

Deposition Planning at the Diavik Diamond Mine

John Cunning, Allison Isidoro

Golder Associates Ltd., Burnaby, B.C., Canada

Claudia Apaz

Golder Associates S.A., Santiago, Chile

Carla Kinakin

Diavik Diamond Mines Inc., Yellowknife, NT, Canada

Abstract

The Diavik Diamond Mine (Diavik), a joint venture of Rio Tinto and Harry Winston, is located on East Island in Lac de Gras in the subarctic climatic region of Canada's Northwest Territories and has been in operation since 2002. Following diamond extraction from the kimberlite ore, the remaining processed kimberlite materials are stored permanently in a Processed Kimberlite Containment (PKC) Facility. Deposition planning has been an integral part of the design and operation of the PKC Facility. Long term deposition planning has been used for scheduling future piping relocations, dam raising requirements, water management, and closure planning. Short and medium term deposition planning have been used as part of ongoing facility operations to achieve objectives such as maintaining a central pond with suitable depth for process water reclaim, beach management, and for commissioning new areas of the facility. Initially, deposition planning services were provided to Diavik by Golder Associates Ltd. (Golder); however, as the mine matured and gained years of operating experience, the ownership of deposition planning shifted to be undertaken by a Diavik employee with Golder providing training, guidance and review support. During recent planning and commissioning of new areas of the PKC Facility, the ability for in-house deposition planning allowed Diavik to quickly evaluate a number of alternative deposition strategies for these new areas and it allowed operators to react to requirements for short term changes in deposition in these new areas, which is typical when operating a facility in a cold subarctic climate. This paper discusses the process by which operational efficiency was gained at Diavik through a collaborative relationship between Diavik and Golder to train Diavik staff in deposition planning and transition Golder's role to provide training, guidance and review.

Site Description

The Diavik Diamond Mine is located on what is informally named "East Island", a 17 km² island in Lac de Gras, Northwest Territories (NT), approximately 300 km northeast of Yellowknife (64° 30' North, 110° 20' West). Figure 1 presents the location of the Diavik Diamond Mine. The Diavik Diamond Mine involves open pit and underground mining of three diamond-bearing kimberlite pipes, designated as A154 North, A154 South, and A418, which were all located off the shore of East Island, under the waters of Lac de Gras.

The mine site lies within the subarctic climatic region where daylight reaches a minimum of 4 hours per day in winter and a maximum of 20 hours in summer. The climate is extreme, with long, cold winters and very short, cool summers. Temperatures are cool, with an average temperature in July of 10°C and in January of -31°C. The mean annual air temperature at the site is approximately -10°C. The mine site is located in an area of continuous permafrost, with permafrost confirmed by thermistors to a depth of 380 m below the island.

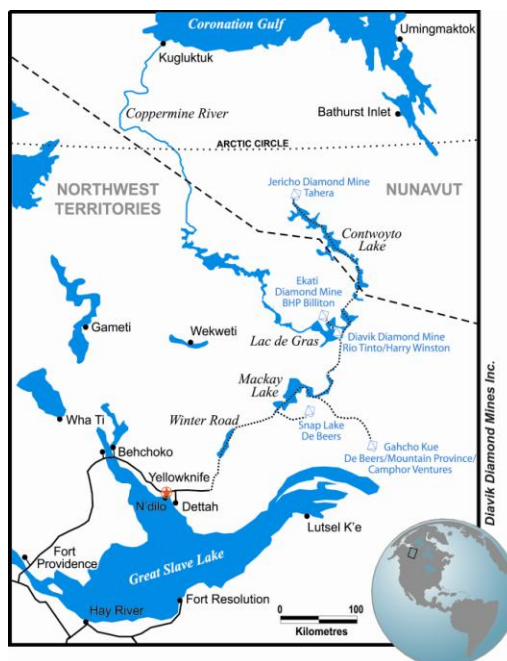


Figure 1: Diavik Diamond Mine Site Location Plan

The diamond extraction process at Diavik produces processed kimberlite (PK) by-products, which are stored in the processed kimberlite containment (PKC) Facility. At Diavik, the diamond recovery process results in coarse processed kimberlite (CPK) consisting of kimberlite particles with grain sizes between 5 mm slotted and 1 mm, and fine processed kimberlite (FPK) consisting of kimberlite particles with grain sizes less than 1 mm. The CPK is trucked from the process plant to the PKC Facility and the FPK is transported as a low-density slurry in a pipeline to the PKC Facility. The plant currently plans to process a total of approximately 2.0 Mt of PK each year, at an average daily rate of up to 6,300 tonnes per day. Stepped reductions in the production rate are planned for later years in the current life of mine plan. Since mining and diamond recovery began in late 2002, a total of approximately 17 million tonnes of PK have been deposited into the PKC Facility. The current facility has been constructed for PK storage of up to 26 million tonnes, and designs for future dam raises are being prepared to provide storage for the life of mine PK tonnage, which is between 40 and 43 million tonnes depending on the kimberlite pipes mined.

PKC Facility Description

The PKC Facility is located in a small valley running approximately east to west across East Island. The facility dams have been designed to provide containment and storage for the FPK and CPK products, and the reclaim water pond, within geomembrane-lined rockfill perimeter dams which are keyed into the frozen foundation (Cunning et al, 2008). Two starter dams, the East and West Dams, were constructed in 2002 to close the ends of the small valley running approximately east to west across East Island. The dams have been raised in stages and as the facility has risen, the North and South Dams have been constructed and raised in stages to complete the perimeter of the containment facility. Following four phases of dam raising since the starter dams were built, the facility now consists of a continuous perimeter dam which is about 5.5 km in length, as shown in Figure 2.

The original design of the PKC Facility involved storage of the FPK within the central portion of the facility (main cell) and storage of the CPK within cells located to the north and south of the main cell. Two internal rockfill dikes were constructed to support the FPK pipelines for perimeter deposition

around the main cell and to separate the fine and coarse PK. In 2007, operational data was reviewed and it indicated that a lower ratio of CPK to FPK was being produced compared to the original design assumption. In addition, CPK proved to be a useful construction material for liner bedding, cover and pipe benches. To facilitate the lower CPK volume, the design function of the South CPK cell was changed to provide storage for FPK and the North cell to provide a combined storage of CPK and FPK.

During operation, in addition to providing permanent storage for the PK products, the PKC Facility is used to temporarily manage water, and a year round reclaim pond is maintained in the PKC Facility. Water within the PKC Facility includes the excess process water from the FPK slurry transport and a large portion of the site wide run-off water from the numerous sediment management ponds constructed around the island. Run-off water from any disturbed area of the mine site is collected in these ponds and then pumped to the PKC Facility pond. A reclaim barge is located in the central PKC Facility pond and ongoing ore processing is carried out using as much reclaim water as is possible. Maximizing the use of reclaim requires detailed site wide water management planning and FPK deposition planning to ensure sufficient water quantity and quality are available at the reclaim barge.



Figure 2: Satellite View of PKC Facility

PKC Facility Deposition Planning

Deposition planning has been an integral part of the design and operation of the PKC Facility. Long term deposition planning has been used for scheduling future piping relocations, dam raising requirements, and water management. Short term deposition planning has been used as part of ongoing facility operations to achieve objectives such as maintaining a central pond with suitable depth for process water reclaim, beach management and for commissioning new areas of the facility.

Short term deposition plans have typically been updated following annual surveys of the PKC Facility deposit. Long term deposition plans have been carried out in association with various stages of life of mine planning and closure planning updates.

A key element to support the deposition planning is the annual survey of the facility deposit, which includes the FPK beaches above water and surfaces below water through a bathymetric survey. These surveys are an important step in defining inputs for the deposition modelling.

The annual survey provides a base surface for deposition modelling, is used to calculate and track the average *in situ* density of the deposit, and allows the pond volume to be measured for input to both the deposition and water balance planning. The annual surveys also allow the FPK beach and under water slopes to be measured as input for future deposition planning. Surveys of the facility are typically completed annually in August, when the pond is completely thawed.

The *in situ* tailings density is tracked using the annual survey surfaces and is calculated by dividing the total tailings production in tonnes by the total volume of tailings. The density can be calculated for the FPK deposited from one year to the next or for the total year to date tailings deposit. The volume of tailings is determined by comparing the annual survey surfaces from sequential years, or by comparing the most recent survey surface with the original facility surface. The *in situ* density of the tailings varies within the facility and is also affected by ice lenses within the tailings deposit. The coarser beach tailings typically have a higher *in situ* density compared to the fine grained slimes in the center of the facility. The *in situ* density calculated using the survey is an average value for the deposit.

The pond volume is calculated using the surveyed deposit surface and the current pond elevation. This pond volume is then compared to the values assumed in the deposition modelling and the input criteria for future deposition modelling are adjusted, as required.

Representative average FPK deposit slopes are determined for the modelling by cutting sections through the annual deposit survey at various locations. The slopes are reviewed and representative slopes are defined for input to the deposition modelling. Historically, two to three beach slopes have been observed in the deposited tailings. A steep slope of approximately 3 to 5 degrees near the spigot, a shallow slope of approximately 1 to 3 degrees along the rest of the above beach section and in some cases a steeper slope of approximately 2 to 4 degrees below the pond, as shown in Figure 3.

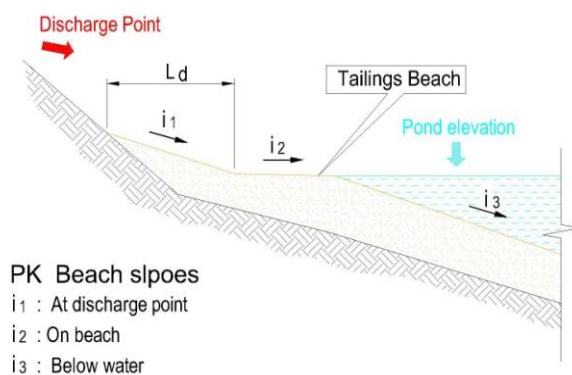


Figure 3: Beach Slope Schematic

Once the design criteria have been set using the bathymetric and beach survey data, deposition modeling is started.

Short term deposition plans have typically been completed annually to provide guidance for the operations crews to manage a central pond with sufficient depth and water quality, maintain suitable beaches adjacent to the retaining dams, and to confirm that a retreating deposition sequence can be completed through the winter. The site has extreme temperatures in the winter due to the subarctic

climate, which leads to a higher risk of freezing a pipeline. To mitigate this risk, Diavik flushes the lines with warm water when changing spigots or if there is a mill shut down, and plans the winter deposition sequence to retreat from further spigots to spigots closer to the mill. Therefore, if a portion of the inactive pipeline freezes, it does not affect the planned deposition. Short term plans have also been prepared to provide guidance for commissioning of new areas of the PKC Facility and to confirm pipeline relocation requirements that have previously been scheduled using long term planning. The short term deposition plan reports provide detailed sequenced deposition steps, which indicate the required length of deposition time from each spigot. A set of figures are prepared that match the steps in the table and present the modelled tailings surface, pond, and active spigot(s). An example set of staged deposition figures are shown in Figure 4.

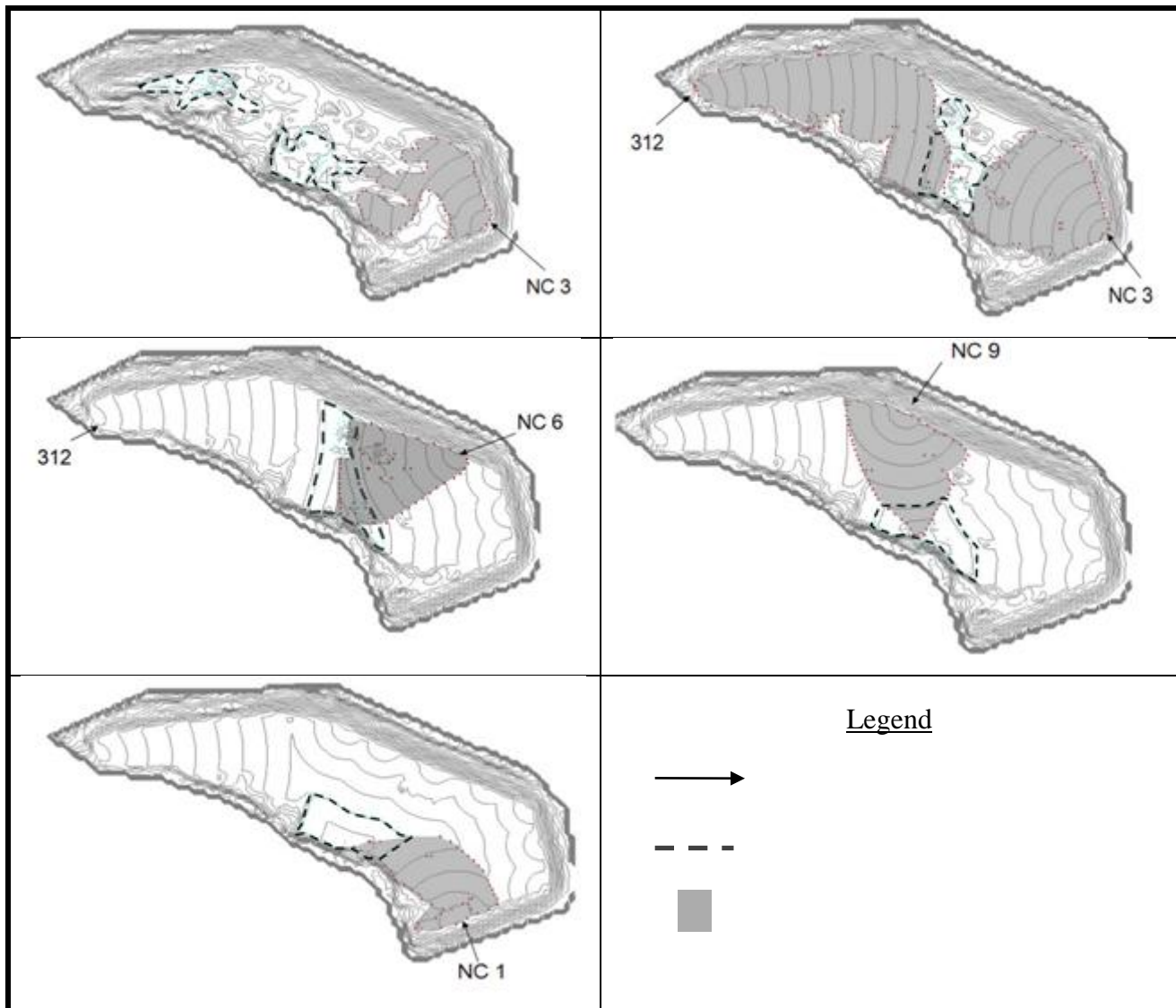


Figure 4: Example Deposition Plan Sequence Figures

Long term deposition plans are typically used to assess the required schedule for raising the containment dams, raising and/or relocating pipelines, and planning for closure. These usually contain less detail in the deposition sequence and are more focussed on the total storage available for a given set of spigot locations. Long term deposition plans are typically completed on an as-needed basis,

which is less frequent than the short term plans but when possible, the planning is conducted following an annual survey.

More recently, long term deposition plans have been used to support updated facility closure planning. The experience gained in short term deposition operations and planning is being utilized to direct long term deposition operations towards the preferred closure configurations. This can allow the facility to reach closure throughout operations rather than undertaking significant earthworks at the post-production stage.

PKC Facility Management Committee

The PKC Facility is a complex facility which involves stakeholders from a diverse group of departments at the Diavik Diamond Mine as well as consultants and contractors. Managing this facility, while balancing the interests of each stakeholder, involves a great deal of communication, co-operation, and planning. The PKC Management Committee was formed in November 2009, to provide a forum for collaborative planning of all stakeholders. Diavik created a new position called the PKC Specialist to be responsible for organizing, chairing and tracking action items derived from the PKC Committee meetings. Figure 5 presents the current department stakeholders in the PKC Management Committee Organization. There are many different stakeholders involved in the operation of the PKC Facility; therefore, communication between the stakeholders is imperative as decisions made by one group can have a significant impact on work being done by another group. Member involvement is diverse including personnel ranging from operators, to Superintendents to Vice Presidents.



Figure 5: PKC Management Committee Organization Chart

By conducting monthly meetings, each stakeholder has the opportunity to update the other PKC committee members with respect to the PKC Facility work they are conducting and upcoming issues can be raised. The PKC Management Committee provides an avenue for facilitating communication

between the stakeholders and pulling resources together to achieve the common goal of sustainable development at the PKC Facility.

To maintain dynamic and informative committee meetings, various subcommittees are regularly formed to investigate specific issues or projects in detail. These subcommittees then update the PKC Management Committee on their progress and of any required changes. By increasing each stakeholder's awareness and by bringing stakeholders together, members of the PKC Management Committee have been a key part of the success in the operation of this facility.

Deposition Modelling Training

In 2009, when the new PKC Specialist role was created, Diavik identified the opportunity to train the PKC Specialist to conduct deposition planning as part of their role. The ability to complete quick, in-house, deposition models was identified as a way to improve efficiency in the operation of the facility by providing the PKC Management Committee with timely information to make informed decisions in response to changes occurring within the PKC Facility. As a result, the PKC Specialist began training in deposition modelling with Golder Associates.

Training was started by having the PKC Specialist visit Golder's Burnaby office for a week of introductory training both in deposition planning and modelling. The training included an introduction to GoldTail, Golder Associates', proprietary tailings deposition modeling software.

After spending a few months learning the software, a second phase of training was initiated with staff from the Golder office in Chile who had previously lead the Diavik PKC Facility deposition planning work. It was identified that the training would be best conducted over a few months with six to eight hour sessions a week. Given the large geographical distance between the two offices, web conferencing tools were used to allow the PKC Specialist to share a desktop screen with the trainer in Chile and vice versa. This made it easy to learn and understand the step by step approach to deposition planning using the modelling software. The training started with an overview of the software functions using a base model of the PKC Facility. The next step in the training included re-creating historic deposition spigotting sequences to obtain an updated FPK surface, using the last annual survey as a base. The final stage involved modelling a short term deposition plan for future deposition in the facility. Since the training has been completed, Golder has continued to provide support to the PKC Specialist, as required, to assist with ongoing modelling and planning requests from the PKC Management Committee members.

Operational Variation from Deposition Plans

Short term deposition sequence plans provide a base plan for the PKC Facility operators to follow; however, there are several operational factors that can lead to changes to the deposition sequence. GoldTail provides the PKC Specialist with the ability to test and plan alternative deposition scenarios in response to the operational factors. At Diavik, key factors which lead to operational challenges and result in the requirement for changes to the short term deposition plan sequence are water management within the facility and winter weather conditions.

Water management accounts for the majority of operational variations from the short term plan. GoldTail provides a valuable tool to model the deposition sequence required to maintain a central PKC Facility pond which supports reclaim barge operation; however, it cannot predict the actual volume of water present at any given time. Historical review of pond conditions are used to trend and predict pond elevation and volume for input to the model. Operationally, daily monitoring is required to ensure that appropriate beach lengths and pond location are maintained. It is common that the

deposition sequence is changed in order to push the pond back from a dam to obtain an appropriate beach length.

Water management includes the quantity and quality of the water at the reclaim barge. The reclaim barge is used to draw water from the PKC Facility to run the process plant. In order to minimize the requirement for fresh make up water, the PKC Facility pond needs to be centered at the reclaim barge and have a sufficient depth to maintain water quality suitable for reclaim. The plant cannot run using water with a high amount of suspended solids. The closer the discharge spigot is to the reclaim barge, the higher potential it will have to increase the amount of suspended solids in the pond. If the amount of suspended solids gets too high, the discharge spigot has to be switched. It is not always easy to model the flow path that the slurry will take when deposited in the PKC Facility, especially during the winter when the pond is frozen and can redirect the flow of the slurry. This is another factor which cannot be modeled using GoldTail and therefore it is not possible to build in to the sequenced short term deposition plan.

The subarctic weather conditions at the site also provide challenges. During the winter months, extreme cold temperatures impede the ability to freely move from one spigot to another. This is due to the potential for spigots and pipelines to freeze when water is not flowing through them. Diavik has a procedure to flush the FPK lines with warm water when changing spigots or, if there is a mill shut down, to minimize the risk of freezing the pipelines; however, blockages due to sections of frozen pipeline can still occur. To minimize the risk of frozen pipelines affecting the deposition, the planned winter deposition sequence is to retreat from further spigots to spigots closer to the mill. Therefore, if a portion of the inactive pipeline freezes it does not affect the planned deposition. Deposition modelling can be used to plan this winter retreating deposition. However, if deposition needs to be moved earlier than planned due to a water management issue, such as suspended solids in the PKC Facility pond getting too high, modelling can be completed to predict if the FPK discharge volume available from the accessible spigots (the spigots between the active spigot and the mill) will be sufficient for the estimated FPK storage required for the remainder of the winter.

Diavik operations crews track the FPK discharge location on a daily basis and record when the deposition locations are changed. This information can be used to model historic deposition sequences using the last annual survey as a base, resulting in an accurate surface of the PKC Facility at any time. The modelled FPK surface provides a base for modelling to address the conditions described above. The results of the modelling provide Diavik with information to make decisions on how to manage the operational factors that are affecting the PKC Facility.

Conclusions

Deposition planning is an integral part of the design, operation, and closure of a tailings facility. Deposition planning at Diavik has been considered in each phase of the facility: dam design, dam construction, slurry deposition during operation, and closure. This case history has presented how the PKC Facility management and planning has evolved with the life of the operation. Improved efficiencies were realized with the forming of a PKC Committee and with training of the PKC Specialist to be able to carry out in-house deposition modelling for both short and long term deposition scenarios with the support and review from the consultant.

Initially, deposition planning for the operation of this facility was provided as an offsite consulting service. Following the owner creating a PKC Management Committee and identifying the position of a PKC Specialist for this facility, a suitable structure was in place to allow the consultant to train the owner to develop in-house deposition planning services. This has assisted all parties involved to quickly and efficiently respond to short term operational challenges. Updates to short term planning have been required, particularly for commissioning new areas and responding to changes in deposition due to the extreme subarctic environment.

The PKC Management Committee forum has also allowed the team to discuss operational experience for input to long term planning as the facility advances towards closure. The knowledge and experience gained from conducting deposition during operations can be used to support a preferred closure configuration that will not rely on significant earthworks to meet closure objectives at the post-closure stage.

References

Cunning, J., Eldridge, T., Isidoro, A., and Reinson, J., 2008. *Dam Construction at Diavik using Bituminous Geomembrane Liners*. Proceedings of the 61st Canadian Geotechnical Conference, GeoEdmonton'08, Edmonton, Alberta. September 21-24, 2008.