WISH as a water management tool in opencast and underground collieries

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Declaration

I hereby declare that this dissertation submitted for the degree *Magister Scientiae* in the Faculty of Natural and Agricultural Sciences, Institute for Groundwater Studies, University of the Free State, Bloemfontein, South Africa, is my own work and have not been submitted to any other institution of higher education. I further declare that all sources cited or quoted are indicated and acknowledged by means of a list of references.

Signed ____________________ Date 14/05/2012

E. Lukas

Acknowledgements

This project was only possible with the co-operation of many individuals. I wish to record my sincere thanks to the following:

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- Special thanks to my Mother and my Mother-in-law for their prayers and support.

In remembrance of

Antonie Lukas 09/10/1928 – 12/02/2006

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List of Abbreviations

Abbreviation	Explanation
%	Percentage
ARD	Acid Rock Drainage
CAD	Computer Aided Design
DWA	Department of Water Affairs
EPA	Environmental Protection Agency
EU	European Union
GIS	Geographical Information System
GUI	Graphical User Interface
ha	Hectare (10000 square metres)
IGS	Institute for Groundwater Studies
m	metres
mamsl	Metre above mean sea level
meq/l	Milliequivalent per litre
mg/l	Milligram/litre
Ml	Mega litre (10^6 litre)
Mm3	Mega cubic metre (10^6 cubic metre)
mm	Millimetre
m^2/d	Square metres per day
m^3/d	Cubic metres per day
mS/m	Milli-Siemens per metre
NGDB	National Groundwater Data Base
l/s	Litre per second
LOM	Life of Mine
LQD	Lowest quantity Detected
Q	Flowrate
S	Storativity
SANS	South African National Standard
T	Transmissivitty
TIN	Triangular Irregular Network
US	United States
USGS	United States Geological Survey
WACCMAN	WAter aCCounting & MANagement
WGS84	World Geodetic System 1984
WCP	Water Control Point
WHO	World Health Organisation
WISH	Window Interpretation System for the Hydrogeologyst
Extension	Software
Shp	ArcGIS (Esri)
Dxf	AutoCAD
Dgn	Microstation
Ws2	WISH
Bmp; Jpg; Tif	Bitmap files.

Chapter 1 Introduction

In the early eighties the Institute for Groundwater Studies (IGS) was commissioned to develop South Africa's national groundwater database also called the NGDB (Kirchner, Morris and Cogho, 1987). The NGDB was developed on a mainframe computer and was located at the Department of Water Affairs (DWA) head office in Pretoria. The NGDB could only be accessed by DWA head office in Pretoria and the subsidiary offices in the provinces. The private sector was not allowed to use the NGDB other than through the DWA. In the second half of the same decennium Professor Frank Hodgson decided to recreate the NGDB as a MS-DOS based program. MS-DOS is an operating system developed by the Micrsosoft Cooperation (Duncan, 1988). This program, called HydroCom, was aimed at the private sector and consisted of HydroBase, the database, and HydroCad for the mapping and graphing of data. After the introduction of Microsoft Windows and the Microsoft Office software the reasoning behind HydroCom changed, the database front-end and the Dbase database were dropped in favour of Microsoft Access and Microsoft Excel. The mapping and graphing part was re-written for MS Windows and the Windows Interpretation System for the Hydrogeologist (WISH) was born. During the next 15 years WISH was re-written twice and evolved in a comprehensive groundwater management tool, capable querying data from the database and plotting maps or graphs including time related or depth related and specialised graphs.

WISH is currently used in many opencast and underground mines throughout South Africa and abroad.

1.1 Objectives / scope of work

The objective of this study is to determine the applicability of WISH as a (ground)water management tool taking in account the following properties:

- Groundwater elevations
- Hydrochemistry
- Geology
- Borehole construction
- Water balances
- Mapping
- Data entering and editing
- Reporting

1.2 Structure of the thesis

This thesis starts off in chapter 2 with a literature review in the form of an Introduction into the capability of different geo-hydrological software packages followed by an in-depth description off WISH in chapter 3. Chapter 4 explains in detail the steps that need to be followed to create a WISH file. Chapter 5 is a discussion about the recharge and decanting of open cast and underground mines this is followed by a chapter explaining the WISH file creation for the included case study. The last chapter in this dissertation focusses on an actual case study.

Chapter 2 Review of literature

Software used as a water management tool in opencast and underground collieries must have support build in for at least the following five major subjects:

- Time series evaluation
- Mine water quality
- Life of Mine
- Water balance

At the end of this chapter a comprehensive internet study on the available software is compressed in a six page table.

2.1 Time series evaluation

Parameters measured, like chemistry and water levels will change during the lifetime of a mine. Support for these time dependant is necessary not only on the map but also in graphs.

2.2 Mine water quality

Mining method, location and geology are the main contributors when it comes to mine water quality. This can best be illustrated by looking at the individual constituents expected in the water according to Hodgson and Lukas (2011):

- Calcium and magnesium are primary constituents that occur as dolomitic lime amongst grains in sandstone and shale, and in cracks in coal. These are normally released very slowly by dissolving into groundwater. A much faster release stems from its reaction with acid mine water. The dolomitic lime buffers the mine water from acidification at a pH of 6.5 until the lime is exhausted. Thereafter, the pH of the mine water will drop. Typical concentrations from this source are 200 – 300 mg/l calcium and 100 – 150 mg/l magnesium.
- Sodium and chloride occurs abundantly in the shale of the Free State Coalfields. Shale in its natural state is impermeable to water flow. When it is fractured in areas of high extraction, then sodium and chloride is released into the water. Typical concentrations are 300 – 600 mg/l sodium, and 200 – 500 mg/l chloride. Associated with this is a very high alkalinity (300 – 500 mg/l as $CaCO_3$), thus raising the pH of the water to between 8.0 – 8.5.
- Pyrite requires oxygen and moisture for oxidation. Unflooded underground workings are therefore ideal breeding grounds for pyrite oxidation. This releases sulphate, iron and manganese into the water. Some sulphate precipitation could occur depending on calcium concentrations in the water. Under anaerobic conditions such as flooded mine workings, most of the manganese and iron will remain in solution. Typical concentrations for these constituents could be 1 500 – 2 500 mg/l sulphate; 1 – 10 mg/l manganese and 1 – 100 mg/l iron.
- Fluoride is a constituent common to the Free State coalfields. Concentrations in groundwater are commonly between 2 – 6 mg/l fluoride.

- Buffering of the mine water against acidification occurs at several levels, firstly by the sodium alkalinity, then by the calcium/magnesium alkalinity. Only when these agents are exhausted, will the pH drop to 3.5 – 4.2.
- By flooding mine workings with water, most of the oxygen is excluded. It is only the newly recharged water that contains dissolved oxygen (<14 mg/l). The latter is too little to have any significant impact on pyrite oxidation.
- Water recharged from surface is regarded as relatively clean at the moment of entry into the ground.

2.3 Life of Mine

Life of Mine (LOM) and scheduling is an integral part of the whole mining plan. The LOM is the future layout of the mine with information on what block is mined during what period. A detailed LOM shows schedules in a month resolution. To create a LOM a good understanding of the geology is needed. This includes knowledge of the overlaying strata, to decide if high extraction is an option, the grade, or expected quality, of the coal to be mined. The grade of coal is not constant for the entire mine and the mixing of coal is a proven method to keep the coal at a more or less constant quality. As mining progresses more knowledge about the geology becomes available. This together with the availability of other resources like machinery (draglines, shovels, continues miners) and people may result in a change layout and scheduling. A LOM will change several times during the existence of the mine. In some cases it may even change more than ones every year.

2.4 Water balance

A water balance for a mine is a balance between the water flowing into the mine. Table 2-1 list some possible water sources entering and leaving the mine.

Table 2-1: Possible water sources entering and leaving the mine.

Water entering the mine	Water leaving the mine
Recharge from rainfall	Evapotranspiration
Lateral flow from surrounding formation	Lateral flow into surrounding formation
Pumping	Pumping
Run-off	Decanting
	Process water (dust suppression, coal washing, drilling, sanitary needs

Although the process waters do not account for huge amounts of water they still are part of the complete water balance.

2.4.1 Underground mines

Given enough time, every underground mine will fill up with water. The rate at which this happens depends on the geology and the availability of water in the overlaying strata (Vermeulen and Usher, 2006). Although every mine needs a certain amount of water to operate, inflow of water into the mine cavity during the operational time of the mine can be a burden. Water entering the mining cavity is assumed to be mine water and the mining company is required to treat any water, independent of the water quality, before releasing in a stream or river (DWAF, 2007). This results in a need for a larger capacity treatment plant.

From a water management point of view the ideal situation would be a shaft build at the highest point in the floor contour of the mine creating first the major haul ways to the deepest points of the mine. As mining continues excess water can be stored in mined areas not being a threat to people or equipment.

Unfortunately this utopia does not exist because economics does not allow this. The next best option is to mine in such way that each section is mined from a higher elevation to a lower elevation creating compartments where water may be stored. Many times even this is not possible due to relatively horizontal seams or geological restraints. In cases like this compartments, for water storage, can still be created by building artificial seals.

Ventilation walls in older underground workings were built from brick and mortar. These walls are strong and act often not only as a ventilation wall but also as a water retaining barrier or seal, compartmentalising the underground. These "seals" are not reliable as they are not designed to withstand the water pressure. The walls may collapse without warning.

2.4.2 Opencast mines

Every opencast mine will receive water from precipitation and almost every rehabilitated opencast mine will decant. The percentage of the rainfall that is recharged into the rehabilitated opencast is depending on:

- The slope of the rehabilitated pit and its direct surroundings.
- The thickness and composition of the topsoil.
- The vegetation of the rehabilitation and its direct surroundings.
- The amount rainfall and intensity of the rainfall events.
- The size of the ramps and the final voids

To estimate the recharge on a rehabilitated opencast the industry relies on the values supplied by Hodgson and Krantz (Table 2-2).

Table 2-2: Water recharge-characteristics for opencast mining in the Mpumalanga area (Hodgson and Krantz, 1998).

Water source	**Water into opencast [% rainfall]**	**Suggested average value [% rainfall]**
Rain onto ramps and voids	20 – 100	70
Rain onto not rehabilitated spoils	30 – 80	60
Rain onto levelled spoils (run-off)	3- 7	5
Rain onto levelled spoils (Seepage)	15 – 30	20
Rain onto rehabilitated spoils (run-off)	5- 15	10
Rain onto rehabilitated spoils (seepage)	5 – 10	8
	[% of total pit water]	**[% of total pit water]**
Surface run-off from pit surroundings	5 – 15	6
Groundwater seepage	2 – 15	10

2.5 Computer software

Water management on a colliery, or anywhere else, is never done by a computer program alone but specialised hydrogeological software can assist the groundwater professional in performing his duties. Many different hydro-geological software packages exist, some of them are of a specialised nature while others are more comprehensive in their features.

Existing hydrogeological software may be divided into six main categories:

- Database
- Aquifer and pumping test
- Geophysical
- Geochemical
- GIS
- Modelling

Research on the internet for “Groundwater Software” delivered about 33900 hits (Google.com 2011/08/08). Paging through the results showed that there are only a few hydrogeological software companies (or sellers) available on the internet. The largest of these are:

- Schlumberger Water Services
- GroundwaterSoftware
- Rockware
- Scientific Software Group
- United States Geological Survey (USGS)

A total of 131 different software packages were found. More than half (68) of these packages are modelling programs or related to modelling programs. Many other software packages were also found on the mentioned websites. Software not specifically related to the hydrogeology field or specialist hardware drivers (interface software to allow interaction between equipment and computer software), these software packages are not mentioned. Examples are: ArcGIS extensions and CAD Software, driver monitoring software. A substantial amount of MODFLOW add-ons were also found, as they are specifically designed for one modelling package they were also filtered.

GoldSym is another product that is used throughout the mining fraternity, but this package is a box model not capable of doing any interpolation. Its usefulness lies in process management.

The easiest way to determine the functionality needed in the software is to step through the process of setting-up a groundwater management system for an underground or opencast colliery.

The different software packages found are listed in Table 2-5.

Using the sections listed in Table 2-3 only 5 software packages scored more than five hits. Only one scored points in all functionalities.

Table 2-3: Action and functionality needed.

Action	Functionality Needed
A locality map must be generated.	Site Maps
Mine outlines need to be imported (making sure these are polygons)	Site Maps
Digitizing maps (When electronic data is not available)	Digitizing
Monitoring positions and collected field data must be entered in the data base.	Data Base
Spatial analysis may be performed	Site Maps / 3D Views
Chemical analysis needed	Chemical diagrams
Time series analysis must be performed	Time Series Analysis
Standards must be enabled	Standard comparison
Average values, Maximum values and percentiles	Statistics
Borehole logs must be entered	Hydrogeological logs
Contours from surface and coal seams must be generated	Contours and Sections / 3D Views
Section must be generated	Contours and Sections
Hydraulic parameter determination	Pumping test
Stage curves	volume calculations
LOM and scheduling information	volume calculations

Table 2-4: Source column in software comparison table

Source	Source URL
1	http://www.Groundwatersoftware.com/software.htm
2	http://www.scisoftware.com or http://www.scientificsoftwaregroup.com
3	http://www.swstechnology.com/groundwater-software
4	http://www.rockware.com/home/lobbyAll.php
5	http://water.usgs.gov/software/lists/groundwater/
6	http://www.ribeka.com/webstruct_en/products/OurProducts.php
7	http://www.argusint.com
8	http://www.geotech.com/envirodata.htm
9	http://www.feflow.info
10	http://www.aquaveo.com
11	http://www.mikebydhi.com
12	http://www.enviroinsite.com/index.html

Table 2-5: Software comparison.

Software Name	Source	DataBase	Pumping test Analysis	Digitizing	Site Maps / Spatial Analysis	3D Graphics / View	Spec. Chemical Diagrams	Time Series Analysis	Statistics	Standards Comparison	Hydrogeological logs	Contours and Sections	Volume Calculations	Completely Editable Map	Other	ARC GIS	RISK Assessment	Modelling Flow	Modelling Transport	Modelling Multi Species	Bioventing /bioslurping
A																					
AHGW	2															•		•	•		
AIRSLUG	5		•																		
AnalyzeHole	5	Excel									•							•	•		
AqQA	4						•	•													
Aqtesolv	4	Proprietary	•																		
Aqtestss	5	Excel	•																		
Aqua 3D	2					•												•	•		
AquaChem	3,4	Access			•		•	•	•	•											
Aquifer Win32	1,2,4		•			•								•							
AquiferTest Pro	3,4		•																		
AquiPack	2	Excel	•																		
Argus ONE	2,7					•						•				•		•	•		
B																					
Bat3 Analyzer	5																	•	•		
BIOF&T	2																	•	•		•
BIOMOC	5																	•	•	•	•
Bioslurp	2																	•	•		•
BioSVE	2																				•
C																					
ChemFlux	2																		•		
ChemGraph	2	Access			•	•	•	•													
ChemPoint / ChemStat	2	Not Specified			•				•		•										
Conduit Flow Process	5																	•			
D																					
Ddestimate	5	Excel	•																		
Didger	1			•										•							
E																					
Enviro Data	2,8	Access / SQL			•			•		•	•					•					
Enviro-Base Pro	3	Not Specified								•											
EnviroInsite	12	User defined			•	•	•	•	•		•	•		•							
EQuIS Geology / EQuIS Chemistry	2				•						•										
Extractor	5																	•			
F																					
FEFLOW	1,9													•				•	•		
Flash	5														•						
FRAC3DVS	3																	•	•		
G																					
Gflow	2																	•			
Grapher	1							•	•												
Groundwater Modelling System	2,10					•						•		•		•	•	•	•		
Groundwater Vista	1,2,4																•	•	•		
GSFlow	5																	•			
GW_Chart	5						•											•	•		
GW Contour	3											•									
GW-Arc	6															•					
GW-Base	6				•			•	•	•		•									
GW-Bore	6				•						•	•									
GW-Mobil	6														•						
GW-Web	6														•						
GWM-2000 & GWM-2005	5																	•			

Continued…

Software Name	Short Description
A	
AHGW	Arc Hydro Groundwater - Geo database design for representing data with ArcGIS
AIRSLUG	Air-pressurized slug tests
AnalyzeHole	Integrated Wellbore Flow Analysis Tool (flow and transport in wells & aquifer systems)
AqQA	Plot chemical diagrams (Piper, Stiff, Ternary, Durov)
Aqtesolv	Spreadsheets for the Analysis of Aquifer-Test and Slug-Test Data
Aqtestss	Several spreadsheets for the analysis of aquifer-test and slug-test data
Aqua 3D	3D Flow and transport model
AquaChem	Comprehensive package for water chemistry
Aquifer Win32	Analysis of Pumping Tests and Slug Tests
AquiferTest Pro	Pumping tests and slug testing
AquiPack	Excel based spreadsheet solution
Argus ONE[2]	A finite element and finite difference numerical pre-processor
B	
Bat3 Analyzer	Real-Time Data Display and Interpretation Software for BAT3
BIOF&T	2D/3D biodegradation/bioremediation flow & transport model
BIOMOC	A multispecies solute-transport model with biodegradation
Bioslurp	An aerial finite-element model to simulate three-phase flow/transport
BioSVE	A screening tool that incorporates soil vapour extraction (SVE)
C	
ChemFlux	Contaminant transport modelling software
ChemGraph	Environmental database (*Specialised Chem diagrams: Only STIFF*)
ChemPoint / ChemStat	Environmental sampling database
Conduit Flow Process	Conduit Flow Process for MODFLOW
D	
Ddestimate	A spreadsheet application for simulating time series and estimating drawdowns.
Didger	Digitizing software
E	
Enviro Data	Database for Environmental data
Enviro-Base Pro	Environmental database only – no interpretation
EnviroInsite	Environmental data visualisation wit strong geology and chemistry
EQuIS Geology / EQuIS Chemistry	Strong geology orientation
Extractor	Extracts data from MODFLOW head or drawdown files or from MODFLOW-GWT
F	
FEFLOW	2D & 3D Flow and transport model
Flash	Excel Based Program for Flow-Log Analysis of Single Holes (VERTICAL FLOW)
FRAC3DVS	3D finite element model steady-state or transient GW flow / transport
G	
Gflow	A stepwise groundwater flow modelling system
Grapher	Line, 2D & 3D Graphs
Groundwater Modelling System	2D/3D Finite element / finite difference pre-processor
Groundwater Vista	2D/3D MODFLOW Flow and MT3D Transport
GSFlow	Coupled Groundwater Surface water flow model based on PRMS and MODFLOW
GW_Chart	Graphing application for MODFLOW, SUTRA, MT3D, HST3D and more. Draws Piper diagrams
GW Contour	Finite element program that simulates multiphase flow and transport
GW-Arc	The Interface between GW-Base 8.0 and ArcGIS/ArcMap for advanced GIS Evaluations
GW-Base	Groundwater Database (Note: Works in Gauss-Krueger or UTM coordinates)
GW-Bore	Manage Borehole and Well Completion Data in GW-Base and visualize it with GW-Bore
GW-Mobil	Data acquisition in the field on a handheld computer (PDA)
GW-Web	With GW-Web your Ground Water Data goes online.
GWM-2000 & GWM-2005	Groundwater management process for MODFLOW

Continued…

Software Name	Source	DataBase	Pumping test Analysis	Digitizing	Site Maps / Spatial Analysis	3D Graphics / View	Spec. Chemical Diagrams	Time Series Analysis	Statistics	Standards Comparison	Hydrogeological logs	Contours and Sections	Volume Calculations	Completely Editable Map	Other	ARC GIS	RISK Assessment	Modelling Flow	Modelling Transport	Modelling Multi Species	Bioventing /bioslurping
H																					
HST 3D	5																	•	•		
HUFPrint	5														•						
Hydro GeoAnalyst	3	Excel/Access/S			•	•					•	•						•			
Hydro GeoBuilder	3					•												•			
HydrogeoChem	2																	•	•	•	
HydrogeoChem2	2																	•	•	•	
Hydrotherm	5																	•	•		
Hydrus 3D Aquifer Chemistry	1																	•	•		
HYDRUS	1																	•	•		
HYSEP	5														•						
I																					
INFIL 3.0	5														•						
Infinite Extent	2		•																		
L																					
LogPlot7	3										•										
M																					
MapViewer	1				•																
MARS 2D/3D	2																	•	•		
MF2K-FMP	5																	•			
MF2K-GWT	5																	•	•		
MF2K-VSF	5																	•			
MIDUSS	1,2														•						
Mike SHE	11																				
MINTEQA2 for Windows	2																	•	•		
MOCDENSE	2,5																	•	•		
ModelMate	5																	•	•		
ModelMuse	5																	•	•		
Model Viewer	5					•												•			
MODFE	5																	•			
MODFLOW SURFACT	1,2,3				•	•												•	•		
Modflow-GUI	5																	•	•		
MODOPTIM	5														•						
MODPATH	2				•														•		
MOFAT	2																	•	•		
MOVER	2																	•	•		
MT3D99	3				•	•						•						•	•		
OPR-PPR	5														•						
P																					
PART	5														•						
PEST	2																	•	•		
PHAST	5																	•	•	•	
PHREEQC	5																			•	
Phreeqcl	5																			•	
PHRQCGRF	5																			•	
PMWin	2				•							•		•				•	•		
Pocket ESA	1														•		•				
Pocket Winlog	1									•					•						
Pollute	1																		•		
PRMS	5														•						
PULSE	5														•						

Continued…

Software Name	Short Description
H	
HST 3D	Three-dimensional flow, heat, and solute transport model
HUFPrint	Tabulation and visualization utility for Hydrogeologic-Unit Flow Package of MODFLOW
Hydro GeoAnalyst	Groundwater, Borehole, and Hydrogeologic Interpretation and Data Management Software
Hydro GeoBuilder	Conceptual model development for FEFLOW and MODFLOW
HydrogeoChem	A coupled model of hydrologic transport and geochemical reactions
HydrogeoChem2	Same as above but now multispecies-multicomponent
Hydrotherm	3D finite-difference model to simulate multiphase GW flow and heat transport
Hydrus 3D Aquifer Chemistry[1]	Graphical Analysis of Geochemical Data
HYDRUS[1]	2D/3D Flow and Transport Model
HYSEP	Hydrograph Separation Program
I	
INFIL 3.0	A grid-based, distributed-parameter watershed model to estimate net infiltration below root zone
Infinite Extent	Pump test analysis software
L	
LogPlot7	Strip log plotting for environmental/petroleum and mining industries
M	
MapViewer	Link data to areas or points on a map
MARS 2D/3D	Groundwater multiphase areal remediation simulation model
MF2K-FMP	Farm Process: Estimate supply-and-demand components of irrigated agriculture
MF2K-GWT	3D GW flow and solute-transport model integrated with MODFLOW-2000
MF2K-VSF	3D finite-difference GW model (MODFLOW 2000) with variably saturated flow
MIDUSS	Simulation and design of storm water management systems
Mike by DHI	Integrated modelling of groundwater, surface water, recharge and evapotranspiration
MINTEQA2 for Windows	Windows version of EPA geochemical speciation model
MOCDENSE	A variable density GW flow and solute transport model
ModelMate	A GUI for model analysis. ModelMate supports UCODE, MODFLOW and ModelMuse.
ModelMuse	A Graphical User Interface for MODFLOW-2005, MODFLOW-LGR, and PHAST
Model Viewer	Model Viewer is a program that displays the results of three-dimensional gw models
MODFE	Modular finite-element model for areal and axisymmetric GW flow problems
MODFLOW SURFACT	2D/3D MODFLOW flow and transport
Modflow-GUI	Graphical Pre- and post-processor for MODFLOW, MOC3D, MF2K-GWT, MT3DMS + more
MODOPTIM	Optimization SW for GW Flow Model Calibration & GW Management in MODFLOW
MODPATH	Particle tracking post-processor for MODFLOW
MOFAT	Multiphase (water,oil,gas) flow and multi-component transport model
MOVER	An three phase finite element model for LNAPL and water recovery
MT3D99	3D mass transport model (advection, dispersion, chemical reactions)
OPR-PPR	A Linear Statistics Program for Assessing Data Importance to Model Predictions
P	
PART	A computerized method of base-flow-record estimation
PEST	Non-Linear parameter estimation software for any numerical model
PHAST	Simlulating GW flow, solute transport, and multicomponent geochemical reactions
PHREEQC	Program for Speciation, Batch-Reaction, 1D Transport, and Inverse Geochemical Calc.
PhreeqcI	Graphical user interface for PHREEQC
PHRQCGRF	Program for Graphical Interpretation of PHREEQC Geochemical Transport Simulations
PMWin	A graphical interface for MODFLOW/MODPATH/PMPATH/PEST......
Pocket ESA	Phase I Environmental Site Assessments
Pocket Winlog	Handheld PC Boring Log and Borehole Data Collection
Pollute	2D Analytical Transport Model
PRMS	Precipitation-Runoff Modeling System
PULSE	Model-Estimated GW Recharge and Hydrograph of GW Discharge to a Stream

Continued…

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R																					
RBCA Tier 2 Analyzer	1,3																	•	•		
RBCA Toolkit for Chemical Releases	1																•				
RECESS	5														•						
RISC5	1																•				
RockWorks	3				•	•					•	•			•						
RORA	5														•						
R-UNSAT	5																		•		
S																					
SEAWAT	5																	•	•		
SEVIEW	1																	•	•		
SHARP	5																	•	•		
Single Well Solutions	1		•																		
SLAEM/MLEAM	2																	•			
SOILPARA	2														•						
SOLUTRANS	2																	•	•		
StepMaster	2		•																		
STLK1 and STWT1	5														•						
Strater	1										•										
Super Slug	2		•																		
Surfer	1,4					•						•	•	•							
SUTRA	2																	•	•		
SVFlux	2																	•	•		
SVHEAT 2D/3D	2																	•	•		
T																					
Tecplot	1					•									•						
TopoDrive and ParticleFlow	5																	•	•		
U																					
UnSat Suite Plus	3																	•			
Utility PIEs	5				•																
V																					
Visual Groundwater	5				•	•					•	•						•	•		
Visual HELP	3														•						
Visual MODFLOW	3				•	•												•	•		
Visual PEST	3																	•	•		
Visual RBCA Toolkit	1																•				
Visual Site Manager	1				•	•		•			•	•		•							
Voxler	1					•															
VS2DH / VS2DI / VS2DT	5																	•	•		
W																					
WellCAD	4										•										
WinFence	1											•									
WinLog	1										•										
WinSieve	1														•						
WISH	***IGS-UFS***	***Excel /Access***	•	•	•	•	•	•	•	•	•	•	•	•							
WMS	2				•	•						•									
WTAQ	5		•																		
Z																					
ZoneConc	5							•											•		

Continued…

Software Name	Short Description
R	
RBCA Tier 2 Analyzer	Risk Based Corrective Action - 2D Analytical Flow and Num. Transport
RBCA Toolkit for Chemical Releases	Risk Based Corrective Action - Risk Assessment
RECESS	A computer program for analysis of streamflow recession
RISC5	Human Health and Ecological Risk Assessment
RockWorks	Integrated geological data analysis, management and visualisation
RORA	The recession-curve-displacement method for estimating recharge
R-UNSAT	Reactive, multispecies transport in a heterogeneous, variably-saturated porous media
S	
SEAWAT	A computer program for simulation of 3D variable-density GW flow and transport
SEVIEW	SESOIL & AT123D (Fate and Transport Modeling)
SHARP	Quasi 3D finite difference model to simulate freshwater / saltwater flow
Single Well Solutions	Slugtest and Single Well Test Analysis
SLAEM/MLEAM	Regional GW model in confined, unconfined and leaky aquifers
SOILPARA	Soil parameter estimation
SOLUTRANS	3D Analytical solute transport model
StepMaster	Aquifer step drawdown test analysis
STLK1 and STWT1	Computer programs for analysis of hydraulic interaction of stream-aquifer systems
Strater	Well Log and Borehole Plotting
Super Slug	Slug test analysis software
Surfer	2D Contouring Software (3D perspective plots)
SUTRA	A 2D GW saturated-unsaturated transport model
SVFlux	Finite element seepage analysis software (2D/3D flow analysis)
SVHEAT 2D/3D	Finite element heat transfer (geothermal) software
T	
Tecplot	A powerful and versatile Visualization Tool for 2D and 3D
TopoDrive and ParticleFlow	2 Models for Simulation & Visualization GW Flow and Fluid Particles Transport in 2D
U	
UnSat Suite Plus	1D unsaturated zone GW flow and contaminant transport
Utility PIEs	Programs for simplifying the analysis of geographic information in U.S.G.S GW models
V	
Visual Groundwater	Enhanced MODFLOW engine with sat/unsat & transport capabilities
Visual HELP	Hydrological modelling software for landfill design and evaluation
Visual MODFLOW	3D GW flow and transport modelling software
Visual PEST	Non-Linear parameter estimation software for any numerical model
Visual RBCA Toolkit	Risk Based Corrective Action - Risk assessment modelling environment
Visual Site Manager	A full-featured environmental database
Voxler[1]	3D Graphics & Animation
VS2DH / VS2DI / VS2DT	Model for simulating water flow and energy transport in variably saturated porous media
W	
WellCAD	
WinFence[1]	Graphically create cross-sections and fence diagrams
WinLog[1]	Creates, edits and prints a variety of borehole and well logs
WinSieve[1]	Enter, edit & print grain size analysis charts
WISH	***Windows Interpretation System for the Hydro-geologist***
WMS	
WTAQ	Program calc. drawdowns & estimating hydraulic properties for confined & water-table aquifers
Z	
ZoneConc	Postprocessor that tabulates concentration stats from data generated by MODFLOW-GWT

Chapter 3 What is WISH

WISH, or the Windows Interpretation System for the Hydrogeologist, is a computer program capable of displaying thematic maps with data and graphs depicting the data in a more specialized way.

WISH consists of:

- A mapping / graphing facility
- A link to data sets

The mapping facility enables drafting and displaying of maps. By linking data sets databases containing hydro-geological data may be superimposed on the map. The databases can be either in Microsoft Excel or Microsoft Access format.

Many data interpretation options are included:

- Time series analysis
- Specialised chemical diagrams
- Pumping test analysis
- Hydrogeological logs.
- Spatial analysis (using point data on a map or plotting point data as contours)

Water balance calculations

- Volume calculations
- Stage curves

WISH was developed especially for the hydrogeologist. WISH is a hybrid between a CAD system, a Geographical Information System, Chemical analysis package, pumping test programs and all other programs a Hydrogeologist will use. Although many of these programs are of a specialist nature and are very powerful, it is the combination that makes WISH unique.

3.1 Overview of the Graphical User Interface

The Graphical User Interface (GUI) is that part of WISH that interacts with the user. When WISH starts the main screen, an empty page, is displayed. This is the location where the actual map is drawn. In Figure 3-1 an overview of the WISH screen is displayed. The main window displays the map and will also be the location where graphs are displayed. On the left hand side of the main window is the property window also called the property pane. This is the window where the document-, layer- or item properties are displayed. The layer control is located on the right hand side. Note that in Figure 3-1 these windows are fixed to the frame (docked). The windows may be enlarged or reduced in width. It is also possible to un-dock these windows, to move them around and dock them at a different location. The two toolbars are visible just above the main window and the property window. The status bar can be found at the bottom of the screen. The status bar will keep the user informed about the status of WISH. When moving the mouse around co-ordinates are continuously updated on the right side of the statusbar. When working in geodetic co-ordinates (latitude / longitude) the current topographic map number is also displayed.

WISH can be operated in two different modes:

- Data Mode (default)
- Design Mode

In design mode the user is allowed to modify the map, to add and remove layers and map items. In data mode the user can interrogate the data, data points may be added, changed or removed from selected datasets and maps and other graphs may be created. In this mode the map is completely locked no alterations to any items other than the datapoints are possible. The user can switch between the two modes using the button. (Button 9 from the upper toolbar Figure 3-2.)

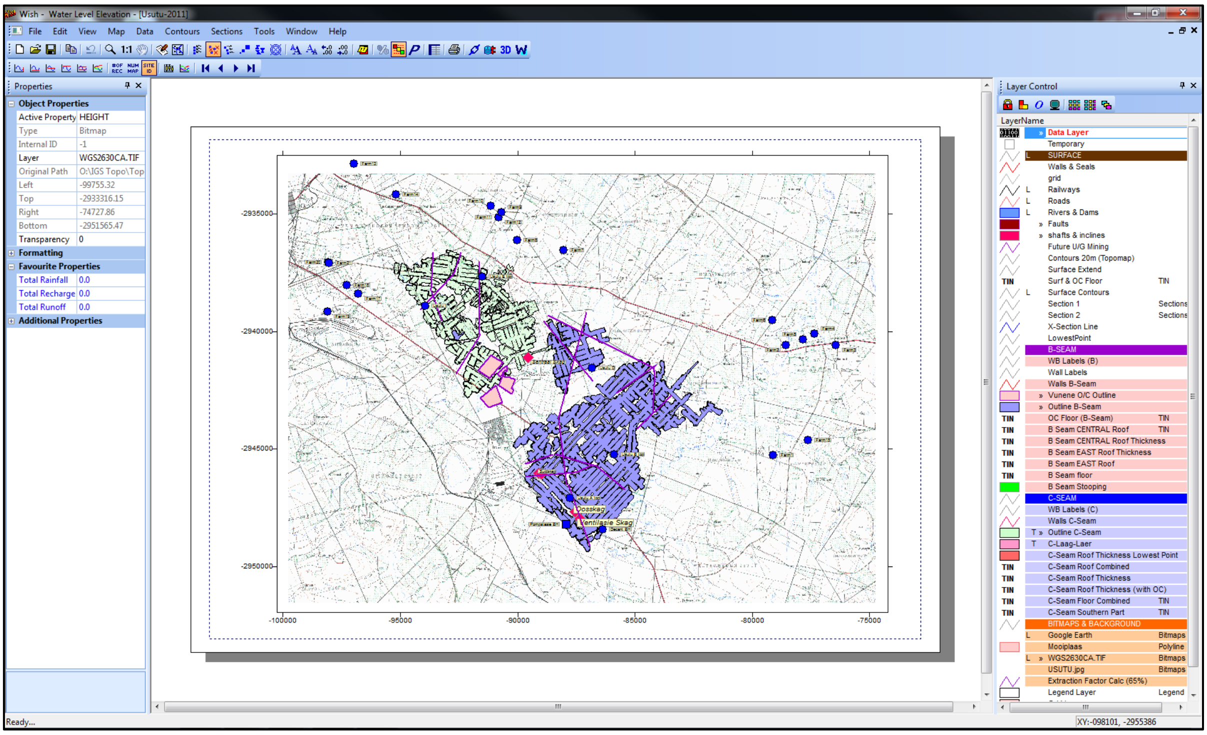


Figure 3-1: Overview of the GUI.

3.2 The toolbar

The toolbar is the strip at the top of the WISH window that contains iconic buttons. Each of these buttons executes a command when clicked on. WISH has two toolbars the upper toolbar supporting general commands (Figure 3-2) and the lower context sensitive toolbar (Figure 3-3). This toolbar will change depending on the functions available for selected data type or selected map item.

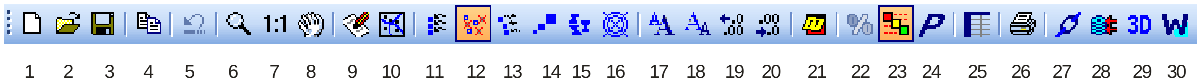


Figure 3-2: The upper toolbar.

Key to Figure 3-2.

1. Create a new WISH document
2. Open existing WISH document
3. Save current WISH file
4. Copy
5. Undo last change
6. Zoom in and out
7. Zoom to full extent
8. Pan WISH document
9. Toggle Data / Design mode
10. Redraw map
11. Site selection dialog
12. Hide unselected points
13. Hide / show data point labels
14. Fixed / Variable data point size
15. STIFF points
16. Radial points
17. Increase data point label font
18. Decrease data point label font
19. Increase number of decimal positions
20. Decrease number of decimal positions
21. Apply date-filter
22. Percentiles
23. Standards
24. Select parameter
25. Data grid
26. Print
27. Link to other WISH file
28. Capture current view
29. 3D View
30. WACCMAN

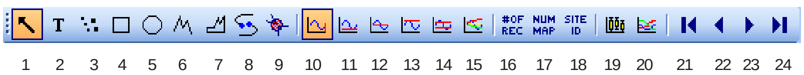


Figure 3-3: The lower (context sensitive) toolbar.

Key to Figure 3-3.

1. Select tool
2. Text
3. Points
4. Rectangles
5. Ellipse / Circle
6. Polyline
7. Polygon
8. Merge polylines
9. Enable snap
10. Display last value measured
11. Display minimum value measured
12. Display average value measured
13. Display maximum value measured
14. Display standard deviation
15. Display trend analysis
16. Display number of records
17. Display number on map
18. Display site name
19. Draw a box- and whisker plot
20. Draw a time graph
21. Display first record / page
22. Display previous record / page
23. Display next record / page
24. Display last record / page

3.3 The map

The mapping facility enables drafting and displaying of maps. In addition to global settings the map consists of a layer-list, where all the layers are defined. The layers in the layer-list are always drawn from the bottom layer to the top layer. Layers may be added to the list or deleted from it. Layers can be moved up and down in the list and may be switched on or off. Every layer has its own item list. The items in these lists are also drawn from bottom to top (or from back to front). The items stored in the layer may be of the following type:

- Point
- Polyline / Polygon
- Rectangle
- Circle / Ellipse
- Text
- Raster (photos and other bitmaps)
- TIN
- Special objects (cross-section, north arrow, scale bar, co-ordinate grid)

The map-items can be added, modified or deleted from the layers. The WISH document structure is displayed in Figure 3-4. The appearance of every item is depending on the formatting applied. The format tells WISH how to draw the item on the map. It contains the following information:

- Fill colour
- Line colour / type / thickness
- Line endpoints (arrows)
- Hatching
- Point type / size
- Font typeface / size / attribute

Every format may be saved in a style for uniformity and rapid assignment.

To create a map from nothing is a timely process. This process can be accelerated by importing existing maps. The different types of files that may be imported are:

- Vector type
    - Shape Files (.shp)
    - AutoCAD (.dxf)
    - Surfer (.bln)
    - Microstation (.dgn)
    - WISH (.ws2)
- Raster files
    - Windows bitmap (.bmp)
    - Jpeg (.jpg)
    - TIFF (.tif)

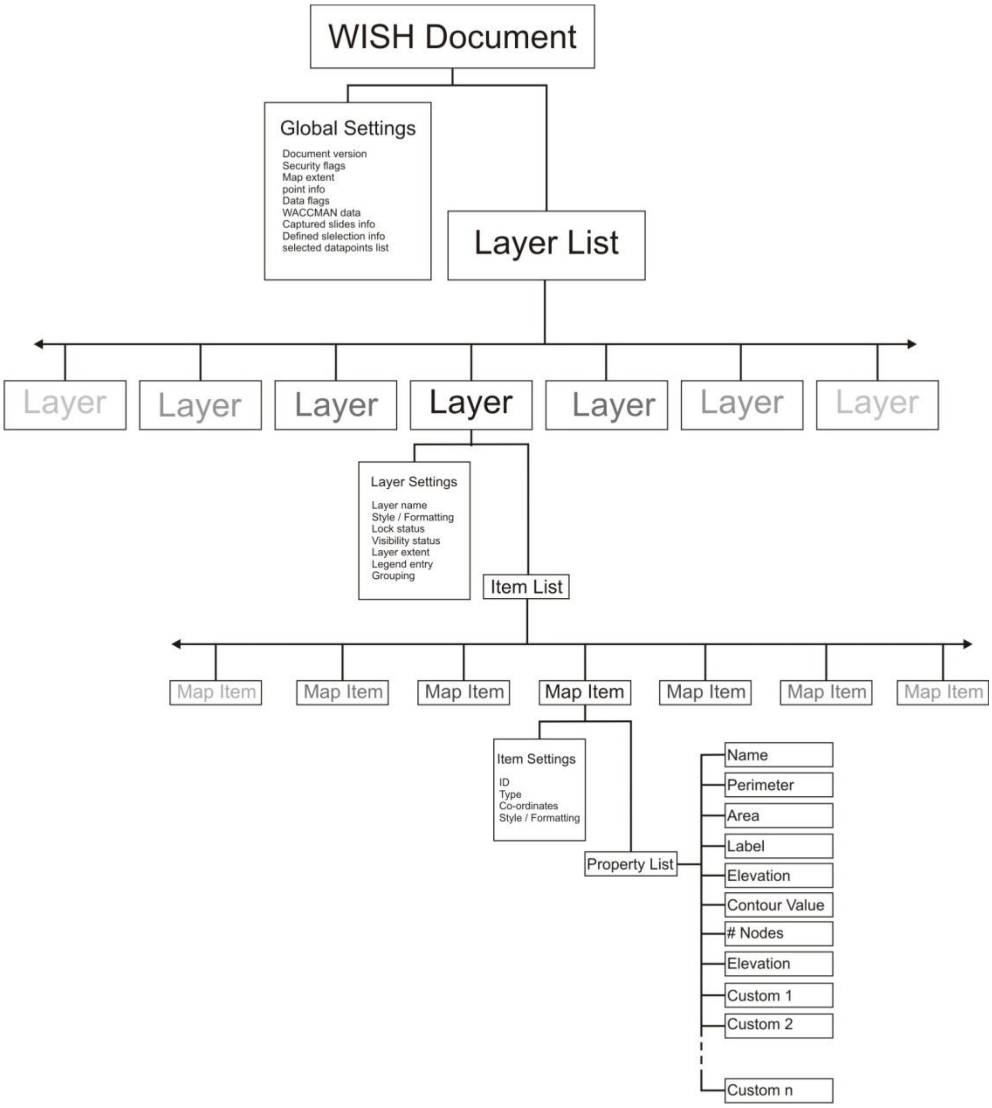


Figure 3-4: WISH Document Structure.

3.4 Contours

A contour in WISH is displayed as a solid surface (as in contrast to a wireframe where only lines are visible). Different contour values are displayed in different colours. A default colour profile is created with warm colours (red, orange) for the high values and cool colours (blue, cyan) for the low values. The profile can be customized, stored and reused on other contours. WISH support two different kinds of contours; grid contours consisting of equally sized and spaced rectangles or contours created from linked arbitrary sized triangles.

3.4.1 Squares

The Grid contours may be invoked from the menu. Grid contours consists out of many little squares. By default a rectangular grid contour, as large as the drawing extent, will be generated. If a polygon is selected, prior to issuing the grid create command, the grid is created inside the selected polygon.

The edges may be jagged depending on the size of the squares and the complexity of the outline. Only one colour is assigned to each rectangle resulting in a "pixelated" contour. To reduce the coarse effect, post contour smoothing options are available.

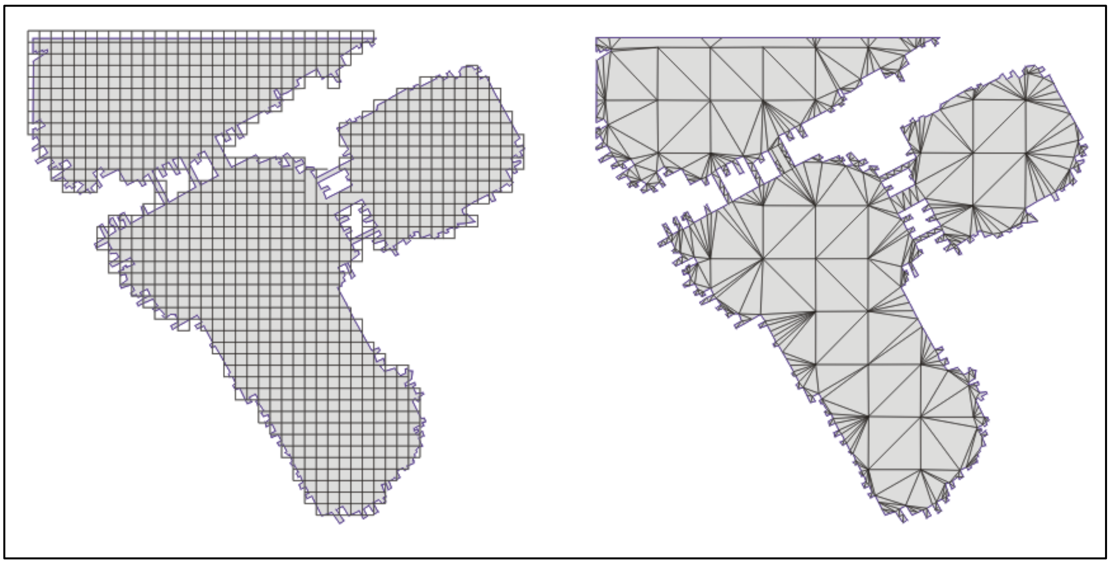


Figure 3-5: Squares vs Triangles.

3.4.2 Triangles

With the very detailed outlines from the underground workings the use of grid contours is not sufficient. Large amounts of detail get lost with the grid contours especially when small barriers are left between compartments. Due to the resolution of the grid two compartments may appear to be connected while in real life they should not. To overcome this shortcoming WISH makes use of TINs (Triangular Irregular Network). A TIN is created by selecting a polygon and selecting the "Create TIN" option. Using this method allows for polygons describing the Mine Lease Areas, opencasts or even complex underground mine cavities to be used as a border for a TIN. The edges of the TIN will follow the outline of the polygon perfectly.

WISH uses the Delaunay triangulation (Delone, 1934) where each node is connected to its nearest neighbour in such way that the vertex forms the side of a triangle. When a circle is constructed through the 3 nodes of the triangle the circle will not contain any other node inside its interior.

A TIN has numerous advantages over the grid contours:

- No jagged edges – the triangles are capable in tracing a polygon resulting in a TIN that fit the polygon like a glove.
- Can be copied to different layers – a TIN can be seen as one entity and can therefore be copied to other layers.
- Calculations between identical TINs are extremely fast – checking properties such as number of nodes, number of triangles and TIN extremities WISH can determine if two TINs are identical. Identical TINs do not use interpolation to determine node values.
- TINs are fixed in position and size.
- TINs do not need to be smoothed.

- A TIN is draws very fast.
- Topographic maps and other bitmaps can be draped over TINs.

A TIN is only a place-holder consisting of triangles without a value. Data must be added after the TIN has been created. Data is not assigned to the individual triangles but to the nodes. When nodes have different values assigned, the triangles are coloured using a gradient fill eliminating the pixilating effect seen in the rectangle grid.

3.5 Data properties

Every item in WISH has properties (data) linked to it. The properties vary from geometric data to storage related properties and even informative properties exist. These properties are displayed in the property window. When maps are imported from a GIS (ArcView and others) using shape files all the properties relating to the items are also imported and stored in the property sheet.

The properties are split into four main categories:

- Object Properties – these are the most important properties, it specifies the type of object, its location in the WISH file, some basic properties (position, perimeter, area) and it allows changing settings depending on the object type.
- Formatting – all items on the map including layers may be formatted here.
- Favourite Properties – any property can be marked as a Favourite Property
- Additional Properties – all other properties.

Like in a GIS, object properties can be added and removed. Properties are of a spatial nature and can include:

- Rainfall
- Owner
- Population
- Land use

Data point properties are not stored in the map but rather in the attached data file.

3.6 The data file

The data linked to a WISH project can be one of the following::

- Excel
- Access
- HydroBase
- AquaBase
- Muniwater

From these five formats the Excel format is the one most widely used. Excel is used to emulate a relational database where each sheet is handled as a table and each column as a field. The data consist of a sheet containing all basic information of each monitoring point and numerous sheets for all the other information. The two types of data that can be gathered for a single monitoring point are time related and depth related data. All time related data is stored in sheets starting with “Time” and all depth related data is stored in sheets starting with “BH”.

3.6.1 Basic information

The basic information (**BasicInf**) sheet is the most important sheet in the whole database. All monitoring sites are defined here. Data stored in the related sheets for sites not defined in **BasicInf** will not be processed! The **BasicInf** sheet has a five required columns:

- *SiteName*
- *Xcoord*
- *Ycoord*
- *Zcoord*
- *Sitetype*

These five columns are mandatory any additional static data may also be stored in this sheet, just add columns as needed.

	A	B	C	D	E	F
1	SiteName	Ycoord	Xcoord	Zcoord	CollarHeigth	SiteType
2	S63	-2928345.00	78506.00	1620.50	0.30	M
3	S01	-2927561.94	79369.87	1620.40	0.30	S
4	S02	-2927536.00	78935.00	1621.00	0.30	S
5	S03	-2929383.00	76453.00	1620.20	0.30	S
6	BH1	-2928263.00	76512.00	1645.50	0.35	B
7	BH2	-2928112.00	77272.00	1638.50	0.35	B
8	BH3	-2928731.00	77414.00	1620.30	0.35	B
9	BH4	-2928952.00	78520.00	1639.00	0.35	B
10	BH5	-2929826.00	79838.00	1677.50	0.35	B
11	D28	-2929358.00	75893.00	1620.20	0.20	P
12	DAM4	-2928235.00	77490.00	1621.00	0.30	P
13	Rain Gauge 1	-2929982.00	76751.00	1639.50	0.75	N
14	Snake River	-2927169.00	79673.00	1620.50	0.30	S
15						
16						
17						

BasicInf / Time Chemistry / Time WL / Time Discharge

Ready 100%

Figure 3-6: Basic Information example.

3.6.2 Time related data

All time related data is stored in sheets starting with the word “Time”. Examples are “Time Chemistry**”** or “Time WL**”**. As many sheets as needed may be added to store the different parameter.

All time sheets need to have the following columns:

- *SiteName*
- *DateTimeMeas*
- The parameter(s) measured

The *SiteName* is the link between the basic information and the time related data. The contents of the *SiteName* field in both the time related data and the basic information must be identical to be a match. The date and time measurement (*DateTimeMeas*) field stores the date and time the measurement was taken and must be entered using Microsoft Excel's date and time format. The parameter measured can either be a single column like WL for water level or Rainfall or any other parameter that is measured in time. Most tables have only one parameter that is measured. The chemistry table has a complete record of all parameters that was analysed for in the laboratory.

3.6.3 Borehole data

Data that is measured down-the-hole like calliper, construction and geology is stored in tables that start with "BH". Examples are: "BH Geology", "BH Diameter" and "BH Yield". Depending on the type of parameter recorded, tables are differently formatted. The most important table in this category is the "BH Geology" as this records the lithology of the borehole. The following columns are listed:

- *SiteName*
- *DateTimeMeas*
- *DepthTop* and *DepthBot*
- *Lithology*
- *Seam*
- *Description* (optional)
- Primary Colour, Secondary Colour, Texture, Primary Feature, Secondary Feature, Feature Attribute, Sorting, Roundness and the different Sieve fractions

The *SiteName* is the link between the basic information and the time related data. The date and time measurement (*DateTimeMeas*) field holds the date and time the measurement was taken and must be entered using Microsoft Excel's date.

The lithology is determined per interval hence a depth to top and a depth to bottom is needed. The lithology is a 4 character code developed for South Africa (Kirchner *et al.,* 1987). A seam name can be entered to differentiate between different coal layers. To enter complete geology records can be very difficult as the primary and secondary colour, texture, primary and secondary feature, feature attribute, sorting and roundness columns must be populated using codes. To sidestep this problem a description column was introduced. The description is plotted as it appears in the Excel file on the borehole log plot. Using this route makes the description non-standard whereas expanded codes always translate to standard sentences. The other tables in this are less complicated. They all have the same columns:

- *SiteName*
- *DateTimeMeas*
- *Depth* or *DepthTop* and *DepthBot*
- Parameter(s) measured

All parameters that are measured over an interval will use the depth to top / depth to bottom parameters measured at a specified depth will use the Depth field.

3.6.4 Pumping test data

Pumping test data may be recorded in this sheet. The pumping test data consists of the following columns:

- *SiteName*
- *ObsSiteName*
- *PumpMethod*
- *DateTimeStart*
- *DateTimeMeas*
- *WaterLevel*
- *PumpRate*

Pumping tests are unique by the *SiteName* and the *DateTimeMeas* as only one pumping test can be performed on a borehole at a given time. The *ObsSiteName* is the borehole used for measurements recorded. The *PumpMethod* is either a “P” for pumped or “R” for recovering (Figure 3-7).

	A	B	C	D	E	F	G
1	SiteName	ObsSiteName	PumpMethod	DateTimeStart	DateTimeMeas	WaterLevel	PumpRate
2	BH1	BH1	P	1998/02/17 08:00	1998/02/17 08:00	20.00	0.00
3	BH1	BH1	P	1998/02/17 08:00	1998/02/17 08:01	20.50	3.00
4	BH1	BH1	P	1998/02/17 08:00	1998/02/17 08:02	21.00	3.00
5	BH1	BH1	P	1998/02/17 08:00	1998/02/17 08:05	22.00	3.00
6	BH1	BH1	P	1998/02/17 08:00	1998/02/17 08:10	23.00	3.00
7	BH1	BH1	P	1998/02/17 08:00	1998/02/17 08:15	23.90	3.00
8	BH1	BH1	P	1998/02/17 08:00	1998/02/17 08:20	24.70	3.00
9	BH1	BH1	P	1998/02/17 08:00	1998/02/17 08:25	25.50	3.00
10	BH1	BH1	P	1998/02/17 08:00	1998/02/17 08:30	26.10	3.00
11	BH1	BH1	P	1998/02/17 08:00	1998/02/17 08:35	26.60	3.00
12	BH1	BH1	P	1998/02/17 08:00	1998/02/17 08:40	27.00	3.00
13	BH1	BH1	P	1998/02/17 08:00	1998/02/17 08:45	27.30	3.00
14	BH1	BH1	P	1998/02/17 08:00	1998/02/17 08:50	27.50	3.00
15	BH1	BH1	P	1998/02/17 08:00	1998/02/17 08:55	27.60	3.00
16	BH1	BH1	P	1998/02/17 08:00	1998/02/17 09:00	27.60	3.00

Figure 3-7: Example of pumptest data.

3.7 Time series analysis

Any parameter entered in the time related sheets may be plotted as a time graph. All time graphs in WISH have a horizontal time axis. When the graph is displayed many option are available to modify the graph and data.

3.7.1 Graph type

WISH support 3 different graph types as a time graph

- Line graph (Figure 3-8).
- Scatter plot (Figure 3-10).
- Bar plot (Figure 3-9).

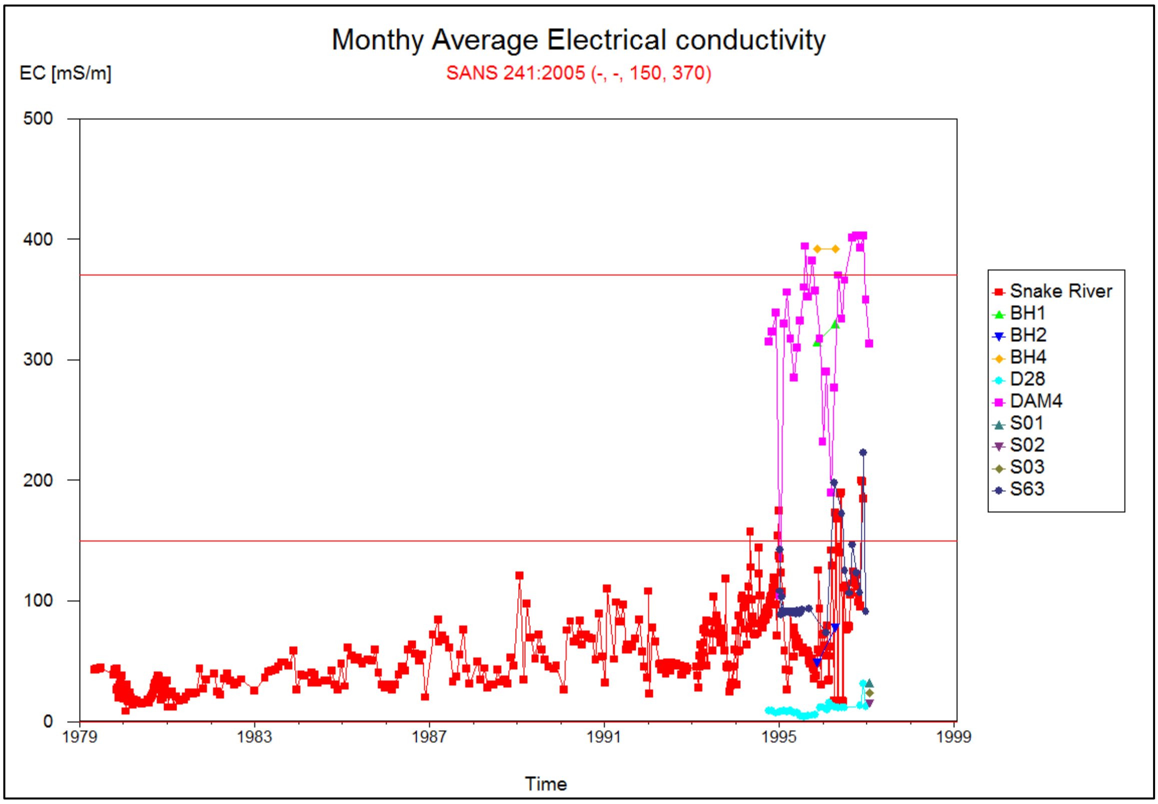


Figure 3-8: Time based line graph.

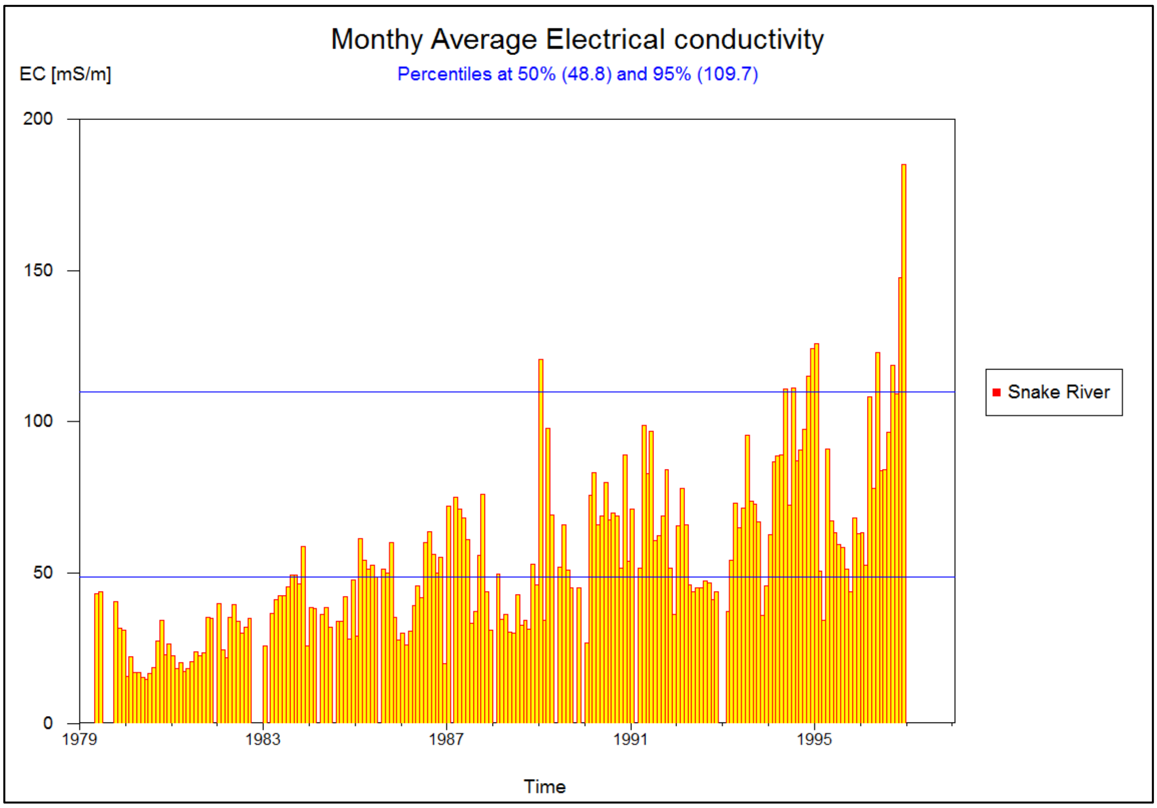


Figure 3-9: Time based bar plot.

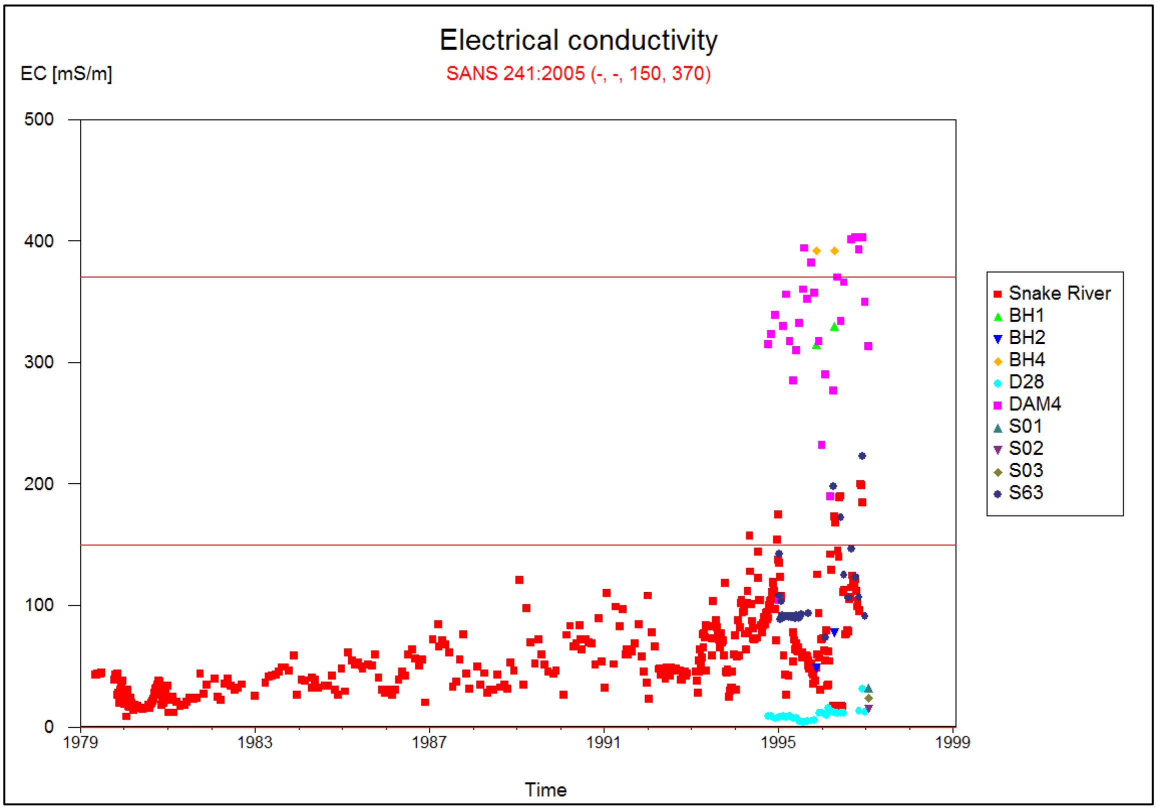


Figure 3-10: Time based scatter plot.

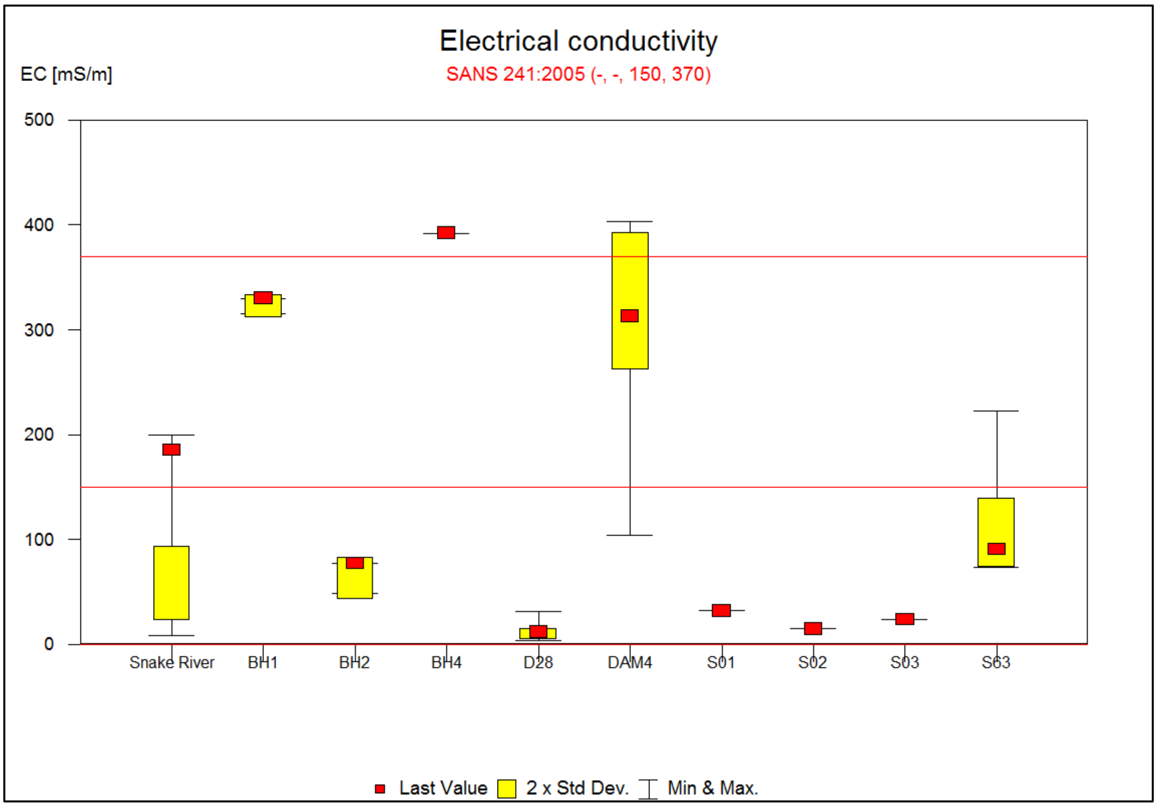


Figure 3-11: Box- and whisker plot.

3.7.2 Statistics

Different type of statistics may be performed on the data

- Bar plots (displaying daily-, monthly- or annual average or sum) (Figure 3-9).
- Box- and Whisker plot (Figure 3-11).
- Correlation (Auto-correlation and Cross-correlation).
- Indicator of average value.
- Percentiles.

When displaying annual data (average or sum) the hydrological year may be changed.

3.7.3 Parameters

Parameters may be added to or removed from the time graph. The different parameters are stacked on top of each other sharing one common time axis (Figure 3-12).

3.7.4 Formatting

All line graphs and scatter plots can be formatted. The properties that can be changed are:

- Line type, thickness and colour.
- Point size and colour.

3.7.5 Axis

The first and last value on the horizontal time axis can be changed as well as the interval used. The X-axis is the same for all the graphs in a multi-parameter plot as depicted in Figure 3-12. The lower and upper values for the vertical axis can also be changed but the scales for the different parameters can be different.

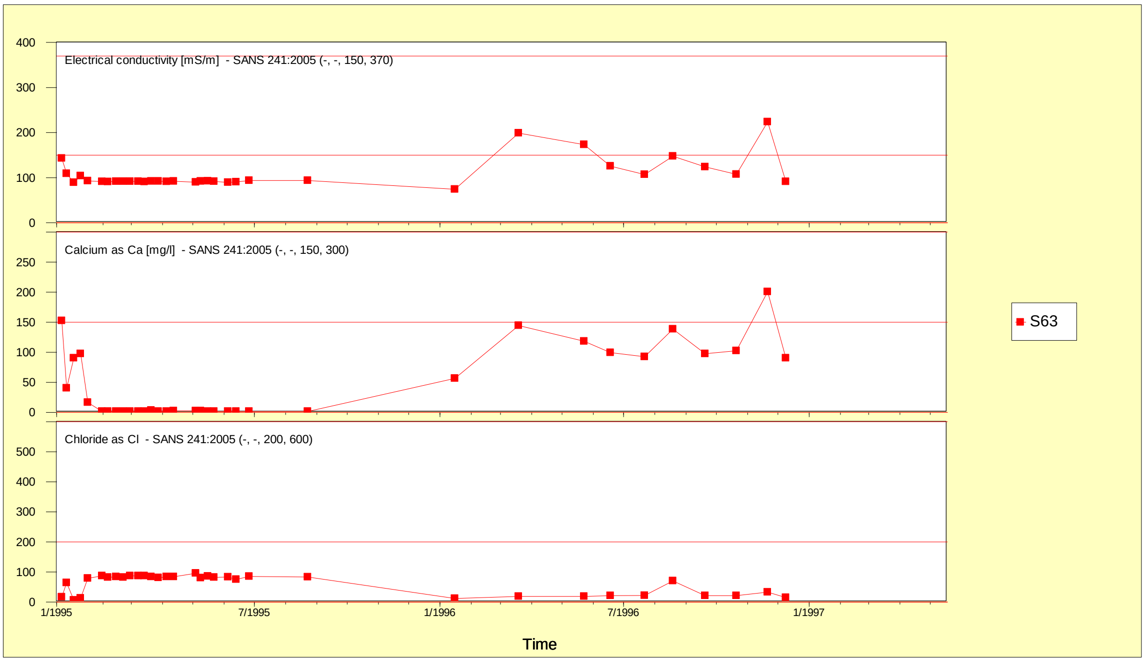


Figure 3-12: Multiple parameters in a Time Series.

3.8 Specialised chemical diagrams

Build into WISH are six specialised chemical diagrams:

- Piper diagram (Piper, 1944) (Figure 3-13).
- Durov diagram (Durov, 1948; Zaporozec, 1972) (Figure 3-14).
- Expanded Durov diagram (Burdon and Mazloom, 1958) (Figure 3-15)
- Sodium Adsorption Ratio diagram (United States Salinity Laboratory, 1954) (Figure 3-16).
- STIFF diagram (Stiff, 1951) (Figure 3-18).
- Schoeller diagram (Schoeller, 1935) (Figure 3-17).

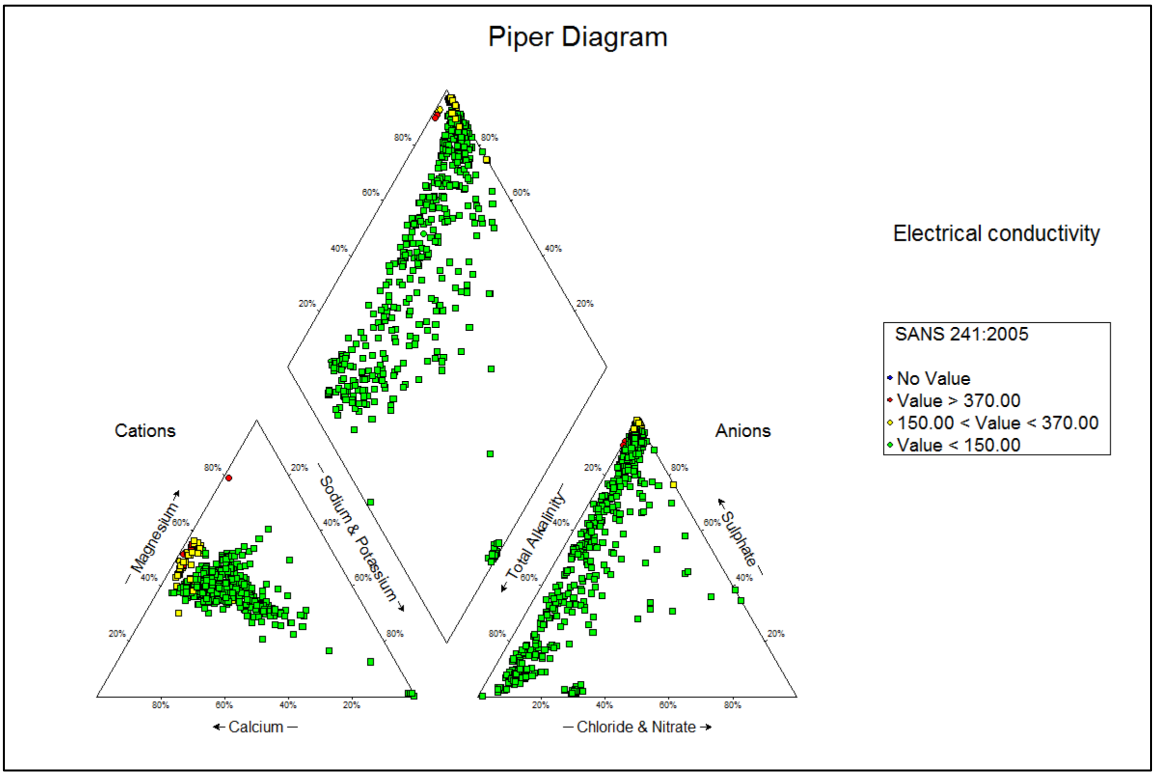


Figure 3-13: Piper diagram.

The first three diagrams are mainly for correlation and water classification. All three diagrams plot the data in milliequivalents per litre [meq/l]. Calculated by WISH, the input from the spread sheet is in milligrams per litre. The graphs make use of 2 triangles one for the anions and one for the cations. Each side of the triangles is marked from 0 to 100 %. The first diagram published in the United States was that of Hill (1940). Piper (1944) independently developed a trilinear diagram similar to the one from Hill. This diagram, with minor modifications, is still used today and is incorporated into the WISH software.

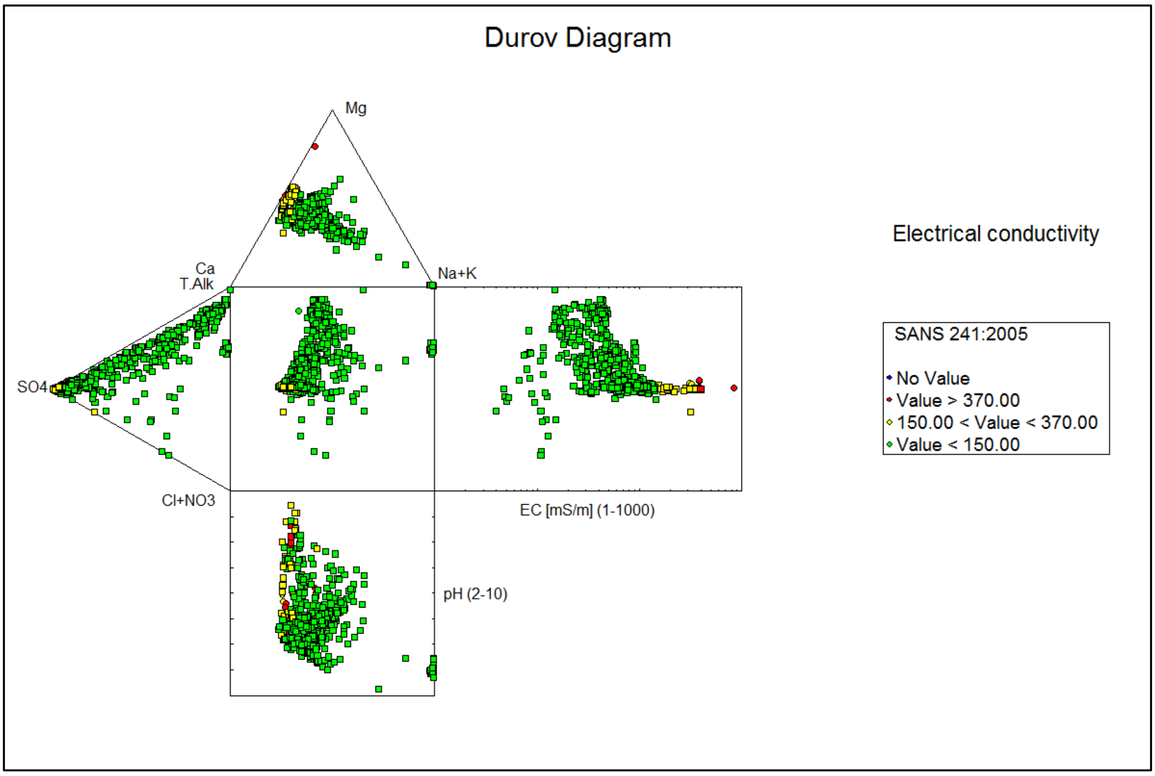


Figure 3-14: Durov diagram.

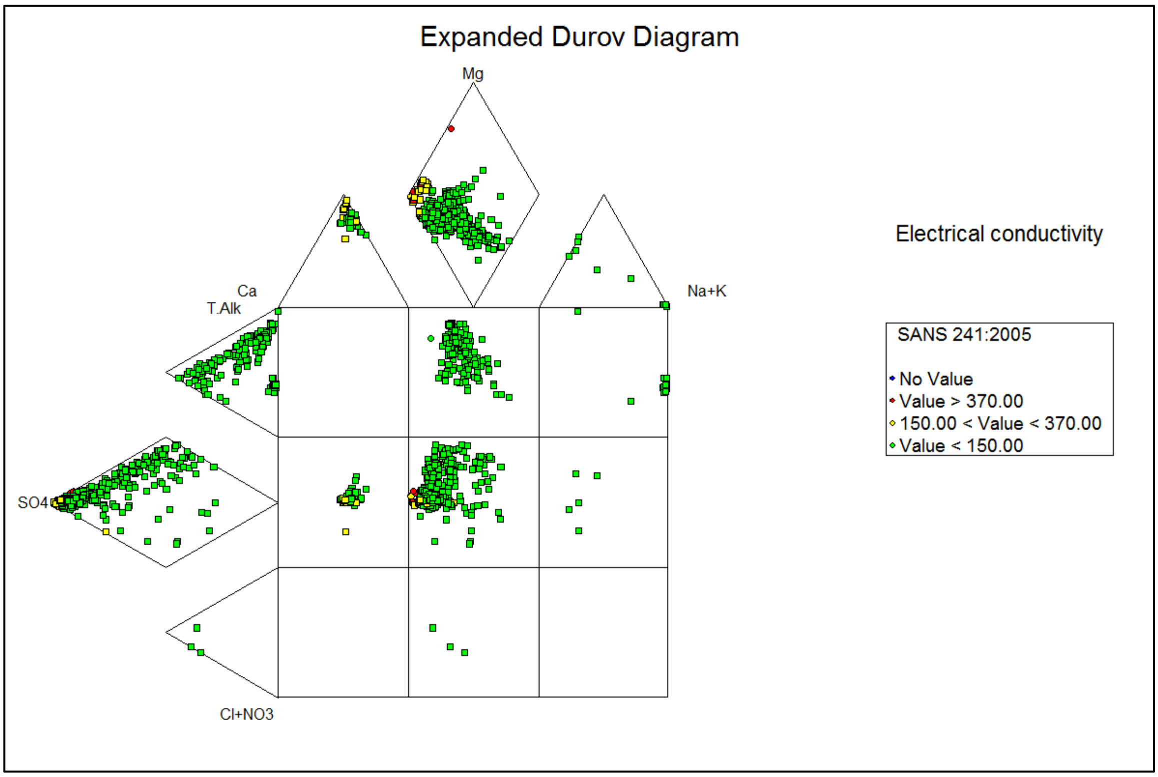


Figure 3-15: Expanded Durov diagram.

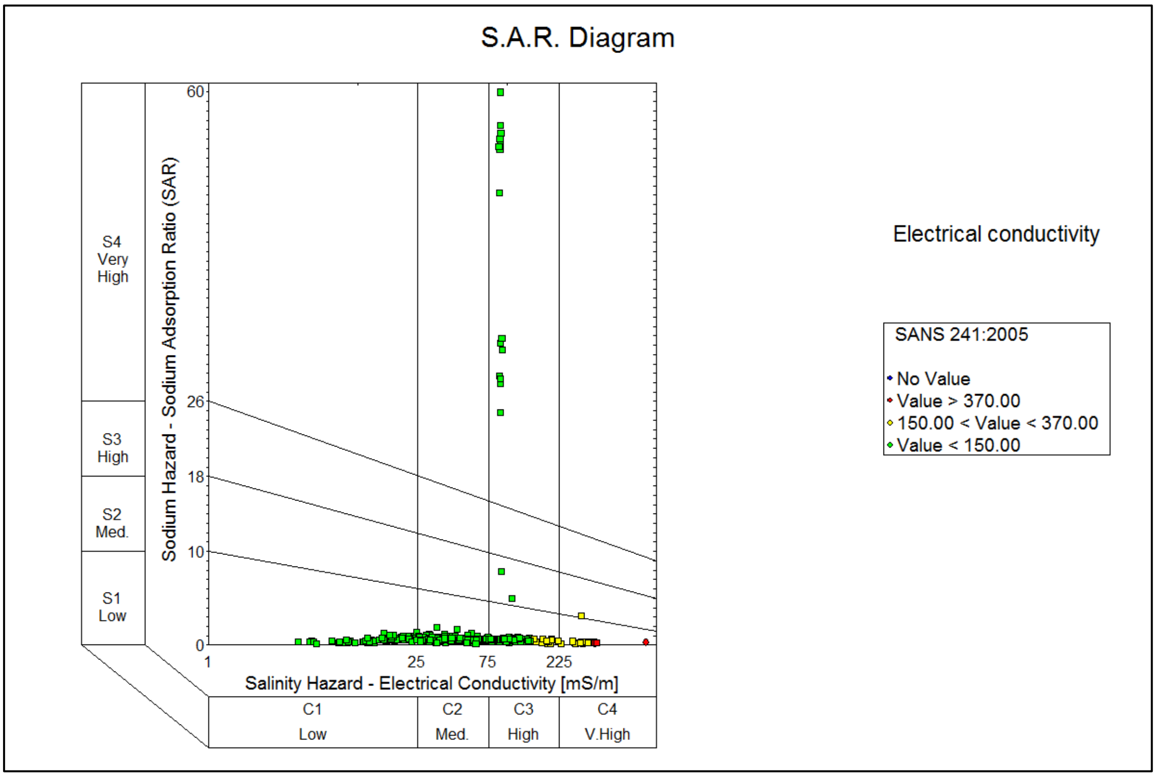


Figure 3-16: Sodium Adsorption Ratio diagram.

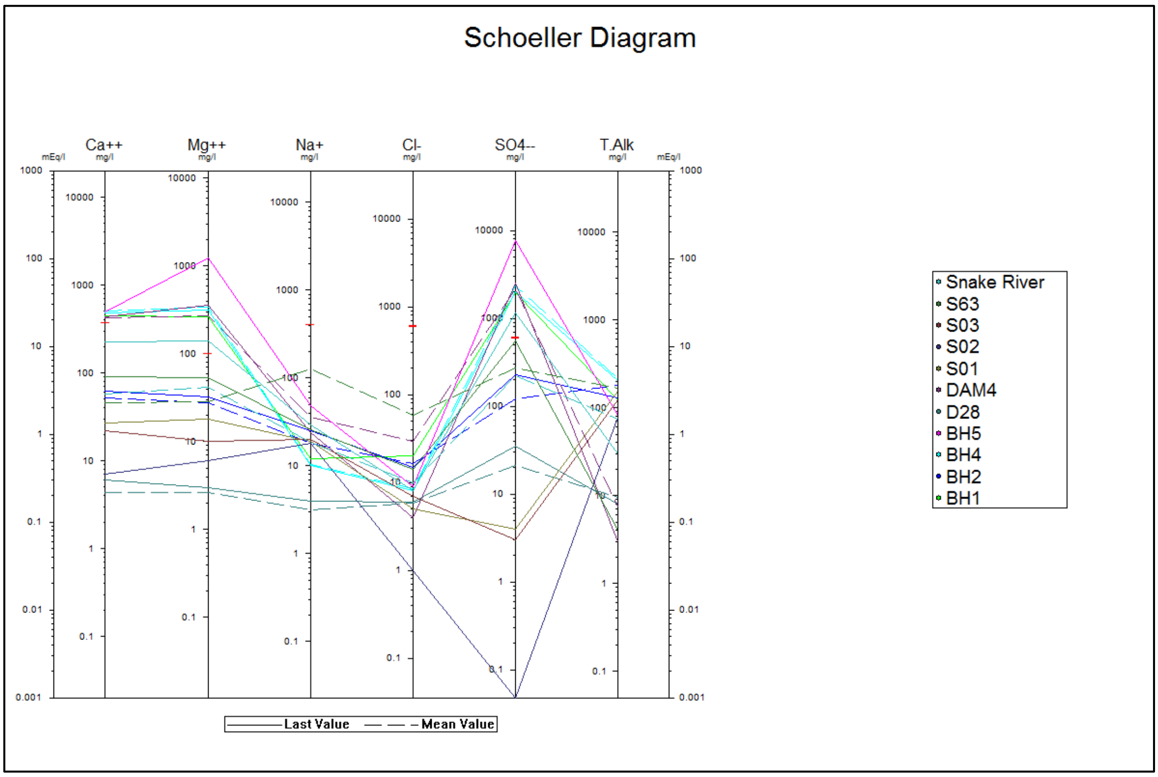


Figure 3-17: Schoeler diagram.

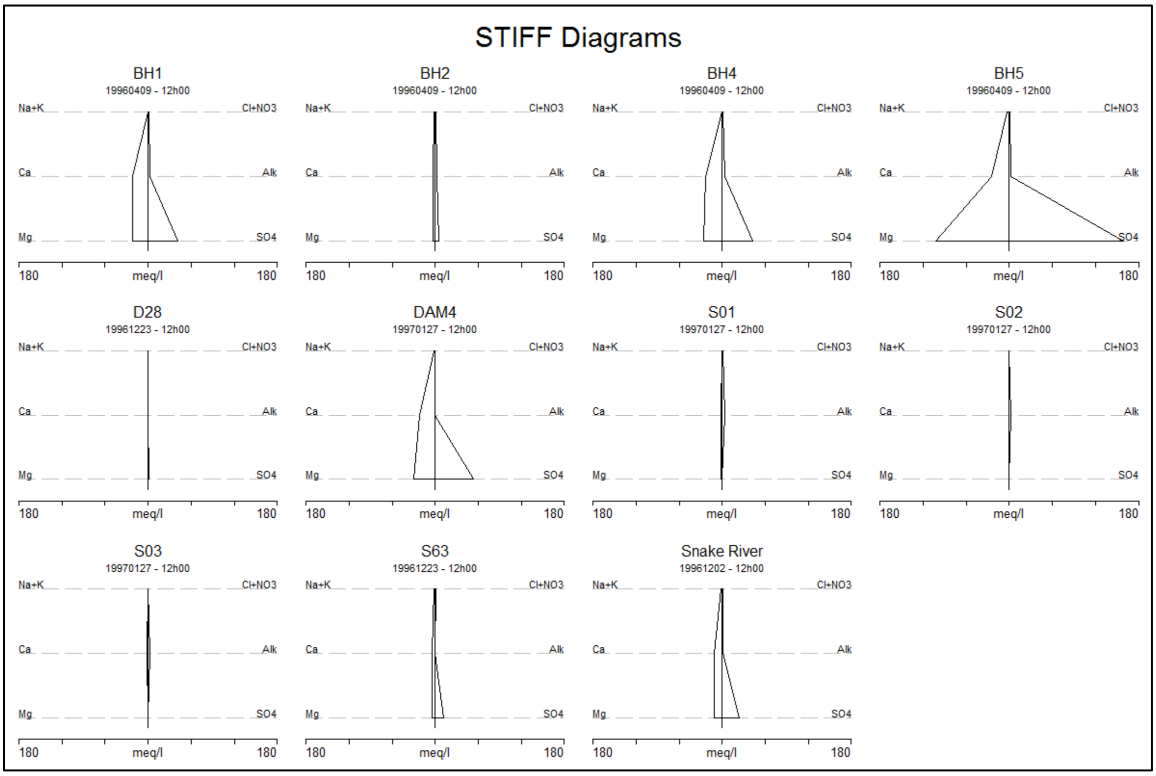


Figure 3-18: STIFF diagrams.

The Durov diagram is basically the same as the Piper diagram with two extra legs allowing pH and EC to be included in the diagram. The Expanded Durov Diagram uses also the trilinear diagram but the two triangles are split into three areas each and projected to a rectangular area with nine different zones.

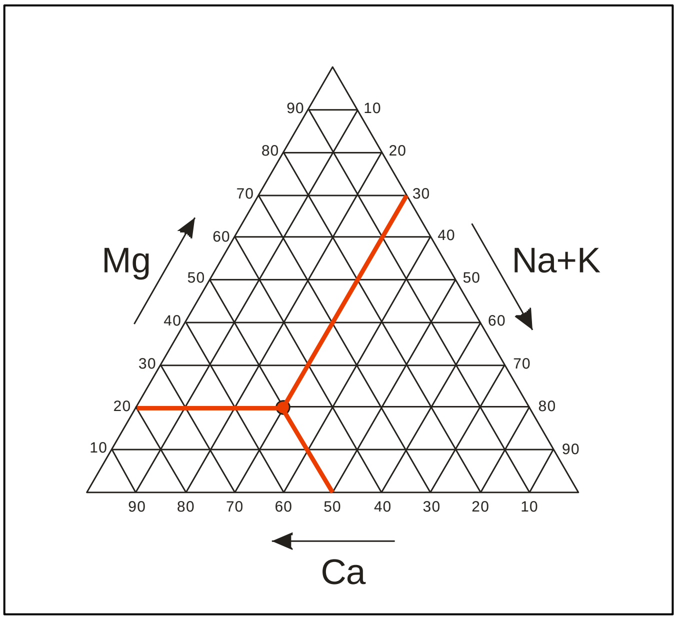


Figure 3-19: Trilinear diagram as used in the Piper and Durov diagrams.

The Schoeller diagram (or nomograph) was developed in 1935. The diagram displays multiple vertical axes one for each parameter displayed. In WISH the number of vertical axes is set to the same number parameters used in the Piper diagram and cannot be changed. The SAR diagram is used to determine if water is suitable for irrigation it uses the following equation (Driscoll, 1986):

$$SAR = Na / (Ca/2+Mg/2)^{0.5}$$

Where sodium, calcium and magnesium are in meq/l. Water with SAR values of 18 and above will result in an excess of sodium in the soil. Water with SAR values of 10 and below is safe and suitable for irrigation.

STIFF diagram displays the major ion composition of a water sample and is used for “fingerprinting”, where the shape of the diagram the ratios between the different parameters represent.

3.9 Pumping test analysis

Groundwater flow is depending on hydraulic characteristics on the geological formations. (Kruseman and de Ridder, 1990) To determine these characteristics pumping test methods were developed. WISH has built in 5 different pumping test methods.

3.9.1 Theis

The first formula developed for unsteady-state flow was developed by Theis (1935). It uses the following assumptions:

- The aquifer is confined.
- The aquifer is infinite in areal extend.
- The aquifer is homogeneous, isotropic and of uniform thickness.
- Prior to pumping the piezometric surface is horizontal.
- Pumping takes place at a constant discharge rate.
- The well is a fully penetrating (penetrates the entire thickness of the aquifer).

The formula allowed for a time factor and storativity. The discharge measured must be the same as the drop of the water level multiplied by the storativity and summed of the area of influence (Figure 3-20).

3.9.2 Cooper-Jacob

Developed by Cooper and Jacob (1946). Based on the Theis method but the assumption that if the pumping test is long enough and the observation borehole not too far the Well function becomes so small that it may be ignored (Figure 3-21).

3.9.3 Hantush’s inflection point method

Also based on the Theis equation but with an extra parameter in the Well function to compensate for the aquifer leakage (Hantush, 1956) (Figure 3-22).

3.9.4 Step draw down

The step-draw-down is a multirate analysis (Jacob, 1947). The test is performed starting with a low pumping rate until the drawdown stabilizes. The pumping rate is than increased to a higher constant rate. At least three steps are needed. Each step must have the same duration. The test determines the linear well-loss coefficient B and the non-linear well-loss coefficient C (Figure 3-23).

3.9.5 Recovery

Also based on the Theis equation (Theis, 1935). After a pumping is performed the water level elevation in the borehole will start to rise. This will continue to rise till the water level is back to its original value. Only the Transmissivity can be determined (Figure 3-24).

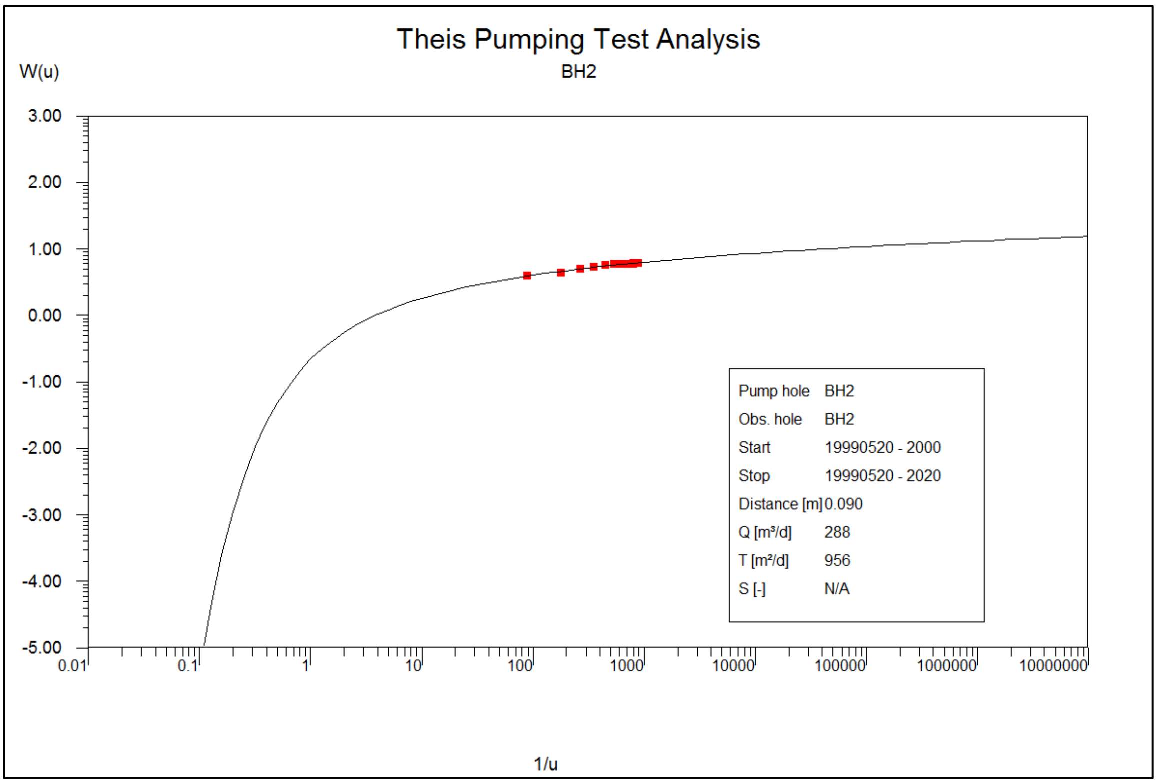


Figure 3-20: Theis pumping test analysis.

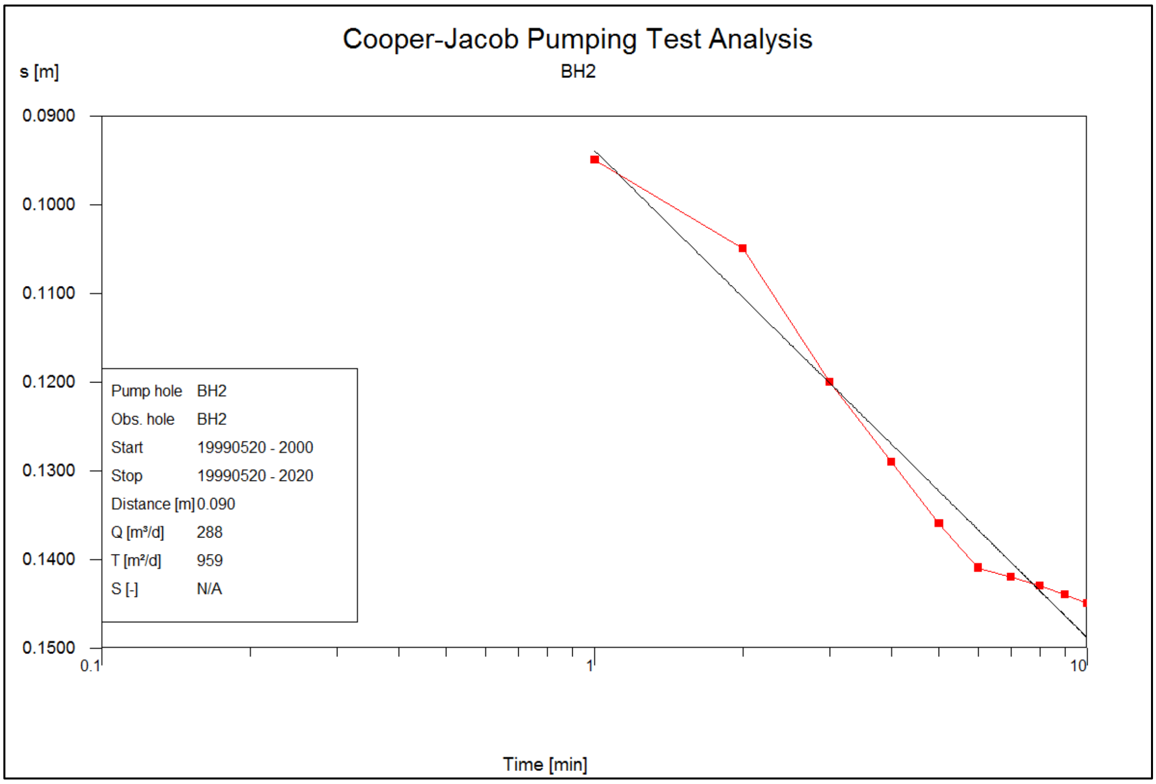


Figure 3-21: Cooper-Jacob pumping test.

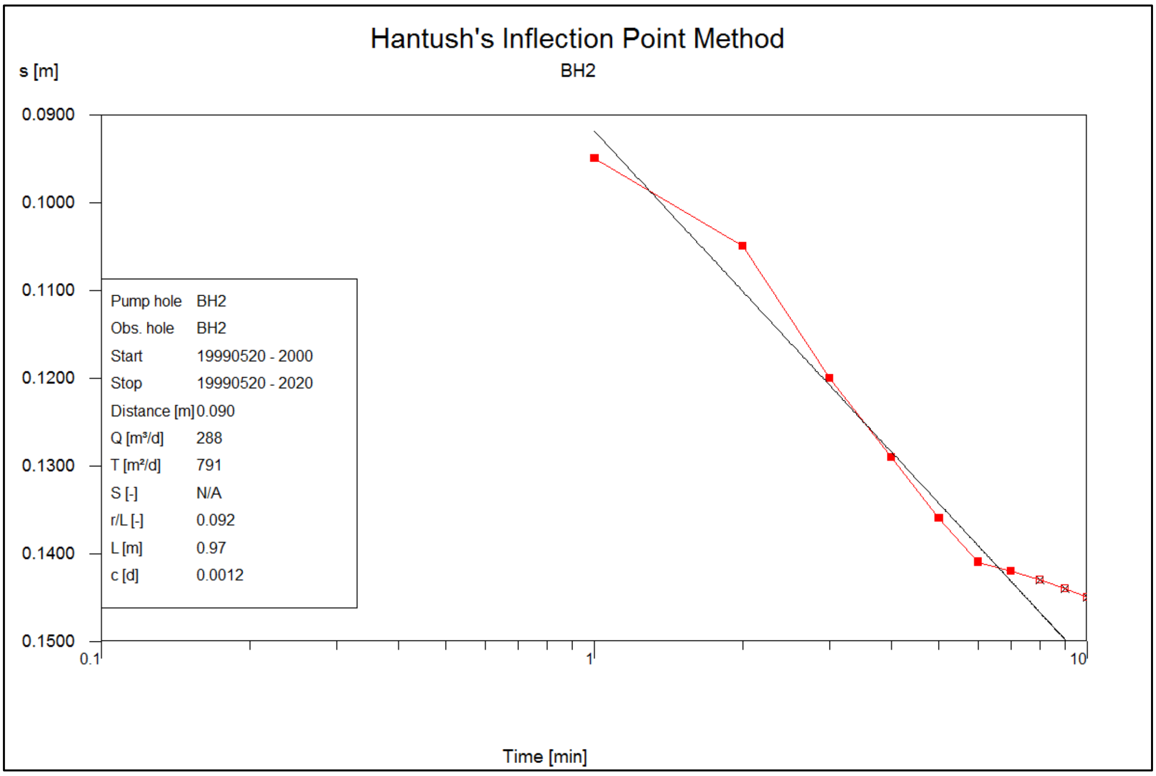


Figure 3-22: Hantush's inflection point method.

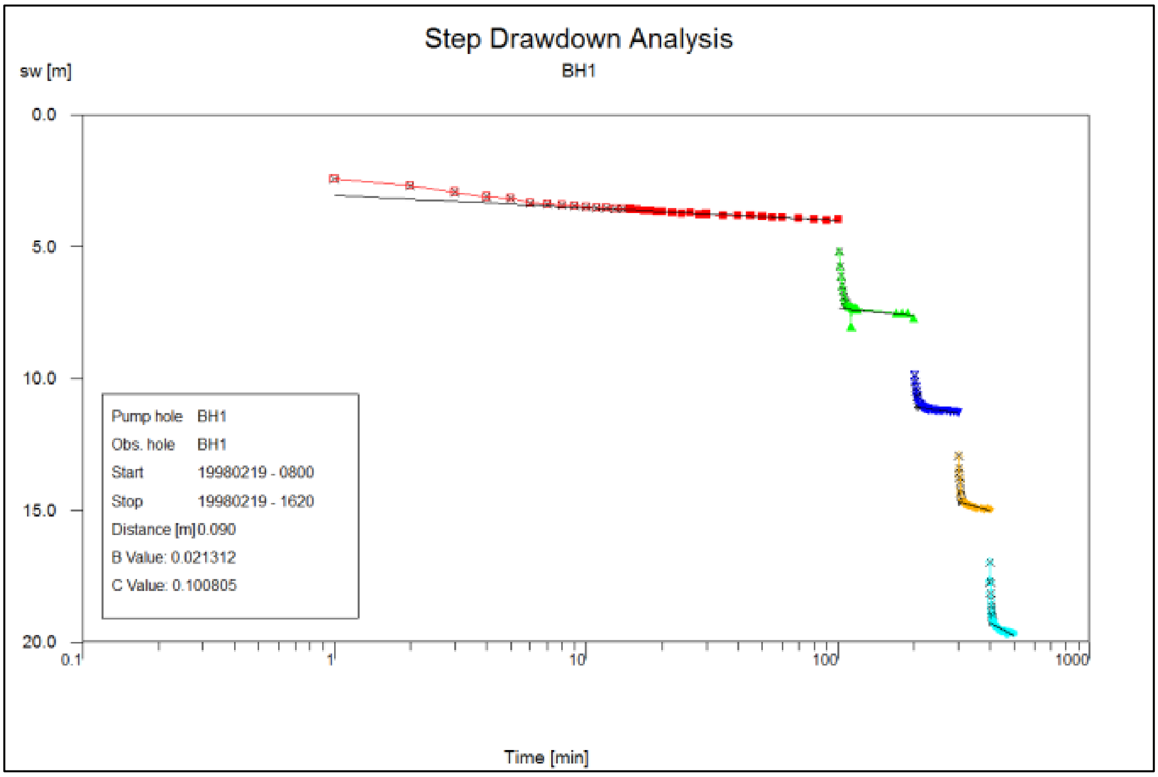


Figure 3-23: Step-drawdown analysis.

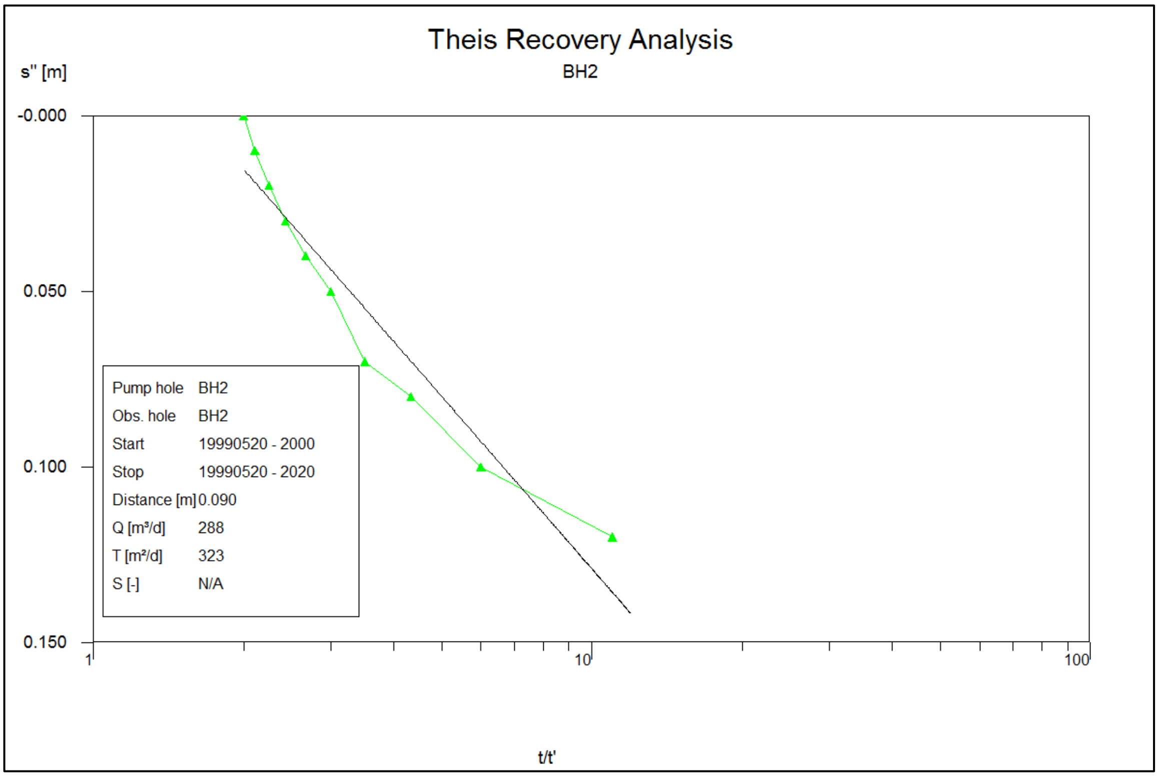


Figure 3-24: Theis recovery analysis.

3.10 Hydrogeological logs

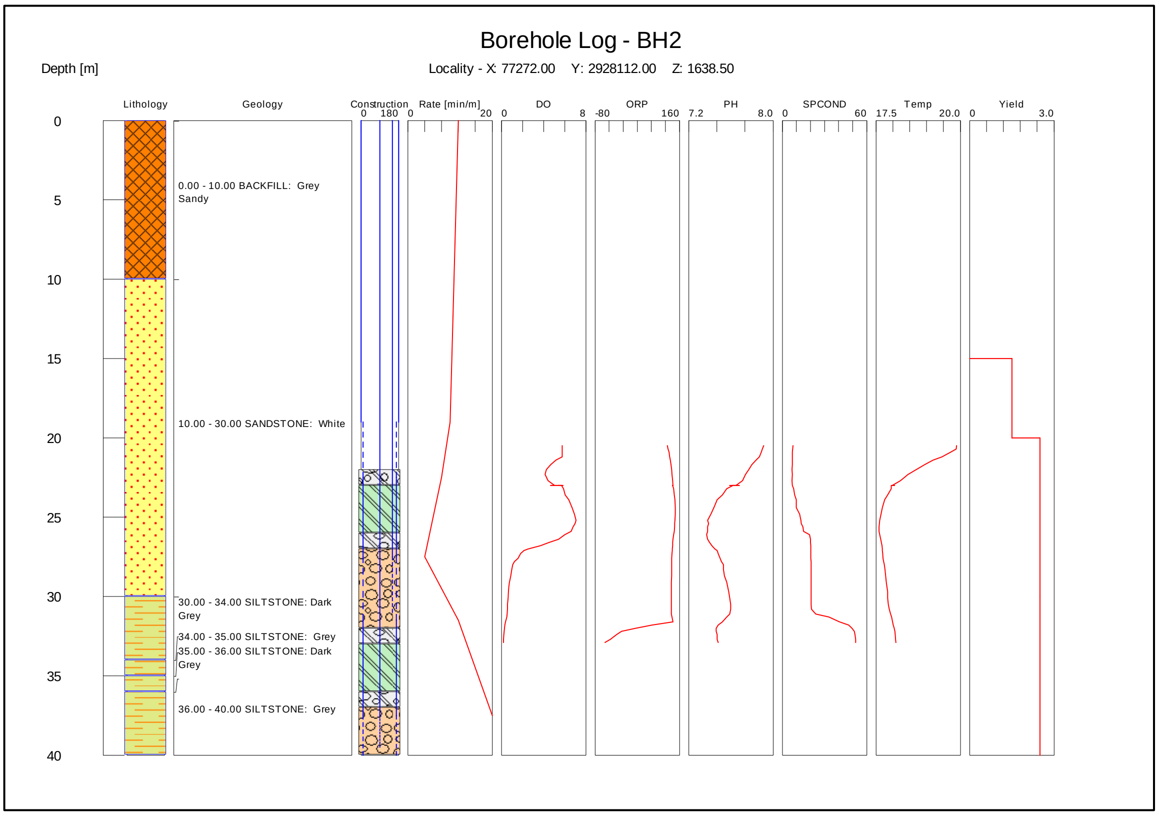


Figure 3-25: Borehole logs (WISH Demo data).

The Hydrogeological logs display the lithology information entered in the BH Geology sheet together with the borehole information entered in BH Construction, BH Yield and BH Parameters. The lithology codes are expanded to readable text in the geology column of the graph. The codes are also used to determine the hatching and colour scheme used in the lithology column. The default hatchings and colour codes are according to Standard Legend (Struckmeier and Margat, 1995). Very detailed logs (or very long ones) can be generated over multiple pages.

3.11 Spatial analysis

Plotting the data on the map is the first step of a spatial analysis. In WISH, this is done by linking the data to a map after which the data automatically comes available for plotting. Any parameter may be plotted, static data from basic information or time related data from any of the time dependant data sheets. Labels are plotted next to the data points showing information such as the site name and the actual value.

Build into WISH is the capability to compare values to a predefined standard. Some standards are readily available after installing WISH. These predefined standards are:

- South African Drinking water standard (SANS 2005:241)
- US Drinking water standard (EPA 816-F-09-004)
- Canadian Drinking water standard (Guidelines for Canadian Drinking Water Quality, Health Canada, 2003)

- EU Drinking water standard (EU Council Directive 98/83/EC, 1998)
- WHO's drinking water standards (1993)

A colour coding is used to indicate the compliance (Green – Comply; Yellow – Marginal; Red – Not comply). Standards may be added or modified. Ad-hoc standards may also be added any numerical parameter.

By default the last value measured is displayed but this may be changed to lowest, highest, average and standard deviation or trend value. Data points may be sized using the actual value they depict. In other words sites with higher values will be plotted larger than sites with lower values.

A data legend containing the parameter, type of value and standard details can be plotted – the data legend will automatically update when the parameter is changed.

3.12 Stage curves and water volume calculations

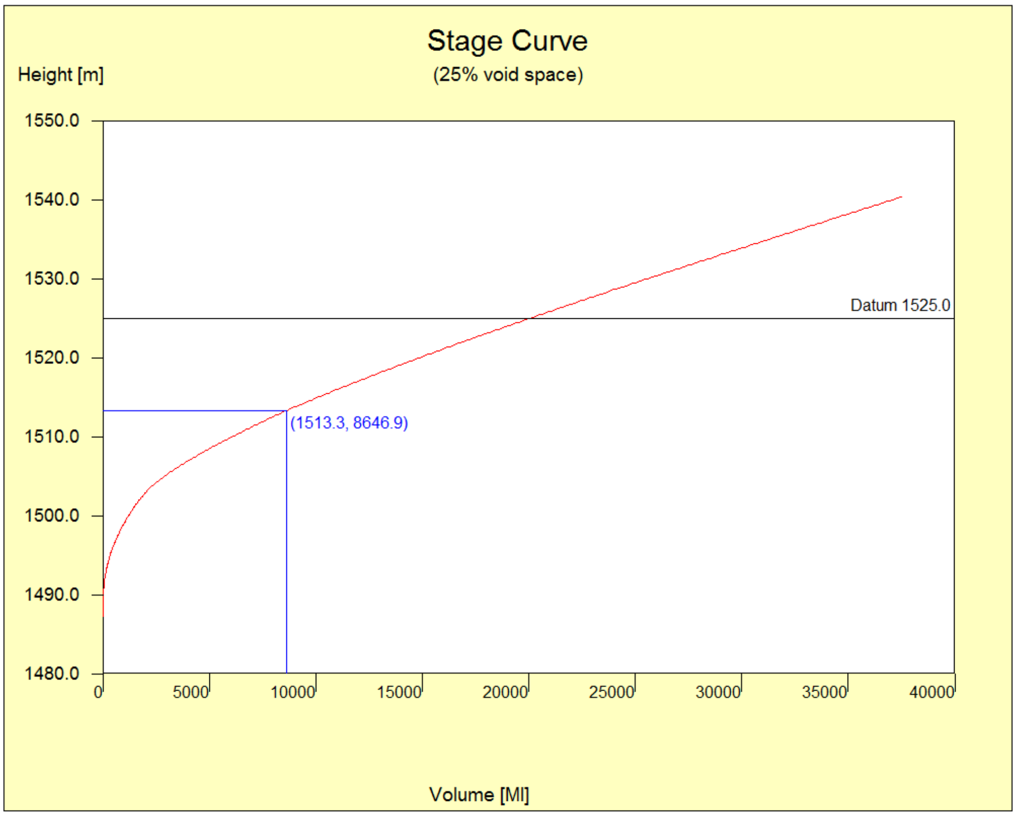


Figure 3-26: Stage curve for opencast mine (unconfined).

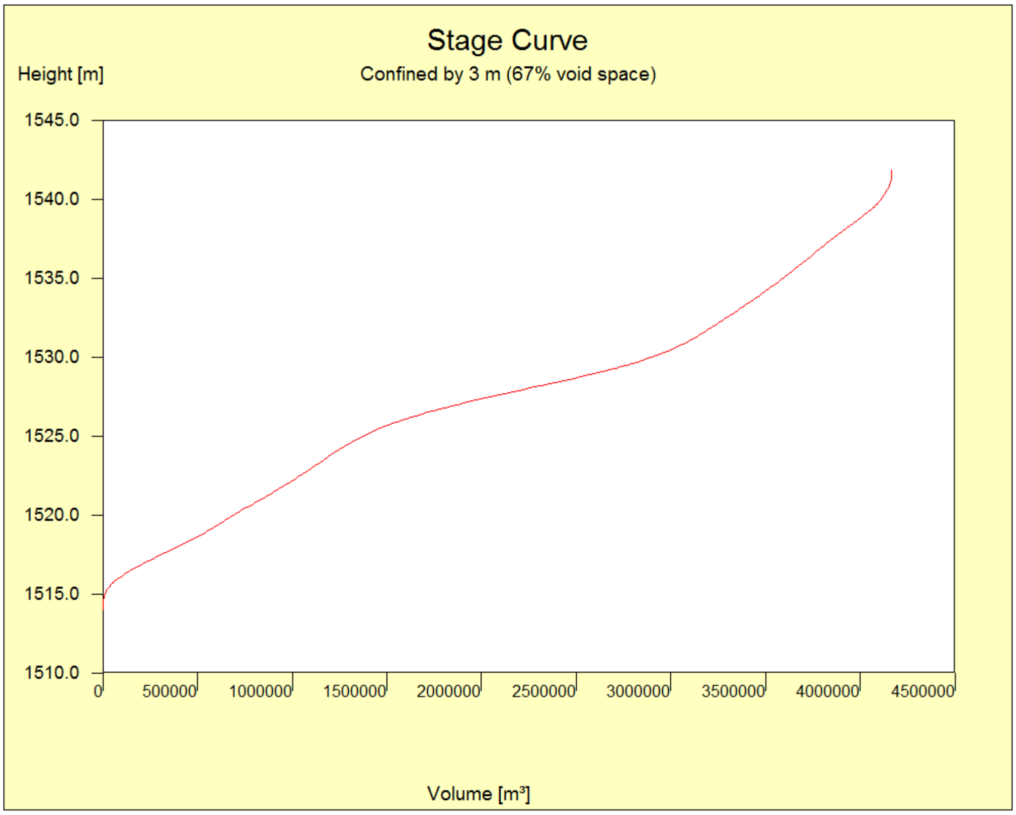


Figure 3-27: Stage curve for underground mine (confined with 3 m).

Stage curves depict the amount of water stored at any given elevation. The curve assumes that the water level elevation is horizontal even if it is not continuous. In Figure 3-26 are two examples of stage curves. The one on the left is an unconfined stage curve as used for an opencast mine. The one on the right is confined as used for an underground mine.

A stage curve is defined in WISH as a graph that displays the relationship between the water level elevation and the amount of water retained on a surface (the bottom of an opencast or the floor of an underground mine). It is primarily used to determine the amount of water inside a mine given a water level elevation. The stage curve can also be used to determine the amount of (water) storage available in a partly flooded open cast or underground mine.

NOTE: Stage curves and other volume calculation related features are only available as part of water accounting and management projects conducted through the author.

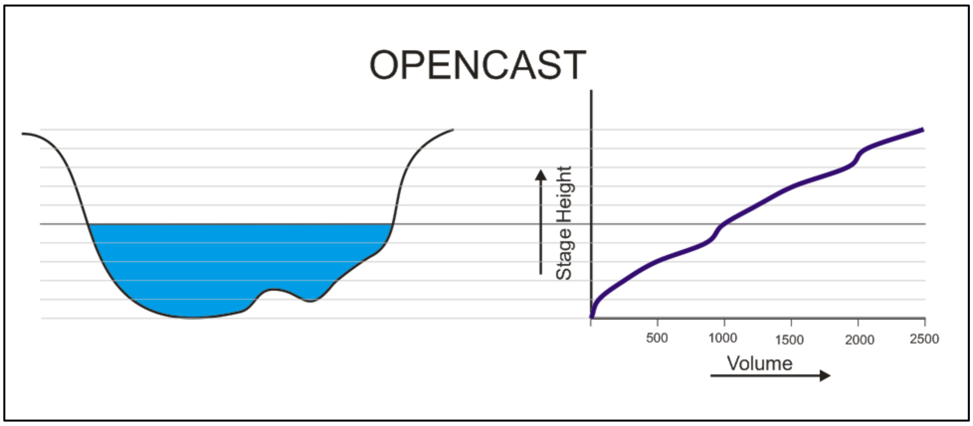


Figure 3-28: Stage Curve for an opencast mine.

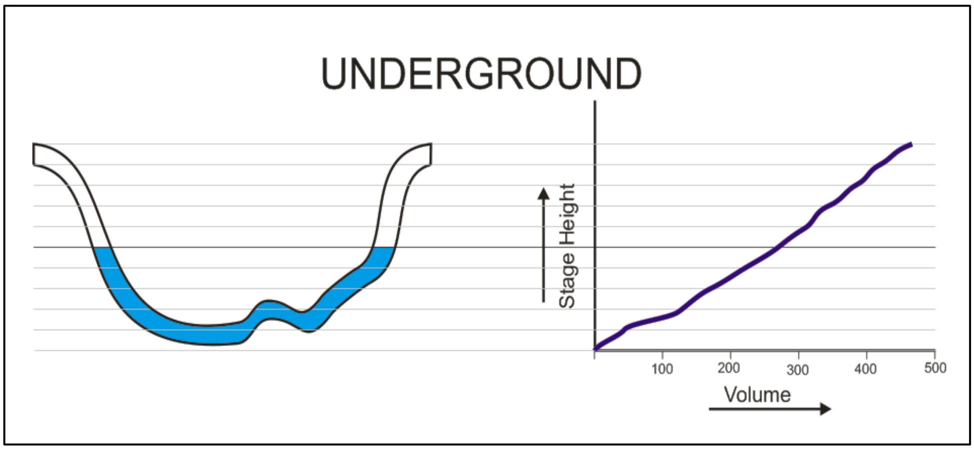


Figure 3-29: Stage Curve for an underground mine.

To calculate the actual water standing the volumes need to be multiplied with the porosity of the backfill material in the case of an opencast or with the extraction factor in the case of an underground mine. The TIN is the basis for all water balance related calculations. To create a stage curve, first generate a TIN or select an existing TIN and from the context menu select Stage Curve….

Chapter 4 Creating a WISH file

To start a new WISH (Windows Interpretation System for the Hydro-geologist) file may look like a daunting task especially to the new WISH user. This section explains, by using a couple of simple steps how to compile a new WISH document.

A WISH project consists of two files, the actual WISH document containing the map, and a file with all the data measured in the field. This data file can be a few different formats but for this thesis only Microsoft Excel is used.

Before a new WISH project is created it is good practice to perform a mine or site visit. During this visit, available data can be collected and data that is not readily available can be requested. The data needed to create a new WISH document can consist of, but is not limited to, the following:

- Old WISH files.
- Mine plans in Microstation or AutoCAD format (DGN, version 7 or DXF up to Release 14).
- Shape files.
- Bitmaps (topographic and other maps).
- Contour data (surface, coal seams).
- Mining data (roof elevation, floor elevation and mining height).

Depending on the quality of the spatial data mentioned above it is possible to create a good looking map. The geo-hydrological data that is to be plotted on the map must be collected during a hydro-census or could also be provided during a site visit.

Special care must be taken when dealing with older mines as the data prior to 1999 is recorded using the Cape datum this in contrast to the current Hartebeeshoek 94 datum with its origin at the Hartebeeshoek Radio Astronomy Telescope (Wonnacott, 2002). The Hartebeeshoek 94 datum is the same as the internationally used World Geodetic System of 1984 (WGS84).

The actual WISH document is an ordered document. The document consists of global document settings and a layer list. The global settings are items like document version, security flags, map extent, point info, data flags, WACCMAN data, captured slides, defined selections and selected data point list (Figure 3-4).

NOTE: *In this chapter and the next chapters reference is made to the context menu. The context menu is the menu that pop-up after selecting an item and clicking the right-hand mouse button.*

4.1 Layer manipulation

The Layer Control (Figure 4-1) displays all layers available in the current WISH file. There are 7 buttons at the top of the layer control from the left to the right:

1. **Layer Lock.**
   Enables individual layers to be locked to protect against accidental editing. Indicated with “L”.
2. **Transparency toggle.**
   Toggles all the fill colours on the entire layer to become semi-transparent. Indicated with “T”
3. **Outline Mode.**
   Sometimes it is necessary to remove all fill colours and to view the layer as a wire model. Indicated with “O”
4. **Visibility toggle.**
   Toggles the layer between a visible and a hidden state. Visible layers are indicated with a chevron “»“
5. **Normal View.**
   Display the Layer Control in its normal view (as here displayed)
6. **Feature View.**
   Display the Layers Control where the layers are grouped by feature.
7. **Slide View.**
   WISH has the capability to capture views; this mode displays the capture slides.

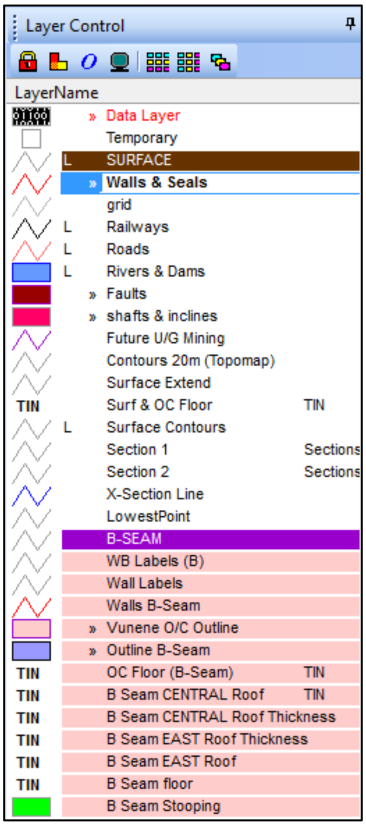


Figure 4-1: Layer Control.

There are no restrictions on the layer names, but duplicate names are not allowed. When displaying the map the layers drawn in reverse order, starting at the bottom and finishing at the top of the list. The top item “Data Layer” is displayed in red because it is a protected system layer. This layer cannot be copied, renamed or deleted. The layer is used to display the data points on the map.

One layer is displayed in bold text (Layer “**Walls & Seals**” in figure 4-1) this is the current layer. When adding manually map-items, points, lines or text, the items are added to the current layer. The current layer can be selected by double clicking in the layer name in the layer Control.

Some layers have a wavy line at the left hand side. The line indicates that the default format of the layer does not contain a fill colour. The default line colour is the colour of the displayed line. Where the wavy line is replaced by a rectangle the default format contains a fill colour and is the same as the colour displayed in the rectangle. Layers where the wavy line is replaced by the word **TIN** the layer contains on or more Triangular Irregular Networks. Layers in the Layer Control may be displayed with different background colours to group the layers.

Opening the context menu on any of the layers enables the user to manipulate the layer or items on the layer. After importing data from DGN, DXF or shape file it necessary to set the line colour, line type / thickness and fill colours. The **Format…** option allows the user to change the appearance of all the items on the selected layer. Any specific format can be saved in a style to be used as a quick assignment option. The style can also be saved in a template to be used in other WISH files to promote consistency in formatting throughout multi-document projects.

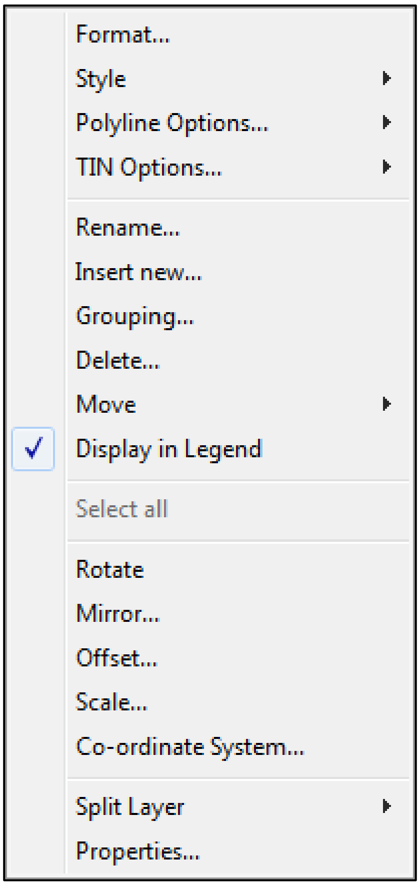


Figure 4-2: Layers control context menu.

The imported polylines from DGN, DXF or shape file are often broken-up into smaller segments, having duplicate nodes or contain line crossings. The *Polyline Options* enables the user to automatically clean-up the polylines and to build them into longer polylines.

Sometimes it is necessary to have more than one TIN on a single layer. To apply setting for all the TINs on the selected layer use the *TIN Options*…. To change the layer name or the feature descriptions use the *Rename…* option. To improve layer visibility in the Layer Control Menu layers may be grouped using colour coding.

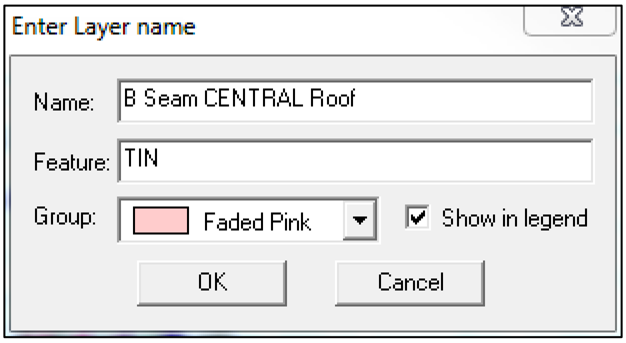


Figure 4-3: Enter Layer Name.

Deleting of layers is supported using the Delete… option.

As layers are drafted from bottom to top it is essential that the order, in which the layers appear, can be changed. Layers can be moved up and down in the list either the *Move* option from the menu or by dragging the layer up or down by the mouse while holding the Alt button depressed.

WISH is capable to create a legend to be displayed on the map. By default all visible layers are included in the legend. To prevent WISH from generating a legend entry for a layer turn of the *Display in Legend* option.

Layers can be rotated in 90 degree blocks or layers may be mirrored over the X- and/or Y-axis.

A layer offset may be applied to all map-items on the layer. The offset is either over the X-axis or over the Y-axis or over both.

When importing data from an un-scaled source it is important to scale the items.

Co-ordinate systems may be different when receiving data from different source. When data is read from an external source it is always imported to a new layer. Layers can change the co-ordinate system separately.

Some data sources plot all the data on one layer. To help differentiate between the different map-items the *Split Layer* options allows for splitting the layer, into several layers, according to Stylename, Line or Fill colour or entity type.

4.2 Create a background map of the area

Readability is one of the most important features of a good map. To help the reader to understand the map quickly it is good practise to use topographic maps as a background. In South Africa the topographic maps are numbered according to the Latitude and Longitude degrees and using a 4x4 sub-numbering in between. The University of the Free State is located on 2926AA. In case it is not known which map to use the user can load the map from South Africa from the demo data, supplied with the WISH installation, and attach the TownCoordinates.xls file. The file contains the locations from "all" cities in South Africa. Go to the Site Selection tool, deselect all sites and select the sitename corresponding with the city or village closest to your area of interest and select OK to perform the selection. In Figure 4-4 are all cities visible but only one (Bloemfontein) is selected. Moving the mouse pointer over the selected city will display the coordinates and map number in the lower right corner.

When importing the map in an empty WISH file the program needs to know if geodetic (Lat/Lon) or default (X,Y) coordinates must be used. In a mining environment the latter must be selected. The default coordinate system uses a Transverse Mercator projection. In a Transverse Mercator the horizontal axis will have multiple origins at each odd whole degree longitudinal position also called LO Band. In other words the XY coordinates for longitudinal values between 26°East and 28°East all use the same X-origin at 27°East. It is possible that the area of interest is situated so that four topographic maps are needed to cover the background (Figure 4-5). The size of the mines are never that large in total extend. The map should be cropped to keep the scale as large as possible. Bitmaps that are cropped may be un-cropped at a later stage if the extend of the area of interest increases. It is advisable to clip the bitmaps after the correct size has been established to reduce the size of the WISH file. Once a bitmap is clipped it can no longer be un-cropped!

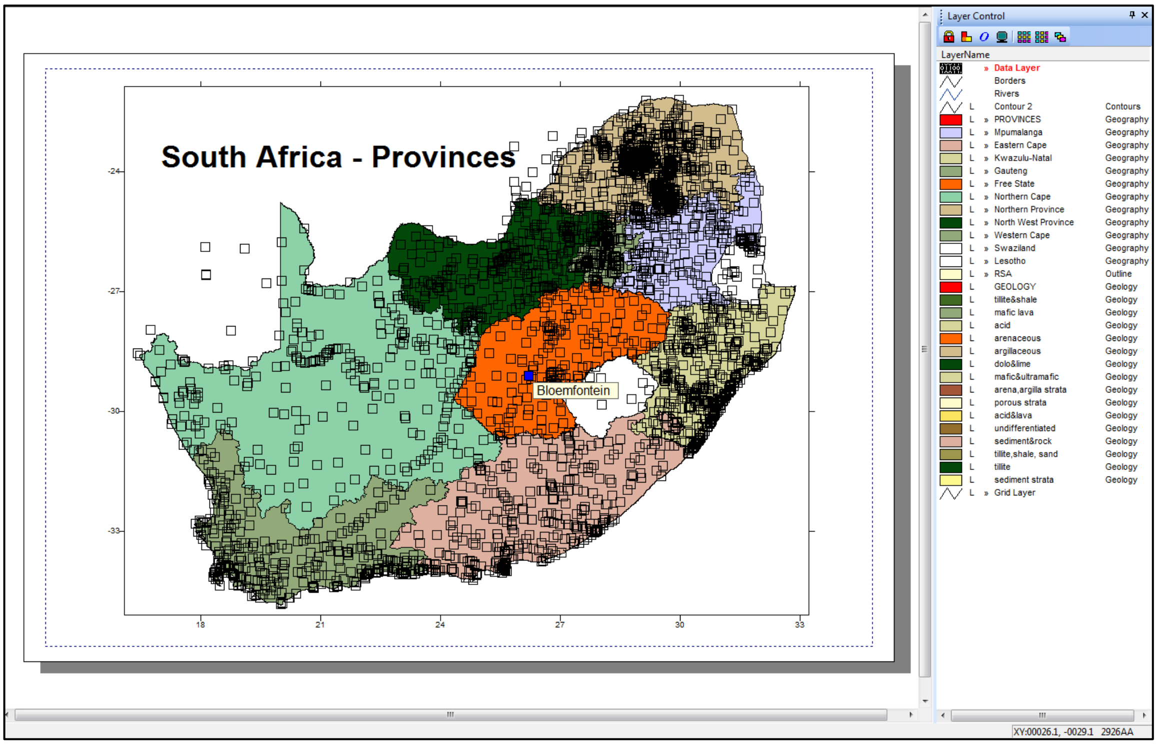


Figure 4-4: Map of South Africa with towncoordinates.xls attached (WISH Demodata).

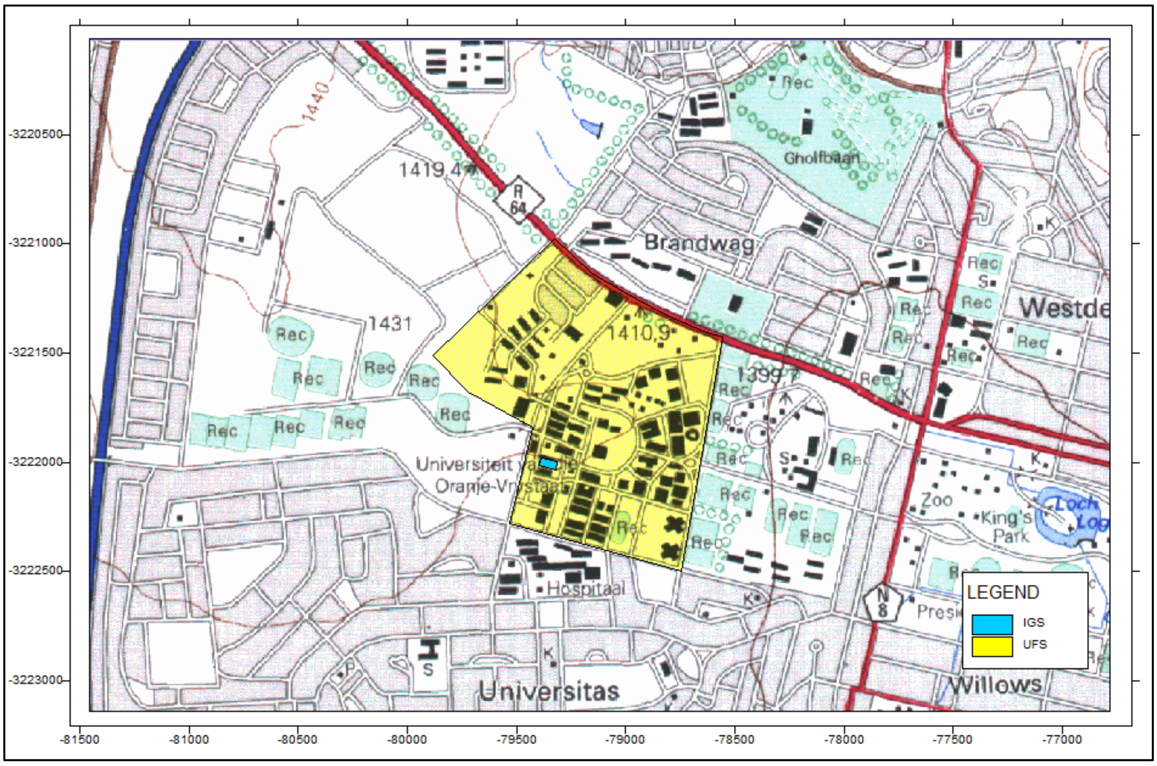


Figure 4-5: Example of information plotted on a topographic map.

4.3 Import existing data from shape files

The use of only a bitmap background is not good enough and some features like rivers, water bodies and roads should also be imported in vector format. For this reason support for shape files has been built into WISH. The topographic shape files created for South Africa are always in geodetic coordinates and a conversion afterwards is needed. To convert the whole map select from the menu MAP->CO-ORDINATE SYSTEM... or if only a few layers need to be converted, select the layer in the Layer View and select CO-ORDINATE SYSTEM... from the context menu.

4.4 Co-ordinate systems

In South Africa different projection methods are used depending on the scale of the map to be produced.

- Albers Equal Area for small scale maps 1:250 000 or 1:500 000
- Transverse Mercator (1:50 000 topographic maps)
- Geodetic Latitude and Longitudes (for any non-technical map)

Maps produced prior to 1999 used the South African Cape Datum. Map created after 1999 used the Hartebeeshoek94 datum, and uses the WGS84 reference system (Wonnacot 2002).

All maps produced for the mining industry will use either Transverse Mercator or another custom co-ordinate system specifically for that mine. Data imported from shape files is always in the geodetic system (in decimal degrees). The vertical axis in South Africa’s co-ordinate system is called the X-axis. It has its origin at the equator and increments going south. The horizontal axis is called the Y-axis and has its origin at every uneven degree crossing and increments to the left.

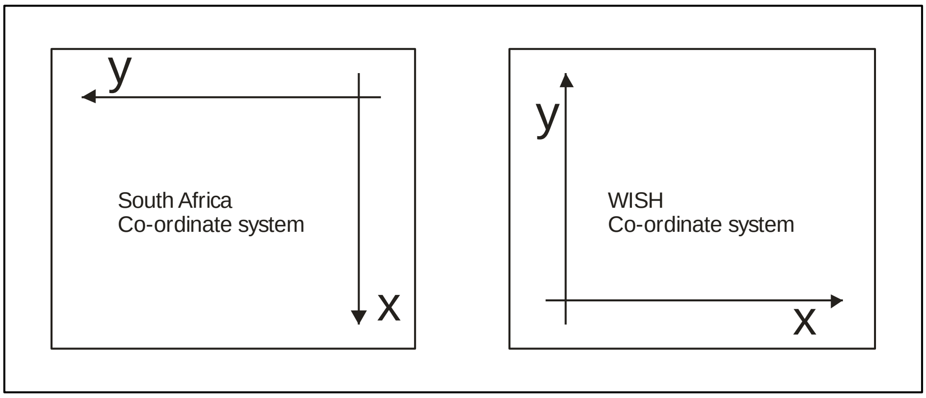


Figure 4-6: South Africa Co-ordinate system verses WISH co-ordinate system.

WISH uses a rectangular Cartesian coordinate system, (Shaum’s Outlines: Beginning Finite Mathematics), see Figure 4-6. To convert the data open the Co-ordinate Conversion dialog. The dialog is split into two parts. The top receives the source parameters and the bottom one the target’s parameters.

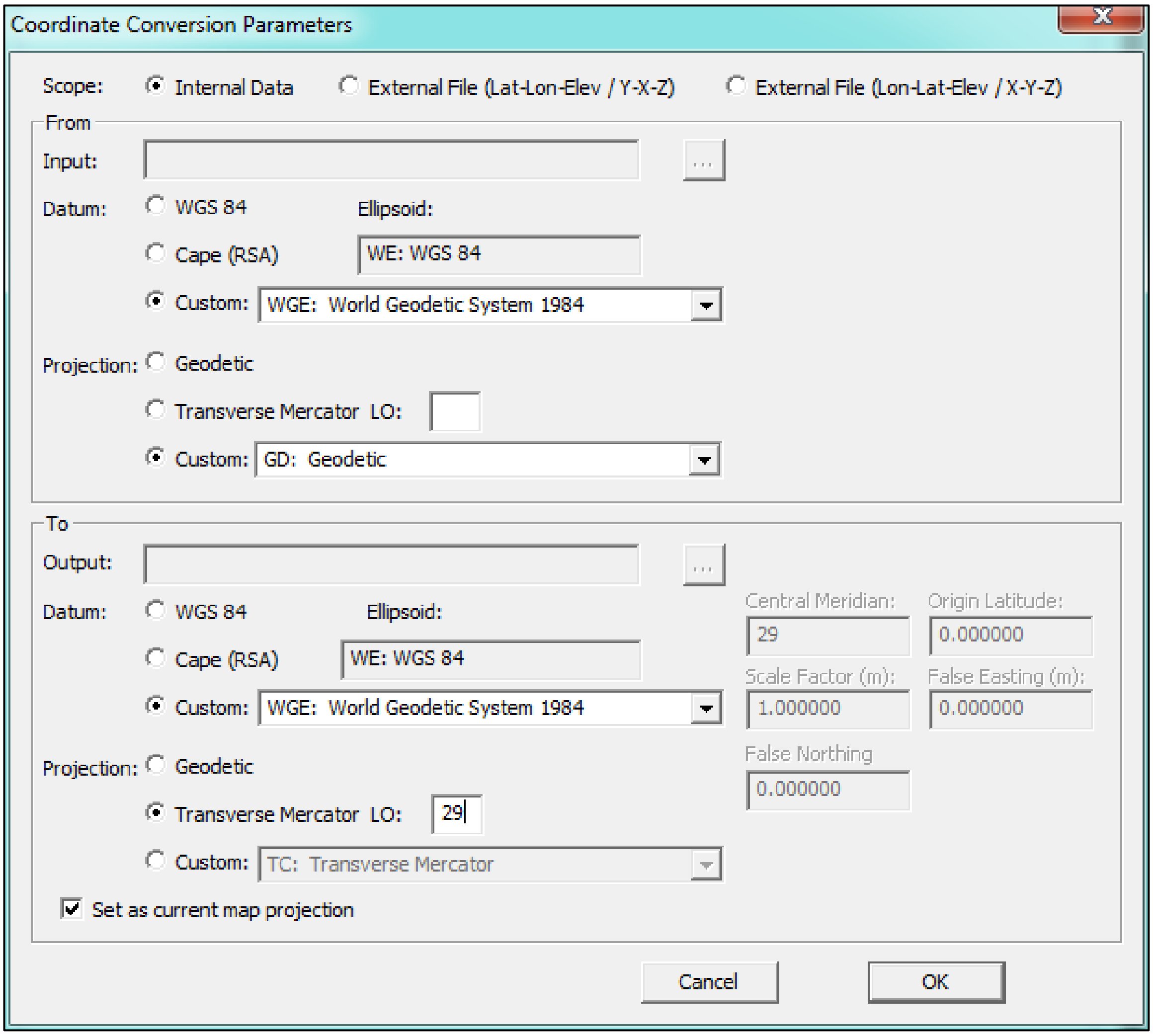


Figure 4-7: Co-ordinate Conversion Parameters.

4.5 Import aerial photography

Aerial photography may enhance readability of the map when used as a background. When a geo-referenced map is provided (map together with a world file), WISH will place the map at the co-ordinates specified. When a non-referenced map is used, the register bitmap option may be used to position the map. The bitmap registration window provides space to enter positions on the bitmap and on the map. When the OK button is selected the transformation is applied. The current version of WISH does not support bitmap rotation. When importing screen captures from Google Earth the following steps should be used:

1. Create and new layer
2. Insert two points just outside the current map extend. (One point in the upper-left and one in the lower-right corner.)
3. Hide all other layers
4. From the menu select FILE->EXPORT MAP…
5. Specify a filename and make sure the file type is Google Earth KML file
6. The coordinate conversion dialog will appear. In the top half enter the maps setting and make sure the bottom half is at Geodetic and WGS84 and select OK

7. Start Google Earth
8. From the menu select FILE->OPEN and select the file created in step 5
9. Google earth will automatically zoom to the right position but some changes to the zoom-level may be required.
10. From the menu select FILE->SAVE->SAVE IMAGE…
11. Switch back to WISH and import the file created in the previous step.
12. Select the Image and from the context menu select REGISTER…
13. The bitmap registration window will appear (Figure 4-8), enter the coordinates for point 1. Instead of entering the coordinates by hand there is a point and click option available. Select the first point button and click on the top left marker on the Google Earth picture. Next click on the second Point button and click on the top left point entered in step 2.
14. Enter the coordinates for point 2
    Repeat the work done in the previous step except now for the lower left point.

Figure 4-8: Bitmap registration.

4.6 Import of mine plans

Mine plans must be imported. WISH has built-in support for DGN (Microstation) and DXF (AutoCAD) files. Not only the mine plans but all mining related feature must be added on the map. These are features like stock piles, water storage facilities, tailing dams etc.

When importing from DGN or DXF the system will ask for a layername prefix. In the case of a DGN file it is also possible to specify a single layer to be imported. During imports from DGN files the information is split-up in features (polylines, arcs and annotation).

It is possible that the original drawing was created using an offset. In many cases a vertical offset of 2800 000 or 2900 000 meter is used. (Older versions of Microstation and AutoCAD could not handle co-ordinates with such large numbers.) WISH has the capability to apply the offset on a layer basis after the map has been imported. To apply the offset select the layers involved and from the context menu select OFFSET…. In the offset dialog enter the offsets over the vertical and horizontal axis and click on OK. The offset is applied to all items on the selected layers. The offset cannot be reversed using the undo button but it is always possible to apply a secondary offset in an opposite direction.

4.7 Clean-up the data contained in the mine plans

Mine outlines needed for the creation of TINs need to be cleaned prior to the generation of the TINs. The draftsman on the mine draw the outline of the mine the same way the outline is altered by continuous digging. Every time a milestone is reached the drawing is updated. This has as result an outline that consist of many small pieces some overlapping. In order for WISH to create a TIN a polygon is needed.

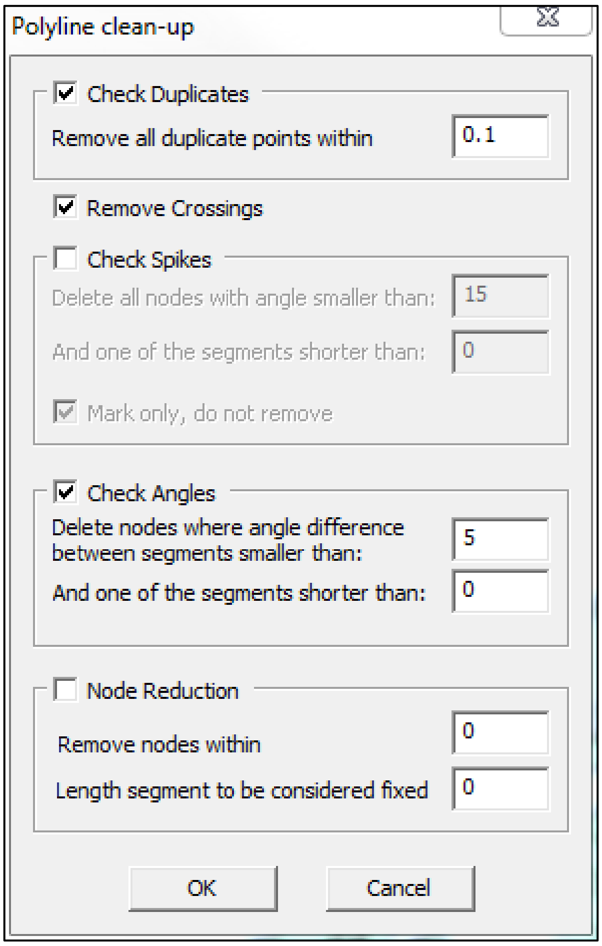


Figure 4-9: Polyline clean-up.

This means that all the single parts need to be joined to one creating one polygon. The polygon should not contain any crossings as this will result in problems once the water-balance calculations are started. Special tools are developed to assist the user in performing certain clean-up task. These tools can either be started on a single polyline on a selection of polylines or on a selection of one or more layers applying the instructions to all polylines on selected layers. The tools include:

- Polyline Clean-Up with the following options
  - *Removal of duplicate nodes.*
    Duplicate nodes or nearly duplicate nodes will result in very small triangles and although numerical instability is not an issue as no numerical modelling is done the network without duplicate nodes will be smaller and easier to create.
  - *Removal of polyline crossings.*
    Polyline crossings will result in overlapping triangles and incorrect volume calculations.
  - *Removal of straight-line nodes.*
    Nodes on a straight line do not carry any value in the geometry of the outline. The user must enter a minimum segment slope difference for the node to remain. (This is the difference in angle of the two joined line segments.) Extra nodes will only result in extra nodes in the TIN and ultimately more triangles.

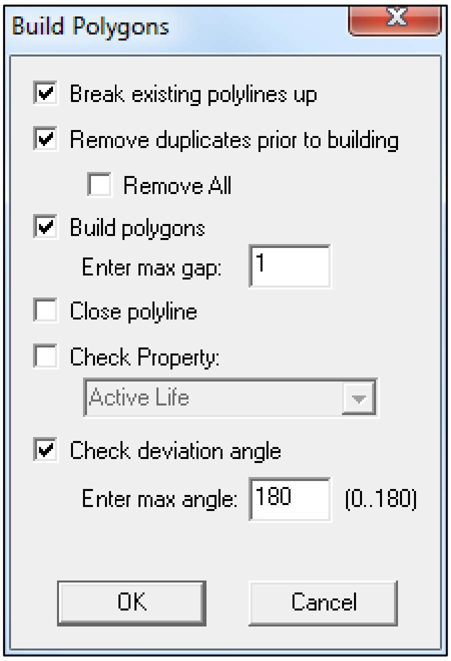


Figure 4-10: Build Polygons.

- Build Polylines
  - *Break-up polylines first.*
    This option allows WISH to break the outline up into two node segments
  - *Remove duplicate segments.*
    In the case of duplicate segments the duplicate will be removed

- *Build polygons.*
  A maximum gap must be entered – when the actual gap is smaller than the one entered here the two line segment are joined.
- *Automatically close polylines.*
  When building the polygon, the begin point and end point can be joined if they are at close proximity of each other.
- *Property filter.*
  When this filter is used only those segments that adhere to the filter conditions will be used in the building process.
- *Angle filter.*
  This filter will prohibit WISH to join polygon segment that would result in a polyline with sharp.

- Delete short lines.
  Some files carry many very short polylines – with this function all lines shorter than the specified length will be deleted.

Although many hours of work can be saved by using these functions, some manual map-editing will always be needed.

4.8 Map-editing

The primary task of WISH is to help the user with the interpretation of geo-hydrological data; therefor WISH is by default in Data Mode. When map editing is needed WISH must be put into Design Mode []. Nine extra tools appear on the secondary toolbar. For the tools to be active the current layer must be unlocked and visible.

The most basic editing tools are listed in Table 4-1 :

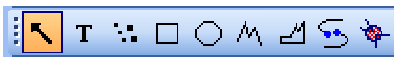


Table 4-1: Editing tools and their function

Tool	Function
Selection tool	To select, move and resize map-items.
Text tool	To enter new text.
Point tool	To insert new points
Rectangle tool	To draw rectangles
Circle tool	To draw circles and ellipses
Polyline tool	To draw new polylines
Polygon tool	To draw new polygons
Merge tool	To weld polylines together
Snap tool	By enabling this tool, objects drawn by the above tools will automatically snap to existing points/vertices if within the snap distance.

Map items can be selected by pressing the left-hand mouse button while positioning the mouse on the outline of the item. Multiple items can be selected by holding down the SHIFT key and selecting items as described above or multiple items can be selected by dragging a rectangle. Only those items completely inside the rectangle will be selected. Selected items can be recognised by a dashed outline, if the item has a fill colour the colour will change to grey and bounding box (rectangle) with eight handles will be visible. Once selected, the item can be moved by dragging to a new position. Resizing is possible by moving the handles around the selected item. Click outside the bounding box to de-select.

It can happen that parts of the outlines are missing. In such cases is it necessary to contact the mine again. If the mine cannot provide the missing part, the outline can be generated by drawing a new polyline using other information like dykes or pillars as guidelines.

All new items are drawn on the current layer. To enter text, select the Text Tool and indicate on the map the position. A pop-up window will appear where the text may be entered. Rectangles and circles must be drawn by indicating one corner holding the mouse button depressed, dragging diagonally to the opposite corner and releasing the mouse button. Polylines and polygons are drawn by moving the mouse and clicking the left-hand mouse button for every node, using a double click to stop drawing. In the case of a polygon the line will automatically close.

Polylines can, except for being moved around and rescaled, also be distorted. To change the shape of a polyline, select the polyline and from the context menu select *Node Edit* or press 'N' on the keyboard. The outline is displayed showing the nodes. The nodes may be moved by dragging, deleted by hovering above and selecting delete from the context menu or pressing the delete button. Nodes can be added by positioning the mouse on the segment, select Add from the context menu. When moving nodes, the distance moved must be at least 3 pixels otherwise the move will not be recognised.

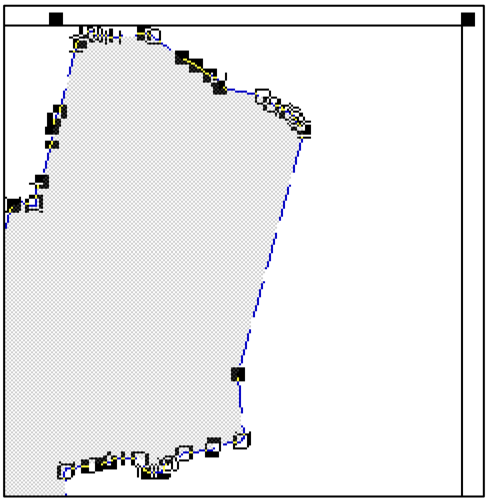


Figure 4-11: Detail of selected polygon in node edit mode.

Map Items can be moved or copied to other layers. After selecting the items, select from the context menu Layer…. And the Select Layer window will appear. Select the action, Move or Copy, select the target layer and click on the OK button.

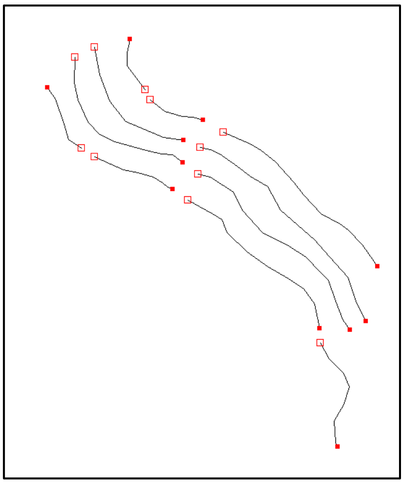


Figure 4-12: Merging polylines.

The last two tools in the list are not drawing tools. The tools are not used create new map-items. The merge tool is used to merge two or more polylines. The merge tool works, like all other drawing tools, only on the current layer. When turning the merge tool on all begin and end points from the polylines are display with red squares. The solid squares are the starting points and the hollow rectangles are end points of the polylines on the current layer. To merge two vertices select one and drag it to the other one. Alternatively a rectangle can be dragged over the two points. If only one point is in the rectangle or if there are more than two in the rectangle WISH will display a warning. There is no restriction in which points can be merged.

The snap tool enables snapping to closest points within a search distance allowing user to draw polylines where vertices draw exactly on top of existing points.

4.9 Format the map

After cleaning and building the polylines different formats for different features should be applied. This improves the readability of the drawing and errors will be easier spotted. During the formatting process the line colours, line types, point types and fill colours may be assigned. By default all items assume a formatting as specified for the layer. A sneak preview of the formatting can be found in the Layer list where the graphic in front of the layer name depicts the line colour and presence of a fill colour. To change any of the formatting for a layer, select the layer from the context menu select: Format… (Figure 4-2).

The dialog window consists of six panels depicted in Figure 4-13. These panels provide all formatting options available in WISH. Note that the Hatching dialog takes precedence over the Fill setting. This means that when a hatching is selected the fill colour is ignored.

To format an item different from the layer format, select the item and from the context menu select Format… The same dialog window will appear and another format may be assigned. When an item is formatted differently from the layer, any changes made to the layer format will not apply to this item. If the layer is included in the legend the format displayed in the legend will be the one from the layer.

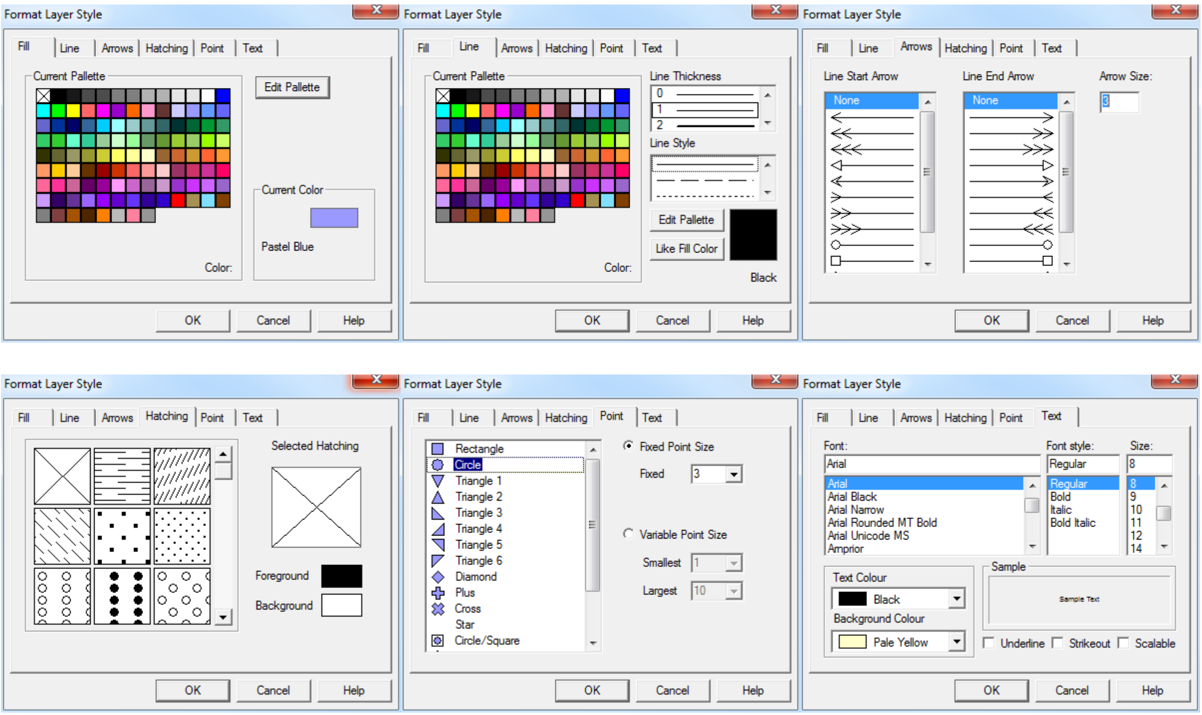


Figure 4-13: All formatting options.

4.9.1 Styles

WISH has built in formats called styles stored in a Style List. New styles may be added to the list and existing styles can be deleted. Styles can also be updated. Styles may be assigned to items on the map. When a style is modified and saved, all items that are formatted using that style, will also change to the new formatting.

4.10 Properties

Every item in the WISH map has a set of properties. These properties range from geometric properties to data and calculated properties. Calculated properties are calculated using other properties.

Properties can be examined in the properties window (Figure 4-14). The properties are split into four major groups:

- **Object properties**: displaying properties directly related to the item type and the geographical position and size.
- **Formatting properties**: alll formatting information from chapter 4.9 is duplicated.
- **Additional properties**: these are the properties not listed in the object properties group.
- **Favourite properties**: any of the listed properties can be promoted to the favourite property group to allw for quick lookup.

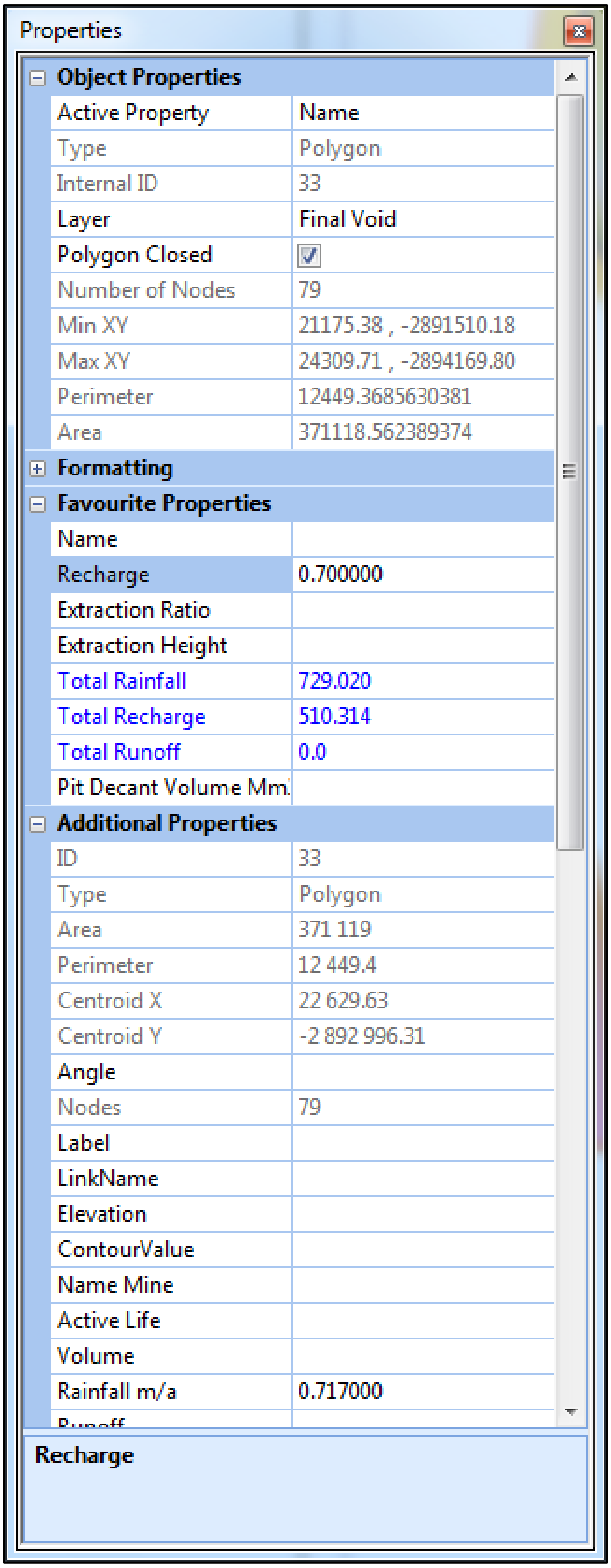


Figure 4-14: Properties Window.

The groups can be either expanded (vissible) or collapsed (hidden). To expand a collapsed group click on the + sign in front of the group name. To hide a vissible group click on the – sign. Values of properties displayed in black can be changed, values displayed in grey can not be changed and values in blue are calculated values.

The active property is the property that is displayed in a tooltip when hoovering the mouse on top of a map-item. This property can be changed to another property by double clicking on any existing property.

Properties can be managed using the Property Management tool MAP->MANAGE PROPERTIES... With this tool properties may be deleted from or added to the list. Properties can either text- or numerical values. The numerical values can be differentiated in integer values (whole numbers) or floating point values (number with a decimal fraction) or calculated values. Calculated values need to have an associated formula. Calculated values and the heading text are plotted in blue to ensure they are easy to spot.

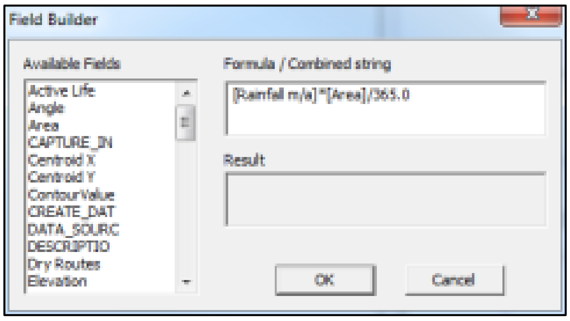


Figure 4-15: The Field Builder to create mathematical properties.

After adding a calculated value the actual calculation must be added. Select the property in the Properties pane. Click now on the button and the Field Builder will appear. The formula needed for the calculation may be entered in the Formula field using normal arithmetic symbols and double click on the Available fields for the parameters.

4.11 Create TINs

After creating a polygon the TIN may be generated.

The water balance calculations rely completely on the existence of contours (Grid or TIN). A Grid (squares) contour is not capable of following the outline of a polygon with the same accuracy as a TIN. These imprecisions will find its way further down the line when it comes to the volume calculations.

First step in creating contours is to select a polygon that will act as a boundary for the contour. To create grid contours select from the menu CONTOURS->GRID CONTOURS (SQUARES)...

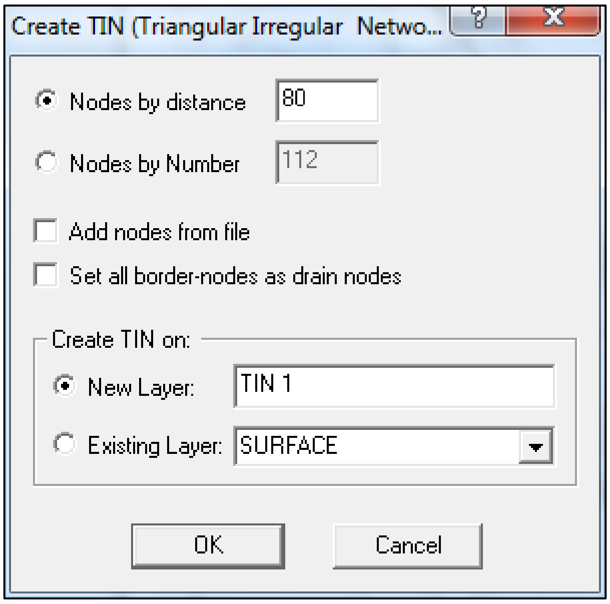


Figure 4-16: Create TIN.

The remainder of this chapter will only focus on the triangle based contours as this method is much more accurate than the square based contours.

Selecting the polygon and opening the context menu (click with the right hand mouse button) and selecting **Create TIN…** opens a window (Figure 4-16).

On the dialog either the distance between the nodes (horizontal and vertical distance is the same) or the number of nodes in a horizontal direction over the full width of the TIN must be entered. Special nodes may be added from a file and border nodes may be marked as drain nodes. By marking all nodes at the border drain nodes it is possible to determine what percentage of a surface is free draining. Note that the time involved to create the TIN depends on the number of nodes and the complexity of the outline.

The TIN created is only a placeholder for data without the data the TIN is transparent. To make the TIN workable, the grid is made visible and it looks like a lot of little triangles all glued together. To allow the TIN to grow to its full capacity data needs to be added. TINs can display data of almost any property, it could be a chemistry value measured at different locations in an area or it could be the rainfall measured at different rain gauges but most of the time the TINs in WISH are used to display an elevation. Actually any data that can be displayed in a contour map can be displayed as a TIN.

To add data the TIN needs to be selected first. From the context sensitive menu select Add Data…. The Interpolation Settings dialog will appear (Figure 4-17).

The data source to use can be either from the current data points, but only if data is attached, external data in x-y-z format or data from other TINs. The interpolation method used is the inverse distance weighting method where points close by carry more weight than point further away. The searching (or selecting) of points bounded by a radius and minimum and maximum points. The value can be assigned to the elevation of the TIN (only visible in 3D view), to the colour or to both (default).

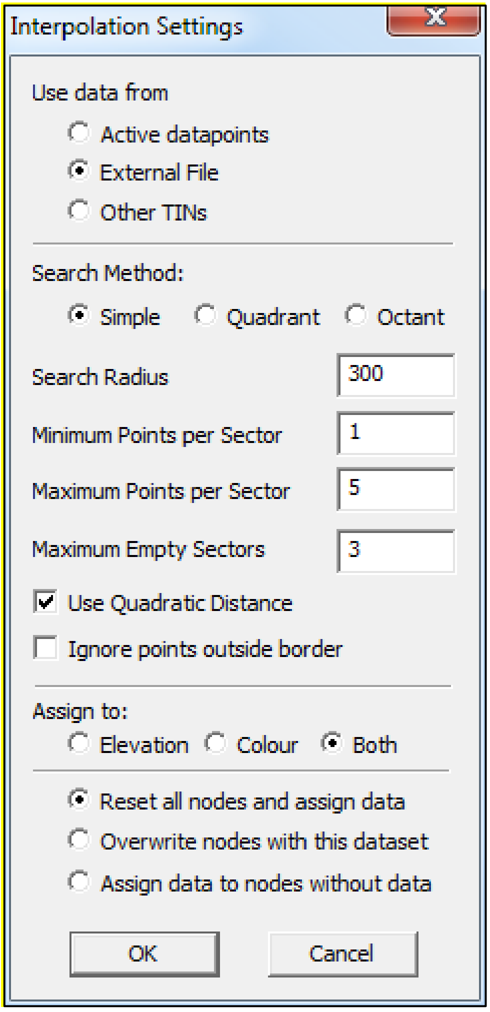


Figure 4-17: Interpolation Settings.

It is also possible to add data from more than one data source. Data can first be assigned from a regional data set and secondly be refined by more detailed localised data. The other way around is also possible where first local data is used and secondly regional data is added to the nodes without data.

When data from an external source is selected and the file is selected a window showing the first eight lines of the file will appear (Figure 4-18). This window must be used to specify the columns representing the X Coordinate, Y Coordinate and Z Values, to change the sign of the data, apply an offset and filter minimum and maximum values.

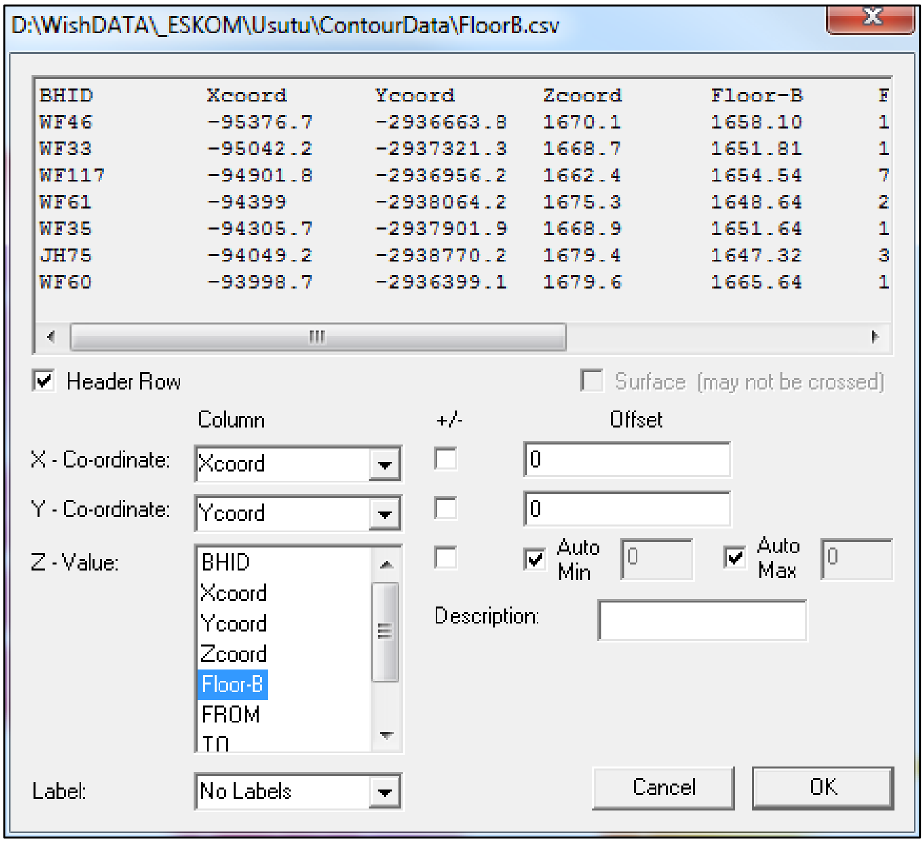


Figure 4-18: Contour External Data.

When data from other TINs must be used a different window will pop-up (Figure 4-19) where the user needs to specify one or two TINs and some basic mathematics between the specified TINs. This allows the user to assign contour values from existing TINs while performing simple calculations. Examples are: The creation of floor contours when only roof contours and mining height are available or the calculation of a roof thickness by subtracting a roof contour from a surface.

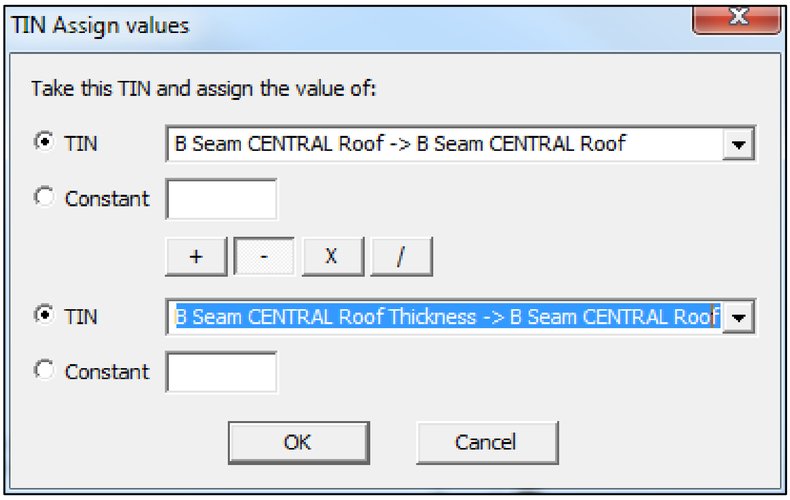


Figure 4-19: Values from other TINs.

4.11.1 Contour colours

After the data has been added to the TIN, colours need to be assigned to make the values visible. By default the colours are assigned, warm colours (red, orange) for high values and cold colours (cyan and blue) for low values. To adjust the colours and intervals select *Contour Levels…* from the context menu (Figure 4-20). By default the minimum and maximum values as well as the interval is automatically assigned. To change the interval click on the levels button and adjust minimum, maximum and interval values. To change the colours click on the Colours button. This will allow changing the colour scheme to a colour ramp (a gradient of colours from one colour to another). Double clicking on a colour or selecting a colour and clicking Modify allows for editing of a single value and colour. Values can also be deleted or added. Using the Add+ button will generate values in between all existing values while mixing the colours to create new colours. The title in the title field is displayed when a legend for this contour is created.

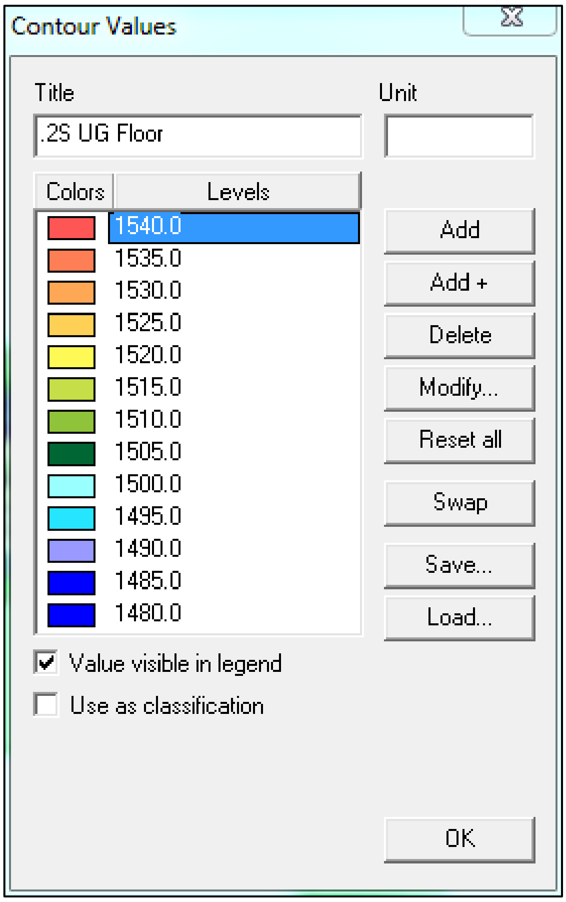


Figure 4-20: Contour Values.

The save button allows for saving the current scheme. Loading a previously saved scheme can be done by pressing the Load… button. This option is created to ensure consistency in colour <-> elevation assignment.

NOTE: A TIN cannot be re-sized or moved around. If a TIN is needed at a different location a new TIN must be generated.

4.11.2 Posting the data

To determine what data is used to create a contour value the data used must be posted. Select Show Posting from the context menu. Only external data can be posted. When moving the mouse over a TIN with posted datapoints, those points used to calculate the contour value at the mouse position will light up

4.11.3 Showing vectors

To emphasize the direction and the steepness of a slope WISH has the capabilities to superimpose arrows on top of a TIN. The arrow is drawn in the direction of the sloop and the length of the arrow is the slope steepness indicator (the longer the arrow, the steeper the slope) (Figure 4-21).

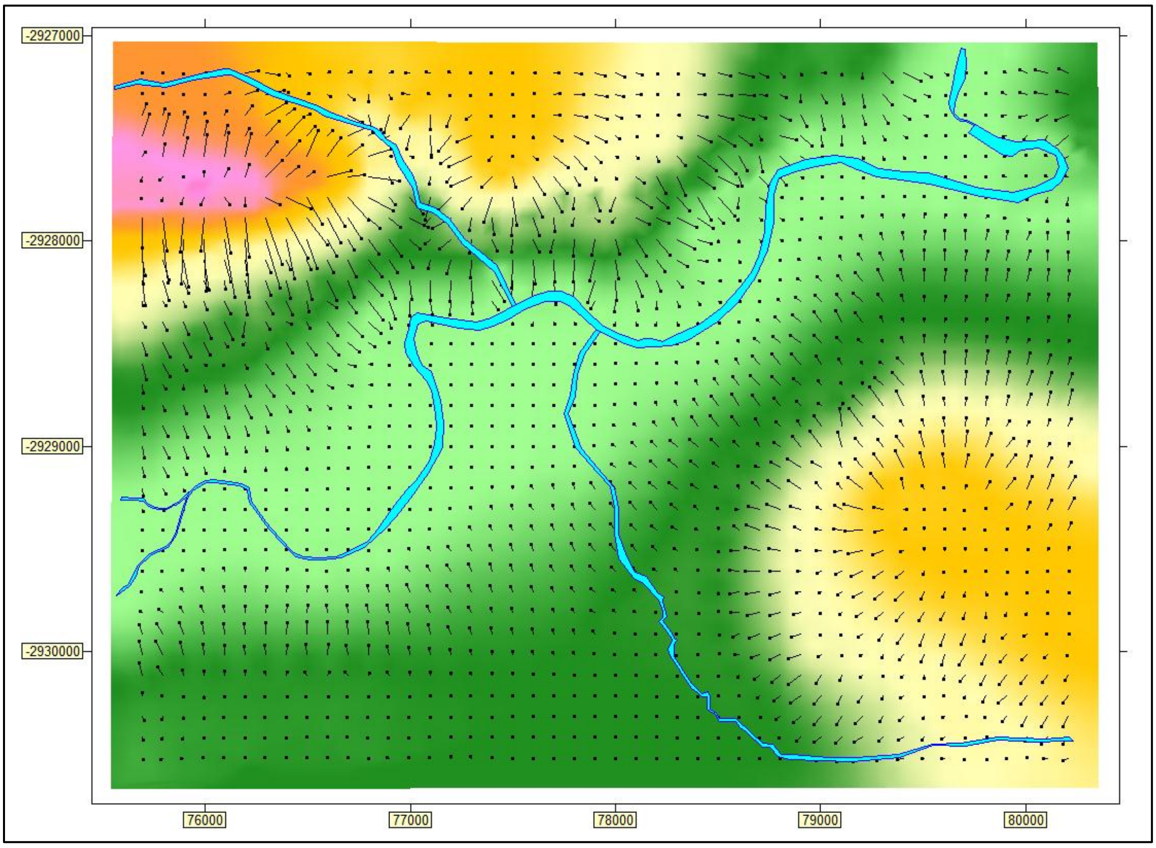


Figure 4-21: Example of surface contours with vectors enabled (WISH Demodata)

4.11.4 Isolines

To create Isolines (contour lines where the z-value is the same for all vertices of the line), select CREATE CONTOUR LINES… from the context menu. The lines are generated on the current layer (the layer in bold in the layer control). Optionally the layer may be cleaned before the line generation starts. Line generation can be for a specific contour value, only the visible levels (visible in the legend) or all defined levels.

4.12 Cross sections

A cross-section in WISH is an intersection of a 3D body with a vertical plane. To create a cross-section a polyline (the cross-section line) must be selected. This is the line that will act like the vertical plane. From the menu select SECTIONS->CREATE... A window, similar to the interpolations settings window from the contours, will appear (Figure 4-22).

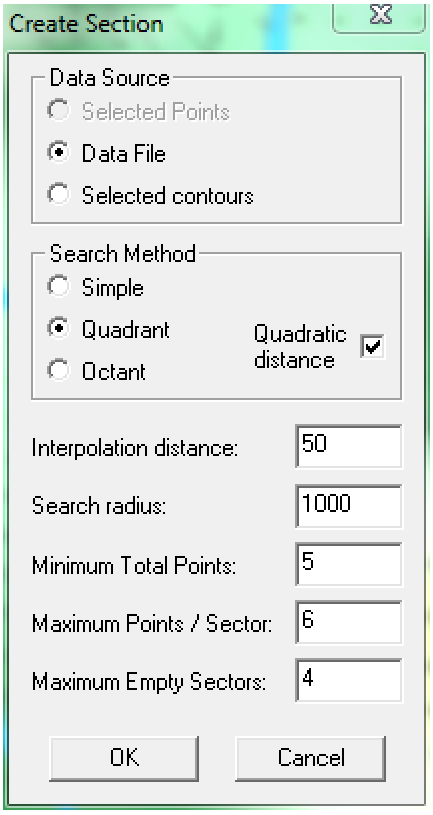


Figure 4-22: Create Section dialog.

The data source to use can be either from the current data points, but only if data is attached, external data in x-y-z format or data from selected contours. When the active data points or points from an external source are selected the interpolation method used is the inverse distance weighting method where points close by carry more weight than point further away. Searching (or selecting) of the points bounded by a search radius and minimum and maximum points. The interpolation distance in the dialog is the distance between the calculated points on the cross-section line. When the selected contours option is specified as the data source all other options except for the interpolation distanced are no longer available as no interpolation will be performed. Values for the cross-section are directly sampled from the selected contours.

When data from an external source is selected and the file is selected a window showing the first eight lines of the file will appear (Figure 4-18). This window must be used to specify the columns that represent the X Coordinate, Y Coordinate and multiple Z Values, to change the sign of the data, apply an offset and filter minimum and maximum values.

In most cases it is easier to create a cross-section from selected TINs. To use this route create the TINs, one for each feature, next select the layers containing the TINs in the Layerview window. Now select the cross-section line and create the cross-section as explained above. When retrieving the data from selected TIN's the creation of the cross-section is very fast.

After creating the cross-section, the mouse cursor will change in square. Use this to indicate the position of the cross-section on the map. The section will draw itself at the indicated position. When moving the mouse cursor across the cross-section an inverted four arrow cursor will indicate the mouse cursor's position in plan.

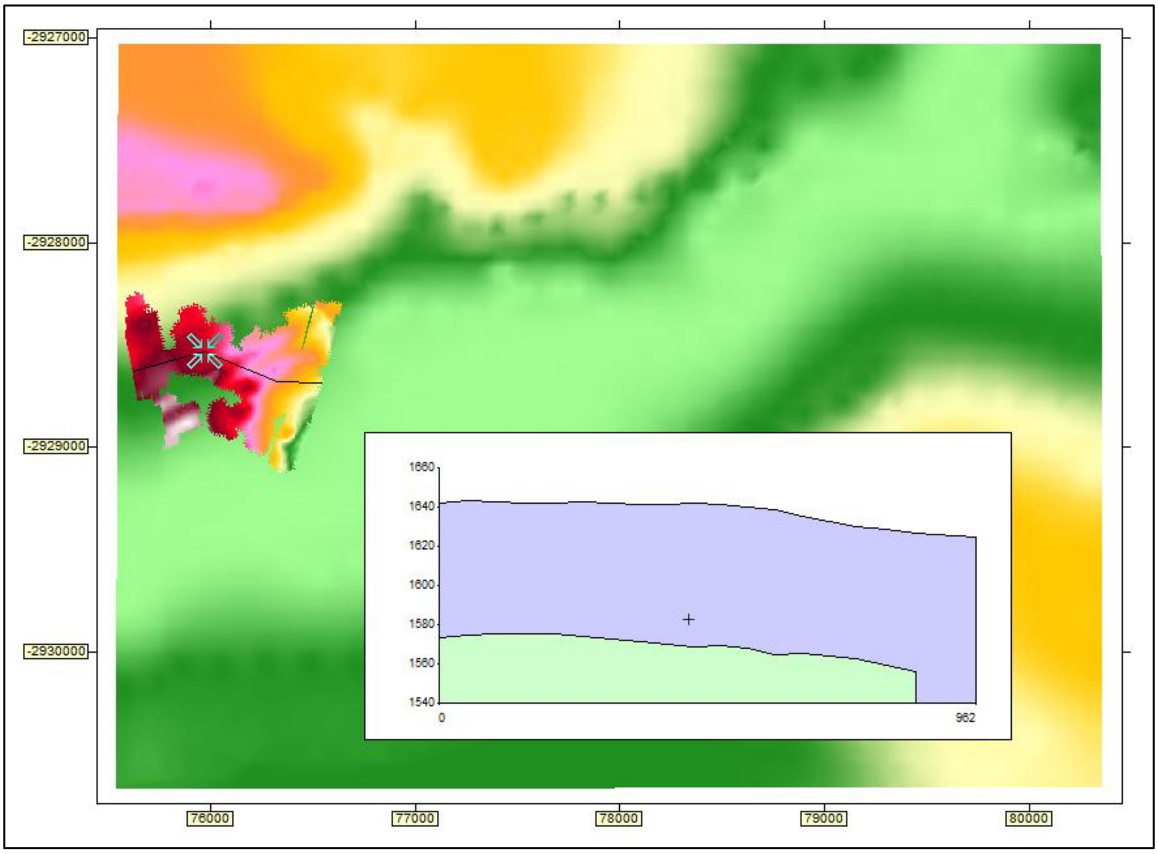


Figure 4-23: A dual layer cross-section (WISH Demodata).

4.12.1 Editing of cross-sections

A cross-section is a miniature WISH drawing. The object contains layers and items inside the layers. Each cross-section layer or TIN is a layer inside the cross-section object. Editing cross-section is possible by selected Edit from the context menu. The contents of the layers control will change to the layers inside the cross-section. Although the information in the cross-section cannot be altered, it is possible change the formatting of each layer. An example is displayed in Figure 4-23.

4.13 Stage curves

The TIN is the basis for all water balance related calculations. To create a stage curve, first generate a TIN using the outline of the mine cavity (opencast or underground) or select an existing TIN and from the context menu select Stage Curve….

A stage curve will be created with the default parameters (Figure 4-24). To change the default settings select Options… from the context menu. In the *Stage Curve Options* window the Title may be set. The x-axis may be multiplied with a porosity factor. In a rehabilitated opencast the backfilled material can never be as consolidated as in the virgin ground. Mine backfill contains a substantial percentage, by volume, of large macro voids. The void volume may equal the spoil swell. Porosity values of 16 % to 23 % have been recorded by field measurements in mine spoils in the coalfields. (Rahn, 1976; Hawkins, 1998). In an underground mine there is no backfill material. For an underground it is necessary to keep pillars inside to maintain a stable roof.

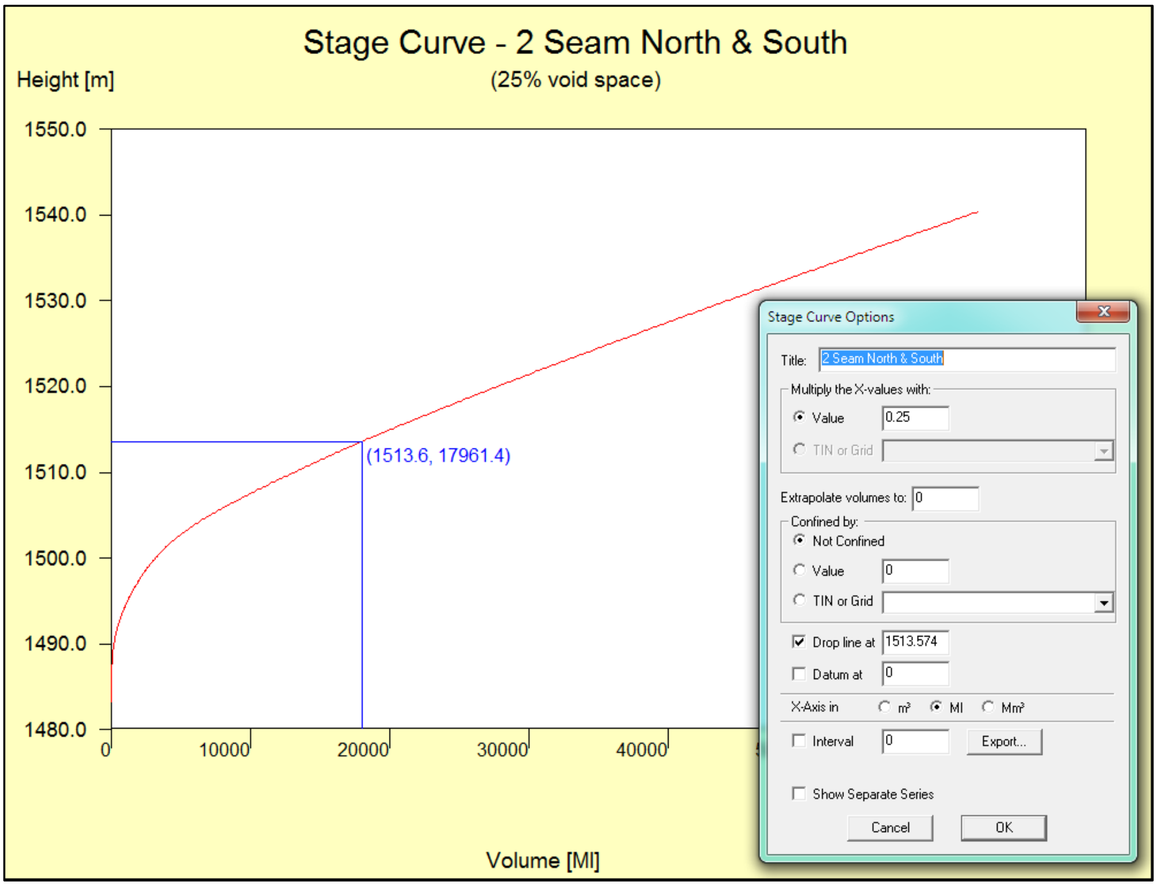


Figure 4-24: Sample of stage curve with the options dialog.

Depending on the depth of mining and the type of rock more than 30 % to 50 % stays behind in the shape of pillars resulting in porosity values between 50 % and 70 %. When detailed drawings with pillar information are available the porosity can be calculated. When a stage curve is created for the first time it is calculated from the elevation of the pump intake to the highest point on the contour. To stop calculation on a lower or higher elevation the *Extrapolate volumes to* field must be entered. An underground mine consist of two layers, a floor and a roof. Any water inside the mine is confined between these two layers. Creating the stage curve should always be done from the floor contour. Using either the roof contour as the confining layer or a single mining height value can be used. A dropline can be added to the graph showing the intersection between the elevation and the curve. The height and volume values of the intersection are added to the graph.

4.14 Water distribution

Water distribution is calculated using the WACCMAN option. WACCMAN stands for Water Accounting & Management. Although WACCMAN is an extension of WISH, WACCMAN is not available for the general user. The only way to obtain WACCMAN is as part of a water balance research project for the colliery. Using an existing TIN and one or more water level elevations WACCMAN can calculate where and how much water is standing on the surface.

To start select a TIN (floor contour) and from the context menu select WACCMAN. The WACCMAN dialog will appear. In order to calculate standing water, *Water Control Points* (WCP) needs to be added to the map. Click on the Add button; indicate on the TIN where a water level elevation is known; add the water level elevation in the Z-Value filed and click on the calculate button.

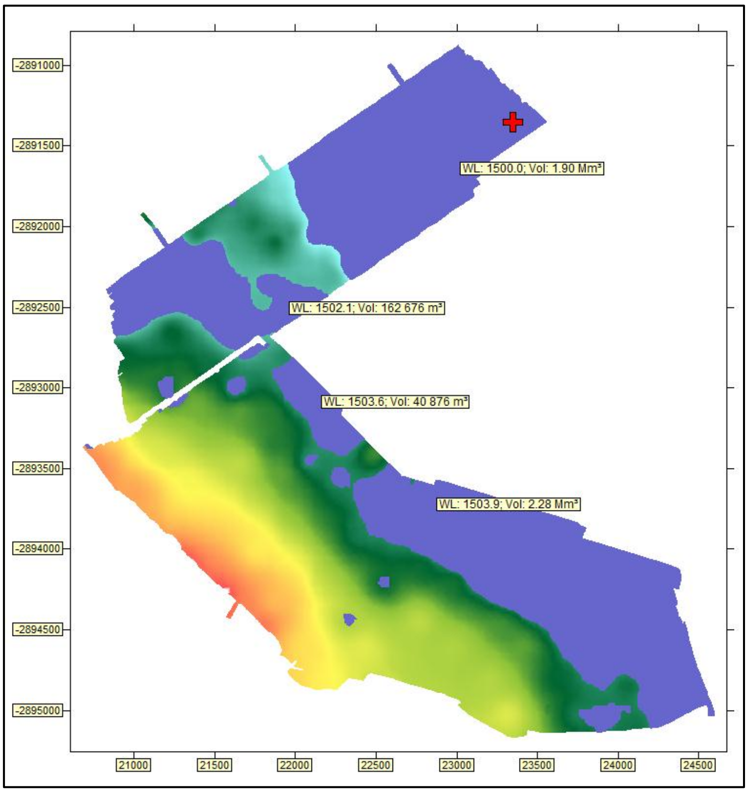


Figure 4-25: Water distribution in an opencast mine showing the WCP as a red cross.

WACCMAN will flood the entire TIN till an elevation equals to the highest point on the TIN and start taking away water at the WCP letting all the water “flow” towards the WCP until the system is in equilibrium and no more water can be removed by the WCP (Figure 4-25). The map will display the places still flooded in blue. If more than one WCP is entered the lowest and WCP have conflicting water level elevation information the lowest elevations are maintained. If there is a water level elevation conflict it means that the information about the surface is not complete. Barriers like a local highs or seals and walls may exist but are not incorporated in the TIN.

After calculation the WACCMAN dialog (Figure 4-26) will display information such as the total water area and water volume. If a decant value is specified the total water capacity can also be calculated. The dialog allows for entering the confining value or layer and the void space percentages.

When WACCMAN is used to manage water in underground mines it is possible to keep haul way passages dry either by inserting numerous WCPs or by drawing path ways on a separate layer and selecting the layer in the *Layer to keep dry* pull-down box.

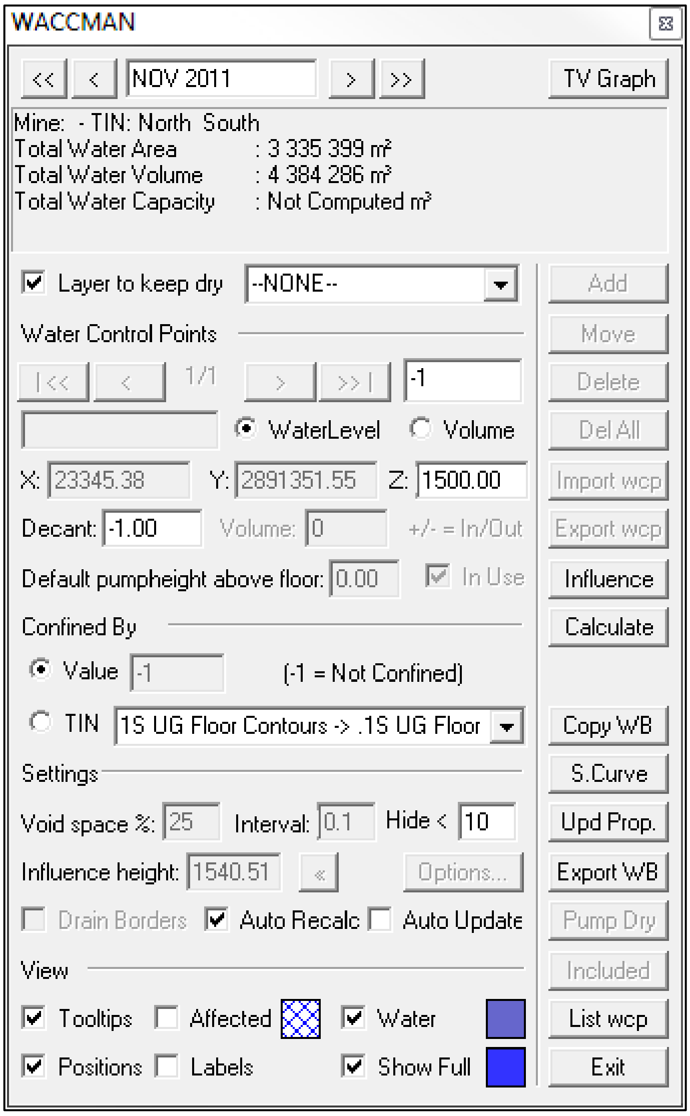


Figure 4-26: The WACCMAN dialog.

View settings in the WACCMAN are toggles for tooltips, WCP positions, affected area, labels, water area and, for undergrounds only, an indicator displaying in a darker blue whether the body is filled to the confining layer. If the mouse is moved over any of the water-bodies a tooltip will pop-up displaying a water level elevation and a pond volume. On the status bar the same information is displayed plus the contour level and the WCP responsible for the water level elevation at that position.

4.15 Special objects

Apart from the cross-section WISH has another four special objects that can be inserted onto the map.

- North Arrow
- Scale Bar
- Legend
- Co-ordinate Grid

To insert the North Arrow select from the menu Map->North Arrow and now indicate the position by dragging a rectangle on the map. To insert a scale bar select Map->Scalebar and follow the same procedure. Both items will be plotted on the current layer using the format of the layer. The scale bar changes its intervals and values if the scale bar is resized.

A drawing is not complete without a legend explaining the features in the drawing. WISH is capable of creating a legend based on the layer information in the Layer Control. The legend can be inserted by select Map->Legend from the menu. The legend is generated on the legend Layer. If the layer does not exist it is automatically created. On the layers which are flagged to be inserted in the legend will be used. Use the layers context menu in the Layer Control to specify if the layer must be listed in the legend. Fill- and line colours are taken from the layer formatting. Items on layers with different formatting than the layer itself will not be displayed in the legend.

To insert a co-ordinate grid select Map->Create Grid from the menu. The grid is created on a separate layer called Grid Layer. If the layer does not exist it is automatically created. The grid is by default auto scaling. This means that it continuously calculates the extent of the visible drawing and adjusts the co-ordinate grid accordingly. Using the properties window these default setting can be changed to a manual grid size. A manual grid can be sized to specific need. The tick marks may be changed to Outside, Inside or Cross. Grid interval can also be adjusted. If the grid is smaller than the extent of the drawing the draw inside only option may be selected to blank everything outside the grid (Figure 4-27).

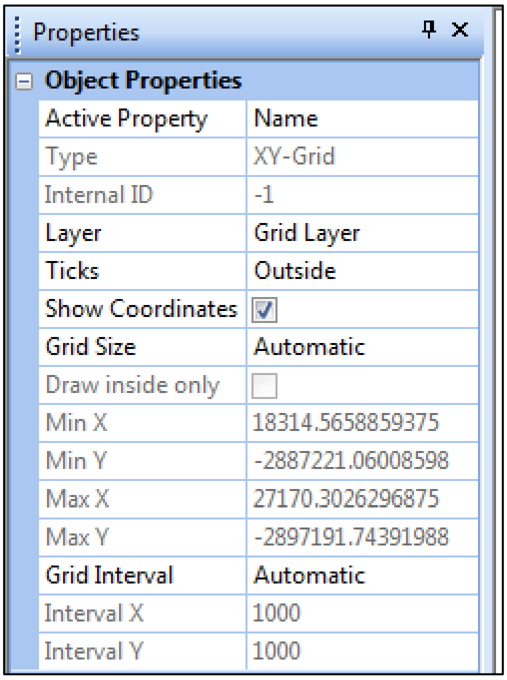


Figure 4-27: Properties window displaying grid settings.

4.16 Create the Excel file

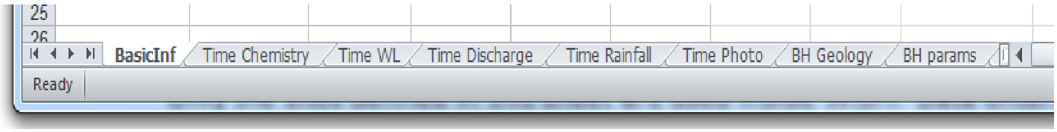


Figure 4-28: Example of tabs in an Excel data file for WISH.

WISH can handle a number of different data formats but Microsoft Excel is the one used most often. The main reason for this is that “everybody” knows Excel. The file must be created according to the example supplied. WISH uses an Excel file as if it is a relational database with the worksheets inside the file as the tables inside the database, as displayed in Figure 4-28, and the columns in each table as the fields in the tables. Special care must be given to the *SiteName* column. The *SiteName* field (column) is mandatory in each table (worksheet) as this is the field used to link the data of each worksheet to the correct sites.

4.16.1 Basic Information

The Basic Information sheet “BasicInf” is the most important worksheet of the complete excel file. Only the sites defined in this sheet are used inside WISH. Data entered in the other sheets without a reference in basic Information will be ignored. Any static data, data that does not change in time or depth, like farm name, farmer’s name, collarheight, location description can be stored here.

The SiteType is a single character code are displayed in Table 4-2.

Table 4-2: Site type codes

Sitetype code	Description	Symbol displayed
B	Borehole	Circle
S	Surface monitoring point	Square
N	Weather station	Triangle

4.16.2 Time Chemistry

To populate the “Time Chemistry” worksheet, water samples are taken and sent to a laboratory that in turn replies in the form of a report and accompanied by a dataset in excel format. The data must be copied into the WISH excel file. Values that are lower than the LQD (Lowest Quantity Detectable) are shown as a value preceded by a smaller than sign: <value. The ‘<’ character is not part of the numerical value. For WISH to read these values WISH must tread every value as text, scan the text for smaller than signs, remove the sign and convert the text to a value and flag the value as a smaller than the LQD value. This process take a lot of computing time and slow down the whole reading process considerably. To overcome this problem WISH uses a minus sign to indicate values smaller than LQD. The negative value does not create a conflict as negative concentrations do not exist. Internally WISH will change the value to a positive one and flagging the concentration as one below the LQD.

4.16.3 Time WL

All water levels measured should be stored here. The actual value stored is the distance from the reference to the water level. The reference could be the top of a casing. The height of the casing above the surface is stored in Basic Information as *CollarHeight*. The water level elevation is calculated by WISH. (Water level elevation = *ZCoord* + *CollarHeight* – water level)

4.16.4 Time Rainfall

All rainfall values must be stored in this sheet. According to the weather bureau of SA rainfall is always measured at 08:00 every day and the unit is mm. Days without rainfall are not recorded.

4.16.5 Time Photo

Sometimes the need arises to store one or more photos for a site. In WISH this may be done by entering information in the Time Photo work sheet. A *SiteName* and a *DateTimeMeas* is needed as well as a title and a path to the file. If the photo is stored together with the project data only a relative paths is needed.

4.16.6 BH Geology

When geology information is available the data must be entered into the BH Geology worksheet. This will enable the user evaluate the down-the-hole data together with the geology. The data can also be used to create 3D surfaces from the different lithology layers.

4.16.7 BH Params

A multi-parameter down-the-hole probe is an essential tool when working in coal mining industry. It measures multiple parameters while lowering the probe. Common parameters measured are Electrical Conductivity, Dissolved Oxygen, Oxidation Reduction Potential, Temperature and pH. These parameters may be entered in the BH Params worksheet.

4.17 Attach the data

When a new project is started it is good practice to perform a hydro-census for two reasons:

- The latest information is gathered
- A better understanding of the area is gained.

During the hydro-census boreholes and other sampling points are located and their position recorded. Water levels are measured water samples are taken for analysis and if the borehole is on top of an underground mine EC profiling is performed. Most of the time the data is recorded in Excel spread sheets simply because this is the most convenient way of storing data. Not all monitoring sites are created for the same reason. Some of the different purposes are:

- Irrigation boreholes
- Drinking water
- Stock watering
- Monitoring boreholes
- Meteorological monitoring

After the map has been created and the excel file prepared the data may be attached to the WISH project. From the menu select FILE->ATTACH DATA->EXCEL DATA… and select the prepared data file. If the one or more data points are located outside the current map extend the user will be offered the option to enlarge the drawing extend to include all data points. If this option is declined, all data points outside the current map extend will be ignored. After attaching the data WISH and no parameter has been selected WISH will try to display the EC (Electrical Conductivity). EC is the default parameter as this is a good indicator of the water quality (Freeze and Cherry 1997).

The sites are displayed in different colours. Sites can either be selected or unselected. Unselected sites do not have a colour (only the outline is visible). Selected sites have are blue and when the parameter displayed is compared against a standard the sites are displayed in green, yellow or red (Table 4-3).

Table 4-3: Comparison colours

Site Colour	*Selected*	*Description*
Blue	Yes	Value is not compared to a standard
Green	Yes	Value complies to the standard
Yellow	Yes	Value is marginal
Red	Yes	Value in outside the standard
Transparent	No	

4.18 Parameter selection

To change between parameters click on the parameter button  and in the Parameter Window double click first the table and secondary the column in the table.

4.19 Site selection

As discussed not all the sites have the same purpose in life. For this reason it is necessary to select only the relevant borehole for each analysis. The process of turning boreholes on and off is called the site selection. In WISH there a four ways to select sites:

- Automatic
- Double clicking / dragging
- Polygons
- Site selection dialog

These methods are discussed in the following four chapters.

4.19.1 Automatic selection

The automatic site selection is based on the availability of data. When selecting another parameter WISH will first deselect all sites and automatically select only those sites with data. This is the default site selection method.

4.19.2 Selection by double clicking and dragging

To select a single site move the cursor above the un-selected site (the site is transparent) and double click. The site will change from transparent to opaque indicating that the site has been selected. Repeat the same actions to deselect the site.

To select more than one site depress the left-mouse button and drag the mouse cursor across the map. The status of the sites within the dragged rectangle is toggled. All selected site will be deselected and all deselected site will be selected.

4.19.3 Selection by polygon

To change selection status from site inside a polygon, move the cursor to the edge of the polygon and click with the right-hand mouse button. From the context menu select:

1. Datapoints->Select Select only the points inside the polygon (clearing the selection first).
2. Datapoints->Add Add all datapoints inside the polygon to the selected set.
3. Datapoints->Remove Remove all datapoints inside the polygon from the selected set.

4.19.4 Selecting sites using the site selection window.

Selecting data points using the site selection dialog is the most powerful way of selecting sites (Figure 4-29).

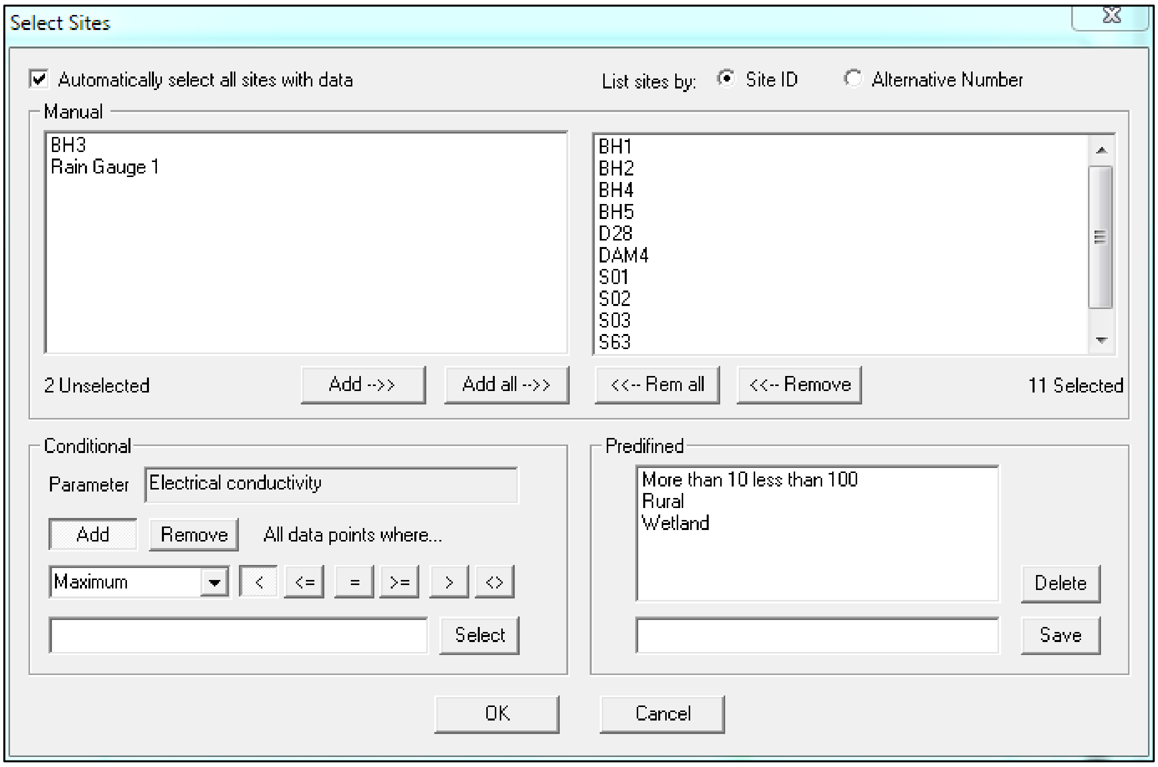


Figure 4-29: Site selection dialog.

Sites can be moved from the unselected list to the selected one just by double clicking on the sitename in the unselected list. Selected sites can be added to the unselected list by using the Add button or be removed by using the Remove button. Conditional site selection or de-selection is also supported by this window. The conditions are all related to the current parameter and the following properties can be compared:

- Statistical: maximum, minumum, average, last value, # records
- Non-statistical: SiteName, alternative name (AltName), string value

Any selected set can be saved as a predefined set for fast selection.

4.20 Time graphs

Time graphs can be created from any of the time dependent parameters. Using the timegraph button all selected sites are used to create the time graph. Should only one site be used in the Time Graph, move the mouse over the required data point and from the context menu select Time Graph (Figure 4-30).

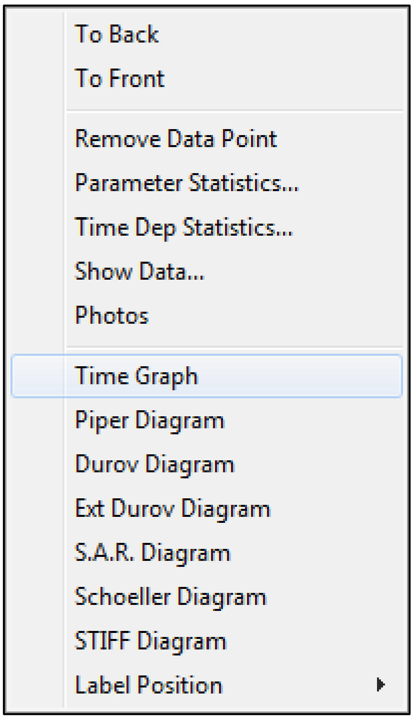


Figure 4-30: Datapoint context menu.

The time graph is created using the default settings. It is the philosophy of WISH to produce a time graph with default setting, and allow the user to change settings if required (Figure 4-31). The context menu enables the user to change the graph to a scatter plot or a bar plot. The bar plot can be adjusted to display average data or total data per time unit. WISH uses the hydrological year to calculate the annual average or annual sum. The hydrological year can also be changed from this menu. In WISH the default hydrological year is the same as the calendar year.

The current standard name together with the standard values can be found just below the title in red. The graph uses a background colours. Points within the green part are in compliance with the standard. Points in the yellow part are marginal and the points in the red part are outside the standard. The standard can be turned on or off with the standard button. WISH has also the capability to display percentiles on the time graph. An upper and lower percentile is calculated. The percentiles parameters may be changed by selecting from the menu DATA->PERCENTILES->DEFINE. To use percentiles click on the percentile button.

Both scales can be adjusted. To adjust the y-scale: click on the y-axis with the right-hand mouse button and select the Format Axis option. Adjust the minimum and maximum values as required. The axis can also be turned into a logarithmic axis and it can have a reversed scale.

The x-scale can be adjusted in a similar manner, clicking on the x-axis and adjusting the first and last date on the axis.

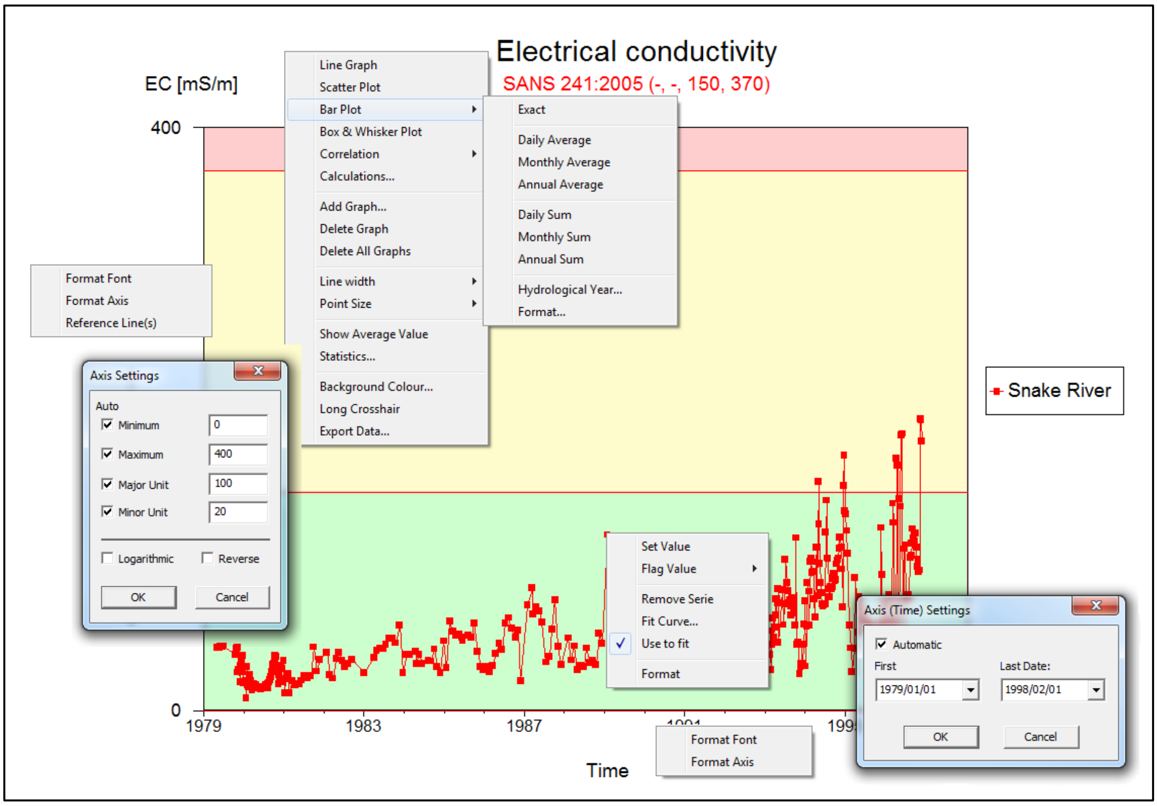


Figure 4-31: Time Graph with context menus.

Graph can be added by selecting Add Graph… from the context menu. This will show the Parameter dialog where the table and parameter to be added must be selected. Only the time dependent data is available. There is no fixed limit on the amount of parameters to be added. Parameters may be removed from the graph by selecting Delete Graph from the context menu. Selecting DELETE ALL GRAPHS will delete all graphs except the bottom one as this is the first one.

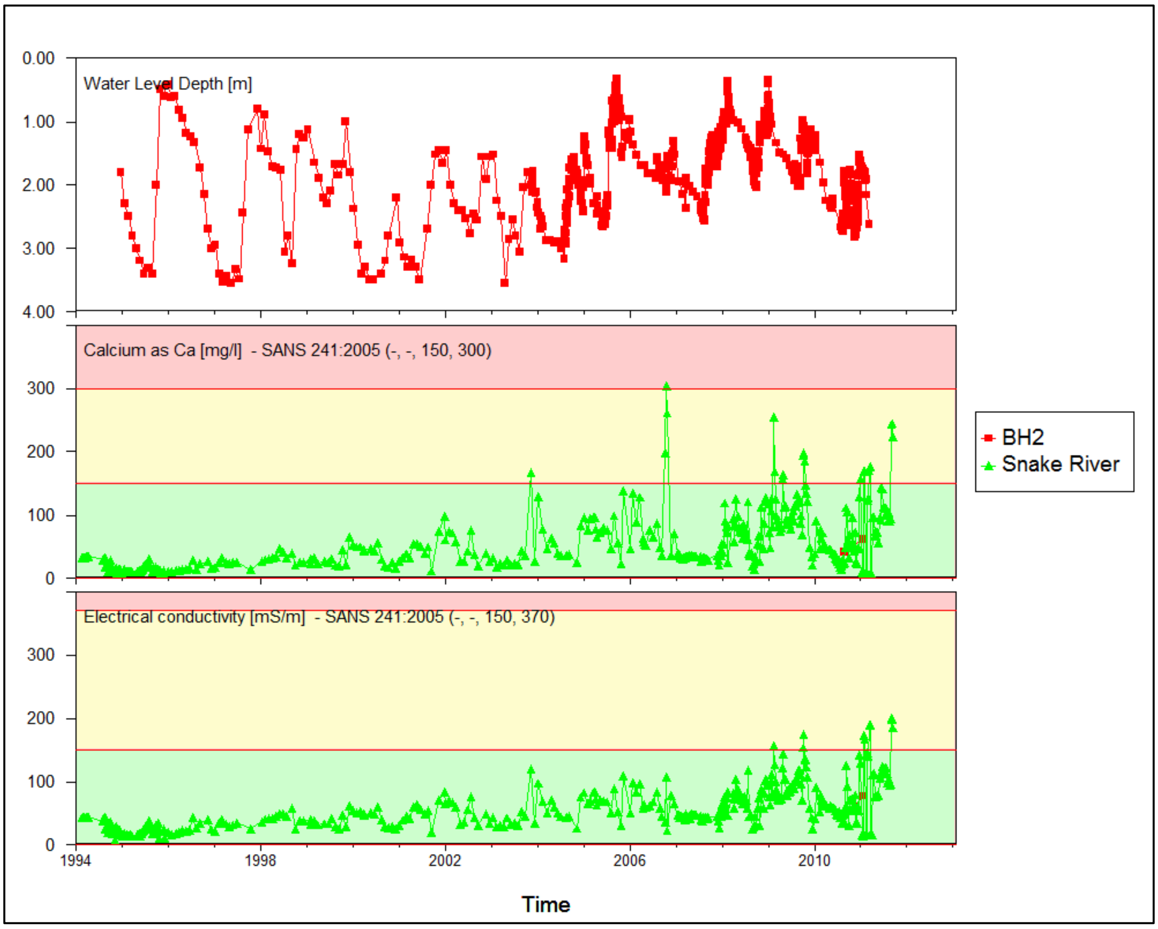


Figure 4-32: Time graph with multiple parameters for multiple sites.

4.21 Specialised chemistry diagrams

Specialised chemistry diagrams plot simultaneous a number of chemical variables. The diagrams include in WISH are Piper (Piper 1944) , Durov (Durov, 1948, Zaporozec, 1972), Expanded Durov (Burdon and Mazloom, 1958), SAR (United States Salinity Laboratory, 1954), Schoeler (Schoeller, 1935) and STIFF (Stiff, 1951).

To generate these any of these diagrams select the sites to be used in the diagram and select

- Piper
- Durov
- Expanded Durov
- Sodium Adsorption Ratio
- Stiff
- Schoeller

The selected diagram will be created using a colour coding to indicate standard compliance. Using the context menu several options may be applied to customise the diagram. When the standard is turned off a colour coding according to the different sites will be used. Alternative name can also be used. When it is possible to group monitoring points according to any parameter it is also possible to colour code the points on the chemistry diagram according to the grouping. To visualize the difference between recent and older samples a colour ramp according to date and time can be generated. Due to the nature of the trilinear plot and the projection to the diamond in the Piper diagram or the squares in the Durov diagrams it is possible for data to hide behind other points. This can be rectified by switching and/or rotating the anions and the cations triangles. Just a word of warning NOT to publish these pictures as this will confuse the reader. To check the validity of the analysis the Ion balance error can be displayed and as a visibility aid reference lines can be added.

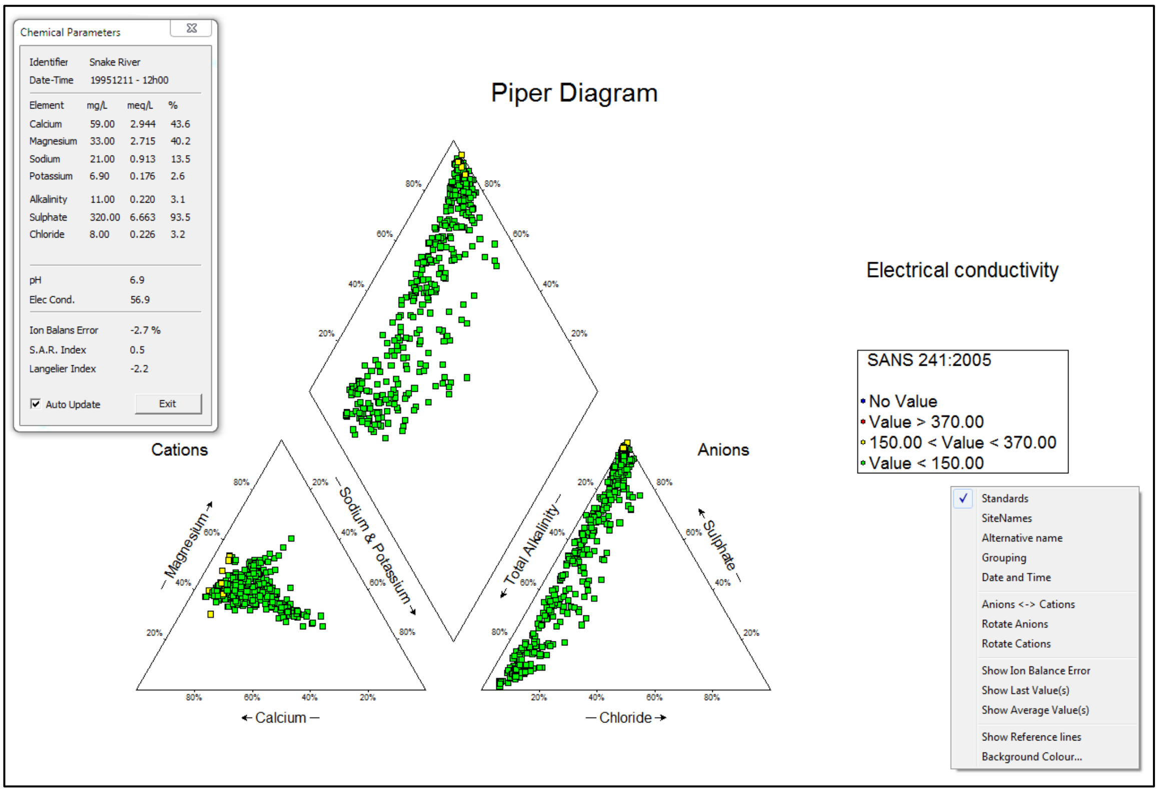


Figure 4-33: Piper diagram with Chemical Parameter window and context menu.

By double clicking on any of the data points a Chemical Parameters window appears (Figure 4-33). This window displays vital information to the chemical composition on that data point. It displays the parameters in mg/l, meq/l and as a percentage.

4.22 Borehole logs

The borehole logs in WISH, see Figure 4-34, display all the data that is measured in down-the-hole. Every parameter is displayed in a separate graph. Any of the parameters may be hidden from view by moving the mouse cursor onto the graph selecting the *Hide Series* option from the context menu. The lithology column may be customized to display colours and hatchings as required. These changes are global and modified colour schemes will be applied on all future lithology logs. The fonts used in the geology column may be altered to fit the user's needs. Each of the columns may be adjusted in size. Move the mouse cursor between two graphs, the cursor changes to a double arrow (pointing left and right) and the size of the two adjoining graphs can be altered. Graphs may be smoothed by using a moving average smoothing technique. If readability is low due to a very detailed geology the length per page may be adjusted. This will result in multiple pages per log.

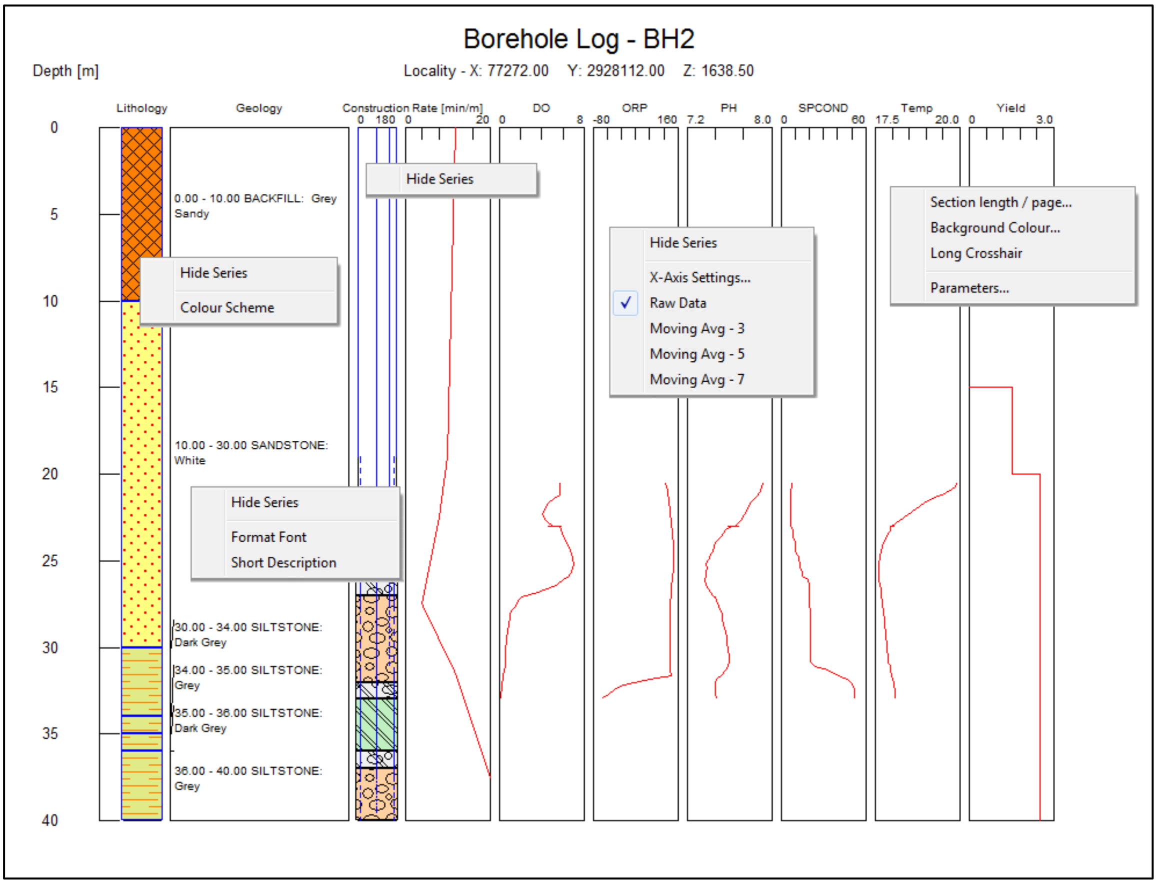


Figure 4-34: Example of a borehole log with all context menus super imposed.

4.23 Pumping Tests Evaluations

To perform a pumping test select from the parameters the pumping tests and water levels. Make sure that the AUTOMATIC SELECT POINTS WITH DATA is tagged.

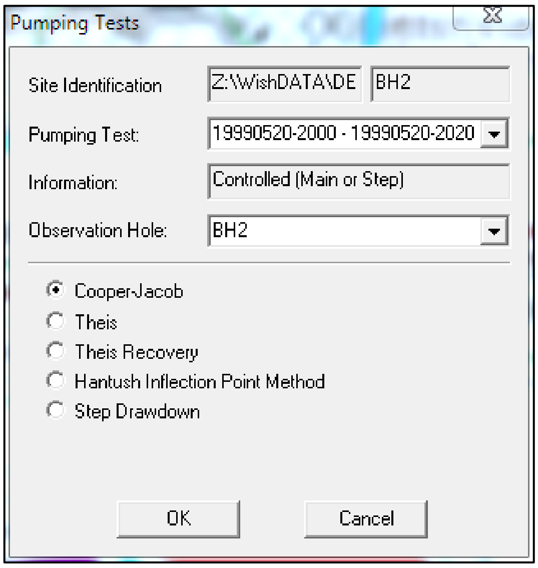


Figure 4-35: Pumping Test selection window.

All data points with pumping test data will be selected and have a blue colour. Move the mouse cursor over one of the selected data points and click the right-hand mouse button. The pumping test dialog (Figure 4-35) will appear where to pumping test and observation hole must be selected as well as the pumping test type to be performed and click on the OK button.

The data will be accessed and the graph for the pumping test evaluation is created. The scaling is automatic. Transmissivity and storage are calculated and displayed.

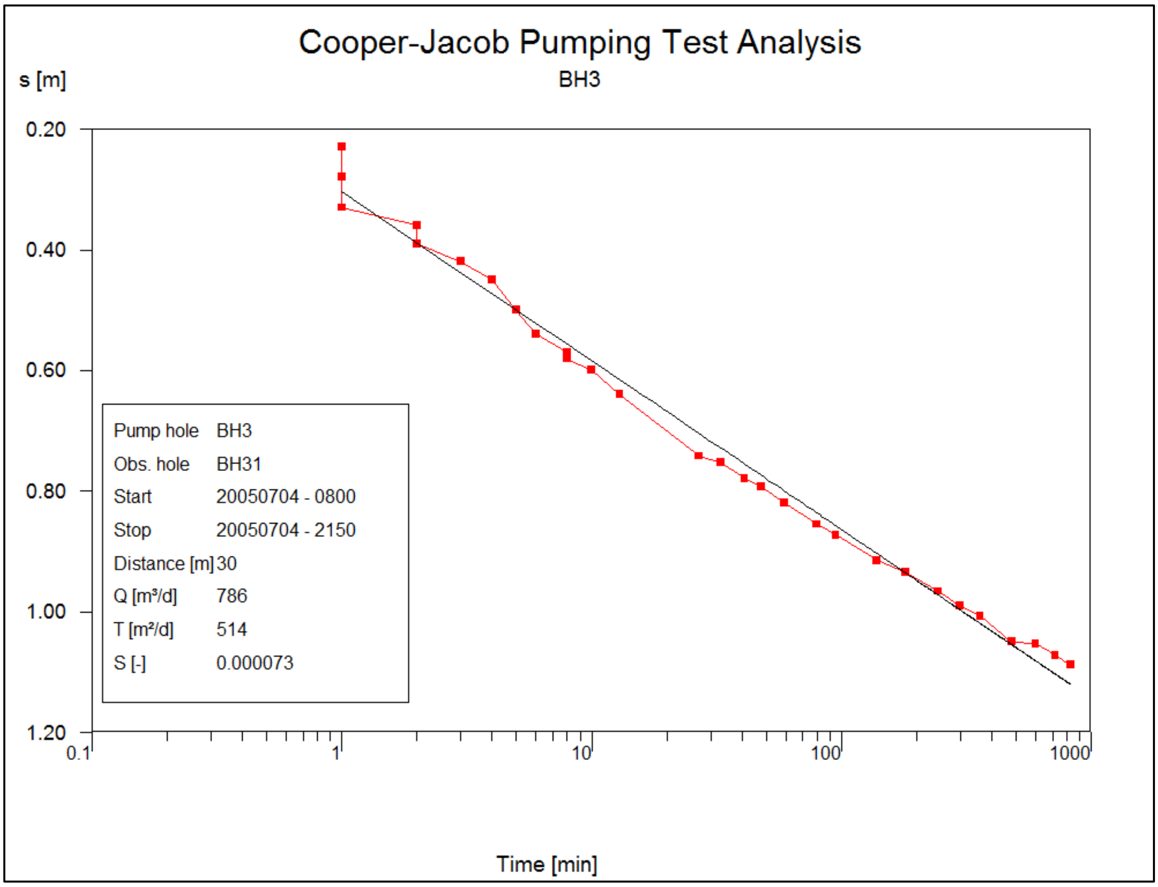


Figure 4-36: Cooper-Jacob Pumping Test Analysis.

By default all points in the dataset are used in the calculations. Double click on a point or drag across one or more points will disable them. Double click on a disabled point or dragging across a few disabled points will enable them. To enable all points select *Reset all Points* from the context menu. The calculations are automatically updated after each action (Figure 4-36).

Chapter 5 Recharge from rainfall and decanting

Mine decant is a currently a very sensitive topic in South Africa. The Oxford English Dictionary defines decant as: "To pour off a liquid by gently inclining the vessel so as not to disturb the sediment". This implies that the flow must be slow. In an opencast mine decant is the overflow from mine water out of the (rehabilitated) pit, in the case of an underground mine when water in a shaft borehole or crack rise to the surface. WISH can calculate, given a few parameters, average daily values for run-off and recharge. These values can be used in the identification of a suitable underground storage compartments, the design of a surface storage dam or the design of a treatment plant. Given the outline of an opencast mine together with the detailed surface contours WISH is able to predict the position of decant.

5.1 Opencast mines

Formal research into the recharge on rehabilitated opencast is not performed. The industry in South Africa uses the recharge rates suggested by Hodgson and Krantz (1995). A new project sponsored by Coaltech investigating the recharge at rehabilitated opencast will start in 2012. The project will focus on the different type of rehabilitation, compaction of the spoils, thickness of the topsoil, sloping of the surface and vegetation.

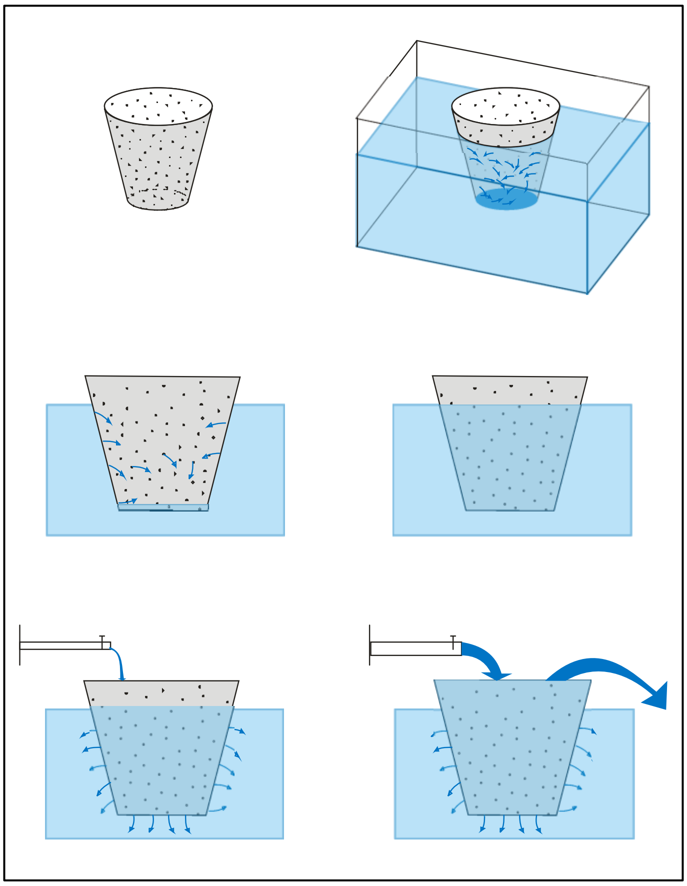


Figure 5-1: Opencast bucket model.

The rehabilitated pit can receive water from rain falling directly on the rehabilitated spoils, the final void and ramps. Rainfall resulting into run-off can flow onto the rehabilitated spoils, the ramps and into the final void. Depressions in the surface will allow for standing water.

An opencast mine is like a bucket with lots of little holes in the sides. Placing the bucket in a pool of water will result in water flowing through the holes into the bucket. The rate at which this happens is, besides a few other parameters, highly dependent on the difference of the water levels inside and outside of the bucket and the size of the holes. Water will continue to flow until the water level inside and outside the bucket are the same. When a little bit of water is added to the bucket the water will leave the bucket through the holes and will stop flowing when the water levels inside and outside are the same again. When the holes are really small this can take quite a while. When a lot of water is quickly added to the bucket, water will not be able to flow through the little holes and the bucket will start to overflow or decant (Figure 5-1).

For a rehabilitated opencast in an unconfined, homogeneous and isotropic aquifer without any precipitation and evaporation it is impossible for the opencast mine to decant. The water in the pit will continue to rise until equilibrium is reached between the water level in the pit and the water level in the surrounding rock. Water entering the opencast at the upstream side will leave the pit downstream (Figure 5-2).

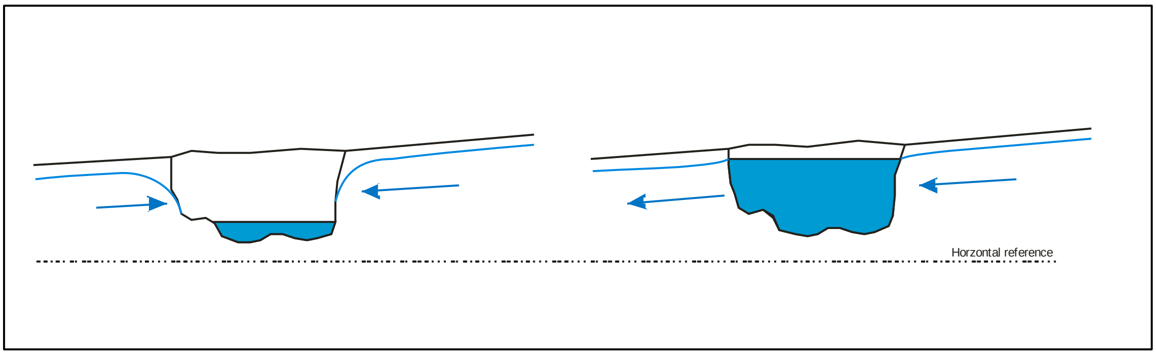


Figure 5-2: Rehabilitated opencast pit without rainfall and evapotranspiration.

The same opencast mine but now in an area with rainfall and evapotransporation but without run-off will never decant as long as the evapotransporation is higher than the rainfall. The water level in the pit will fluctuate depending on the rainfall events (Figure 5-3).

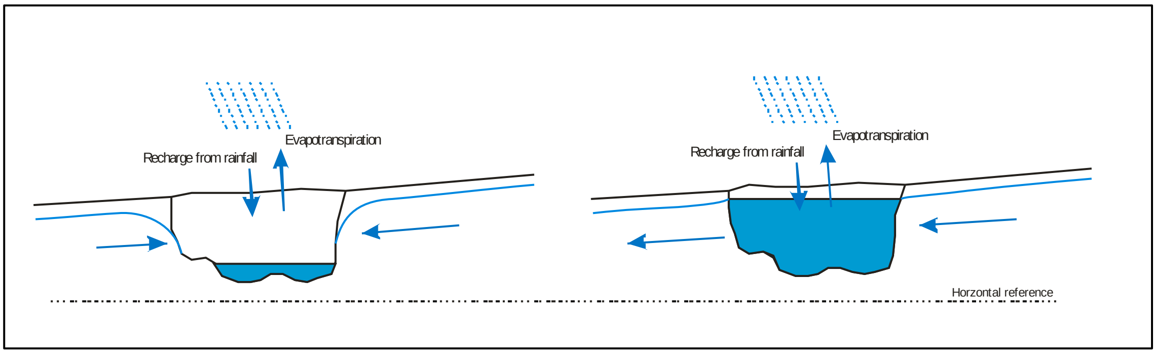


Figure 5-3: Rehabilitated opencast pit with rainfall and evapotranspiration but no run-off.

Adding run-off to the scenario changes the picture drastically. The run-off from the surrounding areas towards the rehabilitated spoils and the higher porosity of the spoils, which result in a higher hydraulic conductance, allows for a faster recharge of the spoils (Figure 5-4).

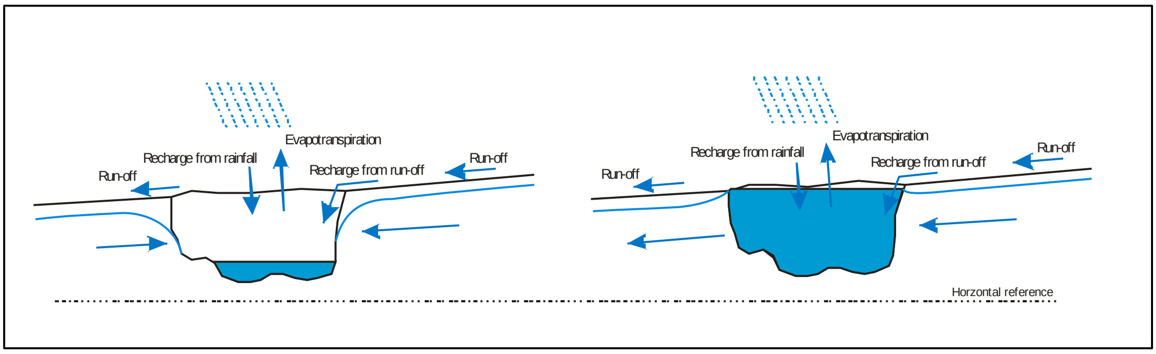


Figure 5-4: Rehabilitated opencast pit with rainfall, evapotranspiration and run-off.

It is therefore important to determine the extent of the area receiving precipitation that can run-off into the rehabilitated pit. This way a volume of water that can enter the pit may be calculated. To minimize the amount of water in the pit the rehabilitation must be constructed that no water from surrounding areas can run-off onto the rehabilitated pit.

5.2 Underground mines

Underground mines can receive their recharge water from the overlaying strata (fed by rainfall) and from lateral flow through the sides. Water moves more easily in the same direction as the layering in contrast to flow perpendicular to the layering ($K_h >> K_v$). Shallow underground mines with total or high extraction are in danger of collapsing roofs resulting in subsidence on surface creating cracks from the surface down to the underground allowing water form ponds on surface and water to flow down from surface into the underground (Figure 5-5).

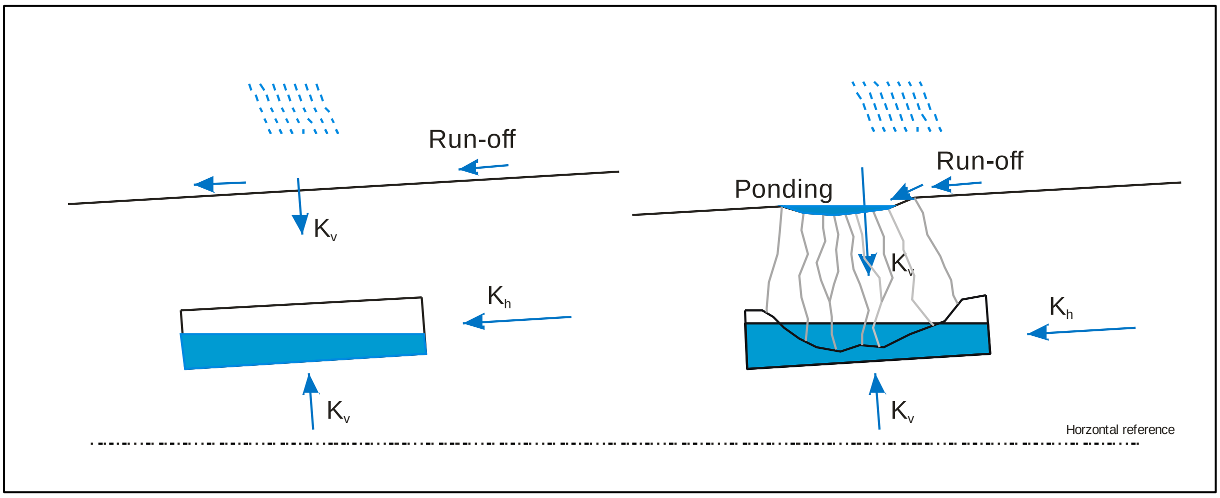


Figure 5-5: Underground mines with and without subsidence.

When a direct connection between the surface and the underground void does not exist the recharge into the void needs to flow through the rock. When the underground workings are not flooded water will enter the void from all sides. Water will flow very slowly through the floor and roof into the void and more easily through the sides. This process will continue until the water pressure inside the working and pressure in the rock is in equilibrium (Figure 5-6).

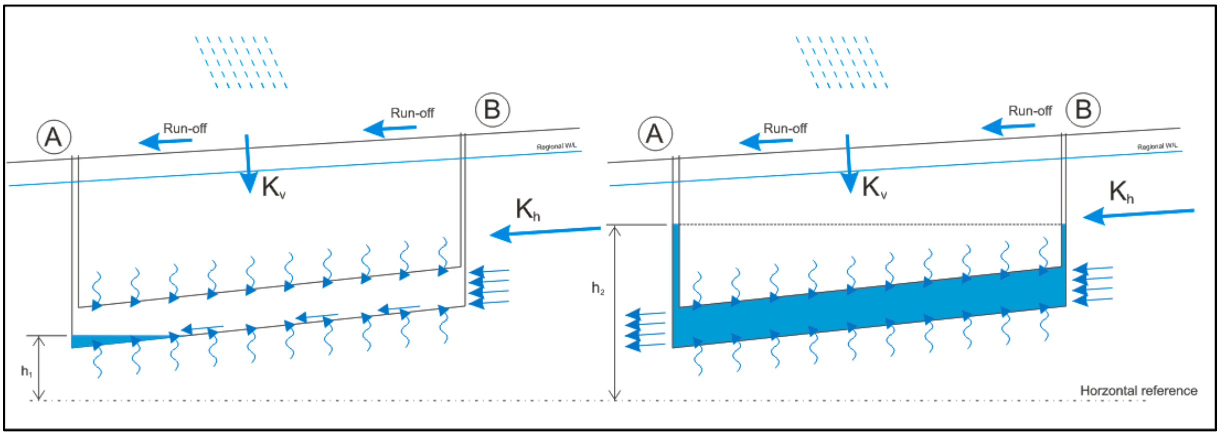


Figure 5-6: Underground workings filling with water.

The hydraulic conductivity of the underground void is much higher than that of the surrounding rock. Water will try to follow the path of least resistance and flow through the workings at a faster rate hereby lowering the pressure inside the workings on the upstream side (B) and creating "space" for extra water to enter from floor and roof. At the downstream side of the workings water can leave the filled void with the same rate at which it entered. The extra water will experience congestion when leaving the underground mine (A), the water pressure will be elevated and the extra water is forced back through the floor and roof into the surrounding rock.

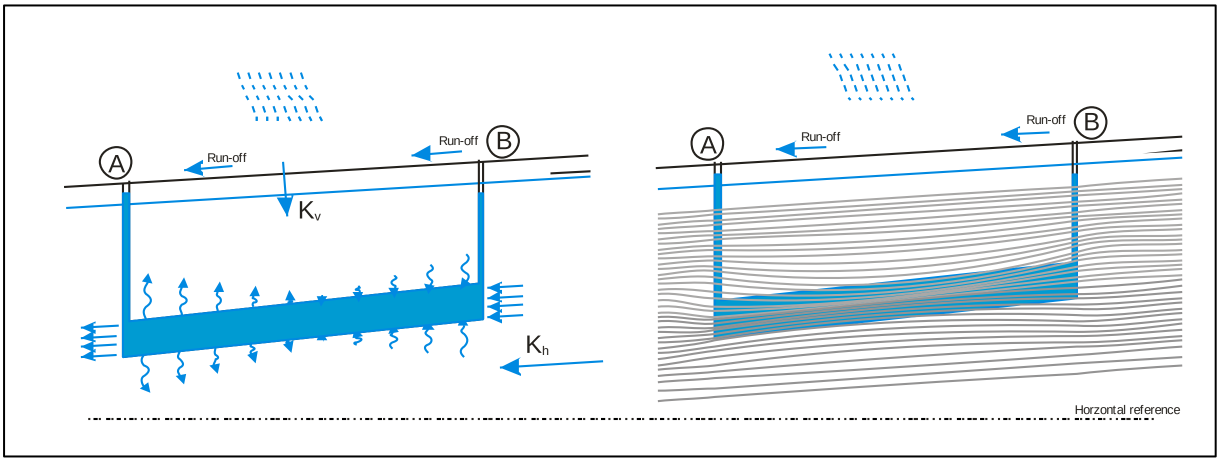


Figure 5-7: Underground working completely flooded with mine void / formation interaction.

The elevated pressure will result in a higher water level elevation. Figure 5-7 the interaction between the groundwater in the mine void and in the formation. A larger throughflow area at the downstream side of the underground will make it easier for the water inside to flow back into the surrounding formation, lowering the pressure and the water level elevation. Removing boreholes-casings at the downstream side is one way of enlarging the throughflow area.

Chapter 6 Using WISH

Interpretation of geohydrological data using WISH (Windows Interpretation System for the Hydrogeologist) is mostly done by the creation of thematic maps, and time series graphs and specialised chemistry graphs. A case study is used to explain the steps needed to create a report.

6.1 Case study: Hydrocensus and groundwater investigation at Usutu Colliery

Usustu is an underground coal mine where active mining has stopped between 1987 and 1990. The mine is expected to be completely flooded. An adjacent open cast mining operation has bought the mining rights and plans to open cast a part of the existing underground.

6.1.1 Plotting data spatially

In the first few chapters of the study relevant background information, the scope of work, the methodology and a location map is shared with the reader. Many of the interpretations are done by the creation of thematic maps. To start a project the first map that should be created is an introduction map depicting the area of interest together with some features so the client can orientate himself. For this project the location map exists of a 1:50000 topographic map with the underground mining and the monitoring points superimposed.

Using the surface contours together with the mine layout is used to describe the surface hydrology. The contours are displayed in 2D and 3D figures.

When an Excel file is attached monitoring (data) points are superimposed on the map. The data can display anything that was measured and entered into the excel file. Borehole data will be plotted as little circles and surface monitoring points will be plotted as squares. The first parameter that will be plotted after the data is attached will be the electrical conductivity. By default the last values measured will be displayed but this can be replaced by highest, lowest or average values. Other parameters may be selected from the list of available parameters (P). The fixed size for the data points can be replaced by a variable point size where the size of the point is in direct relation to the value it represents. Data points may be selected and deselected. Deselected points can be hidden from view leaving only the selected points visible. The selection process can either be automatic (based on the availability of data) or it can be created manually. Selected datasets may be saved for future use. (Figure 7-1, Figure 7-21, Figure 7-22, Figure 7-31, Figure 7-40 and Figure 7-41).

6.1.2 Time series data

All time related data may be plotted on a time dependent graph. WISH automatically calculates the minimum and maximum values for the horizontal time-axis and the vertical axis. Invoking the time graph from the toolbar creates the graph for all selected sites. Invoking the time graph from the map by positioning the mouse above a data point, clicking the right mouse button and selecting *Time Graph…* a time graph for just that particular site will be created. Multiple parameters can be shown simultaneous on the graph by adding parameters. The different parameters will be stacked on top of each other resulting in a graph with one shared time axis and one vertical axis for each parameter. This makes it possible to compare multiple parameters within one graph (Figure 7-2, Figure 7-20, Figure 7-27, Figure 7-28, Figure 7-29).

6.1.3 Detailed maps

To understand the layout and the connectivity between compartments in an underground it is necessary to create a detailed map of the underground with the position pillars, ventilation walls, seals, shafts, faults and dykes displayed. High extraction areas must also be marked on the map as these are areas where subsidence may be expected.

6.1.4 Contour maps

Visualisation of 3-D information is done by using contours. Contours are created using TINs (see chapter) and assigning values. These contours can be displayed in a 2D or 3D mode. Multiple contours may be generated and overlaying contours can be displayed simultaneously in a 3D mode. The values assigned to the TINs may be assigned from a current attached data set or from external data in X-Y-Z format. If the source data is already available in other TINs contour data can be calculated using the one or two existing TINs. One example of a calculated contour can be the roof thickness of an underground mine.

6.1.5 Chemical analyses / specialised chemistry plot

WISH allows the user to create chemistry diagrams just with one click of the mouse button. The expanded DUROV diagram displays the chemical composition of each monitoring site. Stiff diagram were also created for each of the sites.

6.1.6 Borehole logs.

Borehole logs cannot only be used to display lithology and geology but profile information like EC and temperature can also be used. The EC values give a clear indication as to the depth of the mine below surface as the EC values rise as soon as the mine cavity is entered. The temperatures measured, although displayed in the report, are not important as the difference between the minimum and maximum values is less than one centigrade.

6.1.7 Water balance calculations

Using the capabilities of WISH to subtract two contours from each other the remaining thickness and recharge was easily determined. Water bodies were calculated using the layout of the mine and the measured water level elevations. Taken into account the position of the ventilation walls it was possible to compartmentalize the complete underground.

Stage curves were created for each underground indicating for each water level elevation the volume of water in present in the underground.

Chapter 7 Hydrocensus and groundwater investigation at Usutu Colliery

7.1 Introduction

A groundwater study was performed and the results processed by the Windows Interpretation System for the Hydrogeologist (WISH) for Usutu Mine as part of an investigation to determine the current status quo of the colliery. Vunene Mining currently operated an opencast mine above the old Usutu Colliery, and also plan to mine underground in future. It is therefore important for Eskom, the current owners of Usutu, to understand the current geohydrology of the mine for future liabilities during mine closure. Usutu is applying for partial closure (Usutu East and South), and also needs to know what the current groundwater status in both the north and south mines are.

The coal mine has been flooded (recharged) with water as the production has stopped between 1987 and 1990.

7.2 Scope of work

This task covers the water quality and quantity monitoring project which is mandatory requirement as stipulated in the National Water Act and forms and integral part of the legal requirements of the Minerals Act.

The following tasks were identified:

- Site visit to collect all the existing and new data
- Development of the existing WISH database
- Assessment of groundwater network
- Set up of an appropriate conceptual model and construct a model to estimate the interaction between all components that could have an influence on the groundwater of the area as well as the surface water
- Inter-mine flow
- Write of report

It was foreseen that a numerical groundwater flow and mass transport model may only be developed if deemed necessary. Currently the investigators are of the opinion that such a model is not needed, and that a conceptual model, analysing the measured data, will add more value to the investigation.

Collecting and interpreting field data: Field data are essential to understand the natural system and to specify the investigated groundwater problem. The numerical model actually develops into a site-specific groundwater model when real field parameters are assigned. The quality of the simulations depends largely on the quality of the input data.

Conceptualising the natural system: In each model study the natural system is represented by a conceptual model. A conceptual model includes designing and constructing equivalent but simplified conditions for the real world problem, which are acceptable in view of the objectives of the modelling and associated management problems. Transferring the real world situation into an equivalent model system, which can then be solved using existing program codes, is a crucial step in groundwater modelling. The following is included in a model:

1. The known geological and geohydrological features and characteristics of the area.
2. The static water levels / piezometric heads of the study area.
3. The interaction of the geology and geohydrology on the boundary of the study area.
4. A description of the processes and interactions taking place within the study area that will influence the movement of groundwater / minewater, and
5. Any simplifying assumptions necessary for the development of a numerical model and the selection of a suitable numerical code.

Intermine flow model: Calculations regarding the intermine flow between Usutu Colliery and the anticipated new mine in the remaining reserves will be done with the WACCMAN component of WISH.

7.3 Methodology

The following methodologies were used to sample the boreholes during the hydrocensus:

- Measuring water levels

An electronic dipmeter was used for this operation to determine the depth of the water level below the collar of the borehole. It is important to always measure this from the collar of the casing, ensuring uniform measurement.

- Water sampling

Sampling included either a sophisticated pressurized depth sample or a flow-through bailer (depending on the depth of the sample).The bailer was cleaned with de-ionised water before each sample was taken. The samples were stored in 500 ml plastic bottles and transported to the IGS laboratory for analysis.

It is essential that samples should always be taken at exactly the same depth in order to obtain a uniform estimation of the true water quality.

- Chemical analyses for macro- and micro-parameters as specified by the contract were performed by the laboratory at the IGS.

Inorganic parameters:

pH, EC, Ca, Mg, Na, K, P-Alk, M-Alk, Cl, SO_4, NO_3,PO_4. Si, Al, Fe, Mn and B

- Profiling was also performed on a number of mine boreholes to determine if any stratification occurs.

The greatest challenge in this investigation was the fact that no data was available electronically. All data (hundreds of maps) had to be digitized, borehole logs had to be analyzed and retyped into an electronic database from which the different seam contours, overburden depths and surface contours could be contoured. All old ventilation seals and high extraction mining was digitized, and historical water data, as well as current data, was compiled in a database. This resulted in a number of mine visits and meetings to get the conceptual model to a satisfactorily level; it meant that the conceptual model changed a number of times as a clear picture unfolded as the additional data became available.

7.4 Data presentation

All data generated during this investigation were converted into a format compatible with the WISH software package, which is commonly used for geohydrological data processing in South Africa. These data constitute:

- Borehole data
- Water level records.
- Rainfall data
- Chemical analyses.
- Profiling of mine boreholes
- Generation of surface, seam and overburden contours

For the purpose of this report the C-seam mined is referred to as the Northern Mine and the B-seam as the Southern Mine.

7.5 Locality

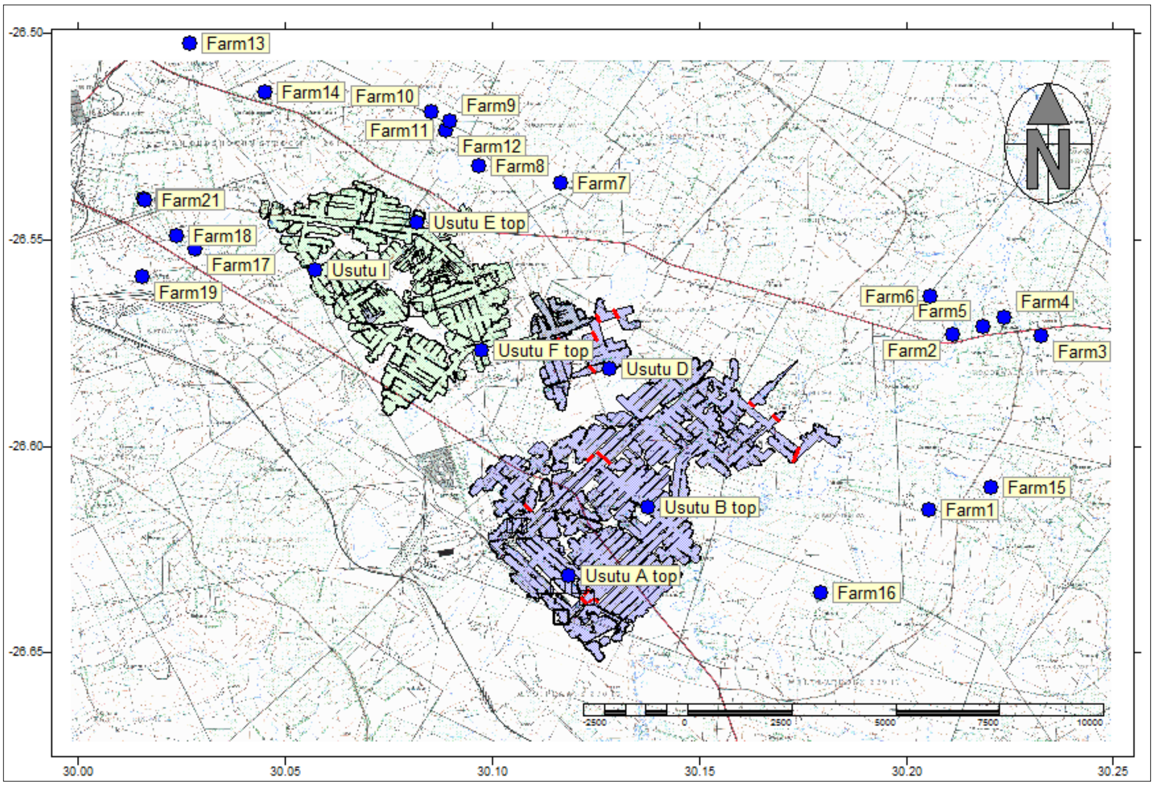


Figure 7-1: Location of Usutu mine and the boreholes in the investigation in geodetic coordinates

Usutu collieries are situated near the town of Ermelo in Mpumalanga, close to Camden Power Station. Figure 7-1 shows the location of the boreholes located during the hydrocensus investigation. The map uses geodetic coordinates.

NOTE:

All maps in this report are in a Transverse Mercator projection (LO 31) and WGS84 is used as datum unless specified differently.

7.6 Surface Hydrology

7.6.1 Rainfall

The annual rainfall (MAP) for the area is 705 mm (SA Weather Service - Rainfall stations: Ermelo no.0442841 8; 0442812 8; 0480170 4; 0479870 X; 1049107 8). Figure 7-2 shows a graph of the average rainfall for Ermelo.

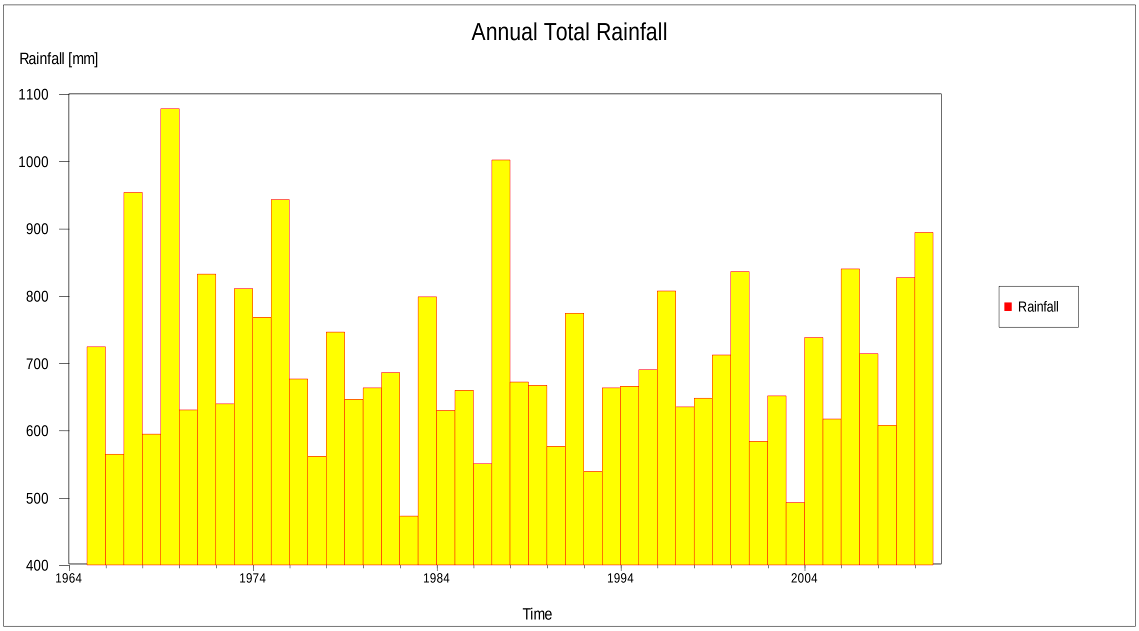


Figure 7-2: Rainfall graph for Ermelo.

7.6.2 Topography

The regional surface contours of the mine itself are illustrated in Figure 7-3. The area topography slopes mostly away from the mining area, as the mining area is situated on a topographic high in the northern part.

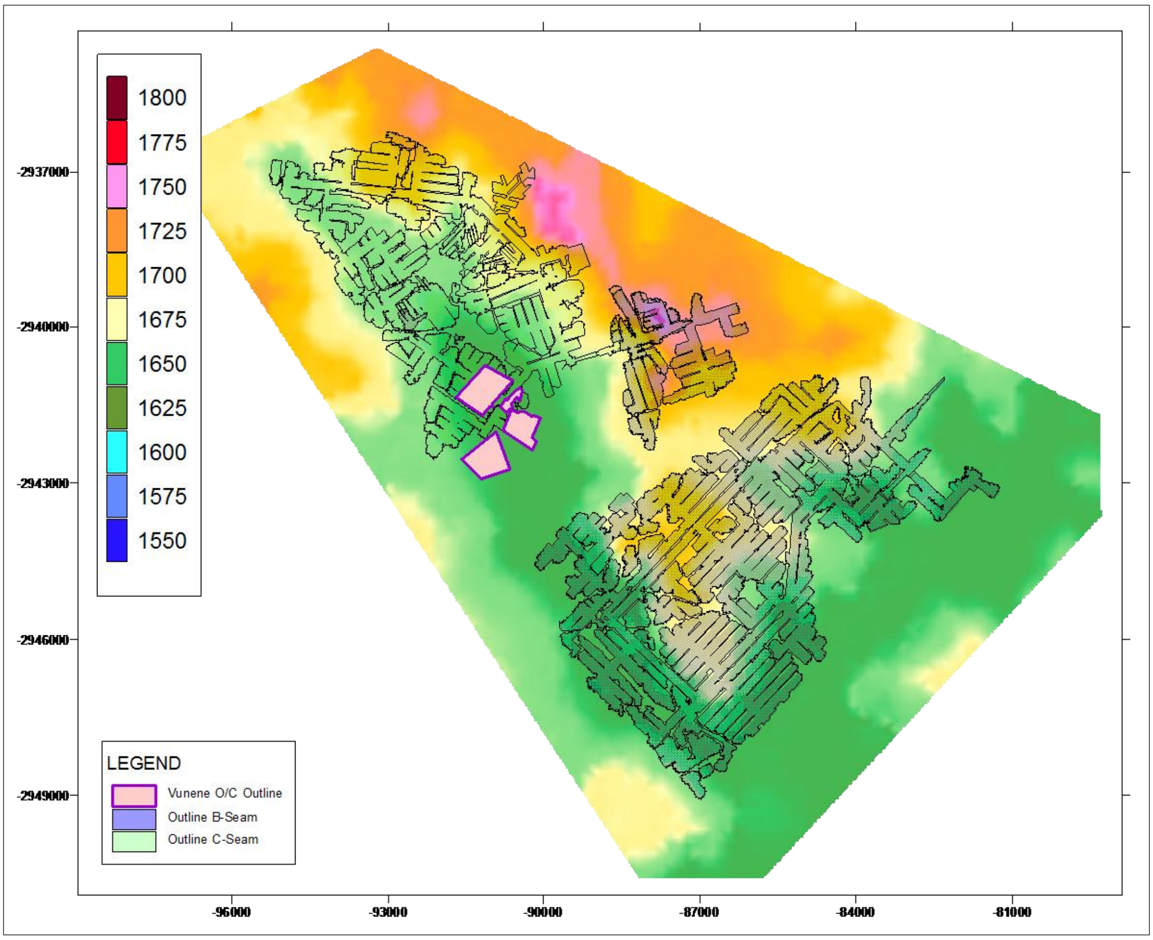


Figure 7-3: Surface contours of the mine area.

In Figure 7-4 the surface topography is displayed in 3D, with the topographic high to the north of the mining clearly visible. The high towards the north west of the Southern Mine is also visible.

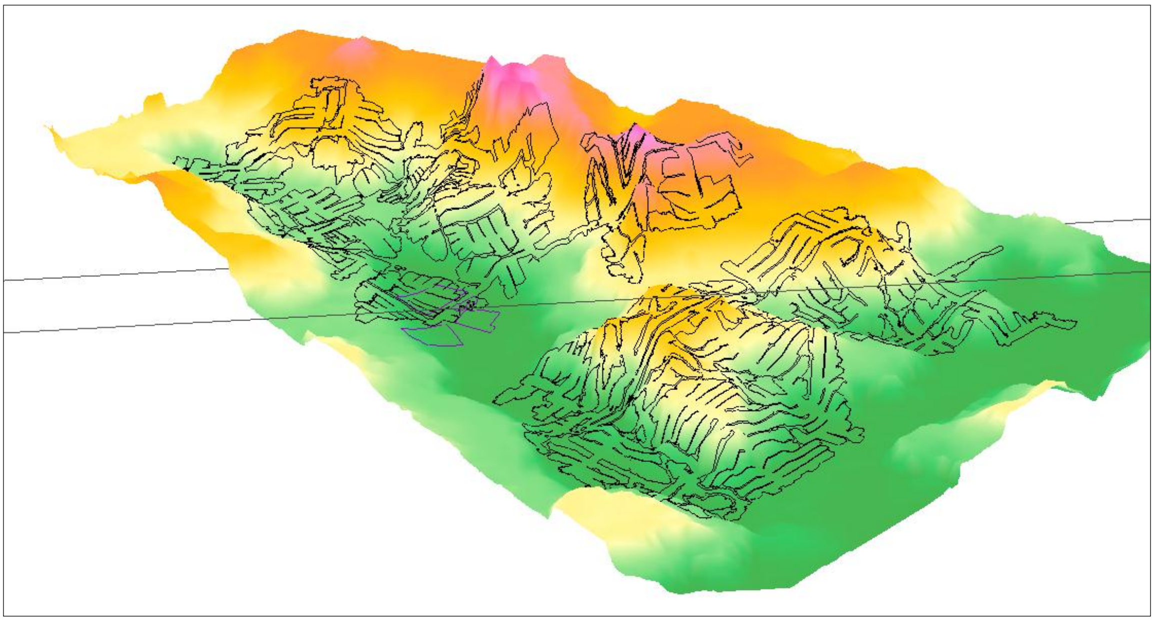


Figure 7-4: visualization in 3D of the surface contours with projected underground and opencast.

In Figure 7-5 the regional surface contours of the area around the mine are displayed in 3-D with the rivers and dams superimposed on that. According to this picture the local drainage pattern is towards the south east.

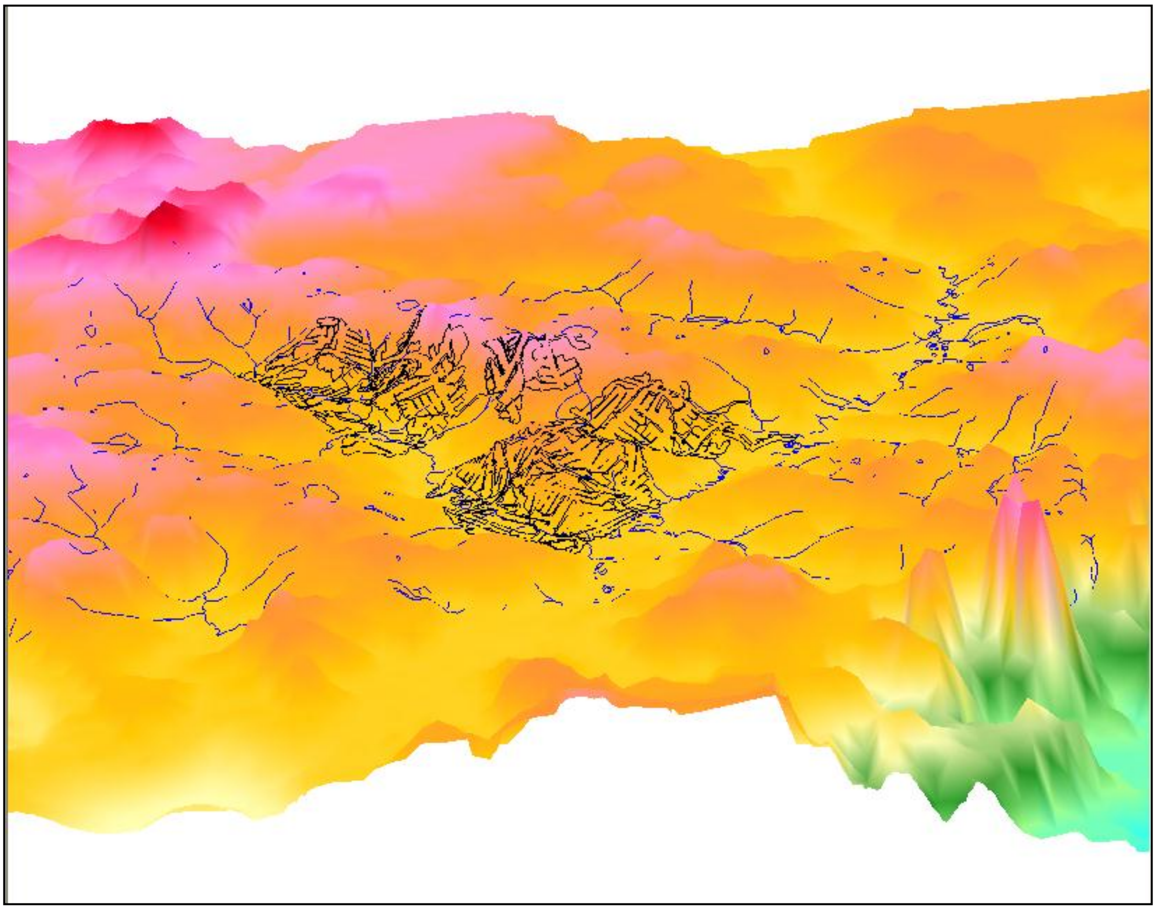


Figure 7-5: Regional surface contours of the area around the mine with rivers and dams.

7.7 Recharge

The assumption necessary for successful application of the chloride method to determine recharge is that there is no source of chloride in the soil water or groundwater other than that from precipitation. Chloride is conservative in the system. Steady-state conditions are maintained with respect to long-term precipitation and chloride concentration in that precipitation, and in the case of the unsaturated zone. However, this assumption may be invalidated if the flow through the unsaturated zone is along preferred pathways. (Van Tonder and Xu, 2000)

General Equation: $R = (P\ Cl_p + D)/Cl$

[R = recharge (mm/a); P = mean annual precipitation (mm/a); Cl_p = chloride in rain (mg/l); D = dry chloride deposition (mg/m^2/a); $Cl_w = Cl_{sw}$ = chloride concentration (mg/l) in soil water below active root zone in unsaturated zone OR $Cl_w = Cl_{gw}$ = chloride concentration (mg/l) of groundwater where for many boreholes the Cl_{gw} = harmonic mean of the Cl content in the boreholes]

The regional recharge was calculated as 5.7 % by using the Chloride method displayed in Table 7-1.

Table 7-1: Cl method for recharge

HARMEAN (mg/l)	CL- rainwater (mg/l)	Recharge (%)
17.54	1.00	5.7

7.8 Mine details

Mining activity ceased between 1987 and 1990. Usutu has mined 2 seams underground, the B and C-seam respectively, with an average mining height of 1.6 m. Currently Vunene Mining has an opencast mine above the C-seam of the northern mine.

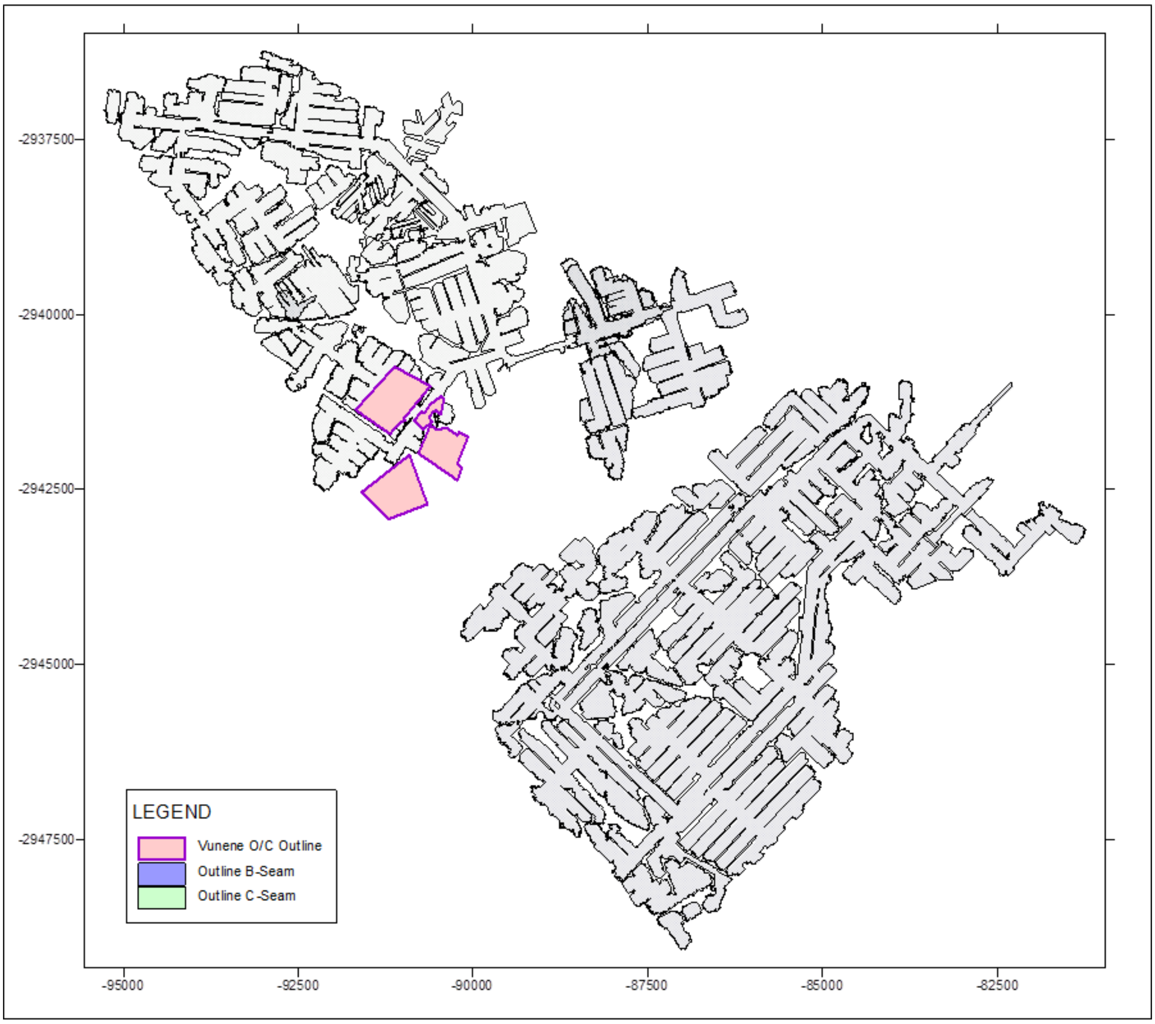


Figure 7-6: Layout of the B-seam and C-seam at Usutu colliery, together with Vunene opencast.

The combined C-seam varied in depth from very shallow (5 m) to nearly 80 m in the north, as illustrated in Figure 7-7. The Southern mine, where the B-seam was mined, varied between 75 m and 160 m, as illustrated in Figure 7-8.

The combined floor contours for both seams is illustrated in Figure 7-9. From this the difference in depth between the two seams is very clear, with the B-seam much deeper than the C-seam.

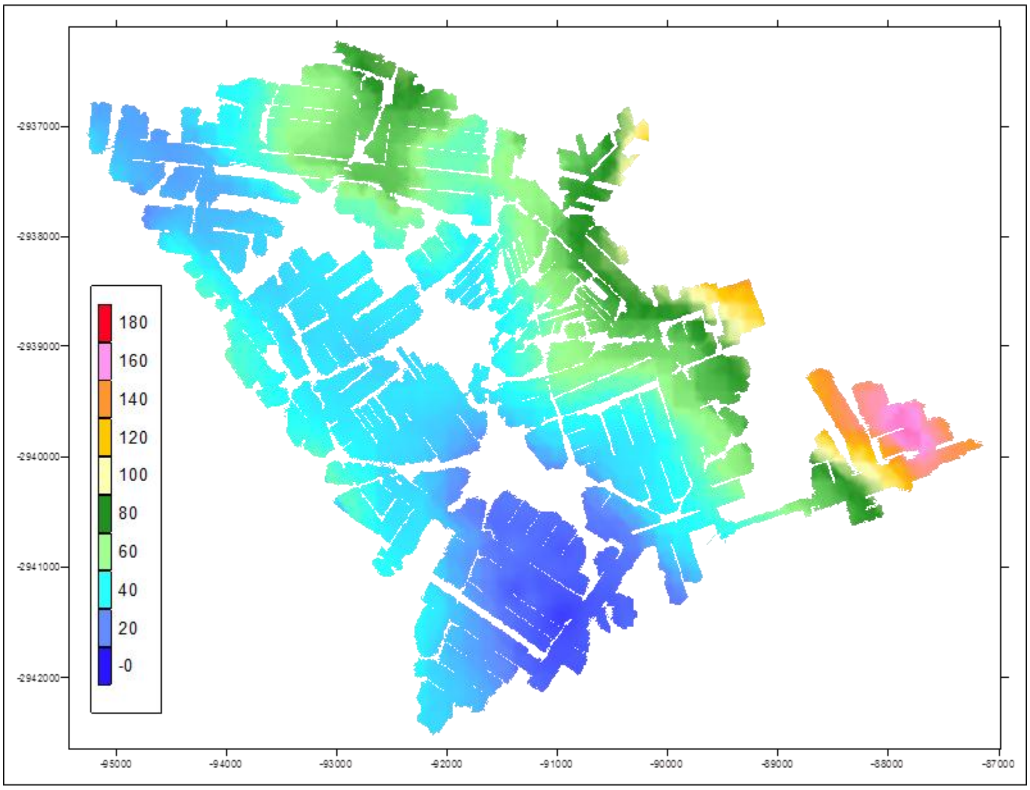


Figure 7-7: Roof thickness of the C-seam (Northern Mine).

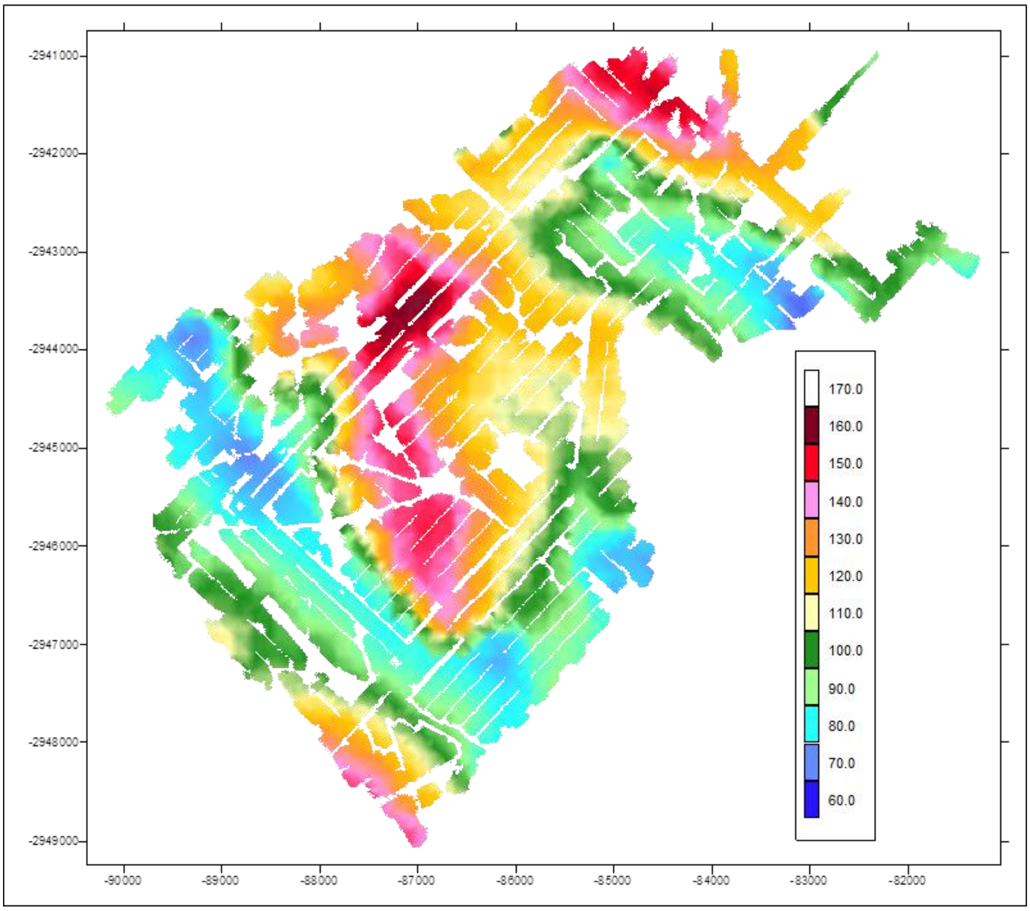


Figure 7-8: Roof thickness of the B-seam (Southern Mine).

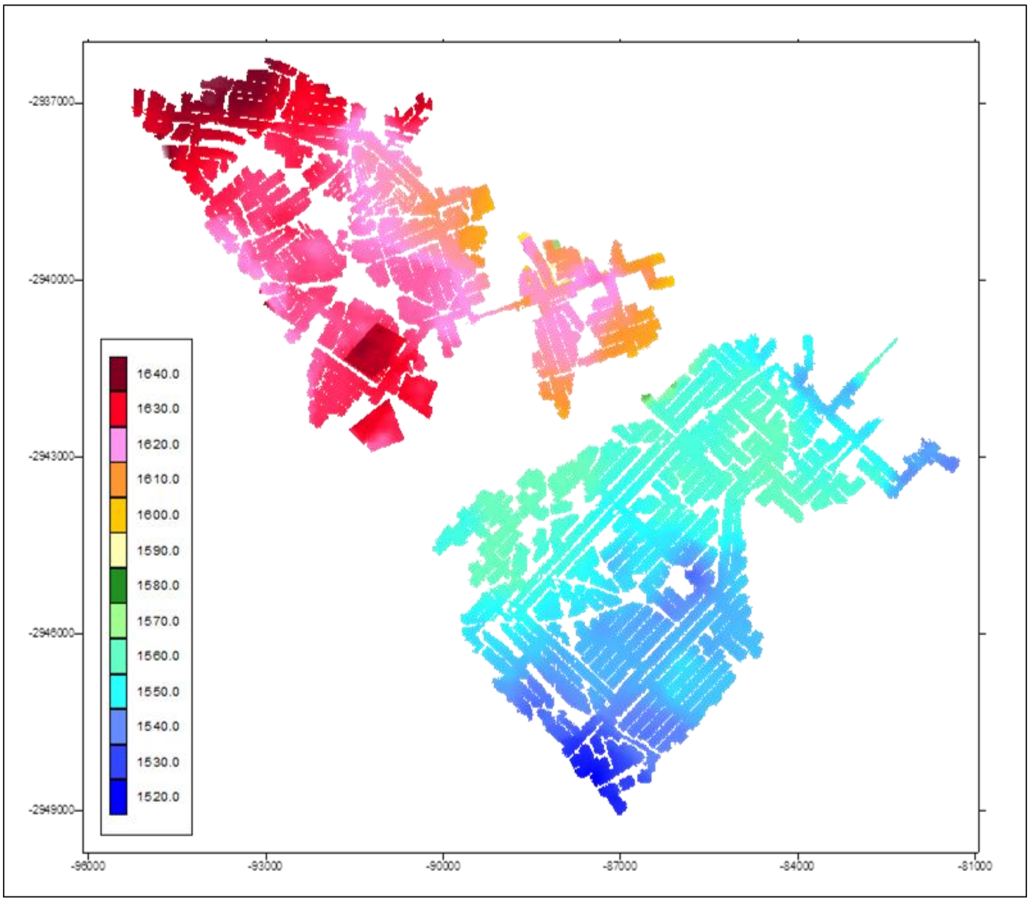


Figure 7-9: The combined floor contours of both the B- and C-seam (illustrated in mamsl).

In Figure 7-10 the surface in relation to the two seam elevations is illustrated in 3D. From this the surface elevation to the north is clear, and the difference in depth for the two seams in relation to the surface is also illustrated. Also illustrated is the position of the Usutu boreholes that are drilled into the mine (*Usutu-A, Usutu-B, Usutu-E, Usutu-F and Usutu-I*).

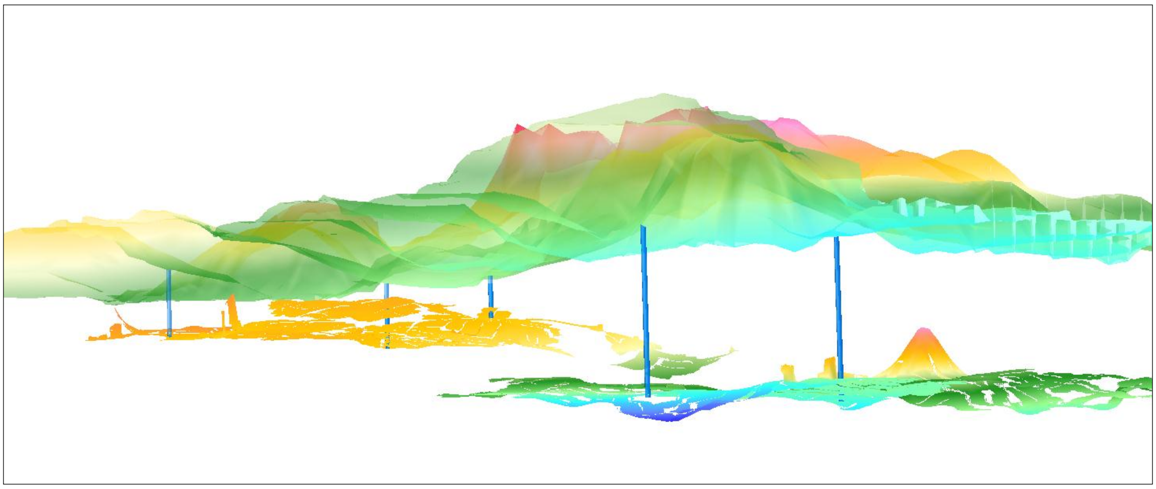


Figure 7-10: 3-D Combined Surface and seam elevation with boreholes into the underground

In order for a mine to function properly, ventilation walls are needed to channel the fresh air away from those parts of the mine that were finished and directed the flow to the front of the mining operations. In the old days these walls were built very solid and sealed corridors completely from bottom to roof. The walls are so strong that they will function as “low pressure” seals resulting in a compartmentalized underground, withstanding pressures created by the recharged groundwater. These seal positions are important in the recharge and management calculations for a mine as well as for the water balance and mine dewatering. The seals in Usutu (also digitized from the old maps) are illustrated in Figure 7-11.

Also important is the barrier between different mines, which will determine mine interflow. The position of the Mooiplaats Colliery to the south of the southern mine is also illustrated in this figure. The shortest distance of the pillar between the collieries is 250 m.

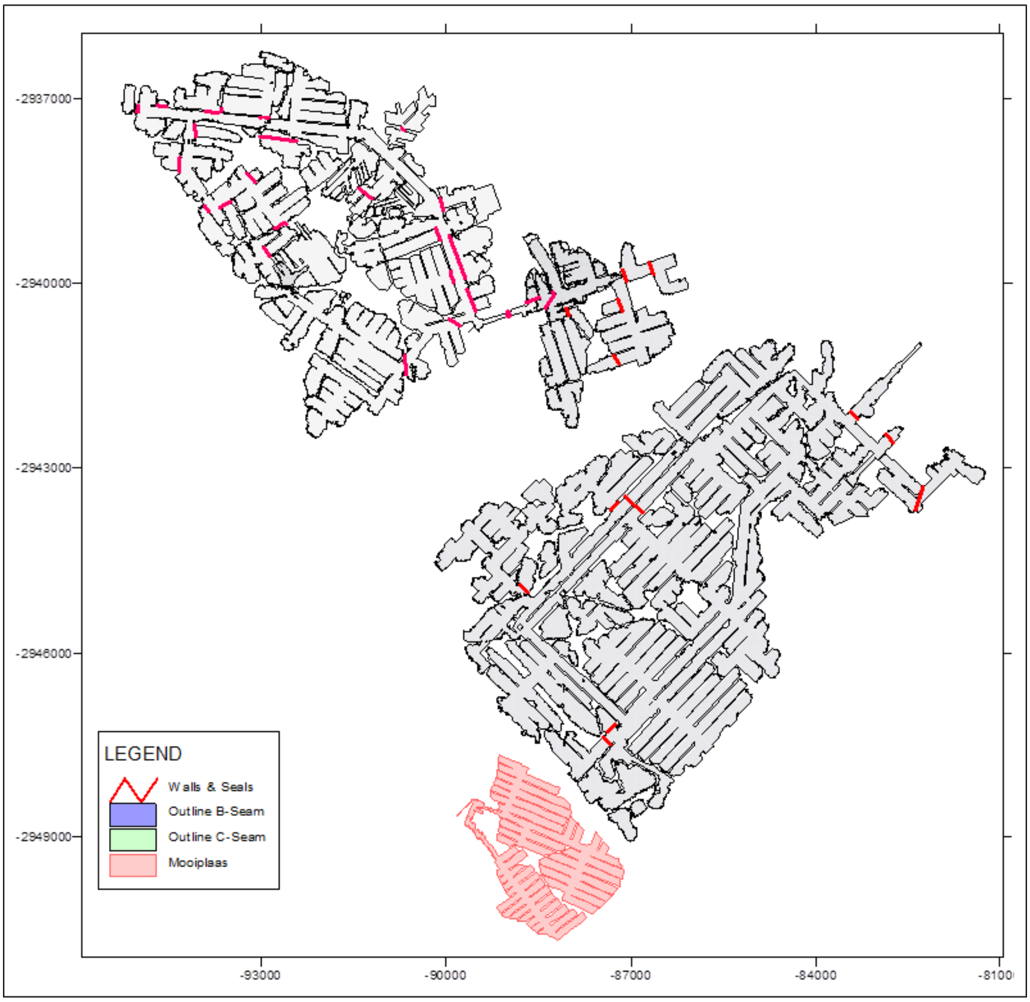


Figure 7-11: Layout of the B- and C-seam illustrating the ventilation walls, as well as the position of the adjacent Mooiplaats Mine.

The faults and dykes in the area were mapped using maps of the mine plans provided by Usutu Figure 7-12. There are a few long faults cutting through the mine. This may have an influence on the water flow inside the mine. It can easily be seen that where a fault occurred the mining stopped and just continued on the other side of the fault. The faults and dykes also play a role in compartmenting the mine as it normally also displaced the coal seams vertically.

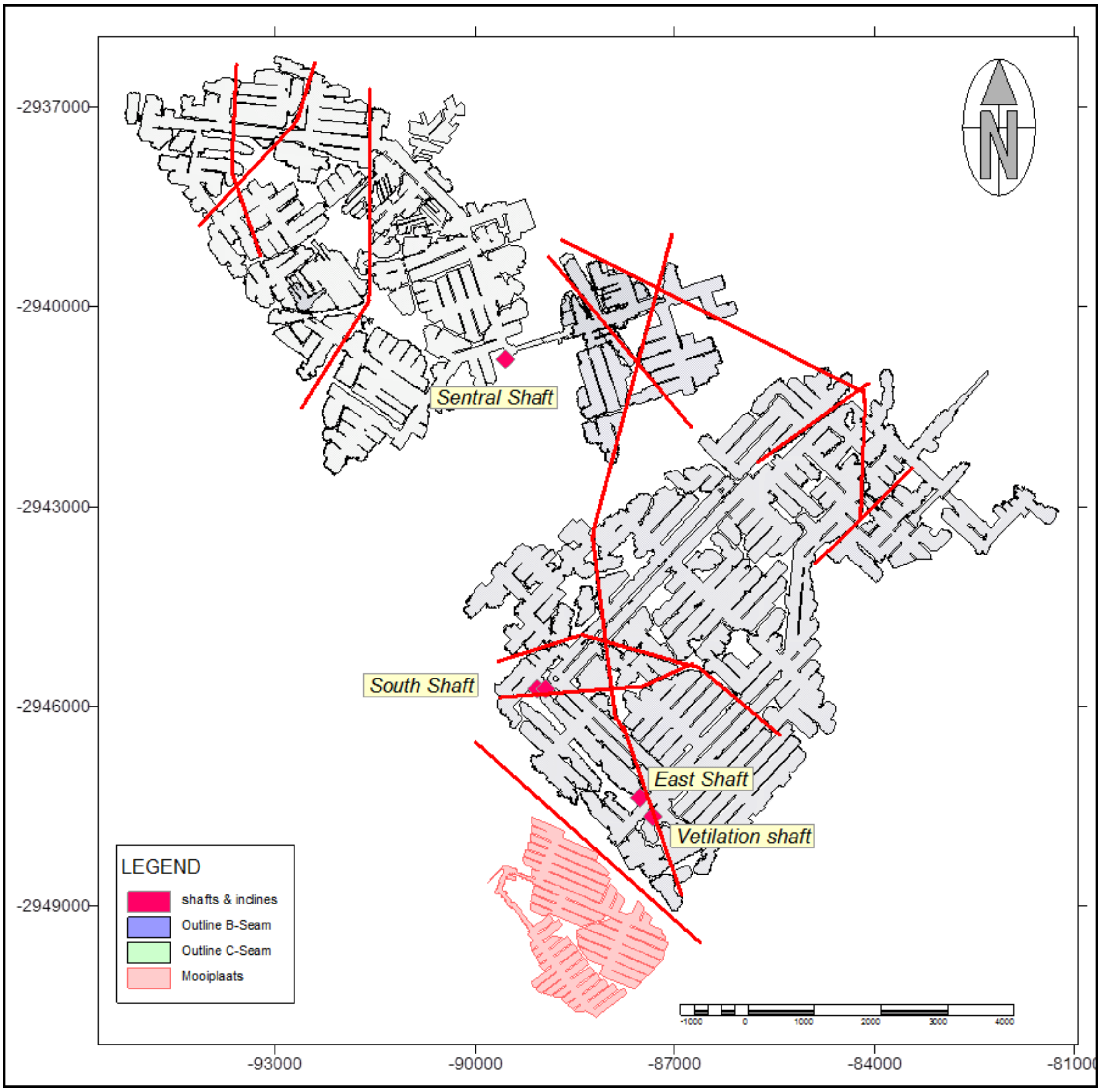


Figure 7-12: Faults and dykes identified inside the mine.

High extraction areas were also identified from the old maps. High extraction was only done in the B-seam; the combined total high extraction percentage was 14 % of total mining area (stooping in the central area is 22 % and in the southern area 13 %). These areas are illustrated in Figure 7-13. These areas may result in subsidence, increasing the recharge factor into the mine (see discussion in Section 7.12 Water Balance Calculations. The position of the shafts may also influence recharge if not properly sealed, and which may also act as decant points if it is lower than the lowest point of mining), is illustrated in Figure 7-12.

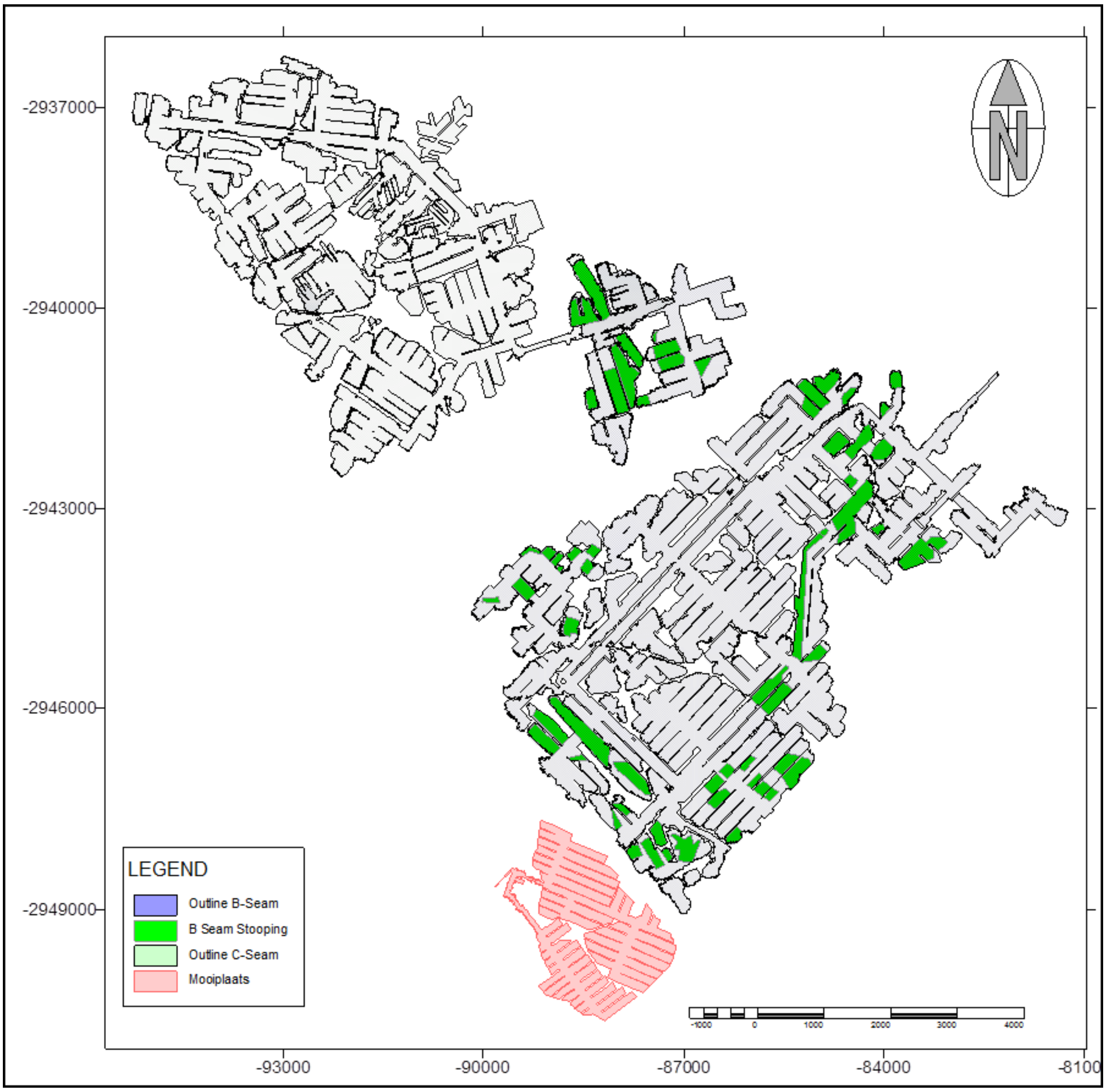


Figure 7-13: High extraction areas identified in the mine.

7.9 Borehole information - hydrocensus

A hydrocensus was performed on the mine property and adjacent farmland during February 2011. The position of these boreholes is portrayed in Figure 7-1 and a summary of all the boreholes is listed in Table 7-2.

Table 7-2: Information on the boreholes during Feb 2011

SiteName	Water Level (m)	Comment
Usutu F	21.60	Running water
Usutu A	3.30	Running water
Usutu B	12.00	Running water
Usutu D	18.00	Running water
Usutu E	28.00	Running water
Usutu I	49.70	Running water
Farm1	3.60	Vlakfontein
Farm2	4.20	P.Cilliers-Roodewal
Farm3	3.98	Rosendal
Farm4	4.02	Rosendal
Farm5	4.07	Rosendal
Farm6	3.00	Sulphur smell S.Cloete
Farm7	20.39	Saambou
Farm8	6.26	Jan Hendriksfontein
Farm9	9.77	Jan Hendriksfontein
Farm10	19.50	Jan Hendriksfontein
Farm11	4.08	Jan Hendriksfontein
Farm12	30.98	Small quantity of water
Farm13	8.20	van Outhoornstroom
Farm14	20.12	van Outhoornstroom
Farm15	2.25	vdMerwe
Farm16	3.30	Bethesta
Farm17	10.60	Trucks
Farm18	3.90	Guesthouse
Farm19	4.00	Panelbeaters
Farm20	4.26	Panelbeaters
Farm21	2.01	Panelbeaters

Table 7-3 provides a summary of the information for each borehole that was sampled in the mine during Feb 2011.

Table 7-3: Sample depth and depth of boreholes in the mine.

Site Name	Borehole depth (m)	Sampling depth (m)
Usutu A top	90	5
Usutu A bottom	90	89
Usutu B top	112	15
Usutu B bottom	112	111
Usutu D		20
Usutu E top	50	30
Usutu E bottom	50	49
Usutu F top	26	23
Usutu F bottom	26	25
Usutu I	48	46

7.9.1 Detail of boreholes inside the mine

7.9.1.1 Usutu A

- This borehole is 90 m deep. The water level is 3.3 m deep.
- The borehole is not locked as the photograph below indicates. It is difficult to locate.

Figure 7-14: Photograph of Usutu A.

7.9.1.2 Usutu B

- This borehole is 112 m deep. The water level in *Usutu B* is 12 m deep.
- The sound of running water can be heard at the borehole.
- The borehole is not locked as the photograph below indicates. It is difficult to locate.

Figure 7-15: Photograph of Usutu B.

7.9.2 Usutu D

- The water level in *Usutu D* was 18 m.
- The sound of running water can be heard at the borehole.
- The borehole is not locked as the photograph below indicates (It is difficult to locate).

Figure 7-16: Photograph of Usutu D.

7.9.2.1 Usutu E

Figure 7-17: Photograph of Usutu E.

- This borehole is 50 m deep. The water level in *Usutu E* is 28 m.
- The sound of running water can be heard at the borehole.
- The borehole is not locked as the photograph above indicates (It is difficult to locate).

7.9.2.2 Usutu F

- This borehole is 26 m deep. The water level in *Usutu F* is 21.6 m.
- The sound of running water can be heard at the borehole.
- The borehole is not locked as the photograph below indicates (It is difficult to locate).

Figure 7-18: Photograph of Usutu F.

7.9.2.3 Usutu I

- This borehole is 48 m deep. The water level in *Usutu I* is 49.7 m.
- The sound of running water can be heard at the borehole.
- The borehole is not locked as the photograph below indicates (It is difficult to locate).

Figure 7-19: Photograph of Usutu I.

7.10 Water levels

The water levels in the mine were measured in July 2009 and again during the hydrocensus; these levels and all the others from the farm boreholes are presented in the time graph in Figure 7-20**.** There is a definite rise in the water levels since 2009, but may be attributed to the exceptional rainy season. These levels should be monitored over time to make meaningful conclusions. In Figure 7-21 the proportional water level distribution for February 2011 is illustrated.

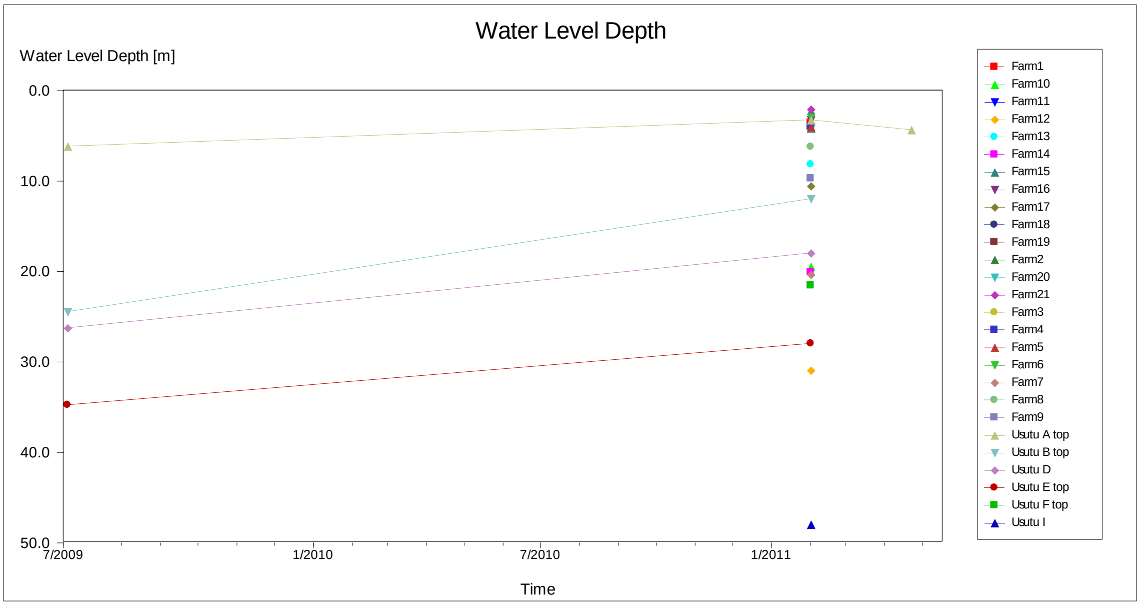


Figure 7-20: Water level time graph of a few boreholes measured since 2009.

- The proportional distribution of the water levels in Figure 7-21 clearly indicates that extraction occurs in some farming boreholes, i.e. the farm boreholes north of the mine. The average regional water level is currently less than 4 m.
- The water levels of the boreholes inside the mine differ for the two mines. The water levels in the southern mine is shallower than those in the northern mine. However, the water levels differ substantially in the different boreholes, most likely the result of compartmentalization due to the ventilation walls. This makes interpretation of the mine water levels very difficult, and a number of additional boreholes have to be drilled to get a clear indication of the exact water levels in the mine.

Three groundwater systems are normally present in the mining areas of the Ecca formations. These are the shallow weathered aquifer, the intermediate unweathered fractured Karoo, and the coal seams (mining area).

The weathered groundwater system:

The top 5 - 15 m in the area consists of soil and weathered rock. The upper aquifer is associated with this weathered horizon. In boreholes, water may often be found at this horizon. This aquifer is recharged by rainfall.

Rainfall that infiltrates into the weathered rock reaches impermeable layers of solid rock underneath the weathered zone. Movement of groundwater on top of the solid rock is lateral and in the direction of the surface slope. This water reappears on surface at fountains, where the flow paths are obstructed by barriers such as dolerite dykes, paleo-topographic highs in the bedrock, or where the surface topography cuts into the groundwater level at streams.

The fractured groundwater system:

The grains in the fresh rock below the weathered zone are too well cemented to allow any significant flow of water. All groundwater movement is therefore along secondary structures, such as fractures, cracks and joints in the rock. These structures are best developed in sandstone, hence the better water-yielding properties of the latter rock type. Dolerite sills and dykes are generally impermeable to water movement, except in a weathered state. In terms of water quality, the fractured aquifer always contains higher salt loads than the upper weathered aquifer. The higher salt concentrations are attributed to a longer contact time between the water and the rock.

Coal Seam (mine):

This system is mined out, with a much higher transmissivity value than the layers above and below it.

- The transmissivity (T)-value of the mined coal seam is very high (in the order of thousands) and the storativity (S) is also very high (65 % in the mined out section as opposed to approximately 0.1 % in typical Karoo aquifers).
- Once the mine has filled up with water, a horizontal piezometric level will occur (this piezometric level is also horizontal during the filling up process). If the piesometric level intersects the surface, decant could take place at the point of intersection if there is a link between this position and the mine (e.g. a borehole).
- The rate at which the piezometric level rises is dependent on the amount of influx from the top layers (or along subsidence areas) and the amount of lateral groundwater outflow.

Once the mine has filled up with water, the piezometric level of the mine will rise with the storage coefficient value of the mine (and not the specific yield) as conditions have changed from unconfined to confined. The flux from the overlying aquifers into the mine aquifer will decrease as the two water levels approach each other.

What is clear from the water levels is that the aquifers above the mining areas are not fully recharged yet, as these pressure levels differ from the regional water table aquifer water levels.

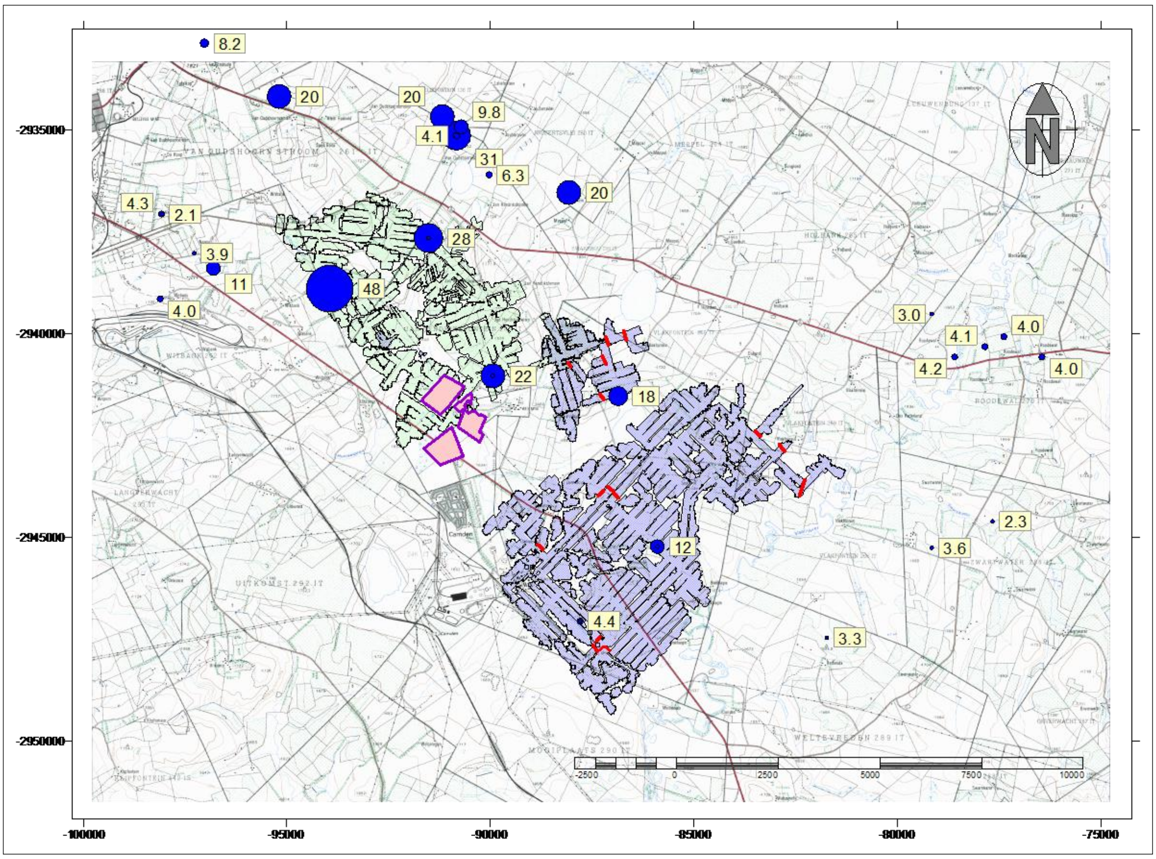


Figure 7-21: Proportional distribution of the water levels measured last measured.

7.11 Chemical analyses

The tables below show the chemistry data for the boreholes over time 2009-2011. All these boreholes were sampled at the top of the water column. During the hydrocensus the mine boreholes were sampled at the top as well as at the bottom in the mine. The boreholes targeted for sampling were all located on the mine with the bottom of the hole in the underground workings, Table 7-4 shows the chemistry in table form of boreholes sampled at the top. Table 7-5 shows the February 2011 values during the hydrocensus when the boreholes were sampled at the bottom as well. The bottom samples were taken at either the B- or C seam depending on the location of the hole. The top samples were taken 5 m below the water level.

7.11.1 Colliery water

The criteria used for inorganic sampling is the SANS 241:2006, and for organic analysis the US EPA Standards. Inorganic water samples are classified as:

- Class I – acceptable (colour coded green)
- Class II - allowable (colour coded yellow)
- Above – not allowable (colour coded red)

Table 7-4: Results of the chemical analyses for the boreholes sampled at the top 2009-2011.

BH number	Date	pH	EC	TDS	TCaCo3	Ca	Mg	Na	K	MAlk
			mS/m	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Usutu A top	2011/02/17	7.4	194	<1	<1	24	17	461	3.3	919
Usutu A top	2009/07/03	7.08	55	356	128	28	14	75	1.9	302
Usutu A top	2009/10/06	8.18	283	1978	106	27	9	665	3.0	1300
Usutu A top	2010/03/26	8.2	323	2246	124	25	15	773	7.4	1527
Usutu A top	2010/06/01	8.39	318	1994	72	17	7	703	3.7	1308
Usutu A top	2010/07/23	8.13	303	2186	144	25	20	734	4.0	1514
Usutu B top	2011/02/17	7.21	32	<1	<1	29	13	18	1.8	121
Usutu B top	2009/07/03	7.03	34	196	124	26	15	21	1.1	133
Usutu B top	2009/10/06	7.12	39	262	153	35	16	26	1.0	156
Usutu B top	2010/03/26	7.29	34	212	124	26	14	24	1.3	132
Usutu B top	2010/03/19	7.47	23	148	71	16	8	18	4.4	79
Usutu B top	2010/06/01	7.47	33	198	117	25	13	23	1.1	126
Usutu B top	2010/07/23	7.22	35	226	125	26	14	26	1.2	142
Usutu E top	2009/07/03	7.37	33	202	130	26	16	18	1.3	258
Usutu E top	2011/02/17	7.07	50	<1	<1	35	11	57	2.8	106
Usutu E top	2010/06/01	7.55	33	206	125	26	15	18	1.3	91
Usutu E top	2010/07/23	7.39	32	212	130	27	16	18	1.4	140
Usutu F top	2011/02/17	6.66	169	<1	<1	176	75	85	5.5	90
Usutu F top	2009/10/06	7.54	44	290	142	34	14	39	2.7	123
Usutu F top	2010/07/23	7.76	40	268	125	29	13	42	2.8	135
Usutu D	2011/02/17	6.54	26	<1	<1	18	5	17	5.6	191
Usutu D	2009/07/03	7.01	25	158	65	18	5	27	1.7	136
Usutu D	2009/10/06	6.87	46	312	116	32	9	50	2.2	138
Usutu D	2010/03/26	6.91	80	608	192	51	16	96	3.5	267
Usutu D	2010/06/01	7.05	24	158	54	16	4	25	2.0	204
Usutu D	2010/07/23	7	28	172	73	21	5	28	1.6	210
Usutu I	2011/02/17	6.2	316			396	108	237	7.1	126

BH number	Date	F	Cl	NO3(N)	SO4	Al	Fe	Mn	NH4(N)
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Usutu A top	2011/02/17	2.06	37	-0.50	154	0.001	0.033	2.67	1.802
Usutu A top	2009/07/03	0.36	6	0.34	10	0.030	2.42	1.09	<1
Usutu A top	2009/10/06	5.93	55	<0.1	310	0.020	0.54	0.39	<1
Usutu A top	2010/03/26	7.4	59	<0.1	360	0.110	0.2	0.4	<1
Usutu A top	2010/06/01	7.59	63	<0.1	338	<1	0.96	0.42	<1
Usutu A top	2010/07/23	6.93	58	<0.1	296	0.040	0.08	0.33	<1
Usutu B top	2011/02/17	0.05	15	0.64	21	0.040	0.050	0	0.181
Usutu B top	2009/07/03	<0.20	15	1.3	20	0.020	<0.01	0.01	<1
Usutu B top	2009/10/06	<0.20	17	1.1	44	<0.01	<0.01	<0.01	<1
Usutu B top	2010/03/26	<0.20	14	0.91	27	<0.01	<0.01	0.03	<1
Usutu B top	2010/03/19	0.43	19	<0.1	23	0.630	1.87	<0.01	<1
Usutu B top	2010/06/01	<0.20	15	0.94	26	<1	<0.01	0.02	<1
Usutu B top	2010/07/23	0.29	14	1.1	25	<0.01	<0.01	0.02	<1
Usutu D	2011/02/17	0.02	9	0.05	1	0.002	0.935	1.36	37.373
Usutu D	2009/07/03	<0.20	11	0.16	16	0.070	1.63	0.23	<1
Usutu D	2009/10/06	<0.20	19	<0.1	125	<0.01	2.68	0.27	<1
Usutu D	2010/03/26	0.36	23	<0.1	275	<0.01	3.55	0.33	<1
Usutu D	2010/06/01	<0.20	12	<0.1	22	<0.01	2.89	0.32	<1
Usutu D	2010/07/23	0.24	9	<0.1	13	<0.01	3.48	0.37	<1
Usutu E top	2009/07/03	<0.20	11	0.46	31	0.090	<0.01	0.01	<1
Usutu E top	2011/02/17	0.41	35	-0.05	9	0.000	0.150	0.20	2.068
Usutu E top	2010/06/01	<0.20	9	0.11	33	<0.01	<0.01	<0.01	<1
Usutu E top	2010/07/23	<0.20	10	0.18	33	<0.01	0.02	0.02	<1
Usutu F top	2011/02/17	0.52	22	0.35	669	-0.004	0.060	1.24	0.596
Usutu F top	2009/10/06	0.64	13	0.81	22	<0.01	<0.01	<0.01	<1
Usutu F top	2010/07/23	0.81	15	0.42	6	0.020	0.02	<0.01	<1
Usutu I	2011/02/17	0.22	26	-0.50	1942	-0.005	0.030	2.14	4.174

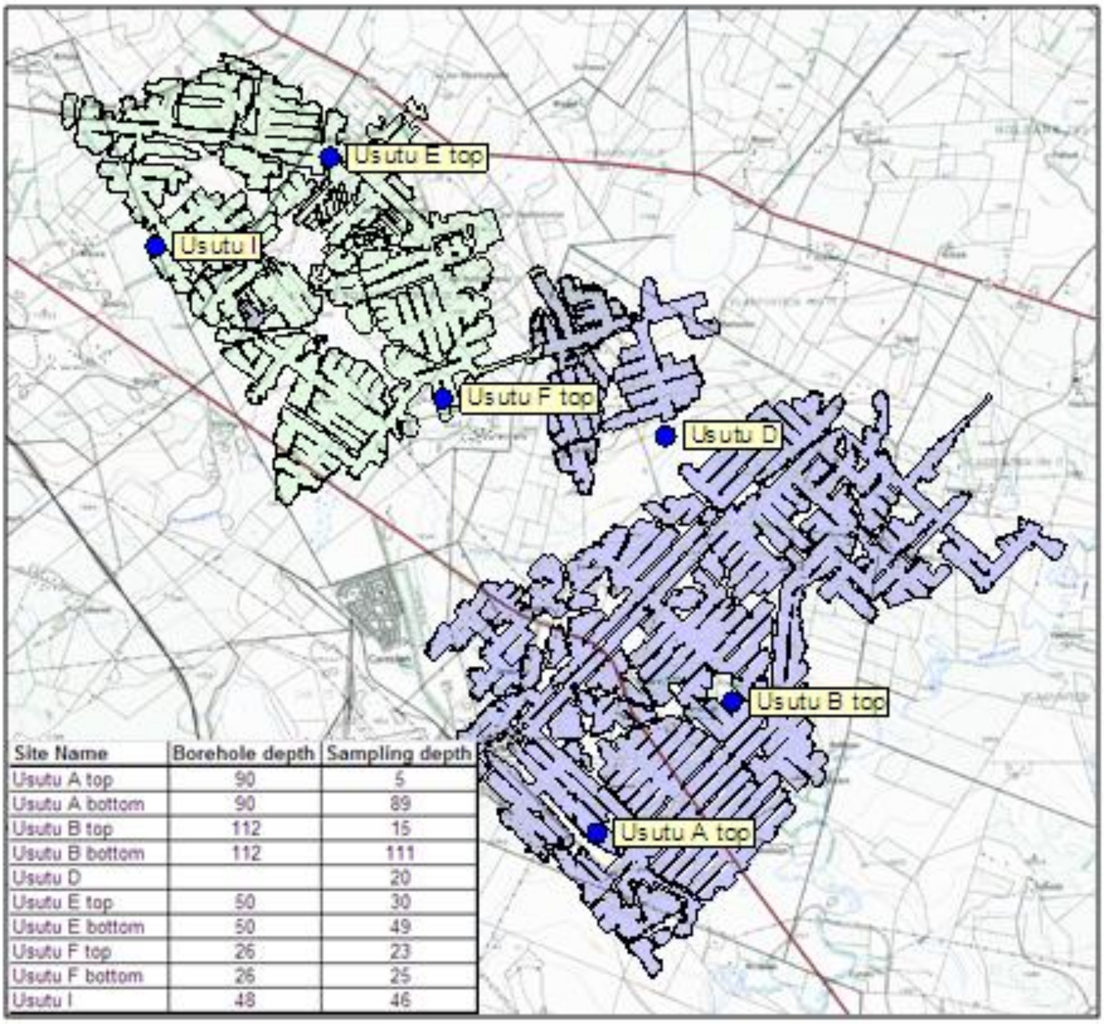
Table 7-5: Results of the chemical analyses for the boreholes sampled during the hydrocensus February 2011.

BH Number	pH	EC	Ca	Mg	Na	K	PAlk	MAlk	F	Cl
		mS/m	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Usutu A-Bottom	8.05	295	17	7	776	4.2	0	1250	6.10	62
Usutu A-Top	7.4	194	24	17	461	3.3	0	919	2.06	37
Usutu B-Bottom	7.01	158	84	34	221	3.3	0	241	0.20	29
Usutu B-Top	7.21	32	29	13	18	1.8	0	121	0.05	15
Usutu D-Usutu	6.54	26	18	5	17	5.6	0	258	0.02	9
Usutu E-Bottom	7.04	49	33	11	59	2.7	0	189	0.39	35
Usutu E-Top	7.07	50	35	11	57	2.8	0	191	0.41	35
Usutu F-Bottom	6.61	192	223	95	97	6.6	0	296	0.28	26
Usutu F-Top	6.66	169	176	75	85	5.5	0	267	0.52	22
Usutu I-Usutu	6.2	316	396	108	237	7.1	0	126	0.22	26

BH Number	NO2(N)	Br	NO3(N)	PO4	SO4	Al	Fe	Mn	NH4(N)
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Usutu A-Bottom	<0.1	<0.4	<0.5	<1	385	0.005	0.08	0.06	2.85
Usutu A-Top	<0.1	<0.4	<0.5	<1	154	0.001	0.03	2.67	1.80
Usutu B-Bottom	<0.1	<0.4	0.22	<1	578	0.002	0.04	0.04	1.18
Usutu B-Top	<0.01	0.04	0.64	<0.1	21	0.040	0.05	0.00	0.18
Usutu D-Usutu	0.07	<0.04	0.05	<0.1	1	0.002	0.93	1.36	37.37
Usutu E-Bottom	<0.01	<0.04	<0.05	<0.1	9	0.002	0.23	0.28	0.96
Usutu E-Top	<0.01	<0.04	<0.05	0.10	9	0.000	0.15	0.20	2.07
Usutu F-Bottom	<0.1	0.14	0.20	0.39	905	<0.004	0.07	1.13	1.38
Usutu F-Top	<0.1	<0.4	0.35	0.34	669	<0.004	0.06	1.24	0.60
Usutu I-Usutu	<0.1	<0.4	<0.5	<1	1942	<0.004	0.03	2.14	4.17

From this table it is clear that there is a definite difference in water quality of the top and bottom samples of those boreholes drilled into the mining cavity.

- *Usutu D* is not drilled into the mine, as is clear from the water quality and as is also illustrated in Figure 7-22.
- *Usutu A* indicates high sodium and alkalinity with sulphate values slightly elevated but still within the drinking water standards. It appears as though the formation has an influence on the water quality in this borehole, even at the top (also see the Stiff diagram in Figure 7-27).
- *Usutu B* also differ top and bottom. Again the sodium is elevated in the bottom sample, with a difference that the sulphate is elevated and not the alkalinity; the coal seam has a definite influence on the sample in the mining cavity.
- *Usutu E* shows no influence from mining activities and it is not clear if this borehole is drilled into the mining cavity or perhaps into a pillar.
- *Usutu F* and *Usutu I* indicates typical coal water reactions, with high sulphate, calcites and magnesium (also see the Stiff diagram in Figure 7-27). The mining depth in this area is shallow compared to the B-seam in the southern mine. It is likely that there is less buffering material, from there the Acid Rock Drainage (ARD) reactions and the subsequent decrease in pH.



Site Name	Borehole depth	Sampling depth
Usutu A top	90	5
Usutu A bottom	90	89
Usutu B top	112	15
Usutu B bottom	112	111
Usutu D		20
Usutu E top	50	30
Usutu E bottom	50	49
Usutu F top	26	23
Usutu F bottom	26	25
Usutu I	48	46

Figure 7-22: Borehole positions with depths and sampling depths.

The expanded Durov diagram (Figure 7-23) and the Piper Diagram (Figure 7-24)clearly indicates that Usutu F and I are mine water, whilst *Usutu B* top, *Usutu E* top and *Usutu D* are unpolluted. *Usutu A* and *Usutu E* bottom is coal mine water.

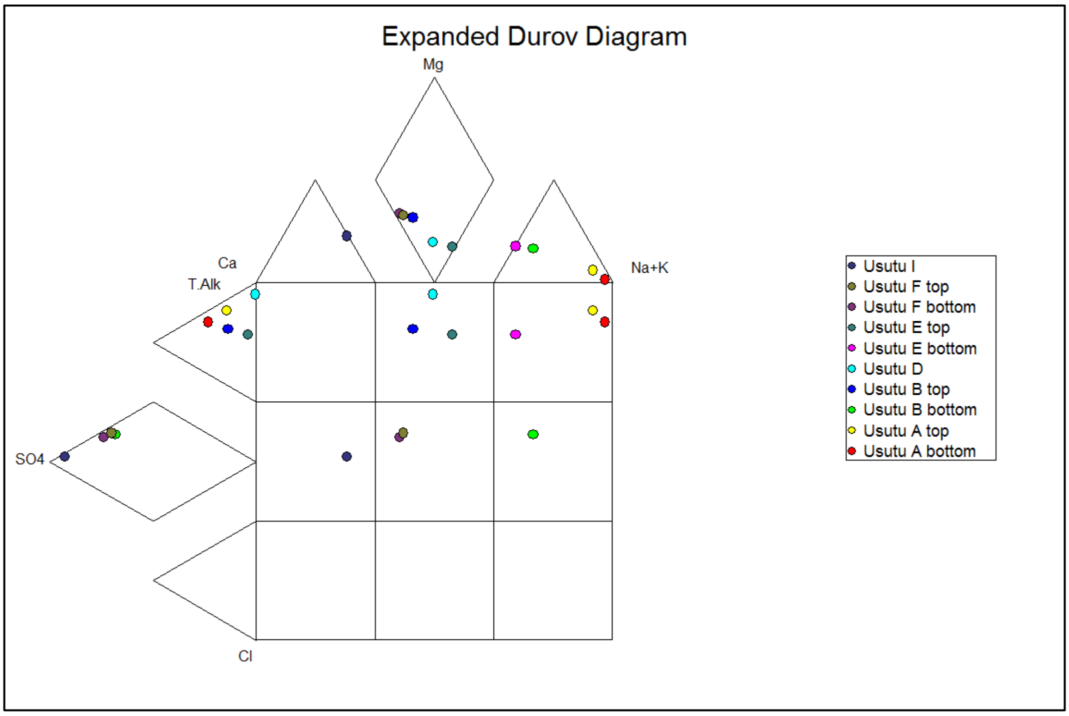


Figure 7-23: Expanded Durov diagram of the Usutu boreholes.

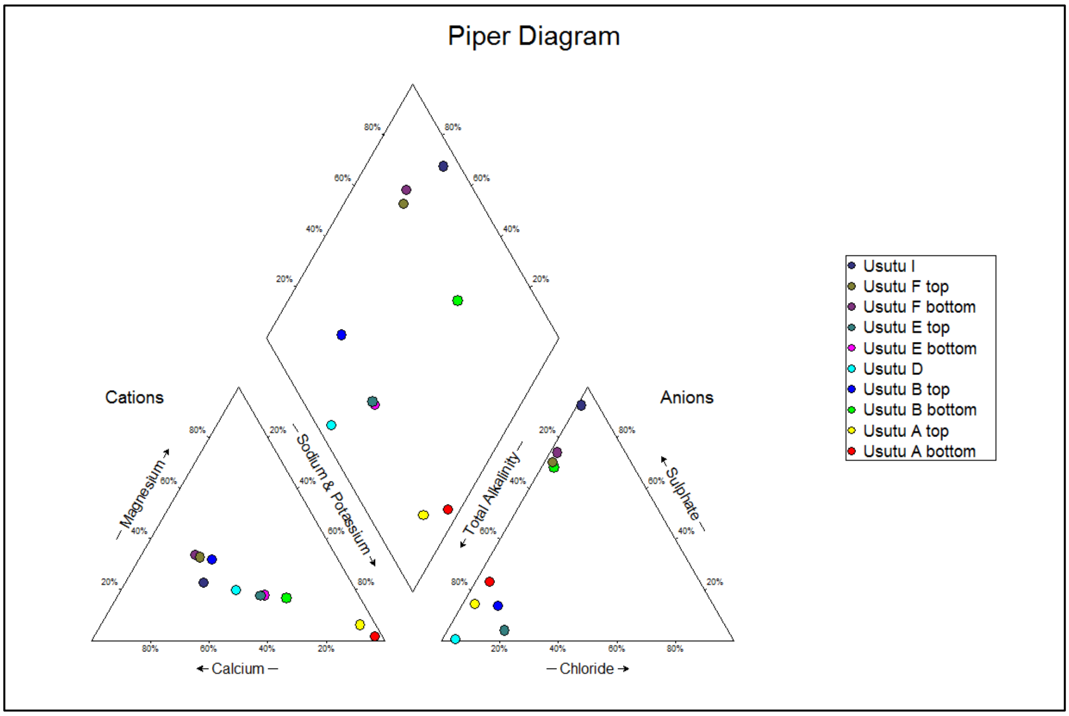


Figure 7-24: Pier diagram of the Usutu boreholes.

Two boreholes were profiled for EC. *Usutu F* (Figure 7-26) clearly illustrates the polluted water in the mining cavity compared with higher up in the water column. *Usutu A* also differs in depth, but the change happens halfway down the water column, strengthening the statement that the sodium-bicarbonate water is geology related.

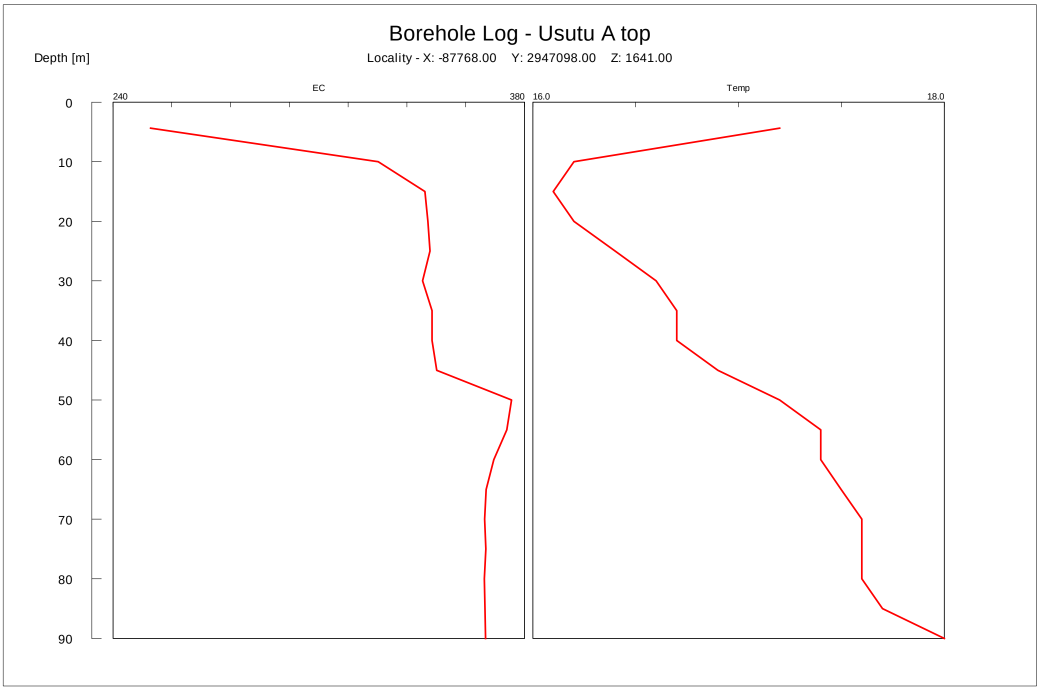


Figure 7-25: EC profiling for Usutu A.

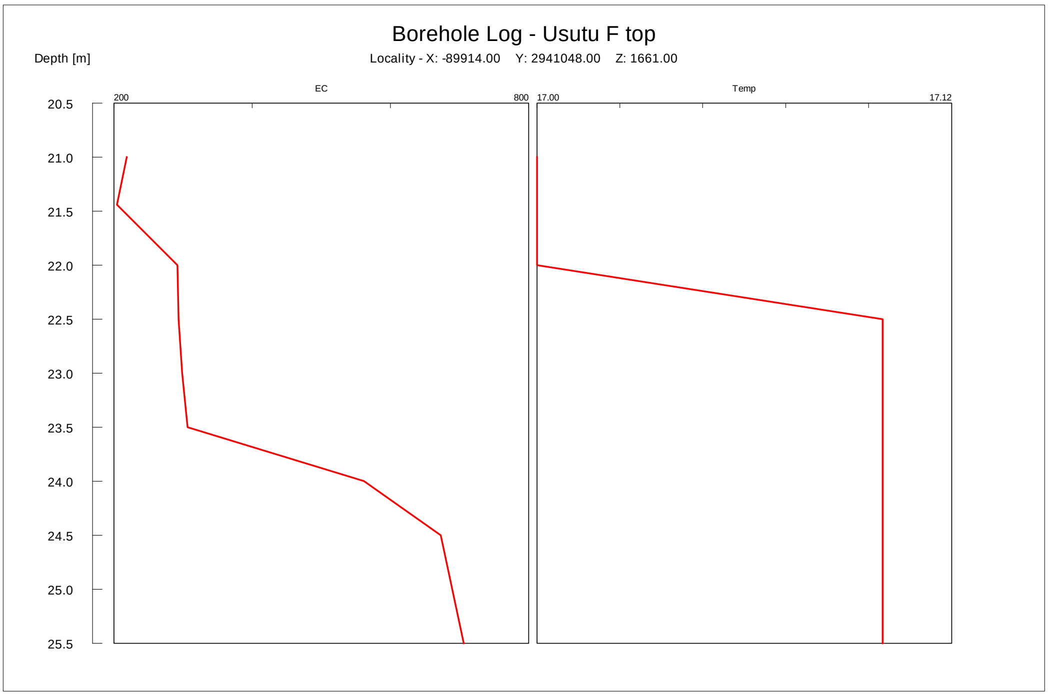


Figure 7-26: EC profiling for Usutu F.

The Stiff diagrams of the boreholes (which compare the water qualities in equivalents) also illustrates that the bottom samples are more polluted than the top samples, with *Usutu I* and to a lesser degree *Usutu F* (bottom) very typical coal mine water.

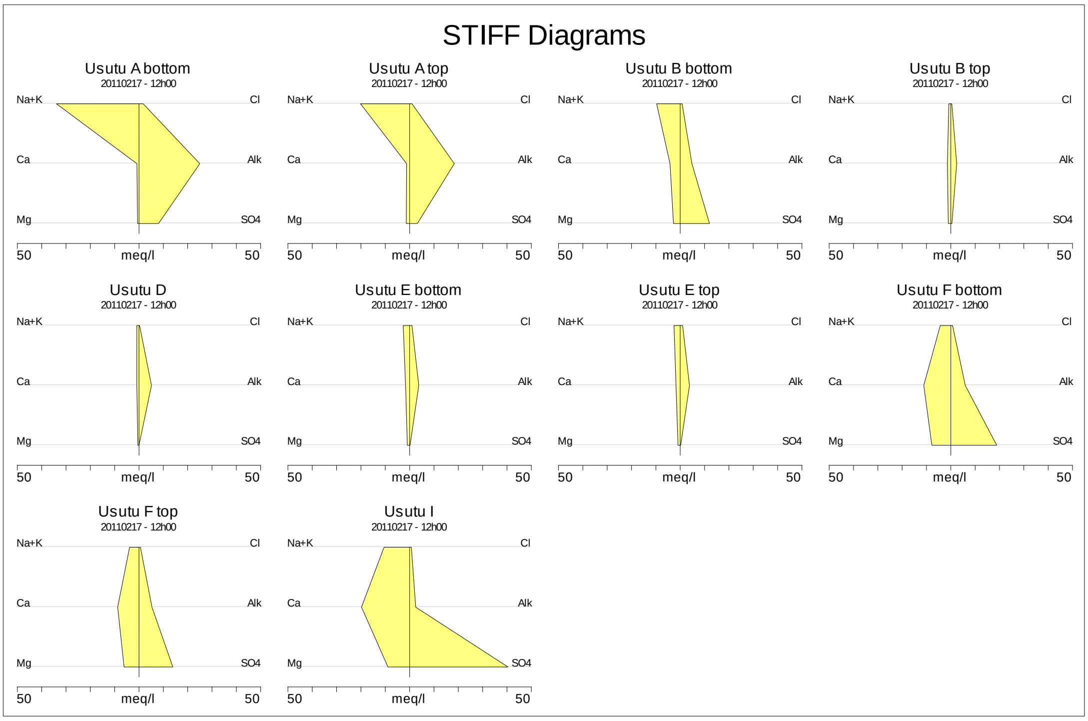


Figure 7-27: Stiff diagrams of the mine boreholes.

The time graph of the mine boreholes indicate that the water quality for the top boreholes did not deteriorate since 2009. The time graphs of all the macro elements follow the same trend. Only *Usutu F* indicated a different value, but this may be because the borehole was sampled at a different depth during the hydrocensus (the water in this borehole is only 6 m deep).

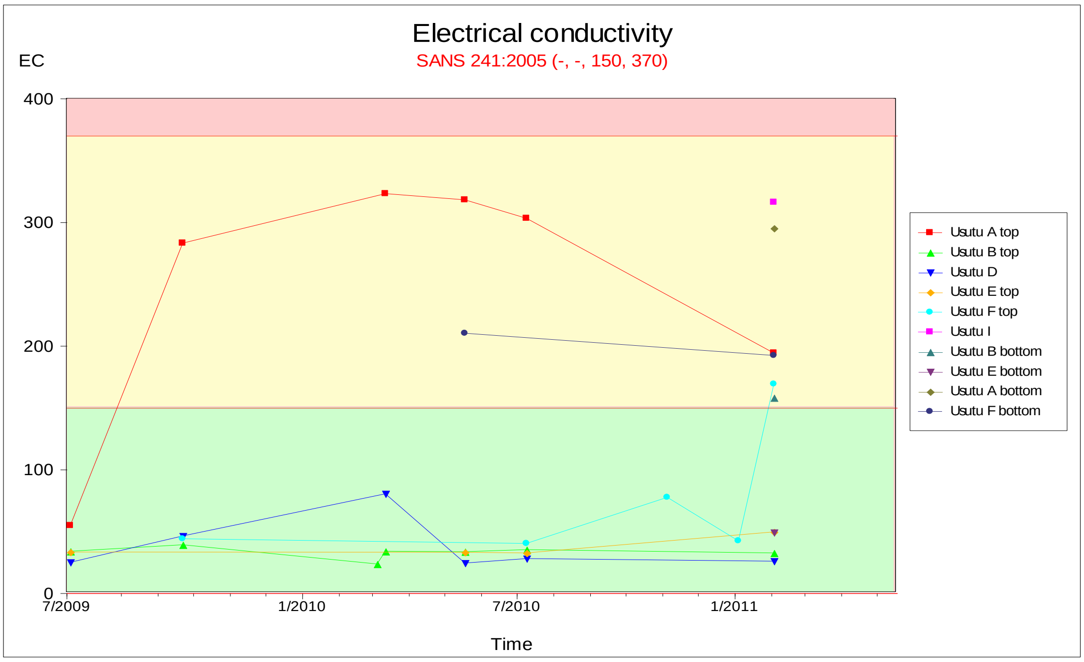


Figure 7-28: Time graph of the EC for the mine boreholes.

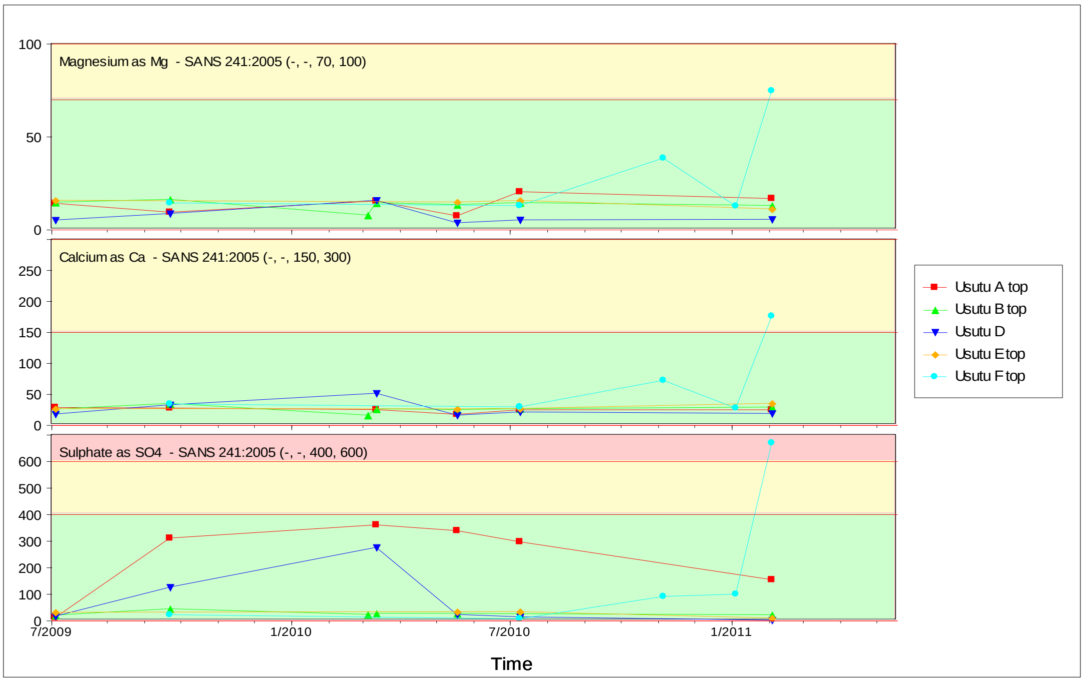


Figure 7-29: Time graph of sulphate, calcium and magnesium of the mine boreholes.

Decant:

It appears that there is a minimum stratification in the water columns in the two mines. Due to the fact that there are a number of ventilation walls (these walls act like seals) in the mine, it reduces any change of pressure that can "push" the mine cavity water up to a decant level.

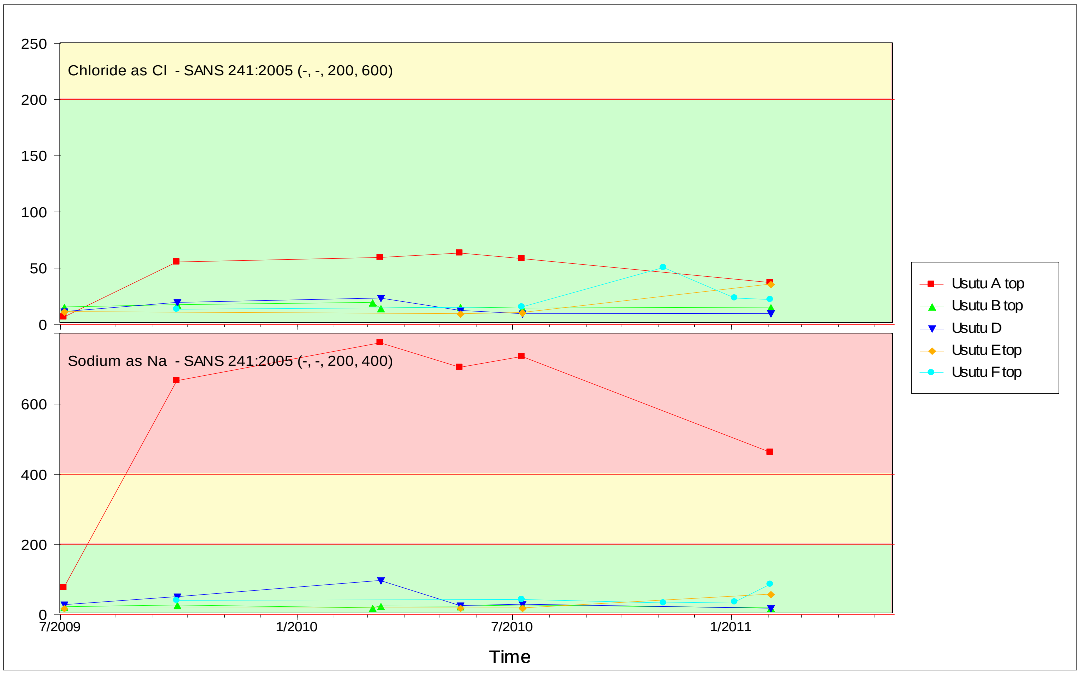


Figure 7-30: Time graph of sodium and chloride of the mine boreholes.

7.11.2 Regional water quality

The EC of only two farm boreholes is available, i.e. *Farm 2* and *Farm 6*. These are portrayed in Figure 7-31. From this it is clear that the regional aquifer water quality is similar to that of the "top" samples in the mine boreholes, indicating aquifer water for most areas above the mine; the exceptions are *Usutu A*, which has completely different sodium- bicarbonate water and *Usutu F* which has only a few metres of water above the mining cavity. This is also nicely portrayed in the Stiff diagrams of the top mine samples and the farm samples (Figure 7-32).

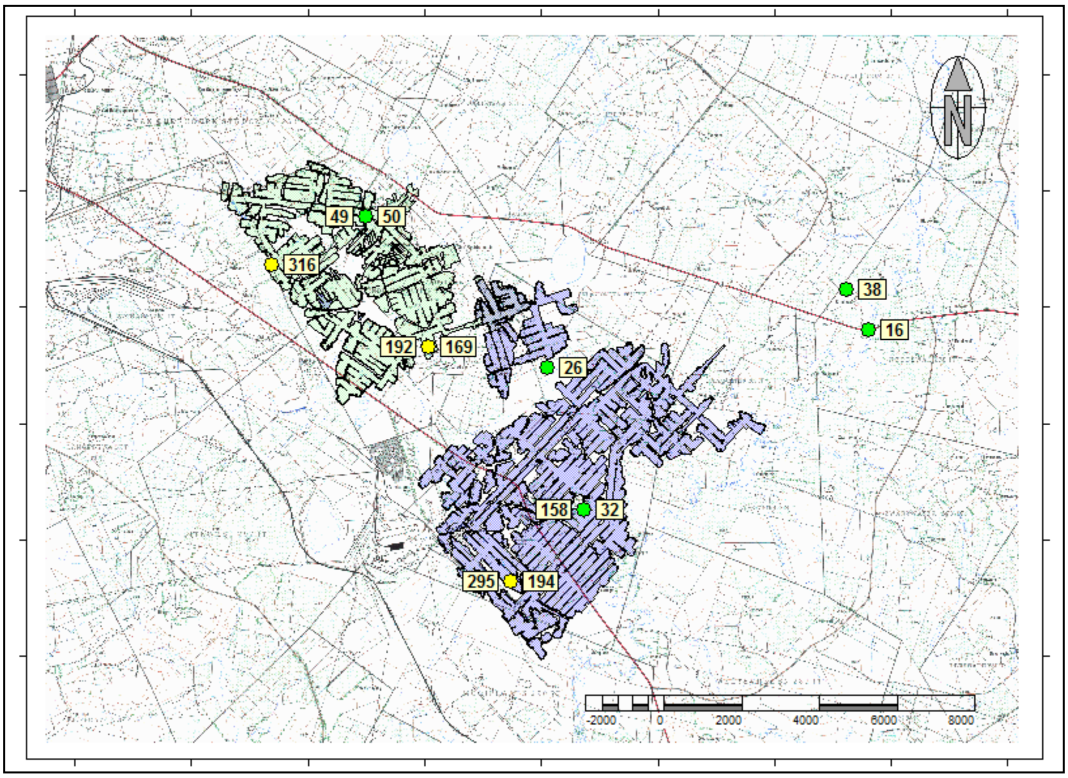


Figure 7-31: EC of all the boreholes measures during the hydrocensus in 2011.

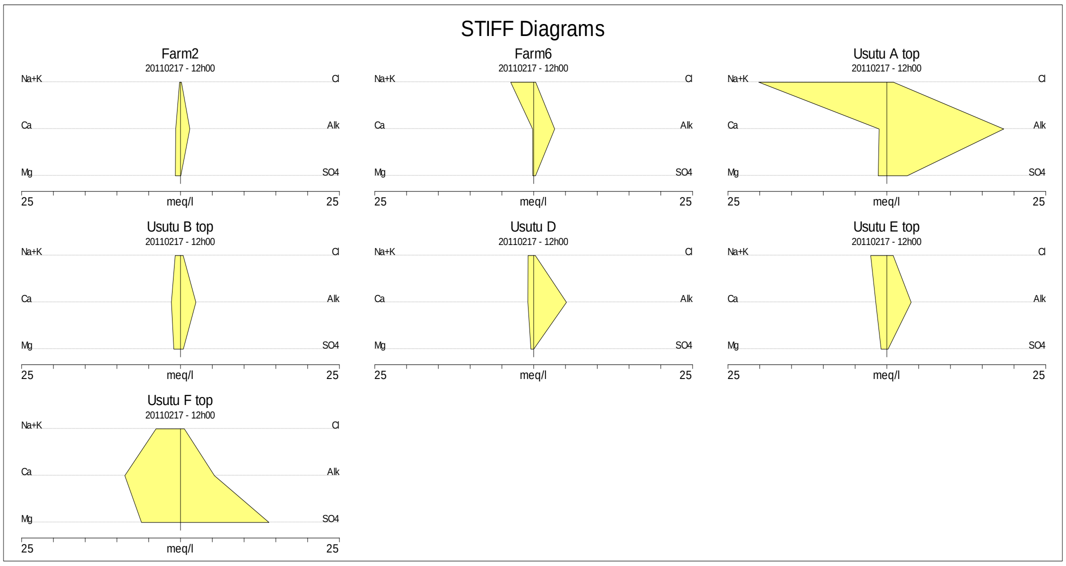


Figure 7-32: Stiff diagrams of the top mine samples and the farm samples.

7.12 Water Balance Calculations

The WISH/WACCMAN software was used to calculate the amount of water stored in the defunct mine. The software calculate the volume of water in the underground taking in consideration the current water level elevations and the geometry of the workings, including mining height, extraction factors and the position of the ventilation walls. Due to the many compartments in the underground and only three water levels in the workings a few compartments show up as being empty. It is highly unlikely that the compartments are empty but without water level information a water volume for a compartment cannot be calculated.

Mine compartments will fill itself with water. The speed at which this happens is defined by the recharge rate which is dependent on:

- Precipitation
- Topography
- Geology
- Depth
- Type of mining
- Whether some form of high-extraction was performed.

It is normal practice to assume a linear relationship between the rainfall and the recharge (Table 7-6). This means that if there are successive years of normal rainfall the flooding process will happen at a constant rate. To monitor this process, water levels in the underground must be measured using boreholes. When the water level elevation reaches the top of the mining cavity the water level will continue to rise until the pressure point P1 is the same as the pressure at point P2. The difference of pressure is measured by the difference of the water level elevations in the underground and in the rock formation surrounding the mine. Water is still entering the cavity but is has no place to go except in the borehole (and shaft), the water level will rise initially more quickly, but decreasing in speed as the difference between the two water level elevations get smaller. When the water level in *Borehole A* (the mining cavity) reaches the same height as in *Borehole B* (regional) the mine is in equilibrium with the surroundings. Under these conditions no more water can enter the workings. If no water is released either by pumping or decanting the whole system becomes part of the regional system and will act accordingly. If the water level elevation intersects with the surface and there is a direct connection between the underground working and the surface (borehole, shaft) water will decant (

Figure 7-33).

Table 7-6: Anticipated recharge to bord-and-pillar mining in the Mpumalanga area.

Description	Recharge as a % of annual rainfall
Influx into bord-and-pillar, deep mining	1-4
Influx into bord-and-pillar, shallow mining	4-9
Influx into bord-and-pillar mining with stooping	4-12

Stooping has been done in some parts of the B-Seam at Usutu colliery. Stooping, the process of removing pillars from the workings, causes the overlaying strata to collapse. Cracks will develop. If these cracks intersect with the surface rainfall water and run-off may flow down directly into the mining cavity. From studies done at collieries where stooping was done (Hodgson *et al.,* 2007), it has been found that normally a recharge rate of 4 – 12 % should be applied, depending on depth of mining and ratio of stooping.

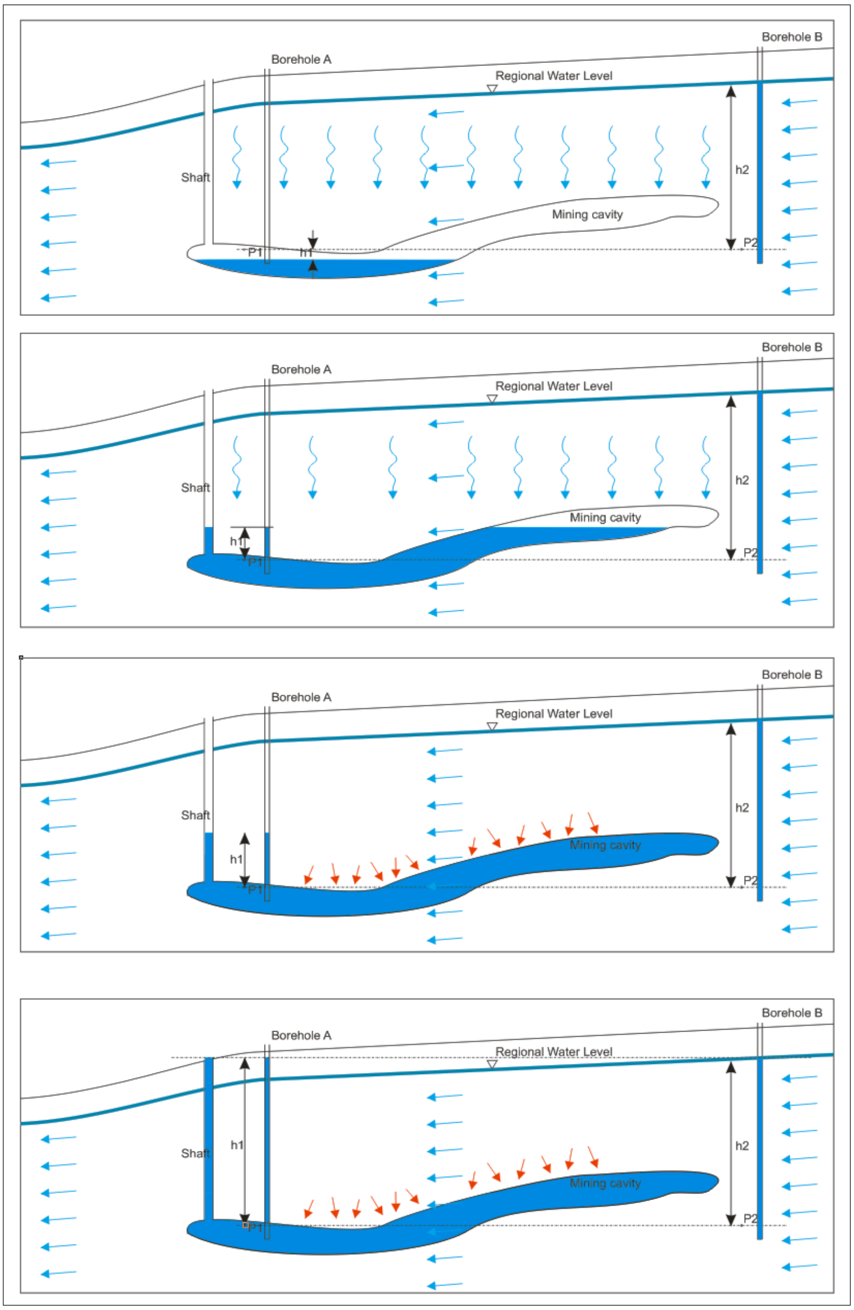


Figure 7-33: Schematic recharge of underground

According to the data the B-seam is completely filled with water. This has happened over the last twenty years (this is the number of years since mining has ceased in the B-seam). From this can be concluded that there must be a recharge of at least 5 %. The C-seam is shallower and no stooping has been done the recharge is also considered to be 5 %.

Prior to the opencast mining activities by Vunene the recharge factors are calculated to:

Table 7-7: Recharge factors prior to opencast mining activities.

Seam	Avg Depth [m]	Area not Stooped [*10^4 m^2]	Area Stooped [*10^4 m^2]	Recharge Factor [%]
C-seam West	44	1560	0	5.0
C-seam Central	125	108	0	0.1 (area under B-seam)
B-seam Central	97	333	97	5.0
B-seam East	107	2125	315	5.0

The Ermelo region receives, according to Weather SA, an average rainfall of 705 mm per annum.

Table 7-8: Recharge volums prior to opencast mining activities.

Seam	Area [*10^4 m]	Rainfall [mm/a]	Rainfall [m^3/day]	Recharge [%]	Recharge [m^3/day]
C-seam West	1560	705	32200	5.0	1610
C-seam Central	108	705	2083	0.1	2.1
B-seam Central	429	705	6607	5.0	330
B-seam East	2440	705	47143	5.0	2357

The total water make for the B-seam is 2687 m^3/day and for the C-seam 1612 m^3/day.

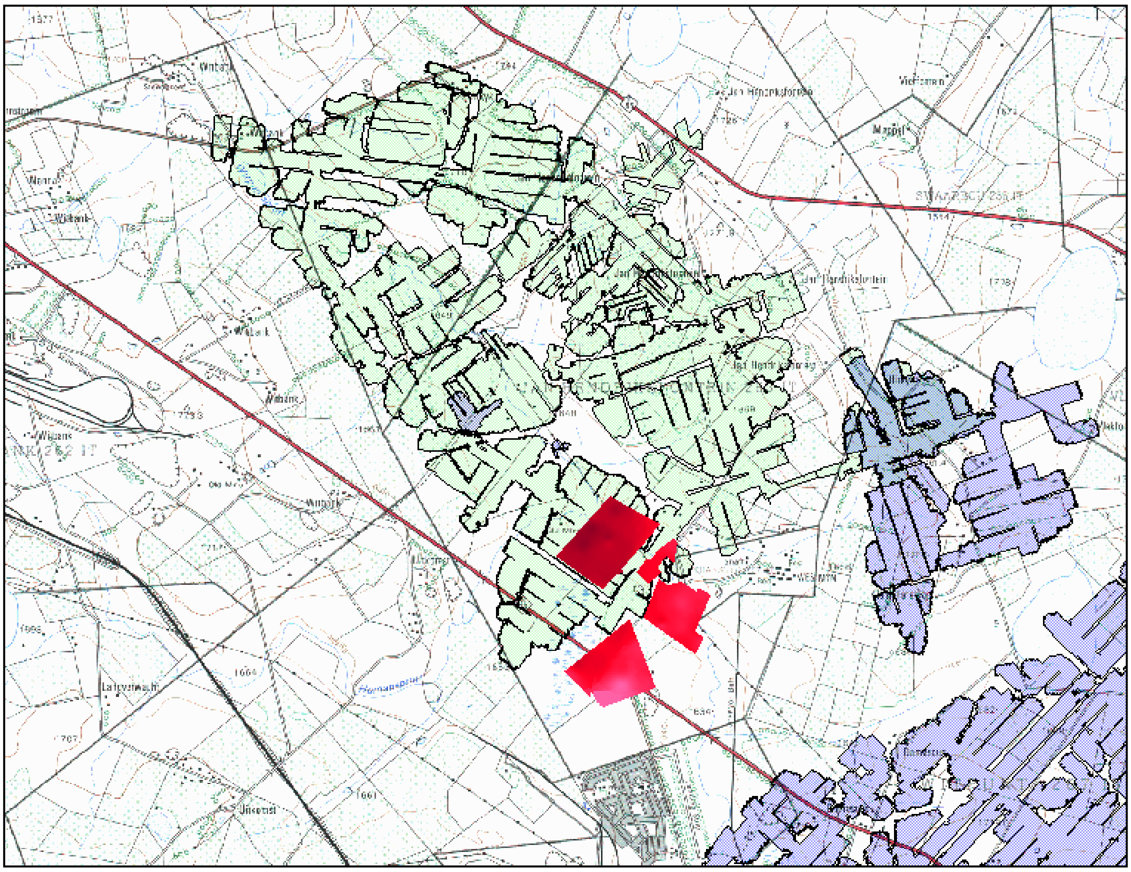


Figure 7-34: Position of the Vunene Opencast Pits in relation to the C-seam.

After the opencast mining activities ended there will be a rehabilitated open cast on top of the old workings (Figure 7-34). From the hydrology it is known that the average evapotranspiration is about 80 % in terms of the rainfall leaving 20 % for recharge on a not fully rehabilitated pit.This means that a pit that is badly rehabilitated and where all rainfall would run-off towards the spoils may expect a maximum recharge of 20 %. A very well rehabilitated pit with free draining from the spoils can expect a recharge of 10 %. The pit is currently in use and is not rehabilitated a recharge of 20 % is assumed.

Only pit A and B are situated on top of the underground the combined size of the two pits is almost 59 ha (588000 m^2). The thickness of the layer between the C-seam underground and the floor of the opencast (B-seam) vary between 10 and 1.6 m. With such a thin layer between the opencast and the underground cracks are imminent. All the water that recharges into the opencast will flow through the cracks into the underground. The amount of water anticipated from the two opencast pits is 588000*0.705/365*0.20 = 227 m^3/day, resulting in a substantial higher water make for the C-seam of 1612+227-22.7 = 1816 m^3/day.

7.12.1 The C-seam

The water level elevation at *Usutu E* is 1647 mamsl (higher that the highest point on the roof contour) indicating the whole mine has been filled. Although the mine is highly compartmentalized and water level elevations are not available for most of the compartments it is assumed that the whole mine is flooded. Pressure heights will differ from compartment to compartment. The total water in the C-seam is currently 17.3 Mm^3 (Figure 7-35).

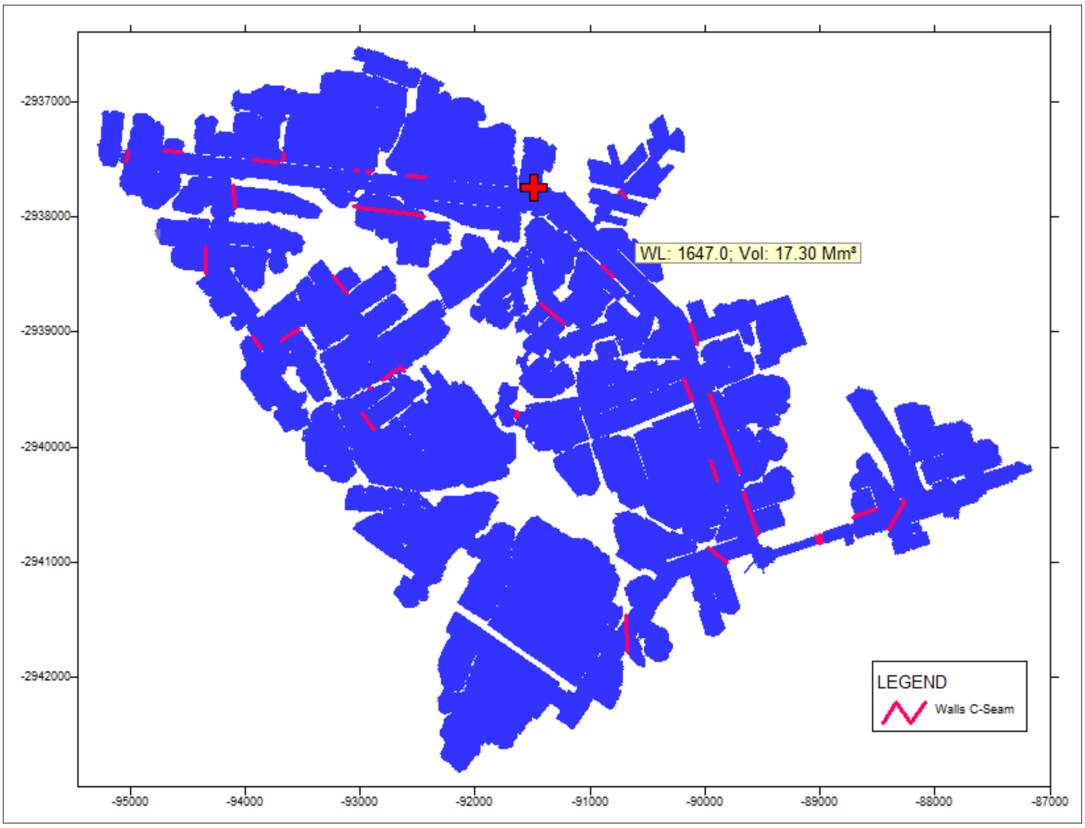


Figure 7-35: Water bodies in the C-seam.

A stage curve depicts the relationship between a stage height (the actual water level elevation) and the volume of water inside the underground. This assumes that the water table is horizontal and continues over whole of the mine. In Figure 7-36 the stage curve for the C-seam is illustrated, indicating that for a water level of 1647 mamsl (*Usutu E* water level elevation) the total water volume will be 17 300 Ml.

7.12.1.1 Decanting of the C-seam

Before the opencast mining of the B-seam decanting of the Northern mine was not expected because the coal seam does not intersect with the surface and current waterlevels inside the underground are far lower than the lowest borehole collar elevation of boreholes inside the C seam. With Vunene opencast on top of the C-seam things has changed. With an expected roof thickness between the underground and the opencast as low as 1.6 m cracks must form, creating a path for mine water to escape from the underground to the opencast. With all the ventilation walls acting as seals it is impossible to predict the water level elevation at the location of the opencast. The water level elevation in the north of the Northern mine is 1647 mamsl. The lowest point on the perimeter of the opencast outline of the opencast pit is 1641 m. If some of the ventilation walls between the *Usutu E* and the opencast collapse the underground can start decanting at the opencast.

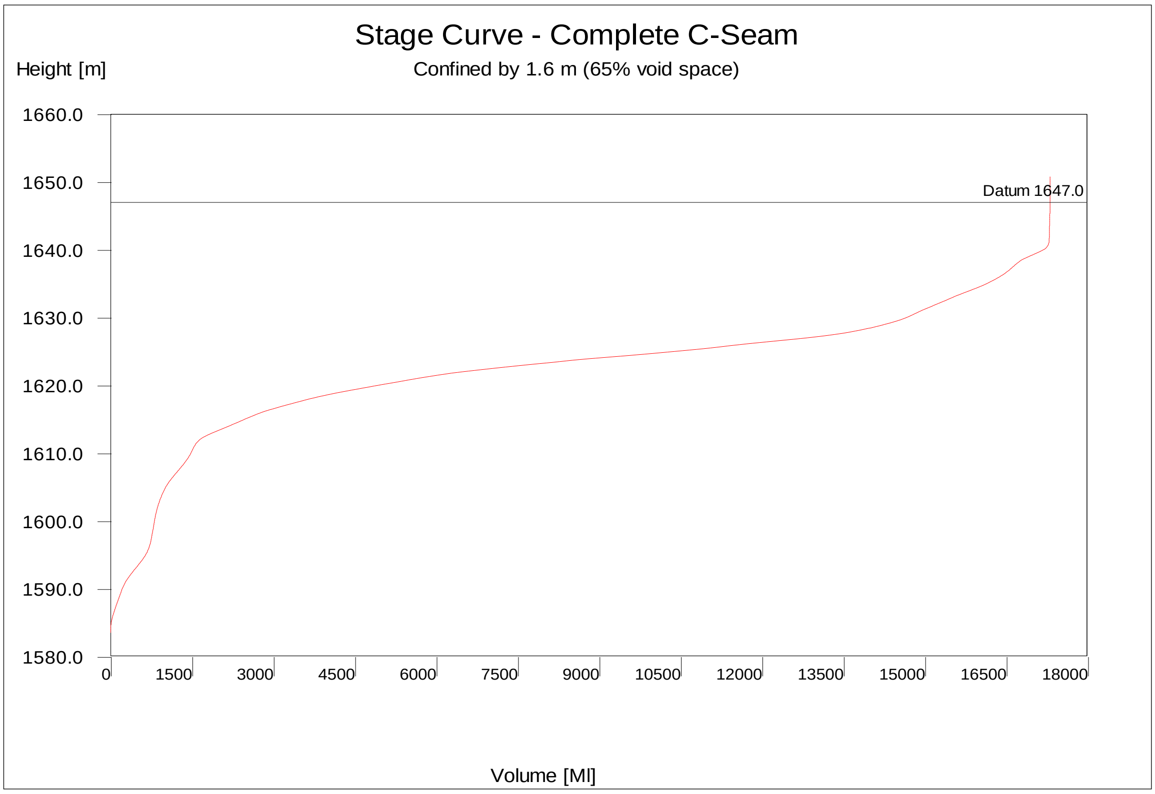


Figure 7-36: Stage curve for the C-seam.

7.12.2 The B-seam

All water level elevations measured in the B seam are much higher than the highest point on the roof contour of the southern mine. Although the southern mine is compartmentalized and water level elevations are not available for all compartments it is assumed that the whole mine is flooded. Pressure heights will differ from compartment to compartment. The total water in the B-seam is currently 25.4 Mm^3.

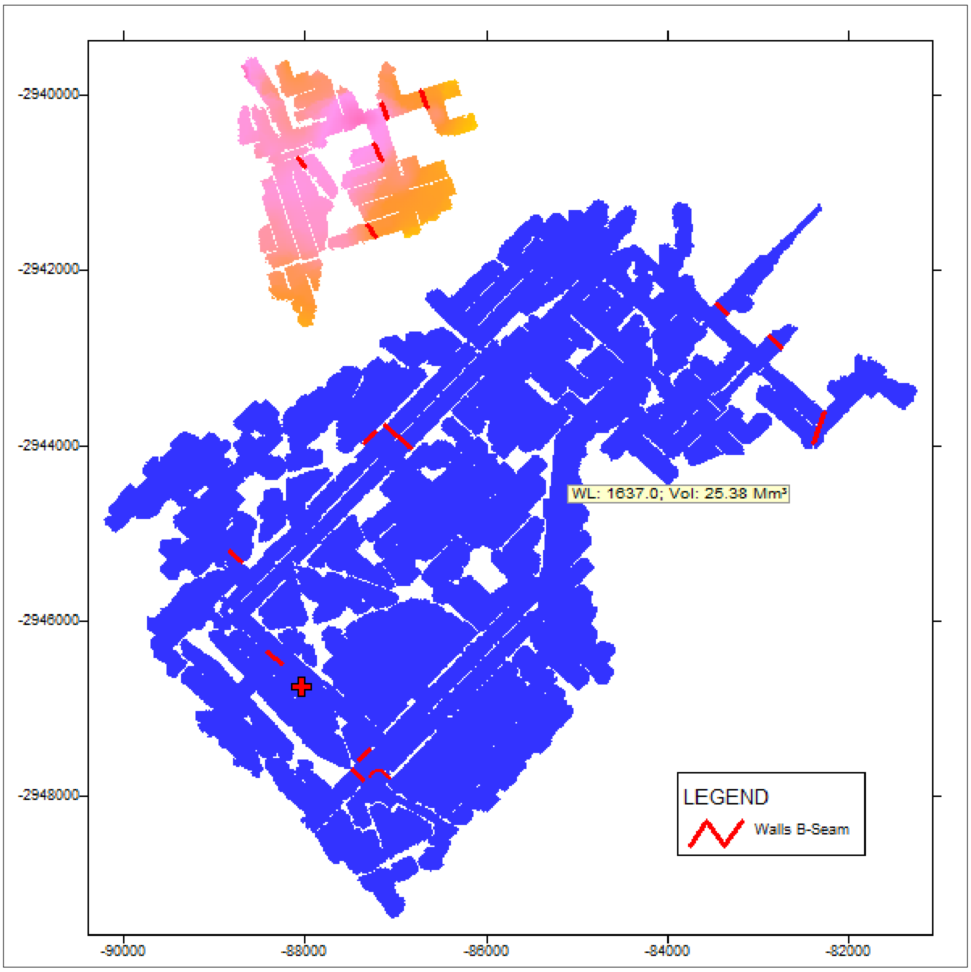


Figure 7-37: Flooded B-seam.

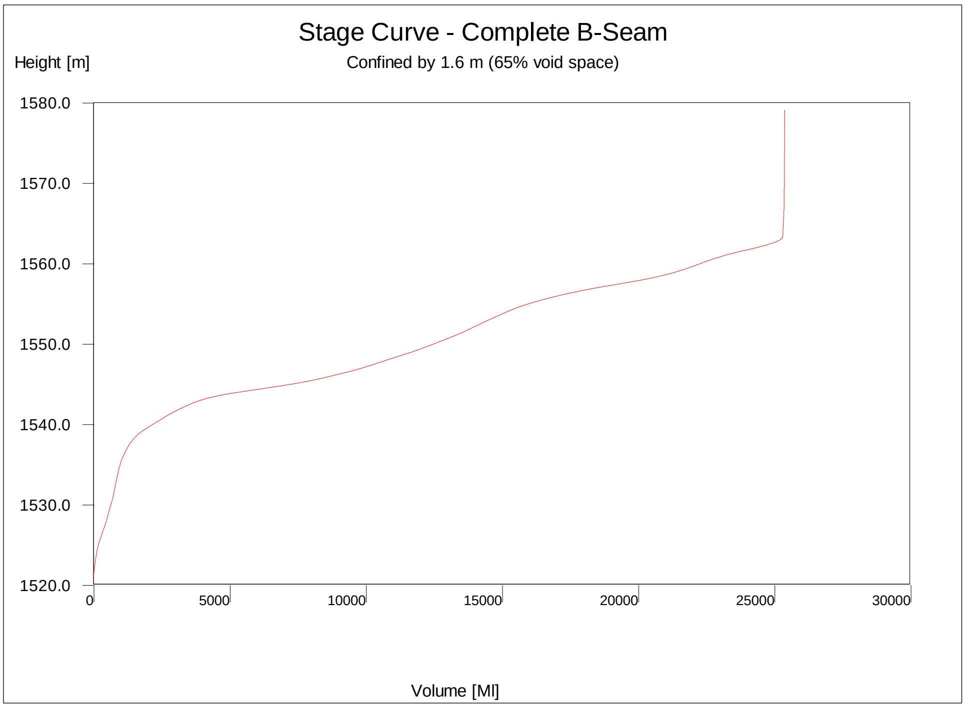


Figure 7-38: Stage curve for the B-seam.

In Figure 7-38 the stage curve for the B-seam is illustrated, indicating that the total water volume will be nearly 25 000 Ml.

7.12.2.1 Decanting of the B-seam

In 2010 there was a borehole decanting water at a supposed rate of 7 l/s. (Figure 7-39). This borehole is situated in the far south of the B-seam (Figure 7-40) in a very isolated panel which (according to mine personnel) was completely sealed off during mining. A possible reason for this sudden decanting may be the collapse of a ventilation wall.

Figure 7-39: Photograph of decanting borehole.

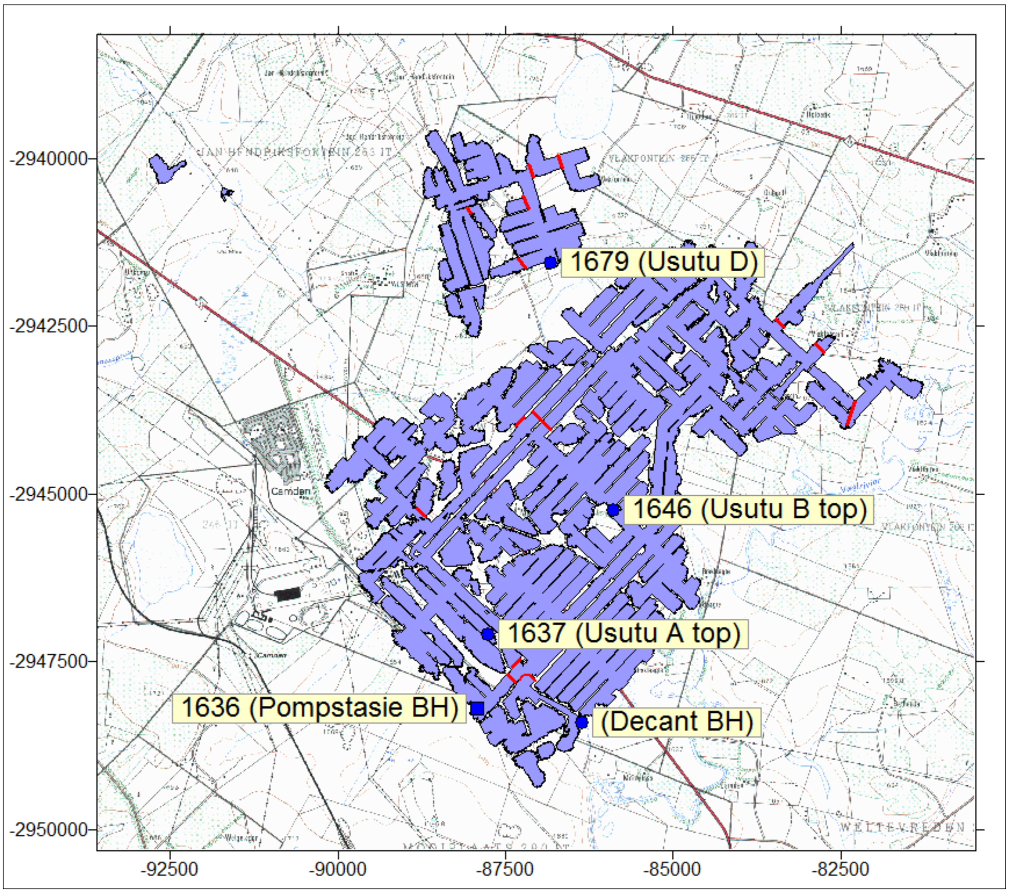


Figure 7-40: Position of the decant borehole in the far south of the B-seam.

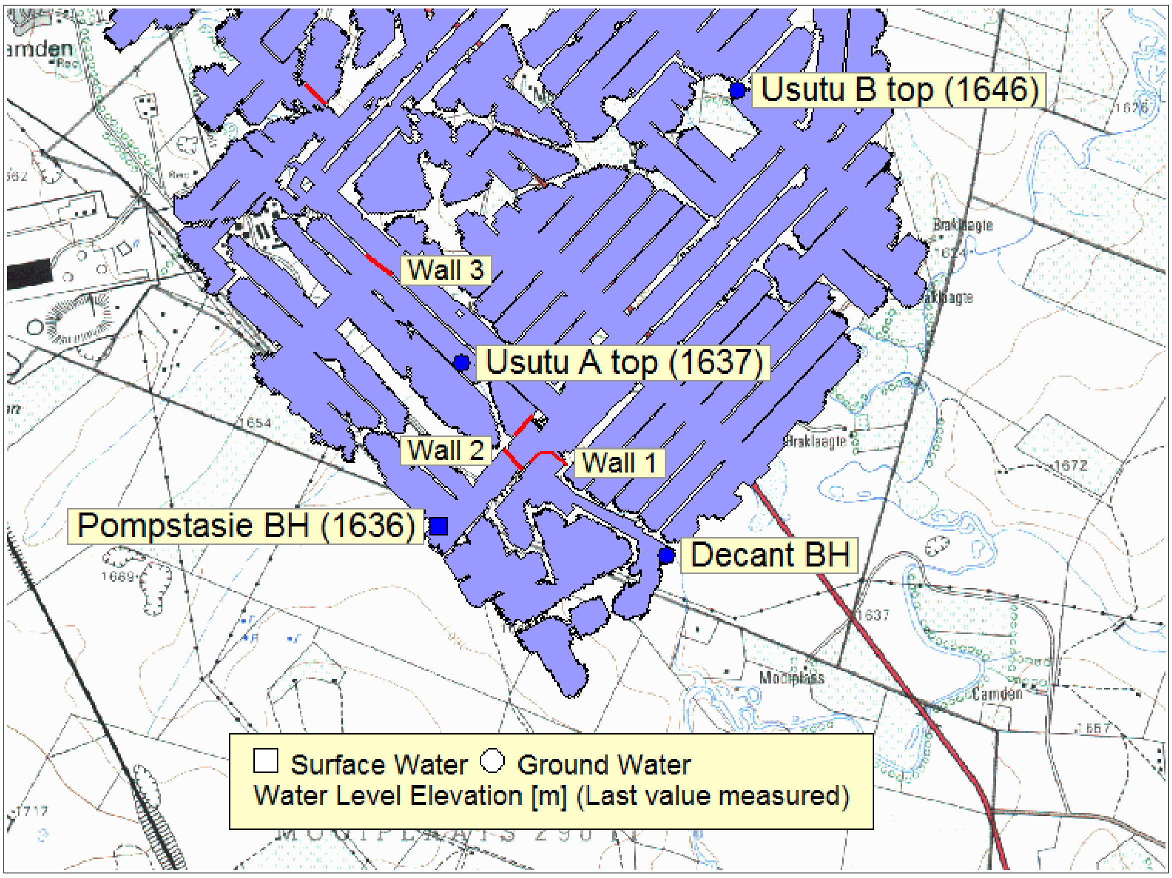


Figure 7-41: Position of the decant borehole close-up.

The collar elevation of the decant borehole is 1633 m. The waterlevel elevation for Usutu B is 1646 mamsl 13 meters higher than the decanting borehole. The collapse of the ventilation wall "Wall 1" indicated in figure 32 is the most probable reason why the borehole started to decant in 2010. Without the collapse of the ventilation wall there is no pressure that can force the water out. The waterlevel elevations at *Usutu A* and the pumped borehole "*Pompstasie BH*" of 1637 and 1636 respectively indicate that the ventilation walls 2 and 3 are still intact. If Wall 3 would collapse the surface elevation of *Usutu A* is 1641 mamsl 4 meters lower than the water elevation at *Usutu B*. The pumping at *Pompstasie BH* lowers the water level in the pumped compartment making Wall 2 more vulnerable to collapse. The surface elevation of the pumped borehole is 1673 mamsl. This elevation is higher than the water level elevation at *Usutu B*. From this can be concluded that with the current water level elevation decanting at *Usutu B* and *PompstasieBH* is not possible. The East shaft, the incline shaft as well as the ventilation shaft are sealed off and cannot decant. There is no information about the water level elevation in the north of the B-seam available. It is advisable to drill a few boreholes to enable monitoring of waterlevels.

7.12.3 The Central B- and C-seam

Both seams are highly compartmentalized and water level information is not available for the different compartments. It is understood that the higher B-seam in the central part is kept dry to remain accessible for future underground mining in a north-east direction. Any recharge in the upper workings (B-seam) is pumped to the lower workings (C-seam). Pumping figures are not available.

7.13 Mine interflow

Several mining operations are currently being conducted in the vicinity of Usutu Colliery.

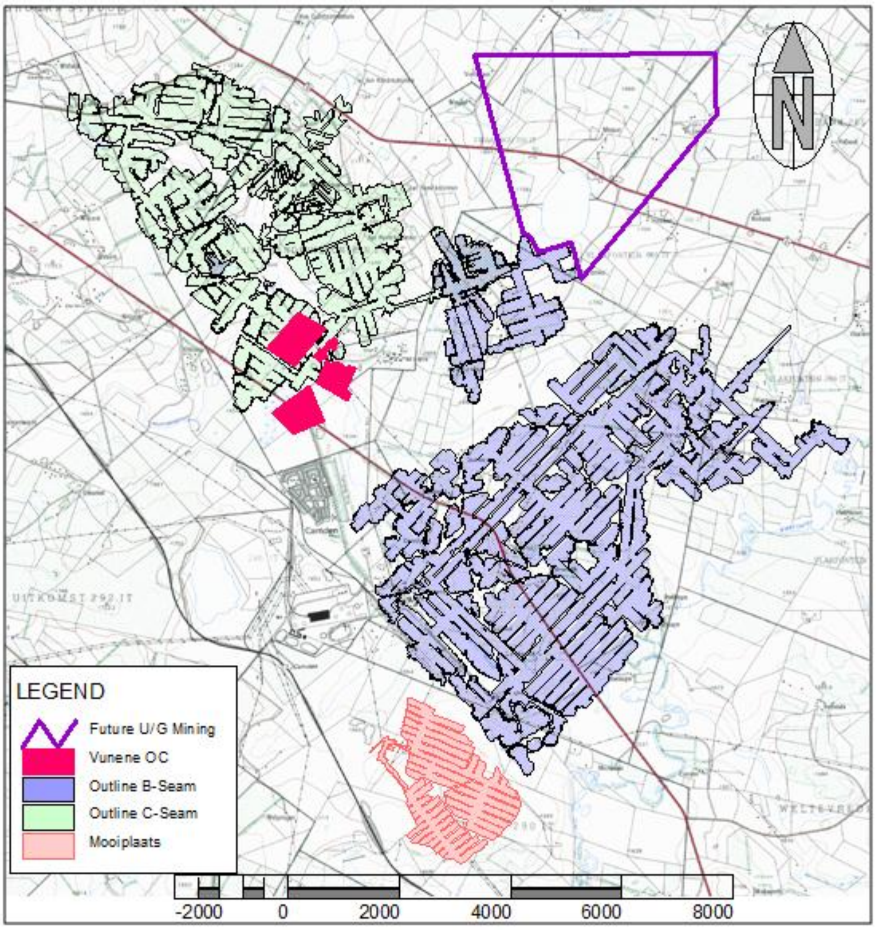


Figure 7-42: Planned future mining and mining adjacent to Usutu Colliery.

7.13.1 Mooiplaats

To the south of the South Mine (B-seam) Mooiplaats Colliery operates. The two collieries are being divided by a regional dyke. The barrier (pillar) between the two collieries is 250 m at the closest point between them. The level of mining also differs (according to the Mooiplaats geohydrologists). It is highly unlikely that any mine interflow will thus occur between these mines, as a pillar of that width will result in an impregnable layer (which will even increase with the presence of the regional dyke that acts as a buffer).

Currently water is being pumped from the Usutu B-seam to provide Mooiplaats Colliery with water (Figure 7-43). Recharge into the Usutu South Colliery is 2687 m^3/day, therefore pumping must be less than this to ensure that the water level does not drop below the roof of the mining cavity. Currently only 0.07 Mm^3 – 0.14 Mm^3 is used on average daily, according to figures obtained from the Mooiplaats geohydrologist.

Figure 7-43: Photograph of the extraction wells pumping water from Usutu South to Mooiplaats Colliery.

During an investigation, including EC profiling of the borehole (Figure 7-44) water running down the borehole could be heard. This is aquifer water draining directly into the mining cavity. These boreholes are situated on a topographic high and water from the high ground thus drain into the mine.

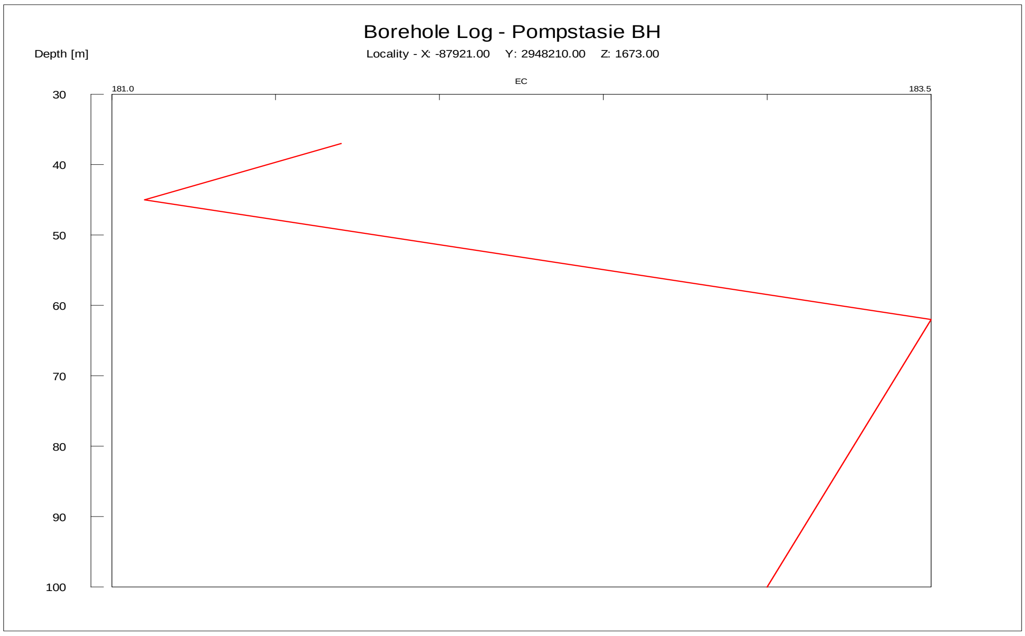


Figure 7-44: EC profiling of the pumping borehole.

The quality of the water being pumped is displayed in Table 7-9. From this it is clear that there is an improvement of the water quality. The measured quality corresponds with the profiling done during the field visit. Flushing is an accepted practice to improve the quality of mine water if the pumping rate (and thus the water levels) is managed properly, keeping the water level above the mining cavity. If the mine stays flooded then no additional oxygen ingress and pyrite oxidation will occur.

Table 7-9: EC [mS/m] quality over time of water being pumped to Mooiplaats Colliery.

	16/11/09	22/01/10	23/02/10	1/07/10	23/07/10	23/08/10	22/12/10	27/01/11	24/02/11	28/03/11
Conductivity	353	344	340	338	352	333	261	223	116	5.2

7.13.2 Vunene mining:

Underground:

The block in the north east of the map in Figure 7-42 indicates the planned future underground mining of Usutu. If this underground mining operation uses the central shaft of Usutu Colliery for entrance, it meant that the mine has to be kept dry. This may result in a constant ingress of oxygen into the old mine workings, which may enhance acid rock drainage. No detailed data is available as yet.

Opencast:

The thickness of the layer between the C-seam underground (mined out) and the floor of the opencast (B-seam), currently mined by Vunene Mining, vary between 10 and 1.6 metres. With such a thin layer between the opencast and the underground cracks are imminent. All the water that recharges into the opencast will flow through the cracks into the underground. The amount of water anticipated from the two opencast pits is 588 000*0.705/365*0.20 = 227 m^3/day, resulting in a substantial higher water make for the C-seam of 1816 m^3/day. There is no water quality available due to the current mining operations, but such ingress through the opencast will result in poor quality water seeping into the underground workings, deteriorating the water currently in these workings. Hodgson *et al*., 2003 indicated that sulphate generation in the flooded underground is less than 2 kg/ha/day (depending on the depth of mining and flooding rate) and that of opencast mining 7 kg/ha/day.

7.14 Conclusions

Using WISH the following is concluded:

- The area topography slopes mostly away from the mining area, as the mining area is situated on a topographic high in the northern part.

Water levels and quality:

- The average regional water level is currently less than 4 m. Some of the farm boreholes to the north of the mine are being pumped, resulting in water levels of deeper than 20 m.
- The water levels of the boreholes inside the mine differ for the two mines. The water levels in the southern mine is shallower than those in the northern mine. However, the water

levels differ substantially in the different boreholes, most likely the result of compartmentalization due to the ventilation walls. This makes interpretation of the mine water levels very difficult, and a number of additional boreholes have to be drilled to get a clear indication of the exact water levels in the mine.

- The regional aquifer water quality is similar to that of the "top" samples in the mine boreholes, indicating aquifer water for most areas above the mine.
- The bottom samples are more polluted than the top samples, with *Usutu I* and to a lesser degree *Usutu F* (bottom) very typical coal mine water. The mine boreholes indicate that the water quality for the top boreholes did not deteriorate since 2009. It also appears that there is a minimum stratification in the water columns in the two mines. Due to the fact that there are a number of ventilation seals in the mine, it reduces any change of pressure that can "push" the mine cavity water up to a decant level. At no point the mining cavity is close to the surface. Therefore no pressure can be created from the water in the mining cavity for mine water to decant. It is therefore unlikely that the borehole that decanted resulted from pressure that has been created from inside the mining cavity. The break of a ventilation seal, creating sudden pressure, may thus be a possibility.
- The regional recharge was calculated as 5.7 % by using the Chloride method. Recharge into the mine was calculated as >5 %.

Mining data:

- The average mining height of 1.6 m
- The combined C-seam varied in depth from very shallow (5 m) to nearly 80 m in the north. The Southern mine, where the B-seam was mined, varied between 75 m and 160 m.
- Also important is the barrier between different mines, which will determine mine interflow. The shortest distance of the pillar between the collieries is 250 m. The faults and dykes also play a role in compartmenting the mine as it normally also displaced the coal seams vertically.
- High extraction areas were also identified from the old maps. These areas may result in subsidence, increasing the recharge factor into the mine
- The total water make for the B-Seam is 2687 m^3/day and for the C-Seam 1612 m^3/day. The total water in the C-seam is currently 19.1 Mm^3. For the B-Seam the total water volume is 22.88 Mm^3.

Decanting:

- The possibility exists that decanting of the B-seam will take place at borehole Usutu A. The only reason it is currently not decanting is the presence of ventilation walls inside the working. Should wall 3 collapse (See Figure 7-41) the B-seam will start decanting!
- The lowest surface elevations of the boreholes in the C-seam is 1661 mamsl, the highest water level elevation measured in the C-seam is 1647. This is 14 m below the lowest borehole collar elevation. The possibility of decanting through the boreholes is small.
- The presence of an opencast on top of the C-seam underground in its lowest point with a roof thickness less than 2 m will allow decanting of the C-seam through the opencast.

To the south of the South Mine (B-seam) Mooiplaats Colliery operates. The two collieries are being divided by a regional dyke. The barrier (pillar) between the two collieries is 250 m at the closest point between them. The level of mining also differs. It is highly unlikely that any mine interflow will thus occur between these mines, as a pillar of that width will result in an impregnable layer

- There is an improvement of the water quality of the B-seam since pumping started, which indicate that flushing (if properly managed) is an treatment option.
- The Vunene mining operations on top of the mined out C-seam will have an influence on the water quality, as the B-seam which is currently being opencast, is only a few meters above the C-seam.

Chapter 8 Conclusions

Geohydrologists have the need for specific software ranging from mapping software to graphing, from chemical analysis to pumping test analysis and from borehole logs to contouring software and even more. Most of the software is available as separate computer programs. Some of these programs require special training. Only one software solution exists that can handle all above mentioned situations. WISH is not difficult to operate and can be mastered by any geohydrologist. The wide range of disciplines covered by WISH makes it *the* program to use.

Going back to the objectives of this study where the applicability of WISH as a (ground) water management must be determined, the following can be mentioned:

- Groundwater elevations.
  The plotting of groundwater levels as well as elevations on map and graph is not a problem for WISH.
- Hydrochemistry.
  WISH has built-in six different specialised hydrochemistry graphs. Hydrochemistry parameters can also be plotted as a time related graph or in a down-the-hole plot.
- Geology.
  A geological log comprising of geology, lithology, construction and other down-the-hole parameters may be plotted in a single borehole log. Contours from a certain geological layer can be created using lithology or seam information.
- Borehole Construction.
  See the previous item.
- Water balances.
  Using the WACCMAN functionality the calculation of water body volumes is quick and easy.
- Mapping
  WISH is built to do the mapping first. From the map the user may go the different graphs. Numerous thematic maps can be created using different background maps, different parameters, different standards and different data selections.
- Data Entering / Editing.
  WISH can handle a wide variety of data sources but the one most often used is Microsoft Excel. Data entering and editing is part of these software packages.
- Reporting.
  The reporting capabilities in WISH lies in the maps and graphs in can produce. Any of these items can be copied and pasted into other documents as a picture or as a metafile.

Any program used by the public, commercially, open source or otherwise, needs to be maintained. WISH needs to be maintained too and even developed further. The responsibility to keep WISH users satisfied rest on the shoulders of both the developer and the WISH user. Interaction between the developer and the user is needed to enable the developer to update the program as the user's requirements are continuously changing.

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Summary

Over the last 15 years the Windows Interpretation System for the Hydrogeologist (WISH) was developed by the author of this thesis. The program is used by numerous mines and consultants all over South Africa and abroad. WISH does not discriminate between mining types as it is just as capable of handling all water issues in the gold mines, platinum mines, iron mines or as the title of this thesis implies coal mines. Many other water related software packages are available. Most of them are developed for a single purpose. (Borehole logs, pumping tests, chemistry graphs or mapping) WISH is different because it can do it all. WISH was developed with the Hydrogeologist in mind. When a graph is requested WISH will create one first and subsequently allow the user to modify the graph. The volume calculations for opencast and underground mines are a breeze and no other existing software can do this with so much ease. Many collieries in South Africa are using WISH, not only for the chemistry and time data capabilities, but also for the management of large volumes of water. Many collieries trust WISH to calculate water capacity and water volumes in the mines. Decisions are taken to build 200 million rand water treatment plants.

This thesis discusses the development and existence of WISH. A comparison with all other (ground) water related software available worldwide followed by a more in detail description of WISH and a quick starter guide on how to create a WISH document. A chapter is dedicated to recharge and decant followed by a discussion on how to use WISH in a real life project.

Opsomming

WISH die “Windows Interpretation System for the Hydro-geologist” is oor die afgelope 15 jaar deur die outeur van hierdie tesis ontwikkel. Hierdie rekenaar program word by talle myne en konsultante in Suid Afrika en in die buiteland gebruik. WISH maak geen onderskeid tussen die verkillende tipes myne nie en kan waterkwessies gemaklik hanteer nie alleen van goud-, platinum- en yster myne nie maar ook in steenkool myne soos die titel van hierdie tesis impliseer. Baie sagteware pakette wat met water verband hou is beskikbaar maar die meeste van hulle is ontwikkel om net een enkele aspek te hanteer dit kan boorgat logs, pomp toetse, chemiese grafieke of die maak van kaarte wees. WISH is anders want WISH kan dit alles doen. WISH is ontwikkel met die geo-hidroloog in gedagte. As ‘n WISH gebruiker ‘n grafiek wil hê dan word een gemaak, daarna kan die grafiek verander word. Die volume berekeninge vir oopgroef en ondergrondse myne is baie gemaklik. Geen ander sagteware bestaan wat dit met so ‘n gemak kan doen. Baie steenkoolmyne in Suid Afrika gebruik WISH nie alleen vir die chemiese grafieke en tyds-afhanklike data vermoëns maar ook vir die bestuur van groot volumes water. Baie steenkoolmyne vertrou op WISH om die water volumes in die mine en die oorblywende stoor vermoë te bereken. Gebasseer op dit, word besluite geneem om 200 miljoen rand se waterbehandelingsaanlegte te bou.

Hierdie tesis bespreek die ontwikkeling en die bestaansreg van WISH. ‘n Vergelykende ondersoek met ander (grond)water sagteware wat gevolg word deur ‘n volledige beskrywing van WISH en ‘n wegspring handleiding wat verduidelik hoe om ‘n WISH dokument te maak. ‘n Hoofstuk gewy aan aanvulling en oorloop gevolg deur ‘n bespreking hoe om WISH te gebruik met ‘n wesenlike projek.