

# Open Pit Water Control Safety: A Case Of Nchanga Open Pit Mine, Zambia

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**Abstract:** Mining in Chingola, Zambia, started underground in 1931, and was catastrophically flooded and closed. The present Nchanga Underground Mine (NUG) started in 1937. The Nchanga Open Pit (NOP) mine started in 1955, situated to the west of NUG, and partially overlying it. Open pit water control safety operations in the Nchanga-Chingola area, have successfully enabled the safe extraction of millions of tonnes of copper ore annually over the past 60 years, from NUG mining as well as the NOP. At the start, Nchanga mining license surface already had NUG, and many watershed divides, with the Nchanga and Chingola streams being the main streams feeding into Zambia's second largest river, Kafue river, and 42% of the year was characterised by heavy rains ranging between 800mm to 1300mm per annum. In this paper, the presence of very significant amounts of seasonal rain and subsurface water in the mining area was identified as both a curse and a blessing. An excess in seasonal rain and subsurface water would disrupt both open pit and underground mining operations. In order for NOP to be operated successfully, stable and free from flooding, coping water management tactics were adopted from 1955 to 2015, including: 1. Underground mine pump chamber pumping system; 2. Piezometer instrumented boreholes; 3. Underground mine 1500-ft sub-haulage east borehole dewatering, beneath the open pit; 4. Nchanga and Chingola stream diversionary tunnel and open drains; 5. Nchanga stream causeway and embankment dam in the Matero School – Golf Club area; 6. Pit perimeter borehole pumping; 7. Outer and inner pit perimeter drains and bund walls; 8. In-pit ramp side drains; 9. In-pit sub-horizontal borehole geo-drains and water; and 10. Pit bottom sump pumps. Application of grout curtains along the Vistula River, Poland, was noted as a possibility in the right circumstances, although it had never been used at Nchanga Open Pit. An additional conclusion was that forward health, safety and environmental end-of-life planning was required for the extensive district-wide infrastructure of the open pit water control system, for public safety after life of mine.

**Index Terms:** Bund wall, Chingola, drain, mine, Nchanga, open pit, pumping, safety, sump, strata, stream diversion, water, Zambia

## 1 INTRODUCTION

The presence of water in and around mining areas is both a blessing and a curse. A blessing in that water is needed to:

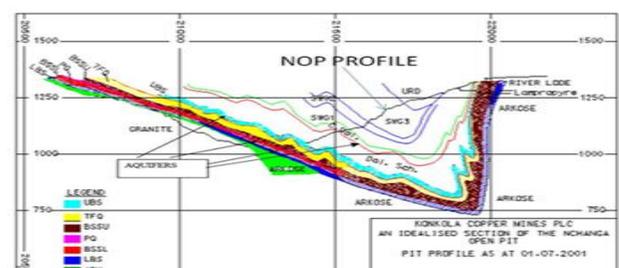
- Suppress dust, in accordance with mining regulations;
- Facilitate mineral processing operations, as plant water; and
- Operate mining machinery such as drills and water monitors.

On the other hand, water in the mining environment can be a curse in that open pit and underground mining operations are susceptible to flooding with injuries to personnel and loss of life, as well as property damage. On balance, uncontrolled water constrains mining production in open pits and underground mines. So everywhere where mining is contemplated or in progress, there must be a well structured plan to control water in the mining area in order to suppress the negative effects associated with it, while maximising the benefits. Historically in Zambia, the presence of water in the mining area has been at the root of many fatal accidents, including the Mufulira underground mine disaster of 1970 when 89 lives were lost (Chileshe, 1992) as well as the Nchanga Open Pit Disaster of 2001 (Silwamba and Chileshe, 2015), which resulted in the loss of ten lives.

### 1.1 NATURE OF THE WATER PROBLEM AT NCHANGA OPEN PIT

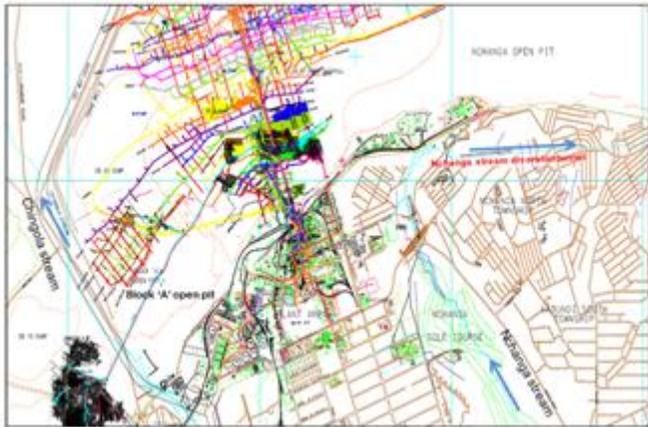
The Nchanga Open Pit (NOP) mine was preceded by the Nchanga Underground Mine (NUG) when open pit operations commenced in 1955. At that time, the mining area was traversed by a number of streams, the largest of which were the Nchanga and Chingola streams (Fig. 1). Sub-surface strata near the copper bearing orebodies included aquifers such as the Upper Roan Dolomites (URD), Chingola Dolomite and Banded Sandstones (BSS), as well as the Nchanga Main Fault Zone and the Lamprophyre Dyke (Fig. 2). NUG mine experienced start-up problems with flooding in 1931 which led to its closure and later re-opened in 1937, and has been in operation ever since, after mastering underground water management strategies. On commencement, NOP faced similar start up challenges to those of NUG in its early stages. In addition to water bearing strata, there were the added dimensions of streams, high seasonal rainfall and surface topography. NOP could not operate or grow successfully, due to the dangers of flooding, unless the seasonal rain water and sub surface strata water problems were resolved immediately or in phases across time. In achieving its water control objectives, NOP also had a duty to ensure it did not compromise the safety of the underlying NUG mine.

**Fig. 1:** Surface Plan showing the current NOP Outline, other open pit workings, underground workings, the Nchanga Stream Diversionary tunnel and Chingola Stream Diversionary Open Drain.



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**Fig. 2:** Dip geological section through the Nchanga Syncline and NOP showing aquifers



**Fig. 3:** Overburden dumps in the proximity of Nchanga Open Pit including a ramp inclining into the pit

## 1.2 OBJECTIVES OF THE PAPER

Identification of strategies adopted to avoid flooding at NOP from 1955 to the present:

- Discussion of the various open pit water control methodologies; and
- Analysis of the safety, health and environmental consequences associated with open pit water control systems at NOP.

## 2 SURFACE TOPOGRAPHY AND CATCHMENT

The Nchanga Mine area, in Chingola, Zambia, is situated on a savannah plateau surface topography comprised of numerous streams, including the Nchanga and Chingola streams, which are tributaries of the Kafue River. The area also experiences high seasonal rainfall ranging from 800 mm to 1300 mm annually. The rain season is from September of one year to April the following year. The sources of water which pose safety hazards to mining are, thus, two-fold:

- Direct rain fall into the open pits and runoff water from the surrounding areas during the rains; and
- Seepage of rain water into the strata, and the migration of such water through the strata of the Nchanga Syncline for several kilometres laterally and in depth, peaking from March to September.

This means that even though it may rain heavily for only five or six months in a year, the effect of the rain water movement in the strata is felt in open pit and underground workings throughout the year. Some of the strata are aquifers with very high water storage capacity and permeability. So boreholes and excavations with exposures of such strata continually discharge water. Artificial topography, created by open pit waste overburden dumping (Fig. 3) from 1955, is also part of the problem, as it has the effect of expanding the water catchment area beyond the pit rim's natural topographical catchment. Since 1955, numerous open pits have joined the NOP, in the vicinity, namely, River Lode, Luano, Block A and Chingola B. Water environments at additional open pits at Chingola C, D, E and F as well as Mimbula and Fitula are here considered too far from NOP to have a direct influence, but may possibly interact as the synclinal and anticlinal structures which interconnect them with NOP are not fully explored on strike and at depth.

## 3 BOREHOLE PIEZOMETER GROUNDWATER MONITORING SYSTEM

During the geological exploration stage it is important to establish the location of water tables and the local water balance, in the mining area. This allows for the subsequent establishment of a sentinel system to monitor the water tables in the region. From the exploration campaign, it is possible to plan and execute a hydrogeological programme which would among other activities, determine aquifers and aquicludes and the associated geo-structures, as well as the presence of water therein. Strategically placed boreholes are then drilled into aquifers and equipped with permanent piezometers or left empty and then piezometer measurements made periodically as required. The piezometer measurements are then used to construct water tables sections and their relationship with mining excavations for the life of mine. This ensures that the mine is constantly aware of the water table during the mine's operations. At NOP over the years this was standard practice and ensured that at all times mining operations were not flooded unexpectedly and most important facilitated slope design taking into account the presence of water in the slope.

## 4 UNDERGROUND DEWATERING OF NOP

The primary system of open pit dewatering at NOP is anchored on the existence of the underground mine below the open pit. NOP came 18 years after NUG mine had been in operation, and took advantage of the lowering of water tables by the underground mine. The underground mine was used to assure open pit dewatering by mining twin haulages under the open pit at 1500-ft level to the 26 East section position. In addition, geotechnical inclines were mined from 1500-ft level below the NOP at 10 East and 15 East to facilitate geotechnical exploration and, equally important, to host dewatering boreholes from NOP down into the underground mine. The whole of the NOP is directly above the underground 1500 twin haulages which leaves only just 700 m on strike, beyond underground dewatering site cover. Underground dewatering boreholes were drilled upward into the base of the NOP from drilling sites, spaced at 60 m to 120 m apart, on 1500-ft level. This assured that water tables in relevant aquifer strata were always below the NOP. However, in terms of strata

water, the problem remained of perched water tables in folded strata, such as in the north west corner, which continued to cause ground movements, requiring continuous pumping to mitigate.

## 5 PIT PERIMETER DRAINAGE

The outer pit perimeter drainage system is a series of ditches which may be connected all round the pit or simply separate drains at the pit perimeter which connect into the natural drainage around the pit such as lakes, streams and rivers, barring water coming from outside the pit perimeter from entering active pit areas (Fig. 4(a)). By topographical surveying, Google maps, Geographical Information Systems (GIS), the water catchment for the proposed life of mine pit can be identified and evaluated in terms of area and volume. It then becomes possible from the topography to identify the location of a suitable pit rim drainage system of ditches, lined or not. These ditches may be dug by excavators or doze-and-load or scraped and the material trucked away to fill out other areas to maximise drainage. The area protected by such a system may be quite extensive, over 5 million square metres at NOP by the late 1990s. The inner pit perimeter system, where necessary, will be very close to the pit rim, to act as a final drain to prevent divertable water from getting into the pit. It may indeed be simply a series of ditches to impound some water as close to surface as possible for local pumping into the nearest drain system for removal from the pit environment. Typically, inner pit perimeter drains cross past ramps into the pit through concrete culvert pipe bridges.

## 6 PIT PERIMETER STREAM DIVERSIONS

Stream diversions are often necessary to complement a pit perimeter drain system when a stream or river cuts across the future orebody or passes within a zone prescribed by mining law to be free of water bodies, 100 m from pit rim in the case of Zambia. The major stream diversion at NOP is the Nchanga Stream diversionary tunnel, of 5 m in diameter, mined in the late 1960s, to allow the NOP to expand eastward from 1970 (Fig. 5(a)).

The Nchanga stream was diverted from south of the NOP eastward for several kilometres under the Nchanga Mine Township, and rejoined the original path north east of the pit. This freed up the central and eastern parts of the present pit for mining from 1970 to the present. The other stream diversion is the Chingola Stream, which has been moved several times towards the west, initially to avoid NUG block caving subsidence areas, and then subsequently, to allow mining of Block A open pit, a neighbour to NOP on the western side (Fig. 5(b)). In order to assure security of both NOP and NUG, in case of catastrophic storm water, say a 100 – or 1000-year storm, an additional feature was the installation of an embankment dam with a causeway across the Nchanga stream in the Matero School/ Nchanga Golf Club Area (Fig. 6). Closure of this dam would allow weeks if not months of doomsday-type surge water storage allowing weather conditions to stabilise.

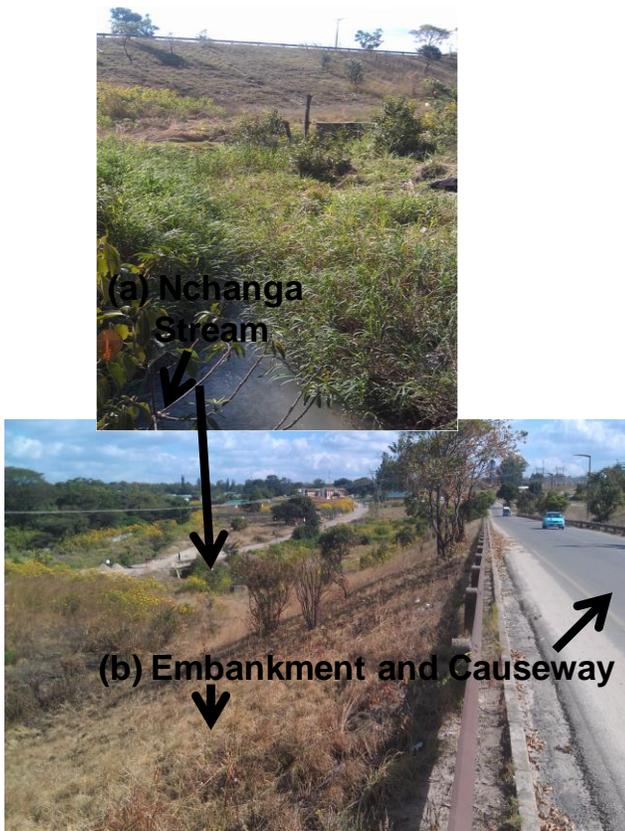


**Fig. 4:** (a) Pit perimeter drain at NOP (b) Ramp side drain at NOP

**Fig. 5: (a):** Portal of Nchanga Stream diversionary tunnel exit rejoining Nchanga Stream. **(b):** Lined open drain Chingola stream diversion next to Block A Open Pit (neighbour of NOP)

## 7 PIT PERIMETER BUND WALLS

Pit perimeter bund walls at NOP were built after open pit mining had been in progress for 40 years. Material in bund walls was a mixture of laterite and waste rock. Local environmental legislation changed, at the simplest, to prohibit the transportation of silt laden water from open pit mining operations into local streams, rivers and lakes. The term 'silt' at NOP means all solids entrained and transported in runoff. The biggest issue was how to catch runoff from waste dumps. Bund walls were built, of a few metres in height, around



**Fig. 6:** Surge water embankment dam and causeway across the Nchanga Stream in the Matero School-Golf Club area, Chingola, for doomsday conditions (opposite views left towards NOP in the north and right south towards the Nchanga Golf Club, Chingola)

The NOP and neighbouring Block A open pit to catch runoff from waste dumps, and to impound such silt laden waters for a sufficient residence time to allow de-siltation, by terminal settling. The water would then overflow through provided overflow pipes into the natural stream and rivers (Fig. 7).

## 8 PIT PERIMETER GROUT CURTAIN

The grout curtain system is not used at NOP, but has been used next to the Vistula River in Poland, Europe. The Vistula River is a major river and had to be prevented from flooding a copper open pit mine, adjacent to the river. This was achieved by drilling and grouting a series of vertical holes between the

river and the life of mine open pit boundary. This created a curtain of grouted rock, to act as an impermeable barrier against water infiltration from the Vistula River. When visited, the system was working well, and is worthy of consideration under the right geological and geotechnical environments.



**Fig. 7:** A section of perimeter bund wall with exit overflow pipes at NOP

## 9 SURFACE WASTE AND STOCKPILE DUMP DRAINAGE

The overburden dumps in the immediate vicinity of NOP contain billions of tonnes of material. The filling of the areas in the relief surroundings of the pit allows water which would otherwise have drained away from the pit area naturally to rise above the elevation of the pit. In terms of topography, the cambering on the surfaces of the dumps and the waste dumps channel rain water towards the pit through waste dump road drains and the roads themselves. Much of this water, though not all, is diverted away from the pit through pit perimeter drains (Fig. 3).

### 9.1 DUMP BUILDING AND DRAINAGE

Waste overburden dumps and long term low grade/refractory ore stockpiles have been built in either of three ways or a combination:

- Scraper dumping;
- Area dumping by truck; and
- End dumping by truck.

In early years, some bucket wheel excavation and conveying dumping was practiced, but this was phased out from the early 1960s, in preference for scrapers. While a dump or stockpile can be built with durable coarse material, which allows the dump to drain seepage rain water freely, this is not always possible for various geotechnical and geological reasons, like lack of the right materials. However, it is important to allow the dump some capacity to drain out safely, otherwise sufficient water may accumulate in the dump over the years to facilitate dump failure. One way is to area-dump a height of a few metres of coarse durable material such as granite or arkose or quartzite at or near the base, to allow the dump capacity to drain freely. This practice also facilitates long term abandonment of the dumps, without regular maintenance. This zone can then be over-dumped by less permeable materials. Notwithstanding the foregoing, the dump material must be

mixed by alternating materials with a view to achieve stability as the dump height increases. Impoundment or sealing of weaker materials by coarser materials is also another option. From recent observations of widespread interference with waste dumps by mineral scavengers, impoundment of weak materials should be done as a last resort.

### 10 IN PIT RAMP SIDE DRAINS

Ramps are designed and mined with drains to accommodate water inflow from above and seasonal rainfall (Fig. 4(b)). The drains are extremely important not only from the viewpoint of water control, but also to avoid runoff water from cascading over the open edge, possibly washing away the open edge and the ramp itself.

### 11 WATER MIGRATION THROUGH STRATA

A percentage, possibly as much as 15 to 20 percent, of the rainfall seeps into the ground, in and around the open pits. This water is transported hundreds of metres or kilometres on strike and dip, dependent on the permeability of the host Nchanga Syncline strata, whose axis plunges 7° towards the North West and westward. The strata in the Nchanga syncline alternates from aquifers to aquicludes, thus water trapped in the aquifers is able to move freely, without much percolation through neighbouring aquicludes. Water impounded in the sumps also infiltrates into the strata below, and continues westward, and often leaks into the neighbouring lower-lying NUG. The actual water transportation mechanism at Nchanga underground and open pit mines has not been established without doubt. What is certain from observation in the open pits and the underground mine, is that water is seen entering strata and sumps on surface and is then seen as excessive water inflow in block caving finger raises in parts of the underground mine (Chileshe, 1992). Observations underground indicate that excess inflow of water in finger raises in affected block caves peaks towards the end of the rainy season, around April, suggesting that transportation takes several months from the start of the rains on surface in late September through to April of the following year.

### 12 IN PIT GEO-DRAINS IN PIT GEO-DRAINS

Empirically, ponded water on surface disappears through evaporation and seepage. This water is then transported through aquifer strata, as discussed in preceding sections. After the NOP Disaster of April 2001, when 10 men were lost in a slope failure, one of the requirements to bring the mine back to safe operation was to reduce the amount of water available in strata which triggers slope failure. Over the years, most slope failures at NOP have been associated with excess water inflow. After the NOP Disaster, it was theorised that a major contributory factor was excessive water in the failed slope. Sub-horizontal geo-drains (Fig. 8(a)) into the southern slopes were identified as one way of permanently depressurising the southern slopes of the NOP central and east. The idea is to drill into aquifers deep in the slope, to allow water drainage.



**Fig. 8:** (a) Sub-horizontal borehole geo-drains at NOP with water coming out even after 14 years (b) Subsurface water coming out of the slopes at NOP (arrowed)

### 13 IN PIT WATER CURTAINS

During the processes of benching and ramping, aquifers are intersected and discharge water freely, as if a water curtain (Fig. 8(b)). This water is impounded and pumped out to surface directly. This reduces the risk that during downward transportation through roadside drains to deeper sumps, the water may well leak into the strata and be transported further underground.

### 14 PERIMETER UNDERGROUND PUMPING

Boreholes equipped with submersible borehole pumps were installed on the south slope after the 2001 NOP Disaster to depressurise the slope and allow the resumption of production. This method was also used for a long time in the North West corner of the NOP as well as at neighbouring Chingola Open Pit D&F (Fig. 9). Lowering of the water tables in various aquifers with this method does work, but needs to be given sufficient time ahead of production.



**Fig. 9:** Pumping from perimeter boreholes at NOP and COP D&F

## 15 IN PIT SUMP WATER

All water, which has not been trapped in ditches and pumped out, is impounded in two sumps at the bottoms of the western and eastern extremities of the NOP. Two methods are used to pump out water from pit bottom.

### 15.1 SUMP SURFACE PUMPING

Water accumulated in the pit bottom is pumped out from the sump at the Eastern Extension by pumps borne on barges. The water is then pumped through pipelines to surface where it is dumped in a drain (Fig. 10).

### 15.2 UNDERGROUND PUMPING

Water from pit bottom sump is mostly pumped into the underground workings (Fig. 11). The water is pumped from a barge floating on the sump water, then through pipelines which then lead to boreholes into the underground mine at 1500 10 East SH1, 2 and 3 as well as 1500 15 East SH 4, 5 and 6, shifting over the years.



**Fig. 10:** Water pumping to surface from a barge on an open pit sump

Through vertical boreholes, the water enters underground inclines through concrete plugs at 10 East and 15 East. The inclines go down to the 1500 Sub Haulage West, from where

the water is taken into the NUG dewatering and pumping system. The water is then pumped to surface from 2800 Pump Chamber. In years with heavy rains, the pumping has ranged from 40 000 to 60 000 m<sup>3</sup>/day.



**Fig. 11:** NOP western sump pumping, showing barge and pipelines for underground pumping

### 15.3 SUMPING ON BACKFILL

In-pit backfilling of the NOP western pit bottom which had reached 465 metre bench on the western side, earning the status of largest open pit in Africa and second in the world, began in 1992 and has progressed through the central areas to the eastern extension of the pit. This has meant that sumps sit on silt and backfill.

## 16 ENVIRONMENTAL AND HEALTH IMPLICATIONS

The water control system is vital in maintaining a healthy environment around Chingola, when it is functioning well by coursing water through the mining area and out into the natural environment which feeds the Kafue river. Apart from mine drainage, it also ensures the proper drainage of the townships located on the surrounding hills. In areas where the water is relatively stagnant, especially in the sump pools which form in the open pits during the rainy season, the main health issue is malarial mosquito breeding. In such cases, active programmes of mosquito larvicide spraying are essential. For the long term abandonment of the mining areas, forward planning is essential to ensure that the structures which are of such benefit to mankind in the present do not become the safety, health and environmental hazards of the future.

## 17 CONCLUSIONS

Open pit water control safety operations in the Nchanga-Chingola area have successfully enabled the extraction of millions of tonnes of copper ore over the past 60 years, from underground as well as the NOP. The system is complex and includes:

- Nchanga underground mine pumping system with primary responsibility to receive open pit sump water for pumping to surface;
- Nchanga underground mine 1500-ft sub-haulage east dewatering boreholes covering the whole pit, except for 700 m on strike at eastern extremity, for dewatering the zone below the pit, ahead of open pit mining.

- Nchanga and Chingola stream diversionary tunnel and open drains for diversion of surface river and rain water from the pit rim, this water in millions of cubic metres per day during the peak flow in the rainy season;
- Nchanga stream causeway and embankment dam in the Matero School – Golf Club area, capable of handling doomsday surge water storage for months to allow the stabilisation of the weather;
- Pit perimeter borehole pumping systems to prevent water from migrating into the pit from surrounding strata;
- Outer and inner pit perimeter drain and bund wall systems to prevent unnecessary surface water from breaching the Pit rim;
- In-pit ramp side drains to control water flow safety to the sumps without allowing roads to be washed away during severe rain storms;
- In-pit sub-horizontal borehole geo drains and water curtains to intercept water migrating through subsurface strata;
- Pit bottom sump pumps with capacity to pump pit catchment water to the underground through boreholes to 1500-ft sub haulage east as well as to surface;
- Forward planning is required for the extensive district-wide infrastructure of the water control system in preparation for long term abandonment of mine workings at Chingola, whenever that comes about.

## 18 ACKNOWLEDGEMENTS

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