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The Technical and Research Committee on Reclamation

THE KETZA RIVER MINE TAILINGS IMPOUNDMENT OPERATION, DECOMMISSIONING AND ENVIRONMENTAL ISSUES

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ABSTRACT

Canamax Resources Inc. operate the Ketza River Mine, a small gold mine in the Yukon Territory some 180 km north-east of Whitehorse. The mine has until now processed oxide ore only, depositing tailings in an impoundment created by the construction of two dams, and the diversion of existing watercourses around the facility. Gold recovery is by cyanidation. The resulting tailings pond water has significant concentrations of cyanide, copper and arsenic. Pond water cyanide concentrations are controlled by seasonal natural degradation and tailings treatment to destroy cyanide using the Inco SO_2 - air process prior to discharge to the impoundment. Pond water is also treated to destroy cyanide using the Inco process, followed by discharge to the environment during a 6 month period per annum covering the duration of higher surface water run-offs. Seepage from the impoundment is collected and returned by strategically located sump and pump-back systems.

Steffen, Robertson and Kirsten (B.C.) Inc. (SRK) was engaged by Canamax to investigate seepage from the tailings impoundment, and was subsequently retained to assist with operating and decommissioning issues related to the tailings impoundment and a proposal to mine and mill sulphide ores, pending regulatory approval. The proposed milling of sulphide ores raised a number of environmental issues regarding the tailings impoundment. Operating conditions could potentially yield higher contaminant concentrations in the tailings pond, which could have a concomitant effect on concentrations in seepage and water treatment plant effluent discharge. Further, decommissioning plans were needed to address the disposal and long-term storage of potentially acid generating tailings.

This paper summarizes the investigations undertaken and predictions made in terms of the proposed milling of sulphide ores, the tailings impoundment and the receiving aquatic environment at the Ketza River Mine. The "sulphide" project at Ketza is considered an example of the sustainable development of a relatively small operation despite potentially adverse environmental circumstances, with development assisted by the assessment of specific environmental issues and the adoption of appropriate mitigative solutions.

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Le site de dépôt à résidus de la mine Ketza River dans un contexte de fermeture de mine et de questions environnementales

par

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et

Canamax Resources

Canamax Resources exploite la mine de Ketza River. Il s'agit d'une petite mine d'or située sur le territoire du Yukon, à quelque 180 km au nord-ouest de Whitehorse. Jusqu'à ce jour, la mine ne traitait que du minerai oxydé et déposait les résidus sur un site de dépôt, créé par la construction de deux barrages et le détournement de cours d'eaux situés autour des installations. L'or y est récupéré par cyanidation. L'eau qui résulte du procédé possède donc des concentrations élevées en cyanures, cuivre et arsenic. Les concentrations en cyanures de l'eau de l'étang sont contrôlées par un traitement des résidus qui vise à détruire les cyanures, à l'aide du procédé Inco SiO_2-air, avant leur déversement dans le site de dépôt. Les eaux de l'étang sont également traitées par le procédé Inco puis déversées dans l'environnement sur une période de six mois par année, représentant la durée de l'écoulement de surface de ces eaux. L'écoulement du site est contrôlé et puis retourné vers le site de dépôt à l'aide de pompes et de réservoirs situés à des endroits stratégiques.

Steffen, Robertson and Kirsten (C.-B.) Inc. (SRK) a été mandaté par Canamax pour étudier l'écoulement du site de dépôt à résidus dans le but de définir les mesures correctives requises. Les services de SRK ont ensuite été retenus d'une part pour examiner les problèmes reliés à la fermeture, ainsi qu'à l'exploitation de la mine et de son site de dépôt, et d'autre part, pour étudier une proposition portant sur les minerais sulfurés de la mine et du concasseur, dans l'attente d'une autorisation réglementaire.

Le concassage proposé des minerais sulfurés a soulevé de nombreuses questions environnementales concernant le dépôt des résidus. Les travaux d'exploitation peuvent potentiellement augmenter les concentrations de contaminants à l'étang de décharge, ce qui pourrait avoir un effet concomitant sur les concentrations présentes dans les eaux d'écoulement et de l'effluent final. En plus, des plans de fermeture étaient requis pour planifier l'enlèvement et l'entreposage à long terme de résidus potentiellement capables de produire de l'acide.

Cette communication résume les études effectuées et les prévisions proposées, en terme de concassage des minerais sulfurés, au site de dépôt et à l'environnement aquatique destiné à recevoir l'affluent de la mine de Ketza River. Le projet des "sulfures" de la Ketza River représente un exemple du développement soutenable d'une exploitation relativement petite, malgré le potentiel de conséquences nuisibles pour l'environnement. En effet, le développement est associé à l'évaluation de questions environnementales spécifiques et à l'adoption des solutions correctives requises.

INTRODUCTION

Canamax Resources Inc. operate the Ketza River Mine, a small gold mine in the Yukon Territory some 180 km north-east of Wnitehorse (see Figure 1). The mine has until now processed oxide ore only, depositing tailings in an impoundment created by the construction of two dams, and the diversion of existing watercourses around the facility. Up to December 1989, 201,403 tonnes of oxide tailings solids have been deposited in the impoundment, an average disposal rate of 305 tonnes/day, although a rate of 370 tonnes/day was reached. Oxide ore reserves were exhausted in October, 1990. Mine operations have been temporarily suspended pending water license amendment to process sulphide ores, and favourable economic conditions.

Gold recovery at Ketza is by cyanidation. The resulting tailings pond water has significant concentrations of cyanide, copper and arsenic. Pond water cyanide concentrations are controlled by tailings treatment to destroy cyanide using the Inco SO_2 - air process prior to tailings discharge to the impoundment. Pond water is also treated to destroy cyanide using the Inco process, followed by discharge to the environment during a 6 month period per annum covering the duration of higher surface water run-offs. Seepage from the impoundment is collected and returned by strategically located sump and pump-back systems.

The mine is located in the Pelly Mountains at an elevation of 1500 metres, and is situated at the headwaters of Cache Creek, an easterly flowing tributary of the upper Ketza River. This river hi turn flows into the Pelly River roughly 12 km south of Ross River.

Mine development began in 1987, and included the construction of the North and South Dams to enable the impoundment of mine tailings in a basin formed by the junction of Cache and Subsidiary Creeks (see Figure 2). The creeks were diverted south around the impoundment area, and an interceptor ditch catches runoff from the north.

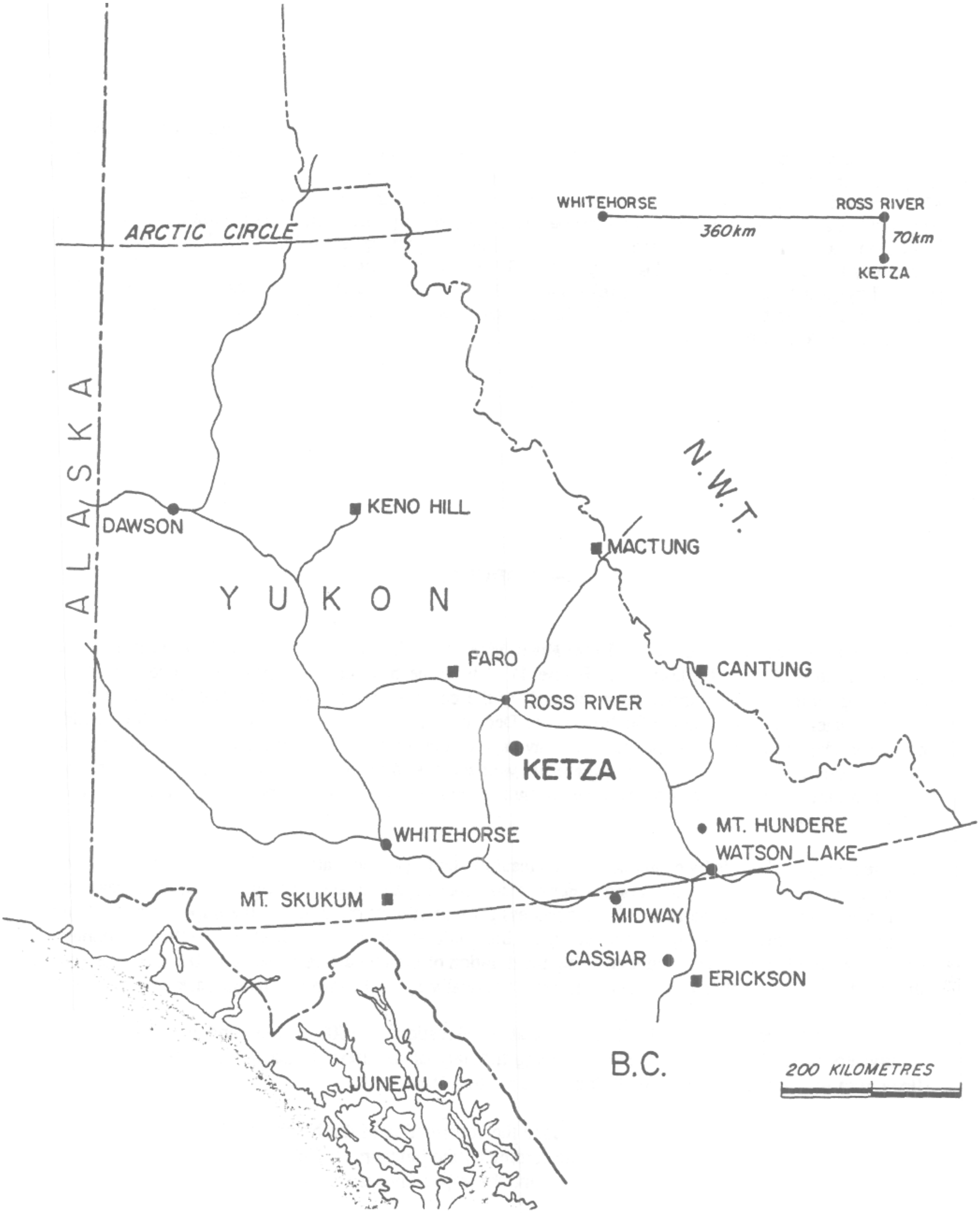
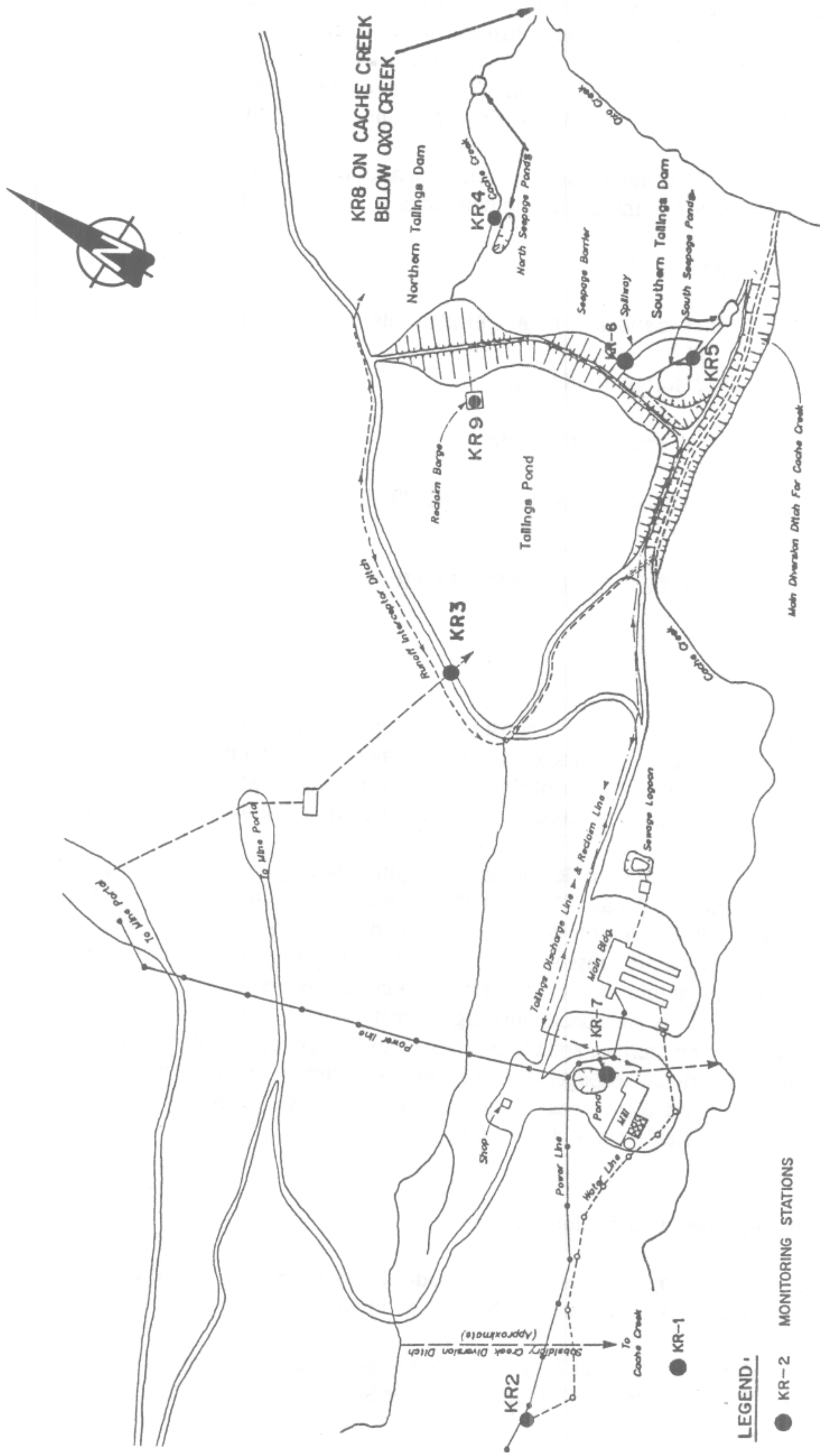


FIGURE 1 LOCATION OF KETZA RIVER MINE



NOT TO SCALE

FIGURE 2 LOCATION OF MINE FACILITIES AND MONITORING STATIONS

Tailings disposal commenced in March 1988. In late 1988/early 1989, increasing contaminant levels in seepage downstream of the dams necessitated the construction of collection and pump-back systems. Uncontaminated run-off and seepage was also being captured such that the volume returned was approximately double the loss, and contributed to a positive pond water balance. With the increasing pond water-level, the water treatment plant was expanded to allow a greater throughput

To assist their application for a permit amendment to mill sulphide ores, Canamax engaged SRK to investigate water quality issues related to the tailings impoundment. Issues investigated were:

- seepage from the impoundment;
- the impact of ammonia concentrations in treatment plant discharge on aquatic resources;
- receiving water quality after decommissioning;
- the storage of potentially acid generating tailings.

A summary of the investigations conducted and solutions adopted is given below.

SITE CHARACTERIZATION

Tailings Impoundment Hydrogeology

Tailings impoundment site selection, design and construction supervision was undertaken by Colder Associates. A thin glacial soil cover over bedrock in the impoundment basin had been defined. The soils were characterized as till-like below a thin cover of drift. Dams were constructed with clay cores keyed into the till soils. The dams are joined via a seepage barrier inserted in a "knoll" of in situ soil.

A site investigation was undertaken by SRK to determine the origin of seepage. This consisted of drilling boreholes, in situ testing, piezometer installation, and the collection of soil and water samples for subsequent laboratory testing. Interpretation of the resulting data permitted the definition of site hydrogeology. Interpreted hydrogeologic cross-sections through the impoundment structures are shown in Figure 3. While the design and integrity of dam structures was confirmed, unit hydraulic conductivities for sub-surface materials were generally and specifically higher than was indicated prior to the construction of the dams. Gravel lenses in cover materials, and the bedrock below the cover, are sufficiently permeable to enable the transmission of significant seepage. Seepage loss estimates were based on flows observed at collection points, and were confirmed by seepage estimates at source based on hydraulic gradients and conductivity data collected during fieldwork and laboratory testing.

Hydrology and Tailings Impoundment Water Balance

Characterization of mine site hydrology was required to model flows in drainages receiving discharges from the mine, and to construct a water balance for the tailings impoundment.

Site hydrology and climate was characterized by Ker Priestman and Associates using regional analysis prior to mine development. Data from regional stations of Water Survey of Canada and the Atmospheric

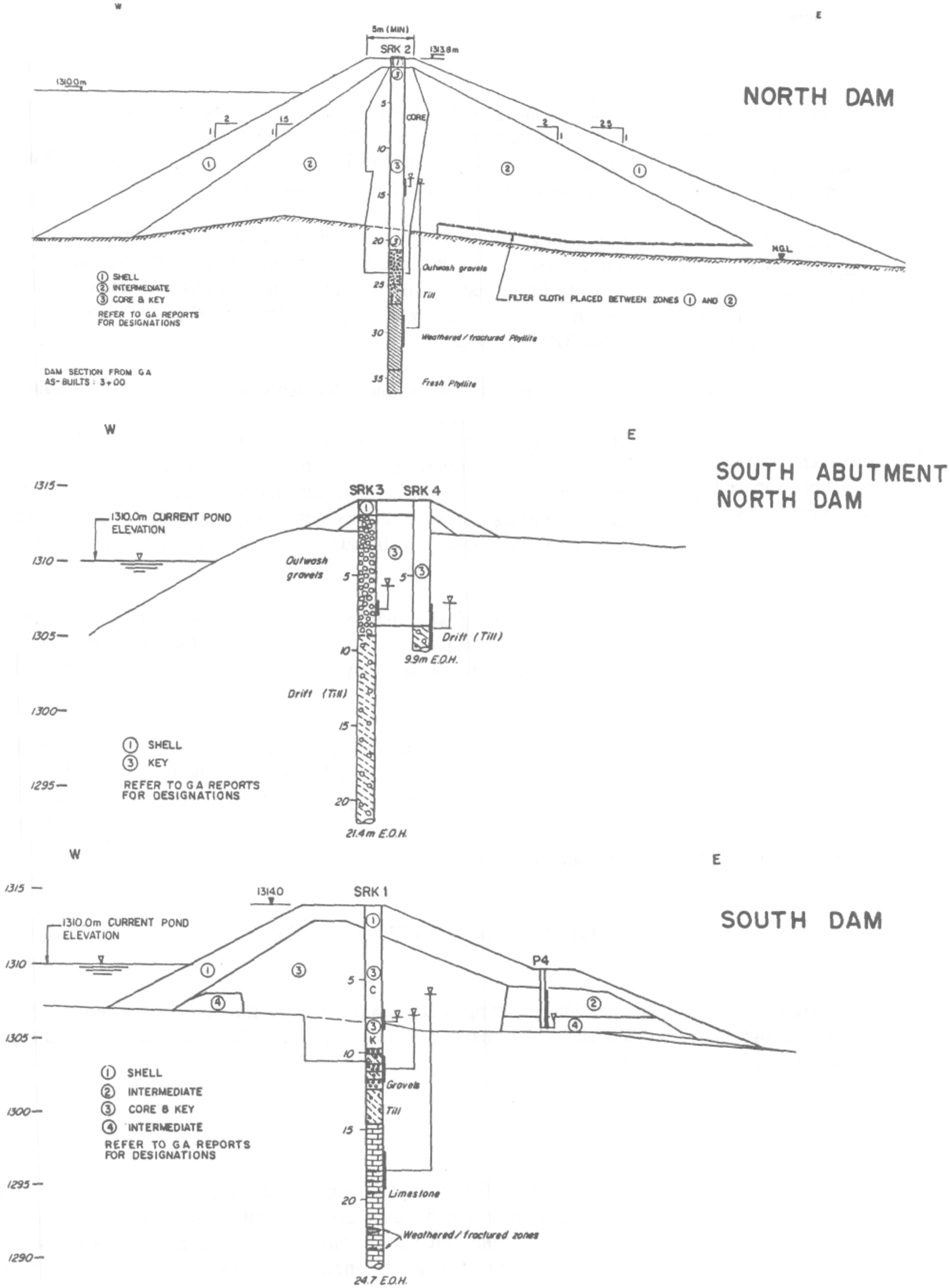


FIGURE 3 HYDROGEOLOGICAL CROSS SECTION THROUGH TAILINGS IMPOUNDMENT STRUCTURES

Environment Service were assembled and analyzed for general trends. The trends formed the basis for the estimation of streamflows in mine site drainages, and of precipitation and evaporation for the tailings impoundment. Precipitation and streamflow records collected at the project site during the years 1985 and 1986 were used to corroborate the results obtained from the regional analysis.

The mean annual precipitation for the tailings impoundment was assessed at 520 mm, comprising 220 mm of rainfall and 300 mm of snowfall as water equivalent. Extremes in annual precipitation totals were calculated by assuming they are normally distributed, consistent with the distributions exhibited by various weather stations in the region. The 1 in 100-year return period high and low annual precipitations for the Ketza site were calculated at 730 and 320 mm, respectively.

Mean annual runoff for the relatively high-elevation mine site catchments was estimated to be equal to a depth of approximately 400 mm. A subtraction of runoff from precipitation yields a residual of 120 mm/year per unit area, the majority of which is likely to be lost to evapotranspiration. An average monthly distribution for runoff was determined. The peak occurs in late May or early June due to snowmelt ("freshet"). Mine catchments are relatively small and, therefore, may also experience annual runoff peaks in the summer during intense rainfall events. Minimum runoff typically occurs in March or April prior to freshet. Annual runoff extremes were estimated by subtracting catchment evapotranspiration from precipitation extremes. This gave 1 in 100-year high and low annual runoff depths of 610 mm and 200 mm, respectively.

Tailings impoundment mass and water balances were developed by estimating inputs and outputs and performing a calibration with the observed pond water-level. Streamflows for 1988 and 1989 were approximated. Evaporative loss from the pond was based on potential evaporation. The water balance is shown in Figure 4.

The rate of accumulation of excess supernatant in the tailings impoundment had been significantly greater than originally projected during the design phase of the Ketza River mine. The primary contributors to this imbalance were leakage from diversion structures and groundwater recharge, and returns from the seepage collection systems. Average annual daily inputs and outputs were estimated at 1921 m^3 and 1304 m^3 respectively. In order to maintain storage equilibrium, an estimated 225,000 m^3 of excess supernatant would have to be treated on average each year. For the six-month discharge window, this equates to a continuous treatment rate of 51 m^3/hour.

OPERATING WATER QUALITY

There were two main issues regarding operating water quality and the milling of sulphide ore: seepage from the tailings impoundment; and, the impact of ammonia concentrations in water treatment plant discharge on aquatic resources.

Tailings Impoundment Seepage

Approaches to reduce seepage losses from the tailings impoundment were based on the interpreted hydrogeology. A reduction in seepage volume would reduce the larger volume of return and improve the pond water balance. Two solutions were considered to be most appropriates: a lowering of the pond water-level by effecting a change in the pond water balance; and, reducing the local and general

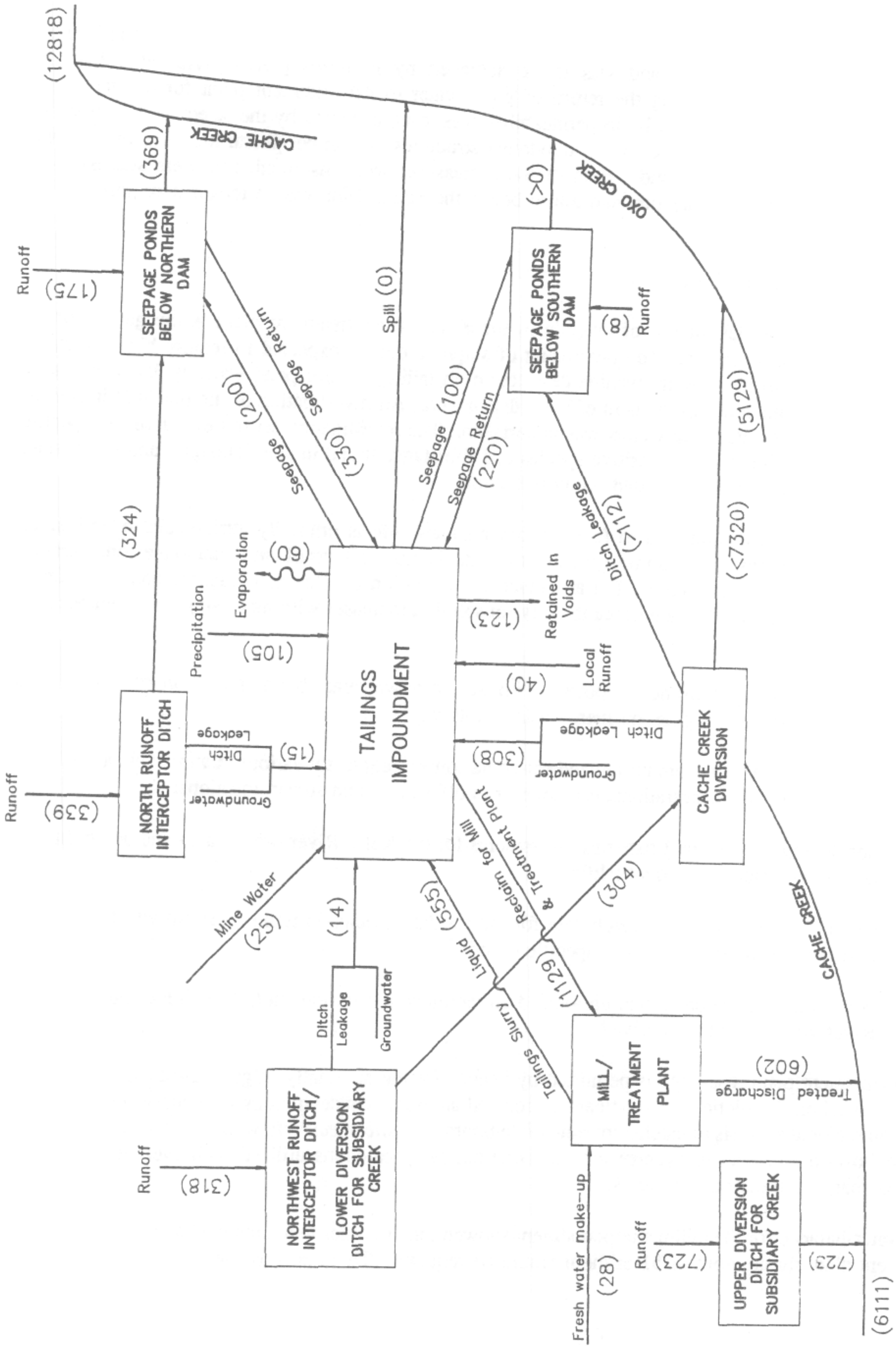


FIGURE 4 CURRENT AVERAGE ANNUAL WATER BALANCE (m^3/day)

permeability of the pond basin through which seepage was taking place. The former would reduce the hydraulic head driving seepage and was to be achieved by minimizing leakage/recharge into the impoundment, and by maximizing the return of pond water to the treatment plant for treatment and discharge. The reduction of pond basin permeability was to be achieved by the selective placement of oxide tailings on the upstream faces of impoundment structures, and in peripheral locations of the pond basin, to form a liner for the pond. Both of these measures were instituted, and were successful in reducing seepage such that collection and return below the South Dam was no longer necessary.

Impact of Ammonia Discharge

A consequence of the destruction of cyanide in the Ketza water treatment plant is the generation of ammonia in effluent discharge. The processing of sulphide ores is expected to require higher rates of cyanide addition. An increase in cyanide destruction on tailings and/or pond water is likely, and may yield higher ammonia concentrations in effluent discharged. An investigation of the potential impact of ammonia discharge to receiving waters was undertaken. The investigation set out to derive site specific criteria based upon the resident sensitive species and life stages found in site drainages, and to consider the impact of effluent discharge based on these criteria.

The toxicity of aqueous ammonia to fish and other aquatic life is primarily attributable to un-ionized ammonia concentrations. It is common practice to relate the toxic effects of ammonia to the concentration of un-ionized ammonia in solution. For any given concentration of total ammonia, the concentration of un-ionized ammonia (and thus ammonia toxicity) in solution increases with increasing water temperature and pH.

The approach taken to determine the potential impact on downstream biota as a result of sulphide ore milling and water treatment plant discharge was as follows:

- computation of in-stream un-ionized ammonia concentrations for various treatment plant discharge total ammonia concentrations, catchment run-off values, and stream locations;

- consideration of several fisheries assessments for the Ketza River project area and determination of resident species of aquatic life;

- summation of relevant research data for the resident species in terms of sensitivity to ammonia toxicity, and derivation of site specific criteria;

- comparison of the computed un-ionized ammonia concentrations in Cache Creek and the Ketza River with the criteria derived.

Water treatment plant discharge is permitted by licence for the nominally "high" run-off months of May through October. Predictions of in-stream un-ionized ammonia concentrations were made for this period based on regional analysis of catchment run-offs supported by site-specific flow measurements. As natural stream flows are subject to average annual variation, the predictions utilized both average annual and 1 in 10 year return period low flows.

The water-balance for the tailings impoundment showed that, in order to maintain a balance, a continuous treatment plant through-put of 51 m^3/hour would be required. This rate was used in the predictions.

Test work was conducted by Coastech Research to assess the potential efficiency of sulphide tailings treatment in terms of cyanide destruction prior to discharge to the tailings impoundment. Product analyses indicated the likely pond water quality on sulphide tailings deposition. *Based* on the test results, water treatment plant discharge total ammonia concentrations of 40 mg/L (as N) on average, with an upper value of 60 mg/L, were assumed.

Un-ionized ammonia concentrations are highly pH dependent. The pH of plant discharge was fixed at 7.5 based on monitoring records. Data from site monitoring stations were used to assign pH values for natural waters. Values ranged from 8.0 to 8.3, with peak pH in the month of August.

A spread-sheet mixing model was constructed to predict downstream values for total ammonia, pH and temperature. Values were calculated by arithmetic division according to flow volume. pH values were calculated by conversion to natural logs prior to mixing. Three downstream locations were chosen for determinations as follows:

- a monitoring station in Cache Creek just downstream of the tailings impoundment;
- the mouth of Cache Creek prior to discharge to the Ketza River;
- the Ketza River just below Cache Creek.

In-stream concentrations of un-ionized ammonia were calculated from the total ammonia, pH and temperature values determined by the mixing model. The resultant concentrations are shown in Table 1.

A number of fisheries assessments for the area were reviewed to determine resident species. This included an assessment by Norecol Environmental Consultants prior to mine development, who concluded that fish abundance, benthic invertebrate productivity and fisheries resource potential in the area is low. The most sensitive aquatic species recorded in the mine catchment were as follows:

- Cache Creek below impoundment - Invertebrates (Mayfly), no fish were recorded;
- Cache Creek mouth - Arctic grayling and slimy sculpin;
- Ketza River - round whitefish.

A literature review was undertaken to derive applicable un-ionized ammonia criteria for the resident aquatic species determined. The following criteria were used to assess potential impacts on aquatic life from effluent discharge:

to prevent **acute lethal** toxic effects toward sensitive fish species (at least double this for invertebrates) < 0.26 mg/L NH_3;

to prevent **chronic** toxic effects toward sensitive fish species 0.03 - 0.04 mg/L NH_3.

Sensitive fish species are considered to include Arctic grayling and whitefish. Less-sensitive species of fish (e.g. slimy sculpins) and freshwater invertebrates (e.g. mayflies) will be afforded a greater degree of protection if these criteria are applied.

TABLE I: Predicted Un-ionized Ammonia Concentrations in Receiving Waters (mg/L as N)

LOCATION	MAY	JUN	JUL	AUG	SEP	OCT
AVERAGE RUNOFF YEAR, 40 mg/L PLANT DISCHARGE						
Cache Creek below impoundment	0.025	0.018	0.047	0.081	0.051	0.055
Cache Creek at mouth	0.008	0.006	0.016	0.030	0.018	0.020
Ketza River below Cache Creek	0.004	0.004	0.009	0.017	0.010	0.011
AVERAGE RUNOFF YEAR, 60 mg/L PLANT DISCHARGE						
Cache Creek below impoundment	0.036	0.026	0.069	0.120	0.077	0.082
Cache Creek at mouth	0.011	0.009	0.023	0.044	0.026	0.030
Ketza River below Cache Creek	0.006	0.005	0.012	0.024	0.014	0.016
DRY RUNOFF YEAR, 40 mg/L PLANT DISCHARGE						
Cache Creek below impoundment	0.032	0.024	0.060	0.101	0.064	0.066
Cache Creek at mouth	0.010	0.008	0.021	0.039	0.023	0.026
Ketza River below Cache Creek	0.006	0.005	0.011	0.021	0.013	0.014
DRY RUNOFF YEAR, 60 mg/L PLANT DISCHARGE						
Cache Creek below impoundment	0.048	0.035	0.089	0.150	0.095	0.099
Cache Creek at mouth	0.015	0.011	0.030	0.057	0.034	0.038
Ketza River below Cache Creek	0.008	0.006	0.015	0.030	0.018	0.020

The computed in-stream concentrations of un-ionized ammonia were compared with the criteria. For Cache Creek downstream of the tailings impoundment, predicted concentrations were below levels known to be harmful to mayflies or other sensitive invertebrate species. For the mouth of Cache Creek, predicted concentrations are consistently below levels that would be acutely lethal to sensitive fish or invertebrate species. In the worst case scenario, the predicted concentrations are around or below levels at which chronic toxic effects toward sensitive fish species (e.g. Arctic grayling) might occur (except for August). For the Ketza River, no acute or chronic toxic effects toward sensitive species of fish or invertebrates were defined for average run-off years and for either effluent discharge concentration scenario. For the worst-case scenario, dry run-off year and 60 mg/L plant discharge, chronic toxic effects are unlikely with the possible exception of August (the predicted concentration equalled the lowest-observed-effect concentration for sensitive fish species.

Based on the assessment, and given the low numbers and potential of fish resources for the locations considered, it was concluded that the discharge of effluent from the Ketza treatment plant is likely to have minimal impact on fish resources for the scenarios modelled and assumptions made. A further reduction in impact would also result from the implementation of impoundment water-balance modifications which would reduce the requirement for water treatment and discharge.

DECOMMISSIONING WATER QUALITY

Receiving Water Concentrations

An assessment of downstream water quality following tailings impoundment decommissioning was performed. It was assumed that the impoundment would not be decommissioned until pond water was of acceptable quality, and seepage collection and return was no longer needed. The impoundment would be decommissioned by breaching diversion structures and allowing the impoundment to flood, wilh discharge via a suitably designed permanent spillway. Cyanide and copper concentrations in pond water were expected to reduce steadily with time to acceptable discharge levels. However, the potential for resolution of arsenic from oxide tailings via the process of molecular diffusion was noted. This could lead to the contamination of spillway discharge, although it was considered more likely that contaminants would not migrate upwards into the water cover. An assessment of downstream water quality was made using the model described above. The impact of drought events on water quality was also simulated based on a 1 in 100-year return period low flow condition. Dilution ratios were estimated to be 3400 to 1 for average year mean monthly flows, and 114 to 1 for the low flow month (March) of a 100-year low flow condition. Calculated potential arsenic concentrations in spillway discharge for these flow conditions, based on upward diffusion only, were 0.004 mg/L and 0.13 mg/L respectively. For average flow conditions, contaminant concentrations in Cache Creek were predicted to remain at or below those recorded during operations. For the low flow month of the 100-year low flow condition, the arsenic concentration was predicted at 0.056 mg/L. The results ignored the potential for natural concentration reduction via the process of attenuation, and demonstrated that the potential for adverse quality in receiving waters long-term was low.

Sulphide Tailings Storage

The potential for acid generation from the sulphide tailings to be placed in the tailings impoundment was noted. It was decided that tailings would be placed such that a permanent minimum 1 metre water cover would be maintained to arrest the acid generation process. A final sulphide tailings surface elevation was predicted using the mass balance model constructed for the impoundment. Using the water balance model, it was demonstrated that the 1 metre cover could be maintained year-round, even during the 100-year low flow period.

CONCLUDING REMARKS

The Ketza River gold mine is a relatively small operation in a remote location which brings with it additional financial constraints due to climatic and access adversities. While the operation employs current extractive technologies, considerations for environmental protection are significant and impose additional financial constraints. The investigations described above demonstrate that, with the quantification of potential environmental impacts and the adoption of mitigative solutions where appropriate, mine developments such Ketza can be sustained, and provide revenue and employment opportunities while incorporating protection of the environment.