Innovative design and solutions for mine water management on an alluvial floodplain

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Abstract

The Curragh North coal mine is located on an alluvial floodplain of the Mackenzie River, in central Queensland, Australia. The catchment area at the mine site is 50,000 km^2 and the site had been inundated during previous floods. Until recently, development of the site had not proceeded due to flooding and water management risks and the difficulties involved in overcoming these risks.

PB's innovative design provided solutions to two problems which were deemed critical to the project's viability, namely a sustainable water supply for the mine and cost-effective flood protection. A holistic design approach was used to address the project's water supply and water management challenges:

- daily water balance modelling of the mine water management system to maximise on-site water harvesting;
- design of a two-way pipeline to enable exchange of water to and from an existing final void, reducing evaporative losses and on-site dam infrastructure requirements;
- creation of dams within reshaped spoil piles to maximise the water harvesting potential as the mine expands;
- design of controlled release points to allow spills to the Mackenzie River only when the river flows are between set limits.

Keywords: water management, harvesting, hydrologic modelling, mining.

1 Introduction

The Curragh North coal mine is located 200 km west of Rockhampton in central Queensland, Australia. Wesfarmers Limited won the right to develop the coal deposit and contracted PB to design the mine's civil infrastructure.

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The development concept for the mine is an open-cut mine producing up to 7 Mt/a of run-of-mine (ROM) coal over a 25-year mine life. The coal will be transported from the Curragh North Mine along a transportation corridor to the existing Curragh Mine for processing and rail load-out.

The mine site is located on an alluvial floodplain of the Mackenzie River where the catchment area is almost 50,000 km^2. The natural floodplain in the vicinity of the mine site is subject to relatively infrequent flooding during events in excess of the 1 in 10-year average recurrence interval (ARI) event.

The mine site is protected from flood ingress by a 22-km-long perimeter levee, designed to provide the dual functions of external flood protection and management/containment of internal site water. The topographic constraints, the mine layout and the dual function of the levee combine to effectively provide a water storage facility located within an area subject to flooding.

This paper describes the water management aspects of the project, including the design of the water harvesting system, which provides a reliable water supply, maximises the time when the pits are available and manages uncontrolled releases of contaminated mine water to the Mackenzie River.

2 Climate considerations

Water is a valuable, yet limited, resource throughout the region. Competing demands from industry, farming, communities and the environment have led to the preparation of governmental regulation in the form of water allocation schemes.

Allocation of water throughout the region must be in accordance with the water supply scheme for the Fitzroy Basin Water Resource Plan (WRP), the Fitzroy Basin Resource Operations Plan (ROP) and the Interim Resource Operations Licence for the Nogoa Mackenzie, all under the *Water Act 2000*.

Due to these regulations, users cannot simply extract water from rivers and streams in an uncontrolled manner. Limited availability of water allocations and the subsequent high costs makes sustainable water management critical to the success of mining projects throughout this region.

Rainfall in the project area is highly variable and typically unreliable. On average, almost half the annual rainfall falls during the summer months from December to February. Based on 100 years of historic data, the average annual rainfall for the mine site is 590 mm.

Temperatures in the area can range from 0°C to over 40°C, with the summer averages between 20°C and 31°C and the winter averages between 12°C and 26°C. Evaporation rates vary markedly throughout the year, depending on the season and the temperature. The average annual evaporation of 2,190 mm is almost four times the average annual rainfall.

3 Water management system philosophy

The philosophy behind the water management system (WMS) for the Curragh North Mine is to retain and re-use as much on site run-off as possible, inside the levee system. The WMS has been designed to:

- provide a reliable water supply for mining operations, for the entire 25-year mine life
- minimise the volume of run-off entering mine pits, thereby maximising pit availability for mining operations
- eliminate uncontrolled discharge and limit the frequency and volume of controlled discharge from the project to off-site receiving waters.

Local run-off within the levee system is directed to a series of water storage dams via overland flow paths and drains. These dams act as both sedimentation dams and as water supply dams. The water storage dams are located based on naturally occurring depressions within the mining area.

Four dams are located alongside the flood levee around the perimeter of the site. These dams collect site run-off and transfer water to a central dam via pipelines. The central dam is connected by a two-way pipeline to a final void at the existing Curragh Mine. The final void is used as a balancing storage, enabling excess water from Curragh North to be efficiently stored at Curragh and then brought back when needed.

Pit water is collected in pit floor sumps and subsequently pumped to the water storage dams for storage and site use. Controlled release points are provided at all water storage dams to ensure that excess water can be safely released to the river. Pit water is only released after it has been diluted in the water storage dams, enabling water quality target levels to be met in accordance with the Environmental Authority (EA) conditions.

4 Water management system layout

The water storage dams have been designed to satisfy the dual functions of meeting mine water demands and controlling contaminated run-off. The water storage dams comprise a lower level excavated sump storage component and a higher level overflow storage component.

The concept of providing sump storage and overflow storage for the dams was adopted to limit nuisance flooding, by storing run-off from minor events below the general ground level. Maximum excavated depths for the sump storages are typically 4 m. This concept also minimises losses to evaporation and seepage due to the reduced surface area of the excavated storage.

During major events, the sump storage will fill and water will spill out onto the overflow storage component. The overflow storage comprises the natural ground beyond the extent of the sump storage and the plan extent of the overflow storage is constrained by the flood levees, spoil dumps, pit protection bunds and the access road. Pit protection bunds provide protection to the pits and will be relocated as mining progresses. The overflow storage areas enable the retention of most of the on site run-off within the levee system by providing large storage volumes above the natural ground level.

The WMS includes five water storage dams. Four satellite dams are located around the perimeter of the mine site and are connected to a central dam via one-way pipelines. While most of the storage dams are excavated below the level of the natural floodplain, some storages are created by ponding against the flood levee and by ponding against highwall dams.

The central dam is connected by a 15 km long two-way pipeline to a final void at the neighbouring Curragh Mine. The final void is used as a balancing storage, enabling excess water from Curragh North to be stored at Curragh and retrieved when needed. The void's small surface area optimises on site water harvesting by minimising evaporative losses. Requirements for additional on-site water storage infrastructure is also reduced, allowing a smaller mine footprint.

After year five, it is proposed to shape the spoil dumps to provide additional internal drainage areas, which will allow surface run-off from the spoil dumps to be captured and stored in dams created within the spoil dumps. These spoil dams are designed to allow collected water to be harvested, transferred back to the water storage dams via pipes or chute drains and then reused on site. This transfer will be controlled with flow valves or stop logs to ensure that flow from the spoil ponds does not occur when the receiving water storage dam is full. Seepage from the spoil dams will pass through the spoil and will eventually end up in the pit sumps, from which it will be pumped to the water storage dams.

The spoil dams are designed as long, narrow storages cut into the batter of the spoil dumps, with balanced cut and fill earthworks. This shape will minimise the interference to spoil dump planning, while also allowing maximum use of the mine area within the levees. This has led to reductions in the mine footprint, the levee length and the construction costs.

A network of drainage channels direct site run-off to water storage dams thereby minimising on-site ponding. Highwall bunds are used to divert water to storages. After year five, spoil will be placed against the flood levee, enabling drainage channels to be formed in the spoil. As the spoil dumps rise in height, additional contour drains will be constructed in the batter face to allow the safe passage of run-off from the top of the spoil batter to the water storage dams

5 Water demands

Water demands for the Curragh North project are satisfied by a combination of clean water captured from site run-off over undisturbed catchment areas, dirty water captured from site run-off over disturbed catchment areas and supplemented clean water pumped from the Mackenzie River. Total water demands were determined by summing the component demands from dust suppression, vehicle wash down, potable use and construction requirements.

Water demands were calculated for six snap shots through the mine's 25-year life span. The maximum predicted water demand for the mine was calculated as 1,300 ML/a and this was expected to occur during years 2-5 of the mine's life.

6 Water sources

Rainfall falling within the perimeter levees is captured, stored and used within the site as the highest priority water supply. The balance of the water requirements is satisfied by a supplementary surface water allocation from the Mackenzie River.

An estimate of groundwater inflow to the pits from the Permian sequence indicated that the groundwater inflows to the pits would be between 100 ML/a and 300 ML/a, depending on the assumed radius of influence.

7 Daily water balance modelling

Daily water balance modelling was undertaken to assess the performance of the WMS. The modelling was used to predict the reliability of supply in satisfying the estimated water demands, to predict the pit availability and to predict the frequency and volume of releases from the WMS.

PB have developed an in-house software package called WAMAN (WAter MANagement), which performs daily water balance calculations and was written specifically for WMS analysis. The rainfall–run-off engine of WAMAN is identical to the well-known AWBM (Australian Water Balance Model).

WAMAN is capable of simulating the long-term behaviour of water management systems, which include complexities such as surface and underground water storages, variable water demands, external supply sources, variable pumping rates and flood harvesting. Model inputs include historic rainfalls, evaporation losses, seepage losses, water demands, supply sources, contributing catchment areas and volumes of on-site storages. Model outputs include catchment run-off, system yield and system spills.

8 WMS reliability

The WAMAN model was used to assess the reliability of the WMS. The reliability simulations conservatively used lower estimates of catchment yield, lower estimates of groundwater seepage and higher estimates of water demands. The model cycled through 75 climate simulations, with each simulation representing a different 25-year period of historic climate record, the starting year being incremented by one year for each simulation. If the WMS was unable to satisfy the total site water demand on any one day in the simulation, the model recorded a supply failure for that day.

For each 25-year simulation, the model then summed the total number of supply failure days and the system's reliability was calculated as the percentage of failure days over the whole simulation period. Statistical analysis was then used to identify the WMS reliability corresponding to the fifth percentile historic driest climatic period. The target reliability for this climatic period was 95%, as instructed by the mine management.

The WAMAN model was configured to ensure that water demands were prioritised. Demands were satisfied first with water captured from local site catchments, with any shortfall being supplemented by the Mackenzie River allocation. A sensitivity analysis was undertaken to determine the optimal volume of supplementary allocation needed to satisfy the target reliability. The results indicated that a supplementary allocation of 600 ML/a was required, which is just under half the total water demands for the mine site.

The time dependency of the supplementary allocation throughout the mine's life was assessed. This assessment endeavoured to identify trends associated with the frequency and volume of allocation required from the river and whether the volume could be reduced over time, as water was stored in the WMS. The results indicated that while the WMS does reduce the dependency on the allocation, the volume and frequency of supplementary water is dominated by the prevailing climatic conditions, with no clear trend being evident.

A sensitivity analysis was performed on the pumping rate from the central dam at Curragh North to the final void at Curragh. This assessment confirmed the benefits of using the final void as a large off site holding tank. Pump rates ranging between 0 and 1,000 L/s were modelled, with the return pump rate set to match the daily demand. As expected, the system reliability improved with increased pumping rate, with the optimal rate being approximately 200 L/s. A pump rate of 80 L/s was needed to satisfy the target reliability.

9 Controlled releases from the WMS

The combination of space limitations within the mine site, large historical storm events and long distance pumping considerations, meant that it was impractical to store all local runoff within the WMS. Instead, the WMS is designed to ensure that controlled releases are infrequent and will not cause environmental damage. Gated release points are provided at all dams to ensure excess water can be safely released to the river in a controlled manner. Release conditions were stipulated by the Queensland Government Environmental Protection Agency's Environmental Authority (EA) for the Curragh North project. These conditions describe the water contaminant levels that must not be exceeded in a release. The conditions further require that release must only occur while the Mackenzie River is in flood (to assist dilution).

The WAMAN model was used to assess the frequency and magnitude of WMS releases to the Mackenzie River. The release simulations conservatively used higher estimates of catchment yield, higher estimates of groundwater seepage and lower estimates of water demands. The model cycled through 75 climate simulations, with each simulation representing a different 25-year period of historic climate record, the starting year being incremented by one year for each simulation. A supplementary allocation of 600 ML/a from the Mackenzie River was assumed.

The total number of spill days and spill events from the water management system were counted for each simulation, with a spill event being defined as one or more days of consecutive spill. Statistical analysis was then used to identify the system spills occurring within the fifth percentile historic wettest climatic period. This climatic period was chosen to represent a conservative situation with respect to the potential volume and frequency of releases, as instructed by the mine management.

The layout of the WMS and the perimeter levee prevent releases during a major flood in the Mackenzie River, as external river levels will be higher than internal dam water levels. Attempted releases during a major flood would likely result in overtopping of the WMS dams and spillage into the pits, due to river ingress.

Combining the EA release conditions with the release limitations during major flood events, results in a small window of opportunity for controlled releases from the WMS, namely when there is a minor or moderate flood in the Mackenzie River, but not when there is no flow a major flood.

Control of WMS releases at times when river levels are lower than the EA threshold or higher than dam water levels, can be achieved by careful operation of the release structures. By monitoring weather forecasts and radar patterns, mine operators can be aware of expected weather patterns, both for the immediate local catchment area and for the regional Mackenzie River catchment. If forecasts show that a large storm is likely to pass over the mine site, then operators can expect local run-off to the WMS dams within a day. Conversely, if forecasts show that a large storm is likely to pass over the regional catchment, then operators can expect river levels to rise within the next three to four days.

10 Water quality

The potential pollutant sources from coal mining activities include coal processing, site maintenance, petroleum storage, acid mine drainage, saline pit water and saline groundwater inflows through the coal seam. Water quality in storage dams was predicted using information gathered from groundwater monitoring at the Curragh North and Curragh mine sites and from direct measurement of water quality in the Curragh mine existing storage dams.

For Curragh North, the poorest quality water will be derived from pit seepage from the coal seam and alluvial aquifers. The inflows to the water management system dams will be sourced from pit seepage, surface water run-off from contributing catchments and from direct rainfall on the dam surface. Saline pit water will be diluted by the freshwater in the storage dams. Settlement of suspended solids will occur in the water storage dams, prior to any controlled release of waters to the Mackenzie River.

The results of groundwater monitoring indicated that electrical conductivity (EC) measurements for all bores at Curragh North are less than the EA trigger level of 4,500 μS/cm, with the exception of one high EC value of 7,600 μS/cm, which was markedly higher than all other readings from surrounding bores.

At Curragh mine, the water storage dams predominantly receive pit water inflows and the EC readings match those from groundwater. The EC readings for Curragh North groundwater are considerably lower, due to the diluting effects of the nearby Mackenzie River. The EC measurements at both mine sites demonstrate that the groundwater quality provides a good indicator of the quality in the water management dams.

A mass balance model was constructed using a spreadsheet to track the accumulation of salt in the water storage dams at Curragh North over time. Inputs to the mass balance model were sourced from the WAMAN modelling, including daily catchment run-off volumes, pumping volumes, release volumes, evaporation/seepage volumes and dam volumes. A salt concentration was applied to each inflow stream and the model tracked the total mass of salt inflow to the dams on a daily basis. Salt was assumed to gradually accumulate in the dams over time, with the only reductions in salt content being due to WMS releases, pumping and dilution. Plots of the salt concentration were prepared to identify the salt concentration during those critical times during WMS releases.

As a worst-case scenario, the highest recorded EC of 7,600 μS/cm was assumed for inflows from disturbed spoil catchments, for inflows and transfers from the out-of-pit spoil dump and for pumping from open pits. An EC of zero was adopted for all natural catchments. The model results indicated that the ponded EC is expected to gradually increase throughout the mine life, as salt is captured in the dams. Towards the end of the mine life, the salt concentration is shown to approach 4,000 μS/cm, which is within the limits specified in the EA.

11 Pit availability

Pit availability is a significant issue affecting mining operations. Water ponding at the bottom of the pits can cause disruptions to mining because mining operations will be delayed while the water is pumped out. It is common practice to excavate a pit sump in the lowest level of the pit, enabling any water entering the pit to naturally drain to the sump, thereby keeping the pit floor relatively dry. The size of this pit sump is critical. If it is too small, then the pit floor will be inundated on a regular basis, resulting in disruptions to mining operations and poor pit availability. If the sump is too big, pit availability will be improved, but pit floor access will be limited, also resulting in disruptions to mining operations.

Pit availability is defined as the proportion of days that the pit sump was not overtopped over the mine's life. The target availability for this scenario was 98% in any one year for all pits, as specified by the mine management.

Pit availability was assessed using the WAMAN model of the WMS. The pit availability modelling was run for the historical period corresponding to the fifth percentile historic wettest climatic period. A supplementary allocation of 600 ML/a from the Mackenzie River was assumed. This climatic period was chosen to represent a conservative situation with respect to the pit availability.

The model results indicated that a 10 ML sump would provide pit availabilities ranging between 96.7% and 99.2% for all dams. Highwall pumping rates of 200 L/s were adopted for the water transfer out of the pit sumps to the adjacent water storage dams. The longest consecutive period that the pits would be expected to be unavailable ranged between three and six days.

Sensitivity testing was undertaken to optimise the sump volume and the highwall pumping rate. Sump sizes ranging between 10 ML to 40 ML were checked and the highwall pump rates were changed from 200 L/s to 100 L/s.

The results indicated that only nominal increases in pit availability would result from increased sump size, but the benefits were outweighed by disruptions to mining. The provision of high rate pumps for the high wall was recommended due to significant reductions in the longest period of pit unavailability (8 versus 28 days), increasing the time available for mining operations.

12 Conclusions

Water is a valuable, yet limited, resource throughout the region. Competing demands from industry, farming, communities and the environment have led to the preparation of governmental regulation in the form of water allocation schemes. Rainfall in the project area is highly variable and unreliable, with almost half of the annual rainfall occurring during the summer months. Average annual evaporation is nearly four times the average annual rainfall.

The philosophy behind the water management system (WMS) was to retain as much run-off as possible on site, thereby reducing the amount of additional allocation required to satisfy the mine’s water demands. Total water demands for the mine were determined by summing the component demands from dust suppression, vehicle wash down, potable use and construction requirements.

PB’s in-house daily water balance model (WAMAN) was used to assess the performance of the WMS of the Curragh North Mine, in satisfying the estimated water demands, in predicting the pit availability and in predicting the frequency and volume of system releases. WAMAN is capable of simulating the long-term behaviour of water management systems, which include complexities such as surface and underground water storages, variable water demands, external supply sources, variable pumping rates and flood harvesting.

The water management system comprises four satellite dams located alongside the flood levee around the mine perimeter. These dams collect site run-off and transfer water to a central dam via one-way pipelines. The central dam is connected by a two-way pipeline to a final void at the existing Curragh Mine, 15 kilometres away. The final void is used as a balancing storage, enabling excess water from Curragh North to be efficiently stored at Curragh and retrieved when needed. This concept optimises the water harvested on site by storing it in an existing deep and narrow void that minimises evaporative losses. In addition, storage of water off site reduces the need to provide additional on-site water storage infrastructure, thereby providing more area for other mining activities.

System reliability was assessed using a conservative worst-case dry climate situation combined with higher water demand estimates. The model results indicated that a supplementary allocation in the order of 600 ML/a was required to meet the target 95% reliability, as required by mine management.

Reshaping of the spoil dumps will provide additional internal drainage areas, allowing capture and storage of surface run-off. The spoil dams have been designed as long, narrow storages cut into the batter of the spoil dumps. This concept allows maximum use of the mine area within the levees, thereby minimising the mine footprint and the levee length and, consequently, reducing costs. The spoil dams will provide additional water harvesting capacity, while their storage volume will also attenuate peak flows during major storm events, resulting in reduced risk of system spills to the Mackenzie River.

Gated release structures were provided at the water storage dams to ensure that excess water can be safely released to the Mackenzie River in a controlled manner. The release criteria require that water can only be released from the mine site only when there is a minor or moderate flood in the Mackenzie River. This means that there is a small window of opportunity within which controlled releases are permitted to occur.

Water quality release limits were stipulated in the Environmental Authority (EA). Dam water quality was predicted using information gathered from groundwater measurements at the Curragh North and Curragh mine sites and from direct measurements of Curragh dam water. Mass balance modelling tracked the accumulation of salt in the storage dams and identified the concentration during those times when WMS releases would occur. The results indicated that the concentration will increase throughout the mine's life, as salt is captured in the dams. Towards the end of the mine's life, the concentration is predicted to approach 4,000 μS/cm, which is still below the EA discharge limit.

Pit availability is a significant issue affecting mining operations and is defined as the proportion of days that the pit sump is not overtopped. Water in the pit causes disruptions to mining operations while waiting for water removal. The target availability was 98% in any one year for all pits, as specified by mine management. The results showed only nominal increases in pit availability due to increased sump size. High rate pumps for the high wall were recommended due to significant reductions in the longest period of pit unavailability.

The project was awarded a high commendation in the Engineers Australia Queensland Engineering Excellence Awards 2006. The judges were 'impressed with the water management system designed to provide a reliable water supply for mining operations, to minimise run-off entering mining pits and controlling off-site discharges to meet Environmental Protection Agency requirements'.

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