or different coloured contours to the same effect (refer Figure 7).

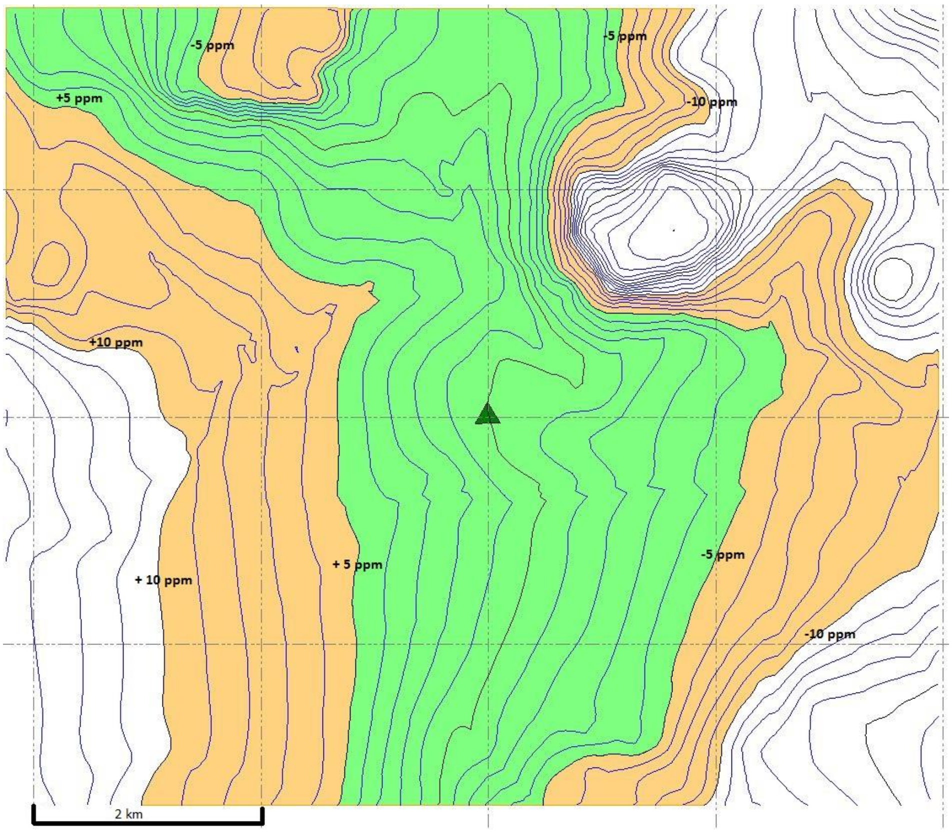

Figure 7 - 5 and 10 ppm Errors for Combined Scale Factors

The boundaries, where 5 and 10 ppm distance errors may be introduced, are now quite clear. On a project this map could be superimposed over an aerial photograph of the site so field surveyors and other professionals could easily discern where significant errors may be introduced due to the LGBC system.

4 Validation

It is necessary to ensure this process is providing reliable information and that the errors indicated on the contours can be trusted. To do this, two points were chosen about one kilometre apart and lying generally along the -10 ppm contour (refer Figure 8).

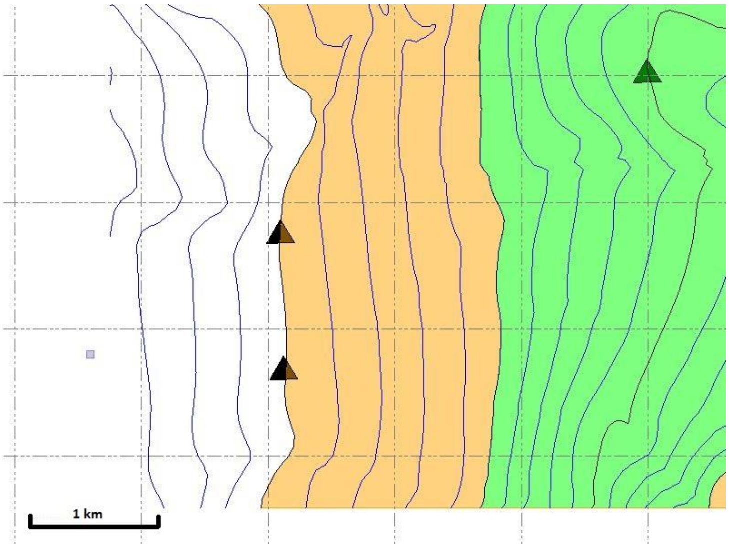

Figure 8 - Validation Points

An inverse report between the two points reveals an ellipsoidal distance of 1075.580, a ground distance of 1075.665 and a gird distance (after applying LGBC system) of 1075.675. As expected the distance from the LGBC system is slightly longer than true ground distance since the ground is actually lower than the grid surface at that point (hence the negative 10 ppm). The ratio of the two distances represents -9.3 ppm, which, allowing for rounding and the fact the points were not precisely on the contour, is very close to the expected -10 ppm. Several other point pairs were checked, which revealed similar consistency with the ppm contours. The conclusion was that the process is valid and reliable.

5 Discussion

Earlier, justification was provided for adopting errors of 5 ppm and 10 ppm (essentially 5 mm and 10 mm per kilometre) because they were related to practical survey accuracy standards. The process described in this paper can be used for any potential errors or accuracy specifications the practitioner may decide is acceptable. From that perspective the process is adaptable and robust. The process can be carried out before starting on a project, or it can be carried out after a LGBC system has already been introduced. In the latter, the combined scale factor would equal one at the project centre point, but the ppm errors would all be produced in the same way as described and the final contours would be the same.

In the example provided, it is obvious that LGBC systems may not be suitable over large areas in steep terrain. Nevertheless, if they are used, this process provides a convenient visual representation of where particular care needs to be taken, and where significant errors in distances may begin to appear.

It is also worth noting that the rapid rise in height due to the peak to the north-east of the project site could just as easily have been a depression due to mining operations or civil construction, so this process may have practical application to many different types of projects.

This process may also be useful on long line surveys such as pipe lines or transmission lines. In these cases, ground distances are required for materials and quantities, and most importantly for cadastral surveys. The process described will allow some planning to be undertaken to make decisions on whether or not LGBCs might be suitable on the project. If the long line survey requires several such local ground-based projections (or ‘zones’), the process described could be used to optimise their positions and configuration to minimise errors and minimise the number of local coordinate projections or ‘zones’.

Another practical application is where an existing construction site, such as a mine, may have been long established with its own particular mine grid. Originally a decision may have been made to convert all ground distances to the mine grid, based on a single combined scale factor. The process described in this paper would allow the production of error maps to allow informed decisions to be made on whether or not the mine grid could be expanded in the future, or if new ‘zones’ needed to be created that would use a different combined scale factor.

6 Conclusion

If properly established, local ground-based coordinate systems can be very useful on large projects, particularly for users who may not have a deep understanding of map projections and scale factors, but they need to be established and used with great care. Of prime concern is how far activities can be carried out away from the central point, and how much the height can change, before significant errors may be introduced in derived distances. This article explained the development and validation of an empirical system to determine distance errors that may be associated with the use of local ground-based coordinate systems on project sites. The process can be used regardless of the distance accuracy that may be considered significant on any particular project. The outcome is a visual representation of potential distance errors that may be associated with the local ground-based map projection. This process will be appealing to existing construction sites such as mines, residential estate developments, and large civil works projects. The process will also allow informed project management decisions to be made on projects in steeply undulating terrain, and over long line surveys such as transmission lines and pipelines.

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Response to reviewer comments

REPORT TO EDITOR

SURVEY REVIEW

SRE649

2016-03-01

A Process to Graphically Demonstrate Distance Errors Associated with Local Ground-Based Coordinate Systems

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Response to Reviewers' Comments

The figures are presently in colour. The author should discuss colour printing with the editor/publisher. The figures might be not readable when printed in grayscale and might require reworking.

Action: Email discussion resulted in the following instructions from the Editor (Email dated 1/3/2016) 'Leave the illustrations in colour, we have an allocation of colour pages from the publisher so we should be able to do yours in colour.'.

(1) A better title would be "A Process to Graphically Demonstrate Distance Errors Associated with Local Ground-Based Coordinate Systems". It is not clear why the author uses the term 'empirical'.

Action: Title changed. The term 'empirical' was used originally since the process outlined in the paper deals with observation/experiment rather than being restricted to theory. It is considered that having 'Graphically Demonstrate' in the title will serve just as well.

(2) It is suggested to merge sections 1 and 2. One-sentence sections are wasteful.

Action: Sections merged as suggested. Sections renumbered as a consequence.

(3) It is suggested to place a space between numbers and units (e.g. 2 km [not 2km]).

Action: Changes made as suggested.

(4) Page 3, line 50 : should read 5 mm (not 5 ppm)?
Page 4, Line 52: should read 10 mm (not 10 ppm)?

Action: Changes made as suggested.

(5) The accuracy specs in surveying have generally two terms, namely a mm-term and a ppm-term. In the past, when steel bands were used, the mm term could be ignored. With GPS and EDM, this is no longer the case. In fact, the mm-term is often the dominant term, particularly when unsupported reflector/antenna rods are used (as noted by the author). Unfortunately, the error sources discussed by the author are of the ppm type. The author should review his switching between ppm and mm. It might not always be appropriate.

Action: Paper reviewed to ensure consistency of approach and several changes made as a consequence. Distance errors do have a 'mm-term and a ppm-term', however, the errors under investigation in this paper only have a ppm- term. I have therefore taken the opportunity to benchmark the errors under discussion against commonly used distance errors by equating them to a single ppm-term at one kilometre. An explanation has also been added at the beginning of the last paragraph in (new) section 2: '*The distance specifications discussed contain both a constant (mm-term) and a further component that varies with distance (ppm-term). However, since the errors under investigation in this paper only have a ppm-term, for the purposes of comparison, distance specifications have been equated to a single ppm-term at one kilometre.*'.

A further sentence has been added to second last paragraph in section 1: '*Note that these potential errors associated with LGBC are in addition to the normal errors associated with the survey measurements.*'.

(6) Fig. 1: Add scale bar. Check if the figure is still useful if printed in grayscale.

Action: Scale bar added as requested. Confirmation received from the Editor that the Figure will be printer in colour. Nevertheless, I also printed the page in greyscale and the relief can still be seen to an acceptable standard in my view.

(7) Fig. 2: Add scale information, horizontal and vertical.

Action: Scale bars added as requested. Vertical is indicative due to the perspective of the view.

(8) Figs. 3, 4, 5, 6, 7: Enlarge scale bar and add contour interval either in legend or, better, by labelling contours in figure.

Action: Scale bars enlarged as requested (Figure 8 included). Contour labels added in Figures as requested.

(9) Page 7: Give an easily accessible (textbook) reference for 'height scale factor' and, possibly, list equation in text..

Action: Sentence added: 'More details on height scale factor including a convenient formula can be sourced from Schofield and Breach (2007, p. 310) who refer to this as the altitude correction.'. Note there is no formula number for this in that text. I am reluctant to quote their formula because this would then mean having to explain each term in the equation. Further, the preceding sentence states '…height scale factor is … the ratio of the ellipsoidal height at the point and the mean radius of curvature of the earth at that point plus the ellipsoidal height'.

(10) Page 6: Give an easily accessible (textbook) reference for the 'point scale factor' and, possibly, list equation in text. E,g, Eq. (8.46a), p. 306, Schofield, W. & H. Breach, 2007. Engineering Surveying, 6th ed., Butterworth-Heinemann, Oxford.

Action: Reference added as suggested. Page number is 305. Sentence added: 'To calculate point scale factors manually readers are referred to Schofield & Breach (2007, p. 305 Eq. 8.46a).'.

(11) References: Generally, the references are based on local material from Queensland, Australia. For a worldwide readership, the references should be as general and as easily accessible as possible.

Action: Two references added to Schofield & Breach (2007), a UK publication. Paragraph three now added to section 1 to provide more on an international flavour.

The author does not give any Survey Review references. Since the topic of the paper is not new, he might wish to scan SR for relating papers.

Action: Paragraph three added to section 1. References contained in this paragraph:

> Cina, A, Manzino, AM & Manzino, G 2016, 'Recovery of cadastral boundaries with GNSS equipment', Survey Review, pp. 1-9.
> O. Demir, BU & Çete, M 2008, 'Turkish Cadastral System', Survey Review, vol. 40, no. 307, pp. 54-66.
> Erenoglu, RC 2016, 'A comprehensive evaluation of GNSS- and CORS-based positioning and terrestrial surveying for cadastral surveys', Survey Review, pp. 1-11.

For general topics, such as formulae, appropriate textbooks should be references (rather than QLD government regulations).

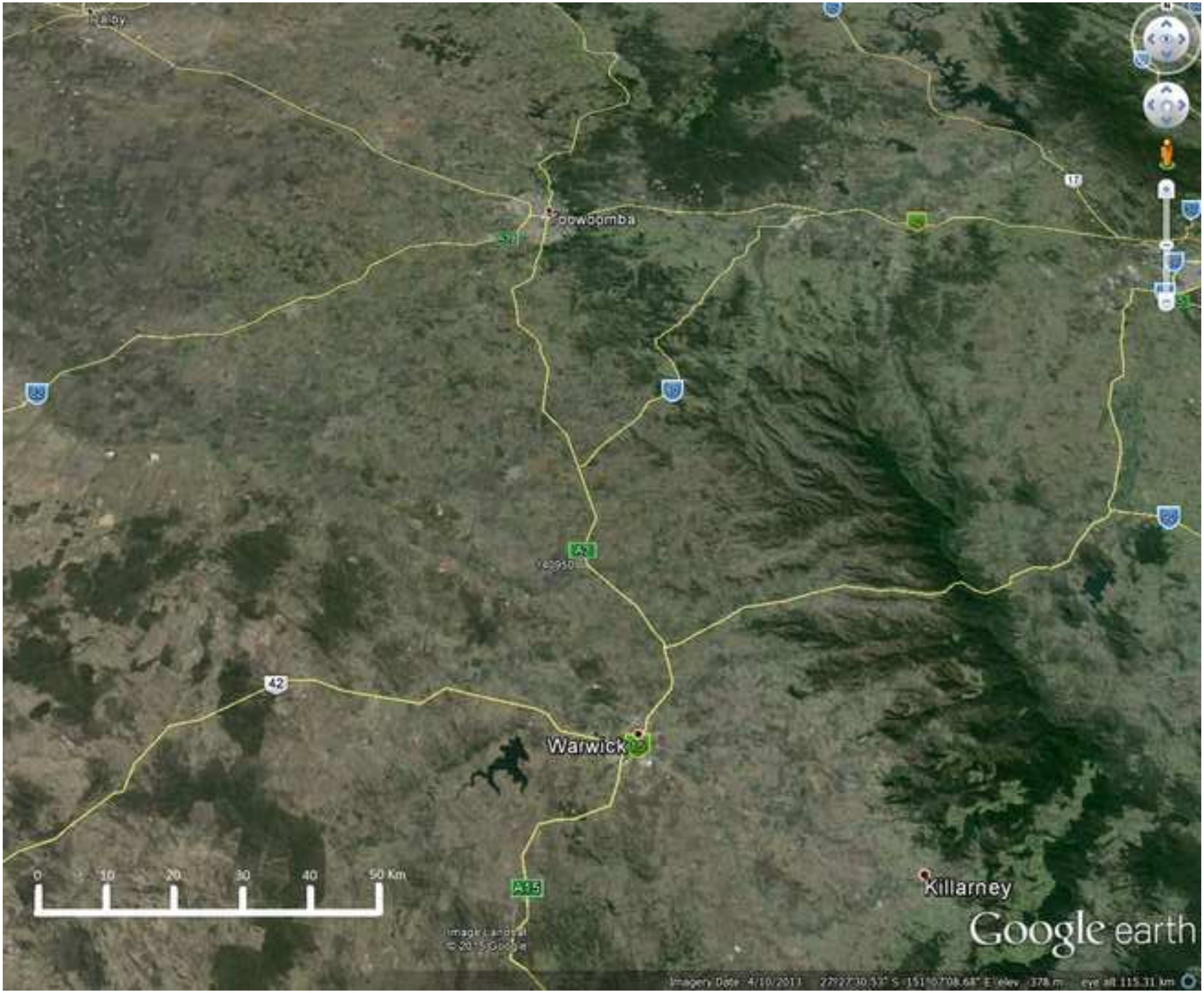
Action: Two references added to Schofield & Breach (2007), for formula relating to point scale factor and height scale factor.

Give web address (URL) for refs 2, 5, 7, 8, if at all available. Presumably, refs 2 and 5 are available from the author. This fact might be added (in brackets).

Action: Note (available from the author) added to 2 and 5, URL not really suitable for 7 since this is referencing software, URL added to 8.

(12) Typing errors:
P 2, L 24: because (not bacause)
P 5, L 56: ... example, Digital ... (not ... example, a Digital ...)

Action: Both changes made as requested.


oowoomba
42
A3
Warwick
A15
Killarney
0
10
20
30
40
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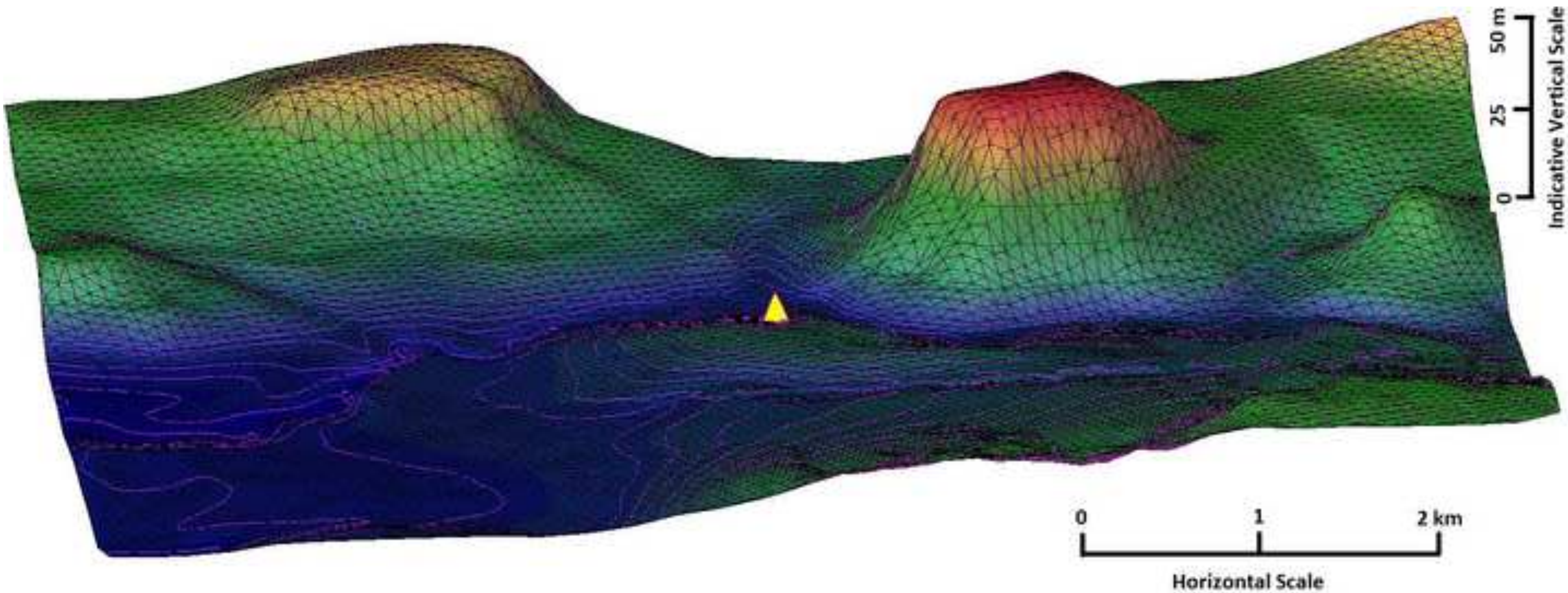
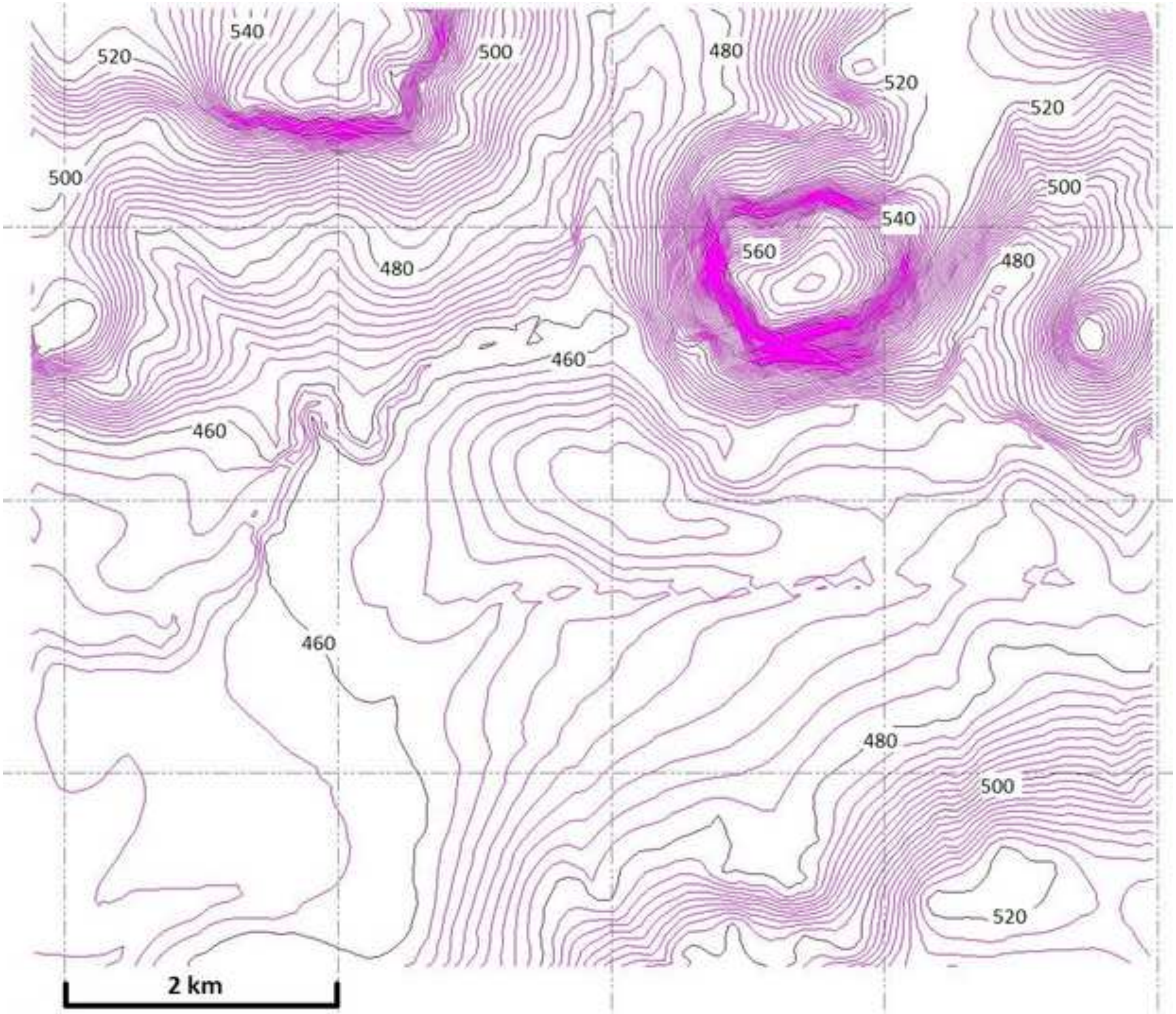
Google earth

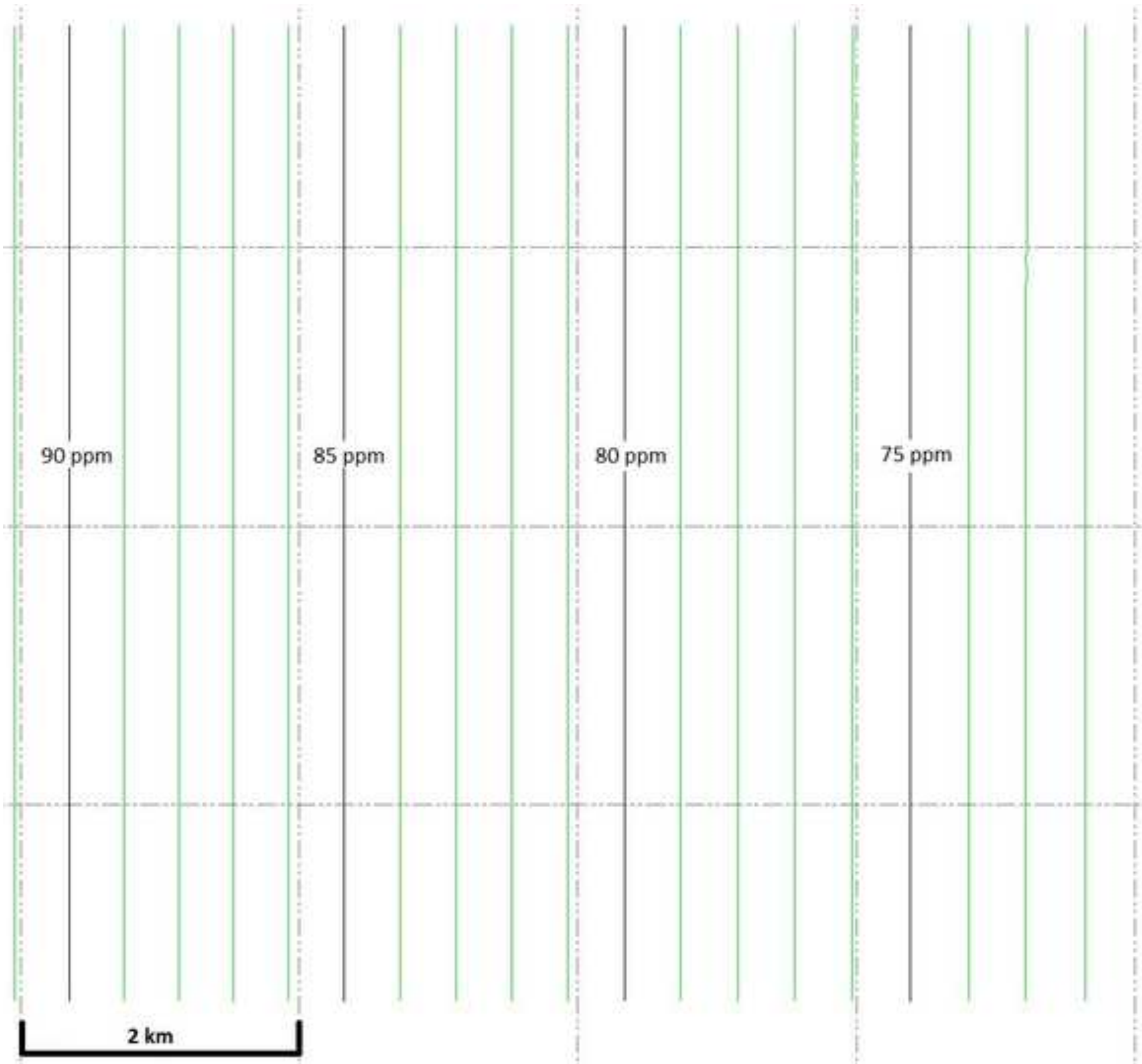

50 m
25
0
Indicative Vertical Scale
0
1
2 km
Horizontal Scale

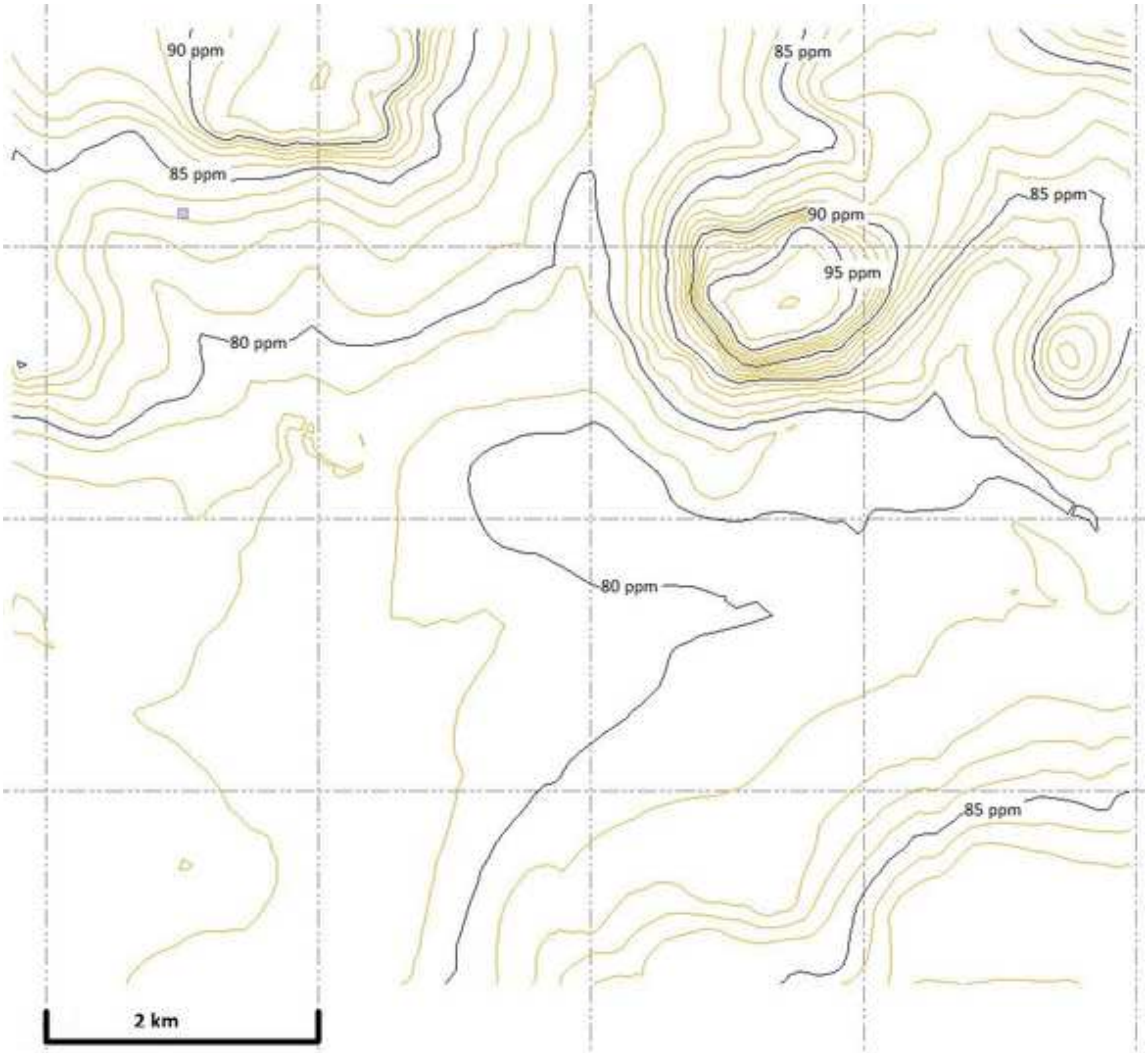
Colour figure Click here to download Colour figure Figure 3 DEM Plan.JPG



Colour figure

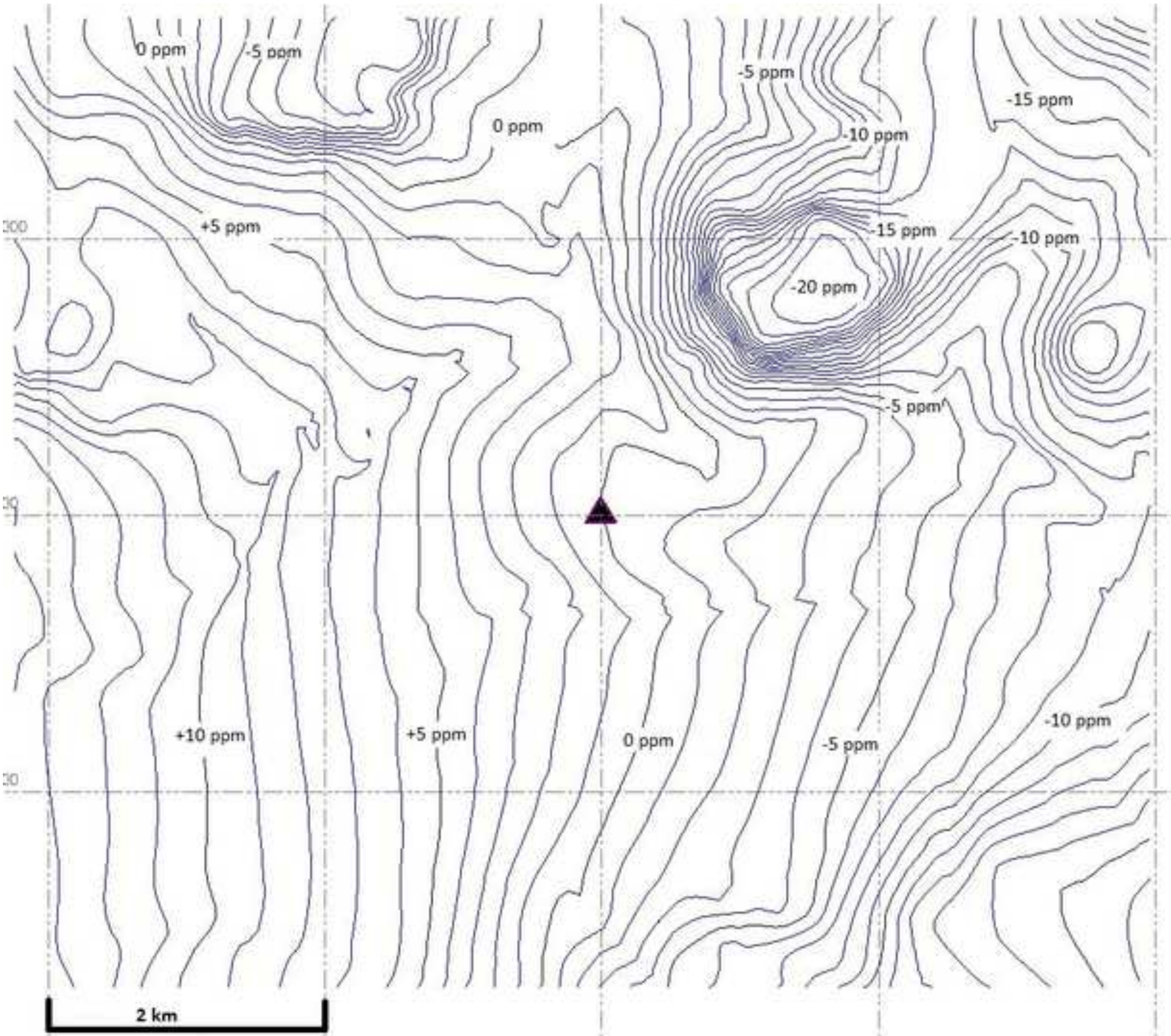
Click here to download Colour figure Figure 4 UTM Scale Factor.JPG




90 ppm
85 ppm
85 ppm
90 ppm
95 ppm
85 ppm
80 ppm
80 ppm
85 ppm
2 km

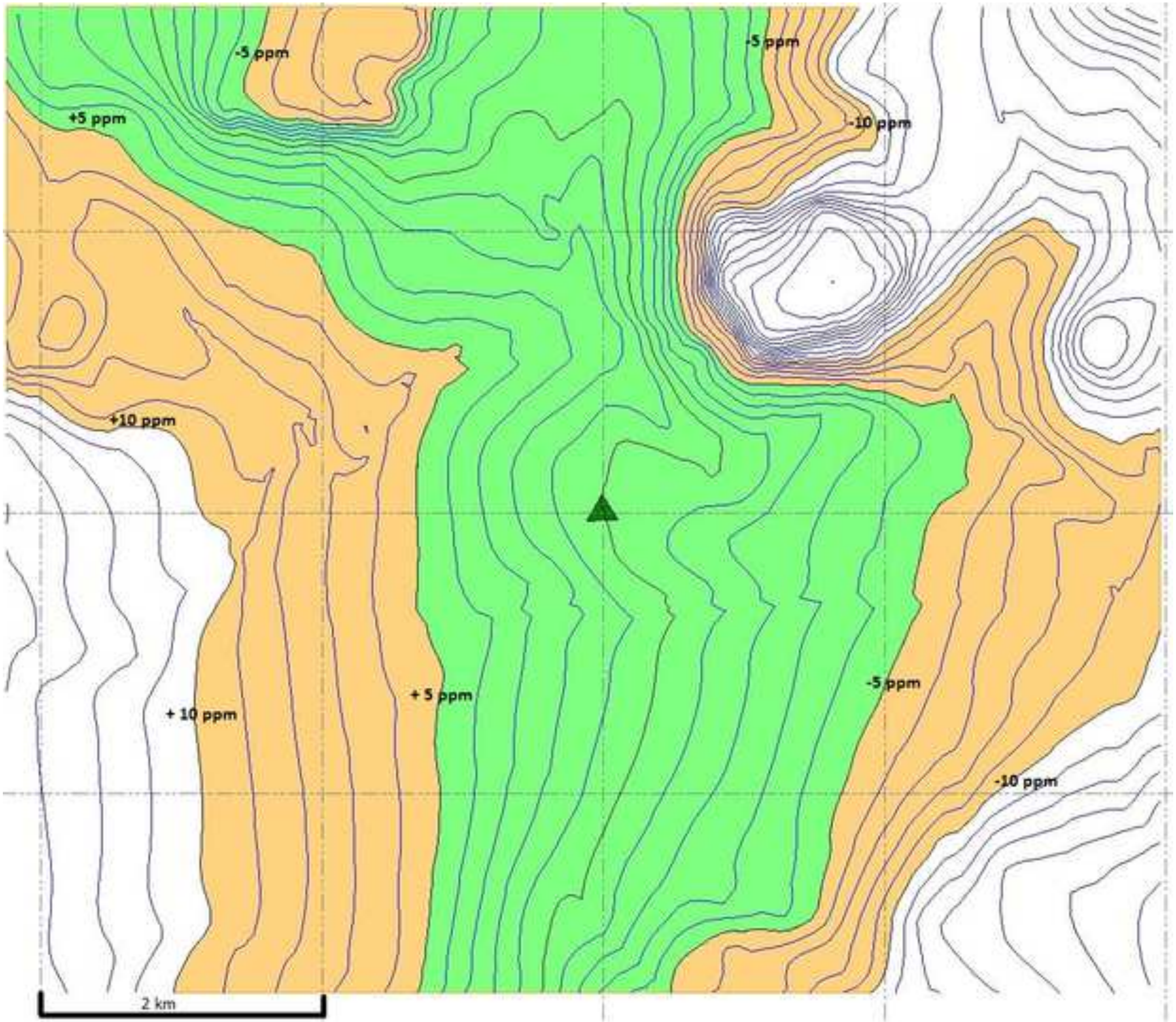
Colour figure

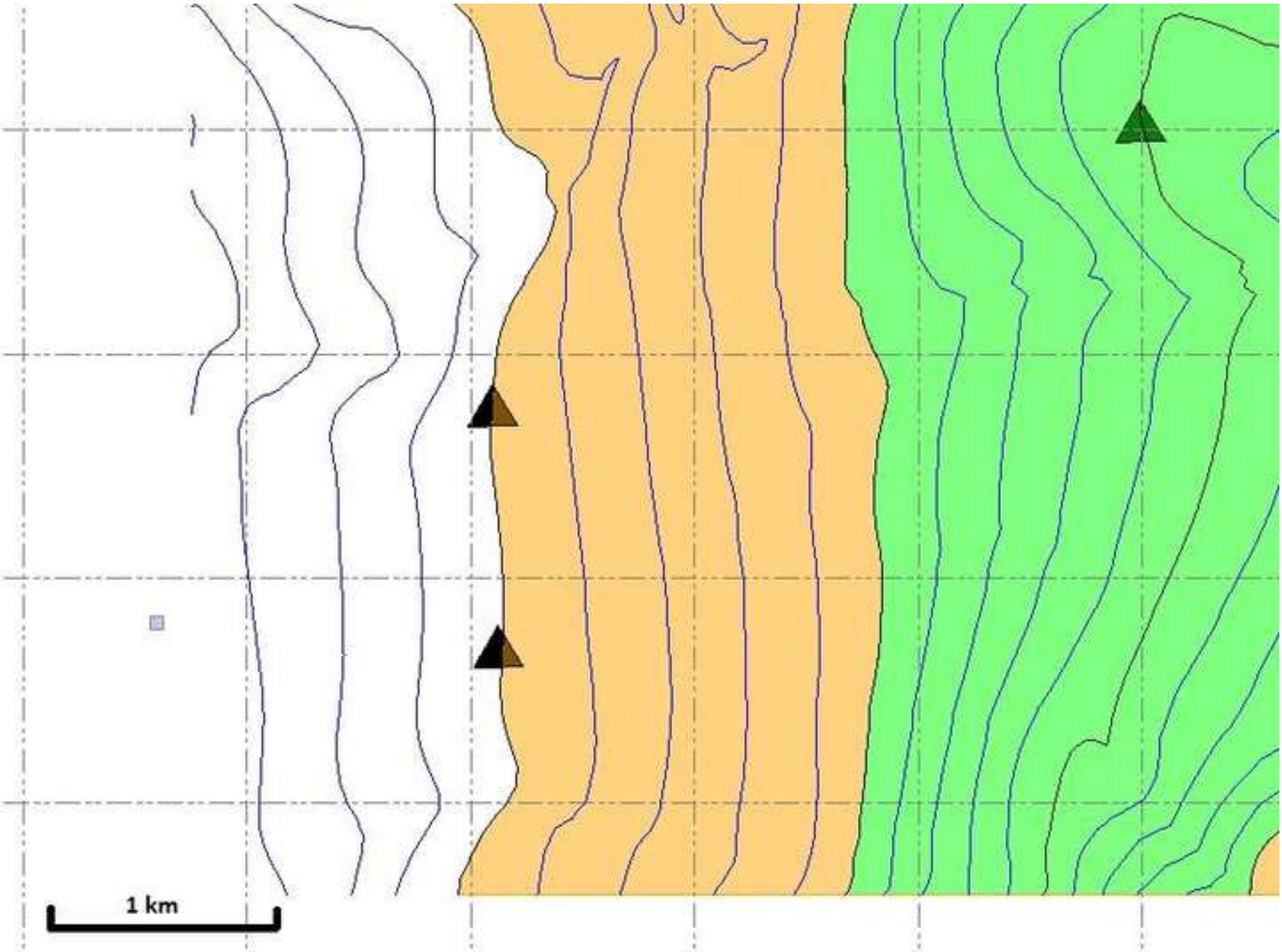
Click here to download Colour figure Figure 6 Combined Scale Factor.JPG



Colour figure

Click here to download Colour figure Figure 7 5 and 10 ppm combined.JPG




1 km

	A	B	C	D
1	ID	Easting	Northing	RL
2	10	395980.162	6901586.618	522.9781
3	20	396230.162	6901586.618	522.2817
4	30	396480.162	6901586.618	522.2242
5	40	396730.162	6901586.618	525.1375
6	50	396980.162	6901586.618	531.2442
7	60	397230.162	6901586.618	537.8336
8	70	397480.162	6901586.618	542.114
9	80	397730.162	6901586.618	546.709
10	90	397980.162	6901586.618	550.08

Colour figure

	A	B	C	D	E	F
1	ID	Easting	Northing	Projection Scale Factor (ppm)		
2	10	395980.162	6901586.618	90.9478		
3	20	396230.162	6901586.618	90.3063		
4	30	396480.162	6901586.618	89.6664		
5	40	396730.162	6901586.618	89.028		
6	50	396980.162	6901586.618	88.3912		
7	60	397230.162	6901586.618	87.7559		
8	70	397480.162	6901586.618	87.1221		
9	80	397730.162	6901586.618	86.4899		
10	90	397980.162	6901586.618	85.8593		