


# Ninth AusIMM Open Pit Operators' Conference 2016

OPO 2016

## *Adapting to Change*

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# NINTH AUSIMM OPEN PIT OPERATORS' CONFERENCE 2016

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# Application of Shuttle Radar Topography Mission Data in Hydrological Analyses of Super Pit and Griffin Coalmine

A K Ghosh[1]

## ABSTRACT

Inrush of water is always an issue, especially for mines located in heavy rainfall areas. Nowadays, mining companies and research institutes have developed many advanced technologies for study and analysis of hydrological processes. In this paper, an advanced method is introduced, which uses the Shuttle Radar Topography Mission Digital Elevation Model (SRTM DEM) data in the Geographical Information System (GIS) platform to simulate the stream distributions around two specific mines: Super Pit and Griffin coalmine in Western Australia. The impact of this approach is important because it reduces the time and economic cost by creating a high spatial resolution hydrological map in the specific areas. The study identifies the flow path of the run-off water, which helps in adopting a suitable water management plan surrounding the case study mines. The results match with the ground reality. Based on the results, the stream structure around Griffin coalmine is more complicated than that of Super Pit. The bifurcation ratio and drainage density are computed to estimate the subsoil permeability characteristics of the two mines. Recommendations have been put forward to prevent and reduce the potential risks of water accumulation around the open pit mines.

## INTRODUCTION

One of the main issues around open pit mining areas is increased rainfall during rainy season. It not only affects the mining cost due to increased pumping but also destabilises the slope and pollutes the surrounding environment as run-off from the sides of the pit area and associated waste rock dumps deposits contaminated silts in low-lying areas.

Water drainage is more challenging issue for Queensland mining companies and local government compared to that of Western Australian mines. In rainy season, mines located in central Queensland coalfields are required to regulate water discharge to avoid serious water flooding (Humphreys and Abbott, 2009). In terms of water management, it is important to recognise the water (stream) flow system before constructing any water structure around mining areas for successful storage and effective use for future.

Water is indispensable for the mining industry, especially for mineral processing. In extended dry regions, effective water treatment is necessary for maintaining mining production. For instance, the total water usage of the Fimiston mill (which processes ore from the Super Pit) in 2004 was 7Gl (Cocks *et al*, 2009). However, the annual direct infiltration of rainfall in Collie basin is 18Gl (Varma, 2002). According to the description of Cocks *et al* (2009), the mining industry will face severe problems of water shortage as mines are located in rural areas, which require companies to conduct more investigation of water systems around mining areas.

It is more difficult to deal with water-related issues at open pit mines after the mine is in operation. It is therefore necessary to plan for and implement water systems and water treatment facilities before an open pit mine is in operation.

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In this paper two mines have been selected as case study mines. One is Kalgoorlie Super Pit, which is located in a dry region of Western Australia with relatively low rainfall (Cocks *et al*, 2009). The other one is Griffin coalmine, which is located in the humid Collie basin region which experiences annual rainfall of 1000 mm and infiltration of 20Gl (Varma, 2002). This study will develop a model for representing the hydrological characteristics by analysing the morphometric parameters in the study area. Based on the hydrological theory, the bifurcation ratio and drainage density of stream structures will help to identify the subsurface permeability and infiltration capacity of the study areas.

## MATERIALS AND METHODS

Traditionally, to construct the hydrological structure for a specific area, National Elevation Data is required to build the vector data set and transform to raster data set for hydrological analysis. However, the development of Shuttle Radar Topography Mission (SRTM) data set has improved the efficiency for constructing a hydrological structure. SRTM data is the first tool for collecting interferometric radar data to generate a nearly global (80 per cent) Digital Elevation Model (DEM). It was published by NASA in 2001 (Walker, Kellndorfer and Pierce, 2006).

With respect to SRTM data, Yenilmez *et al* (2010) stated that if evaluation of a drainage system is done without Geographical Information System (GIS) tools, it would be a cost and time-consuming activity due to the vast requirement of samples to be collected.

Martinez *et al* (2010) has revealed that as DEM grid size increases, average slope gradient decreases and the drainage network becomes increasingly simplified. Geomorphic descriptors such as the width function, cumulative area distribution and hypsometric curve appear largely insensitive to DEM scale. The area-slope relationship loses definition in the diffusive region of the curve at large grid scales; however, the fluvial region appears largely insensitive to the changes in DEM resolution.

Although, the latest version of SRTM data is the finished filled 10 m DEM data set, this version is only available when the user has sought it from the official department. Therefore, the applied data in this study is the version two filled finished (SRTM) 30 m DEM, which is available online free of charge.

## DATA ANALYSIS

From the data configuration, SRTM data can conform to the hydrological construction. Based on the Esri® ArcMap™ 10.3.0.4322 software, the process for mapping the water flow system integrates the topography elevation, land satellite imagery and geological structure.

The first step is filling the voids. The next step is the simulation of the water system and subsequently the stream order analysis.

### Shuttle Radar Topography Mission data filling

The surface elevation at the rim of the Fimiston open pit is approximately 420 m Australia height datum (Bawden and Zhan, 2006). According to the description of Varma (2002), the average elevation in the Collie basin region is about 204 m. When the GeoTIFF SRTM data has been imported in ArcMap, some voids are accompanied with the data. The voids are caused by the blocking of mountains and the scanning process of radar system (Shortridge, 2006). The void filling is an important procedure before processing the flow direction function as the voids may affect the calculation of flow accumulation. In ArcMap 10.1 (ArcGIS, 2012), the raster calculator can help users to create and execute a single-line algebraic expression by using a simple, calculator-like tool. There are several functions to fill the voids. The first step is to use conditional function to differentiate the negative raster data.

Figure 1 is the layout after voids filling. It manifests that the voids have been covered by circles and the minimum display value has adjusted to zero.

At the last step of void filling, the conditional function can integrate the finished voids filled raster data into one detailed raster data.

### Flow accumulation

The filled and finished SRTM data are required for the purpose of water delineation, hydrological analysis and to use the function of flow accumulation by accumulating weight of all cells and to determine the flow into each downslope cell in the output raster. As simple as the description, flow accumulation is determined to simulate the water movement around two mining areas.

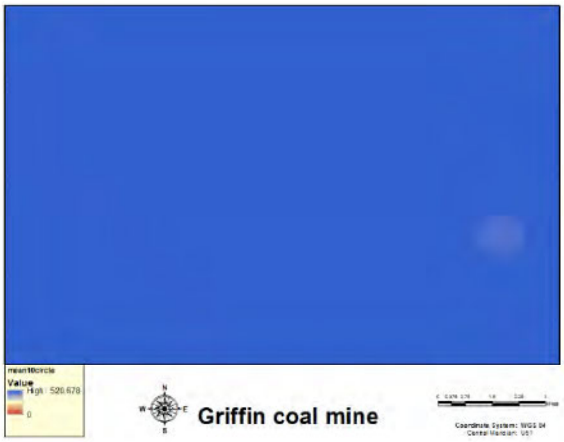


**FIG 1** – Layout after voids filling of Griffin coalmine.

The fill function is used to fill the sinks or peaks in the surface raster to ensure the proper delineation of streams and basins. The fill function is similar to the void filling, but the working objectives are different. The fill function aims to correct the discontinuities of derived drainage network and the purpose of void filling is to fill the missing data. As shown in Figure 2, the fill function can fill the sinks or remove the peaks in the surface raster to ensure the proper delineation of streams and basins.

After the fill function, the next step is construction of flow direction. The purpose of generating flow direction is to create a raster of flow direction from each cell to its steepest downslope neighbour. The working method of flow direction in ArcMap 10.1 is referred to an eight-direction (D8) flow model and follows an approach presented in Jenson and Domingue (1988). Figure 3 shows the coding sequence of flow direction of surrounding cells.

Normally, the flow direction is on the steepest slope. However, if a one-cell sink locates next to the physical edge of the raster or has one NoData cell as a neighbour, it would not be filled due to insufficient neighbour information. The input surface raster for processing the filled SRTM data and the function *force all edge cells to flow outward* should be chosen to ensure that all cells at the edge of the surface raster will flow outward from the surface raster. Figure 4 is the layout of flow direction around two mines. From Figure 5, some lines are obvious in the layout of Griffin coalmine due to the scanning process of SRTM data. The lines are formed due to the slope elevation.

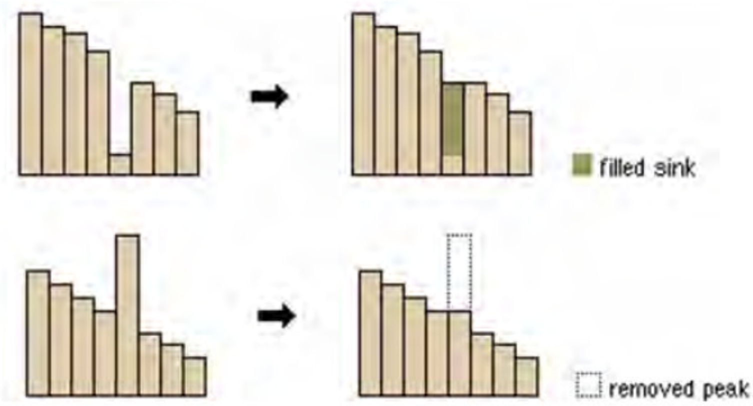


**FIG 2** – Working process of fill function.

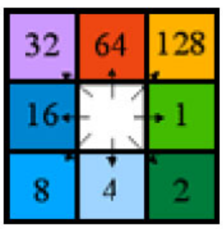


**FIG 3** – Flow direction coding of surrounding cells.

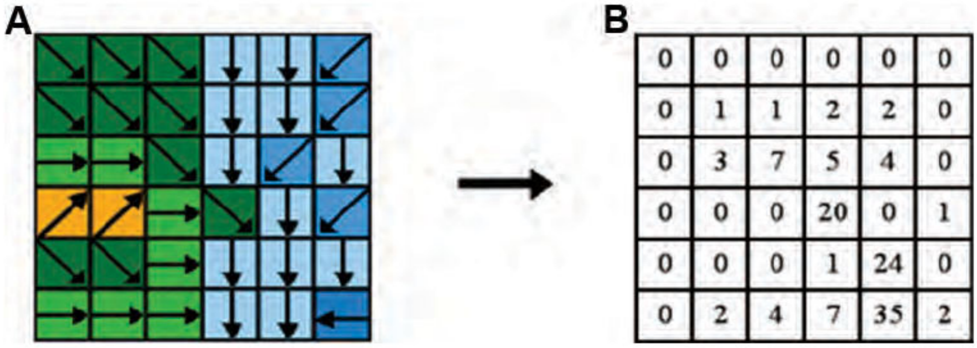


**FIG 4** – Flow accumulations process: (A) flow direction; (B) flow accumulation.

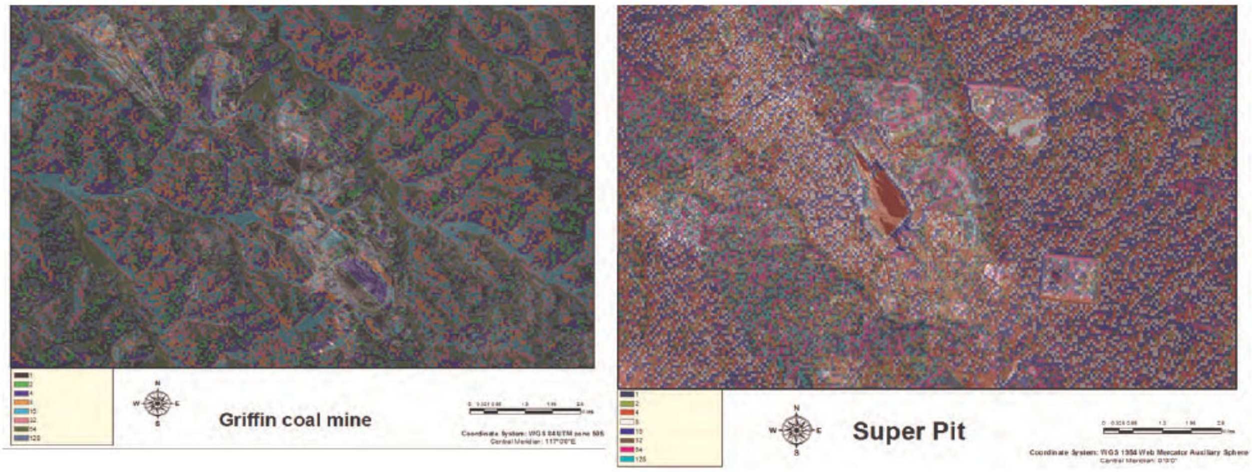


**FIG 5** – Flow direction of two mining areas.

After the generation of flow direction, the next step is the construction of flow accumulation to visualise the flow. The purpose of flow accumulation is to create a raster of accumulated flow into each cell. The result of flow accumulation is a raster of accumulated flow to each cell, as determined by accumulating the weight for all cells that flow into each down slope cell. Figure 5 is the computation from flow direction to flow accumulation. The left image shows the direction of travel from each cell and the right one is the number of cells that flow into each cell.

For the process of flow accumulation, the input surface raster is the result that is created by flow direction. Figure 6 is the result of flow accumulation. From Figure 6 it can be seen that two unclear main streams have been generated based on the calculation of floating point. To better visualise it, the logarithmic function in raster calculator is used to adjust the range of values of raster data. In this way more small streams can be processed which is shown in Figure 7.

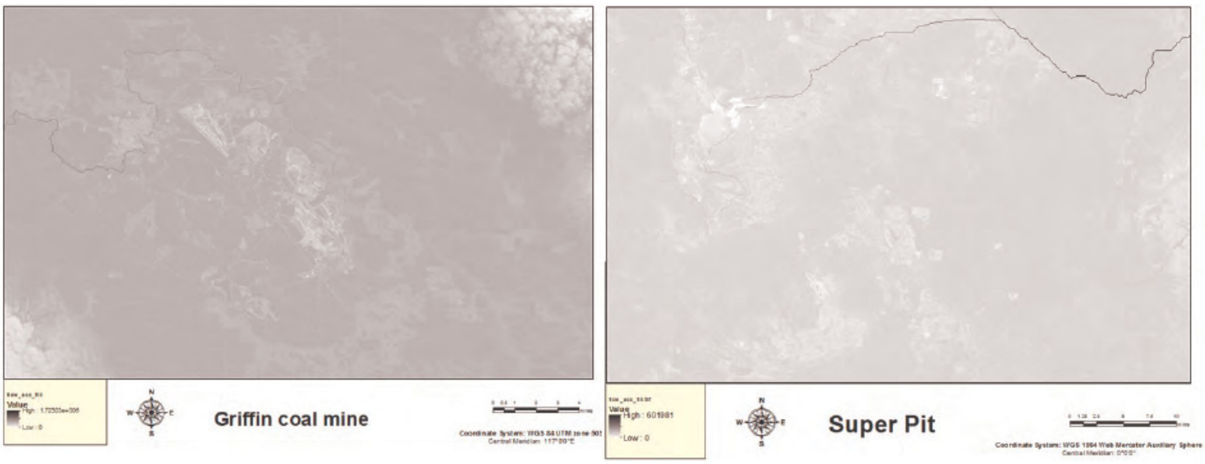


**FIG 6** – Flow accumulation of two mining areas.

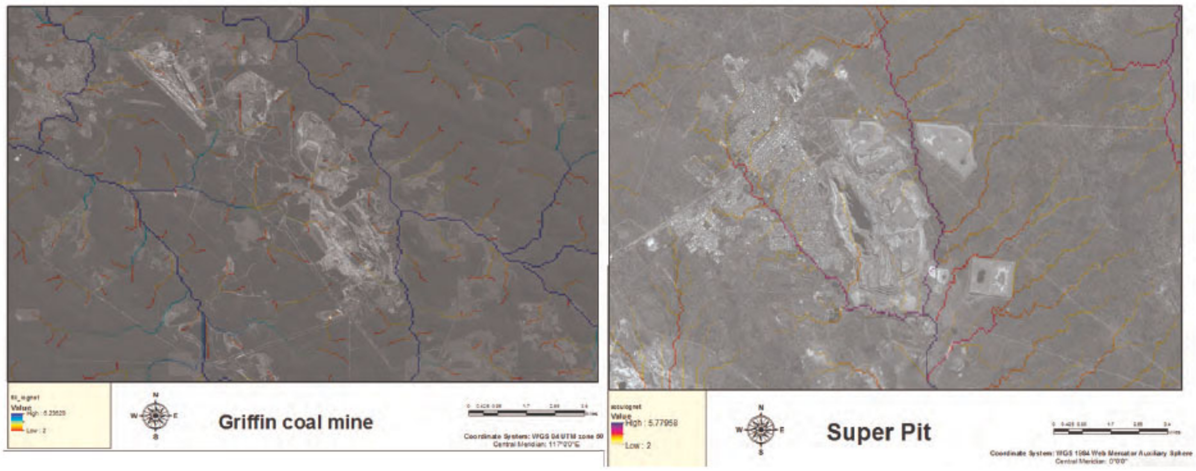


**FIG 7** – Flow accumulation network of Griffin coalmine and Super Pit.

Figure 7 shows the flow accumulation network of the Griffin coalmine and the Super Pit. Figure 8 shows realistic drainage networks with persistent structure are built and the logarithmic flow accumulation layout creates more detailed streams.

From Figure 8, the similarity between the stream generated by ArcMap and the real condition (red and blue arrows) are quite acceptable. Although the mountain shadowing problem of SRTM may cause some differences, the variations are mainly shown in the turnaround of streams.

## Stream order analysis

The last step is to construct the stream distribution around mining areas. The stream order function assigns a numeric order to segments of a raster representing branches of a linear network.

To construct a higher quality output of stream order, the input stream raster should be the flow accumulation network and the flow direction, which are derived from the same surface. Also in the section of the flow accumulation network, the stream network raster has set the value of 100 or more, so it is better to visualise the streams with higher flow accumulation value. The layouts of stream order sequence around the Super Pit and Griffin coalmine have been shown in Figure 9. At this stage, only the stream order values greater than three have been displayed as to better analyse the impact of water systems.

From Figure 9, it is observed that the Griffin coalmine has more streams that have accompanied with higher stream order than the Super Pit. Besides, as the arrows are pointing, there is a sixth order stream (green colour) passing through the coal mining areas and some lower order streams

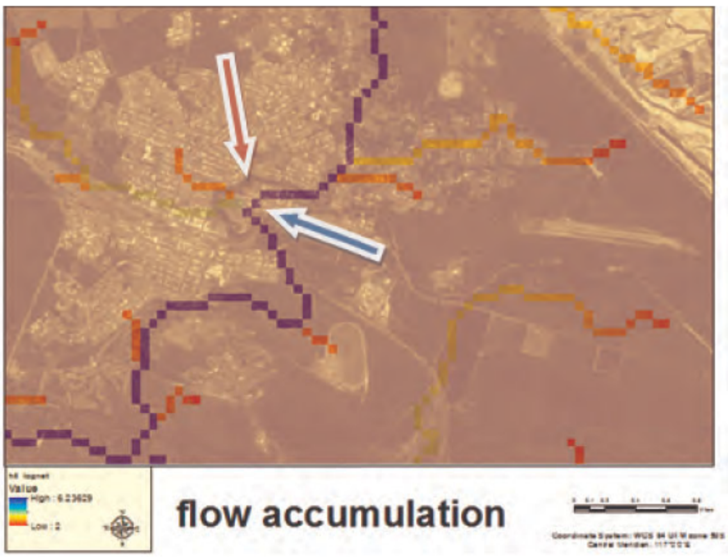


**FIG 8** – Flow accumulation comparison with land satellite imagery.

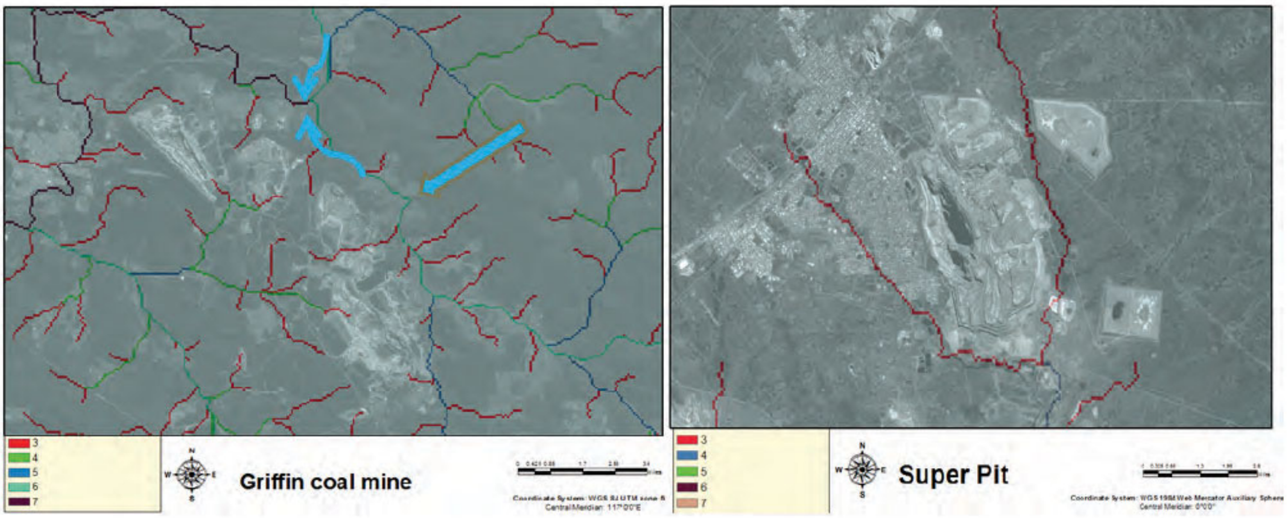


**FIG 9** – Stream order distribution around Griffin coalmine and Super Pit.

are distributed around the pit. Meanwhile, two six order streams are joined to form seven order stream in the north of open pit. In comparison, the Super Pit has only two third order streams and both of them are far from mining areas.

Based on the description of Cocks *et al* (2009), the Super Pit would not experience water flooding situations because the water drainage system has been updated and helps the mine to collect the rainfall. Compared to the Super Pit, the flow system at the Griffin coalmine is more complicated and risky if the rainfall suddenly increases and the groundwater cannot be drained effectively. The run-off water may infiltrate into the soil and affect slope stability of the highwall. Therefore, the theoretical morphometric approach can be applied for the Griffin coalmine.

## Bi-furcation and drainage density analysis

After the stream order analysis, the morphometric theory is used to identify the stream characteristics around the Griffin coalmine. The first approach is to use bi-furcation ratio. The bi-furcation ratio is used to express the ratio of the number of streams of any given order to the number of streams in next higher order. The equation is shown as:

$$R_b = \frac{N_{u-1}}{N_u}$$

where:

$R_b$ = bi-furcation ratio

$N_u$ = stream segment order

The other approach is drainage density. Drainage density shows the closeness of spacing of channels. Based on the result of drainage density, the subsoil structure can be estimated. The equation of drainage density is:

$$D = \frac{L_u}{A}$$

where:

$L_u$ = total stream length

$A$ = area

The total stream length is a significant hydrological feature of a basin as it reveals surface run-off characteristics of relatively smaller streams (Figure 10). Smaller lengths are characteristics of areas with larger slopes and longer lengths occur due to flatter gradients.

Table 1 shows the result of bi-furcation ratios and drainage densities. The average bi-furcation ratio is calculated as 3.2 and the average drainage density is 10 km/m$^{2.}$

According to Strahler (1964), bi-furcation ratios characteristically range between 3.0 and 5.0 for basins in which the geological structures do not distort the drainage pattern. But the bi-furcation

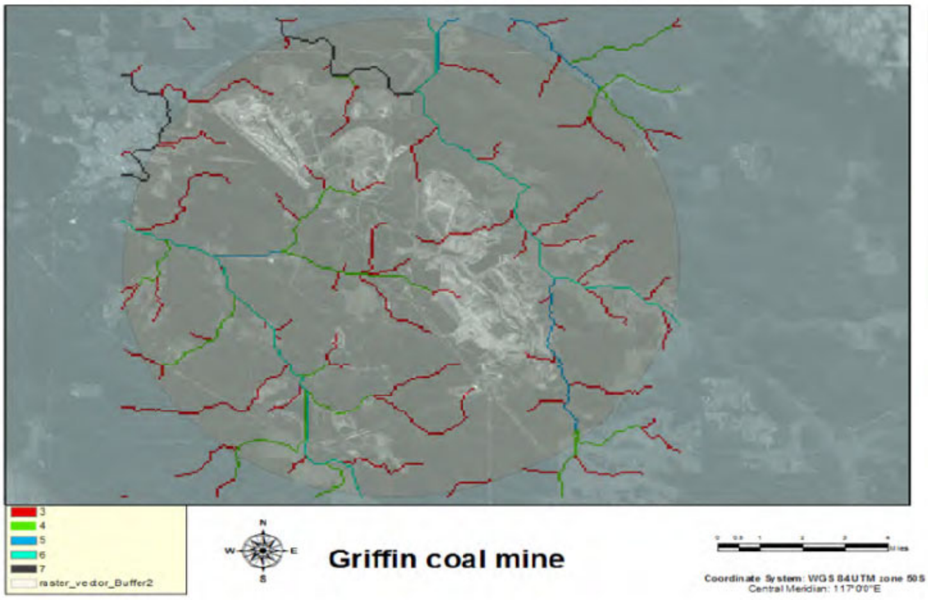


**FIG 10** – Five $km^2$ buffer zone around Griffin coalmine.

ratios of fourth, sixth and seventh order do not fall within the standard range and indicate that the area does not conform to the characteristics of a natural stream which suggests that the geological structures are interrupting the drainage pattern. Deviation from the characteristic range indicates that the terrain is characterised by variation in lithology and topography.

The drainage density of Griffin coal (value: 10), which is high compared to the study of Nageswara, Swarna and Arun (2010). The comparatively high value indicates that the subsurface material is impermeable and vegetation in the basin is sparse. Therefore, the surface structure around Griffin coalmine is rocky, which is good for the water drainage. In the heavy rainfall season, increasing the number of pumps and some water catchments are recommended to avoid pit lake formation.

## CONCLUSIONS

The morphometric parameters evaluated using GIS helped in understanding various terrain parameters such as nature of the bedrock, infiltration capacity, run-off, etc. Similar studies in conjunction with high resolution satellite data will help in better understanding of the landforms and their processes and drainage pattern demarcations surrounding an open pit area for water structure planning and management. Watershed management is one of the most important aspects of mine planning for its successful implementation during development and operational stages.

**TABLE 1**

Result of bi-furcation ratio and drainage density.

| Stream order | Stream length (km) | Stream number | Bi-furcation ratio |
|---|---|---|---|
| 1 | 404 | 1000 | |
| 2 | 181 | 350 | 2.9 |
| 3 | 107 | 80 | 4.4 |
| 4 | 41.7 | 14 | 5.7 |
| 5 | 14 | 4 | 3.5 |
| 6 | 30 | 3 | 1.3 |
| 7 | 13.1 | 2 | 1.5 |
| Total value | 790.8 | 1098 | |
| Mean value | | | 3.2 |
| Drainage density | 10 | | |

The present study demonstrates the usefulness of GIS for morphometric analysis with respect to hydrologic response of the mining area. Morphometric parameters can help in the decision-making process for water resources management. By understanding the morphological parameters, appropriate attention can be paid towards soil conservation and flood control measures during rainy season.

The two case study mines, Griffin coalmine (Collie) and Super Pit (Kalgoorlie) are located in two different climates. The Super Pit is unlikely to have water flooding issues as only a few lower order streams are present there. The Griffin coalmine also has negligible infiltration. The second and third order streams may cause inundation in the mine due to their bi-furcation ratios lying between three and five. The high drainage density and bi-furcation ratio show the water will flow out of the pit. Inducing advanced drainage pattern like clean run-off catchment boundary, tailings storage facility area and water management dam in suitable locations around the pit may be useful.

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