Coal Operators' Conference

Faculty of Engineering and Information Sciences

2006

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Recommended Citation

Daniel R. Palamara, G. Brassington, Phil Flentje, and Ernest Baafi, High-Resolution Topographic Data for Subsidence Impact Assessment and SMP Preparation: Methods and Considerations, in Naj Aziz and Bob Kininmonth (eds.), Proceedings of the 2006 Coal Operators' Conference, Mining Engineering, University of Wollongong, 18-20 February 2019
https://ro.uow.edu.au/coal/55

HIGH-RESOLUTION TOPOGRAPHIC DATA FOR SUBSIDENCE IMPACT ASSESSMENT AND SMP PREPARATION: METHODS AND CONSIDERATIONS

Daniel Palamara[1], Gary Brassington[2], Phil Flentje[1], Ernest Baafi[1]

ABSTRACT: Corporate and social requirements relating to sustainable mining practices have resulted in an increasing need for identification and assessment of natural features that may be susceptible to coalmine-induced subsidence. Natural features such as, cliff lines, watercourses and steep slopes, that are typically susceptible to subsidence-induced impacts can often be identified and quantified using high-resolution topographic data and a geographic information system (GIS). Once identified, digital representations of these features can be used in the impact assessment process and for Subsidence Management Plan (SMP) preparation.

This paper demonstrates the use of topographic data for site characterisation and feature identification purposes by mapping susceptible areas for a study site, including valley floors, steep slopes, drainage lines, and erosion-prone areas. It also discusses the potential use of topographic data and GIS for assessing subsidence impacts through knowledge- and data-driven approaches. The assessment of pre- and post-subsidence hydrological conditions is also shown for two swamps within the study area. The area over the proposed Dendrobium Area 2 operation in the Southern Coalfield was chosen as a case study site, and high-resolution airborne laser scan data were acquired for the site from BHP Billiton.

INTRODUCTION

Ground movements attributable to coalmine subsidence have long been associated with effects to surface infrastructure, and more recently, natural features. Traditionally, the focus of subsidence impacts has been geared mainly towards man-made features such as transport infrastructure, buildings and installations, and pipelines (Kratzsch, 1983; Whittaker and Reddish, 1989). More recently, however, increasing attention has been given to natural features and impacts have been documented on features such as watercourses (Sidle et al., 2000), cliffs and steep slopes (Kay, 1991; Holla and Barclay, 2000), and aquifers (Booth, 2002; Dumpleton, 2002).

There is therefore a pressing need for coalmine operators to assess and understand potential subsidence impacts to natural features, both because of their social and environmental responsibilities but also because of legislative requirements. In NSW, these requirements are embodied in the Subsidence Management Plan (SMP) process, which came into effect during March 2004. SMPs are designed to satisfy increasing public and stakeholder concerns about environmental impacts associated with coalmine subsidence in NSW. The SMP process is comprehensive and includes requirements to assess potential impacts of subsidence to both natural and man-made infrastructure (Regan, 2003). Section 6 of the SMP Guidelines (NSW DPI, 2003) states that SMPs must "provide information that: (1) Characterises the nature, extent and magnitude of the expected subsidence impacts due to the proposed mining, and (2) Identifies priority risks, highlighting the expected subsidence impacts with high risk levels and /or potentially severe consequences.".

One class of tools that offer significant potential for subsidence impact assessment is Geographic Information Systems (GIS). At its core, GIS exhibits the capacity to access, manipulate, analyse, and visualise spatial data. This then facilitates the derivation of new spatial data based on the attributes of existing, sometimes incongruent, spatial data sets (Figure 1). Although the large-scale use of GIS for subsidence impact assessment is yet to be realised, the successful application of GIS to complex spatial problems in other fields attests to its suitability for the task. Pertinent examples can be found, for example, in the work of Flentje et al. (in prep) or Chau et al. (2004) in the field of landslide management, Zhou et al. (2003) for regional land subsidence hazard mitigation (related to groundwater extraction), or Mansor et al. (2004) for natural risk management.

Central to the successful application of GIS to any problem is the acquisition of suitable data. While many datasets are required for comprehensive subsidence impact assessment, one dataset in particular that has broad application is topographic data. Digital topographic data can be sourced through a range of processes, including

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digitisation of topographic maps, aerial photogrammetry, terrestrial or airborne laser scanning, satellite-borne radar, and ground-based surveys including the use of Global Positioning Systems (GPS). Regardless of the source, once the topographic data have been interpolated to form a surface, usually through the creation of a digital elevation model (DEM), the data can readily be incorporated into GIS-based terrain analyses.

Perhaps one of the areas in which GIS-based analyses can be most readily applied, in terms of subsidence impact assessment and SMP preparation, is the "…full land use description and impact assessment, including the physical landforms and environment of the area…" upon which SMPs will be "built" (NSW DPI, 2003). On its own, the potential uses of topographic data include site characterization, feature identification, hydrological modelling, and more. When combined with other pertinent datasets in a GIS, topographic data can potentially be used to assess or predict potential impacts. The aim of this paper is to:

1. document some of the typical analyses that can be performed using GIS and suitable topographic data,
2. demonstrate how these fundamental analyses can provide a useful starting point for further assessments, and,
3. outline some of the main limitations and considerations that need to be understood for the efficient and effective use of the technology available.

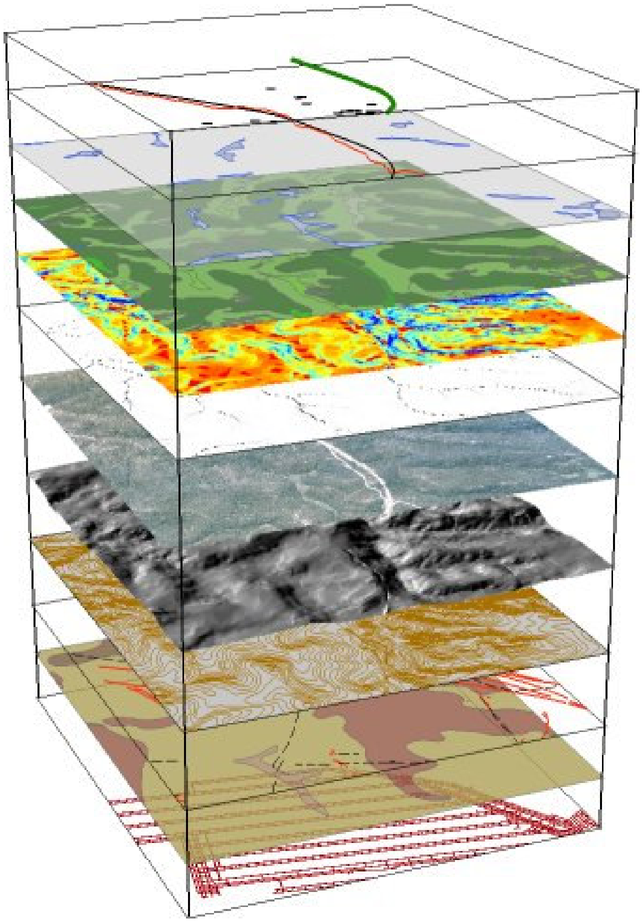

Fig. 1 - The overlay of multiple spatial layers in GIS

The layers shown here include (from the top down) transportation, swamps, vegetation, the topographic wetness index, drainage lines, aerial imagery, a hillshade model of the topography, topographic contours, structural geology, regional geology, and mine plans. The ability of GIS to consider the attributes of multiple varied datasets at the same locations provides tremendous capacity for spatial modelling and analysis.

DATA AND OVERVIEW

This paper uses the proposed Dendrobium Area 2 mine, operated by BHP Billiton (BHPB), as the main case study for demonstrating the supporting role of GIS and topographic data in the subsidence impact assessment process. Beyond the use of a mine plan and subsidence predictions, the assessments shown here rely only on topographic data derived from an airborne laser scan survey conducted in February 2003.

The topographic data were interpolated into a digital elevation model (DEM) using triangulation and pixel resolution of 2 m. The choice of interpolation method and DEM resolution was based on the mean point spacing of the raw data and a comparison of interpolation methods as outlined in Palamara et al. (submitted). A 2.5D representation of the study area is shown in Figure 2 using a hillshade model of the topographic data.

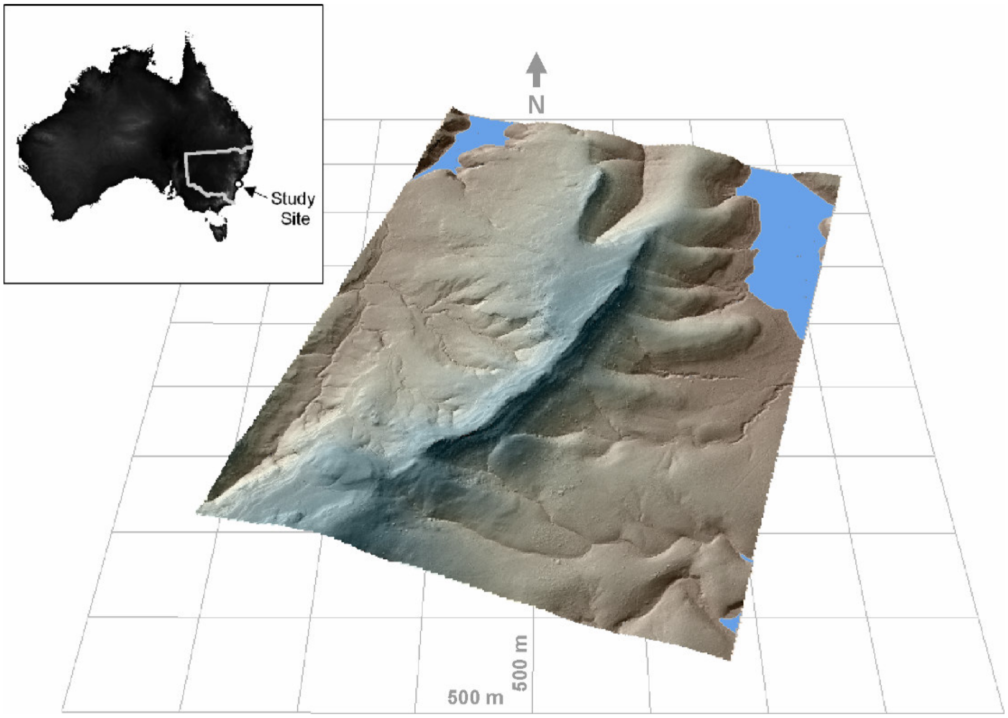

Fig. 2 - The study area, situated over the proposed Dendrobium Area 2 operation. The figure shows a hillshade model of the 2 m DEM derived from airborne laser scan data

SITE CHARACTERISATION

Many studies have demonstrated that topographic data and GIS can be used to perform a wide variety of terrain analyses, particularly with regard to hydrological analyses (Jensen, 1991; Moore et al., 1991; Wilson and Gallant, 2000). The site characterisation process can exploit these, and other, capabilities of GIS to identify areas that are likely to be susceptible and therefore warrant further assessment. In this instance, the examples presented here include the identification (i.e., mapping) of valley floor areas, major drainage lines, steep terrain (including cliffs), and erosion prone areas. Other natural features or attributes that can be readily characterised using topographic data and, in some cases supplementary data, include watersheds, flood prone areas, surface wetness/soil moisture and other important aspects.

VALLEY FLOOR AREAS

Valley floor areas that are subjected to mining-induced subsidence are potential sites for the occurrence of upsidence (Holla, 1997; Waddington and Kay, 2003a), which can result from valley closure. The identification of valley floor areas, which typically coincide with the location of rivers and creeks, can therefore be used to highlight areas of potential subsidence impacts.

Waddington and Kay (2003a) have indicted that 'valley depth' is one of the major factors controlling the magnitude of upsidence. Measuring valley depth through the use of digital topographic data is one method of both identifying low areas in the terrain (such as valley floors) and also quantifying the magnitude of relief. Figure 3 shows valley floor areas for the study site. In this instance, relative low points in the surface were identified by comparing the height at each location (i.e., each 2 m pixel) with the 'regional' height derived as an average of all heights in a 100 m radius surrounding each pixel. The choice of radius is arbitrary and can be easily modified. The most appropriate radius may be different for different types of analysis and is the subject of ongoing research.

Valley floor areas can subsequently be identified as areas in which the local height is less than the regional average height, and the magnitude of this difference provides an objective and accurate measure of valley depth. In Figure 3 relatively low areas (greater than 10 m height difference) are evident in many locations, but the maximum depth does not exceed 20 m. The deepest areas (15 m – 20 m depth) are situated in the large gully to the north of the study site (under the middle panel), and in the depression in the bottom left corner of the study site.

This method using GIS analysis can be considered superior to manual methods of measuring valley depth because it is independent of manual bias and inaccuracies, can be rapidly derived, is repeatable, and the results are available in digital format, which facilitates their possible use in modelling pursuits or empirical predictions. Furthermore, it does not suffer from the same problems that the manual method faces with undulating or irregular terrain (Waddington and Kay, 2003a).

DRAINAGE

Potential changes to watercourses in the form of surface fractures and water loss, ponding, and altered sedimentation regimes are a common concern in mine subsidence impact assessment. It is therefore critical to accurately identify drainage areas within the study site and to derive the appropriate attributes.

The continued and increasing use of GIS in hydrological studies has produced many techniques for the characterisation of regional hydrology, which naturally includes the identification of streams or drainage lines. Interpretation of watercourses and drainage lines can therefore be readily derived from topographic data using a variety of spatial algorithms and methods. Most methods generally involve the calculation of flow direction, upslope contributing area or flow accumulation, and surface slope and aspect, all of which is readily performed using only topographic data.

Figure 4 shows the prominent drainage lines within the study area. These will typically correspond to the location of known watercourses (subject to the accuracy of the DEM used to derive them). In Figure 4, as in most cases, the derivation of drainage lines based on topography will highlight all areas where surface water is likely to accumulate and flow, though in reality these areas do not always correspond to permanent watercourses. Nevertheless, the identification of drainage lines – whether permanent or ephemeral – is important given the potential impacts associated with both topographic changes and surface/sub-surface fracturing associated with subsidence. In Figure 4 it is evident that there are numerous drainage lines which lead to major watercourses, and eventually into the dams within catchment areas. Many of these features coincide with the proposed mining area or the 'valley floor' (upsidence) areas identified in Figure 3, and can therefore be flagged for further assessment.

The automated identification of drainage lines using digital topographic data offers numerous benefits over reliance on external drainage data, whether it is in digital or hardcopy format. The derived drainage data is likely to be more accurate and up-to-date than data extracted from topographic maps or the associated spatial databases, as shown in Figure 5. It is also likely to be more comprehensive since, as outlined previously, the technique will identify drainage areas that do not necessarily correspond to established watercourses, but instead reflect preferred or likely flow paths for accumulated surface water. Minor watercourses that are unlikely to be recorded on topographic maps or regional drainage databases will also be captured by this method. Also, by having the watercourse data in digital format it is possible to perform further analyses, such as stream order calculations or the comparison of pre- and post-subsidence profiles.

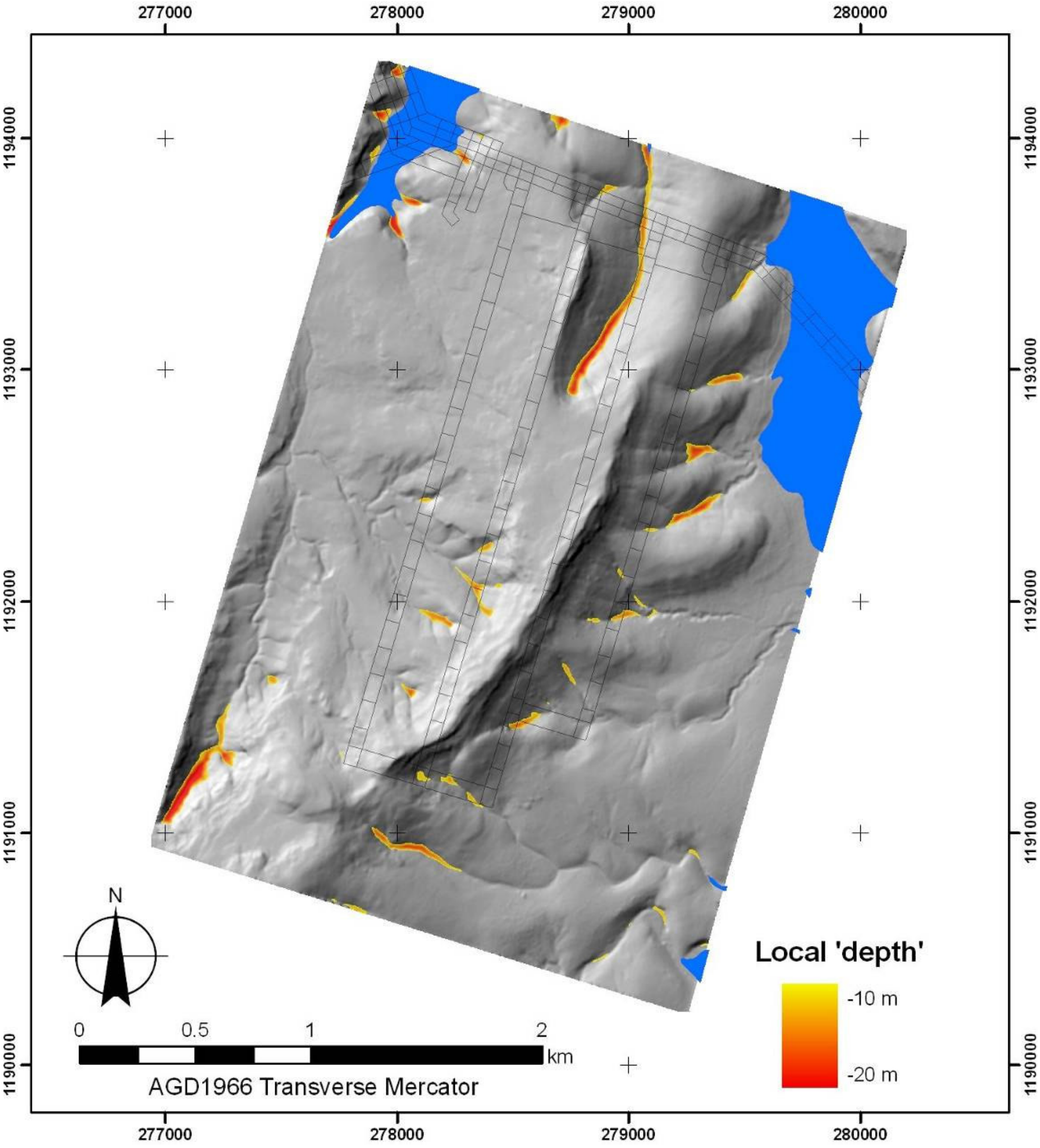

Fig. 3 - Valley floor areas

Pixels corresponding to valley floor areas were identified by comparing the local height with the average height over an area measuring 100 m in radius from each pixel. Depths of greater then 10 m were considered to correspond with valley floor areas. This objective, repeatable, and accurate technique rapidly identifies low areas in the terrain which, due to valley closure, may be prone to upsidence impact. Both the depth at which to assign the classification of 'valley floor' (in this case, 10 m) and the radius of the 'regional' average (100 m) are somewhat arbitrary and can be modified to suit the site.

STEEP TERRAIN

The identification of steep terrain, which can be susceptible to mine subsidence impacts due to its intrinsic instability and propensity for rock falls is relatively straightforward if high-resolution data are used. Figure 6 shows areas that may be susceptible to mine subsidence impacts based on the classification of surface slopes from the topographic data. To derive this image, slope values (in degrees) were calculated for the entire study area using the topographic data outlined earlier, and the resulting slope classes were classified using a simplified version of the slope classification table of McDonald et al. (1998). Relatively flat areas are shown in Figure 6 since these areas may be susceptible to flooding associated with subsidence-induced vertical movements. In this instance, though, the study site does not contain large expanses of flat ground. There are, however, many areas with very steep slopes which occur over the proposed mining area. In particular, there is a long (~2 km) extent of steep slopes situated directly over the proposed longwall panels.

As well as identifying and mapping these susceptible areas digitally, the topographic data can also be used to partially assess or predict subsidence impacts to these areas using either knowledge- or data-driven modelling, as outlined in Palamara et al. (2006) and Zahiri et al. (in press) and in a later section of this paper.

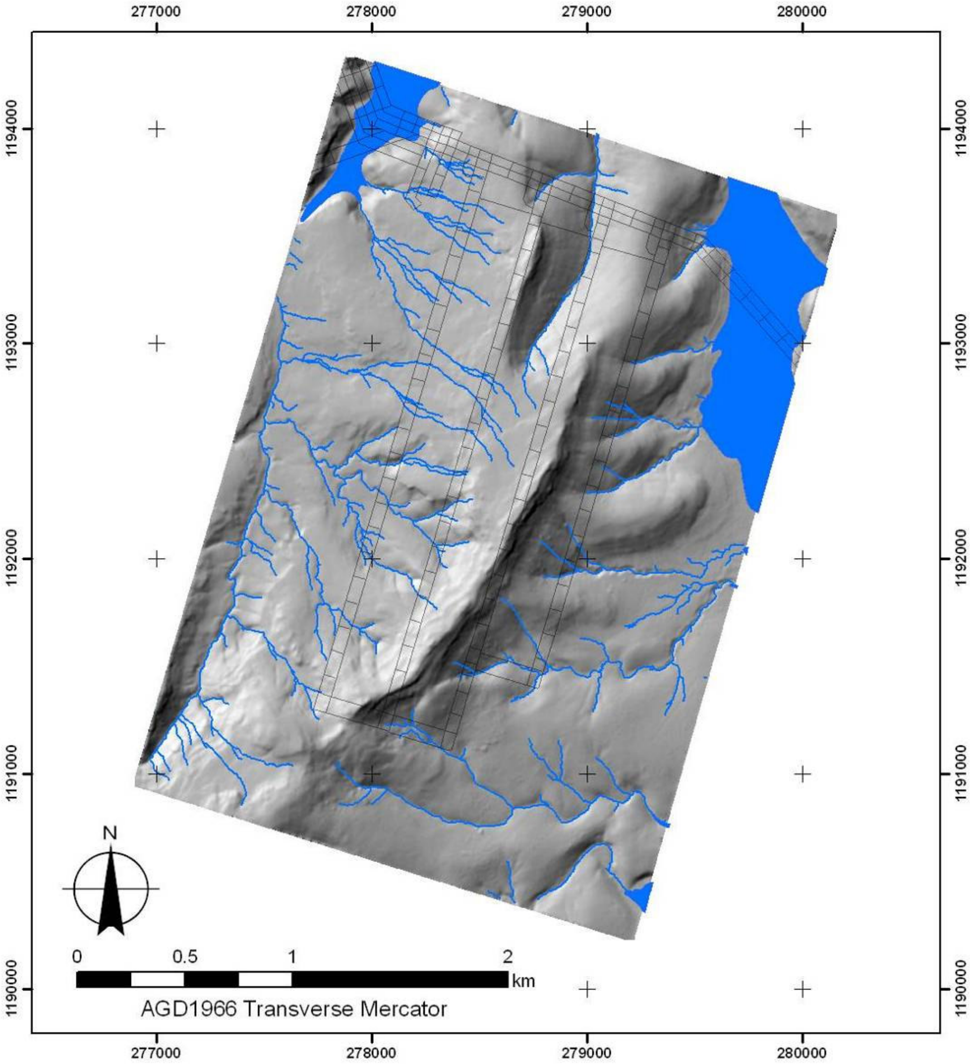

Fig. 4 - Major drainage lines for the study area

These lines were derived using the 2 m DEM and stream identification functions that are available in most GIS. The method allows for the objective and accurate identification of possible drainage line. The fact that each drainage line is available as a digital object in GIS facilities further analyses such as comparison of pre- and post-subsidence height profiles, stream order assignment, and a determination of relative valley depth for each pixel along the drainage line.

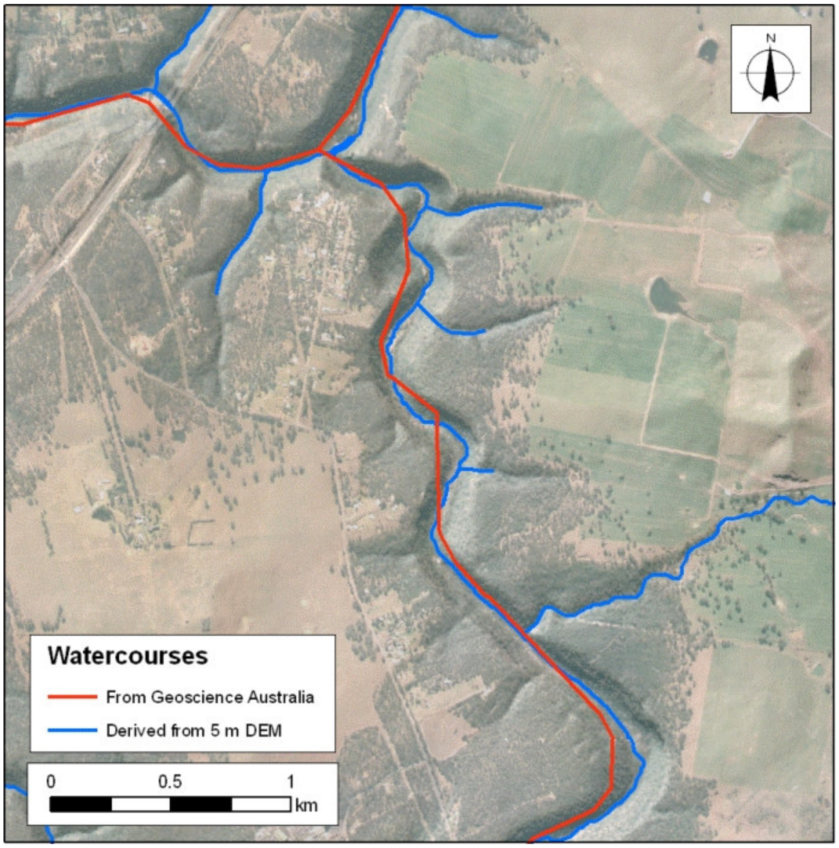

Fig. 5 - Watercourses over a sample area from two different datasets

Note the inaccuracies in the 1:1,000,000 scale Geoscience Australia data set (red). The drainage network does not conform to the channel areas shown in the aerial photograph. The inaccuracies in these widely available data sets preclude them from being useful for subsidence impact assessments. The DEM-derived watercourse vectors conform to the channels somewhat more closely and were derived within ArcGIS™ using the freely available TauDEM extension (Tarboton, 2003). The sample shown here is situated near Appin, NSW, and the DEM-derived watercourses are based on a 5 m DEM provided by the University of Wollongong school of Earth and Environmental Sciences.

EROSION-PRONE AREAS

Mining subsidence has potential to either initiate or increase erosion through (1) the removal of vegetation due to water loss and drying, gas escape, rock falls or slope failure, or by (2) altering surface gradients and flow patterns. It is therefore worthwhile mapping erosion potential prior to mining, so that potential impacts can be quantified and if necessary mitigated. Numerous studies (Boggs et al., 2001; Pistocchi et al., 2002; Lufafa et al., 2003; Hoyos, 2005) have demonstrated that, to some extent, the quantification and mapping of erosion potential, and the identification or erosion hotspots, can be achieved using GIS and topographic data. For mine subsidence impact assessment, the aim of erosion mapping is to highlight areas that warrant further investigation, in the form of either field observations or more detailed modelling (perhaps incorporating further factors), and also locations that should be monitored due to erosion potential.

While more than one method exists, most GIS-based assessments of erosion potential employ the universal soil loss equation (USLE) or a revised form of this index (RUSLE), which is relevant for sheet and rill erosion. The index incorporates numerous parameters that are relevant to erosion, such as soil erodibility, slope and slope-length, runoff, surface and cover management, and conservation practices (Renard et al., 1994; Hoyos, 2005). Other methods also require a combination of parameters in order to model erosion potential well. However, it is also possible to model erosion potential using topographic factors alone, by using just the slope and slope-length factor (termed the LS factor) from the USLE or versions of the stream-power indices (Wilson and Gallant, 2000).

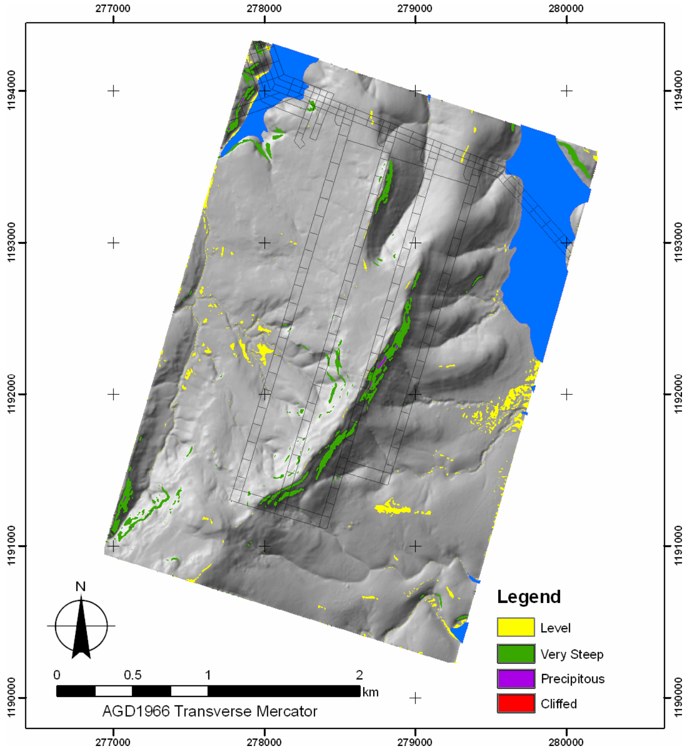

Fig. 6 - Potentially susceptible terrain based on surface slope.
Susceptible terrain, such as level ground or very steep/precipitous slopes, was identified by classifying the surface slope values using the table of McDonald et al. (1998).

While erosion mapping based on topography alone will not present a complete picture of the actual erosion potential in the study site, it is useful for mine subsidence impact assessment because it will identify areas of potential risk that may warrant more in-depth modelling (incorporating all the suitable factors, not just topography) or field observations.

Figure 7 shows erosion potential as mapped by the LS factor (Desmet and Govers, 1996) from the (R)USLE for the study area. The LS factor is dimensionless it can be difficult to interpret; therefore in Figure 7 the results are classified by quantiles. This is somewhat a subjective representation, since the quantiles of the LS-factor will vary for each study site, though it succeeds in demonstrating which areas are most prone to sheet and rill erosion – namely the flanks of the ridge in the centre of the study area, and sections within the drainage gullies to the northand the south west of the area. As pointed out by Desmet and Govers (1996), the highest values occur primarily in areas with steep slopes and in zones of flow concentration.

This approach to the identification of erosion prone areas has the benefit of being easily and rapidly implemented and, as with the other analyses shown previously, the susceptible areas are mapped in digital format and can therefore be analysed and manipulated as required. However, it must be stressed that generic erosion mapping such as this is limited by many factors and should only be used as a guide on erosion potential when combined with assessment of other important aspects.

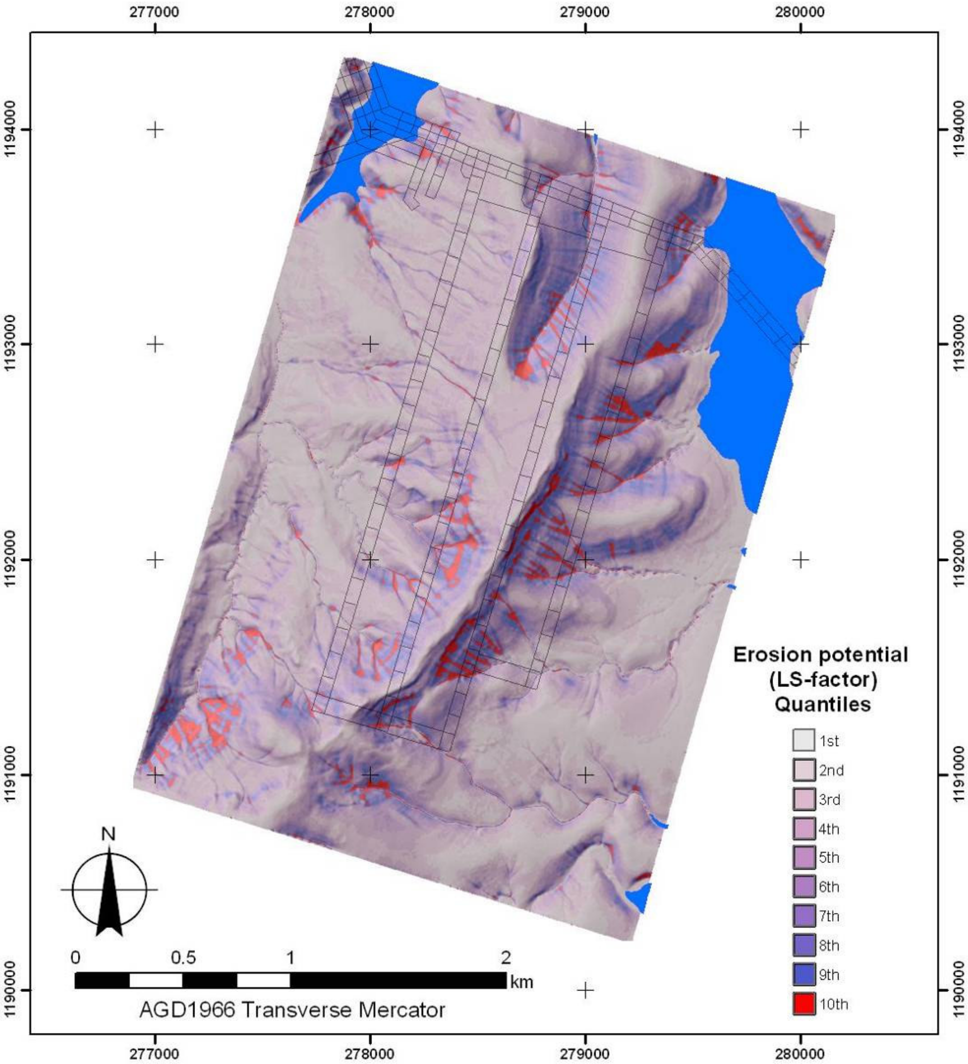

Fig. 7 - Erosion potential for the study site, based on the LS-factor.
The LS factor is the topographic component of the (R)USLE, and when calculated in the absence of other factors only provides a partial insight into potential erosion patterns. The LS factor (and the USLE) was designed for use of relatively flat slopes and is known to overestimate erosion potential on steep slopes. Despite its shortcomings, this figure demonstrates how the LS factor (or other erosion indices based on topography alone) can potentially be used to identify areas that may be susceptible to subsidence impacts. Note, in particular, the area (marked in red) at the head of the gully towards the north of the study site, as well as the confluence of high LS factor values within some of the drainage areas on the flanks of the central ridge.

ASSESSMENT

Topographic data can also feature heavily in the subsidence assessment stage, using either the natural features identified as part of the site characterisation process, or other forms of digital data. Various examples of GIS-based subsidence impact assessment, based primarily on the use of topographic data, are presented here including:

1. The measurement of stream profile changes using pre- and post-subsidence surfaces,
2. The assessment of subsidence impacts to cliffs and steep slopes (demonstrated for a different study site), and
3. Mapping of hydrological changes due to vertical movements, both in general and for two specific swamps within the study area.

STREAM PROFILES

Once an object has been recorded spatially within a GIS it is possible to extract attributes from other digital spatial data layers at that location for the purpose of analyses. For comparing changes to specific natural features due to subsidence it is possible to derive a post-subsidence surface (using subsidence predictions), and then compare the height changes for each feature.

Figure 8 shows the change in height profiles for two selected sections of drainage lines; both occur directly over the proposed mining area. The post-subsidence surface was derived using subsidence prediction data provided by Mine Subsidence Engineering Consultants (MSEC) Pty Ltd. For both profiles the areas of greatest change are readily evident, and in the second profile the location of a probable natural (i.e. pre-subsidence) pond is evident. The comparison of pre- and post-subsidence profiles could help with the identification of areas in which subsidence might result in flow reversal, ponding, or fracturing.

CLIFFS AND STEEP SLOPES

The following section describes the assessment of potential subsidence impacts to cliffs and steep slopes using two fundamental approaches, both of which can be readily performed within a GIS if the suitable supplementary data are available; a more detailed description of these approaches can be found in Palamara et al. (2006).

In the first instance, a knowledge-driven approach can be adopted. This requires an in-depth understanding of the pertinent factors which influence the magnitude or severity of the subsidence impact. The GIS is then used, where possible, to quantify each factor in order to provide a final assessment of possible subsidence impacts. For example, Waddington and Kay (2003b), in their handbook, outline a knowledge-based assessment system for cliffs. Many of the factors outlined in their assessment system, such as the 'extent of mining', and 'degree of public exposure,' can be either derived directly within a GIS (using topographic and other data), or incorporated into a GIS. A type of 'multicriteria' analysis, which is commonly implementing using GISs for site selection and suitability analyses (Malczewski, 2004) can then be performed, where each factor is derived for each point in the study area, weighted, and summed according to the specifications of the assessment system.

An alternative, which does not require an in-depth understanding of the relevant factors, is data-driven modelling. This can be accomplished through a variety of methods, but in all cases require a suitable database of mapped subsidence impacts, so that the data-driven model can empirically identify and weight the relevant factors. Unlike knowledge-based assessment, which generally provides a classification of the system under examination, data-driven modelling will typically provide a 'probability' value based on the confluence of the relevant factors. Further information on this case study is available in Zahiri et al. (in press), which uses a database of rockfalls associated with the nearby Tower Colliery workings for the modelling experiment.

Although vastly different in their output and implementation, both methods can be readily performed using GIS and rely heavily on topographic data. Furthermore, they can be implemented for a variety of natural features, not only steep slopes and cliffs.

HYDROLOGICAL CHANGES

Subsidence impacts can be attributed to two main mechanisms – topographic changes associated mainly with vertical movements and surface and subsurface fracturing associated with zones of tension and compression. The majority of subsidence impacts can be attributed to this later mechanism, which is unfortunately relatively difficult to model and predict. Conversely, because accurate subsidence predictions are readily available, subsidence impacts associated directly with topographic changes are relatively easy to model.

For example, the plethora of hydrological indices that can be readily calculated using GIS and topographic data can be used to evaluate subsidence impacts relating to topographic changes alone by the simple comparison of pre- and post-subsidence surfaces. The same parameters outlined in the site characterisation section, and more, can be evaluated for subsidence-induced changes.

A comparison of these parameters was performed for two swamps which occur within the study area. Swamps are known to be sensitive to environmental changes and are potentially important in subsidence impact assessment (Horsley and Brassington, 2004; Horsley, 2003). Pre- and post-subsidence values for some hydrological attributes were extracted for the two swamps which occur in the study area (Figure 9) and compared to determine how the swamps may be influenced by subsidence (Table 1). The swamps were mapped digitally, in the first instance, by Horsley (2003) and have been adjusted in this exercise based on the visual inspection of high-resolution (20 cm) aerial photography.

Table 1 shows that changes in hydrological parameters, associated with altered topography due to predicted subsidence, are minimal. For Swamp 1, which is situated directly over the proposed mining area, the most noticeable change is a decrease in catchment area. The term 'catchment area', for a GIS or terrain analysis perspective, is tantamount to the flow accumulation for a cell, and refers to the count of cells which flow into a particular cell. If runoff values are known (in this case they are not) they can also be included to derive a more accurate estimate of the amount of water flowing into a particular cell. In this case, subsidence is predicted to decrease the catchment area for Swamp 1, on average, by 14 %. The impact of such a change on swamp health is not contemplated here, but is worth noting for subsidence impact assessment purposes. When other parameters are considered, this change in catchment area is manifested as a slight decrease in the mean and maximum wetness index within the swamp area, and also a slight decrease in the value of the corresponding erosion indices. Swamp 2, which is not situated directly over the proposed longwalls, is expected to undergo only a slight decrease in catchment area, and therefore not experience significant changes due to topographic adjustments.

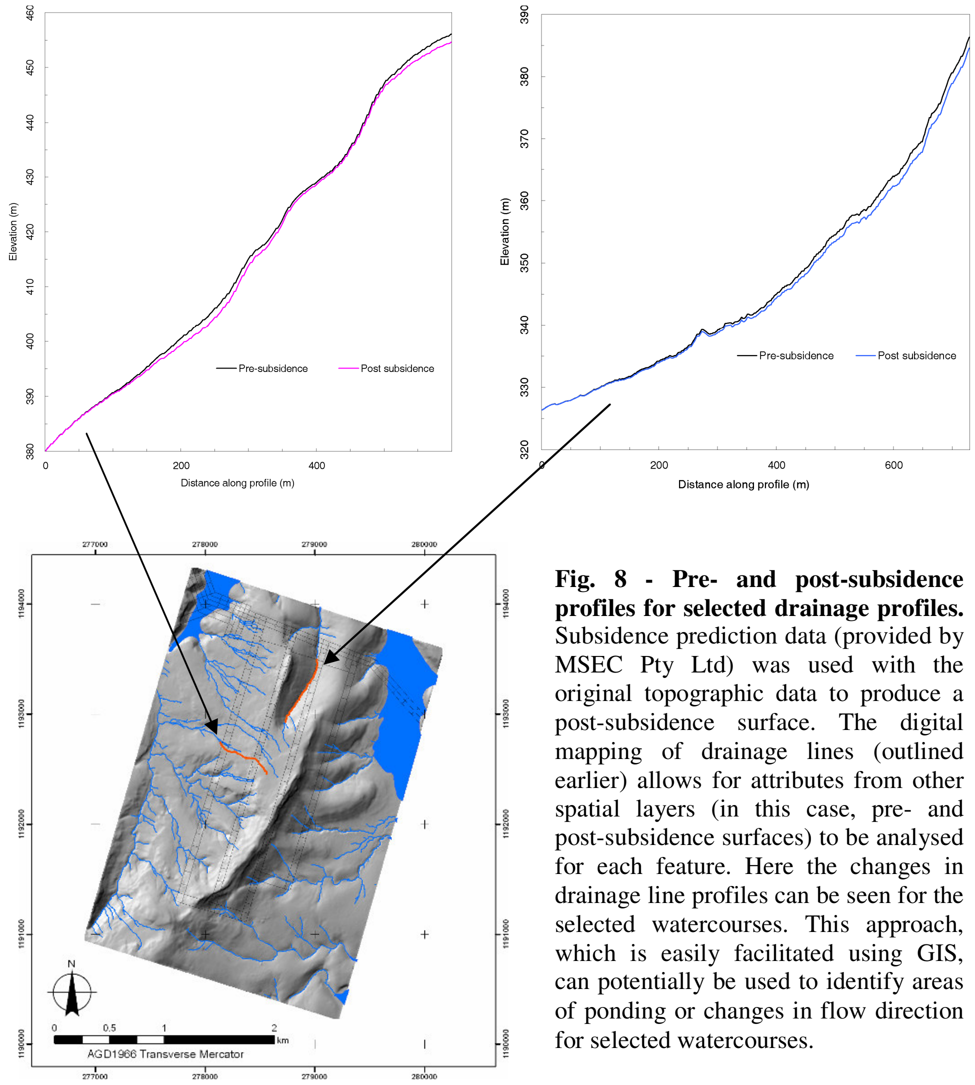

Fig. 8 - Pre- and post-subsidence profiles for selected drainage profiles. Subsidence prediction data (provided by MSEC Pty Ltd) was used with the original topographic data to produce a post-subsidence surface. The digital mapping of drainage lines (outlined earlier) allows for attributes from other spatial layers (in this case, pre- and post-subsidence surfaces) to be analysed for each feature. Here the changes in drainage line profiles can be seen for the selected watercourses. This approach, which is easily facilitated using GIS, can potentially be used to identify areas of ponding or changes in flow direction for selected watercourses.

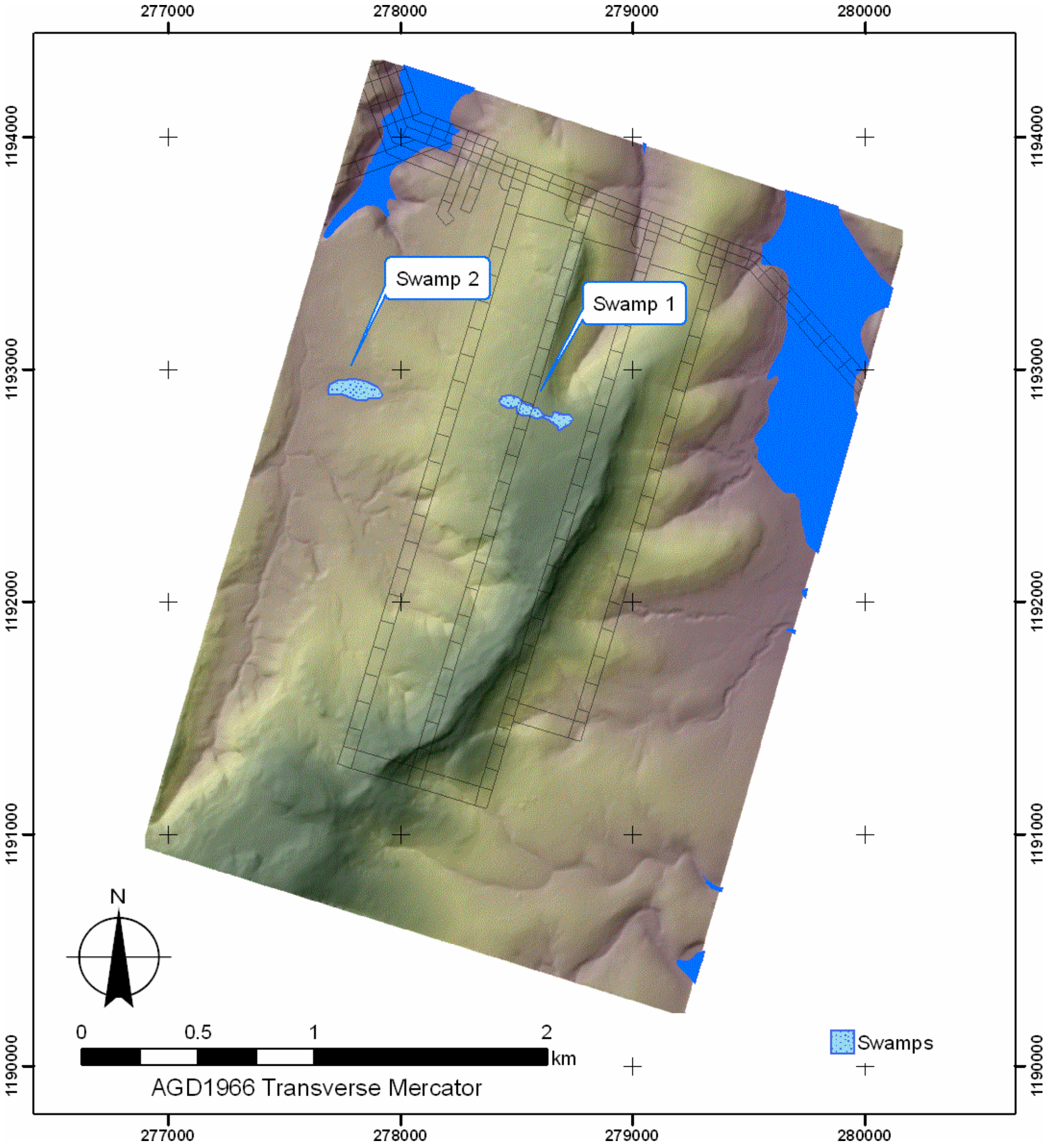

Fig. 9 - The location of swamps within the study area.
The swamps were originally mapped and identified by Horsley (2003). The swamp boundaries have been modified here based on the visual inspection of high-resolution aerial photography. Swamps are potentially susceptible to mine subsidence because of their strong dependence of hydrological conditions. An example evaluation of these swamps, in light of the topographic changes associated with the predicted subsidence, is given in the text.

Table 1 - A comparison of selected pre- and post-subsidence hydrological parameters for swamps within the study area.

Parameter	Swamp 1			Swamp 2		
	Pre	Post	Change	Pre	Post	Change
Subsidence (mean)	-	0.9 m	-	-	0.0 m	-
Subsidence (max.)	-	1.7 m	-	-	0.0 m	-
Wetness Index (mean)	8.3	8.1	-0.2	9.7	9.7	0.0
Wetness Index (max.)	10.2	11.6	1.4	16.6	16.5	-0.1
LS factor (mean)	6.7	6.5	-0.2	5.4	5.4	0.0
LS factor (max.)	26.9	29.7	2.8	20.0	19.8	-0.2
Stream Power (mean)	69	60	-9	212	207	-5
Stream Power (max.)	552	510	-42	3048	2976	-72
Slope (mean)	6.4°	6.5°	0.1°	4.0°	4.0°	0.0°
Slope (max.)	11.9°	13.4°	1.5°	8.2°	8.2°	0.0°
Catchment Area (mean)	1,150 cells	982 cells	-168 cells (-14%)	7,596 cells	7,403 cells	-193 cells (-3%)
Catchment Area (max.)	5,465 cells	4,575 cells	-890 cells (-16%)	196,109 cells	191,463 cells	-4,646 (-2%)

Refer to Figure 9 for the location of the swamps. These changes were calculated using hydrological analysis functions intrinsic to the SAGA 2.0b GIS and topographic data. The largest change is evident in the post-subsidence decrease in catchment area for Swamp 1. This means that, based on the predicted subsidence, the area from which surface water will collect and flow into Swamp 1 will decrease due to topographic changes. Spatially variable runoff has not been considered in this analysis. It is not clear what effect, if any, this will have on the swamp, since channel processes may prove indifferent to this change. Even though the changes shown here are likely to be of little consequence, they demonstrate the capacity of topographic data, when coupled with GIS, to provide for fundamental subsidence impact assessment.

DISCUSSION

The aforementioned analyses demonstrate the capability of GIS to perform 'accurate' and rapid site characterisation and preliminary identification of susceptible features for subsidence impact assessment. The results of these analyses are summarised in Figure 10, which shows some of the natural features in the study area that are potential susceptible to subsidence impacts, which include:

1. the swamp situated directly over the proposed mine area,
2. some 'valley bottom' areas that are greater than 15 m lower than the surrounding average heights,
3. the steep slopes, particularly those near the centre of the proposed longwalls, and
4. large areas with relatively high erosion potential.

The benefits of this approach to subsidence impact assessment, which entails the use of digital topographic data and GIS, are numerous:

1. The results shown here were accomplished without the need for fieldwork,
2. were rapidly derived,
3. are readily repeatable using different parameters if necessary, and
4. the product is in digital format and can therefore be easily distributed, visualised, and manipulated.

The map shown in Figure 10 could serve mainly as a starting point for further, more detailed analyses. When supported by established empirical methods, knowledge-based assessment systems, or databases of mapped impacts suitable for data-driven mining, the analyses presented here can be extended from simple mapping exercises to predictive projects with relative ease.

There are, however, some important considerations associated with this approach. For example, the analyses presented within this paper have been derived using a topographic surface generated from airborne laser scan data. Not all topographic data share the high vertical accuracy and horizontal resolution of airborne laser scans. The horizontal resolution of topographic data will be one of the controlling factors which determine what type of terrain analyses can be undertaken and how reliable the results will be. As resolution decreases (that is, pixel size becomes larger) steep slopes and narrow features become more difficult to resolve. Slope-based classification, as shown earlier for the mapping of steep slopes and precipitous areas, becomes difficult. Even at 5 m resolution the ability to identify cliffed areas based on slope is severely limited. The visual inspection of hillshade or 2.5D representations will remain a valuable tool for the estimation of possible cliff areas, even with lower resolution data, but field mapping will more than likely also be required. Similarly, the identification of drainage lines will also become difficult as resolution decreases, and other methods such as field observations and aerial photograph interpretation may be needed.

Other considerations include the need for specialist software and comprehensive databases of subsidence impacts. Without these critical inputs, the scope for actual assessments using digital data and GIS is somewhat limited. At this stage, output such as that shown in Figure 10 cannot be considered as 'susceptibility maps' because it is not clear how the susceptibility of each feature should be assessed. As suitable mapped impacts become more available it may be possible to develop risk assessment maps that consider frequency and consequence of the subsidence impacts. When that occurs, GIS will become a critical tool not only for the presentation and assimilation of data for subsidence impact assessment and SMP purposes, but also to meet the requirement outlined in Harvey (2003), which is to "…be able to categorically determine the degree of impact a particular amount of subsidence will have on a surface feature…".

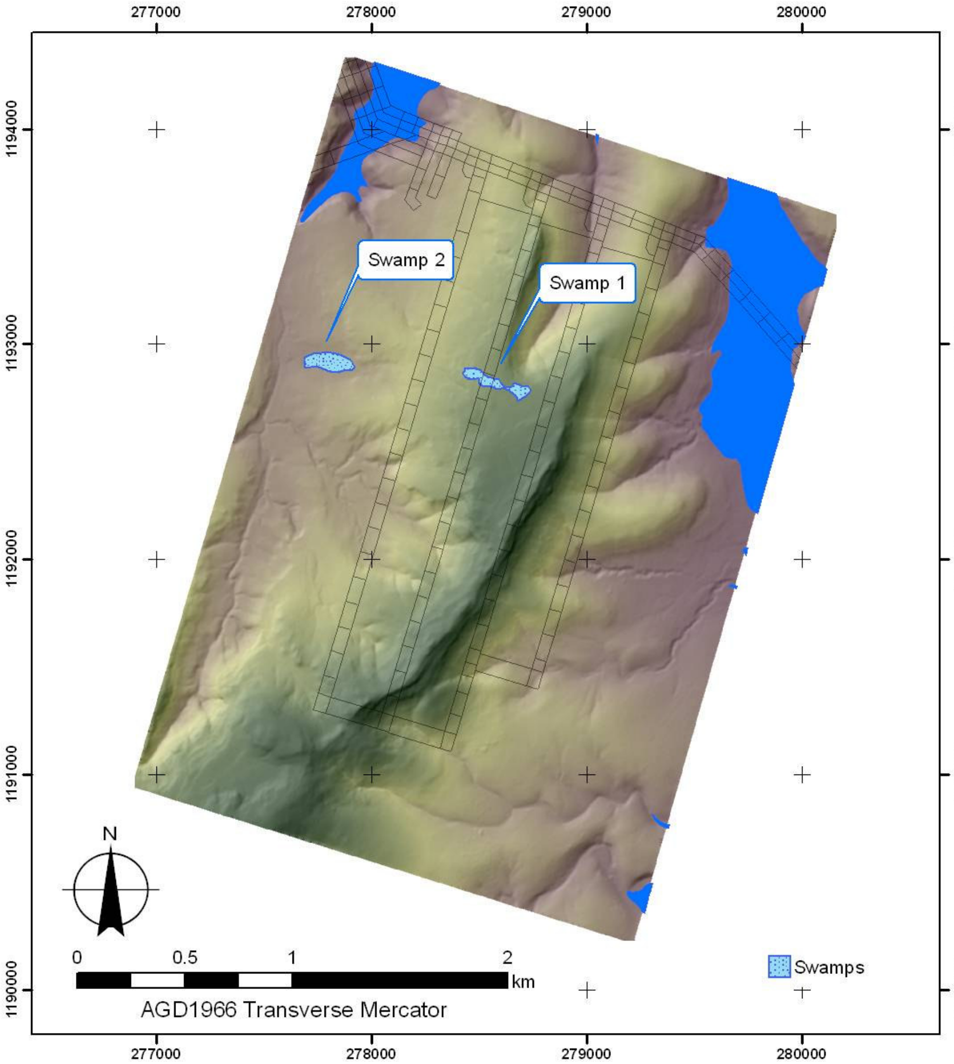

Fig. 10 - An overview of the site characterisation for the study area

The figure summarises the characterisation process outlined in the text and displays some of the features that can be considered most susceptible to subsidence impacts. The analyses required to derive this figure are relatively straightforward and require only topographic data. The figure demonstrates the capability of GIS to act as a starting point for subsidence impact assessment by accurately mapping, and in some cases assessing, potentially susceptible features.

ACKNOWLEDGEMENTS

This work was supported by an ACARP grant (C14031). Thanks to MSEC Pty Ltd for supplying subsidence prediction data and various individuals from within BHPB for providing data and advice.

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