Faro Mine Complex
Future Water Quality Prediction

2007/08 Task 17b – FINAL

Prepared for

Deloitte and Touche Inc.

On behalf of

Faro Mine Closure Planning Office

Prepared by

SRK Consulting
Engineers and Scientists

Project Reference Number
SRK 1CD003.106

February 2009

Faro Mine Complex

Future Water Quality Prediction

2007/08 Task 17b – FINAL

Deloitte and Touche Inc.

Interim Receiver of Anvil Range Mining Corporation
Suite 1900, 79 Wellington Street West
Toronto, ON M5K 1B9

On behalf of

Faro Mine Closure Planning Office

SRK Consulting (Canada) Inc.
Suite 2200, 1066 West Hastings Street
Vancouver, B.C. V6E 3X2

Tel: 604.681.4196 Fax: 604.687.5532
E-mail: vancouver@srk.com Web site: www.srk.com

SRK Project Number 1CD003.106

February 2009

Executive Summary

Water quality predictions have been prepared previously for the waste rock, tailings, and pit lakes at the Anvil Range Mining Complex. These predictions were input to a site wide model to develop estimates of contaminant concentrations in the receiving water. By accounting for a number of factors for which better information now exists, it is possible to improve these water quality predictions. This report describes work that has been completed under 07/08 Task 17b in relation to future water quality predictions.

The two main contributors of contaminant loads on site consist of the waste rock dumps and the tailings impoundment. The methodology for predicting water quality associated with each of these contributors has been modified. In particular, the method for predicting the water quality at the waste rock dumps has been modified to account for (i) closure measures, and (ii) the neutralization potential availability. Similarly, the methodology for predicting the water quality at the tailings impoundment has been modified to account for closure measures.

A simplified site wide water balance has been developed using an EXCEL model that accounts for the revised source terms. The simplified water and load balance model has been run a sufficient number of times to establish its functionality.

The EXCEL model is now ready to be converted into Goldsim, and indeed this process is already underway as part of a separate scope of work by others.

*   *   *

Report Title:	Faro Mine Complex, Future Water Quality Prediction, 2007/08 Task 17b – Final
Prepared by:	SRK Consulting Project 1CD003.106
Date Submitted:	February 2009
Supersedes:	N/A
Number of Pages:	10 / 19 (Body / Total Report)
Number of Appendices:	1

Table of Contents

List of Appendices

1 Introduction

In previous years, water quality predictions have been prepared for the waste rock, tailings, and pit lakes, and input to a site wide model to develop estimates of contaminant concentrations in receiving water. There is a desire to simplify the presentation of these predictions to make them more understandable by non-specialists, and specifically to develop a figure showing the development of contaminant concentrations over time. However, there is also a reluctance among the specialists in this work to assign time scales to what are inherently very uncertain predictions.

This report describes work that has been completed under 07/08 Task 17b in relation to future water quality predictions. When linked to work undertaken by others, the ultimate intent is to develop a simple computer model that is capable of generating water quality estimates that (a) provide non-specialists with a sense of the time scale over which concentration changes are expected to develop, and (b) fairly represent the uncertainties that specialists know to be important.

The final result of the work undertaken under 07/08 Task 17b, and related work by others, is expected to be adequate to support analysis of the selected closure methods by the governments, and to provide a basis for further work related to the environmental assessment (EA) and human health and ecological risk assessment (HHERA). It is hoped that interim results will also be of assistance in the final public consultation about the closure alternatives.

2 Background

A review of the strengths and weaknesses of the previous water quality predictions is provided below:

1 The estimates of contaminant concentrations in waste rock seepage have covered current, intermediate future and worst case future geochemical conditions. Calculations have also been completed to estimate the time scales over which each waste rock dump will become acidic, but these have not been directly related to the estimates of contaminant concentrations. The time dependent effects of the short-listed closure measures were not incorporated into the previous prediction methods. Recent work on the dump water balances suggests that there is some attenuation of water within the dumps, and there is also evidence of contaminant attenuation in the groundwater systems below the dumps. Neither of those effects is expected to be significant over the long term, but they need to be accounted for in any predictions of contaminant loadings over the next 10-20 years.

2 For the Faro tailings, estimates of porewater displacement have been combined with porewater quality estimates to provide time-based estimates of contaminant loadings from the base of the tailings deposit. Attenuation below the tailings and within the aquifer has recently been

demonstrated to be important in limiting the ultimate release of these contaminants. Attenuation has not been accounted for in the predictions presented to date.

3 The pit lake water quality predictions consider overall water balances for the pit lakes to develop time dependent estimates of contaminant concentrations. However, the predictions use very conservative estimates of wall rock loadings which have not been calibrated against the now substantial body of pit lake monitoring data.

4 All of the source concentration estimates incorporated significant uncertainties. As noted by the independent peer review panel (IPRP), such uncertainties are always inherent in predictions of this type. To date, these uncertainties have been accounted for only by considering three estimates to represent the range of future water quality, (i.e. “Future 1”, “Future 2”, and “Future 3”).

5 Other uncertainties arise in translating the estimated source concentrations to estimates of receiving water quality. Specifically, the long-term effectiveness of covers and collection systems will influence how much of the contaminants make it from the respective sources to receiving water. To date, these uncertainties have been dealt with by two methods. The first was the development of receiving water quality estimates using a range of assumed cover and collection system performance. The second was the use of the risk rating system to qualitatively characterize the risk associated with meeting particular levels of performance. Although the IPRP has agreed with the estimates of cover and collection performance used to date, they agree that uncertainty remains in these estimates. The IPRP has also recommended substantial changes to groundwater collection methods for the Faro area, with the intention of significantly improving the expected performance.

Therefore, to meet the requirements of the IPRP, time based water quality predictions for the waste rock were developed. The issues related to water quality predictions for the dumps include:

1 Overall water balance for the dumps (i.e. rate of infiltration, wetting and transport through the dumps);

2 Proportion of the dumps contacted by infiltration (i.e. selective flowpaths);

3 Distribution and occurrence of acid generating minerals, acid consuming minerals and distribution of leachable metallic forms within the dumps;

4 Rate of oxygen ingress, acid generation and acid consumption;

5 Relative rates of metal release (e.g. effects of galvanic protection leading to selective leaching); and

6 Effects of closure measures on transport and geochemical processes.

If these factors can be addressed, it may be possible to develop time based estimates of water quality for the waste rock dumps. However there remain a number of uncertainties associated with the characterization of the waste rock contained in the dumps, the water balance and transport through the dumps, and the oxidation rates.

The approach taken for the development of time based estimates for the waste rock dumps was to develop a deterministic model in which the length of time after closure is selected along with cover type. The result is a predicted concentration at any one time. Consideration was given to the number of years until acidic drainage would be observed from a particular waste rock dump based on current measures of oxidation rate in the dumps. Then, assuming covers are placed, the oxidation rates were adjusted to reflect the changed conditions. This will result in a revised rate of NP and AP depletion and a lower 'theoretical' maximum rate of acid generation. The existing water quality prediction (average and maximum concentrations) were used as a measure of potential conditions that may develop, and the rates of depletion were used to estimate the probable conditions at various time intervals into the future based on the depletion calculations.

3 Scope of Work

In broad terms, two steps were completed under the Task 17b work scope. The first was to revise the methods used for the source water quality predictions so that they incorporate all of the processes that are known to be important to the timing of contaminant releases. The second was to incorporate the revised source term predictions into the site wide water and load balance, which was developed using an EXCEL spreadsheet. This simplicity of the EXCEL spreadsheet makes it very easy to assess the accuracy of the model and to rapidly complete sensitivity assessments based on various input parameters. A detailed description of the mechanics of the EXCEL model is provided in Appendix A.

A third step, which follows sequentially but is independent of the scope of Task 17b, will be to convert the EXCEL model into Goldsim, a program suitable for visualizing and simulating how systems evolve over time, thereby facilitating predictions of future water quality. Goldsim will be used to run the revised water and load balance with a range of inputs selected to represent the remaining uncertainties. The results of the third step will be time-base predictions of contaminant concentrations with "error bars" denoting the uncertainty.

3.1 Step1 - Revised Water Quality Predictions

3.1.1 Waste Dump Water Quality Predictions

As noted before, the waste rock dump seepage quality will be influenced by the closure measures and NP availability.

The effect of the closure measures (i.e. covers) will affect the rate of infiltration as well as the rate of oxygen and thus the rate of oxidation within the dumps. The rate of infiltration is being assessed as part of the overall cover evaluation program. Nonetheless, the rate of infiltration has been adjusted in the current modelling using best engineering judgement values. A best engineering judgement value for the percentage reduction of oxygen entry associated with various cover types was also used. Therefore, the effects of covers on potential oxygen entry, oxidation rates and available NP have been assessed.

Acid neutralization and secondary mineral formation have been determined by the availability of NP. Consideration has been given to NP availability, and its depletion.

The source concentrations for waste rock were updated using seepage data collected to 2008.

3.1.2 Tailings Water Quality Predictions

The tailings model developed in 2005 was developed as an independent EXCEL model. In the current revision, the model was integrated with the waste dump module.

In transferring the EXCEL model into Goldsim, some changes will be made to the tailings model. First, the propagation rate will be adjusted to account for cover placement. This will be done by dividing the rate used in the 2005 model by the original infiltration (used in 2005) and then multiplying by the infiltration associated with the selected cover treatment. The second change, which will be done as part of future work outside the current scope, will be to include an assessment of the potential impacts from attenuation in the peat layer below the tailings facility.

3.1.3 Pit Water Quality Predictions

Pit water quality predictions were left as a separate, stand alone model. In the EXCEL model completed in 2008, water volumes entering the pits were estimated. The model uses this number to determine the volume of water treated and discharged by the water treatment plant.

The pit water quality prediction model is expected to be updated in 2009.

3.2 Step 2 - Revised Site Wide Water and Load Balance

The site water and load balance has been simplified as follows:

- The pit lakes have been considered in isolation, which negates the need for iterative calculations that have previously been used to maintain the water balance in each of the pit lakes.
- Creeks have been assumed to be efficient with no losses prior to a monitoring point. However, waste rock seepage that escapes the groundwater collection systems is assumed to report to the respective drainage system and is accounted for at the monitoring point for that drainage system. Seepage that is captured is pumped back to the pit for ultimate water treatment. It was assumed there is no leakage from the pits.
- Previously, the site water and load balance calculations considered monthly time-steps. While this is useful to establish seasonal variations in water quality, annual time steps have been

included in the model as these are much simpler for the purpose of longer term predictions reflecting a range of uncertainties. However, the monthly time steps were maintained to help facilitate the ecological risk assessment.

These revisions have resulted in an EXCEL model that can estimate step function arrival times for contaminants from each area. The step functions for each area have been summed to obtain global loadings over time.

Collection efficiencies have been applied as before to determine net loadings to the receiving environment. Receiving water concentrations have been estimated as required.

The revised source term and simplified water and load balance models developed under Task 17b have been run a sufficient number of times to establish that the EXCEL spreadsheet reasonably models the site wide water balance.

4 Conclusions

The methods used for the source water quality predictions have been revised so that they incorporate more, but not all, of the processes that are known to be important to the timing of contaminant releases. These have been incorporated into an EXCEL spreadsheet that provides a simple model of the site wide water and load balance.

The EXCEL model is now ready to be converted into Goldsim, and indeed this process is already underway as part of a separate scope of work by others.

This report, "**Faro Mine Complex, Future Water Quality Prediction, 2007/08 Task 17b – FINAL**," was prepared by SRK Consulting (Canada) Inc.

Prepared by

ORIGINAL SIGNED AND STAMPED

Diana Sollner, M.A.Sc., P.Eng.
Senior Mining Environmental Engineer
SRK Associate

Reviewed by

ORIGINAL SIGNED AND STAMPED

Cameron C. Scott, P.Eng.
Principal Engineer

Appendix A

Technical Memorandum "Mechanics of Revised Faro Site Water and Load Balance." Updated from August 7, 2008

SRK Consulting (Canada) Inc.
Suite 2200 – 1066 West Hastings Street
Vancouver, B.C. V6E 3X2
Canada

vancouver@srk.com
www.srk.com

Tel: 604.681.4196
Fax: 604.687.5532

Technical Memorandum

To:	File 1CD003.106	**Date:**	Updated from August 7, 2008
cc:		**From:**	Diana Sollner
Subject:	Mechanics of Revised Faro Site Water & Load Balance	**Project #:**	1CD003.106

This memorandum describes the mechanics and the underlying assumptions of the model developed as a simplification of the site water & load balances developed in 2005.

1 Objective

The objective of this project was to consolidate the model into a single Excel file and to simplify its coding based on the short list of closure alternatives remaining under consideration. In addition, the model should be able to calculate load and concentration at specific points in time.

2 Assumptions for Waste Rock

There are a number of assumptions inherent to the model:

- When a dump goes acidic, the seepage quality instantly switches from neutral chemistry to acidic chemistry. Transition periods are not considered.
- Water storage in the dumps is not considered. Therefore, precipitation that falls on a dump in a given year is assumed to report as seepage from the dump that same year.
- Oxidation products generated in a given year dissolve and report to the seepage that same year.
- The proportion of dump seepage reporting to various drainage areas was assumed in previous water & load calculations. The same assumption was carried forward into this revised model. The values used in the model are presented in Table 1.
- The infiltration rates used for the various types of covers are assumed values based on the performance of similar covers at other sites. No site specific testing was done to confirm that these infiltration numbers reflect the performance standard that can be expected at Faro. The values used in the model are presented in Table 2.
- The NP availability rate and the NP depletion rate modifiers shown on the "Inputs" sheet are assumed values. Laboratory testing is ongoing to determine these values.
- There are no seepage losses from Faro, Grum or Vangorda pits. However, Zone II pit does have seepage losses similar to the other dumps.
- Water quality for various water flows remains the same as in the 2005 models. The exception is that the seep quality for the dumps has been updated with monitoring data to the end of 2006.
- Attenuation is not accounted for in this model.
- All diversion ditches are 100% efficient, i.e. all background water does not get contaminated by mine components.
- The surface runoff quality of covered dumps will be the same as the water quality of background runoff.

Further discussion on the assumptions associated with the waste rock dump predictions can be found in Chapman (2004). Base values, such as dump surface areas, can also be found in this report.

Table 1: Catchment to Which Dump Drainage Reports

Name	% Entering Catchment Area						
	Main Pit	X23	Guardhouse Cr	X2	Between X2 & X14	V27	V8
Upper Northwest		50%	50%				
Middle Northwest		50%	50%				
Lower Northwest		50%	50%				
Lower Parking Lot			100%				
Upper Parking Lot			100%				
Faro Valley North	100%						
Faro Valley South	100%						
Main Dump West		100%					
Main Dump East		70%		30%			
Intermediate				100%			
Upper Northeast	50%			50%			
Lower Northeast				100%			
Outer Northeast				100%			
Zone II West				100%			
Zone II East				100%			
Ramp Zone				100%			
Ranch				100%			
Southwest Pit Wall	100%						
Low Grade Stockpile A	30%	70%					
Low Grade Stockpile C	30%	70%					
Fuel Tank W		100%					
Fuel Tank E		100%					
Mt. Mungly East		100%					
Mt. Mungly West		100%					
Medium Grade Stockpile		100%					
Oxide Fines Stockpile		100%					
Stock Piles Base		100%					
Crusher Stockpile		100%					
Outer Haul Road West		20%		30%	50%		
Outer Haul Road East				100%			
North Fork Rock Drain				100%			
Vangorda dump						98.50%	1.50%
Grum dump						99.50%	0.50%

Table 2: Infiltration Rates for Various Covers

Cover Type	% of Mean Annual Precipitation
no cover	45%
relocation	0.5%
rudimentary	20%
low infiltration	5%
very low infiltration	2%

3 Derivation of Tailings Concentrations

The derivation of the sulphate and metal concentration predictions for the tailings impoundment area are described in Chapman *et al* (2005). A brief summary is given below.

The prediction model is based on detailed profiling and monitoring of the tailings impoundment. Several tailings samples were collected, representing discrete depths within the impoundment and coarse and fine grained tailings. Metal and sulphate concentrations were determined via the shake flask extraction test, then those results were extrapolated to provide porewater concentrations.

Test results showed three peaks, each at a discrete depth. The peaks for sulphate and metals were observed at consistent depths. The locations of these peaks were monitored. The infiltration rate was estimated based on the rate of advance of the sulphate and metal fronts within the tailings bed. An infiltration rate was estimated for both coarse and fine tailings. The propagation rate in coarse and fine tailings was calculated as the infiltration rate divided by the volumetric moisture content.

Future sulphate and metal concentrations were predicted by estimating how far the sulphate and metal fronts would advance due to the precipitation infiltrating into the surface of the tailings impoundment. In this calculation, it was assumed that sulphate and metal concentrations will not attenuate as they progress through the tailings bed. Furthermore, the concentrations in the porewater above the front will be close to zero since all sulphides would have been oxidized and the oxidation products would have been transported out in the main front.

Sulphate and zinc concentrations in 0.5m layers in each of the areas of the tailings impoundment were calculated for each year from 2002 to 2010. From 2010 to 2100 the calculation is for every 2nd year. From 2100 to 2300 the calculation is every 5 years. From 2300 to 2750, the calculation is every 10 years.

Predicted metal concentrations were calculated as a proportionality to sulphate using measured porewater data as a reference. In other words,

$$Metal_{predicted} = \frac{SO_{4\,predicted} * Metal_{ref}}{SO_{4\,ref}}$$

The reference data used was sample A1-1 (0.5m depth) for average conditions. Sample TP7 (0m depth) was used for maximum conditions. Metals that were predicted using this method were Al, As, Cd, Ca, Cr, Co, Cu, Fe, Pb, Li, Mg, Mn, Ni, P, Si, Ag, Sr and V.

The total load leaving the tailings impoundment in a given year was calculated as the load passing through the contact between the base of the tailings impoundment and the original ground surface. This was done by determining the area of the contact surface at 0.5m depth intervals and calculating the load passing through each discrete contact surface area. The load calculation was made using the property values specific to coarse or fine tailings, whichever was present above the discrete contact surface.

4 Model Structure

The flowsheet for the model is presented in Figures 1 to 3, attached. The load calculated at the Pelly River consists of five (5) load contributors:

- Faro waste rock dumps
- Vangorda waste rock dumps
- Faro tailings
- Water treatment plant effluent
- Background runoff

The load of selected parameters are calculated for key locations:

- X2
- X23
- Guardhouse Creek
- X14
- Mouth of Rose Creek
- Mouth of Anvil Creek
- V27
- V8
- Mouth of Vangorda Creek
- Pelly River below Vangorda Creek
- Pelly River below Anvil Creek
- Pelly River at Pelly Crossing

Parameters for which loads have been calculated include:

SO_4	Na	As	Pb
Cl	Co	Cd	Ni
Ca	Mn	Cu	K
Mg	Al	Fe	Zn

The core model consists of 15 sheets. These are summarized below.

Sheet – Inputs

The inputs sheet is where all user selections are made. The rest of the model is driven from this sheet. The variables a user can modify include:

- Year closure activities are completed
- Number of years into the post-closure period
- The mean annual precipitation for the 3 mine areas
- Choice of using the average or maximum seepage quality values in calculating dump seepage quality.
- Groundwater collection efficiency for the various dump groups.
- The infiltration rate for various cover types
- The NP depletion rate for each cover type
- The NP availability rate
- The cover type over each dump and tailings subareas

Sheets – Zn and SO_4 Load Balance

These sheets calculate the load originating from each source, eg each dump and tailings area.

Load is calculated as:

*Load = Concentration * water volume*

Concentration values are obtained from the sheets Faro_WQ_Estimate, VG_WQ_Estimate, WQZinc, WQSulphate and WQ Data. Water volume is obtained from the sheet Water Balance.

The load and water volume at a particular point in the catchment area are calculated as a sum of the loads and water volumes from the dumps, tailings, water treatment plant effluent and background components reporting to that point. These groupings remain the same as in the 2005 model.

Sheet – Water Balance

The water volume originating from each dump, tailings area, water treatment plant discharge and background catchment area is calculated on this sheet. The results from this sheet feed into the Zn and SO_4 load balance sheets.

The total water volume originating from a dump or tailings compartment is calculated as:

Water volume$_{T(\text{each dump/tails})}$ *= surface area * mean annual precipitation * seasonal distribution * split for seepage & runoff reporting to a specific drainage catchment*

This total water volume is split into three pathways:

Water volume$_{T(\text{each dump/tails})}$ *= surface runoff + seepage collected in groundwater pumping system + seepage escaping collection*

where:

*Surface runoff = water volume * (1 – cover infiltration rate)*

*Seepage collected = water volume * cover infiltration rate * groundwater collection efficiency*

*Seepage escape = water volume * cover infiltration rate * (1-groundwater collection efficiency)*

In addition to the dumps and tailings impoundment area, the volume of water entering the water treatment plant (and exiting as treated effluent) is calculated as:

Water treatment plant volumes = Σ seepage collected + direct precipitation on pits – evaporation from pit lakes

The water volume coming from background catchment areas is calculated as:

Water volume$_{(\text{background})}$ *= surface area * mean annual runoff * seasonal distribution*

The values used for the variables in the total water volume calculation are listed separately on the following sheets:

Sheet Surface Areas & MAR – surface areas for all components, mean annual runoff
Sheet Dump Drainage Split – split for seepage & runoff reporting to a specific drainage catchment
Sheet Seasonal Distribution – seasonal distribution, the percentage of annual precipitation, annual runoff and water treatment plant discharge reporting to the receiving environment each month.

Sheets – Faro_WQ_Estimate & VG_WQ_Estimate

These sheets calculate the parameter concentrations in seepage from each waste rock dump in Faro and Vangorda, respectively. For a detailed discussion of the derivation of source concentrations, the reader is referred to Chapman (2004).

Sheet – NP_AP_Depletion

The ABA data assigned to each waste rock dump is tabulated on this sheet. The NP value is multiplied by the NP availability, which is selected on the "Inputs" sheet. From this base data, the time to NP depletion is calculated. This value is used to switch dump seepage concentrations to an acidic drainage profile from a neutral drainage profile in the Faro_WQ_Estimate and GV_WQ_Estimate sheets.

For a detailed discussion on the derivation of these calculations, the reader is referred to Chapman (2004).

Sheets – WQZinc and WQSulphate

These sheets calculate zinc and sulphate concentration at each 0.5 m increment of depth in the tailings impoundment, in each of the subareas in the impoundment, for the years 2002 to 2750. The derivation of water quality predictions is discussed in Section 3, above.

Sheet – WQ Data

This sheet lists the parameter concentrations used for background runoff and water treatment plant effluent. The values used are the same as in the 2005 model.

5 References

Chapman, John, 2004. *"Water Quality Estimate for Anvil Range Waste Rock – Draft."* Report prepared for Deloitte & Touche. SRK Project Number 1CD003.50. November 2004.

Chapman, John; Vic Enns, Ron Nicholson, Bud McAlpine, Valerie Chort, Christoph Wells and Daryl Hockley, 2005. "Rose Creek Tailings Source Concentrations." Presentation to the Anvil Range Mining Corporation Technical Workshop January 19 – 21, 2005.

Figures

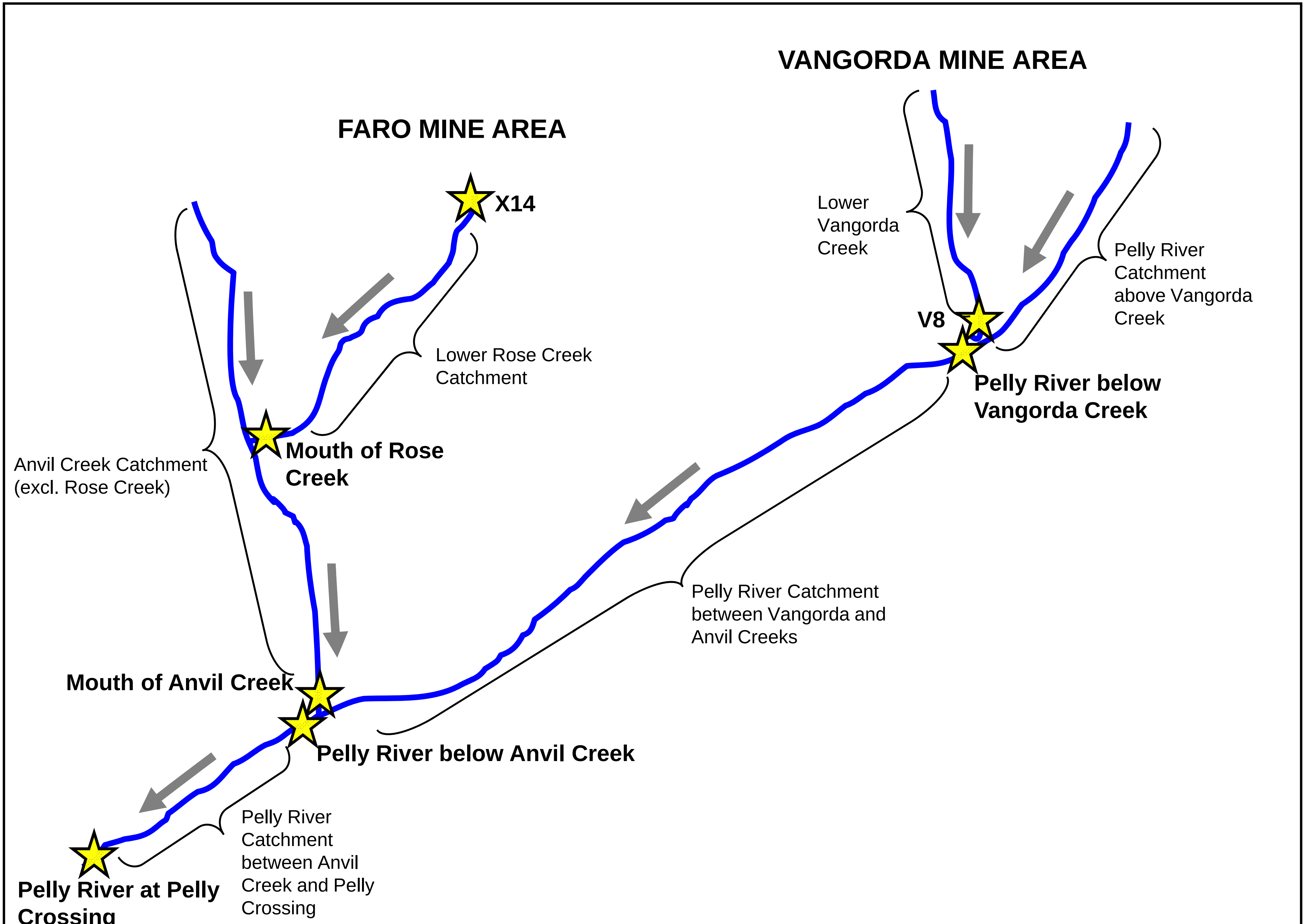

Figure 1: Flowsheet for Faro Mine Complex

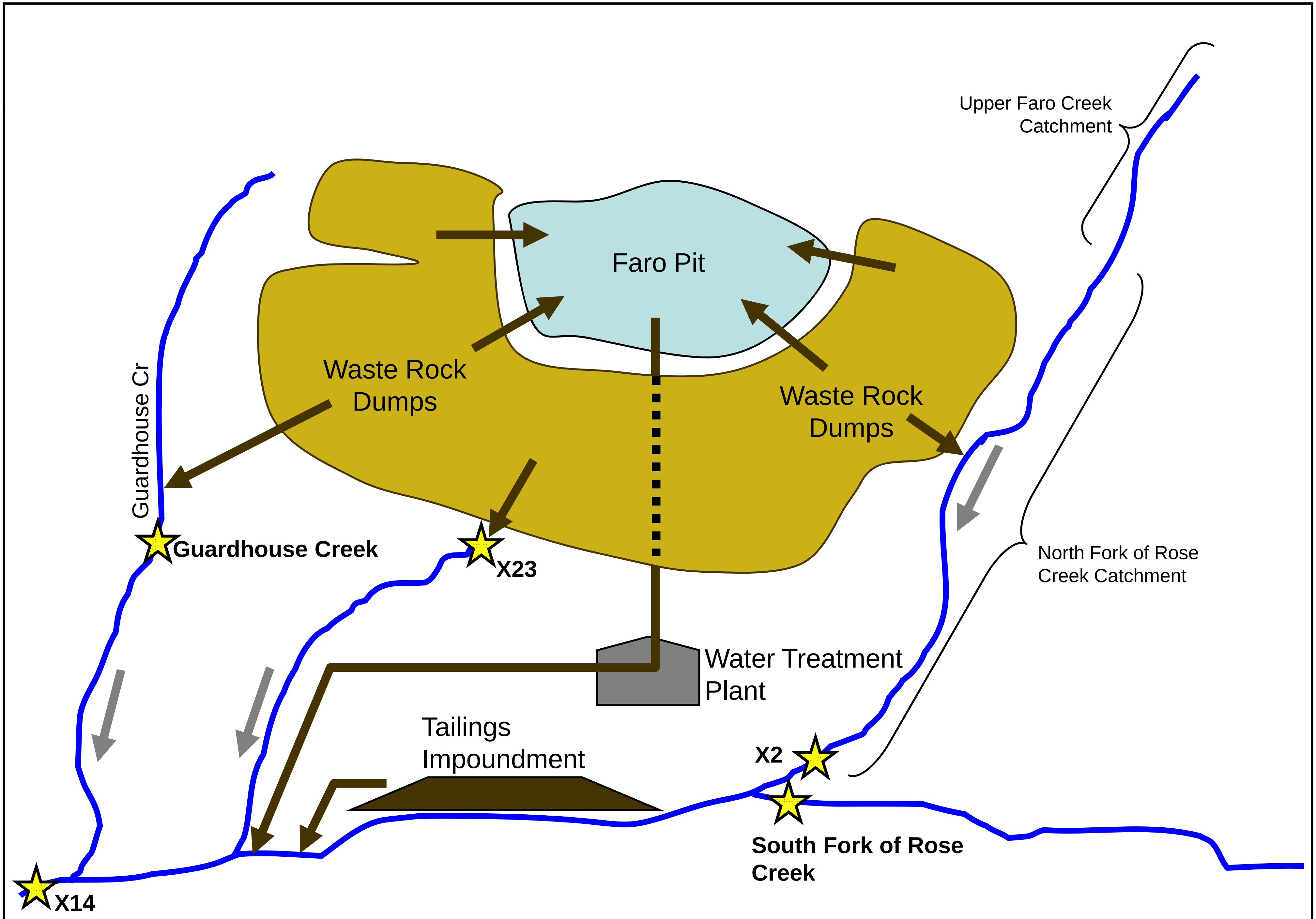

Figure 2: Flowsheet for Faro Mine Area

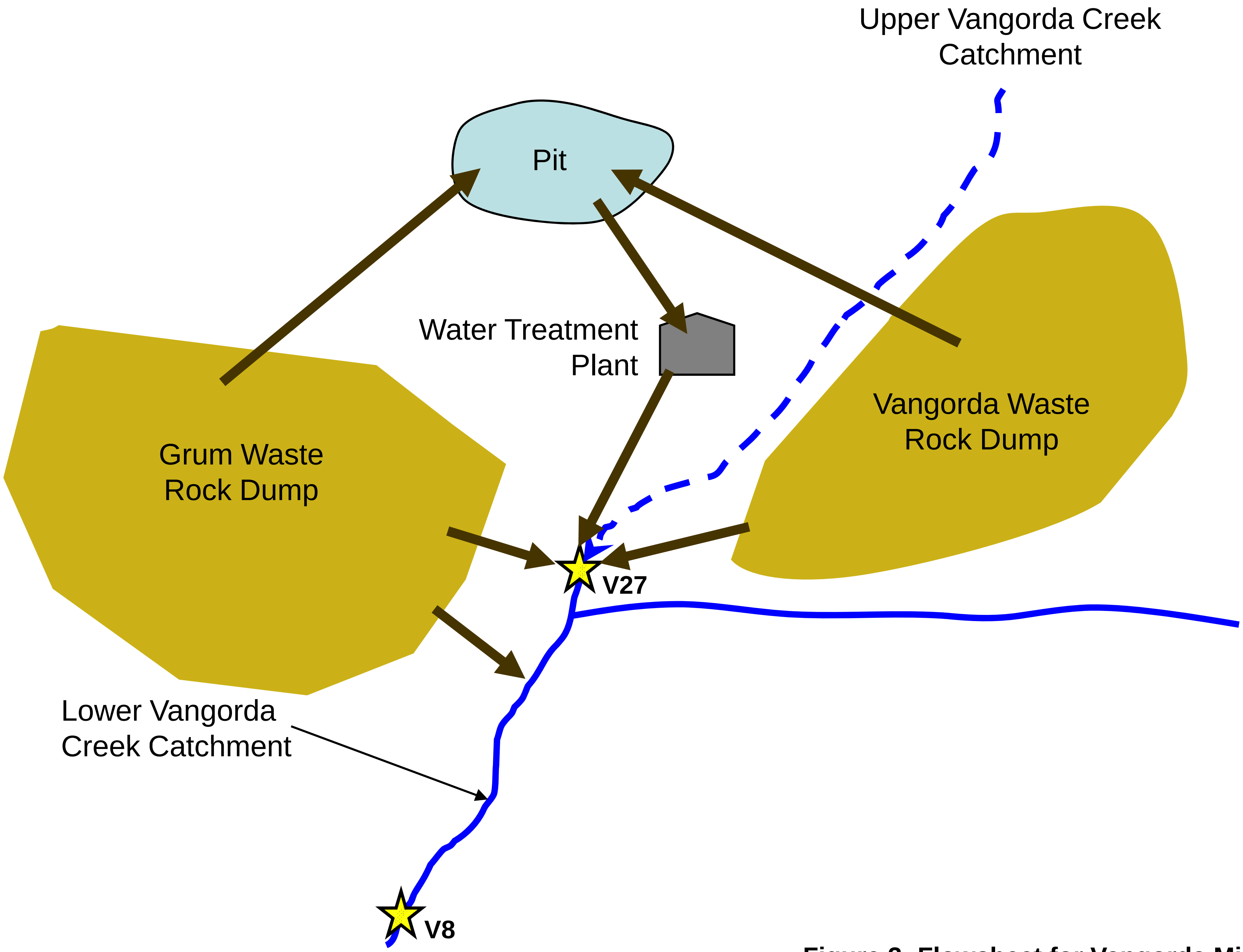

Figure 3: Flowsheet for Vangorda Mine Area