Recharge Flooding

Eelco Lukas[1], Danie Vermeulen[1]

[1]*Institute for Groundwater Studies, University of the Free State, Bloemfontein, 9301, South Africa*

Abstract

Many mines in South Africa and other parts of the world have altered the local geology by extracting the coal seams. The change in geology also changed the geohydrology. Voids are left to fill with water. Partly from surface- and stormwater, but most will be groundwater. In geohydrology, it is termed the mine recharge. The recharge depends on several factors, ranging from the mining methods to geological settings.

This paper will discuss an extension developed for WISH (Windows Interpretation System for Hydrogeologists) that simulates the recharge and flooding of the mine workings and identify the areas where water will collect.

Introduction

Recharge and mine flooding (opencast or underground) occurs in every minethat intersects the watertable. Recharge is a natural process and is a phenomenon that can occur at different rates over the full extent of the mine. Many factors influence the recharge, such as rainfall and rainfall intensity, surface topography, depth of mining, geological structures, presence of subsidence, surface structures, and the state of rehabilitation in case of an opencast mine. Given the same annual rainfall, the volume of recharge water will continue to grow while the mine is further developed.

Traditional recharge calculations are performed over the entire extent of a mine. The calculations result in a single value of recharge for the combined workings. However, only having a recharge volume value does not give the complete picture of the water distribution in a mine. It does not specify which compartments or parts of the compartments are flooded first. Changing the recharge volume calculation to a per depression calculation establishes a distributed flooding method. The total amount of recharge water is still the same, but the places where the flooding starts are now distributed over the entire surface.

Flooding an underground mine through of recharge is very slow. The speed at which this happens is highly dependent on the permeability of the overlying strata. Table 1 below summarises the current understanding of this phenomenon for the Mpumalanga Coalfield (Vermeulen *et al*. 2006; Hodgson *et al*. 1995). The Time-to-Fill column indicates the time it will take for the underground to flood when assuming a mining height of 3 m, an extraction rate of 66% and an annual rainfall of 1000 mm.

Recharge water, also called *water-make*, entering the mine cavity will be collected in small floor depressions. If the recharge is low, the small amounts of infiltrating water will evaporate, even before it accumulates on the floor and is transported by the ventilation system to the surface. When the recharge is higher than the evaporation, the volume of mine water will grow and slowly finds its way towards the deeper (lower) parts of the mine floor. This raises the question, which sections will stay accessible, and which sections will flood?

Methodology

For a surface depression to exist, the depression needs to have a deepest point. It is possible for a surface depression to have more than one deepest point, but only when there is no rise in the surface between these points.

Puddles of water, *or water bodies*, will always start their existence and are always centred around the deepest (or lowest) points in the surface depressions. It is also possible to turn this statement around. Every lowest point (or cluster of lowest points) will have a single water body. Therefore, a water body

Table 1 Expected recharge per mining method at the Mpumalanga Coalfield.

Mining Method	Recharge as a percentage of the annual rainfall	Time to fill in Years
Shallow Bord-and-Pillar	6 – 9 %	22.2 – 33.3
Deep Bord-and-Pillar	1 – 4 %	50.0 – 200
Partial Stooping	4 – 9 %	22.2 – 50.0
Total Extraction	6 – 13 %	15.4 – 33.3
Longwall / Shortwall	15 – 20 %	10.0 - 13.3

will always be associated with the lowest point. Different parts of the surface, *let's call them elements*, may drain towards different depressions. Those parts of the surface where water flows towards the same depression are part of the same waterbody, even if they are not flooded. To make things easier, all water intercepted by the surface drains towards the same depression and attributes to the waterbody. It is, therefore, possible to calculate the volumes of water consisting of intercepted rain for each waterbody. Although it is needed to calculate the amount of water that falls on the individual surface elements, we focus on the total volumes of the water bodies.

WISH (Lukas, 2012) has the functionality to create 3-D surfaces. These 3-D surfaces can be created using the topographic surface, a geological formation, a lithological layer, the floor of a mine cavity or even the roof of the mine cavity. WISH uses Triangular Irregular Networks (TINs) to describe the surface. A TIN consists of nodes and elements to describe a surface. Nodes of the TIN are fixed in a horizontal plane but can be adjusted vertically.

The process of creating the water bodies starts with the identification of the recharge nodes on the surface. The recharge nodes are those nodes where the water starts accumulating on a surface. Nodes connected to this node will all have higher surface elevations. Due to the undulating nature of a typical mine floor, many recharge nodes will be identified. Each node and element will have a recharge node assigned. Simply put, the recharge node is the node where water would flow to when it is allowed to flow freely. The recharge node is not necessarily the deepest or lowest node of the TIN, but it will be the lowest node in a depression. Figure 1 displays a part of a mine floor with random colours assigned to the water bodies. A square indicates the lowest node for each water body.

When the recharge nodes are identified, the (potential) water bodies are created. The waterbody consists of all the nodes and elements that drain towards the recharge node. The amount of precipitation intercepted by each triangle (element) is calculated, then multiplied by the recharge factor and totalled for the elements draining towards the same water body and transferred to the recharge nodes.

All the depressions are described as (possible) water bodies and placed in a list. There is no preference to which water body comes first. Starting with the first water body in the list, the adjacent water body with the lowest connection is determined. This connection is also the maximum water level elevation used to compute the water holding capacity of the depression. When the volume of recharge water is less than the capacity, the water body is filled with available water. When the volume of recharge water exceeds capacity, the depression is filled to the maximum level. Because water will start to overflow, all the excess recharge water will be added to the recharge water of the connected water body. The water added to the water body is subtracted from the recharge water. If the water level in the connected body is at the same level, the two water bodies are merged. The following water body in the list is selected, and the process starts over again. After all water bodies in the list are processed, we start over from the beginning of the list. Water bodies without any recharge water left are skipped. The simulation finishes when all recharge water is transferred into the waterbodies.

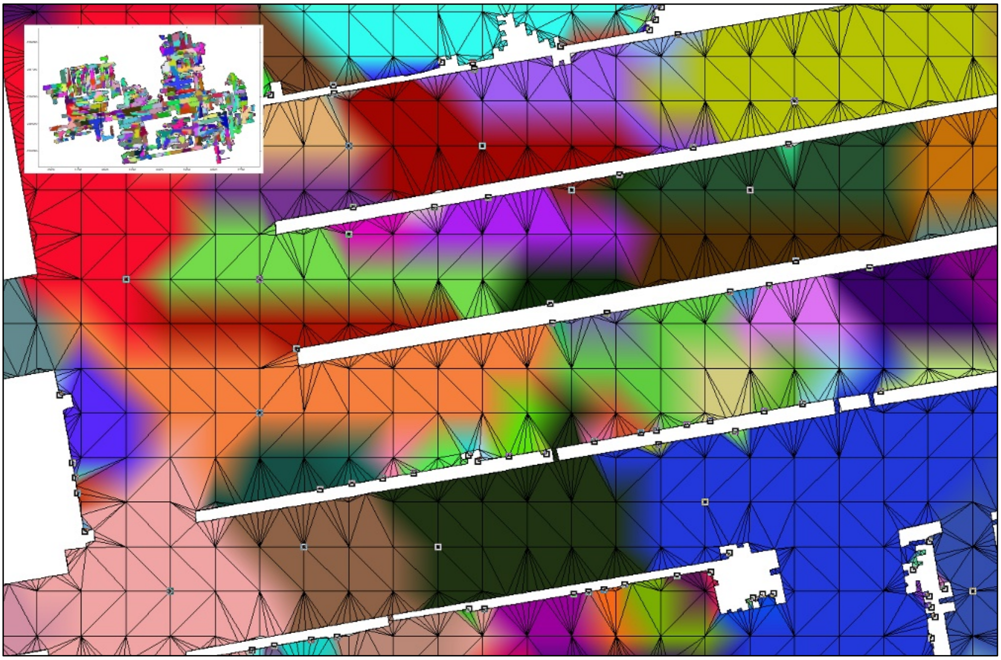

Figure 1 *Depressions in a mine floor using random colours; a square indicates the lowest node.*

Results

The mine used in the study is fictive. The mine's layout is a combination of several existing underground workings, as are the surface- and the mine floor contours. The site is situated in the Mpumalanga Province. The total footprint of the mine is 1560 ha. The mine area is a gently flowing surface with an average elevation of around 1750 mamsl, an average mining depth of 100 m and an extraction rate of 72%. Four rainfall scenarios were tested from a low rainfall of 250 mm to a high rainfall of 2000 mm.

A TIN was created using a 60 m nodal distance (42835 nodes and 47045 elements). Figures 2 and 3 below show the mine's topographic surface and mine floor in 3D, the depth of mining (or roof thickness), the areas used to assign the recharge rates and the final floor geometry with the recharge rates and the individual area sizes. The sizes were used to calculate an expected recharge volume.

Table 2 shows the results of the four flooding scenarios after applying water to the surface and the water has found its resting place. It shows the expected recharge, as calculated by WISH, the recharge after the simulation is completed, the difference

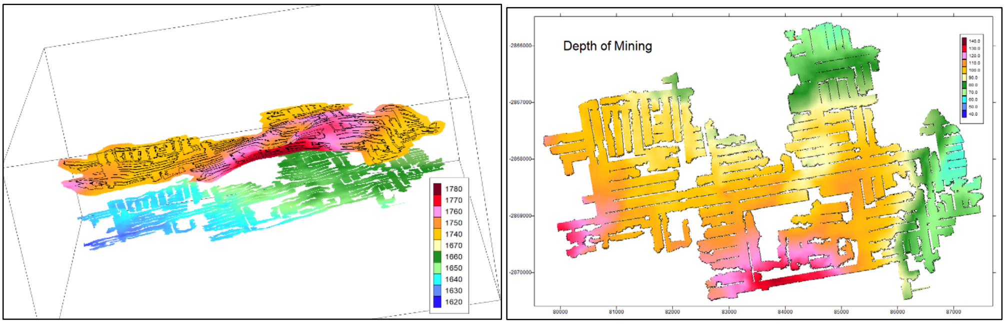

Figure 2 *Surface and floor; Depth of mining.*

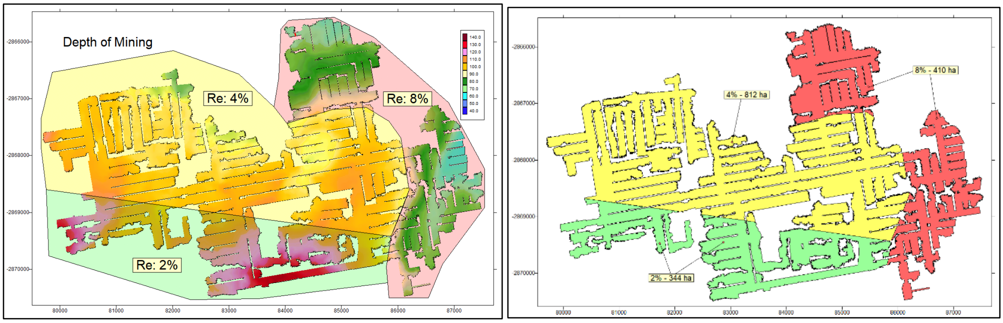

Figure 3 *Assigning recharge rates; Area sizes per recharge rate.*

Table 2 *Simulation result in numbers.*

Rainfall [mm]	Recharge Expected [m^3]	Recharge Simulated. [m^3]	Difference [m^3] (%)	Flooded area [ha]	Water-bodies Left #	Iterations # (Cycles #)
100	72542	72532	-9.8 (0%)	140.5	2333	4902 (21)
500	362710	362690	-20 (0%)	272.2	1993	5657 (25)
1000	725422	725572	+151 (0%)	358.7	1846	5982 (32)
2000	1450843	1450561	-282 (0%)	451.9	1688	6536 (72)

between the expected and simulated recharge in cubic metres and a percentage of the predicted recharge, the total area flooded, the number of water bodies left and the number of iterations it took as well as the number of times simulation needed to go through the list of water bodies.

Although the method described above calculates the distribution for the entire workings, this method can also be applied for a small part of the mine. In such a case, only the small part will have recharge factors assigned, while the remainder of the workings will have a zero (0) recharge rate. WISH calculates the water distribution in that part of the mine and any recharge water spillage into the remainder of the mine. Knowledge about the volume of water spilt and where it flows is essential for the safety of the workers underground. When the spillage is little, water will evaporate and be removed by the ventilation system. When the spillage becomes substantial, the mine may decide to build a water retaining wall to keep the active workings dry.

Table 3 lists the progress of the recharging simulation. During the first pass through the list with waterbodies, almost half of all expected recharge water is transferred to the waterbodies.

The first pass also resulted in 3002 iterations (the number of water bodies in the list). Many of the water bodies were filled to the brim, and the overflow nodes and target waterbodies were identified. The second pass had 850 iterations (3852-3002), only those water bodies with capacity left were visited, and 301 water bodies were merged. During

Table 3 *Simulation progress – 100 mm of rainfall.*

Cycle	Expected Recharge [m^3]	Simulated Recharge [m^3]	Difference [m^3]	Difference [%]	# WB	Iterations
1	72542.1	31528.2	41014.0	56.5	3002	3002 (3002)
2	72542.1	45970.1	26572.1	36.6	2701	850 (3852)
3	72542.1	50801.9	21740.3	30.0	2591	382 (4234)
…						
19	72542.1	72402.4	139.8	0.2	2336	2 (4898)
20	72542.1	72523.3	18.8	0.0	2334	3 (4901)
21	72542.1	72532.3	9.8	0.0	2333	1 (4902)

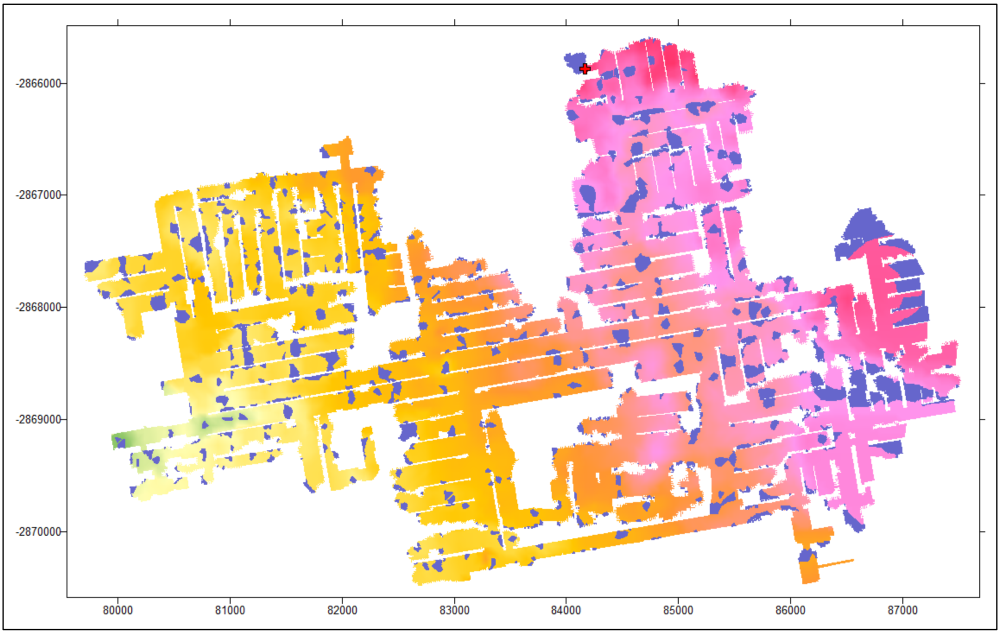

Figure 4 *Rainfall 0.10 m – 72532m³ in 5397 iterations.*

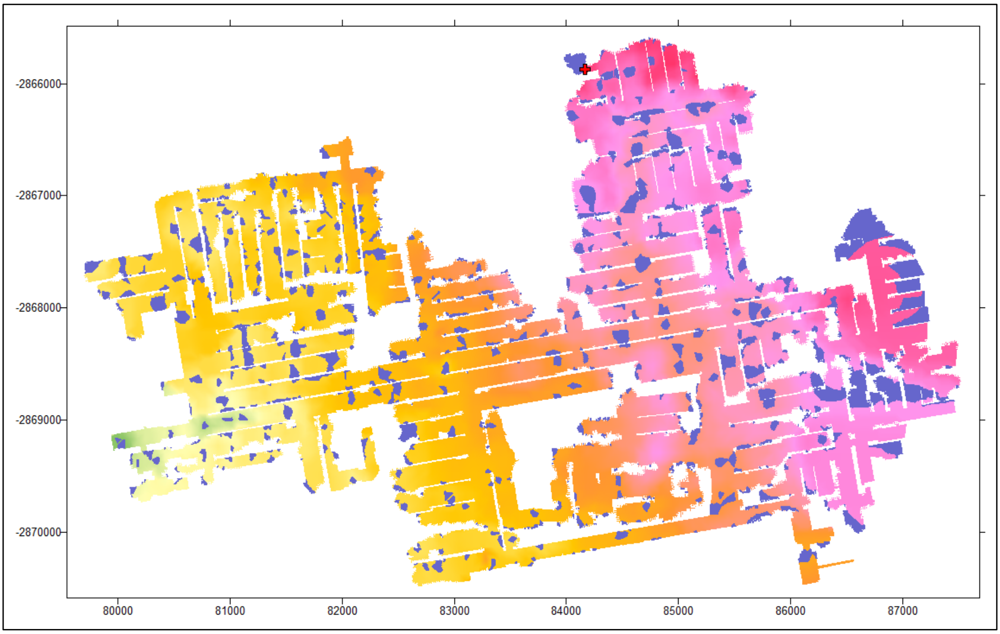

Figure 5 *Rainfall 0.5 m – 362690 m³ in 4902 iterations.*

the third pass, another 110 water bodies combined and the error between the volume that must be recharged and the amount already in the water bodies declined to 30%. After the 21st pass, the absolute difference between expected and simulated recharge is smaller than 10 m³, there are 2333 water bodies left (669 were merged), and the simulation took 4902 iterations. Figures 4 to 7 show the result of flooding after 100, 500, 1000 and 2000 mm rainfall.

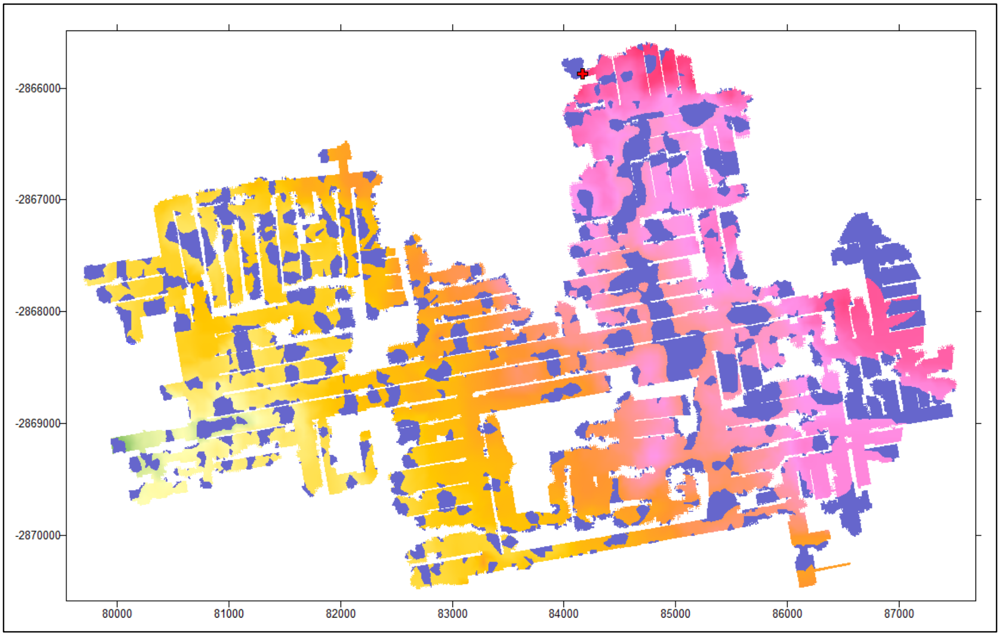

***Figure 6** Rainfall 1.0 m – 725572 m^3 in 5982 iterations.*

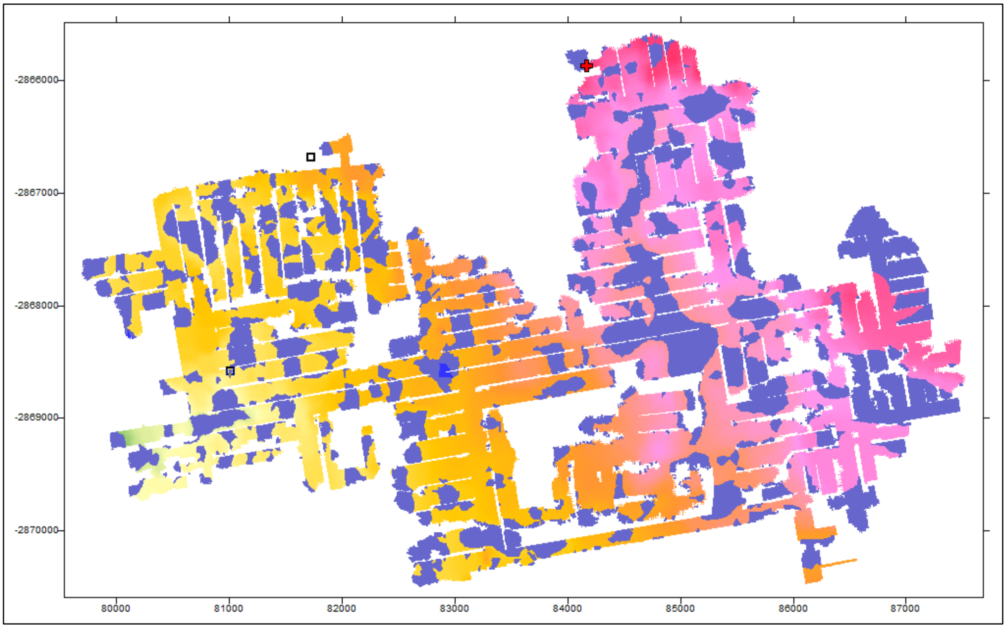

***Figure 7** Rainfall 2.0 m – 1450561m^3 in 6536 iterations.*

Using the same flooding technique, it is possible to simulate a calamity-flooding by "releasing" a large volume of water in a single water body and calculating the overflow into the adjacent water bodies. An example of a calamity-flooding can be the failure of a water-retaining wall.

The flooding simulation software relies heavily on the data available from the mine and the expertise of the geohydrologists concerning the recharge rates. The new simulation software can be used not only during the planning stages but also during the development of the mine to determine the placing of transport belts and which roads can be used as escape routes in case of flooding and ultimately save equipment and lives.

Conclusion

The software described here can be used to predict the locations on a surface where water may accumulate, and it will indicate which sections will stay accessible and which will flood.

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