Abstract
This paper reviews 2 field trips to the Waihi Goldmine (2007/9) and the application of water auditing techniques to assist with Waihi’s Environmental Water Management Strategy. In New Zealand’s high rainfall areas the legal and regulatory framework for water use in mining is structured differently to Australia’s water allocation rights to abstract water for mining operations. New Zealand’s Resource Management Act 1991 enables mining operations to abstract, treat and discharge water via the Act’s Resource Consents and Water Rights Bill. Therefore, the mining operation must obtain ‘Consents’ permission from local and regional authorities to manage their water stocks. Water monitoring and quality testing is carried out by Waihi Goldmine’s Environmental Department and local and regional testing authorities. The integration of both water quality testing and water quantity measurement is integral to complying with the RMA ’91 ‘Consent’ to discharge treated water from Waihi Goldmine’s water treatment plant and its newly commissioned reverse osmosis treatment plant. Apart from process water feed to all aspects of the mining operation this paper examines the non-process water flows and the management of the treatment of non-process water at a set discharge parameter both with quality and quantity under the RMA ’91 ‘Consent’ conditions. The findings contribute towards a water management strategy that assists with the site’s ongoing ability to deal with water treatment and discharge of an area in a high rainfall region.

1.0 INTRODUCTION

1.1 History
Gold was first discovered in the North Island at Kapanga Creek, Coromandel, NZ in 1852. 26 years later gold was discovered at Pukewa (Martha Hill), now the town of Waihi, located at the base of the Coromandel Peninsula. Then in 1894, The Waihi Gold Mining Company of London had the rights to mine gold at the Martha Hill Mine and at their battery and gold recovery plant, adopted and pioneered the cyanide process, where plant trials preceded the carbon/leach and elution processes currently in use at goldmines around the world. Buy 1952 the Martha Hill underground mine workings ceased and the Cornish Pump-house that dewatered the diggings to a depth of 600m was shut-down and groundwater returned to its pre-mining water level. In
the 1970’s increasing gold prices triggered a renewed interest in mining the remaining gold out of Martha Hill. Due to previous workings causing a degree of environmental degradation to natural resources of the Waihi region, environmental considerations in new planning and operations of prospective mining projects were established.

A series of water rights applications were submitted and were subject to a ‘Resource Consent’ limitation on the amount of water used in the operations and its quality on discharge. Further, by the early nineties New Zealand’s Mining Act 1971 was repealed through the enactment of the Resource Management Act (RMA) and the Crown Minerals Act and became the RMA 1991 changing the statutory framework although not extinguishing existing mining licences. The RMA ’91 sets out a series of amendments pertaining to mines using land, beds of lakes and rivers, the use of water and water quality on discharge or seepage from mining operations. Newmont, The Gold Company now owns and operates the Waihi Goldmine, to comply with water quality conditions set by NZ’s Resource Consents and Water Rights Bill, comprehensive routine monitoring is carried out. This includes groundwater quality and water table monitoring, measuring meteoric water, surface water flows, groundwater recharge, embankment stability and aquatic vegetative growth surveys in ongoing remediation work. Apart from Newmont’s environmental impact assessment on water usage, both District and Regional Councils carry out independent water monitoring.

1.2 Geology
The Coromadel Peninsular sits across the Hauraki Gulf from Auckland in New Zealand’s north island. Gold and silver were formed on the peninsular from Coromandel in the north to Waihi Town sitting at the base near the east coast. Intensive volcanic action over millions of years changed the landscape and rising geothermal vents caused massive geological upheaval. Transformation of the topography caused by a further 5 million years of weathering and erosion have also seen the exodus of the volcanic hotspot that is now located near Rotarua in the central plains. The years of weathering have exposed geothermal vents that formed complex lattice-works of quartz veins just below the surface. The Martha-Lode is the largest vein at 1.6 km long, 30 metres wide and running to a depth of 600 metres. Epithermal gold and silver were found to be embedded in not only quartz material but also pyrites
and feldspar contained within the lattice structures below the Martha Hill and more recently, the Favona Decline lease. The Favona Decline commenced operations in 2005 and currently 12 rock faces are being worked from over 2,350 metres of decline. Production stoping supplies the Waihi Gold Mill with over 800 m³ of gold ore per day. The decline is adjacent to the Waihi Plant and Favona ore has more gold per tonne and a higher ratio of gold to silver compared to Martha Pit ore.

Through volcanic action of the past, thick layers of mostly Ignimbrite and Andesite rock types are welded around the quartz veins. Heavy deposits of volcanic ash and breccia layer the upper geological formations. Other rock types include calcite, oxidised clays and tuffs that were formed at different depths or raised to the surface via geothermal vents. Mining out the quartz veins generates large quantities of waste rock that when conveyed from the mine, has to be classified in terms of whether it is potentially acid forming (PAF) or non-acid forming (NAF). Non-oxidised Andesite and volcanic Breccia are PAF materials that when mined out, are initially treated with a neutralising agents such as lime, prior to being deposited into the PAF stockpile. NAF waste rock, mainly oxidised Ignimbrite, reports to the tailings storage facility (TSF) embankments and road construction. Acid mine drainage (AMD) is a common problem that occurs at mine sites around the globe. In high rainfall areas such as the Coromandel Peninsular, unchecked rainfall runoff releases the sulphate acid potential from exposed non-oxidised rock. This quickly turns surrounding water catchment areas into high acid, extremely low Ph environments that are un-inhabitable.

1.3 Hydrology
TSF 2 at the Waihi Mine Site was decommissioned in 2001 due to reaching its maximum levy-bank height and limitation as per the Resource Consent and Water Rights Bill (RMA 1991). TSF 1A receives all mining process barren slurries and supernatant is decanted from TSF 2 and 1A either to the mill process water tank or to surrounding holding ponds. In high rainfall events it is necessary to balance the runoff inflow to offset the water level reaching maximum depths in the tailings dams. Prior to reusing the decant water return to the gold plant, it requires pre-treatment to remove metals including copper, complexed with cyanide in tailings gangue. Waihi Gold Mine’s main water source is from dewatering operations carried out in the Martha Pit and Favona Decline. This water represents inflow of groundwater and
rainfall runoff and is characterised by the presence of sulphates and metals, mainly iron and magnesium in solution. The quantitative aspects are that the Resource Consent and Water Rights Bill allow an annual daily maximum of 10,000 m³, to be dewatered.

The annual average rainfall at Waihi is a little over 2000 mm and this creates a net surplus of mine water over Newmont’s Waihi Goldmine’s leased area of operations. Due to the presence of highly mobile heavy metals, metalloids and acid producing sulphates in non-process mine water an extensive water treatment plant (WTP) has been established to deal with the potential for downstream pollution of ground and surface waters. To manage safe disposal of excess mine water and waste process water a pre-treatment of up to 5000 m³ of cyanided water is oxidised to destroy the cyanide content prior to further treatment. In the main water treatment process, 15,000 m³ of non-cyanided water has metals and trace ions removed using standard water treatment procedures. Water is then transferred to polishing ponds that ensure full compliance is met concerning Ph levels and allowable limits of metals and metalloids. The discharge points are the Ohinimuri River and Ruahorehore stream and there flow volumes are constantly monitored. The Resource Consent allows no more than a combined total of 20,000 m³ of treated wastewater to be discharged per day or the discharge of wastewater equal to the portion of 15% of the total river/stream volume at the time of discharge. Small weir spillways have been constructed to measure and monitor river flow rates near the two main wastewater discharge points.

2.0 Methodology
The Waihi Goldmine in New Zealand’s north island is a very large and complex site that includes an open cut pit, decline, tailings storage dams, waste rock stockpiles and processing plant. The Martha Pit and administration office are in the Waihi Township and all other mine facilities are located 12 kms towards Waihi Beach. The Ohinimuri River is the major water source for the area and winds around farming communities, valleys and by the Waihi Gold Mill outside of town. The Waihi Goldmine operation has a net surplus of water compared to Newmont’s Western Australian goldmines. Where most mines in WA source groundwater via bore-pumps and pit de-watering, Waihi reclaims water from mainly rainfall driven sources. Ideally, the water that Waihi receives is pure rainfall however, the runoff and collection in the Martha Pit
and other areas becomes contaminated. This requires some form of pre-treatment prior to its use in the gold recovery process or suitable quality for discharge into the Ohinimuri River.

The Favona Decline has recently produced high levels of metalloids in its gold ore and this has been hard to contain and remove from waste slurries and particularly water treated in the WWPT and discharged. Through a series of consultations with local community groups, Newmont has secured future high quality water discharge with the construction of a reverse osmosis (RO) plant. This case study will help to analyse the probabilistic water data supplied by plant metallurgists and engineers, to predict the impacts of non-process water on TSF 1A, the WTP and the new RO plant. Plant water data is a predicted off flow volumes and water levels projected to December, 2010. For the purposes of this study, non-process water flows will be analysed and where necessary, some process water flows will be incorporated and for example; TSF rainfall capture and TSF decant water to process water reserves. With the aid of a water flow diagram and conceptual water audit exercise, recommendations will be summarised to produce an outline of water efficiency and conservation measures.

3.0 Results

3.1 Water Quality and Non-Process Water Balance
Non-process water is derived from rainfall run-off, seepage, excess TSF/pond decant water and treated wastewater that is held in the final polishing ponds prior to discharge. Process water is used in all mine operations including water used for dust suppression on mine roads, conveyors and areas of soil disturbance. It is sourced mainly from pit and decline dewatering operations and treated according to fit for purpose use. Raw process water is used in the front end of gold recovery operations whereas, treated potable water reports to the elution process where the gold reaches the final recovery stage. Apart from process requirements for water suitability in the gold recovery operation the Resource Consents requirement for non-process water quality on discharge differ considerably. Compliance of set conditions relevant to water, sediment and biological monitoring are covered under discharge permit 971318 and land use permit 971319 and 971320 of the RMA 1991. The relevant limits are that treated wastewater discharges comply with specified targets on Ph, water temperatures, dissolved oxygen, Weak Acid Disassociated (WAD) Cyanide,
suspended solids, acid-soluble metals and metaloids. Normal compliance values are to be met 97% of the time over which the WTP has been discharging during a quarterly period.

![Waihi Goldmine Non-process Water Circuit (June 2007)](image)

**Figure 1. Waihi Goldmine Non-Process Water Circuit**

Figure 1 indicates that rainfall driven runoff accounts for over half of the non-process water balance during the high rainfall winter period, which is between the months of February to August. During the month of June 2007 the amount of seepage from the TSF’s indicates that the low seepage account for TSF 2 is due to the decreased hydraulic action of a well compacted and disused TSF bed compared to a far greater seepage loss through the more recently constructed bed of TSF 1A. In Fig. 1 the movement of water between TSF’s and the collection ponds accounts for the differences to water in and water out of the respective reservoirs. The mean average allowable discharge volumes per month is approximately 600,000 kL and as highlighted in Fig. 1, the discharge volume was slightly less than the maximum allowable limit giving rise to a fine balance of controlling and managing the non-process water flows to stay within the consented allowable discharge limit.
4.0 Conclusion

4.1 Water Management Strategy

Meteoric inflow and groundwater flows are self-sustaining in terms of providing make-up water to the Waihi Gold Mill for the duration of mine operations, discounting the need to draw water from the local river. Therefore, strategies are in place to manage Newmont’s Environmental Five Star Standards for specific mine and metallurgical processing. They include the provision of a site-wide water balance to make available effective monitoring of water flows based on establishing best practice towards operational goals in water management. The inclusion of key performance indicators to be put in place to define and measure progress towards mine water usage and management, then ultimately achieving environmentally sound mine closure. On
going monitoring programs help provide information towards this operational goal. The scope of the Environmental Five Star Standard underlines the need to proactively manage impacted water through the agency of a site-wide water balance and a site-wide planning tool. Some examples of a strategic approach include the evaluation of the WTP capacity to treat process and non-process water influxes. A probabilistic methodology is applied to normal operations leading to mine closure. It includes the risks and costs related to acid water collection, conveyance and treatment under normal and extreme events. The design and engineering of TSF’s at Waihi is such that excess non-process water directional flows are intercepted by lined holding ponds at downstream junction points at certain intervals from the TSF embankments. The strategy must also include the potential impacts of mine and metallurgical operations on downstream users and the downstream hydrological regime. Therefore, a probabilistic evaluation of regional watershed infiltration, base flow and interflow is simulated to assist with forecasting stormwater runoff, seepage volumes from tailings, pits/declines and undisturbed watersheds.

Site-wide water management planning assists with understanding and quantifying the mine’s hydrological environment. It analyses the potential impacts of uncertainty on complex interrelated water systems in which the mine and metallurgical process operates. It proactively determines the impacts of mining on water quality and quantity serving as a platform for continuous improvement towards successful environmental monitoring programs that require forecasts of capital and operational costs related to water management. An assessment model of a site-wide water balance is conceived to form a clear understanding of the system to be modelled. Building a conceptual model involves dividing the system into a series of linked sub-systems, defining the key components and their relationships, highlighting all relevant feedback mechanisms. Mitigation measures are built into design features of life of mine (LOM) plans and include optimisation of system to collect, convey and treat acid rock drainage ARD impacted water. Furthermore, the water management strategy could include a bioreactor process to treat ARD during the operation of the mine and continue to treat ARD in mine closure and onwards. New developments in this field are proving to be very effective in ARD control and treatment, not only with acid reducing bacteria within bioreactor columns producing fast turn around hydraulic
retention periods, but also with controlled engineered wetlands, specifically constructed to cope with high acid water influxes.

The proper management of non-process water diversion, collection and treatment is central to the effective control of environmental conditions over Waihi Goldmine’s leased area. Typically, sites with an effective water management strategy maintain a water balance model as an effective tool for informed risk based decision making. However, the effectiveness of this is complex when considering the definitions and processes of all parameters and can be summarised by the following points of discussion. Climate, surface water, groundwater, facility layout and material or geological characteristics are a combination of all the major elements. The combinations of these elements are assembled in such a way as to provide a practical and consistent format. The model recognises uncertainty and is probabilistic in nature taking into account the variability inherent in the prediction of various inputs to the model. Therefore, the model is simulated at time step frequencies appropriate for the location and maintained through inspections, monitoring and physical updates as a function of changes in mine plans or facility conditions. Continuous improvement of maintenance procedures support site operating procedures and a structured methodology monitors key performance indicators for ongoing full compliance of Waihi Goldmine’s ‘Consents’ permit. Water management strategies are most successful when using a structured methodology and the framework supports the full spectrum of mine planning and decision support activities.


