

**Surface Water and Hydrological Aspects pertaining to
the proposed Volspruit Mining Co Ltd, located on the
farm Volspruit 326 KR, Limpopo Province, South Africa**



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List of Acronyms and Abbreviations

Item	Description
~	Approximately (e.g. ~10 m wide = "approximately 10 m wide")
>	Greater than
<	Less than
3-D or 3D	Three dimensional
AED	African Environmental Development
CAD	Computer Aided Drawing
DTM	Digital Terrain Model
DEM	Digital Elevation Model
GIS	Geographic Information Service
GN	Government Notice (followed by an number)
HRU	Hydrological Research Unit (a division of the Civil Engineering Department of the University of the Witwatersrand in South Africa)
mamsl	Metres above mean sea level (elevation)
MAP	Mean annual precipitation (rainfall, measured in millimetres)
MAR	Mean annual run-off (the amount of the annual rainfall that reaches a watercourse, measured in millimetres)
N	North
PCD	Pollution Control Dam
RI	Return interval (pertaining to floods, e.g. RI of 100-years)
RI's	Plural of RI (Return Intervals)
ROM	Run of Mine (ore)
S	South
SG	Surveyor General (e.g. SG Diagram)
SOB	Sulphate Oxidising Bacteria
TML	Thabazimbi-Murchison Lineament
TSF	Tailings Storage Facility or Tailings Dam
WRD	Waste-Rock Dump



Surface Water and Hydrological Aspects pertaining to Volspruit Mining Co Ltd, located on the farm Volspruit 326 KR, Limpopo Province, South Africa

Changes Between Revision 00 and Revision 01

28 November 2012. When the original study was done in 2011, limited information was available for the proposed mine (such as layout plans, information relating to the groundwater ingress into the pits, water disposal options, etc.), while some misconceptions, relating to the Nyl River and its associated wetland existed. Thus, two separate documents, a baseline study, describing the hydrology and water quality of the Nyl River as it existed prior to mining, and a separate document, an impact assessment, incorporating the design of the mine surface and underground infrastructure. This later report would primarily be aimed at describing the impacts of the Nyl River on the mine and the impacts of the mine on the surface hydrology of the Nyl River and its flood plain.

However, our terms-of-reference was changed and we were requested to combine all the findings into a single document, this document.

This document, named "*Revision 01*" therefore incorporates the combined findings of the baseline study carried out in 2011 and the more recent impact assessment and includes inputs from the groundwater specialists relating to the quantities and modelled qualities of the water that will be pumped from the mine during its lifespan and also after closure.

Changes Between Revision 01 and Revision 02

12 April 2022. The study for the original report was carried out in 2011 and the report compiled in 2012. Since then some aspects of the mine plan has changed and AED was again approached to update the original report to include the changes. The most significant changes were related to the locations and shapes of the tailings storage facility (TSF), the waste-rock dump, as well as some of the pollution control dams. AED was given a Google Earth file named "*Model.kmz*" that showed the new mine



layout plan. Although this model showed the new sites in plan, it did not include an elevation map of the site, as did the previous AutoCAD file we worked from in the original study. We therefore used the same elevations for (e.g.) the new TSF and the new waste rock dump as we had in the file for the original ones.

During the time-slot we were allocated to do the site visit for the updated report, there was no or limited flow in the Nyl River, therefore no additional water samples were collected for the new report. However, given the stability of the Nyl River system, AED is of the belief that very little change had occurred over the past 10 years and that the 2011 samples would still be representative of the aquatic conditions today.

Changes Between Revision 02 and Revision 03

29 July 2022. AED was able to access information from recently-completed other specialist studies, in particular the groundwater report by du Toit and Terblanche (*du Toit & Terblanche, 2022*). This provided new information and our report was altered to incorporate this new information.

Additionally, some of the figures in this report were altered to incorporate the new mine surface infrastructure.

Finally, the report was streamlined and some duplication of certain parts was removed.

Executive Summary:

This document describes the surface water and hydrological aspects of the proposed Volspruit Mine in relation to the Nyl River and its associated wetland.

The initial part of the study, presented as a separate document, and which focussed on a fatal flaw analyses, primarily aimed at addressing the issues of flooding of a mine located in close proximity to a river with a large catchment, was identified as a potential serious area of concern and thus the 100-, 50- and 10-year flood lines were modelled and plotted on maps of the proposed mine. This part of the study showed that, unless some form of flood barrier is constructed, opencast (and for that matter,



shallow underground) mining will not be possible as the north pit of the mine, located right at the edge of the Nyl River will certainly flood during at least one (likely more) of the rainy seasons it will be in operation. For this reason, a conceptual flood barrier was designed, based on the highest elevation floodwaters would reach during a flood event with a probability of occurring every 100 years. This work is described in the first report published in 2010 (Krige & Bond, 2010) and its addendum (Krige & Bond, 2011). Although the mine has made some changes to the shape of the flood barrier, it will still be as effective as the conceptual one, as the barrier's crest will be at the same elevation AED recommended in the flood line reports.

This current) document focuses on describing the general surface water and hydrological aspects of the Nyl River and its associated wetland. Although the Nyl River wetland covers an area of about 24 000 Ha and is over 6 Km wide in places (upstream from the proposed mine), covering a distance of about 84 Km (from the beginning of the Nyl River wetland upstream from the Nyalsvley Nature Reserve to the confluence of the Rooisloot with the Nyl River), it was realised that this wetland cannot be separated into smaller sections or compartments, as it forms a single, mostly uniform entity (from a hydrological perspective, at least). It is therefore not possible to study the hydrology of the small part of the wetland at, and associated with, the proposed mine without having to include the rest of the wetland up- and downstream from the proposed mine as well. It was also noted that cognisance had to be taken of the interaction between surface and groundwater and although this report is not intended to include a groundwater analyses, it became apparent that surface- and groundwater could not be studied in isolation, as there is too much of an overlap between the two disciplines, particularly at this site. The reason for this is that the Nyl River wetland is located on the surface of an in-filled alluvial river valley, in places up to 35 m deep. It was originally assumed that water flowing on surface could recharge into this alluvial fill, only to reappear at the outlet of the wetland. It was further assumed that there would not be a definite separation of surface- and groundwater at this site. However, it became apparent during the course of this study that at this particular stream/alluvial aquifer there was a definitive separation (in the form of a clay aquitard) between the surface water flowing in the flood plain on the surface of the wetland and the alluvial-filled aquifer underlying the wetland.



This document subsequently describes the hydrology and other surface water aspects (water quantities and water quality) of the Nyl River and its associated wetland. It also addresses certain aspects of the water quality within the Nyl River and its associated wetland.

This study has revealed some astounding facts about the Nyl River and its wetland.

The first and most important is that the river should not exist in its present location. Its direction of flow contradicts all logic. It is assumed that its present-day direction of flow has resulted from a geological event, probably associated with one of the many faulting events occurring within this area, but it is presently not sure exactly how and why the river changed its course. In our report, we have given some reasoning on our interpretation of the events that caused the surface water flow to change direction.

Stemming from the above it is shown that, in spite of its vast size, there is a precariously delicate balance maintaining the in-filled alluvial river basin and the wetland on its surface. We have shown that there are many factors playing a combined role in maintaining the alluvial fill and the wetland on its surface and by modifying any one of these factors, the process leading to the eventual demise of the alluvial bed and the wetland on its surface, could be initiated. The ultimate fate of the wetland could go in two opposite directions. Firstly, by altering the conditions at its outlet, by removing the barrier keeping the rest of the alluvial material in position, the wetland will be eroded away via the Mogalakwena River. The second potential cause for the demise of the alluvial riverbed and associated wetland could rise from the fact that the river flows in the wrong direction in the first place and that in certain areas, only a few metres elevation separates the present wetland bed from the adjacent catchment falling away from the Nyl River. If this barrier is breached, the Nyl River is likely to change its course, roughly in the centre of the wetland, towards the Olifants River, signifying the end of Nyl River wetland.

The second result from this study shows that, contrary to common belief, there is a much smaller interaction between surface- and groundwater than what was believed initially. Normally, when a river flows on an alluvial-filled river basin, there is an



unhindered interaction between the surface- and groundwater. In most cases the river flowing on the surface also marks the water table in the aquifer underlying the river within the alluvial bed. If groundwater is removed from the aquifer, the surface stream merely tops it up again.

As a result of the extent and morphology of the Nyl River floodplain, however, our study has revealed that, apart from the areas along the edges of the floodplain and along the channels of the incoming rivers before these “flood out” onto the floodplain, there is very limited surface-groundwater interaction due to an aquitard separating the water on the surface of the wetland and the groundwater in the deeper, coarser parts of the in-filled alluvium, underlying the wetland. Although there would still be some surface-groundwater interaction, this interaction would not be as pronounced as it would be within other hydrologically similar systems. This lead AED to postulate that abstraction of groundwater by a mine located alongside the Nyl River may not have as great an impact on the surface water environment as it would have had under other similar conditions elsewhere.

From purely a hydrological perspective and using the information available at the time of the study, it does not appear that the establishment of a mine in this particular area would have a particularly significant effect on the surface water hydrological environment, compared to what was believed initially.

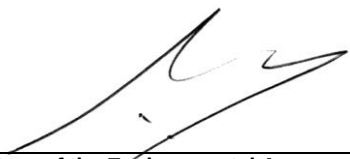


Declaration of Independence:

The independent Environmental Assessment Practitioner

I, **Garfield Krige. Pr.Sci.Nat. Aquatic Science (Reg. No. 400068/10)** declare that I:

- act as an independent Environmental Practitioner in this study of the surface water and hydrological aspects pertaining to the Volspruit Mining Co Ltd;
- do not have and will not have any financial interest in the undertaking of the activity, other than remuneration for work performed in terms of the Environmental Impact Assessment Regulations, 2006;
- have no and will have any vested interest in the proposed activity proceeding;
- have no, and will not engage in, conflicting interests in the undertaking of the activity;
- undertake to disclose, to the competent authority, any material information that have or may have the potential to influence the decision of the competent authority or the objectivity of any report, plan or document required in terms of the Environmental Impact Assessment Regulations, 2006;
- will ensure that information containing all relevant facts in respect of the application is distributed or made available to interested and affected parties and the public and that participation by interested and affected parties is facilitated in such a manner that all interested and affected parties will be provided with a reasonable opportunity to participate and to provide comments on documents that are produced to support the application;
- will ensure that the comments of all interested and affected parties are considered and recorded in reports that are submitted to the competent authority in respect of the application, provided that comments that are made by interested and affected parties in respect of a final report that will be submitted to the competent authority may be attached to the report without further amendment to the report;



Signature of the Environmental Assessment Practitioner:

African Environmental Development

Name of Company:

29th July 2022

Date:



Surface Water and Hydrological Aspects pertaining to the Volspruit Mining Co Ltd, located on the farm Volspruit 326 KR, Limpopo Province, South Africa

Introduction and Background:

Volspruit Mine has acquired the rights to exploit the Platinum Group Elements (PGE) contained in the Grassvalley Body of the Rustenburg Layered Suite, in the southern-most section of the Northern Limb of the Bushveld Complex, underlying a contiguous portion of land, which includes the farm Volspruit 326 KR and parts of the farm, Zoetveld 294 KR, near Mokopane (Potgietersrus), Limpopo Province, South Africa. It is planned to access the ore body through two open pits, a northern and southern pit, both locating in very close proximity the Nyl River and its associated wetland.

E-Science Associates (Pty) Ltd were appointed to deal with the environmental issues relating to the Mining Right application and subsequently, African Environmental Development (AED) were commissioned as a specialist sub-contractor to evaluate the surface water and the hydrological aspects pertaining to the proposed new mine. AED was again appointed in 2021/2022 to update the original surface water report in order to accommodate the changes in the Volspruit's mine layout.

Initially a fatal flaw analyses, done in 2010, focussing mainly on the impact of a 10-, 50- and 100-year flood in the Nyl River adjacent to the proposed opencast pit was carried out. These flood lines were modelled and evaluated in terms of several different scenarios. Initially, the 100- and 50-year flood lines were modelled and reported on in 2010 (*Krige & Bond, 2010*), while a second flood line model was done early in 2011 to also include the 10-year flood lines of the Nyl River adjacent to the proposed northern opencast pit (*Krige & Bond, 2011*). All these studies revealed that, unless some form of flood barrier was established between the northern pit and the river, neither opencast nor shallow underground mining would be possible at Volspruit. Subsequently, a conceptual flood barrier, to be constructed from overburden and waste rock recovered from the mine, was designed as part of this study.



The document following the initial flood line document (Volspruit Mine - Surface Water Report Rev01.doc) focused on a general description of the surface water and hydrological aspects pertaining to the proposed mine and the adjacent Nyl River. This document recorded the baseline surface water and hydrological conditions at Volspruit and the Nyl River wetland, i.e. the conditions before mining activities commence. The results would then be used to evaluate the performance of the mine in terms of the surface water quality and quantities.

Preliminary studies have shown that, in addition to the surface water of the Nyl River that would have a definite impact on an opencast mine in that particular location, the fact that this area has undergone extensive tectonic deformation in the past, resulting in significant geological faulting in the area intended to be mined, would cause a high rate of water ingress into a conventional opencast mine. The groundwater report (*du Toit & Terblanche, 2022*) has, however, revealed that, in spite of what was initially thought, water ingress into the two mine pits would not exceed approximately 4 Ml/day during the period in the life of the mine when the greatest ingress of groundwater into the mine would be experienced.

Subsequent to the 2010-2012 studies, the mine surface infrastructure layout has changed and AED was requested to update the previous report to include these changes.

To understand the hydrological dynamics that could have an impact on the mine, it is firstly necessary to understand the Nyl River and its associated flood plain and the underlying alluvial-filled aquifer. For this reason, we have included the following section, describing this unusual and somewhat unique river basin.

A Brief Description of the Nyl River Floodplain

Geologically speaking, the watercourse in which the Nyl River flows formed a deep valley, carved out of the bedrock on which it flows. Subsequent to its formation, this valley has been in-filled with debris (rocks, grit sand and finer material), presumably washed off the Waterberg Mountain Range to form a flat and very wide floodplain on which the Nyl River flows today.



Still on a geological timescale, the Nyl River flows on weathered basalt of the upper Karoo Supergroup – refer to the item annotated "JI" in **Figure 5**, before crossing the Zebediela Fault and flowing onto rocks of the Bushveld Complex. Over time it cut a deep channel into the bedrock over which it flowed. It is not quite clear how this valley was formed, but one of the theories is that the river existed before the Zebediela Fault occurred and that the flow was in its current direction (i.e. northeastwards). Geological forces then slowly, and in separate events, displaced the land south of the fault downwards, relative to the land to the north of the fault and subsequently, the much younger Karoo rocks south of the fault now locates in contact with the much older rocks of the Bushveld Complex north of the fault. The theory continues that a deep valley was carved out of the bedrock under the Nyl River before the Zebediela Fault was formed and that the erosion of Nyl River into the rocks to the north of the fault was able to keep up with the rate of up-down displacement along the fault. If this assumption is true, the author believes that the depth of the historic river channel must be significantly deeper to the south of the fault, compared to its depth in its reach north of the fault. This theory can be confirmed/refuted by drilling of boreholes across the different parts of the river valley (up- and downstream of the Zebediela Fault). Currently, there is by no means confirmation of the above theory and subsequently it cannot be assumed that this is what actually occurred. There are other theories as well.

If the above theory is **not** true, the hydrology of the proposed Volspruit Mine cannot be studied in isolation, without also including the hydrology of the entire Nyl River floodplain. The wetland and the alluvial aquifer underlying it is a single hydrological unit and cannot be fragmented and studied scientifically in isolated sections. The entire wetland must be considered as a whole, in spite of its large size. Similarly, the surface hydrology is considered being intertwined with the geological material from which the basement of the wetland is made and which contains the groundwater underlying the wetland. For this reason the surface water can also not be studied without including some aspects of the local and regional groundwater and the geology.

The wetland associated with the Nyl River is also referred to as the *Nylsvlei*. Part of this wetland has been declared a nature reserve and named the *Nylsvley* Nature



Reserve. The entire Nylsvlei wetland is a declared RAMSAR site. To avoid confusion between the different names (Nylsvlei and Nylsvley) we will not use the name “Nylsvlei” in this report, but only the terms “Nylsvley Nature Reserve”, when referring to the nature reserve (refer **Figures 4** and **17** for its location) and the name “Nyl River wetland”, when referring to the wetland associated with the Nyl River or the Nylsvlei.

The Nyl River originates in the sandstones (and some basalt on the plateau) of the Waterberg to the southeast of the proposed mine and, although both its tributaries, the Great and Little Nyl Rivers, initially flow in narrow channels on bedrock, near the confluence of the two streams, the river rapidly spreads out into a wide floodplain with no defined stream channels, which extends for about 70 Km from the confluence of the two streams, to the point where it once again flows in a defined channel on bedrock, i.e. some distance upstream from the confluence of the Dorps River, Rooisloot and Groot Sandsloot (alias: Pholotsi) with the Nyl River.

The floodplain consists of mainly transported Quaternary Era alluvial material, which has in-filled the original river valley, in places up to 35 m deep, to form a wide alluvial floodplain. This floodplain, in addition to its biological importance, also acts hydraulically as an extensive groundwater reservoir, linking to a certain extent, the surface water (in limited parts of the Nyl River) with the deeper groundwater aquifers below and to the sides of the alluvial aquifer.

The Nyl River floodplain is a seasonal wetland in the semi-arid parts of the Limpopo Province. With an area of about 24 000 Ha and a length of a bit over 70 Km, it is the largest example of a floodplain wetland in South Africa. This internationally renowned conservation area includes the Nylsvley Nature Reserve, a designated RAMSAR Wetland of international importance, which is home to more than 420 bird species, including 102 water birds, of which 58 breed on the floodplain. It supports 61% of the breeding population of inland water birds south of the Zambezi and Cunene Rivers, while 92% of Southern African water bird species have been recorded here at some time or another. Other inhabitants of the river and the floodplain are some 70 mammal species, 58 reptile species, 16 fish species, about 10 000 insect species.



The floodplain owes its existence to the geological characteristics of the region, its basin having probably been modified as a result of the Zebediela Fault, the southern boundary of the Thabazimbi-Murchison Lineament (TML), crossing under the Nyl River immediately to the south of the proposed Volspruit Mine. The river basin lies between the Waterberg Mountains to the northwest and the Springbok Flats, a large featureless expanse, to the southeast. In its upper reaches, the floodplain is confined to the local synclinal basin and is relatively narrow (<1.8 Km wide). As the floodplain widens, the river channel gradually decreases in size through the Nylsvley Nature Reserve, and eventually disappears altogether to form an extensive, flat floodplain immediately downstream from the reserve. In the vicinity of the Zebediela Fault, the river channel reforms as a river draining the wetland and possibly also draining some water from the alluvial aquifer underlying the wetland where the wetland becomes progressively narrower. At this point the river's name changes to the Mogalakwena River, which continues mostly on bedrock (and not on alluvium) towards its confluence with the Limpopo River.

The river that shouldn't be

If the Nyl River is viewed on a contour map, something appears to be wrong with the map. The Nyl River flows in a direction of disagreement with the surface topography. Theoretically, the Nyl River should not be where it is located at present; it should rather flow at right angles to its present course.

Post-Karoo movement along the Zebediela Fault and the many other smaller faults in this area created the river basin within which the Nyl River flows today. It is not quite clear exactly how this basin formed in the first place as it does not follow any of the known faults in the area. Furthermore, a large part (the part where the wetland is at its widest (i.e. the area south of the Zebediela Fault) locates on weathered basalt of the upper Karoo Supergroup (refer **Figure 5** – marked “J1”). The more recent faulting associated with the Zebediela Fault is the fourth and last generation of fault deformation occurring in the Grassvalley Body of the Rustenburg Layered Suite after emplacement and consolidation of the Bushveld Complex (*van der Merwe, 2007*). The earliest generation of faulting was an episode of north-south trending reverse faulting. The second generation is portrayed by west-northwest-striking faults. This is also roughly the direction of the Nyl River and may give a clue to its direction of flow.



Third-generation faults strike northeast and are assumed to be post-Waterberg. The fourth and final period of faulting occurred in post-Karoo times and is best demonstrated by the almost east-west-striking Zebediela fault (*van der Merwe, 2007*).

One or more of these faulting episodes created a trough, which was subsequently in-filled with alluvial material eroded off the Waterberg Mountain range. The author postulates that, prior to the faulting that created the trough, surface water flow occurred in an easterly to southeasterly direction, i.e. from the Waterberg towards the Olifants River in the east, likely via the Grass Valley River. This hypothesis is supported by the fact that there is a large fan of transported material, spreading out from where the Nyl River flows at present, across the western parts of the Springbok Flats. At some stage in the past, the southwest-to-northeast trough formed, which cut off this flow and re-directed it to the upper reaches of the Mogalakwena River.

McCarthy (*McCarthy et al, 2011*) believes that the obstruction in the trough, resulting in the in-filling of the trough along which the Nyl River flows, was not formed by a solid geological obstruction, such as a dyke or rock outcrop or other hard blockage, as is common for most other alluvial in-filled river basins, but was rather formed by alluvial fans forming in the area where the Dorps River, Rooisloot and Groot Sandsloot enters the Nyl River at the downstream end of the Nyl River wetland (*McCarthy et al, 2011*). This material, deposited in the Nyl River valley, caused a series of obstructions in the flow of the Nyl River, reducing the gradient of the upstream part of the river and resulting in the areas upstream from these tributaries to also become in-filled with alluvial material transported into the basin from the tributaries flowing off the Waterberg Mountains to the northeast of the Nyl River Basin.



Satellite Photo 1: A satellite photograph of one of the three alluvial fans; this one made by the Dorps River where it enters the Nyl River from the east. It is presently used intensively for agricultural purposes. As can be seen, this fan of coarse sediment has caused a partial blockage in the flow of the Nyl River (flowing from south to north), displacing the river channel all the way across the valley to the west. This blockage has caused back-ponding and gradient reduction further upstream, contributing to valley fill occurring further upstream (Photo courtesy Google Earth, 31/07/2010)

McCarthy (McCarthy *et al*, 2011) describes how the climate had also played a vital role in the deposition of alluvial material due to the semi-arid nature of the area. These climatic conditions did not create sufficient and simultaneous flow in the Nyl River to clear the obstructions caused by the coarse alluvial deposits from the Dorps River, Rooisloot and Groot Sandsloot at the end of the Nyl River basin, hence the preservation of the present alluvial wetland. As long as these semi-arid climatic conditions prevail, and the two rivers, the Dorps River and Rooisloot (and to a lesser extent, the Groot Sandsloot - alias Pholotsi - further downstream), continue to deposit alluvium at a greater rate than the rate at which the Nyl River can erode these deposits away, the Nyl River wetland and floodplain will continue to be maintained in its present state.

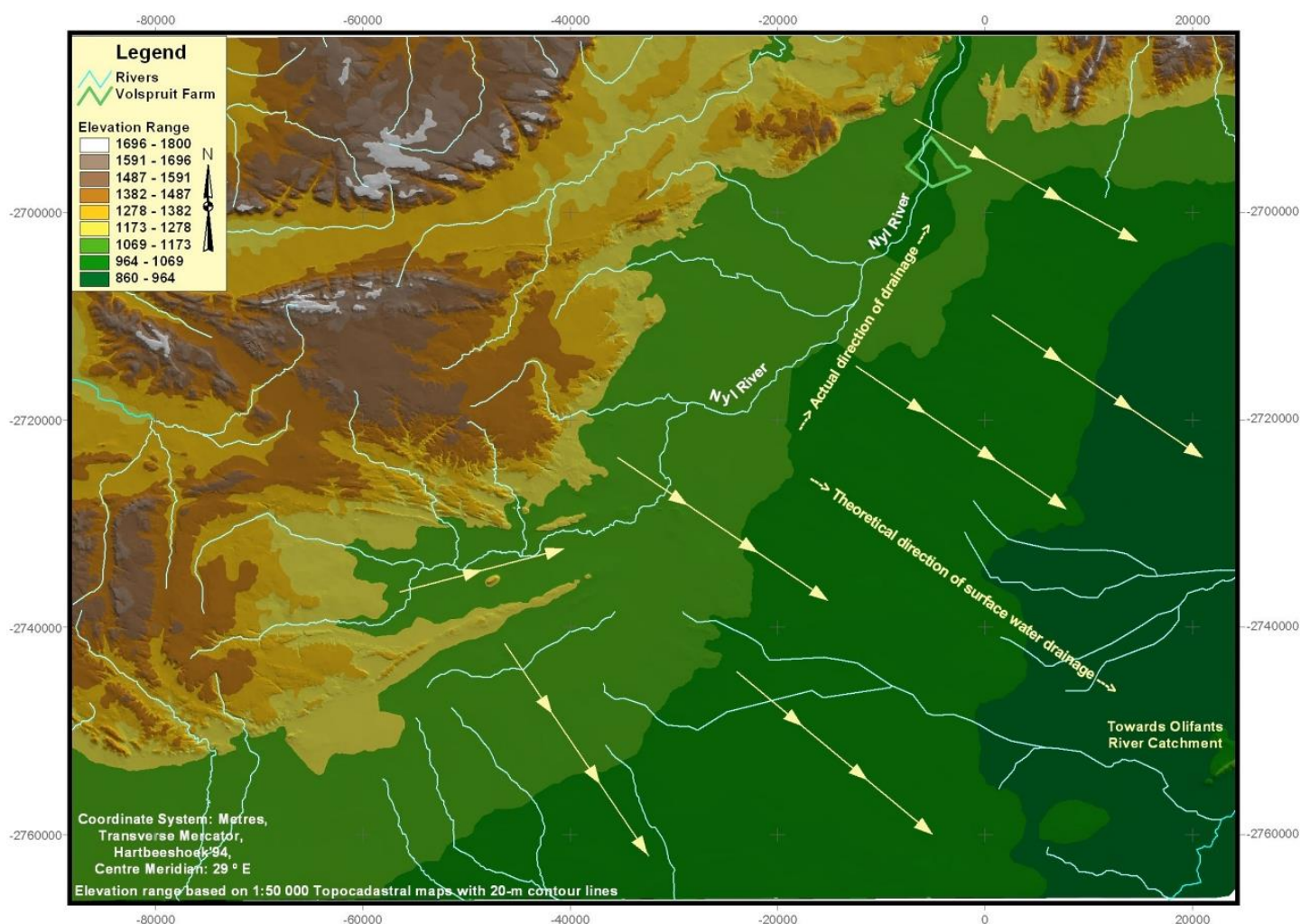


Figure 1: The Topography of the Nyl River Basin clearly shows that in reality, the Nyl River flows in a direction contradicting normal logic (i.e. from a topographical high to a topographical low). The arrows show the expected direction of surface water flow towards the Springbok Flats in the east and southeast, while it is obvious that the Nyl River does not follow this path, especially in the area of the word, “Actual” where the actual direction of drainage is indicated.

However, the author believes that the floodplain has reached close to its maximum elevation possible and cannot be filled much further without initiating a decant towards the Springbok Flats, the historic and natural direction of flow. **Figure 1** shows the largest part of the Nyl River on a backdrop of the surface topography. In this elevation map, dark green represents the lowest elevations, with lighter greens to yellows to light and dark browns to light greys indicating progressively increasing elevations. Under normal circumstances it would be expected for water to flow at right angles to the direction of the contour lines. Not so in the case of the Nyl River Basin! The Nyl River actually flows in the same direction as the contour lines. This



anomaly in the flow direction of the river confirms that the valley created by the deformation of the earth's crust, possibly by the localised faulting, has caused the Mogalakwena River to capture (or "hijack") the upper reaches of the Nyl River, diverting to towards the north.

Examination of the 5-m contour lines of the area, sourced from the Chief Surveyor General office, show that in a particular area of the Nyl River (shown in **Figure 1**), the elevation of the wetland surface is ≤ 2 -m from the point of overtopping into the Springbok Flats.

The Fate of the Nyl River Wetland

If significant amounts of additional alluvium were to be deposited in this basin, the basin will begin to overtop and surface water may start flowing at right angles to the direction followed by the present-day Nyl River, towards the Springbok Flats and ultimately into the Olifants River, i.e. it would revert back to its presumed historic direction of flow, probably joining up with the Grass Valley River, a tributary of the Olifants River.

Contrasting to the above processes occurring naturally, human interference in the form of global climate change, modifying the amount and format of rainfall, and urbanisation/agriculture/change in land use, resulting in an alteration in the run-off rates within the Nyl River catchment (paved areas, sand mining in the alluvial deposits associated with the Nyl River, creating of artificial channels through the wetland, constructing of bridges/culverts/barriers across the wetland (increasing the erodability of the water at these bridges, etc.), could very well alter the erosion potential in the vicinity of the barrier, formed by the alluvial deposits from the Dorps River, Rooisloot and Groot Sandsloot at the end of the alluvial deposit of the Nyl River, in such a manner that increased erosion could eat away the barrier that sustains the entire Nyl River floodplain deposit. It must constantly be borne in mind that the huge alluvial deposit in the Nyl River basin is not held in place by a solid rock formation or other firm geological feature, but rather by some more (soft and erodable) alluvial material deposited at its outlet. Presently, the balance happens to be in favour of the deposition of material from the three eastern tributaries exceeding



the erosion potential of the Nyl River. Human or climatic changes can rapidly change this balance in the other direction.

The author, however, believes that, should current conditions continue to prevail, the Nyl River basin will, over time, continue to be filled with alluvial material, from upstream sources, until the basin begins to decant on surface towards the Springbok Flats. Sub-surface groundwater decant could already be occurring. This process will probably take place over a period of centuries or millennia. However, when this does happen, a new channel will form within the area indicated in the caption of **Figure 1** and the Nyl River will be diverted back to the Olifants River catchment. The new channel will erode rapidly due to the increased gradient towards the east and this will, over time, cause most of the wetland to dry up. As the new channel increases in size and depth, the closest part of the Nyl River (to the northeast of the decant point) will begin reversing its direction of flow, i.e. it will, begin draining towards the decant channel.

In human time-scale, this event is not imminent, but cognisance should nevertheless be taken thereof, as human activities could speed up either of the two processes that would determine the fate of the present-day Nyl River wetland (decant to the Olifants River or erosion of obstruction at Dorps River, both events leading to the eventual demise of the wetland) by several orders of magnitude. It must be kept in mind that the Nyl River and in particular, its alluvial wetland, is not as ordinary as one may think. It only exists (somewhat precariously) as a result of a series of incidental geological and climatic events. The surface hydrology could easily revert back to its original direction of flow, i.e. towards the Olifants River.

1. Description of the Catchments, Surface Water Flow Patterns and Water Quantities

1.1 Description of the Catchment

The proposed Volspruit Mine locates in an area between the Waterberg Mountain Range to the west and the Springbok Flats to the east, sloping very gradually towards the Olifants River, roughly 60 Km to the east of the proposed mine. Geologically speaking, recent (post-Karoo), movement along the Zebediela Fault (or



any of the other faults in the region) had played some role in deformed the earth's crust in this particular area, resulting in the formation of a river basin running in a southwest-northeasterly direction. This depression has subsequently been in-filled with transported alluvial material, mainly off the sandstone and weathered basalt of the Waterberg Mountain Range, to a depth of up to 35 m in places. The surface of this in-filled basin now supports the largest river floodplain wetland in South Africa.

In the preceding section (***Introduction and Background***), it is shown that, prior to one of the faulting episodes in the area, either surface drainage may have occurred in a direction off the Waterberg Mountain Range eastwards towards the Olifants River, or the river has "always" flowed in its current direction, and its rate of erosion into the uplifted rocks north of the Zebediela Fault could keep up with the up-down movement along the fault. If the former scenario is true, the disturbance caused by the fault created a northeasterly deflection of surface water flow direction into the newly formed channel representing the present-day Nyl River, flowing in a predominantly northeasterly to northerly direction.

The proposed opencast Volspruit Mine locates on the eastern bank of the Nyl River. The southern-most sector of the Northern/Potgietersrus Limb of the Bushveld Complex, which Volspruit Mine intends exploiting, partially underlies the floodplain of the Nyl River. The Bushveld Complex stops abruptly at the Zebediela Fault, immediately south of the proposed mine, south of which much younger upper Karoo basalt is found due to the up-down displacement along the Zebediela Fault.

The mine falls in quaternary catchment, **A61E**. Refer **Figure 2** for detail of the quaternary catchments.

The Nyl River becomes the Mogalakwena River further downstream after the confluence of the Dorps River, Rooisloot and Groot Sandsloot with the Nyl River.

Quaternary catchment **A61E** has a mean annual precipitation (MAP) of 624.58 mm and a mean annual run-off (MAR) into surface streams of 46.3 mm (*Midgley et. al. 1994*) (*Middleton & Bailey 2005*). This means that on average, 46.3 mm of the annual rainfall in this catchment will actually drain into the Nyl River as surface run-off.



The Nyl River originates as two tributaries, the Great- and Little Nyl Rivers, both originating on the farm, Groot Nylsoog 447 KR. The Great Nyl River flows generally eastwards, while the Little Nyl River initially flows north, but gradually turns into an easterly direction, forming a flattened arc, and after flowing through the town of Modimolle (Nylstroom), the confluence of the two tributaries occurs on the farm, Doorndraai 415 KR, after which the river continues in an easterly direction as the Nyl River.

As shown in **Figure 6**, a third, and less known, but equally important, tributary of the upper Nyl River originates on the farm, Cyferfontein 601 KR (refer **Figure 6** for its location). This non-perennial stream also follows a generally easterly direction before disappearing into the extensive alluvial in-fill of its original riverbed. This alluvial continuation of the unnamed stream has its confluence with the main alluvial in-filled channel of the Nyl River in the centre of the Nylsvley Nature Reserve, some 23.5 Km from where the alluvial material in this channel started. So although this stream is not visible for most of its travel on surface, there is a significant river present in the in-filled alluvial channel below the surface.

Downstream from these confluences described above, the Nyl River continues across and through the largest floodplain wetland in South Africa, of which the Nylsvley Nature Reserve forms merely a small part (refer **Figures 4** and **6**). This alluvial, in-filled riverbed contains most of the water found in the Nyl River, even though this water is not visible on surface for most of the time. After passing the Zebediela Fault and proposed Volspruit Mine, nearing the downstream end of the wetland where the river channel narrows, the Nyl River passes the streams, Dorps River, Rooisloot and Groot Sandsloot (alias Pholotsi) entering the Nyl River from the eastern side. These are, in fact, the first streams entering the Nyl River from the east, all other streams up to this point enters the river from the west, flowing off the Waterberg Mountain range towards the Nyl River. This is not surprising as the topography of the Springbok Flats to the east and southeast of the Nyl River **falls away** from the Nyl River; hence, rainwater falling on the Springbok Flats, in places right next to the right-hand bank of the Nyl River, would also **flow away** from the Nyl River and not towards it. The largest part of the Springbok Flats is classified as an endorheic basin, i.e. a catchment basin that only has an input and no water leaving it.



The Springbok Flats in terms of its endorheic nature will be discussed in a little more detail in the following section (**Section 2.1**).

The sediment deltas or fans deposited in the Nyl River, originating from the three rivers entering the Nyl River from the east, has resulted in a partial blockage in the Nyl River, which caused the gradient reduction and initiated the in-filling of the rest of the Nyl River valley with alluvial material (*McCarthy et al, 2011*). According to McCarthy (*McCarthy et al, 2011*) the majority of sedimentation occurred in the interval between ~1164 and ~1487 AD. This time period corresponds with the end of the Mediaeval Warm Period, an anomalously warm interval during the late Holocene period, and with the early part of the Little Ice Age, characterised by colder and generally drier conditions, but with periods of increased storminess. This also supports the theory that climate had played an important role in the deposition of the alluvial material in the Nyl River valley.

After the confluence of these (eastern) rivers with the Nyl River, the river continues northwards as the Mogalakwena River through the Glen Alpine Reservoir up to its confluence with the Limpopo River some 290 Km downstream from the confluence of the Rooisloot with the Nyl River.

The Limpopo River rises in central Southern Africa at the confluence of the Marico and Crocodile Rivers, and flows effectively eastwards to the Indian Ocean. It is around 1 750 Km long, with a drainage basin 415 000 Km² in size. Its mean annual discharge is around 170 m³/s at its mouth near the town of Xai Xai in Mozambique. The Limpopo is the second largest river in Africa that drains to the Indian Ocean, after the Zambezi River.

The Limpopo River flows effectively eastwards, but in a great arc across the African continent, first zigzagging north, then northeast, then turning east and finally southeast. It serves as an international border for about 640 Km, separating South Africa to the southeast from Botswana to the northwest and Zimbabwe to the north. There are several rapids as the river falls off Southern Africa's inland escarpment.



Its main tributary is the Olifants River (Rio dos Elefantes in Mozambique), contributing around 1 233 Million m³ of water per year. In addition to the Mogalakwena River, other major tributaries include the Shashe River, Mzingwane River, Crocodile River, Mwenezi River and Luvuvhu River.

The port town of Xai-Xai, Mozambique, is on the Limpopo River near its mouth. Downstream from its confluence with the Olifants, the Limpopo River is permanently navigable to the sea, though a permanent sandbar prevents access from the Indian Ocean by large ships, except at high and spring tide.

The waters of the Limpopo are sluggish and silty, especially over the Mozambiquan plains. Rainfall is seasonal and unreliable. In dry years, the upper parts of the river only flow for 40 days/year or less. The upper part of the drainage basin is arid, in the Kalahari Desert, but becomes less arid as the river progresses further downstream.

The Limpopo basin is home to about 14 million people (in 2000).

Refer to **Figures 2 to 7** for details relating to the location of Volspruit Mine, in relation to the relevant surface streams and their catchments.

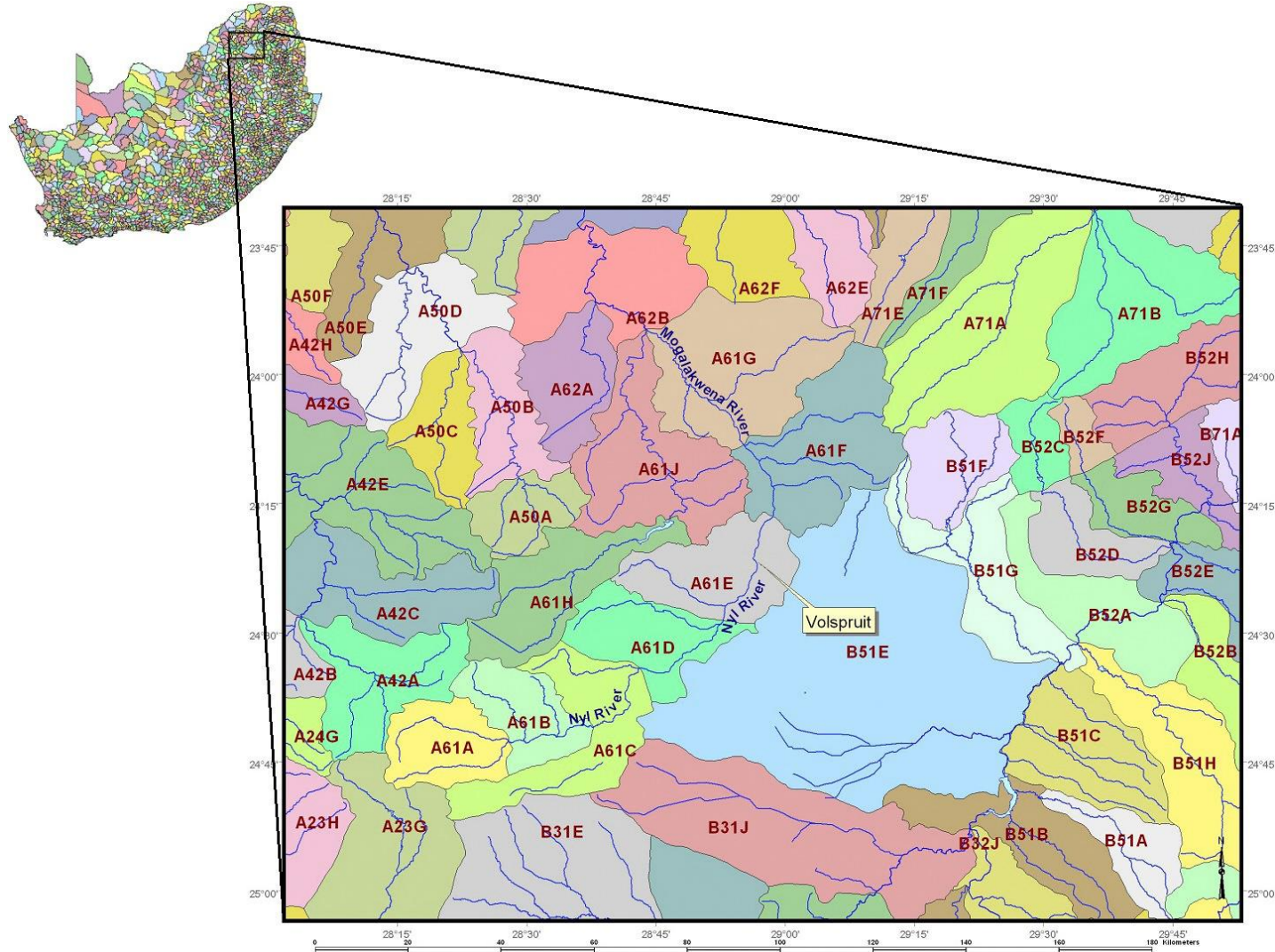


Figure 2: The location of the Volspruit Mine on a map showing the quaternary catchments.

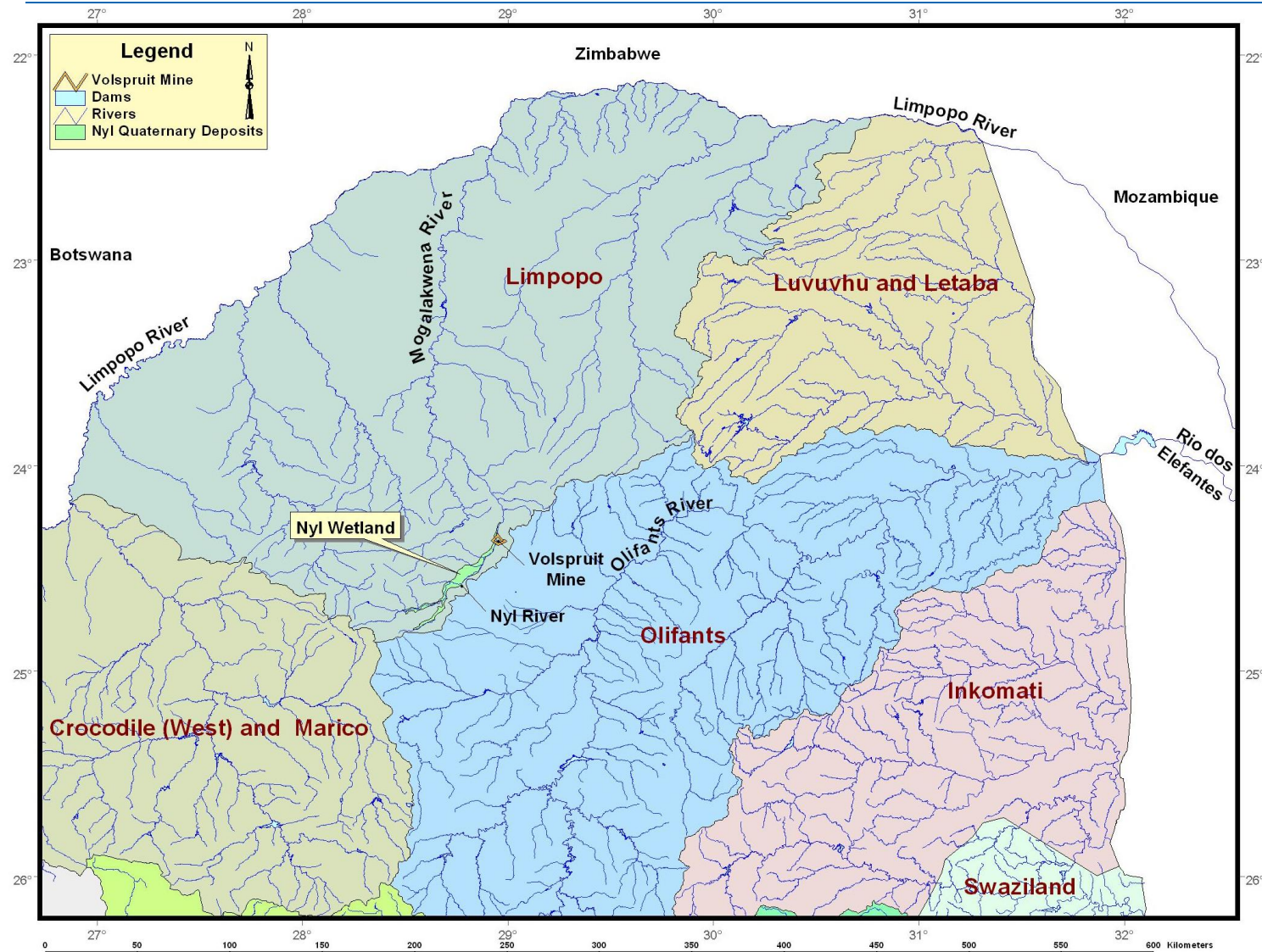


Figure 3: the proposed Volspruit Mine in relation to the Water Management Agencies of the rivers flowing eastwards to the Indian Ocean. (Parent Data: Dept Water & Sanitation)

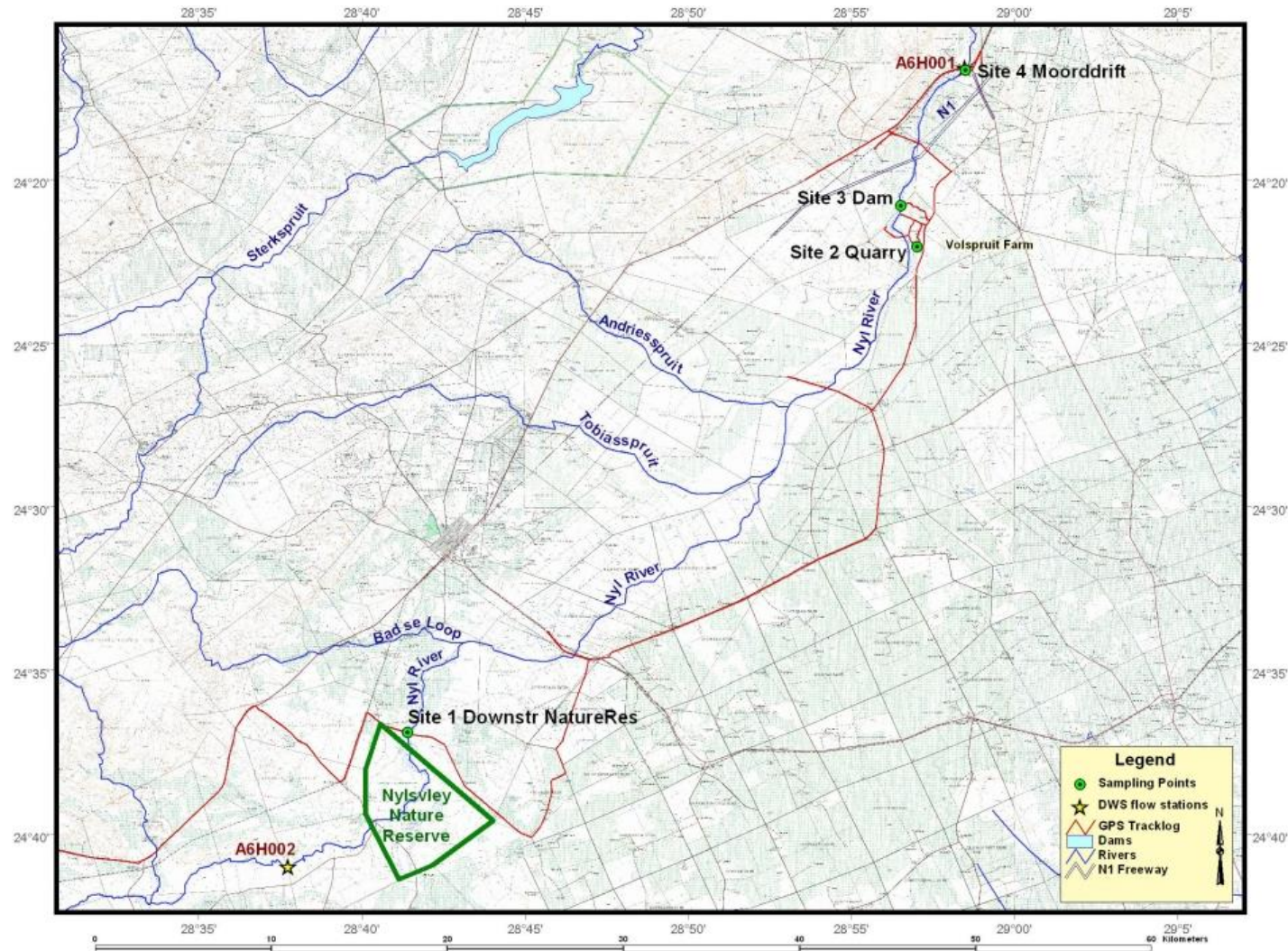


Figure 4: The proposed Volspruit Mine showing the Nylsvley Nature Reserve, the surface streams/ rivers, the sampling sites used in this report and the GPS track log recorded during the collecting of samples.

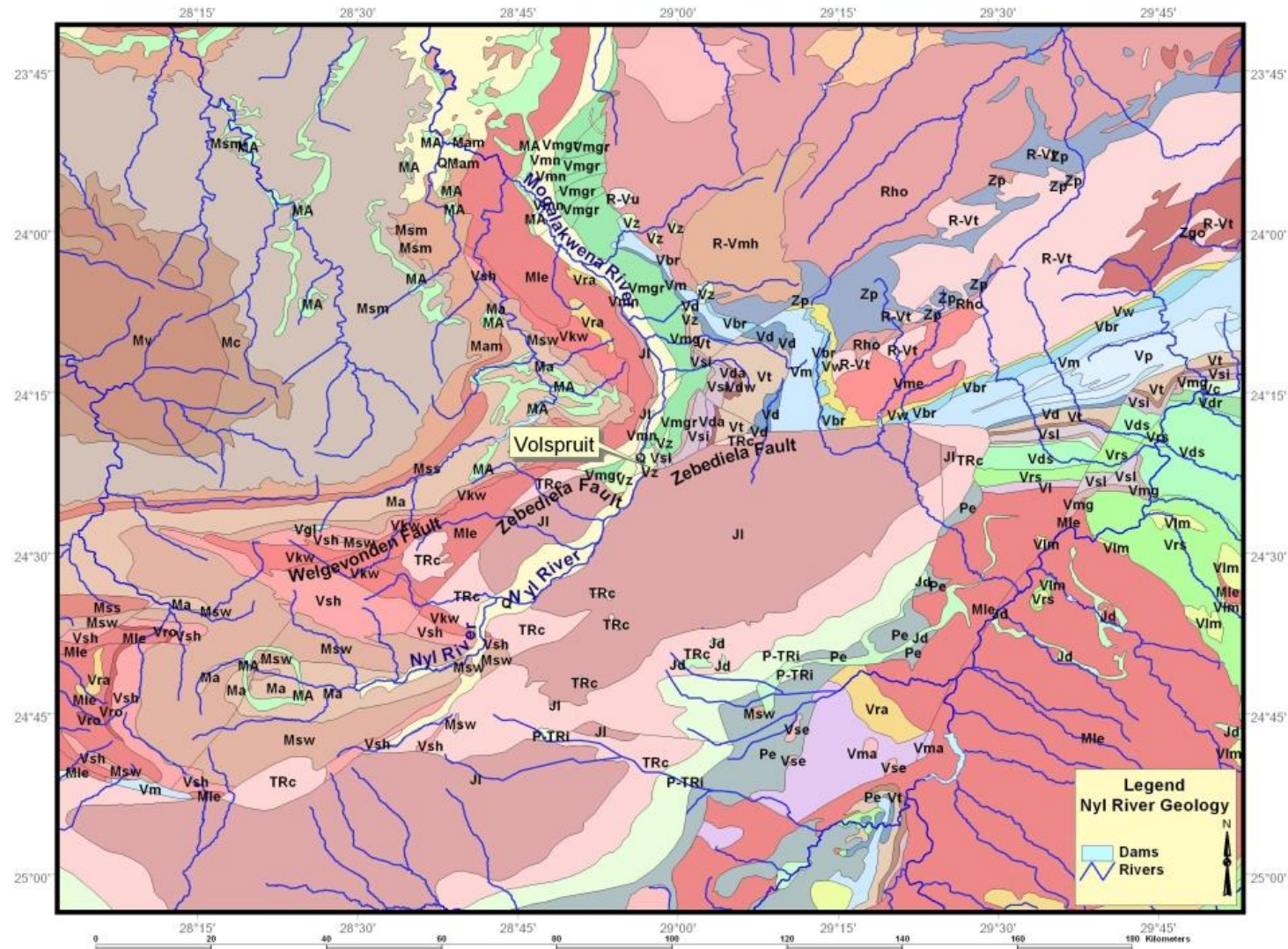


Figure 5: The geology in the vicinity of the proposed Volspruit mine, showing the complexity of the geology associated with the Nyl River and the Northern Limb of the Bushveld Complex. (Data: Geological Survey Series)

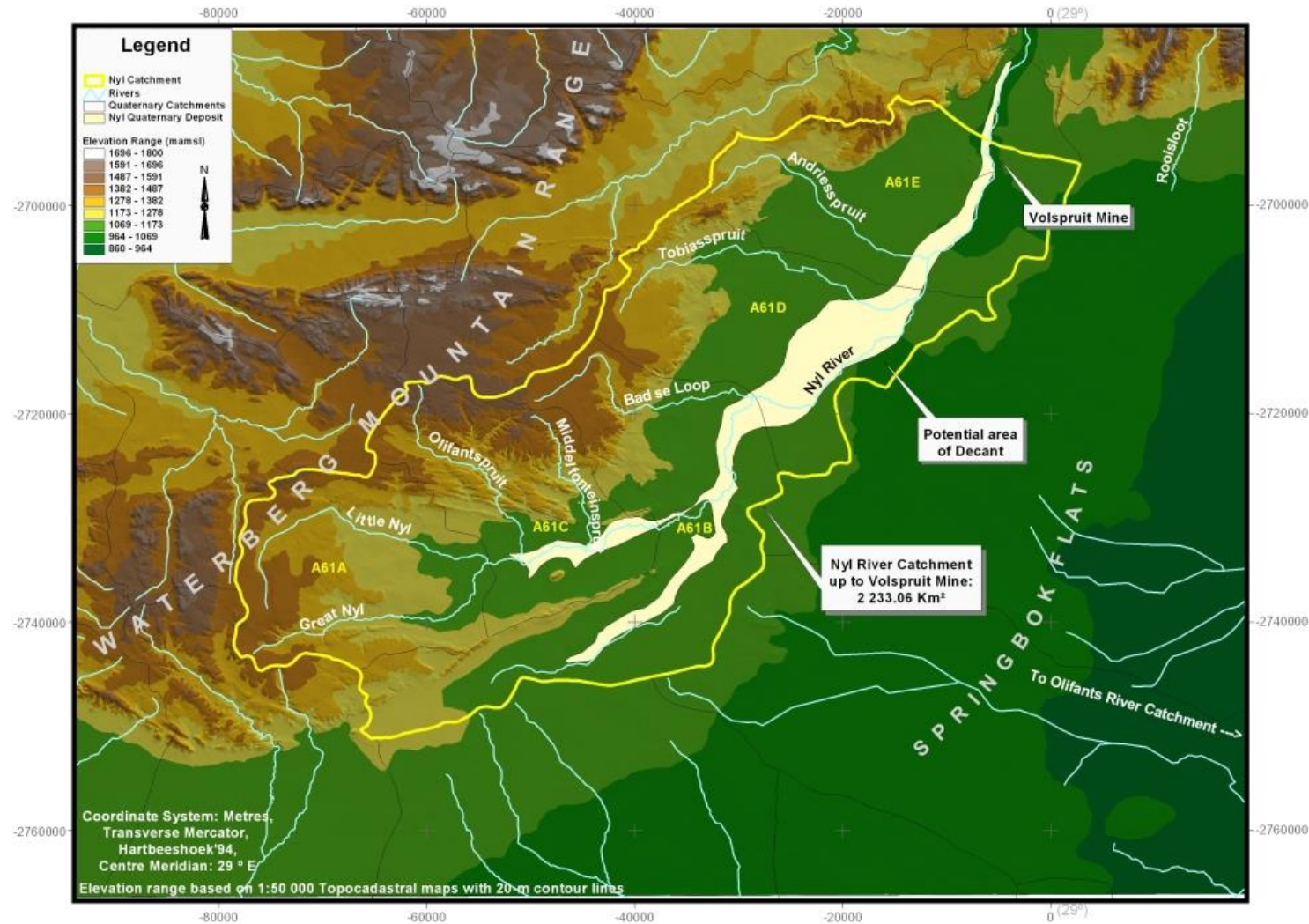


Figure 6: The general topography surrounding the Nyl River in the vicinity of the study area, showing the area in-filled with alluvial material, the quaternary catchments, and the tributaries entering the river from the Waterberg. The alluvial in-fill associated with the unnamed stream originating on the farm Cyferfontein 457 KR is clearly visible as it flows through quaternary catchment A61B up to its confluence with the Nyl River in the same catchment.

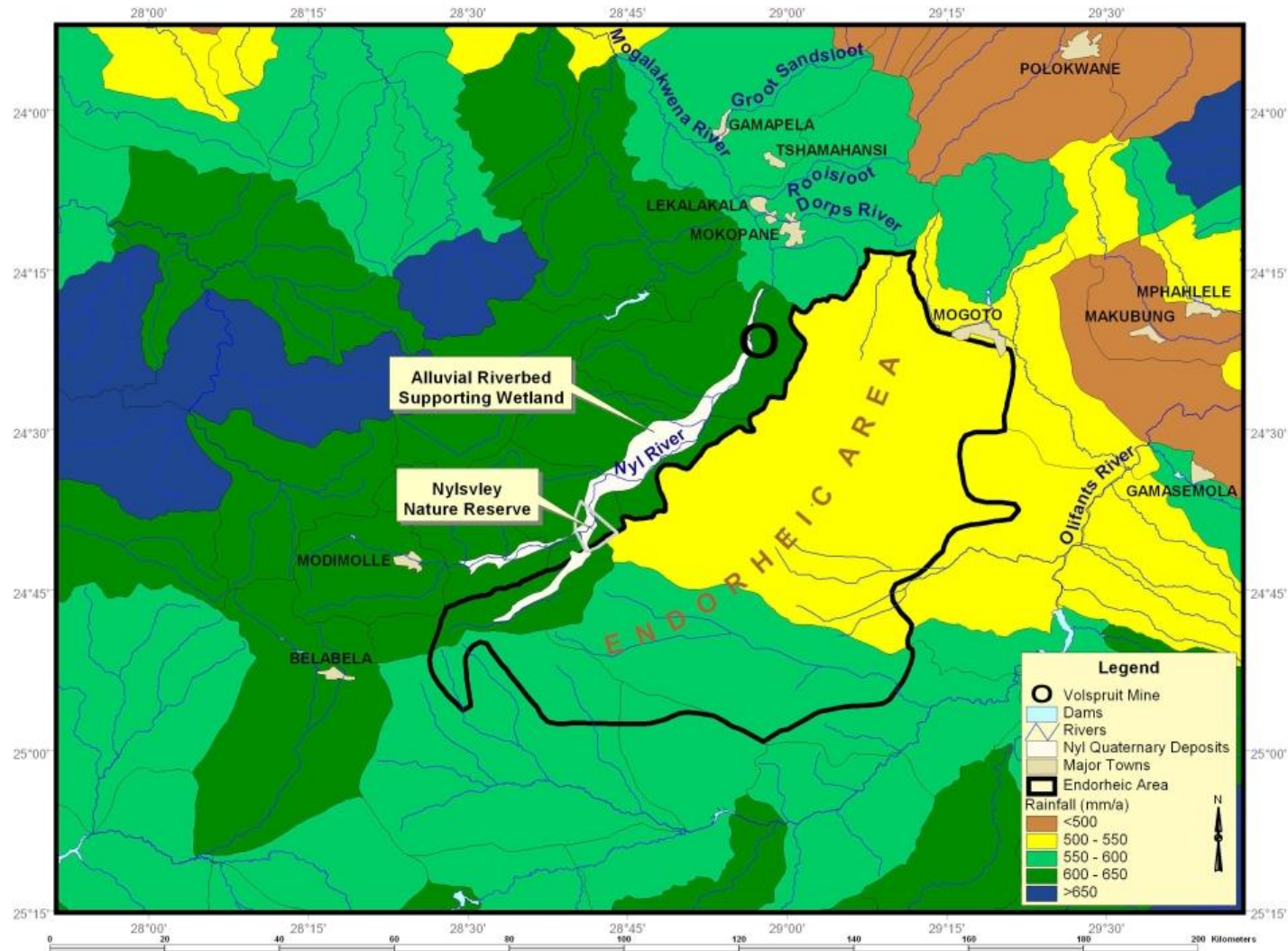


Figure 7: The Study area, including the Nyl River Wetland and its catchment, on a map showing the average annual rainfall for the areas surrounding the study area. (Data: WR2005)

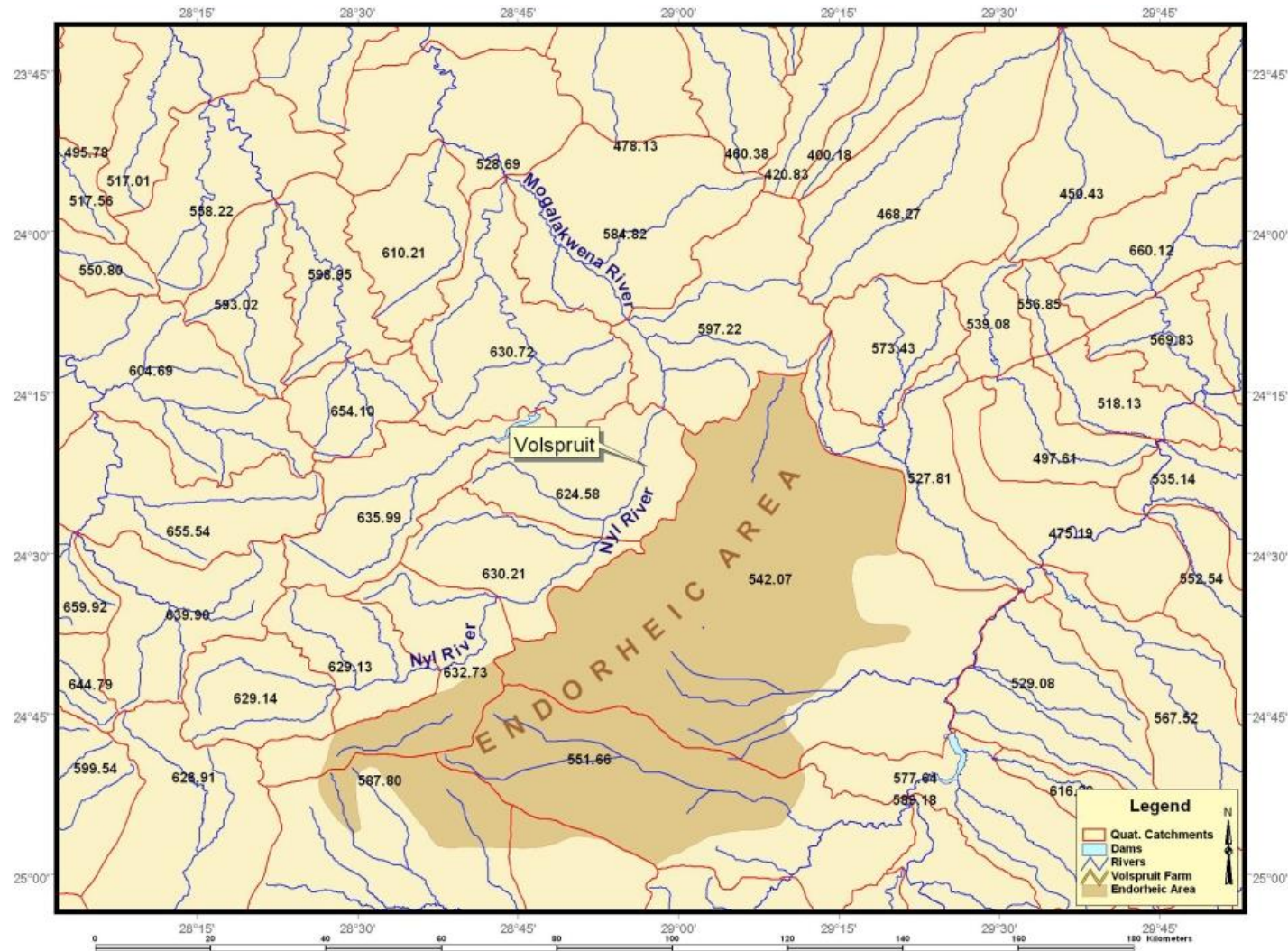


Figure 8: A map showing the endorheic areas associated with the Springbok Flats to the southeast of the Nyl River. (Data: WR2005)



1.2 The Springbok Flats Endorheic Basin

An endorheic basin is a catchment that only has an inflow and no visible outflow on surface, i.e. it is a dead end catchment or a catchment “black hole”. Water entering it theoretically never leaves it in a visible form. All water falling onto such a basin is lost as evaporation or as groundwater recharge. A good example of an endorheic basin is a crater or caldera (inflow in the form of rainwater or snow, “outflow” as evaporation). Among others, the entire Kalahari Basin is classified as an endorheic basin, as, although this basin has several (mostly dry) rivers traversing its surface, effectively no rainwater falling within the catchment of this basin ever reaches the Orange River. All rainwater is lost as groundwater recharge or as evaporation.

The author does, however, not agree with the definition of endorheic areas and considers this definition to be somewhat subjective and not scientifically accurate. The problem with endorheism is that it only accounts for **observed** (visible) water leaving a catchment and water loss is often observed in a rather subjective manner. As an example, rainwater recharging a groundwater aquifer seems to have been lost, but is, in fact, not really lost; it merely flows from a visible location to an invisible one. Similarly, the process of evaporation does not destroy the water, even though it disappears from sight!

To explain what is stated above; the endorheic basin in quaternary catchment, C24C (upstream from and including Ventersdorp), demonstrates the incorrect perception of an endorheic basin clearly. This quaternary catchment is almost in its entirety perceived to be an endorheic basin (*Middleton & Bailey, 2005*), as most of it comprises of dolomite with a very high infiltration rate. The area also has an extremely low gradient with no visible watercourses (this is, in fact, analogous to the description of the Nyl River wetland). There are no (or highly undefined) water channels across the surface of the catchment and all rainwater falling on this catchment is either lost as evaporation or (mostly) “lost” as groundwater. However, near the downstream end of the catchment, immediately upstream from the town of Ventersdorp, locates a strong spring, the Skoonspruit Eye, the origin of the Skoonspruit. This is effectively the decant point of the “endorheic” catchment upstream from the eye. The fact that one cannot see the water flowing across the



surface of the catchment does not mean that it has mysteriously disappeared from the face of the earth. It merely flows sub-surface and leaves the basin at the eye.

As far as the Springbok flats are concerned, the author believes that a similar event is occurring here. Historically (prior to the Mogalakwena River Hijacking the Nyl River - at least according to one of the theories) the streams originating in the Waterberg and now flowing into the Nyl River wetland crossed this area and continued across the Springbok Flats to the Olifants River, probably via the Grass Valley Stream (shown in **Figure 9**). This assumption is also supported by the fact that there is a large fan of transported sediment (alluvial matter) across this part of the Springbok Flats, responsible for the many high-yielding boreholes in the area between the Nyl and Olifants Rivers (refer **Figure 9**). So, in contradiction to this catchment being an endorheic basin, the author believes that it is a water-rich basin, but due to the porous nature the alluvial and other weathered material on its surface and due to the flat nature of its surface area, this water does not flow in surface streams, but rather within the alluvial and weathered matter below its surface towards the Olifants River.

The above also suggests that the Nyl River wetland decants sub-surface towards this endorheic area across a wide part of its eastern bank.

As a result of the southwest-northeast striking river basin forming, the Mogalakwena River had “captured” or “hijacked” the upper Nyl River and redirected its flow towards the north. In geological time scales, this is a temporary event and eventually the Olifants River catchment will reclaim this section of its catchment and the water will, once again, flow off the Waterberg Mountains across the Springbok Flats to the Olifants River.

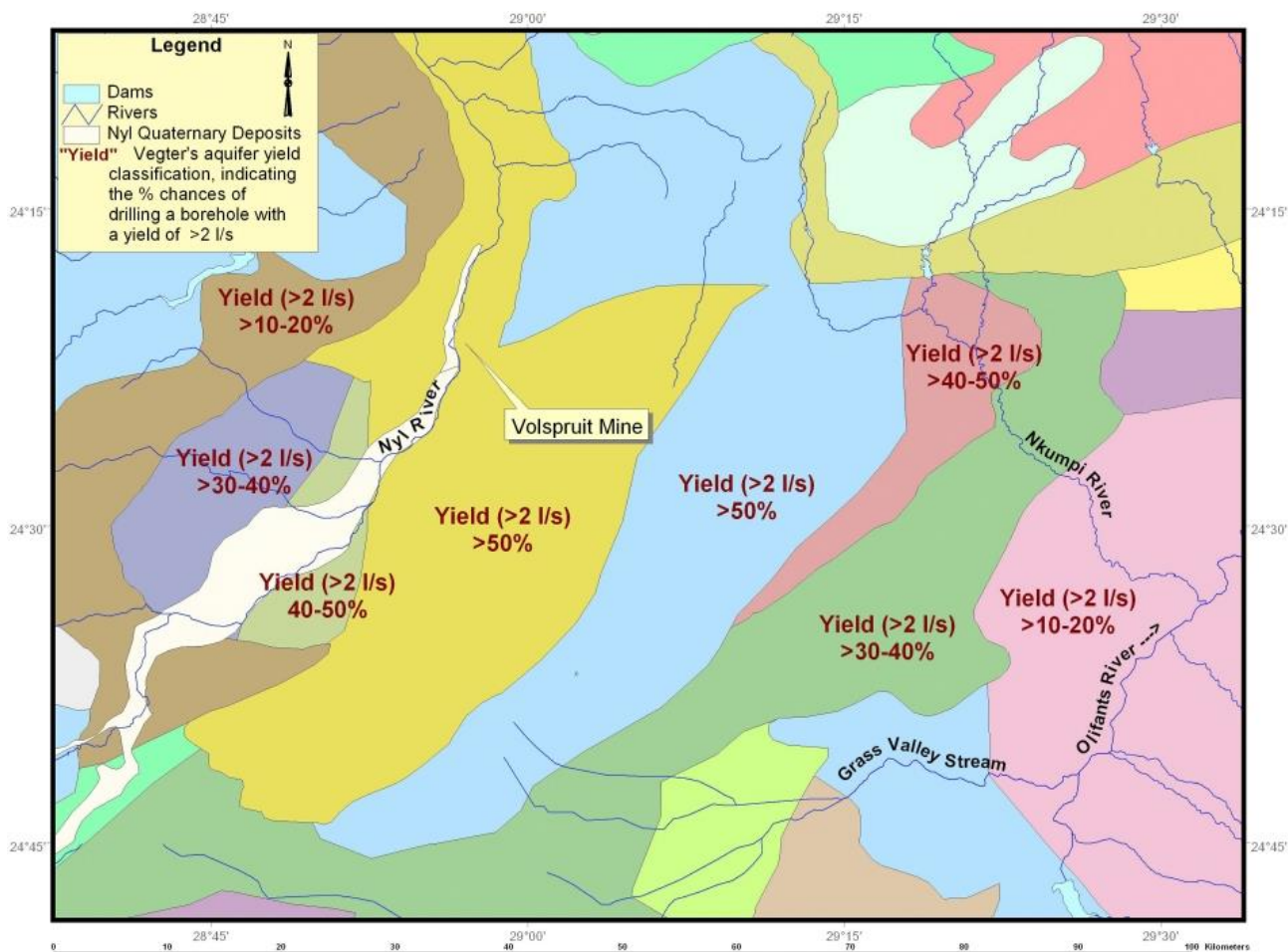


Figure 9: Vegter's borehole prospects (showing borehole prospects for yielding >2 l/s). The areas producing the highest probability for high-yielding boreholes, are shown as ">50%". The fan referred to in the text of **Section 1.2** is depicted as the yellow and blue areas to the east of the Nyl River, annotated as ">50%".

1.3 Surface Water Flow Patterns of the Nyl River Wetland

The Nyl River Wetland is inundated on an irregular, but mostly seasonal, basis. It receives surface run-off water flowing into the floodplain from its two main tributaries, the Great and Little Nyl Rivers, as well as from the other tributaries, rising in the Waterberg Mountains to the northwest of the floodplain. Water enters the floodplain initially in river channels. These river channels gradually disappear as the gradient lessens and eventually, flood-out occurs, i.e. the water is spread over the floodplain in the form of sheet flow rather than channel flow. Most of this water (about 70%) is eventually lost as evaporation with only a small amount entering the underlying alluvial aquifer as groundwater. Towards the end of the wetland, i.e. a short distance



upstream from the proposed Volspruit Mine where the wetland begins to narrow just before it crosses the Zebediela Fault, the river channel reforms once again.

The wetland is not inundated every rainy season. The high rate of evapotranspiration, and ponding losses specifically, ensures that floodwaters do not leave the floodplain every year and the floodplain often becomes an inland delta. From historical records, it has been found that the inlet channel is inundated 7 out of 10 years, the low elevation floodplain grasslands 4 out of 10 years and the entire floodplain, 6 out of 10 years (*Higgins et al, 1996*). In seasons of above-average rainfall, particularly when there has been a carry-over of water in the Nyl River from the previous wet season, some 9 000 to 16 000 Ha of the Nyl River valley can be inundated. These floodwaters can persist for some months into the dry season and even occasionally into the following rainy season, though more frequently the waters gradually recede until only the deeper parts of the main channel retain water.

As described in the preceding sections, the reach of the Nyl River from the confluence of the Great and Little Nyl Rivers in the southwest up to a relatively short distance south of the study area (Volspruit Mine), follows a course along a depression cut out of the weathered basalt (and Bushveld Complex north of the Zebediela Fault), most probably by waters flowing historically in the Nyl River. This depression is in places up to 35 m deep and several kilometres wide (up to 6.6 Km) and has in its entirety been in-filled with transported alluvial material originating primarily off the Waterberg Mountain Range. The part of the wetland between the Nylsvley Nature Reserve and the proposed mine is about 45 Km long, although two relatively narrow sections also extend further upstream for another 20 and 23 Km respectively for the Nyl River and the unnamed stream to the south of the Nyl River (referred to in this report as the “*Cyferfontein Stream*”). Although the wetland narrows near the proposed mine (Volspruit Mine), it continues as a relatively narrow (alluvial-filled) wetland for another 20 Km beyond the proposed mine, up to where the sediment fans, discharged from the Dorps River, Rooisloot and Groot Sandsloot, continues to maintain the integrity of the upstream part of the wetland. From this point onwards, the name of the Nyl River changes to the Mogalakwena River. The entire wetland locates on the surface of this in-filled alluvial bed.



Unlike most other in-filled river valleys, the Nyl wetland (alluvial in-filled river valley supporting a wetland on its surface) is not held in place by a firm rock formation, but rather by (soft and erodable) alluvial material constantly being deposited by the Dorps River, the Rooisloot and, to a lesser extent, the Groot Sandsloot to the north of these two streams. In other words, the blockage in the Nyl River, that created the alluvial in-filled basin in the first place, is made up of soft, albeit coarse, material, which, under the right conditions, could be eroded away relatively easily. However, as long as the rate of alluvial deposition by these streams into the narrower part of the Nyl River (the end of the wetland) continue to exceed the rate at which the Nyl River erodes this material away, the Nyl River wetland will continue to exist.

There are several other factors that maintain this balance. Probably the single most important factor is the present-day climate. The integrity of the Nyl River wetland has been preserved by the fact that the rainfall over the catchment of the vleis has remained relatively low and erratic for a long time. Rain occurs in the form of thunderstorms over small areas and therefore all rainwater in all the tributaries hardly ever reaches the wetland simultaneously (while transporting large quantities of eroded material at the same time). If, as a result of climate change, a higher rainfall is experienced and the rainfall “input” becomes more constant, the balance at the outlet end of the wetland could very well be tipped in the other direction and increased erosion could eventually remove the barrier at the outlet of the wetland. Due to the short life of the Volspruit mine compared to the rate of climate change, this is unlikely to occur during the lifespan of the mine.

In addition to climatic conditions presently maintaining the integrity of the wetland, the fact that, on average, only 30% of the water entering the Nyl wetland reaches the outflow end of the wetland (*McCarthy et al, 2011*) ensures that the water leaving the wetland does not have sufficient energy to cause erosion in these parts of the wetland. Obviously, the gentle slope (about 0.0007 m/m upstream from Volspruit) also plays a role. Furthermore, the river channels entering the wetland from the Nyl River, as well as from the other tributaries flowing off the Waterberg Mountains, soon cease to exist as the floodplain is reached and floodwater is spread over the entire surface of the wetland in the form of sheet flow, rather than channel flow. The energy of the flowing water decreases from $>1\,000\text{ W/m}^2$ in the upper reaches of the



tributary channels where the gradient is high, to $<10 \text{ W/m}^2$ where the streams spread out onto the floodplain. The fact that the energy in the streams decreases so much also has the effect that only the finest material will be kept in suspension for prolonged distances into the wetland. The coarser material is deposited at the edges of the floodplain and along the remaining river channels (before these channels disappear into the flat floodplain – the flood-out area). Only the finest suspended matter and the particles transported in the form of colloidal suspension are transported for any substantial distance onto the surface of the floodplain. When these fine suspended particles are eventually deposited (when the floodwaters dry up, more-or-less, on a seasonal basis) it deposits thin clayey layers that are all but impervious to water movement. For this reason, the aquifer located in the deeper and coarser alluvial basin fill, does not receive substantial recharge from the water spread seasonally over the surface of the wetland, in spite of prolonged period of inundation (on average, several months per year), but rather from recharge in the upper reaches of the channel beds entering the wetland (where coarser material is deposited) and along the edges of the wetland where streams off the mountains enter the wetland from the northwest. This statement is further supported by Tooth et al (*Tooth et al, 2002*), where the report states, "the thin clay layers deposited by sheetflows appear to effectively seal the floodplain surface against infiltration".

Although the hydrogeological assessment (Hachmann, 2022) mainly focussed their study on the surface area at the Volspruit Mine, and not primarily on the Nyl River wetland, the 3 cross sections (of a total of 7) that did intercept the Nyl River wetland, indicated that the hydrogeological response at the wetland was "responsive" (in contrast to "recharge"), meaning that groundwater infiltration would be limited.

Likewise, and in support of the above, the updated groundwater report (*du Toit & Terblanche, 2022*) states that there is a significant unsaturated zone below the Nyl River bed, even during and after extreme flood and rainfall events. This suggests that there is no direct hydraulic link between the surface water in the Nyl River floodplain and the aquifer below the floodplain.

So, due to the fact that the water flowing into the wetland loses almost all of its kinetic energy, in addition to the fact that it loses about 70% of its volume through diffuse



losses (evaporation, evapotranspiration and possibly leakage into the adjacent Springbok Flats aquifer, as explained in the Introduction and Background section and shown in **Figure 1**), the fact that the water spreads over a floodplain several kilometres wide and flows as sheet flow rather than channel flow and the fact that the 30% of the inflow, which eventually leaves the in-filled alluvial basin, does so over a prolonged period of time as a result of the attenuation properties of the wetland and alluvial basin fill through which it flows, channels are not readily cut into the outflow end of the floodplain, even though the river valley narrows significantly in this region.

This process is presently in balance and as long as the *status quo* remains (deposition rate at the outlet equal to, or slightly exceeding, the erosion rate of the Nyl River), the alluvial basin fill, which supports the wetland on its surface, will remain intact. The 100-year flood line report (*Krige & Bond, 2010*) also indicates that the protection berm will not increase the flow rate during a 100-year flooding event and subsequently will also not increase the erosion rate of the Nyl River at the Volspruit Mine.

1.4 Surface Water Flow Patterns at Volspruit Mine

As described in **Section 1.1**, the proposed Volspruit Mine falls within quaternary catchments A61E and is also located very close to the Nyl River and its associated wetland. As can be seen in the topographical map in **Figure 4**, the area on which the proposed mine is to be located falls to the east of the river with the topography generally falling towards the watercourse. Surface water is expected to flow away from the study area towards the southwest, west and northwest. **Figure 10** shows the actual drainage patterns of rainwater across the study area.

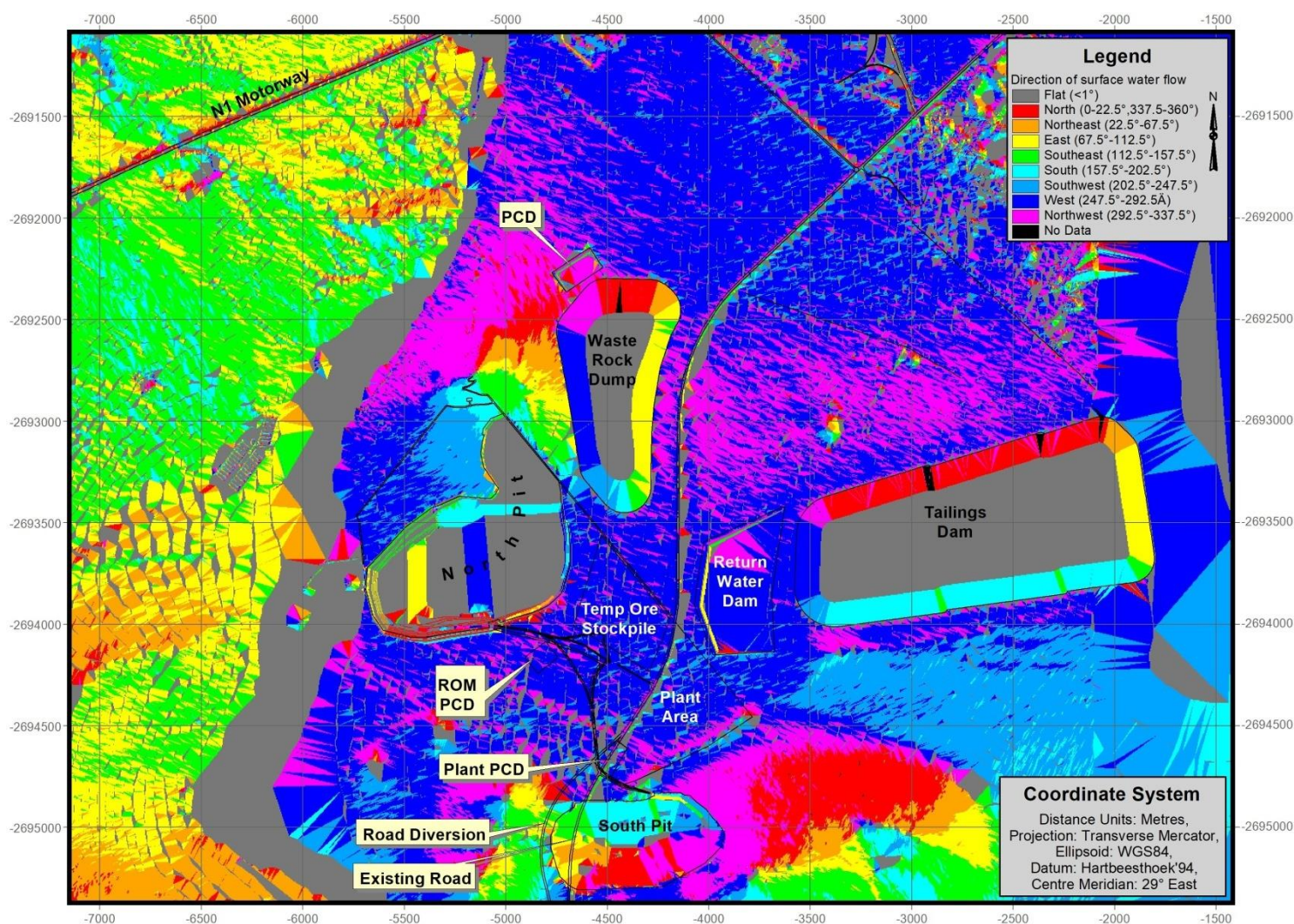


Figure 10: The direction of surface water flow across the proposed mining area of Volspruit Mine.

Figure 10 confirms that rainwater (or any other water) falling on the surface of most of the areas on which mining infrastructure will be located, will actually drain towards the Nyl River, except where there are hills and “*koppies*” (hillocks) as well as where there are TSFs, rock dumps and pits. In those instances, water would flow radially away from the centre of the hill/dump or inwards to the centre of a pit from where it will be pumped out of the pit. By and large though, all rainwater flowing off the entire area earmarked for mining infrastructure would sooner or later drain towards the river.

Conversely, the above statement is not correct further upstream (southwest of the proposed mine) in the Nyl River as demonstrated in **Figure 11**. Water falling on the

northwestern bank of the river will, as expected, drain towards the river. However, rainwater falling on the southeastern bank of the Nyl River would, in contradiction to logic, **drain away** from the river and not towards it! The reason for this is described in detail in the introduction under the heading, "***The River that shouldn't be***".

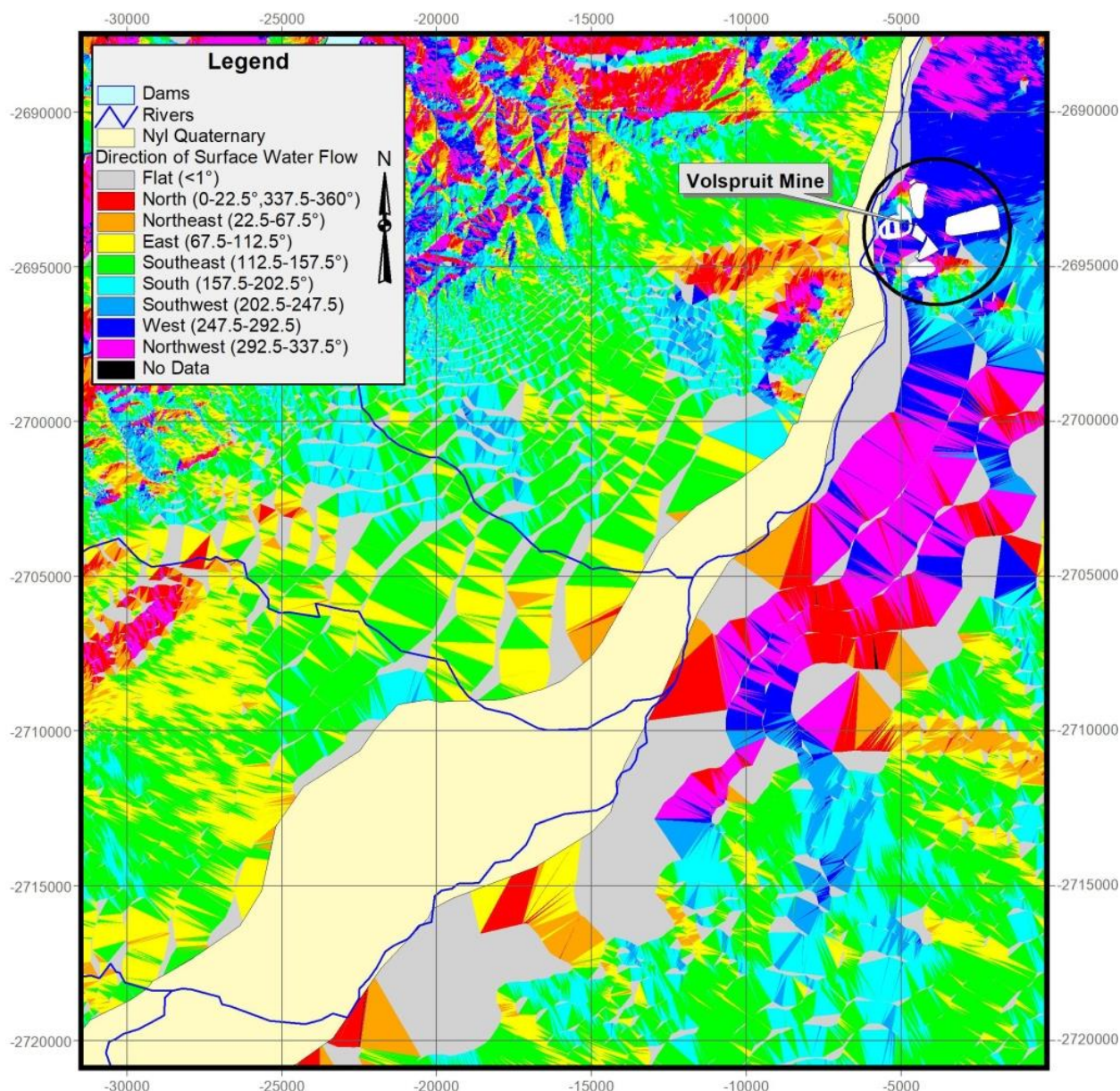


Figure 11: The direction of surface water flow upstream from the proposed mine shows that in places along the eastern bank of the Nyl River, the surface drainage is away from the river. This flow direction is indicated by the orange, yellow and green colours (indicating northeast, east and southeast) and the grey areas (indicating flat areas along the Nyl River). The direction of surface water flow was produced using the SG 5-m contour lines, thus elevation differences of <5-m will not be shown, hence the grey areas along the Nyl River's western edge



The topography of a drainage area also dictates the volumes and speed (implying energy) at which water would run off a particular piece of land. In other words, if water runs off a very flat area, the amount of water flowing off this area would be less than for example, water running off a very steep terrain. Water flowing off the flat area would also contain less energy, i.e. erosion would occur at a slower rate, but more importantly, the water would have more time to infiltrate into the ground through the surface and would also not have sufficient energy and turbulence to hold sediment in suspension and these materials will be deposited.

For this reason we also produced **Figure 12**. In **Figure 12**, we show the slope of the land in degrees rather than the direction of flow as shown in **Figures 10** and **11**. This will give an indication of the energy that surface run-off would have and will also provide an indication of the time run-off water would spend on the surface while flowing off the land. This, in turn, will control the evaporation loss, the infiltration rate into the ground and the rate and particle size of the solids that could be held in suspension.

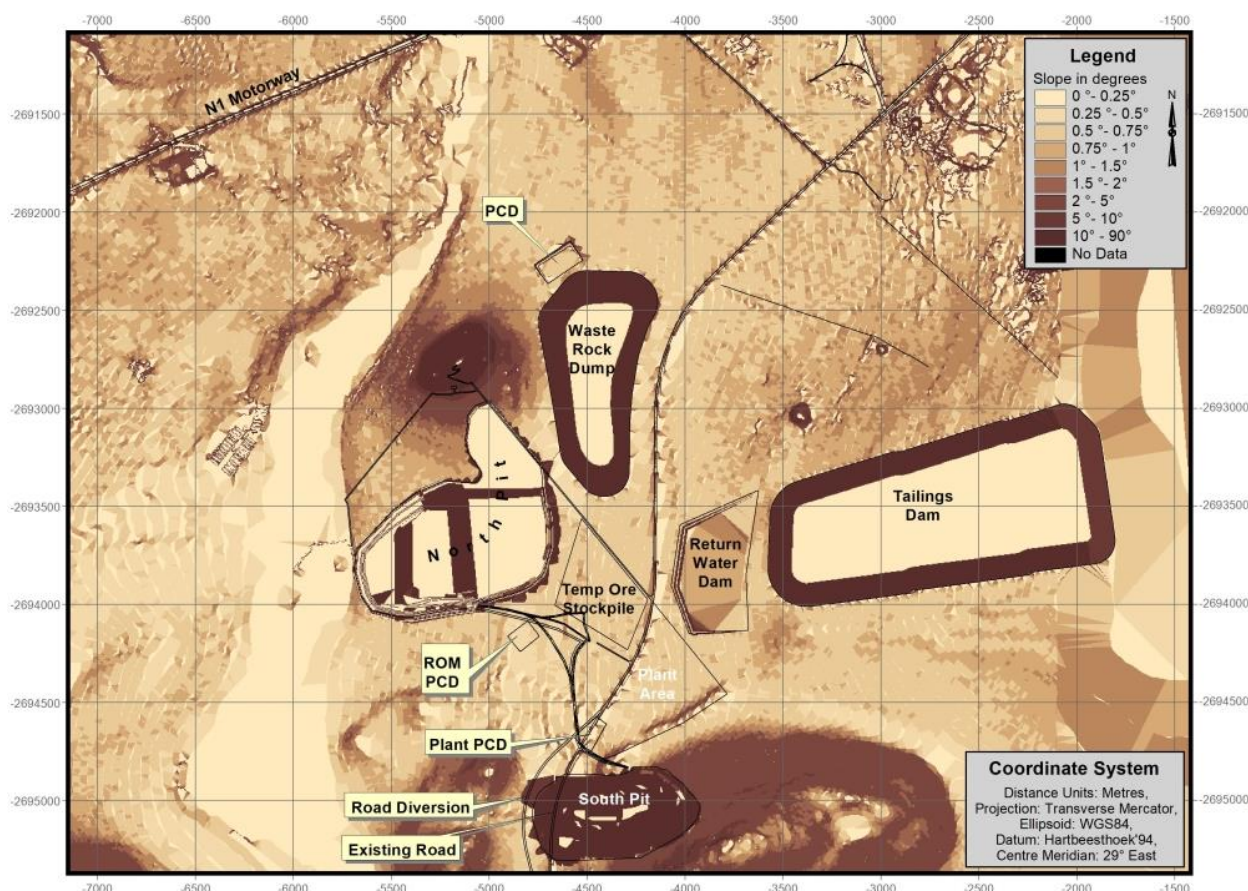


Figure 12: The slope of the land on which the Volspruit Mine will locate. As can be seen from this drawing, the land is extremely flat in all the areas associated with the river floodplain, indicating that surface flow would occur at a slow rate, providing ample time for infiltration into the ground or evaporation/evapotranspiration. Most of the ground on which the mine resides is steeper as a result of the hills in that area.

1.5 Surface Water/Groundwater interaction in the Nyl River Floodplain

As stated in **Section 1.3**, the energy carried in the flowing water dictates the amount and particle size of the suspended matter carried in a stream. Fast-flowing water draining off mountains contains high levels of energy and can keep large particles in suspension. During larger storms it also has sufficient energy to roll larger stones and rocks downhill along the watercourse. However, once this water reaches the foot of the mountain and the floodplain below that area, a significant amount of this sediment is dropped out of suspension when the water spreads out onto the floodplain.



On the slopes of the Waterberg Mountain range, to the west and northwest of the Nyl River floodplain, the gradients are steep and that subsequently, water flowing in the tributaries of the Nyl River would be capable of transporting large amounts of sediment eroded off the mountains. This sediment could also contain large particles and even boulders. When reaching the edges of the floodplain where the gradient rapidly drops to almost perfectly flat (on average a fall of <0.0007 m/m), the water cannot hold the same amount of solids in suspension and it deposits its solids load progressively from boulders to coarse gravel and sand to fine silty material as it progresses into the floodplain, away from the foothills of the mountains. This effectively means that the coarser alluvial material will be deposited along the edges of the floodplain and along the edges of the flow channels of the incoming rivers, where these still exist, while the fine to very fine material will be deposited as thin clayey layers on the flat part of the floodplain. According to Kleynhans et al (Kleynhans et al, 2010), the deposition of slightly coarser material along the edges of the channels entering the floodplain has the effect of building levees, i.e. slightly elevated zones along the edges of the channel, which, to a certain extent, prevents floodwaters over-spilling these levees during the peak of the flood from returning to the channel, once the flood begins to subside.

This selective deposition of sediment has had the effect that the large flat part of the floodplain has developed a relatively impermeable floor, through which very limited water movement can occur. This also means that, contrary to what would be expected from an alluvial-filled river basin, the seasonal floodwaters inundating the Nyl River floodplain **do not contribute to any significant amount of groundwater recharge** of the aquifer occupying the coarser material found in the deeper parts of the alluvial fill below the wetland. The two water bodies are effectively separated by the fine material, which is continually being deposited in the form of very fine alluvial clay layers on the flat part of the Nyl River floodplain. Additionally, and as explained in **Section 1.2**, groundwater decants likely occurs along the eastern bank of the Nyl River wetland **away** from the wetland. Thus, groundwater does **not** contribute to the base flow of the surface water flowing in the Nyl River, at least not at the part of the wetland at, and upstream from the Volspruit Mine. Some groundwater to surface water recharge may, however, occur further downstream where the Nyl River wetland narrows. The above statement is supported by the groundwater report (*du*



Toit & Terblanche, 2022), which confirmed that there is a significant unsaturated zone in the alluvial aquifer below the clay layer just below the surface of the floodplain and that the aquifer is filled from below, rather than from the surface.

Additional support for the above statement comes from an unlikely source, i.e. the manner in which larger trees, forming “atoll-like” islands on the surface of the floodplain of the Nyl River, play a role in concentrating salt below the island. According to Tooth et al (*Tooth et al, 2002*), the vegetation occurring on the surface of the floodplain has caused numerous, elevated, circular “islands” with woody fringes and sparsely-vegetated to totally barren centres, characteristic to the broad, flat, un-channelled parts of the floodplain. Tooth shows that trees with deeper root systems are responsible for the formation of these islands. During the dryer parts of the season when the floodplain surface dries up, these trees tap water from the deeper parts of the floodplain and this then supports a small colony of other plants around the original plant. Over time, the selective osmotic suction power of the trees’ root systems (selectively taking up water but excluding the salts not needed by the plant) causes a build-up of salt (mostly sodium chloride) in the sediment immediately below the island, reaching down to about 6 m below the surface. Vegetation continues to build the island into a small “atoll-like” shape on the floodplain. The saline concentration in the centre of the island eventually becomes so high that this part of the island can no longer support vegetation, hence the “bald” patches in the centre of the islands. Refer to **Photo 1** for detail of these “islands”.



Photo 1: The atoll-like vegetated “islands” forming on the floodplain surface of the Nyl River, responsible for concentration of sodium chloride below the surface of the island (*Satellite photography courtesy Google Earth 01/01/2008*)

Sodium chloride is one of the most soluble salts and subsequently also one of the most mobile salts in an aqueous environment. The fact that this salt builds up, and **remains** in a concentrated form within the underlying deposits below the islands, provides additional support to the previous statement of the limited water transmission through this layer and between surface- and groundwater, resulting from the fine-grained sediment immediately below the surface of the wetland in the Nyl River floodplain.

Coarser material is deposited along the incoming river channels where these enter the floodplain and also along the channel bed. Theoretically, this coarser material in the channel bed will provide a greater transmission rate of water through the channel bed into the groundwater aquifer deeper in the alluvial material underlying the floodplain. However, the deposition of transported material adjacent to the river channel when this channel overflows onto the floodplain, leads to the development of levees along the edges of the channels of the incoming watercourses, preventing



floodplain waters from returning back to these channels, has negated this effect to a significant extent. This effectively means that much less groundwater-recharge into the deeper aquifer underlying the wetland occurs through channel bed losses than would normally occur.

Additionally, the deposition of the bulk of the sediment by the rivers flowing off the Waterberg Mountain Range to the west and northwest of the Nyl River wetland in the area where the rivers fan out onto the floodplain (on the western to northwestern banks of the river), together with the fact that there is, for all practical purposes, no inflow from the east or southeast, has caused the discernible part of what remains of the channel in which the Nyl River flows, to be displaced across the valley to the southeast and east (i.e. to the right-hand bank of the river). For this reason it appears as if the Nyl River flows along the eastern to southeastern edge of the in-filled alluvial deposit in the vicinity of, and upstream from, the proposed mine and not in the centre of the floodplain, as would be expected.

1.6 Average Flow Quantities

The rainfall in quaternary catchment A61E is 624.58 mm of which 46.3 mm (MAR) reaches surface watercourses annually as surface run-off (*Midgley et. al. 1994*) (*Middleton & Bailey, 2005*).

The surface areas that could potentially produce contaminated run-off, at Volspruit Mine, are shown in **Table 1**. The surface run-off from these surfaces will be contained in pollution control dams and return water dams, and will not be allowed to flow into the Nyl River.

Using the mean annual run-off (MAR), it can be calculated that the proposed mining infrastructure, with the combined surface area as estimated above, would intercept some 158 066 m³ surface run-off to the Nyl River annually (about 433 m³/day). This amount of water is negligible when viewed in context of the catchment of the entire wetland. Most of these surfaces will be classified as contaminated areas and this water would have to be treated or re-used before release into the environment.



Site	Area (m ²)
North Pit	667 840
South Pit	325 656
Waste Rock Dump	483 375
Tailings Dam	1 268 126
Tailings RWD	231 983
Ore Stockpile Area	161 657
Total Plant Area (excl PCD)	241 220
Plant Area PCD	14 039
Waste Rock PCD	26 109
ROM PCD	12 820
Total Surface Area (m²):	3 432 825
Total Surface Area (Km²):	3.43

Table 1: The surface areas of the different surface infrastructure units from which surface water would run off during rainy periods. This water will be contained on site as it may be contaminated

In general, it has been shown that virtually no surface run-off reaches the Nyl River anyhow from the southeast, as most of the land adjacent to the river and its floodplain, in the general vicinity and to the south of the proposed mine, falls away from the river. Subsequently, this side of the river does not contribute to any meaningful recharge of the water on the floodplain and, although the proposed mine does locate on a slope towards the Nyl River wetland, the contribution of this portion of land is negligible when compared to the total northwestern catchment of the wetland.

This effectively means that, under normal, the amount of surface run-off water intercepted by the proposed mine, from the Nyl River, is negligibly small.

Using an average of 624.58 mm mean annual rainfall (MAR), it can thus be calculated that, on average, a volume of ~2 132 MI, originating from rainfall, will fall over the entire mine surface area per annum. However, of this rainfall, only ~**158 MI/a** (158 066 m³/a) will drain off the study area into the Nyl River, the balance being “lost” either as groundwater recharge or as evaporation/evapotranspiration.

Mining activities will alter the surface water run-off values, in particular by creating hard and impenetrable surfaces, as rainwater falling on these paved or roofed areas will produce a greater surface run-off than normal veld would have. It is therefore necessary to calculate the surface run-off from these surfaces as well in terms of GN704. These volumes will be discussed in the following section, **Section 1.7**.



1.7 Projected Peak Flow Quantities

As is common knowledge, rainfall does not occur in average amounts throughout the year, but occurs on a seasonal basis. Once in a while a storm will occur which will exceed the average rainfall by a significant amount. In particular, as far as mining is concerned and in terms of Government Notice GN704 of the National Water Act of 1998 (Act 36 of 1998), both the 50- and 100-year return period rainfall events must be modelled.

1.7.1 Flood Lines of the Nyl River at the proposed Volspruit Mine

Legal Considerations:

Government Notice GN704 specifically dealing with the location of mines in relation to flood lines, promulgated in terms of the National Water Act of 1998 (Act 36 of 1998), legislates that no residue deposit, dam, reservoir or any of its associated infrastructure may be placed within the 100-year flood lines or within 100 m from a river's edge, whichever distance is the greatest. It continues that no opencast or underground mine may be located within the 50-year flood line of a stream or river (or within 100 m from the edge of a river, whichever distance is the greatest) and neither may one erect any sanitary convenience, fuel depots, reservoir or depots for any substance which causes or is likely to cause pollution of a water resource within the 1:50 year flood-line of any watercourse. So, as far as mining is concerned, both the 50- and 100-year flood lines are required in terms of the National Water Act of 1998.

It was common knowledge that flood elevations at the proposed Volspruit Mine could potentially be a fatal flaw in terms of the feasibility of the mine. The ore body locates right alongside (and to a degree, into) the floodplain of the Nyl River and this ore body can only be accessed through an opencast mine. The flood lines were consequently modelled in 2010 and 2011 to determine exactly to what elevation floodwaters would rise, what measures would be required to protect the mine and also to comply with the requirements of GN704, summarised above.

Discussion of the Flood Line Work:

Please refer to report AED00151/2010 dated 22/07/2010 (*Krige & Bond, 2010*) for details on the methods and results of the 100-year flood line study pertaining to this project.



The modelling of flood lines is done in two general steps. The first part of the process is the modelling of a design storm falling over the catchment of a river at, and upstream from the study area. This is done using modelling techniques described in the publications, Report No. 1/72, *“Design Flood Determination in South Africa”*, 1972, and *Report No 1/74 “A Simple Procedure for Synthesizing Direct Runoff Hydrographs”* 1974, produced by a joint venture between the CSIR and the Hydrological Research Unit (a division of the Department of Civil Engineering at the University of the Witwatersrand). This step produces a discharge at the study area in m³/s. We then use software, developed by AED, to simulate the discharge from the design storm flowing through the cross sections across the river, using Mannings theory for open channel flow (Chow, 1954). This step produces elevations for the floodwaters at each of the cross sections. The actual flood lines are then derived from these points. The results of the 50- and 100-year flood lines are published in a report, *“50- And 100-Year Flood Lines For The Nyl River At The Volspruit Mine On Portion 1 Of The Farm Volspruit 326 KR, District Mokopane”* (Krige & Bond, 2010), while the results for the 10-year flood was published as an addendum to the above report by AED (Krige & Bond, 2011). All the detail on the modelling techniques and the results, including the CAD files are incorporated in these two reports.

One of the issues that transpired from these studies was that even a flood with a return period of 10 years would in all likelihood spill over into the North Pit should this pit not be adequately protected from such a flood event. For this reason a conceptual flood barrier was designed to keep the North Pit dry during a 100-year (and any shorter return period) flood. It is envisaged that this barrier will be about 6.5 m high at the edge of the Nyl River, i.e. to the west of the North Pit to provide a freeboard of 0.5 m during the 100-year flood.

The second and very important issue that emerged from the flood line study was that the backwater of the N1 road bridge over the Nyl River will form a temporary “dam” upstream from the bridge during a 50- or 100-year storm and due to the very low fall in the river along its reach covered by the floodplain, the elevation of the 50- and 100-year flood lines as a result of this temporary dam would be higher than the elevation created by the flood barrier itself (i.e. by narrowing the river channel by the barrier). This meant that neither the 50- nor the 100-year flood lines would be

elevated by the construction of the flood barrier, as the flow restriction caused by the N1 motorway bridge had already elevated the original flood lines to an elevation higher than the elevation of the flood lines resulting from the flood barrier. To a lesser extent, the same is true for the 10-year flood. For this reason the flood line for each of the return periods remains at a single elevation, such as would be the case along the sides of a dam, for the entire length for the reach of the Nyl River that was modelled.

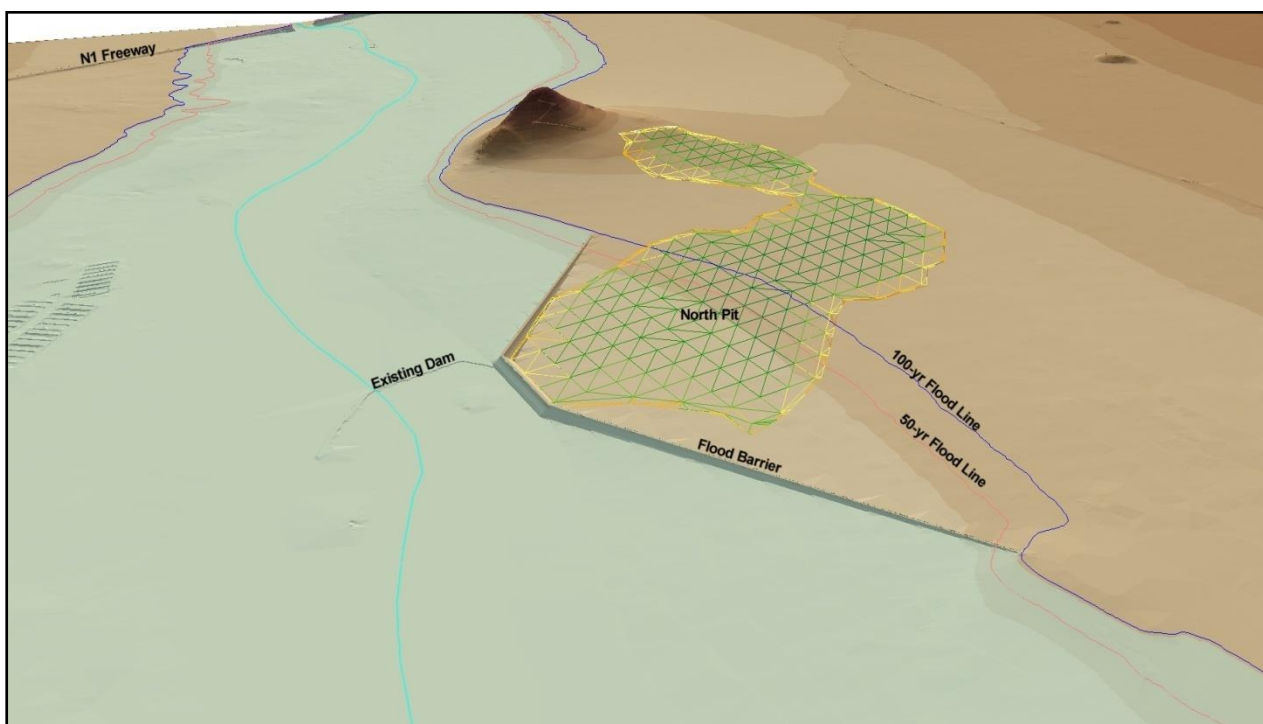


Figure 13: The Nyl River during a modelled 100-year flood, showing the location of the North Pit and the protection the conceptual flood barrier will afford to the pit

1.7.2 The Attenuation effect of the Nyl River Wetland during a storm with a 50-year return period

The study by Kleynhans (*Kleynhans et al, 2010*) was aimed at determining the attenuation effect a large floodplain such as the Nyl River wetland would have on the downstream reach of the river, in this case, the Mogalakwena River, by using hydrological modelling techniques. In his conclusions, Kleynhans (*Kleynhans et al, 2010*) points out that, although a large wetland such as the Nyl River wetland could have a significant attenuation effect on flows during severe flood conditions, this effect could quickly be negated by the presence of downstream tributaries. Moreover,



the impact of flow attenuation on downstream inundation areas is also dependent on valley shape. In the case, the Mogalakwena River, the river had a relatively steep sided valley, which meant that increase in flood impacts without the wetland would be relatively minor, even when the downstream tributary inflows were included.

In addition, Kleynhans (*Kleynhans et al, 2010*) suggests that the ability of wetlands like the Nyl River wetland to perform a base flow maintenance function through regulation of surface flows alone may not be significant, due to the losses (evaporative and recharge) in the wetland itself.

AED's report has also shown that, due to the very fine nature of the silt deposited on the largest part of the wetland, there is very limited interaction between the water on the surface of the wetland and the groundwater in the aquifer in the deeper, coarser alluvial sediment below the surface. Unlike the wetlands of e.g. the Lesotho plateau, which do possess significant water attenuation properties, the geomorphology of the Nyl River wetland is such that this is not true of this particular wetland.

So, contrary to common belief, it appears that the Nyl River wetland provides relatively minor protection in the form of flood attenuation to the downstream reach of the river. Similarly, due to the large evaporation surface area of the Nyl River wetland, it also provides only very limited base flow maintenance, i.e. keeping the river flowing during dry periods.

1.7.3 Determination of the run-off volumes from a 50-year flood occurring in the vicinity of the proposed Volspruit Mine

In terms of GN704 Section 6 (b), (d) and (f), promulgated in terms of the National Water Act of 1998 (Act 36 of 1998), all dams, canals, pollution control dams, etc. must be designed so that spillages do not occur as a result of a 50-year, 24-hour flood event taking place and that water flowing in clean and dirty systems must not mix during this particular storm event.

To determine the amount of total surface run-off, in this section, we modelled a storm with a 50-year return period falling over an area of 78.5 Km² (i.e. a circular thunderstorm with a 5-Km radius), which includes the mine at its centre. The total

volume of water that would be produced by this storm will then be determined. The surface run-off will be reported as a volume per square meter surface area, which will be used during the design of the mine to determine the sizes of, e.g. pollution control dams. The area modelled is shown in **Figure 14**.

Graph 1 shows that a total surface run-off of 723 027 m³ would occur over the entire 24-hour period off natural veld in Veld Zone 8 (Bushveld). This converts to **9.2 l/m²**. Of course, these calculations were assuming natural veld, which will not be the case when mining commences. These figures are therefore adapted, as shown in the following section.

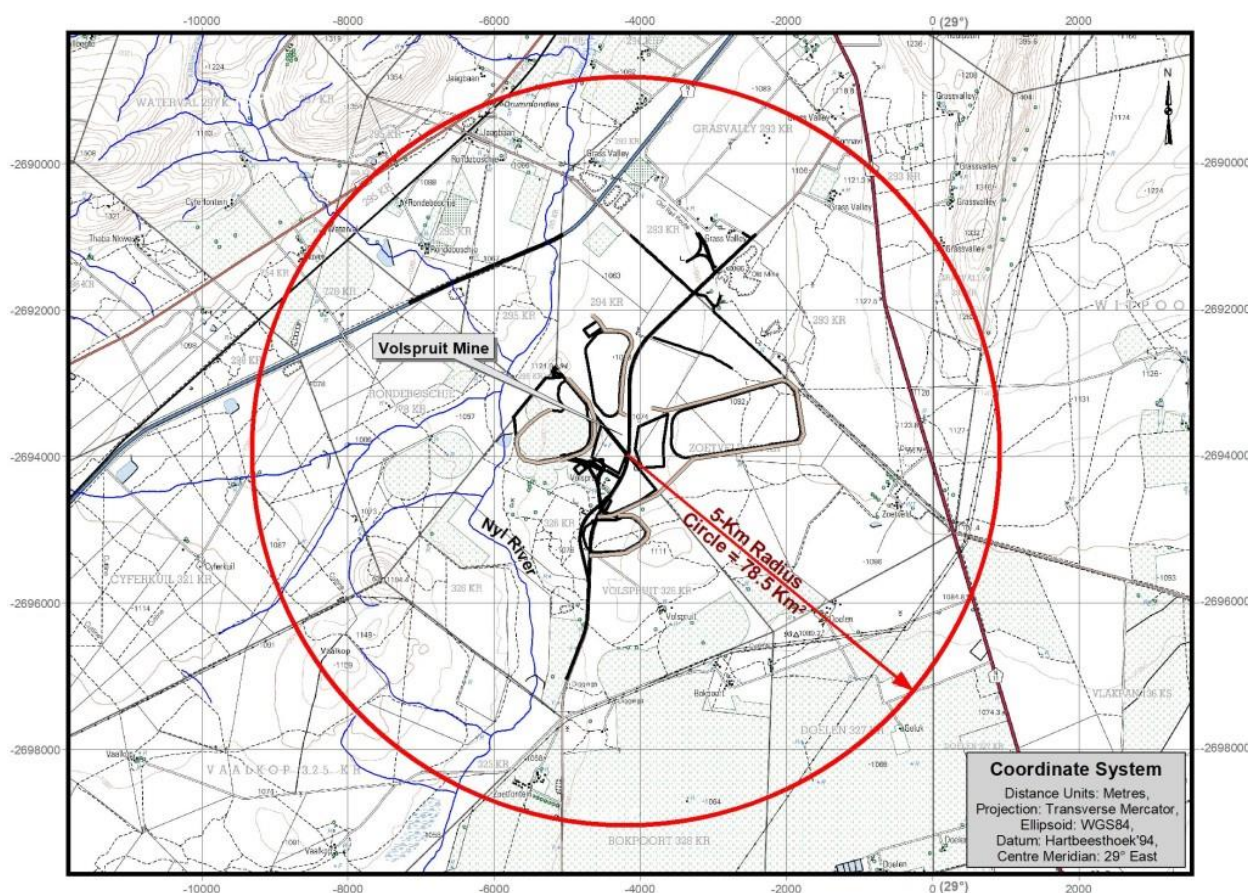
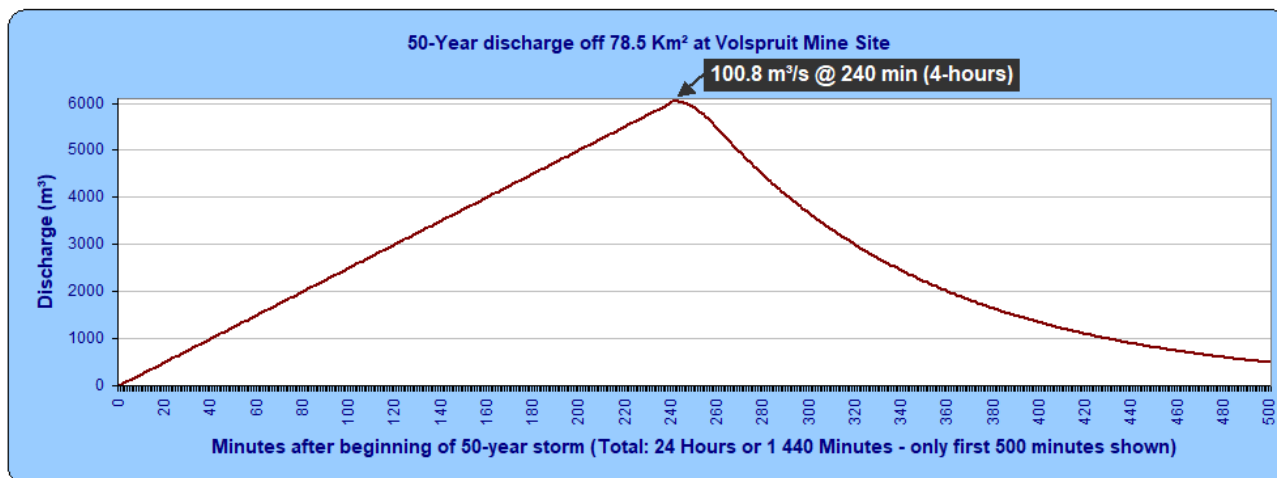


Figure 14: The area used around the mine to model a storm with a 50-year return period. The circle has a radius of 5 Km representing a surface area of 78.5 Km²

The results are summarised in **Graph 1**, below.



Graph 1: The discharge produced by a 50-year storm for the first 500 minutes of a total period of 24 hours. This storm produced a total run-off of 723 027 m³ over the entire 24-hour period off a surface area of natural grassveld of 78.5 Km² in Veld Zone 8 (Bushveld)

According to the Hydrological Research Unit (*Midgley, 1982*) and using Mannings roughness coefficients and coefficient C in the normal rational formula ($Q = CIA$) for the various surfaces found in the mining environment, the following run-off values can be expected within this particular area:

Surface Type	Run-off	Units
Natural Open Grassland (Coefficient C = 0.10)	9.2	l/m ² (Graph 1)
Railway Yards	27.6	l/m ²
Offices (coverage equiv. to residential areas)	36.8	l/m ²
Industrial Area up to 50% covered:	64.4	l/m ²
Industrial Area >50% covered:	73.6	l/m ²
Streets, Pavements, etc.	73.6	l/m ²
Roofs	82.8	l/m ²
Open Dams Collection (i.e. no outflow)	92	l/m ²

Table 2: The different surface run-off values for different surface types normally associated with mining environments

Using the per-m² run-off values shown in **Table 2**, run-off volumes for the surfaces at Volspruit Mine were calculated, the results presented in **Table 3**.



Surface run-off during 50-year (24-hour) storm		
Site	Area (m²)	Run-Off (m³)
North Pit	667 840	36 865
South Pit	325 656	17 976
Waste Rock Dump	483 375	13 341
Tailings Dam	1 268 126	70 001
Tailings RWD	231 983	21 342
Ore Stockpile Area	161 657	7 436
Total Plant Area (excl PCD)	241 220	17 754
Plant Area PCD	14 039	1 292
Waste Rock PCD	26 109	2 402
ROM PCD	12 820	1 179
Total (from contaminated areas):		173 845
Total (from less contaminated areas):		15 743
(Waste-rock Dump + its PCD) Final Total:		189 588
(say...200000 m³)		

Table 3: The estimated surface run-off volumes that can be expected from the various surfaces likely to be found at Volspruit Mine, flowing off all the potentially contaminated surface areas during a storm with a return period of 50 years

Please note:

The values discussed above (run-off in litres per square metre of surface area) are volumes that would actually run off a particular surface and is not the total rainfall falling on that surface. In almost all instances, the volume running off any surface will be less than the amount of rain falling on that surface. The only exception is open dam surfaces, where every litre of rainfall falling on the dam surface will actually remain in the dam, provided that the dam already had some water in it at the time of the storm.

1.7.4 Storm Water Handling at Volspruit Mine

In terms of Regulation 6 of GN704, dealing with the “[capacity requirements of clean and dirty water systems](#)”, the following paragraphs comprise excerpts of the relevant sections in this notice:

“[Every person in control of a mine or activity must:](#)

- (a) [design, construct, maintain and operate any clean water system at the mine or activity so that it is not likely to spill into any dirty water system more than once in 50 years;](#)



(b) design, construct, maintain and operate any dirty water system at the mine or activity so that it is not likely to spill into any clean water system more than once in 50 years

(f) design, construct and maintain all water systems in such a manner as to guarantee the serviceability of such conveyances for flows up to and including those arising as a result of the maximum flood with an average period of recurrence of once in 50 years”

The Government Notice therefore clearly states that a drainage system must be designed and maintained so that contaminated and uncontaminated waters with flow rates up to that produced by a storm with a 50-year return period are kept separate from each other.

For this reason the 50-year storm falling over the mining area was modelled. We recommend that the conceptual storm water flow diagram shown in **Figure 15** be implemented at Volspruit Mine.

In order to store the surface run-off, intercepted during a storm with a return period of 50 years from the contaminated surfaces at Volspruit mine (listed in **Table 3**), a conceptual pollution control system was designed, as shown in **Figure 15**.

There are two main components of the proposed storm water system, prevention of uncontaminated water from entering contaminated areas and containment of contaminated water within contaminated areas.

Prevention of uncontaminated water from flowing onto contaminated areas:

The first component, the prevention of uncontaminated water from flowing onto contaminated areas, is done through the emplacement of berms, made mostly of topsoil and to a lesser extent, overburden in strategic, upgradient areas. The use of topsoil also ensures a storage place for topsoil in areas that will not become contaminated.

The berms are indicated in **Figure 15** as broad, light-coloured brown lines. These berms are placed in all upgradient areas from potentially contaminated areas, deflecting rainwater run-off around the area it protects. These protected areas include the two mine pits, the tailings dam together with its return water dam and the waste rock dump. It is not necessary to protect the sites of the plant (concentrator and smelter areas), as the infrastructure that will be installed at these sites will be done on raised, probably concreted platforms. Subsequently, rainwater will flow around these sites without having to install a berm on the upgradient side of these sites.

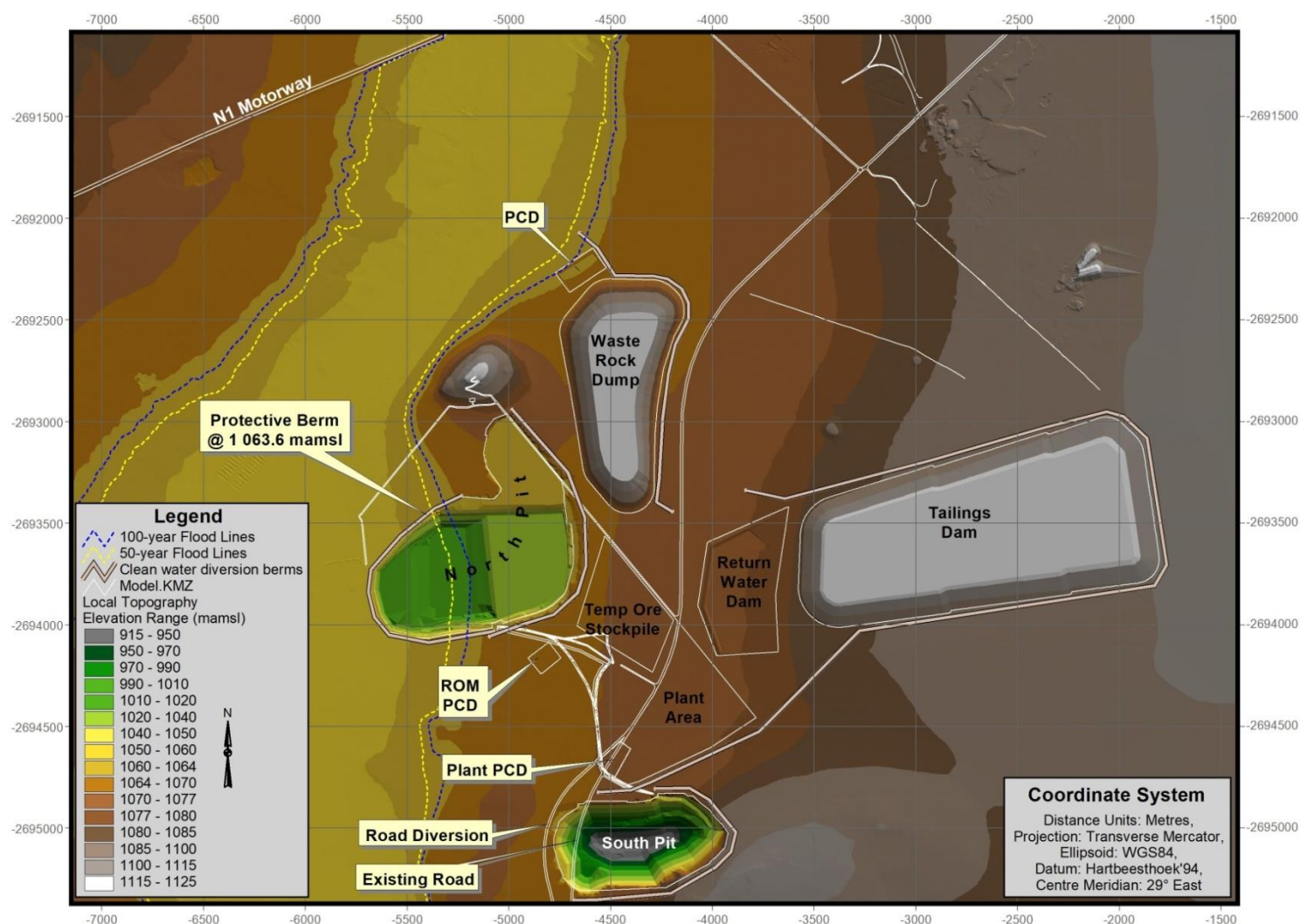


Figure 15: The proposed surface infrastructure layout of Volspruit Mine. This diagram also shows the conceptual layout of the storm water drainage berms



Due to the land falling away to its north, the protective barrier along the eastern side of the Waste-rock Dump (i.e. on the opposite side to the Nyl River) will direct storm water to the north around the northern part of the dump and also around the northern side of the Waste-rock Dump's PCD to the Nyl River. Rainwater falling in the area between the Waste-rock Dump and the eastern side of the North Pit will be diverted southwards around the southwestern corner of the North Pit and will discharge just south of where the Protective Flood Barrier begins. The topography is the highest on the eastern tip of the South Pit (as it locates alongside a hillock), thus the berm constructed along this side of the pit will divert water to both the north and south around the pit to the Nyl River. Water falling east of the Tailings Storage Facility (TSF or Tailings Dam) will be diverted around the northern and southern sides of the TSF. Water flowing along the northern berm of the TSF will be let out in the veld north of the RWD of the TSF. It will continue along the natural direction of flow towards the Waste-rock Dump's Berm along its eastern side. This berm will then collect and direct the flow of clean water around the northern tip of the Waste-rock Dump to the Nyl River. Water flowing around the southern side of the TSF will be diverted to the southwest along an extension of the diversion berm running along the southern side of the TSF. This berm will prevent this (uncontaminated) water from flowing on to the ROM stockpile and the plant area. It will pass between the southern tip of the Plant Area and the northern side of the South Pit.

Essentially, the berms as indicated in **Figure 15** will prevent uncontaminated surface run-off from mixing with water flowing over potentially contaminated surfaces at Volspruit Mine.

Containment of contaminated water within dedicated contaminated areas:

It was calculated (refer **Table 3**) that almost 200 000 m³ contaminated water would be produced by rainwater flowing off, or falling on, areas that could potentially be contaminated. This water must be stored on site and re-used in the mining or beneficiation processes.

There are 3 dedicated PCD's (Waste-rock PCD, ROM PCD and the Plant PCD) as well as the RWD of the TSF (which also acts as a PCD).



It was calculated from its contour lines that the RWD at the TSF has a volume of 571 016.611 m³. The WRD PCD was also calculated using ArcView's 3D Analyst. It has a volume of 26 800.641 m³. We did not have details of the other two PCD other than the plan derived from the drawing, "*Model.KMZ*", thus we assumed a usable depth of 1.5-m for both the ROM PCD and the Plant PCD. The volumes were thus calculated as 25 640 m³ for the ROM PCD and 28 078 m³ for the Plant PCD.

The PCDs' volumes are summarised in **Table 4**.

PCD	Run-Off (m ³)	Volume (m ³)
TSF-RWD	16 509	571 016
Plant Area PCD	14 039	21 059
Waste Rock PCD	26 109	26 801
ROM PCD	12 820	19 230

Table 4: A summary of the storage volumes of the PCDs at the Volspruit Mine site in relation to the volumes required to be stored during a 50-year flooding event

In all instances, the PCDs have storage capacities exceeding the required storage volumes, which will be produced by a 50-year storm.

All the PCDs also locate outside the 100-year flood lines of the Nyl River (although the WRD PCD only just makes it).

1.8 Rainfall and Evaporation at the proposed Volspruit Mine

Table 5 shows the average monthly rainfall for Mokopane (Potgietersrus) as well as the average number of days per month on which rainfall occurs.

According to **Table 5**, the mean annual precipitation at Mokopane is 543 mm. Mokopane is the closest town to the proposed mine where full rainfall records are available. It does, however, not fall in the same quaternary catchment as the proposed mine, but rather in an adjacent quaternary catchment (A61F).

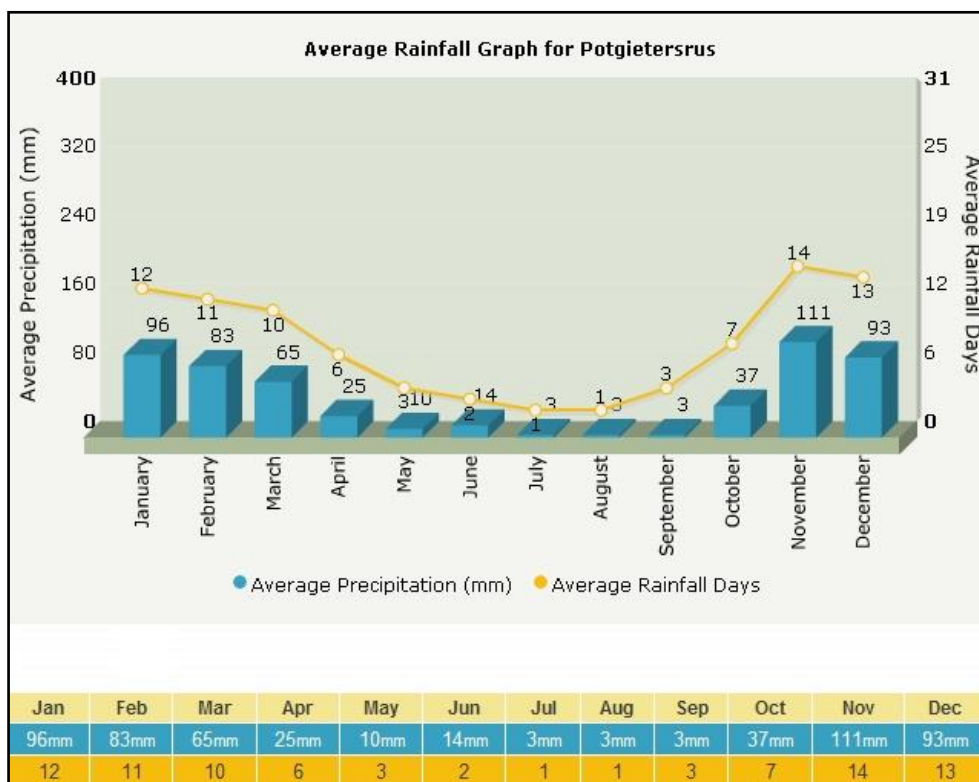


Table 5: The rainfall for Mokopane (Potgietersrus) Courtesy www.worldweatheronline.com

Figure 7 shows the mean annual rainfall for the quaternary catchments associated with the proposed Volspruit Mine while **Figure 16** also shows the actual mean annual precipitation values derived from the many privately operated rain-gauging stations around the area. **Figure 16** is presented on a 1' (one minute) grid.

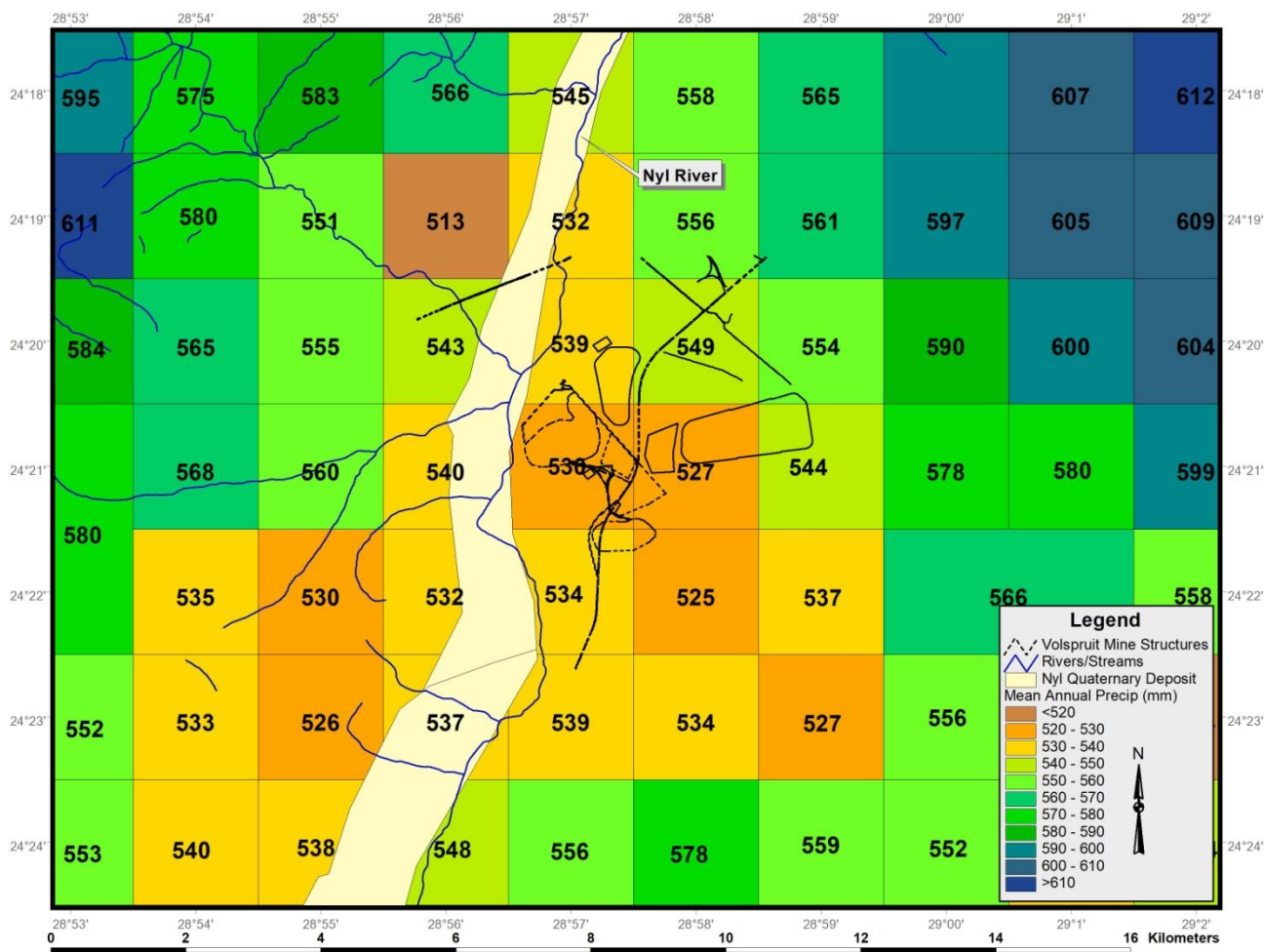


Figure 16: The Mean Annual Precipitation (MAP) for the area surrounding the proposed Volspruit mine on a 1-minute grid (Data: WR2005) shows that the MAP at the proposed mine is significantly lower than the MAP of 625.58 mm for the entire quaternary catchment A61E

It is clear from **Figure 16** that the MAP at the proposed Volspruit Mine (MAP: ~530 to 550 mm) is significantly lower than the average rainfall for the quaternary catchment within which it locates, quaternary catchment A61E (MAP: 625.58 mm). This is due to the catchment including certain parts of the Waterberg Mountain Range where the rainfall runs into the mid 600's (mm). As far as mining is concerned, it is probably always better to receive lower rainfall and the mine locates in a significantly dryer area than the rest of the quaternary catchment.

The average A-Class Pan evaporation for the Volspruit area is shown in **Figure 17** (evaporation data courtesy WR2005).

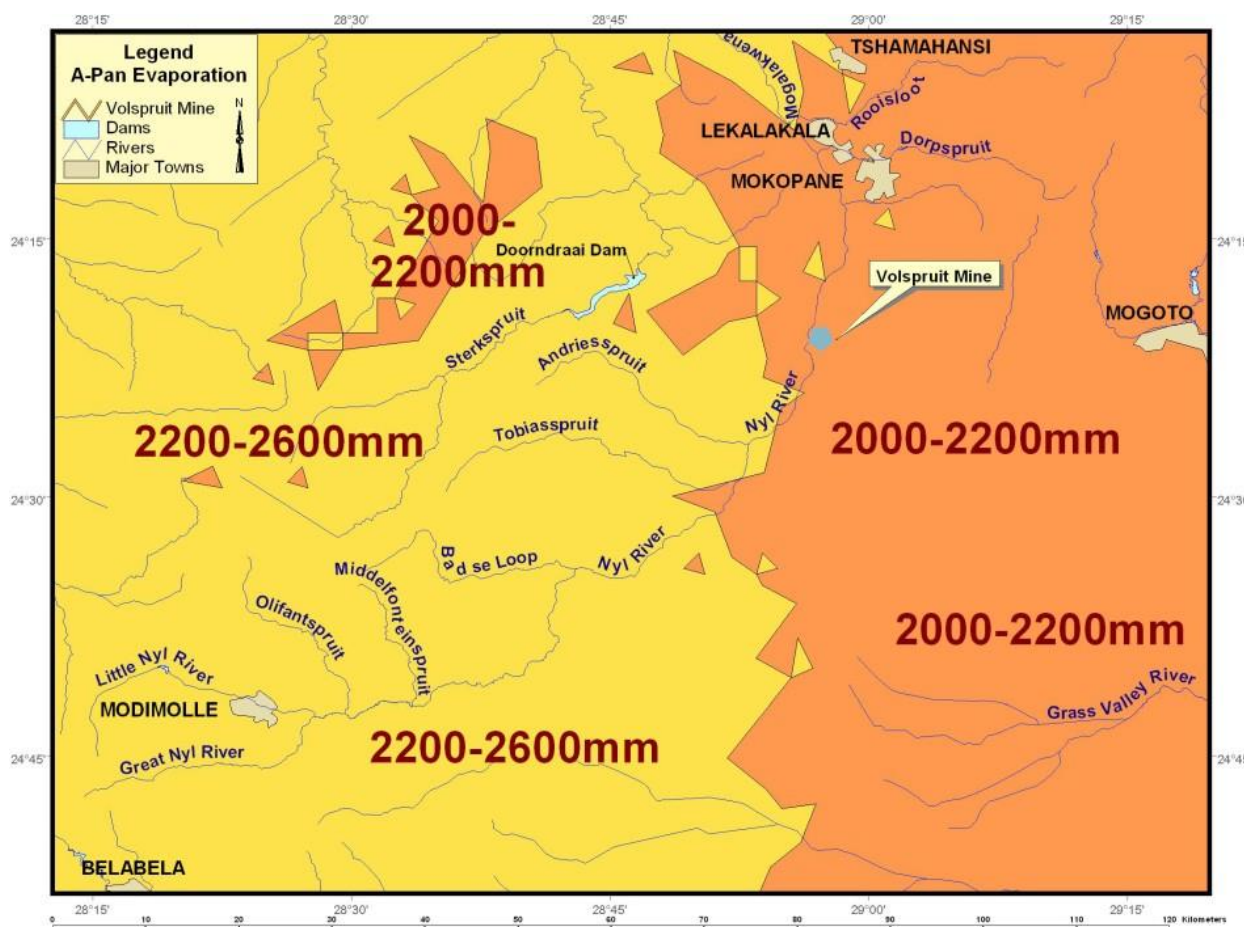


Figure 17: The average A-Pan Evaporation rate for the areas surrounding the Nyl River wetland and the proposed Volspruit Mine

Different reference sources report different evaporation rates, while there is sometimes confusion between the Symons Class Pan Evaporation (S-Pan) and the American A-Class Pan Evaporation.

For clarity, the conversion between S-Class Pan and A-Class Pan Evaporation rate is as follows:

$$A\text{-Class Pan} = 26.3622 + (1.0768 \times S\text{-Class Pan})$$

$$S\text{-Class Pan} = -16.2354 + (0.8793 \times A\text{-Class Pan})$$

Some references quote the mean annual evaporation (MAE) for the Nylsvley Nature Reserve as 1 250 mm (A-Pan) or 1 700mm (S-Pan) (the two records don't tally!) while some references quote the A-pan as being twice the MAP, i.e. about 1 100mm. None of these values tally! For the purposes of this report AED has standardised on



the evaporation rate reported by WR2005 (*Middleton & Bailey, 2005*). These evaporation ranges are presented in **Figure 17** and are significantly higher than any of the other reported evaporation rates.

In his M.Sc. dissertation, Kleynhans (*Kleynhans, 2004*) determined that the most appropriate **evapotranspiration** rate (evaporation resulting from transpiration by plants) to be used at the Nyl River wetland is as follows:

Evapotranspiration (in mm) (MT Kleynhans, 2004)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Totals
Daily	2.3	3	3.7	4.4	4.7	2.6	2.2	1.9	1.6	1.6	0.4	2.3	30.7
Monthly	71.3	90	114.7	136.4	131.6	80.6	66	58.9	48	49.6	12.4	69	928.5

2. Surface Water Quality

2.1 Description of the Sampling Points

As part of this study, several water samples were collected. These samples were submitted to *DD Science*, a SANAS-accredited analytical laboratory, for analyses. A summary of the results is presented in **Table 3** and the laboratory analyses report is presented in **Appendix 1**.

The sampling points are shown in **Figure 18** and will be described briefly hereunder.

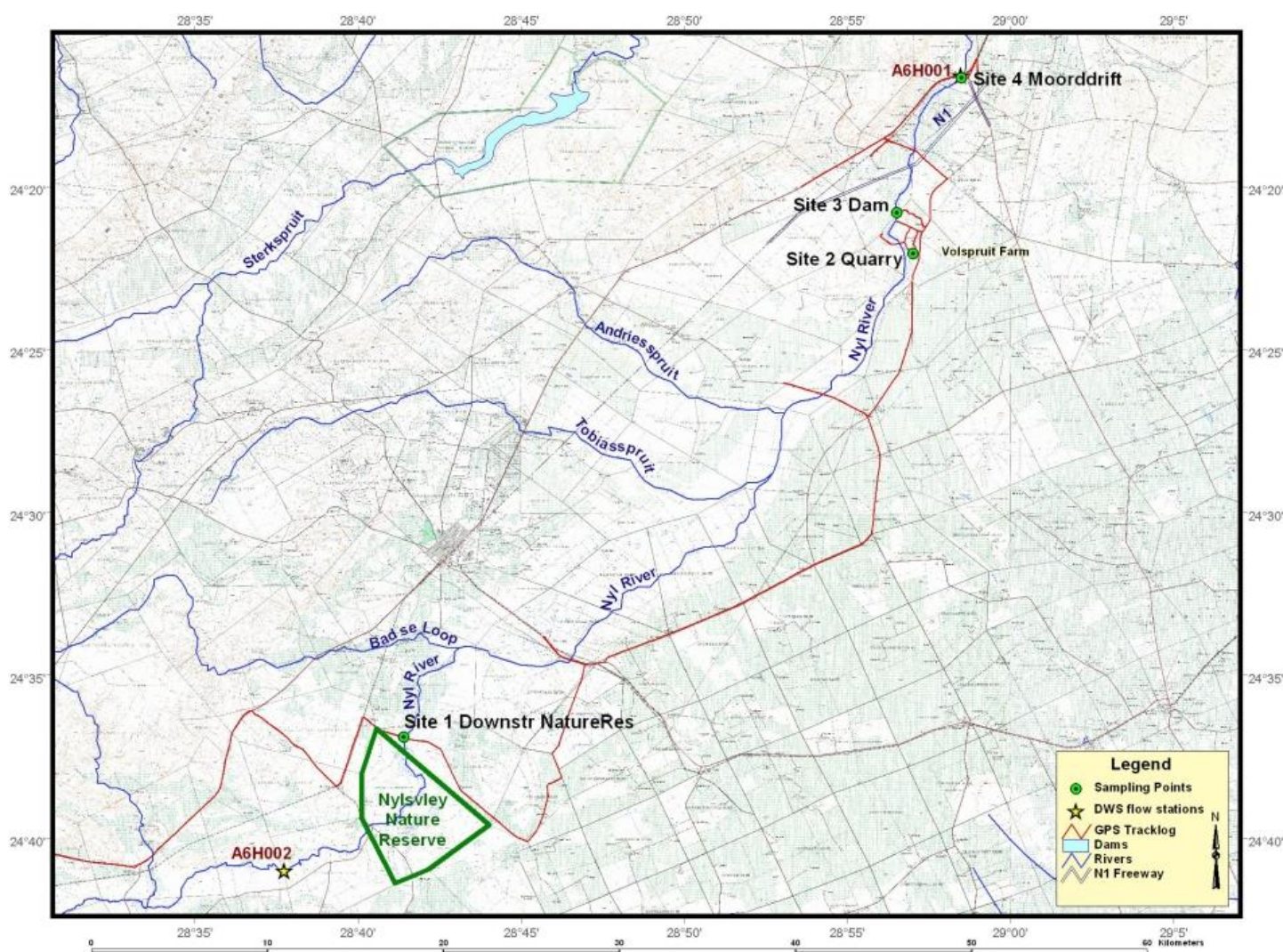


Figure 18: The sampling sites visited and/or sampled as part of this study

2.1.1 Site 1 Downstream of Nylsvley Nature Reserve

The first sampling site locates immediately downstream from the Nylsvley Nature Reserve where a dirt road crosses the wetland. The site locates on the farm Vogelsfontein 527 KR. At this point, the wetland is approximately 6 Km wide.



Photo 2: The first access point to the Nyl River downstream of the Nature Reserve is at a point where a road crosses through the wetland. The wetland spans in both directions approximately the same distance to the trees on the horizon of this photo (*Photo G. Krige 08/07/2011*)

2.1.2 Site Alternative 1



Photo 3: Site Alt 1. This site locates at a second road and railway crossing over the Nyl River Wetland The DWA flow-gauging marker and other measuring devices are visible in the photo (Photo G. Krige 08/07/2011)

Site Alt 1 locates at a second dirt road and railway line crossing over the Nyl River wetland o the farm, du Toit's Kraal 532 KR. Due to its close proximity to Site 1, we did not collect a sample from the river at this point. The wetland is also roughly 6 Km wide at this point.

2.1.3 Site Alternative 2

This site is located on the farm, de Hoop 334 KR some 22.2 Km to the north of Site Alt 1, where the next dirt road crosses the Nyl River wetland. As this point the river had dried up completely as can be seen for the area around the flow gauging instrumentation behind the bushes.



Photo 4: Site Alt 2, some 22.2 Km downstream from the previous site. As can be seen, the Nyl River was completely dry at this point when the photo was taken (*Photo G. Krige 08/07/2011*)

2.1.4 Site Alternative 3

This site locates some 10.3 Km downstream from the previous site, Site Alt 2, on the farm, Volspruit 326 KR, where a raised farm road crosses the Nyl River wetland and is close, but upstream, from the proposed Volspruit Mine. As was the case at Site Alt 2, the wetland was completely dry at this sampling point at the time of our site visit. Although the provincial roads crossing the Nyl River wetland were fitted with several culverts through which water could pass under the roadway, this crossing has some pipes in a single location roughly in the centre of the wetland. This could lead to accelerated erosion and channel formation through the wetland.



Photo 5: Site Alt 3 near the proposed Volspruit Mine. Here a farm road crosses over the Nyl River wetland, which was completely dry at the time of sampling. (*Photo G. Krige 08/07/2011*)

2.1.5 Site 2 Quarry



Photo 6: Site 2 Quarry. This sampling site is located at a borrow pit near the Nyl River and possibly represents a mixture of rain- and groundwater (*Photo G. Krige 08/07/2011*)

This is the second site from which we collected a sample. The quarry or borrow pit, on the farm Volspruit 326 KR, is located on the eastern bank of the Nyl River some 650 m upstream (south) of Site Alt 3. It locates roughly 440 m from the centre of the

Nyl River, placing it possibly still within the alluvial riverbed. Its water level was at around 1 055 mamsl, while the surface of the wetland where the road crosses the wetland at Site Alt 3 also located at this same elevation (note: handheld GPS accuracy). It appears as if sand and gravel was mined at this quarry, probably for building the nearby provincial gravel road. Although there were some boulders (to the left of the photo), these rocks seem to be loose rocks and not part of a bedrock formation. The quarry also had a lot of calcrete exposed along its sidewalls. The wetland in the vicinity of the quarry, as well as Site Alt 3 is under 1.5 Km wide. The Nyl River and its wetland pass between the quarry and the hills in the background of the photo. The slightly elevated hill roughly in the centre of the photo is called, Vaalkop, and is 1 159 mamsl high.

2.1.6 Site 3 Dam near N-Pit



Photo 7: Site 3. This sampling site is at the dam in the Nyl River at the edge of the North Pit of the proposed Volspruit Mine. Refer to **Figure 13** where the dam wall, referred to as, “Existing Dam”, is actually shown under the floodwaters during a 100-year flood adjacent to the conceptual flood barrier. A comparison of the flood barrier wall in **Figure 13** and the existing dam in this photo provides some measure of scale as to the height of the proposed flood barrier in comparison to the existing dam wall (*Photo G. Krige 08/07/2011*)

This sampling site locates at an existing farm dam in the Nyl River. The dam wall is actually constructed just within the Volspruit side of the boundary between the farms, Volspruit 326 KR and Rondeboschje 295 KR. The wall is constructed from rock,

probably sourced from the nearby Grass Valley Chrome Mine, now flooded and closed. As can be seen in **Photo 7**, it does not hold much water, given the amount of material used in the construction of the dam. It appears as if seepage occurs relatively unhindered through the dam wall. The sample we collected was actually sourced from a pool on the downstream side of the dam wall (where the wall makes a sharp bend to the left in **Photo 7**. It locates some 2 Km downstream from Site Alt 3. The hill on the horizon to the left of the photo locates just outside the western boundary of the Nyl River wetland and is fitted with a trig-beacon at an elevation of 1 194.4 mamsl. The floodplain is only about 1.1 Km wide at this point.

2.1.7 Site N1 Bridge

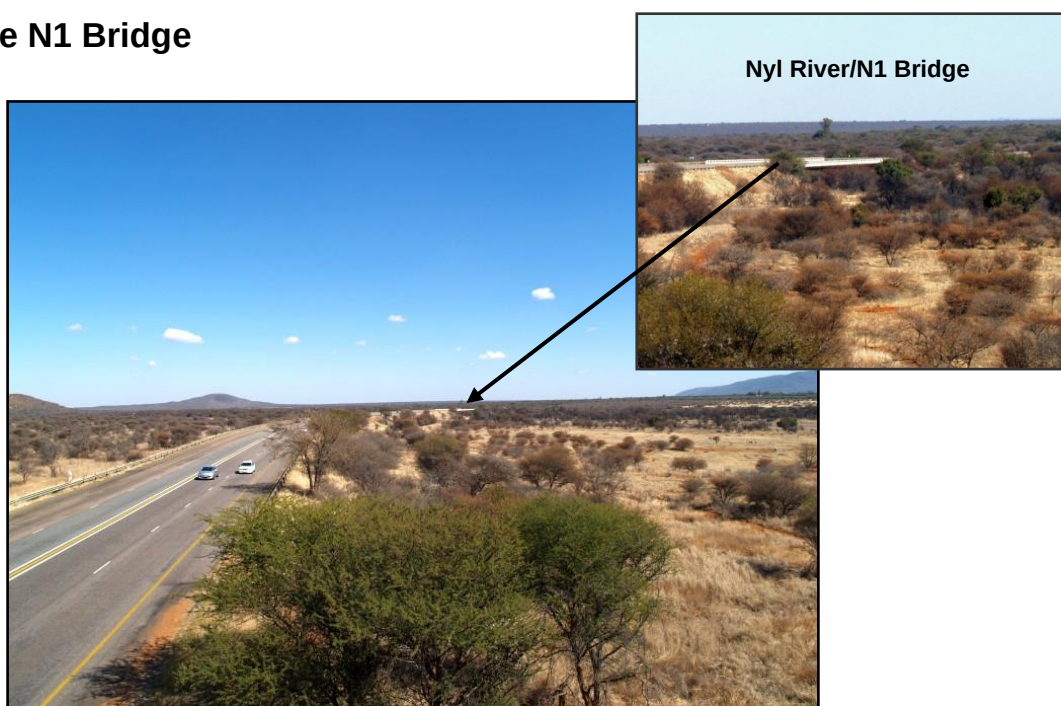


Photo 8: The place where the N1 Freeway crosses the Nyl River. The bridge is just visible in the centre of the photo after the turn in the roadway. There was no water in the river at the time of the site visit (*Photo G. Krige 08/07/2011*)

This site locates at the N1 roadway crossing on the farm, Rondeboschje 295 KR. There are two bridges over the Nyl River, the N1 and another road to the defunct Grass Valley Chrome Mine. The photo (**Photo 8**) was taken from the latter road where it crosses over the N1. The Nyl River passes through the right-hand part of the photo and, as can be seen from the photo, was dry at the time of sampling.

2.1.8 Site 4 Moorddrif

This sampling site marks our furthest downstream sample of the Nyl River and is located at a place with the somewhat sinister name of “Moorddrif” (murder ford or drift!). It locates on the farm, Moorddrif 289 KR. At this site, there was, once again, water in the Nyl River from which a sample could be collected. It is about 9 Km downstream from Site 3, the dam at the proposed North Pit of Volspruit Mine and some 6 Km downstream from the N1 Bridge.



Photo 9: Site 4, Moorddrif located some 7 Km south of Mokopane (Potgietersrus). Our last (downstream) sampling site, where the Nyl River wetland narrows to < ½ Km. A railway line and road crosses the Nyl River at this point (*Photo G. Krige 08/07/2011*)



Photo 10: This photo was taken viewing upstream (south) from below the railway bridge at Moorddrif. It shows the Nyl River flowing through a relatively narrow, downstream part of the wetland with the Waterberg to the right of the river valley (*Photo G. Krige 08/07/2011*)

All these sites were visited and photographed on the same day during the middle of the winter (i.e. beginning of July). It is clear from the succession of sites visited that the Nyl River flows intermittently, having water in the general vicinity of the inflow into the wetland and at the downstream end of the wetland before the river flows off the wetland onto bedrock. Most of the central part of the wetland was dry at the time of the site visits. This is more-or-less representative of the seasonal stages through which the wetland goes. It receives water during the summer; the floodplain is inundated with water (although this does not occur on a regular basis, i.e. it is not flooded every year) and then it dries up again, primarily due to evaporation and evapotranspiration from plants. The sites from which we were able to collect samples would also dry up within a month or two from collecting of the samples. This includes the farm dam (Site 3), which locates roughly in the middle of the otherwise dry central part of the wetland during this time of year. The dam held some of the water back, but this water would also soon be evaporated off the surface of the wetland.

2.2 Discussion of the Water Quality

Table 6 is a summary of the water quality at the sampling points on 08/07/2011.



The results of the samples collected on 08/07/2011 were compared to the South African National Standard, SANS 241-1:2015. SANS 241 is the official drinking water standard for South Africa. Previous versions of this standard provided 2 levels of quality, Recommended (Class I) and Maximum Allowable for a predefined period (Class II). The latest release, SANS 241-1:2015, has simplified the standard significantly by removing some of the unnecessary determinants from the standard (determinants such as calcium, magnesium and potassium that do not really pose a health hazard to humans or animals). At the same time the standard has been brought in line with the World Health Organisation standards and the concentrations of some determinants were either increased or decreased. As far as gold mining is concerned, an important change was the increase of the upper standard limit for uranium from 15 µg/l (i.t.o. SANS 241:2011) to 30 µg/l in the current (2015) version. The most important change, however, was the abandonment of the different classes (or concentration ranges) in the standard. These classes (or varying degrees of “grey” between “good” and “bad”) caused unnecessary confusion in the past. In only a few instances does SANS 241-1:2015 still quote more than one standard limit for a particular determinant, but this differentiation is only there to distinguish between aesthetic (taste, colour, scaling discolouration of plumbing fittings properties of the water), operational (water treatment plant parameters) and health parameters.

For ease of identification, the entries in **Table 6** were colour-coded. If a determinant complies with SANS 241-1:2015, it is colour coded green, if it exceeds only the aesthetic or other non-health concentration, but still complies with the health concentration, it is coloured yellow, while determinants exceeding the health concentration are coloured orange. If there is no standard for a particular determinant, it is left white. If a determinant is listed in the 2006 version of the standard but not in the 2011 version, and the 2006 Class I range is exceeded, it is also colour-coded yellow.



Sample ID → Determinant ↓	Units	Site 1 Downstr. Nature Reserve	Site 2 Quarry	Site 3 Farm Dam	Site 4 Moorddrif	SANS 241-1:2015 (Edition 2) (Unless specified otherwise)		
						Standard Limits	Risk	
Physical and Macro Determinants								
pH	@25°C	6.6	9.2	7.2	7.6	≥5.0 - ≤9.7	Operational	
Conductivity	mS/m @25°C	11	98	22	75	≤170 mS/m	Aesthetic	
Total Dissolved Solids	mg/l @180°C	75	666	150	510	≤ 1 200 mg/l	Aesthetic	
Total Hardness	mg/l CaCO3	17.9	67.5	35.9	88	0-50: Soft, 50-100: Moderately Soft, 100-150: Slightly Hard, 150-200: Moderately Hard, 200-300: Hard, >300: Very Hard (DWAF1996)		
Total Alkalinity	mg/l CaCO3	29	459	70	168			
Sulphate	mg/l	<50 (22)	<50 (43)	<50 (24)	<50 (12)		250 and 500 mg/l	Acute Health: ≤500 Aesthetic: ≤250
Nitrate	mg/l N	0.4	0.4	0.5	0.4		≤11 mg/l	Acute Health
Orthophosphate	mg/l P	0.1	0.1	0.1	0.1	1 mg/l Special Standard ito. GN 991 of 18 May 1984		
Chloride	mg/l	16	76	19	83	≤300 mg/l	Aesthetic	
Calcium	mg/l	4	74	9	29	<150 mg/l (SANS 241:2006 Class I)		
Magnesium	mg/l	1.9	14	6.3	19	<70 mg/l (SANS 241:2006 Class I)		
Sodium	mg/l	9.3	27	11	45	≤200 mg/l	Aesthetic	
Iron	µg/l	62	37	930.9	48.6	300 and 2 000 µg/l	Cronic Health: ≤2 000 Aesthetic: ≤300	
Potassium	mg/l	3.9	3.5	9.8	9.9	<50 mg/l (SANS 241:2006 Class I)		
Metals by ICP Mass Spectroscopy								
Aluminium	µg/l	4.87	4.40	1157.90	0.79	≤300 µg/l	Operational	
Antimony	µg/l	0.08	0.03	0.17	0.10	≤20 µg/l	Chronic Health	
Arsenic	µg/l	0.30	0.25	13.60	0.60	≤10 µg/l	Chronic Health	
Barium	µg/l	45.80	132.90	94.70	72.70	≤700 µg/l	Chronic Health	
Beryllium	µg/l	0.02	0.01	0.05	0.01			
Bismuth	µg/l	0.01	0.03	0.02	0.03			
Caesium	µg/l	1.38	0.10	1.95	0.10			
Cadmium	µg/l	0.01	0.01	0.10	0.02	≤3 µg/l	Chronic Health	
Chromium Total	µg/l	0.20	1.00	5.27	0.20	≤50 µg/l	Chronic Health	
Chromium(VI)	µg/l	<0.03	<0.03	<0.03	<0.03			
Cobalt	µg/l	0.90	0.06	2.90	0.20	≤500 µg/l (SANS241:2011)		
Copper	µg/l	43.00	0.96	245.00	5.29	≤2 000 µg/l	Chronic Health	
Indium	µg/l	0.001	<0.001	0.002	0.001			
Lanthanum	µg/l	0.05	0.01	0.70	0.01			
Lead	µg/l	0.19	0.05	2.20	0.50	≤10 µg/l	Chronic Health	
Lithium	µg/l	0.56	3.50	2.06	1.40			
Mercury	µg/l	0.90	0.97	0.80	1.78	≤6 µg/l	Chronic Health	
Molybdenum	µg/l	0.18	0.20	0.50	0.29			
Manganese	µg/l	19.90	0.79	15.00	1.10	100 and 400 µg/l	Cronic Health: ≤400 Aesthetic: ≤100	
Nickel	µg/l	7.50	1.38	59.00	1.99	≤70 µg/l	Chronic Health	
Platinum	µg/l	0.02	0.02	0.05	0.05			
Rubidium	µg/l	2.07	0.47	3.60	2.59			
Selenium	µg/l	0.50	0.40	3.08	0.38	≤40 µg/l	Chronic Health	
Tellurium	µg/l	0.01	0.01	0.03	0.08			
Thallium	µg/l	0.06	0.20	0.10	0.29			
Tin	µg/l	0.20	0.04	0.10	0.03			
Titanium	µg/l	0.29	0.20	47.80	0.06			
Tungsten	µg/l	0.10	0.18	0.30	0.50			
Vanadium	µg/l	0.25	2.78	3.90	0.10	≤200 µg/l	Chronic Health	
Zinc	µg/l	28.70	11.00	52.00	1.56	≤5 000 µg/l	Aesthetic	
Uranium	µg/l	0.40	2.49	3.89	0.70	≤30 µg/l	Chronic Health	

Table 6: The surface water samples collected from the Nyl River and adjacent quarry in the vicinity of the proposed Volspruit Mine on 08/07/2011

In the case of sulphate, SANAS protocol determines that if a value is lower than 50 mg/l, the laboratory must report the value as <50 mg/l. This, however, poses a problem for us, as we require the actual sulphate values for some of our calculations. Our arrangement with the laboratory is therefore that they report the values on their



official report as <50 mg/l, but that they provide us with the actual values. These values are subsequently shown in brackets in **Table 6**.

Where any of the determinants in **Table 6** exceeded the SANS 241 Standard, this particular determinant is usually discussed individually, but as only three determinants exceeded the standard and all three of them at the same site (the farm dam), we will rather discuss the particular site hereunder.

2.2.1 Site 3 Farm Dam: Elevated Fe, Al, As, Cu, Ni and Zn

The iron, aluminium and arsenic concentrations exceeded the SANS 241:2015 standard. Iron only exceeded the “aesthetic” range, but both arsenic and aluminium fell beyond the “human health” range of the standard.

In addition to these three determinants, there were other determinants at this same site that were higher than would be expected when compared to the same determinants at the other sampling sites in the Nyl River. Among others these determinants were Copper, Nickel and Zinc. All these elements are associated with agricultural chemicals and we believe that the proximity of the dam from which the sample was collected to the large centre pivot irrigation systems near the dam is potentially the reason for finding these elements in these concentrations in the farm dam water. Under normal circumstances, they should not have been there in these concentrations. These elements are not present in these concentrations at the up- and downstream sampling points.

Photo 11 shows the proximity of agricultural activities to the farm dam in the Nyl River.



Photo 11: The proximity of agricultural activities to the farm dam in the Nyl River is probably responsible for the fact that several elements associated with agricultural chemicals, were elevated in the sample from this dam (*Photograph courtesy Southern Mapping, 2010*)

2.2.2 General discussion of the water quality

In general and ignoring the elements discussed above which were likely from an agricultural and not a natural origin, the water quality of the samples associated with the Nyl River were of an exceptionally good quality. The water complied with the SANS 241:2015 drinking water standards (chemically, we did not do the microbiological analyses) in all respects. This does not come as a surprise as water being filtered through a wetland is usually “polished” in a wetland. The Nyl River wetland happens to be the largest floodplain wetland in South Africa. So all three samples collected directly from the wetland were of an excellent quality (ignoring the anomalies in the farm dam).

The water from the quarry also complied 100% with SANS 241:2015, but had a high pH and alkalinity when compared to the other samples. It also had the highest conductivity/TDS of all the samples. We believe that this is due to the fact that the water from the quarry is a mixture of surface- and groundwater and that this water has been mineralised to a certain extent by the minerals associated with the geology into which the quarry was made. The water in the quarry is also subjected to evaporation and subsequent concentration of chemicals. In **Section 2.1.5**, we mentioned the calcrete deposits found in the quarry. This is possibly the cause for



the slightly elevated alkalinity and pH. Nevertheless, in general, all the samples were of an excellent quality.

2.3 A Comparison of Major Cations and Anions making use of a Piper Diagram

The Piper Diagram can be used to “fingerprint” a water source based on its equivalents (not concentrations) of the major cations and anions found in the water.

The character of the water sample collected from the Nyl River is illustrated by the Piper Diagram in **Figure 19**.

The Piper diagram, introduced by Arthur Piper in 1944, is one of the most commonly used techniques to interpret water chemistry data. Although originally intended as a tool for groundwater only, the Piper Diagram is just as useful in interpreting surface water quality, especially if mining activities have impacted upon the water quality in these streams. This method comprises of the plotting of cations and anions on adjacent tri-linear fields, with these points then being extrapolated to a central diamond field. Here the chemical character of water, in relation to its environment, can be observed and changes in the quality interpreted. The cation and anion plotting points are derived by computing the percentage equivalents per million for the main diagnostic cations of Ca^{2+} , Mg^{2+} and Na^+/K^+ , and anions Cl^- , SO_4^{2-} and $\text{CO}_3^{2-}/\text{HCO}_3^-$.

Different waters from different environments always plot in diagnostic areas or “hydrochemical facies”. The upper half of the diamond normally contains water of static and disordinate environments, while the middle area normally indicates an area of dissolution and mixing. The lower triangle of this diamond shape indicates an area of dynamic and co-ordinated environments. Sodium chloride brines normally plot on the right hand corner of the diamond shape while recently recharged water plots on the left-hand corner of the diamond plot. The top corner normally indicates water contaminated with gypsum (SO_4^{2-} mine impact).

In general the top half of the diamond contains static waters and other unusual waters high in Mg/Ca Cl_2 and Ca/Mg SO_4 . The lower half contains those waters normally found in a dynamic groundwater basin or surface stream environment.



Mixtures of any two waters in any proportion plot along a straight line joining their respective points in each of these diagrams. Water therefore being invaded by e.g. an industrial effluent will plot a vector towards the analysis of the invading fluid.

Water plotting in the upper half of both the cation and anion triangles would be referred to as magnesium sulphate-type water. Water plotting in the lower left hand side of the cation triangle and the lower right hand side of the anion triangle would be calcium chloride-type water. If both cation and anion compositions plot in the middle of the two triangles, then the waters would be referred to as mixed cation-mixed anion-types. If water plots near the middle of one of the edges of the triangles, then one might refer to, e.g., magnesium-calcium sulphate water.

If waters are the result of mixing of two different end member waters, then the compositions of these waters should plot along a straight line in each of the fields of the diagram. On the other hand, if the compositions do not plot along a straight line on the Piper diagram, then the waters cannot be related by simple mixing between two end members. If the waters do plot along a straight line, this is not necessarily definitive proof that mixing did occur, but it is strongly suggestive and other tests can be designed to prove mixing.

Unpolluted rainwater will plot in the left-hand corner of the central diamond field of the Piper Diagram. As this water flows over or through the substrate, it accumulates minerals from this substrate through which it flows and the point where it plots will move across the central diamond field of the Piper Diagram and, depending on which mineral/s act on it, will either move up or down the diagram.

On the other hand, when water flows through a wetland where ion exchange and adsorption occurs, in addition to the vegetation associated with the wetland removing some of the minerals from the water, samples could move across the Piper Diagram in an opposite direction as described in the above paragraph. This reverse movement is quite apparent in the Piper diagram from the Nyl River.

For ease of identification, we have annotated some of the general areas in the Piper Diagram in **Figure 19**.

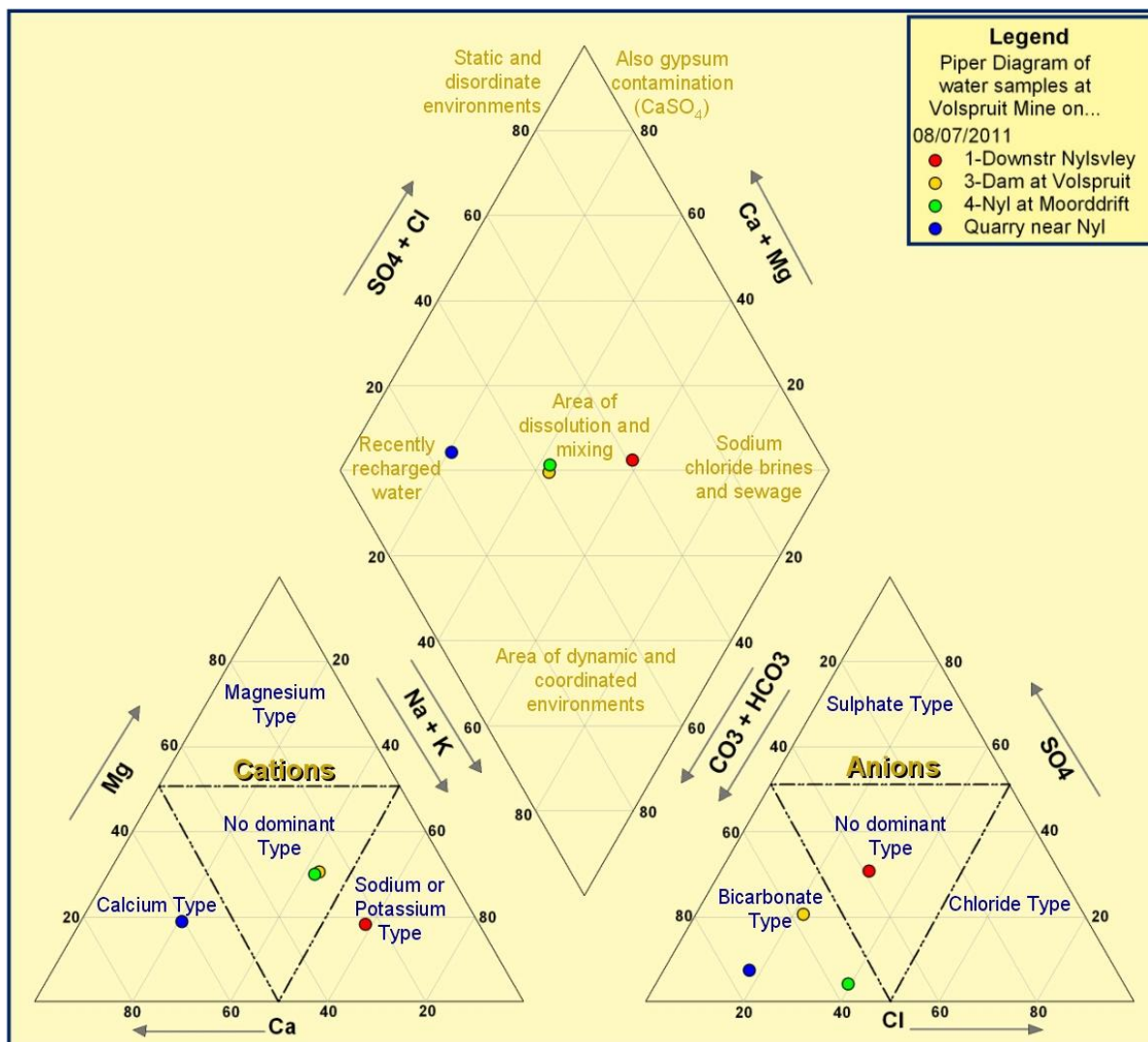


Figure 19: Piper Diagram of the water samples collected at the Nyl River on 08/07/2011

The Piper diagram shows the reverse trend of mineralisation discussed in the preceding section. Under normal circumstances, rain water with virtually no minerals in solution plots near the left-hand side of the Piper Diagram and then, as it becomes mineralised by the substrate over which it flows, it moves across the diagram towards the right-hand side, and depending on exactly which minerals are acting on it, would move up or down in the diagram.

The opposite, however, occurs in the Nyl River. Slightly mineralised water (with a potassium character) leaving the Nylsvley Nature Reserve (represented by the red dot) plots further towards the right of the diagram than the other two samples further downstream (orange dot of the farm dam and the green dot of the Moorddrif sample).



This improvement as the river progresses downstream demonstrates the excellent filtering properties of the Nyl River wetland.

Another justification for the reversal in direction of the movement of the points across the Piper Diagram could potentially be the impact from tributaries entering the Nyl River wetland between the sampling points. However, these samples were collected during the winter, months after the rain had fallen, i.e. during the phase of drying-up of the wetland, and it is unlikely that dilution could have played a part during this season.

It is more likely that the ability of a wetland to “filter” out minerals by ion exchange, adsorption onto clay and/or organic matter and through the uptake by plants, has resulted in the improvement of the water quality of the wetland.

In spite of a distance of about 9 Km between the farm dam and Moorddrif sampling sites, the two sites had virtually identical characteristics (the agriculturally-related metals found at the dam sampling site would not affect the location at which the sample would plot in the Piper Diagram).

The quarry sample, plotting even further to the left of the diagram, indicates that this sample is closer to rainwater than to groundwater, but the alkalinity and high pH could be responsible for the precipitation of some of the minerals or for preventing these minerals from going into solution in the first place.

3. Acid Mine Drainage (AMD) at Volspruit Mine

In South Africa, AMD production is mostly associated with gold and coal mining activities. Both these minerals are primarily mined in sedimentary rocks, with the large deposits of gold found in the sedimentary rocks of the Witwatersrand Supergroup, deposited under anaerobic conditions (before free oxygen occurred in the earth’s atmosphere), while coal was deposited under aerobic atmospheric conditions in the sedimentary rocks of the Karoo Supergroup.

When gold was deposited in the Witwatersrand rocks, there was no free oxygen in the atmosphere, and subsequently, the sulphur (a very common element on earth)



would exist in its reduced, sulphide form and even when on surface, oxidation would not occur. This means that large quantities of sulphide material were deposited in the rocks when the Witwatersrand Supergroup was formed.

On the other hand, when coal was deposited in the much younger Karoo Supergroup rocks, there was free oxygen in the earth's atmosphere. However, there was also life on earth and due to the deposition of coal occurring under swampy conditions, anaerobic biological decomposition of organic matter in these swamps reduced the organic sulphur to sulphides during the early coal-forming processes.

So for two totally opposite reasons, reduced sulphide minerals are associated with both gold and most of the coal deposits in South Africa. The exception is anthracite that was de-volatilised during extreme heat "treatment" when it was metamorphosed from bituminous coal to anthracite coal.

In both bituminous coal and gold deposits, the sulphide mineral is usually in the form iron pyrite.

The Bushveld Complex is not a sedimentary deposit, but rather of volcanic origin. As sulphur is an abundant element in the crust of the earth, it must be expected that there would also be sulphide minerals associated with volcanic intrusions, such as the Bushveld Complex. After all, the old English name for sulphur was "brimstone" referring to the sulphur found around the brims of volcanoes. It must therefore be expected that sulphur will be present in its reduced (sulphide) form in most volcanic rocks. In the case of the Bushveld complex in the vicinity of Volspruit, the sulphur is in the form of chalcopryite, a copper-iron sulphide mineral which looks similar to iron pyrites. However, sulphide in the form of chalcopryite is not as abundant in the igneous rocks of the Bushveld Complex as the iron pyrites associated with coal and gold deposits in South Africa.



Photo 12: Chalcopyrite together with quartz crystals (photograph Wikipedia, 2012)

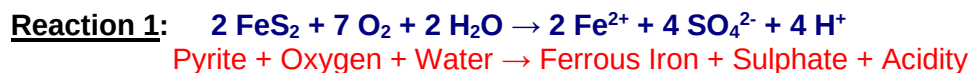
Pyrite, with a chemical formula of FeS_2 (iron disulphide) which, in its un-oxidised form, superficially resembles the colour and sheen of gold is often also referred to as “*fool’s gold*”, especially in the gold mining industry where it usually also occurs in abundance. As stated above, the sulphide in the igneous rocks are mostly present in the form of chalcopyrite, but essentially it looks, and chemically acts, the same as the “*fools gold*” found in the goldmines.

As long as pyrite and other sulphide-containing minerals remains buried deep underground within the rocks of the Bushveld Complex, the sulphur remains in a stable, reduced state. However, when it is exposed to oxygen in the presence of water, a series of chemical reactions may occur, which will ultimately give rise to the production of acidic water. During this process a particular group of bacteria, collectively referred to as the “*sulphur oxidising bacteria*” (SOBs), play a role in increasing the rate at which these chemical reactions take place.

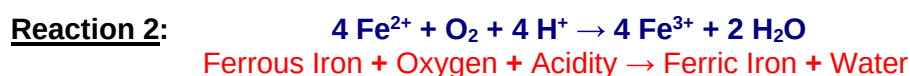
The chemical reactions shown below use iron pyrites as the mineral in which the sulphide is contained, but it could be any of the other sulphide minerals found in association with platinum mining. The valences of the sulphur element would remain the same in any form of pyrite.



There are four chemical reactions that characterise the chemistry of pyrite weathering to form AMD:



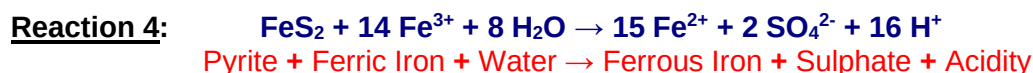
The first reaction in the weathering of pyrite consists of the oxidation of pyrite by oxygen. Sulphur is oxidised to sulphate and ferrous iron is released. This reaction generates two moles of acidity for each mole of pyrite oxidised.



The second reaction involves the conversion of ferrous iron to ferric iron. The conversion of ferrous iron to ferric iron consumes one mole of acidity. Certain aerobic bacteria (the SOB's) increase the rate of oxidation from ferrous to ferric iron. This reaction rate is pH dependent with the reaction proceeding slowly under acidic conditions (pH 2-3) with no bacteria present and several orders of magnitude faster at pH values near 5 and in the presence of bacteria. This reaction is referred to as the "**rate determining step**" in the overall acid-generating sequence.



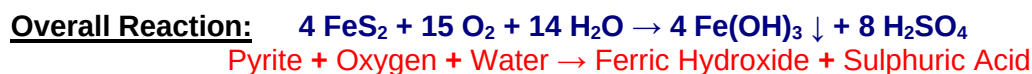
The third reaction that may occur is the hydrolysis of iron. Hydrolysis is a reaction, which splits the water molecule. Three moles of acidity are generated as a by-product for every mole of ferric iron consumed. Many metals are capable of undergoing hydrolysis, not just iron. The formation of ferric hydroxide precipitate (solid) is pH dependent. Solids form if the pH is above about 3.5 but below pH 3.5 little or no solids will precipitate.



The fourth reaction is the oxidation of additional pyrite by ferric iron. The ferric iron is generated by reactions 1 and 2. This is the **cyclic and self-propagating** part of the overall reaction and takes place very rapidly and continues until either the ferric iron or pyrite is depleted. Note that in this reaction, iron is the oxidising agent, not oxygen. **The reaction is therefore not reliant on the availability of oxygen in any form!**



All four of the above reactions can be summarised as follows:



Overall, one mole of pyrite creates 2 moles of sulphuric acid. Note that only reactions 1 and 2 require the presence of oxygen. The only factor governing the rate at which reactions 3 and 4 will occur is the pH (a low pH slows the reactions down or brings it to a halt, while a higher pH increases the reaction rate) and the availability of ferric iron.

During mining operations, ever-increasing underground rock surfaces containing pyrite and other sulphur-containing minerals are exposed to the effects of oxygen and water, setting the chemical reactions shown above into motion. Mining activities also introduces the SOBs that speed up the process. Additionally, the overburden, some of which also containing significant quantities of sulphide material will be broken and replaced loosely (not compacted to anywhere near the degree of compaction it used to be before mining) back in the mine pit. Oxygen and water, required to initialise the AMD process, will have free access to the sulphides and the AMD-producing process will initialise shortly after mining begins.

Once water becomes acidic, it will dissolve any other metal that may be present in the aquatic environment. AMD water therefore contains high concentrations of available dissolved metals, in addition to its acidic properties. As aluminium is the most abundant metal in the Earth's crust, this metal will be one of the first to show increasing concentrations when the AMD process begins.

As part of the groundwater study (*du Toit & Terblanche, 2022*), some geochemical modelling (not just acid-base accounting) was done on the rocks recovered from the two mine pits at Volspruit. A model was done to simulate what would occur in the two pits while mining is taking place and also what would occur in the waste rock dump, temporarily stored on surface before it is backfilled into the pits. A second series of models then predicted what would happen with the sulphur after closure of the mine.



The following paragraphs are excerpts from the groundwater model (du Toit & Terblanche, 2022) and summarise the potential of acid formation due to the sulphides in the rocks that will be mines or disturbed during mining and after mining.

Acid generation capacity of the rock

It was concluded that the ore is intermediate to potentially acid forming. However, the sulphides in the ore are mostly chalcopyrite and pentlandite, which are not reactive enough for long-term acid generation.

Leach Testing

Results confirm that very little leachable contaminants are to be expected. Sulphate specifically leached at concentrations ranging from below detection level to 20mg/L maximum.

Wetland assessment

It was proven by work conducted by GPT that the unsaturated zone underneath the river is filled from below, and not from the river. The deduction is that the clay layer in this area is indeed impermeable and that the flood needed to overtop the clay before infiltrating.

Potential contaminants from backfilled pits

Since the sulphides in the ore are of low concentration and consist mostly of chalcopyrite and pentlandite, which are not reactive enough for long-term acid generation, is very unlikely that the pit backfill material will produce acid rock drainage.

The above excerpts from the groundwater study geochemical modelling indicates that AMD will not be an issue during the life of the mine and neither will it become an issue after mine closure. This supports AED assumptions relating to AMD.

Water pumped from either of the two pits will subsequently always be usable for both drinking purposes or for that matter, any other agricultural application. It will thus not be necessary to treat the mine water to remove the sulphate at any time during mining or after closure of the mine.

4. Water Handling at Volspruit Mine

Table 7 shows the expected average volumes of water that would be collected off all the surfaces of the mine (as shown in **Table 1**) that will flow to the various PCDs. **Table 7** incorporates each of these surfaces areas, its run-off expressed as a fraction of the mean annual run-off for the quaternary catchment and calculated as an



expected volume that could potentially be collected by the PCDs on a month-to-month basis.

Month	Run-Off (m ³ /month)	Run-Off (m ³ /day)
Jan	150 085	4 841
Feb	129 761	4 634
Mar	101 620	3 278
Apr	39 085	1 303
May	15 634	504
Jun	21 887	730
Jul	4 690	151
Aug	4 690	151
Sep	4 690	156
Oct	57 845	1 866
Nov	173 536	5 785
Dec	145 395	4 690
Total:	848 919	28 090

Table 7: The expected average rainfall volumes that will flow to the PCDs off all the surfaces on a monthly and daily basis

It must be kept in mind that rainfall does not occur in averages, especially not in these semi-arid parts of South Africa. Nevertheless, these values provide an indication of the volumes of rainfall run-off that will be “harvested” by the PCDs off the mining surface. Furthermore, the months May to September often get no rain, therefore the values in **Table 7**, based on average rainfall figures is probably an overestimation.

The groundwater report (*du Toit & Terblanche, 2022*) estimates the average groundwater recharge into the mine during the period when the largest volumes would ingress into the mine pits at 4 MI/day (it varies between 3 000 m³/day and 4 000 m³/day). In other words, the volumes that could be expected to enter the PCD would be approximately 8 MI/day for the months of December, January, February and March, with about 9 MI/day for November. During the rest of the year, the volumes will be much lower and as stated above, it must be expected that almost no water would be harvested as rainwater during the months of May to September. The usage of water for mining is about 2 MI/day, leaving another 8 MI for other uses on and off the mine. TSF's PCD will have a volume of ~500 MI (**Table 4**, read in conjunction with **Table 3**), of which the first 200 MI must be reserved for the 50-year storm, should such a storm occur during the life of the mine. The balance (300 MI) is available for storage of normal rainwater and underground water. The evaporation in



this area is 2 100 mm/a (refer **Figure 17**). The surface area of the PCD is ~200 000 m² when it is full to capacity. We will use a surface of 130 000 m², as the dam will never to be full unless the 50-year storm occurs. It can thus be calculated that the dam will lose water as evaporation off its surface on average 273 000 m³/annum (i.e. 0.75 Ml/day). Therefore, during the peak of the mine's life, a volume of slightly more than 6 Ml/day will have to be disposed of either by discharge into the Nyl River, by irrigation, by recharge back into an adjacent aquifer through borehole recharge or by some other means. However, during a large part of the life of the mine, the amount of groundwater will be significantly less.

5. Drainage Density

Drainage density is the total length of all the streams and rivers in a drainage basin divided by the total area of the drainage basin. It is a measure of how well or how poorly stream channels drain a watershed. It is equal to the reciprocal of the constant of channel maintenance and equal to the reciprocal of two times the length of overland flow.

Drainage density depends upon both climate and physical characteristics of the drainage basin. Soil permeability (infiltration difficulty) and underlying rock type affect the run-off in a watershed; impermeable ground or exposed bedrock will lead to an increase in surface water run-off and therefore to more frequent streams. Rugged regions or those with high relief will also have a higher drainage density than other drainage basins if the other characteristics of the basin are the same.

Drainage density can affect the shape of a river's hydrograph during a rainstorm. Rivers that have a high drainage density will often have a more "flashy" hydrograph with a steep falling limb. High drainage densities can obviously also indicate a greater flood risk.

High drainage densities also mean a high bifurcation ratio (higher number of division nodes of a drainage basin "tree").

The Nyl River is a particularly strange river as, at least at and upstream from the proposed mine, it almost has no catchment along its southeastern bank, as the land



rapidly falls away from the river, not towards it. On the other hand, all the inflow into this part of the river occurs from the other side of the river.

The catchment of the Nyl River up to the Volspruit Mine is **2 233 Km²**. At the same time, the length of the river is **278.5 Km**.

The drainage density of this part of the Nyl River is subsequently **0.124 Km/Km²** (or **0.124 Km⁻¹**) (*Km watercourse/Km² of catchment*). Any drainage density lower than ~1 Km/Km² is considered to be low, subsequently, the Nyl River has a particularly low drainage density in this area and it is therefore unsurprising that deposition rather than erosion occurs in the Nyl River wetland.

6. The potential future impact of Human Activities on the Surface Hydrology of the Nyl River Wetland and on the Aquatic Environment

6.1 *Natural Impacts on the Nyl River and its Wetland in General*

The Nyl River is in many respects an unusual river. It not only boasts South Africa's largest floodplain wetland, but the mere fact that it is where it is today is also somewhat incidental to a geological event that started some 3.1 Billion years ago, the Thabazimbi-Murchison Lineament (TML) when two ancient Cratons collided. Effectively, a large block of the earth's crust was displaced upwards by several kilometres between the Melinda Fault running roughly west-east near the northern border of South Africa and the Zebediela Fault passing through the Nyl River wetland immediately to the south of the proposed Volspruit Mine. This fault has resulted in a crustal deformity, giving rise to a catchment basin forming which was subsequently in-filled with alluvial matter eroded off the Waterberg Mountain Range. This fault possibly also resulted in the Mogalakwena River capturing or "hijacking" a part of the Olifants River catchment (the Nyl River), adding it to the Limpopo catchment upstream from its confluence with the Olifants River in Mozambique. For part of its course along the Nyl River wetland, the river flows at right angles to the general fall of the land, i.e. it flows in the same general direction of the contour lines and not perpendicular to them, as would be expected. This is probably all due to the faulting that occurred in this area, originated by the TML.



Additionally, unlike most other in-filled river basins, the Nyl River's in-filled material is not kept in place by a solid rock formation (a "plug" in the river basin) but rather by "soft" material, i.e. relatively coarse alluvial material transported into the Nyl Basin by the three rivers entering it from the east at the end of the in-filled basin, north of the proposed mine in the vicinity of Mokopane (Potgietersrus). The continued existence of the in-filled river basin is held in balance by the rate of deposition of sediment by these three rivers being equal or slightly greater than the rate of erosion by the Nyl River at the outlet of the wetland.

On the other hand, if deposition at the outlet of the Nyl River by these three rivers **far** exceed the erosion rate in this area and deposition upstream occurring off the Waterberg continues to increase the elevation of the Nyl River wetland, the Nyl River may well in future "break through" its precariously limited eastern bank and start flowing downhill towards the east, i.e. towards the Olifants River across the Springbok Flats, probably joining up with the Grass Valley River, a tributary of the Olifants River.

The large evaporation surface area, provided by the Nyl River wetland and locating on the surface of the in-filled alluvial bed, presently serves to limit the outflow of the Nyl River to a rate ensuring that the deposition of sediment from the three eastern tributaries is in balance with the erosion rate of the Nyl River at the outlet of the wetland. Only about 30% of the water entering the Nyl River wetland leaves it at its outlet side. 70% is lost as evaporation and evapotranspiration.

Similarly, the very flat nature of the wetland ensures that only the finest sediment, eroded off the Waterberg, is transported all the way onto the central flat part of the wetland, the coarser sand, gravel and boulders being deposited along the edges of the wetland when the rivers fan out onto the floodplain. The sedimentation of this very fine material has created a layered clayey deposit in the central and largest part of the wetland, which limits surface-groundwater interaction to a very low rate, resulting in a separation of surface water on top of the wetland from the groundwater in the deeper, coarser material in the in-filled alluvial material underlying the wetland within the in-filled river basin. This, in turn, causes most of the water on the surface of the wetland to remain there and is eventually lost as evaporation, rather than flowing



via the alluvial aquifer below the wetland (where almost no evaporation or other water losses would occur) and out the other side. If this were to occur, greater volumes of water would reach the outlet of the wetland and considerably more erosion would take place, potentially tipping the balance in favour of the eventual loss of the wetland.

Due to the extensive geological faulting in this area, the water in the alluvial aquifer underlying the wetland is quite likely connected to many other aquifers surrounding it. However, the water flow rates in these aquifers seem to be in balance, giving support to our theory that the Nyl River alluvial basin is already decanting sub surface towards the east, i.e. towards the Springbok Flats, and that this leakage is partially responsible for the high availability of groundwater to the east of the Nyl River wetland. This effectively also removes excess water out of the system, ensuring that only limited water leaves the Nyl River wetland at its outlet, further ensuring that the rate of erosion by the water leaving the wetland is not excessive and that only limited erosion would occur in this reach of the river.

All these factors contributing to maintain the continued existence of the Nyl River wetland are presently in balance, albeit a delicate balance. Manmade changes to the environment could easily upset any of these balances. A simple example of this is alluvial sand mining. If excessive sand quarrying occurs near the outlet of the wetland, the groundwater balance could be upset and potentially larger volumes of groundwater could be released, causing increased erosion of the deposited material holding back the entire alluvial bed behind it. On the other hand, if quarrying or other excavations are carried out in the central part of the wetland, this could result in a breach of the aquitard formed by the silty deposits immediately below the vegetation layer in the wetland, draining water from the wetland into the groundwater aquifer. If quarrying or other excavations are allowed along the eastern side of the Nyl River wetland in the area where decant is most likely to occur, this could potentially speed up the rate at which the Olifants River would reclaim the Nyl River catchment.

There are many more examples of how manmade interferences with the alluvial deposit or wetland or further development within the catchment of the Nyl River wetland (more dams in the feed rivers, more water abstracted from the feed rivers,



etc.) could potentially impact on the wetland and the river. For example, we have no idea on how global warming and its associated climate change would impact on this wetland and the balances maintaining it. Similarly, construction of roads across the wetland, limited culverts under these roads, farming practices which has already encroached on many areas of the wetland, urbanisation, as can be seen on **Satellite Photo 1** and many more factors may tip the delicate balance of the wetland in either of the possible two directions.

Either way, there are potentially only two ultimate fates for the Nyl River and its wetland. Although it will probably remain in its present state for time to come in spite of the continued increase of man-made impacts on it, global warming or some of the other factors mentioned above could cause the flow of the Nyl River to increase and ultimately erode away the alluvial “plug” that maintains the in-filled alluvial river basin upstream from the three rivers entering it from the east. This will eventually result in most of the sediment being removed from the basin, creating a river flowing in a deep channel on bedrock. On the other hand, the continued deposition of sediment onto the surface of the Nyl River wetland could elevate the wetland to such an extent that it begins to decant to the east, towards the Olifants River, its historical direction of flow. It does not have to be elevated by much (a metre or two will probably be sufficient!) to initiate such a scenario! In this case, the sediment in the in-filled river basin would also eventually be removed and the flow direction of the Nyl River would be reversed in the section upstream from the breach up to about where the river passes over the Zebediela Fault. A new channel will form across the Springbok Flats, probably linking up with the Grass Valley River flowing into the Olifants River and the current tributaries (Andriesspruit, Tobiasspruit, Bad se Loop and the two upper Nyl tributaries, the Great and Little Nyl Rivers) will become tributaries of the Grass Valley River. The Nyl River and its associated wetland will ultimately cease to exist.

6.2 The Impact from the Volspruit Mine on the Surface Water Environment of the Nyl River

Although it was initially believed that there would be a direct interaction between the water on the surface of the Nyl River wetland and the groundwater in the alluvial aquifer immediately underlying the watercourse, this now appears not to be the case.



This study, as well as other studies conducted in the area, has shown that there is an all but impermeable layer of clay material on or near the surface of the Nyl River wetland. This material forms an aquitard that prevents surface water from recharging into the alluvial aquifer underlying the wetland. Once surface water reaches the wetland it remains there, on average only 30% of this water will leave the area as surface flow at the “outlet” of the wetland, while the bulk will be lost as evaporation and evapotranspiration off the surface of the wetland. The amount of water that would recharge into the alluvial aquifer underlying the wetland is negligible.

In addition to the above lack of interaction between the surface and groundwater of the Nyl River wetland, is the fact that initially it was believed that the Zebediela Fault and the many other faults that criss-crosses the area earmarked for mining at Volspruit would account for an enormous amount of water ingress into the mine pits. This belief has been disproved by other studies, in particular the groundwater study (*du Toit & Terblanche, 2022*). At the peak of mining it appears that a manageable volume of only 4 Ml of groundwater will be removed from the two mine pits daily. At the same time the water requirements (particularly at the plant) at Volspruit Mine during this same period will be approximately 2 Ml/day.

7. Conclusions and Impact and Risk Assessment

As far the surface hydrology is concerned, it appears at this stage that a mining operation in this particular area will not necessarily have any significant negative impact on the Nyl River wetland. Even the construction of a flood barrier discussed in **Section 1.7** would not have a negative impact on the floodwaters during a 50- or 100-year flood event. The damming effect caused by the N1 Bridge has already taken care of this (*Krige & Bond, 2010*).

Furthermore, the fact that the surface water on, and the groundwater below the wetland, is effectively isolated from each other by a very effective aquitard layer just below the surface of the flat part of the wetland, negates the fear that the abstraction of water from the aquifer intersected by the mine pit would drain the wetland surface. It appears as if these two water bodies act independently from each other.



7.1 Mining within the 50- or 100-year Flood Lines

GN704 legislates that no opencast or underground mine may be located within the 50-year flood line of a stream or river (or within a horizontal distance of 100 m from a river, whichever distance is the greatest). The Government Notice does not define whether the 100-m horizontal distance must be measured from the centreline of the river or from the edge of the river. It merely states, “*within a horizontal distance of 100 metres from any watercourse or estuary*”. In the case of narrow streams this does not matter, but in cases of a broad wetland, such as the Nyl River Wetland, it does.

It is clear that mining at the north pit will occur right into the wetland and the flood line study done in 2010 confirms that mining would indeed occur into the 100-, 50- and even the 10-year flood lines of the Nyl River. Permission will be obtained from DWS to proceed. Additionally a flood barrier was designed to protect the North Pit from the 100-year flood.

All other surface infrastructure is located outside the 100-year flood line.

7.2 Pollution Control during and after mining at Volspruit

It has been shown by the groundwater study (*du Toit & Terblanche, 2022*) that the amount of acid generation would be negligible, as sufficient buffer capacity exists in the surrounding groundwater to neutralise the relatively small amounts of acid that may be generated. The production of sulphate will hardly reach a concentration of 200 mg/l in the North Pit and only 150 mg/l in the South Pit during the mining operations. These values will decrease to below 60 mg/l once mining ceases and the pits are backfilled. Subsequently, neither sulphate nor the AMD normally associated with sulphates should pose a problem at this mine.

8. Impact Identification and Risk Assessment

8.1 Risk Identification

As shown in this surface water report, and substantiated by the groundwater report (*du Toit & Terblanche, 2022*), the potential for environmental water pollution from this



particular platinum mine is several orders of magnitude smaller than the pollution potential from mines operating at other ore bodies, such as the Witwatersrand gold fields.

It is unlikely that any AMD problems would be experienced at this mine. Likewise, the amount of sulphates produced from the mine pits and from rainwater percolating through the waste rock dump will also be relatively low.

The groundwater report and the samples collected by AED from the quarry shows that the geology underlying the mining area has high acid neutralising properties. The pH alone of the water from the quarry was 9.2. This is exceptionally high and is probably associated with the high calcium carbonate content in the ground.

The surface run-off in the vicinity of the proposed mine is insignificant in relation to the flow in the Nyl River and its associated wetland, possibly also its associated alluvial aquifer. Apart from very localised changes, it is expected that the mine will not have much effect on the hydrology of the Nyl River or its associated wetland.

Bearing in mind what is said in the above paragraphs, the potential risks from the Volspruit Mine, relating to surface water and hydrology, identified in this report, will be discussed in the section below:

8.1.1 Surface Hydrology

Interception of surface run-off to Nyl River:

Although some surface run-off will be intercepted by the proposed mine, in comparison to the catchment of the Nyl River, this volume will be negligible. The water intercepted by the mine will be used on-site for mining purposes.

Pollution control dams adequately sized:

The pollution control dams (PCDs) are adequately sized to contain surface run-off from all contaminated areas produced by a storm with a return period of 50 years, falling over the catchments of these dams. There will still be a significant volume of spare capacity left in the TSF return-water dam to be used for the storage of groundwater pumped from the two mine pits.



Surface infrastructure outside 100-year flood lines or 100m from stream:

In all cases, all surface infrastructure will locate outside the 100-year flood lines and also outside the 100-m buffer from the centreline of the river. The mine will subsequently be in full compliance with GN704 relative to flood lines in these areas.

However, the north pit will extend into the Nyl River wetland and also into the 100-, 50- and 10-year flood lines. Permission will be obtained from DWS to mine the ore body in this area. A flood barrier will be constructed to protect the mine from a 100-year flood event.

This flood barrier will narrow the 50- and 100-year floodplain of the Nyl River, but due to the backwater of the N1 road bridge, the flood barrier will **not** alter the 50- or 100-year flood line on the opposite side of the Nyl River.

8.1.2 Water Quality

Low pollution potential ore and waste rock that will be mined at Volspruit:

It has been shown that the ore that will be mined at Volspruit contains very little sulphides that could result in AMD production. The groundwater study (*du Toit & Terblanche, 2022*) has shown that the amount of sulphate production at this mine would never reach the aesthetic standard limit of SANS 241:2015.

Likewise, the geology as such in the vicinity of the mine has an alkaline character and in the event of acid production occurring, this acid will rapidly be neutralised by the geology.

Potential pollution from Volspruit Mine not directly into the Nyl River or its wetland:

The PCDs for the mine are adequate to intercept all surface run-off from the areas they serve under both normal circumstances and from storms with return periods of up to 50 years.

Even if an accidental spillage were to occur, it has been shown that AMD would not play as an important role at this mine as it would have at many other mines in South Africa. Accidental spillages from this particular area could more likely entail



hydrocarbons (oil grease or diesel fuel) released due to vehicle, or other types of accidents, or chemical reagent spillages.

High water quality of the Nyl River:

The water that was sampled in the Nyl River wetland at Volspruit was of an exceptionally high quality. The only area where contamination potentially from human activities was observed was at the proposed mine (the farm dam in the Nyl River), and this pollution is believed to be from farming origins.

Sewage disposal:

The sewage produced at Volspruit will be treated in a sewage treatment plant and the effluent will be discharged into the mine water circuit for re-use. Subsequently, no sewage effluent will be discharged into any natural surface water.

8.2 Impact Assessment

The following section will list the impacts identified in this study and assess the risks associated with these impacts:

- Consequence of occurrence in terms of:
 - Nature of the impact (negative / positive);
 - Extent of the impact, either local, regional, national or across international borders;
 - Duration of the impact, either short term (0-5 years), medium term (6-15 years) or long-term (the impact will cease after the operational life of the activity) or permanent, where mitigation measures by natural processes or human intervention will not occur;
 - Intensity of the impact, either being low, medium or high effect on the natural, cultural and social functions and processes.
- Probability of occurrence which describes the likelihood of the impact actually occurring and is indicated as:
 - Improbable, where the likelihood of the impact is very low;



- Probable, where there is a distinct possibility of the impact to occur;
- Highly probable, where it very likely that the impact will occur;
- Definite, where the impact will occur regardless any management measure.

In order to assess each of the factors for each impact the ranking scales below are used.

Magnitude (M)	Duration (D)
10 – Very high (or unknown)	5 – Permanent
8 – High	4 – Long-term (ceases at the end of operation)
6 – Moderate	3 – Medium-term (5-15 years)
4 – Low	2 – Short-term (0-5 years)
2 – Minor	1 – Immediate
Scale (S)	Probability (P)
5 – International	5 – Definite (or unknown)
4 – National	4 – High probability
3 – Regional	3 – Medium probability
2 – Local	2 – Low probability
1 – Site	1 – Improbable
0 – None	0 – None

$$\text{Significance} = (\text{magnitude} + \text{duration} + \text{scale}) \times \text{probability}$$

The maximum value of significance points (SP) is 100. Environmental impacts are rated as high (H), moderate (M), or low (L) significance on the following basis:

- More than 60 points indicates high (H) environmental significance (RED)
- 30 – 60 points indicate moderate (M) environmental significance (YELLOW)
- Less than 30 points indicates low (L) environmental significance (GREEN)

The surface water and hydrological impact assessment, shown as phases, construction, operational and closure, is shown in table form in the embedded table below:



Please double click on the above icon to open the table in MS Word format. The table uses a custom page size to fit the entire table and can therefore not be included directly in this document



9. References

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Appendix 1: Laboratory Analyses Certificates

DD Science Analytical Certificate



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