Appendix H.

Solomon Flood Management - Report (Final Rev 1) 101210

BUILDING A BETTER WORLD

Solomon Flood Management

Prepared for Fortescue Metals Group

Final Revision 1, December 2010

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QUALITY ASSURANCE STATEMENT

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REVISION SCHEDULE

REV. NO.	DATE	DESCRIPTION	PREPARED BY	REVIEWED BY	APPROVED BY
1.0	6/12/10	Interim Draft Report	K Amor	T Kerr	J Campbell
2.0	6/12/10	Final Revision 1	K Amor	T Kerr	J Campbell

This document contains information about MWH, particularly about the culture of our organisation and our approach to business, which would be of value to our competitors. We respectfully request, therefore, that it be considered commercially sensitive.

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Executive Summary

This report provides a preliminary assessment of the surface water hydrology of the Solomon Mine catchments and options for protecting the proposed open pits and mining infrastructure during flood events.

The work also includes an assessment of the potential impacts of the mining operation on the natural hydrological regime and downstream environment.

Eleven options to manage floods during mining were identified. These included the so called “do nothing” or status quo option which is the default option of providing basic mine site stormwater drainage management such as road culverts, low bunds around pit boundaries etc but no major flood management structures.

The combined area of the pits and catchments impacted by the proposed mine extension is approximately 342km^2. This represents 1.7% of the overall Lower Fortescue catchment and is therefore not expected to impact significantly on flow volumes and sediment regimes downstream of the mine.

The cost of not implementing a flood management scheme was also considered in terms of the cost of power to pump floodwater from the pit. The investigation considered but did not estimate costs associated with loss of production, site cleanup etc. It is recommended that these costs be assessed before commencing the options assessment workshop including a formal decision making process such as MCA. A summary of the capital costs of each option and costs and time to pump water out of the pits if the option is not implemented in provided in Table 7-15.

Following feedback from FMG on this document and completion of the proposed options assessment workshop a final version of the report will be produced.

At this stage only the 100 year ARI flood event has been modelled to provide an assessment of the relative cost and benefit of each option. The next step will be to model 50, 20 and 10 year flood events to compare the difference in cost and benefit to designing to a lower standard than the 100 year event.

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1. Introduction

1.1 Objective

The objective of the Solomon Surface Water Management Project is to assess the hydrology of the Solomon Mine catchments and determine the preferred options for flood mitigation works to protect the open pits, infrastructure and mining operation during flood events. The work also includes an assessment of the potential impacts of the mining operation and flood management options on the existing drainage system and hydrology downstream of the proposed mine. An estimate of the capital cost of options is also provided.

A list of options has been identified for consideration at the concept level and is the focus of this report. It is intended that the list of options will also be the basis for discussion at the workshop.

This is an interim version of the report and presents the options identified so far, background information on the hydrological and hydraulic assessment, concept plans and rough costs. The final report will be prepared following comment from FMG and collation of results of the proposed options/risk workshop.

A significant part of the work so far has been the development of hydrological and hydraulic models. The 2D hydraulic model of the Solomon mine provides FMG with a tool to assess the impact of floods and evaluate and compare various options for managing waters and reducing impact on the mining operation.

1.2 Background

The Solomon mine is located 50km north of Tom Price and is near to the Karijini National Park. Resource drilling began in 2007 and mining is expected to commence in 2011. Figure 1-1 shows the location of the Solomon Mine within the wider Fortescue Watershed.

The mine operation is expected to continue until at least 2031 representing a mine life of at least twenty years. The main pit is 28km long and is divided into the Valley of the Queens (Queens) pit to the west and Valley of the Kings (Kings) pit to the east. The two areas are separated by an almost imperceptible drainage divide about 3.5km to the west of the outlet of the Kangeenarina South catchment as shown on Figure 1.2.

The Kings and Queens pits will have an average depth of 70m and will intercept runoff along their length. The largest catchment to be intercepted is the 120km^2 North West catchment also shown in Figure 1-2. The second largest is the 56 km^2 Kangeenarina South catchment. Following Stage 2 of the mine plan (year 2), runoff from these two catchments will be blocked by the Kings pit.

The catchment designated for the Tailings Storage Facility (TSF) is adjacent to the Kings pit and runoff from the catchment can be diverted away from the Kings pit.

The Fire Tail pit area is to the north east of the Kings pit and is located mainly on elevated ground away from significant drainage channels and so will require minimal flood management works. Figure 1.2 shows the pit boundaries and catchment divides.

The Solomon mine is upstream of the Weelumurra Springs which are an area of environmental significance. The Weelumurra Creek drains into the Fortescue River at a point 205 km from the coast.

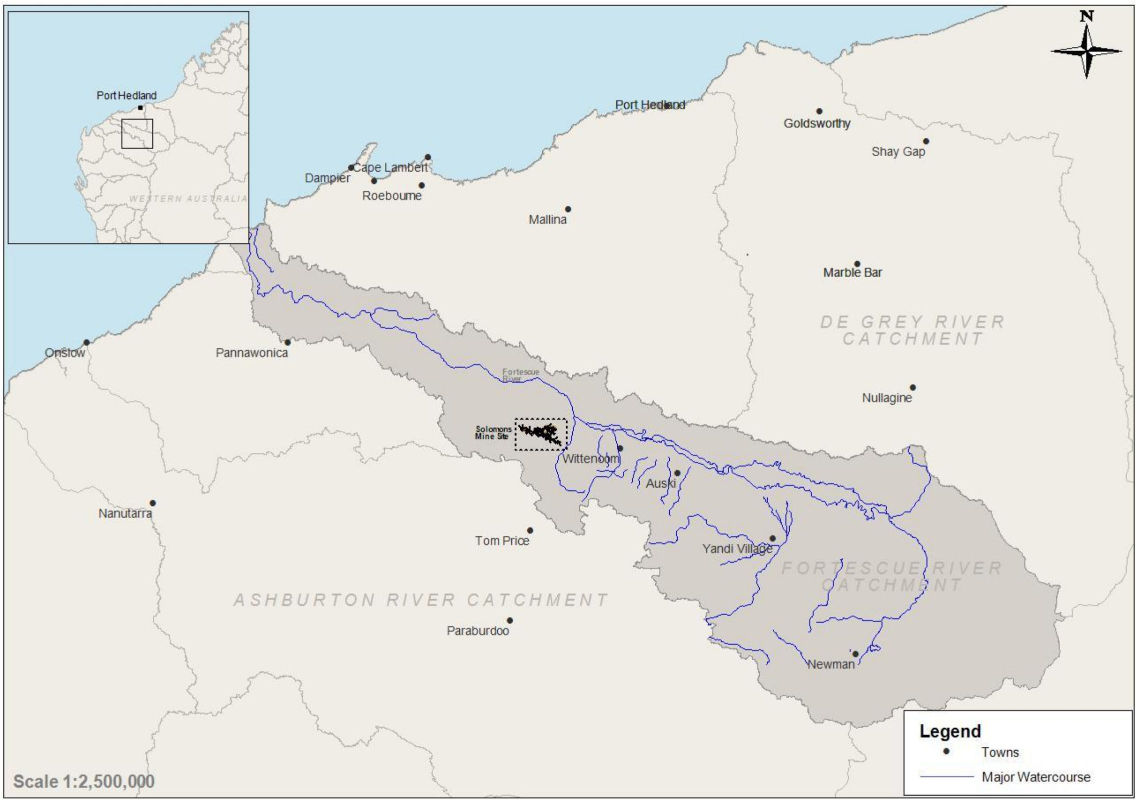


Figure 1-1: Location Map and Minesite

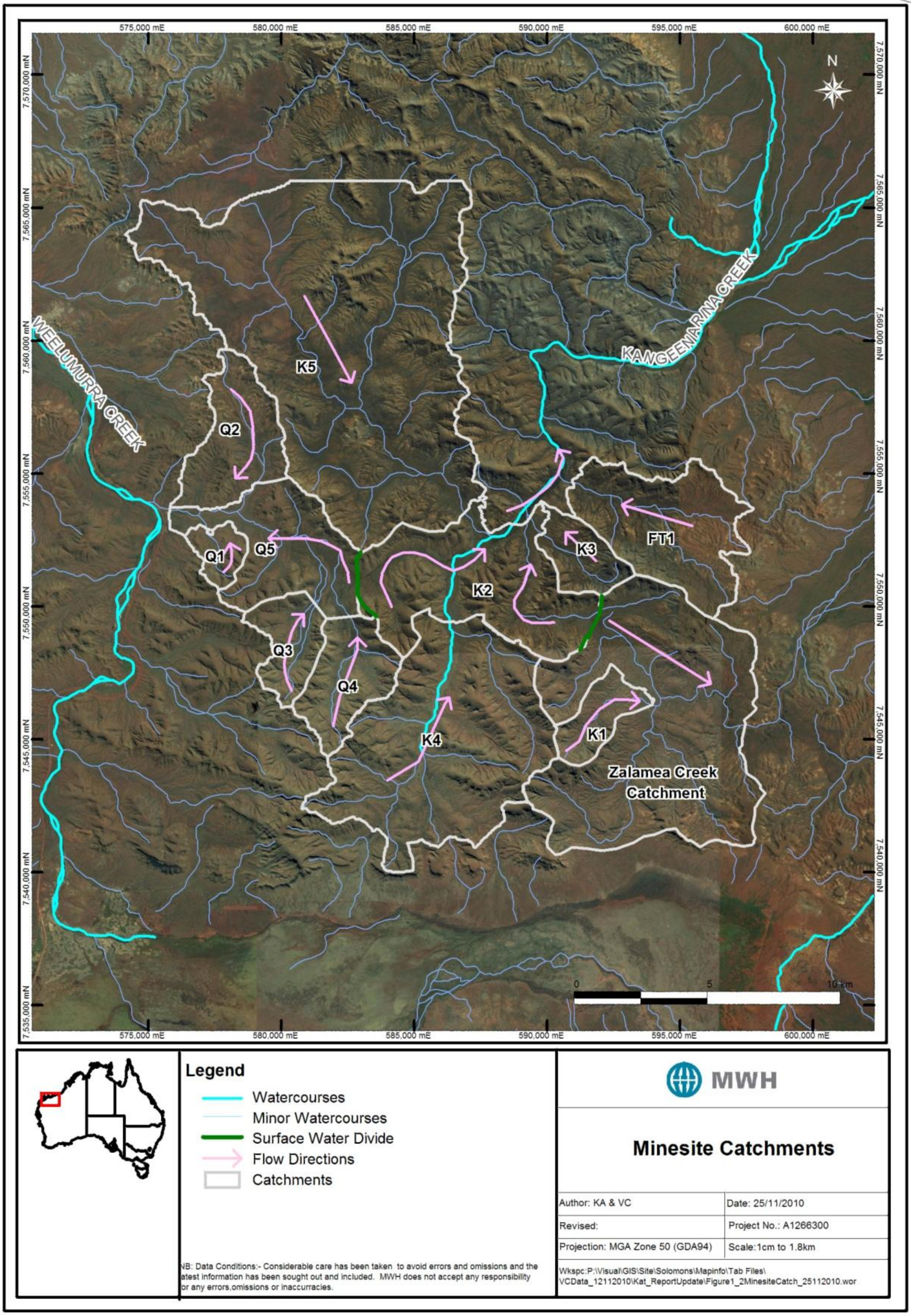


Figure 1-2: Minesite Catchment Boundaries

1.3 Flood Management Options Summary

This section provides a summary list of the flood management options identified. Section 7 provides a more detailed description of the options and an assessment of the relative performance of each option. Section 8 provides an assessment of the impact of implementing the proposed options for each of the 5 time periods of the current mine plan.

1.3.1 Summary

The design standard generally adopted for major elements of the proposed flood protection works is 100 years Average Recurrence Interval (ARI). As recommended in guidelines prepared by the Australian National Committee on Large Dams (ANCOLD) all emergency spillways associated with detention dams will be sized for the 1,000 year ARI flood.

For this interim report the 100 year ARI flood event has been modelled to provide an assessment of the relative cost and benefit of each option. The next steps will to model 50, 20 and 10 year flood events to compare the difference in cost and benefit to designing to a lower standard than the 100 year event.

The expected operational life of the mine is 20 years or more. The current mine plan is divided into five time horizons as shown in Figure 1.3. Options to protect the mine from flooding are required only when that section of the mine has commenced operation. Therefore plans of the flood protection options were compiled within five maps representing the evolution of the mine and the structures required to provide flood protection at each stage.

As described in Section 4.4, the CID is located mostly within the existing active drainage channel. In areas such as the main valley of the Queens pit, a significant proportion of the catchment will eventually be taken up by the pit. A similar situation will occur within the south eastern part of the Valley of the Kings. In these areas there are no clear options for diverting flood waters around the pit. Also, as the pit occupies such a large part of the catchment, the benefit of excluding a relatively small proportion of runoff from entering the pit is less.

On the other hand, the two largest catchments within the project area contain very little pit area. These are the South Kangeenarina (K4) catchment and the North West (K5) catchment that discharges just north of the Trinity area. These catchments have the potential to generate significant peak flows and volumes which if not controlled will discharge into the pit.

A discussion of the probability of a particular flood occurring within the life of the mine is included in Section 1.4.

1.3.2 Flood Management Options Considered

In order to more easily identify catchments and the options associated with them, an arbitrary labelling convention was adopted. The convention uses K1 to K5 for the Valley of The Kings catchments and Q1 to Q5 for options considered for the Valley of The Queens mine.

Table 1-1 lists the options considered during the assessment and Figure 1-4 shows their location.

Table 1-1: List of the Possible Flood Management Options

Catchment ID	Option Name	Description	Time Horizon (Stage)
		Valley of the Kings	
K1	K1 Bund and Diversion Channel	Temporary bund and diversion channel to direct flows from small catchment south toward Zalamea Creek during intermediate stage of mine life.	1 to 3
K2	K2 Bund and Diversion Channel	Diversion of flows from small catchment around south extent of pit to direct flow into Zalamea Creek	2 to End
K3	K3 Bund and Diversion Channel	Diversion of flows from TSF catchment away from pit boundary and to minimise impact on ore processing area to the north	2 to End
K4	K4 Land Bridge	Land Bridge from outlet of South Kangeenarina catchment to north side of Trinity to downstream of Firetail catchment. Mine plan will need to be modified to delay mining a slice of ore beneath the land bridge until the end of the operation. The bridge will also provide a transport link between the South Kangeenarina and Queens areas to the processing area adjacent to Firetail.	2 to End
K5	K5 Detention Dam	Detention dam to contain flood water from large $120km^2$ North West catchment	2 to End
		Valley of the Queens	
Q1	Q1 Bund and Diversion Channel	Diversion of flows past the southern end of the Queens pit.	3 to End
Q2	Q2 Bund and Diversion Channel	Diversion of flows past the northern end of the Queens pit.	3 to End
Q3	Q3 Detention Dam	Detain floodwaters from the catchment to the south of Queens pit to attenuate flows.	5 to End
Q4	Q4 Detention Dam	Detain floodwaters from the catchment to the south of Queens pit to attenuate flows.	4 to End
Q5	Q5 Drainage Channel	Relatively low capacity drainage channel to transfer water to downstream of the mine from the two small southern detention dams (Q3 and Q4). The channel would also intercept some hillside runoff that would otherwise flow into the pit.	5 to End
	Do Nothing (Status Quo)	For all options there is the alternative of letting floodwater flow directly into the pit and gravitate down-slope to a pit floor sump area. Water would be pumped out after the storm event.	All stages

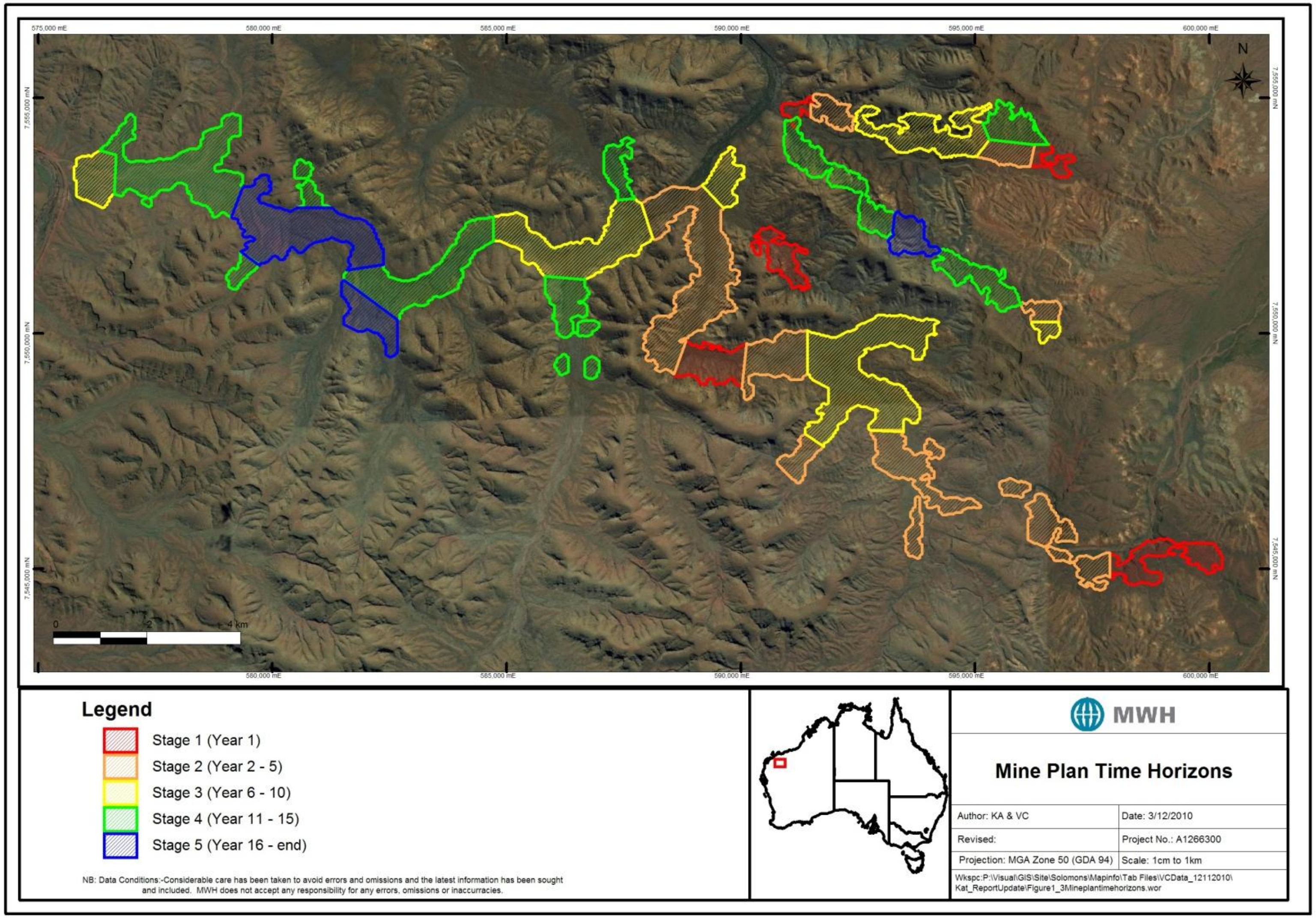
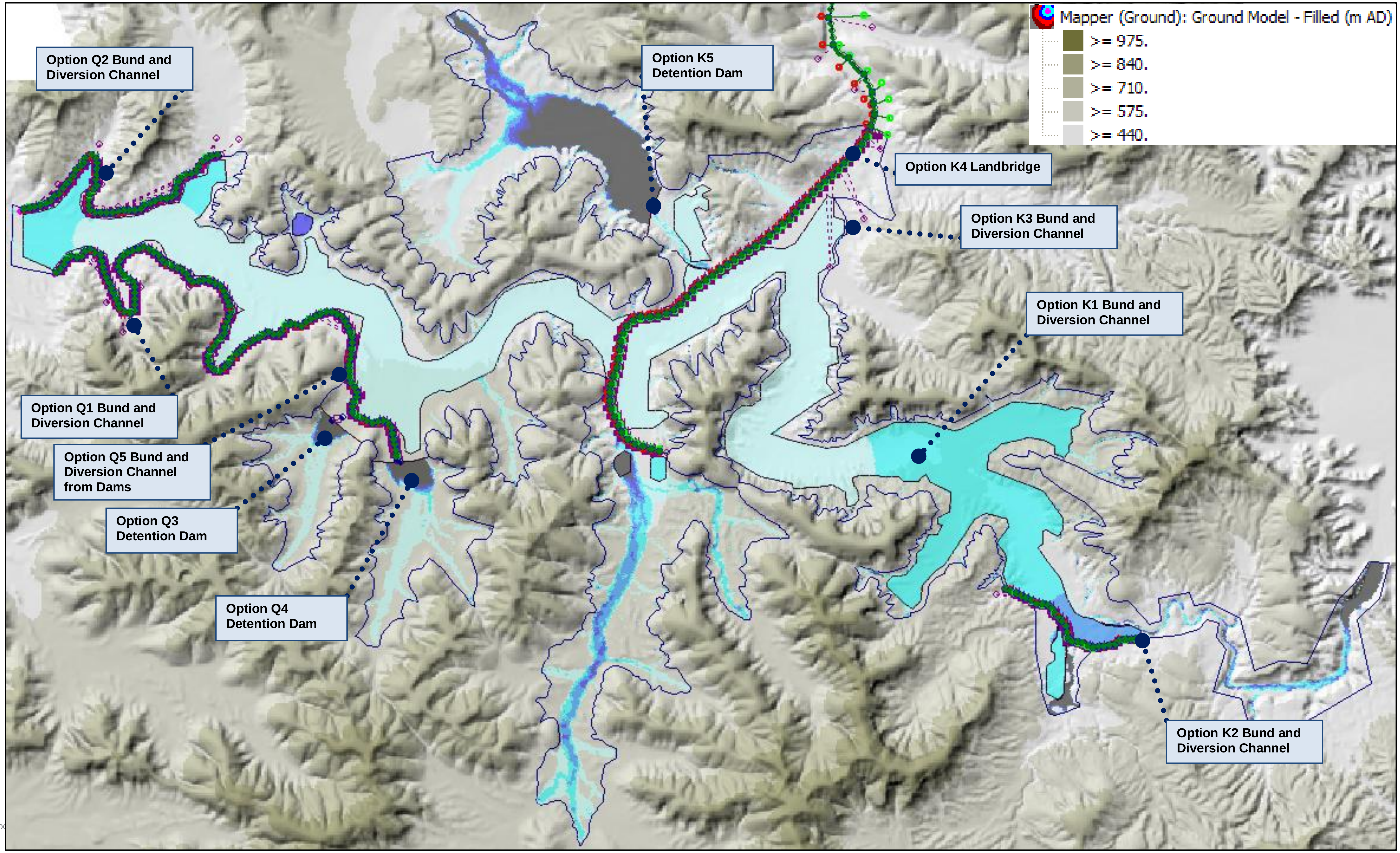


Figure 1-3: Mine Time Horizons

Figure 1-4: Flood Management Options



1.4 Design standard adopted

The design standard adopted in this report for key elements of the flood protection options is the 100 year ARI flood event. An alternative standard of 50 years is also discussed. A 1000 year ARI standard will be adopted for detention dam emergency spillways.

The following relationship describes the probability of a design standard being exceeded during the operational life of the mine where (*p*) is the probability of a rainfall event exceeding the design standard over the course of the mine operation lifetime, (*Tr)* is the 100 year design standard criterion, and (*n*) is the design life of the mine understood to be around 13 years.

For example: for an *n*=20 year design life for the entire project, the probability (*p*) of encountering a *Tr*=100 year ARI rainfall event is given by

$$p = 1 - \left[\frac{(T_r - 1)}{T_r}\right]^n = 1 - \left[\frac{(100-1)}{100}\right]^{20} = 0.18$$

In other words, there is a 18% chance that a 100 year ARI event (or greater) flood will occur in the next 20 years in which case the pit will receive runoff overflows that exceed the surface water management scheme capacity.

Table 1-2 summarises the design standards adopted, along with the estimated risk of exceedance.

Table 1-2: Design Standard & Probability of Exceedance

Design Element	Engineering Assessment		
	Design Life	Design Standard	Risk of Design Exceedance
Detention Dams	20 yr mine life	100 yr ARI detention capacity, 50 yr ARI detention capacity, 20 yr ARI detention capacity 10 yr ARI detention capacity, 1000 yr ARI spillway capacity	*Tr = 100, n=20, p= 18%* *Tr = 50, n=20, p= 33%* *Tr = 20, n=20, p= 64%* *Tr = 10, n=20, p= 88%* *Tr = 1000, n =20 p= 2%*
Diversion Channels & Bunds	20 yr mine life	100 year ARI capacity 50 year ARI capacity 10 year ARI capacity	*Tr = 100, n=20, p= 18%* *Tr = 50, n=20, p= 33%* *Tr = 10, n=20, p= 88%*

Assuming a mine life of around 20 years, there is an 18% chance of the 100 year capacity dams and diversion channels being exceeded By comparison, a 50 year ARI structure has a 33% chance of its capacity being exceeded during a 20 year period and a 10 year ARI structure has a 88% chance of being exceeded during a 20 year period.

2. Catchment Characteristics

2.1 Regional Catchment

The Solomon Stage 1 mine site is located in the Hamersley Ranges within the Fortescue River Basin, approximately 50 km north of Tom Price. Karajini National Park is to the south east of the project area. The Fortescue River Basin as a whole has an area of 49,710 km^2. It is divided into two sections, the Upper and Lower Fortescue River catchments, with catchment areas of 29,820 km^2 and 19,890 km^2, respectively.

The Upper catchment incorporates the area upstream of Goodiadarrie Crossing and is relatively flat with the downstream portion of the main Fortescue River flowing through a marshy area (Fortescue Marsh) with poorly-defined channel geometry. The major tributaries contributing to the Fortescue Marsh are Weeli Wooli Creek, Yandicoogina Creek and Mindy Mindy Creek.

The Lower Fortescue catchment can be divided into two sections. The upper Lower Fortescue is between Gregory's Gorge and Goodiadarrie Crossing, this part of the catchment is flat and the river channel is poorly defined. The Solomons Stage 1 project area contributes to this section; the upper watershed of the Lower Fortescue River. The remaining Lower Fortescue Catchment has better-defined river channels with the main Fortescue River draining in a north westerly direction and discharges into the Indian Ocean at Diver Inlet. The major tributaries of the Fortescue River are Portland River, Booyema Creek, Macklin Creek and Nallanaring Creek.

The upper catchment of the Lower Fortescue River is bounded by the Chichester Range in the north and the Hamersley Range in the south. In the south, the old plateau surface is being incised by streams, creating deep gorges such as Munina and Dales Gorge in the east and Wittenoon and Range Gorge in the west. Streamflows through the gorges drain into the Fortescue River in the north. These streams are ephemeral, except for chains of large pools, supplemented by groundwater seepages that may last for considerable periods. Most of the south-flowing streams to the north of the catchment, within the Chichester Range, discharge into the Fortescue River. However, they are often lost as recharge into the alluvial soils of the Fortescue Plain before reaching the river as surface drainage.

2.2 Local Catchment

The Project catchment area contributes to the upper Lower Fortescue River Watershed, as discussed in Section 2.1. The major catchments of the project area are shown in Figure 1-2. The catchments of the Valley of the Queens drain in a westerly direction towards the Weelumurra Creek. Weelumurra Creek flows in a northly direction along the western boundary of the Queens Pit and converges with the Fortescue River approximately 35km downstream of the project area.

Kangeeenarina Creek is the main drainage system through the Kings and project area, flowing in a north easterly direction towards the Fortescue River plains. The Kangeenarina Creek Catchment extends nearly to Hamersley Road in the south and to the foot hills of Mount Margaret in the north as shown in Figure 1-2.

The Zalamea Creek catchment encompassing the eastern section of the Kings drains in a north easterly direction towards the poorly defined Southern Branch of the Fortescue River, which converges with the main Fortescue River channel not far downstream. The catchment divide between the Kangeenarina Creek and Zalamea Creek within the Kings Pit area is not a well defined boundary. A slight topographic rise acts as the catchment boundary.

2.3 Geomorphology

The ranges where the Solomon Mine is located are a remnant of a much larger mountain system. This results in the main valleys having significantly larger capacity than is required to drain the existing catchment area. This has resulted in the valley floor filling up with sediment and gives rise to very flat channel gradients.

The geomorphology and in particular, drainage direction is influenced by the slope of the CID and the underlying indurated conglomerate. These units are (generally) tilted to the northwest which means they are exposed at high elevations in the southwest and are buried beneath the existing landform to the northwest.

Although the tilted CID results in a generally northwest trending drainage system, more recent geological events (subsidence in the eastern area of the site?) have resulted in the formation of a relatively steep incised channel which now drains to the east. This results in a catchment divide occurring in the middle of a valley flow as indicated in Figure 1-2.

2.4 Landsystems

Figure 2.1 displays the different land systems of the local Solomon area. The predominate land systems are:

- Newman Land System: Rugged jaspilite plateaux, ridges & mountains supporting hard Spinifex grasslands;
- Boolgeeda Land System: Stony lower plains below hill systems supporting hard and soft Spinifex grasslands and mulga shrublands;
- Platform Land System: Dissected slopes and raised plains supporting hard spinifex grasslands;
- River Land System: Active floodplains and major rivers supporting grassy eucalypt woodlands, tussock grasslands and soft Spinifex grasslands.

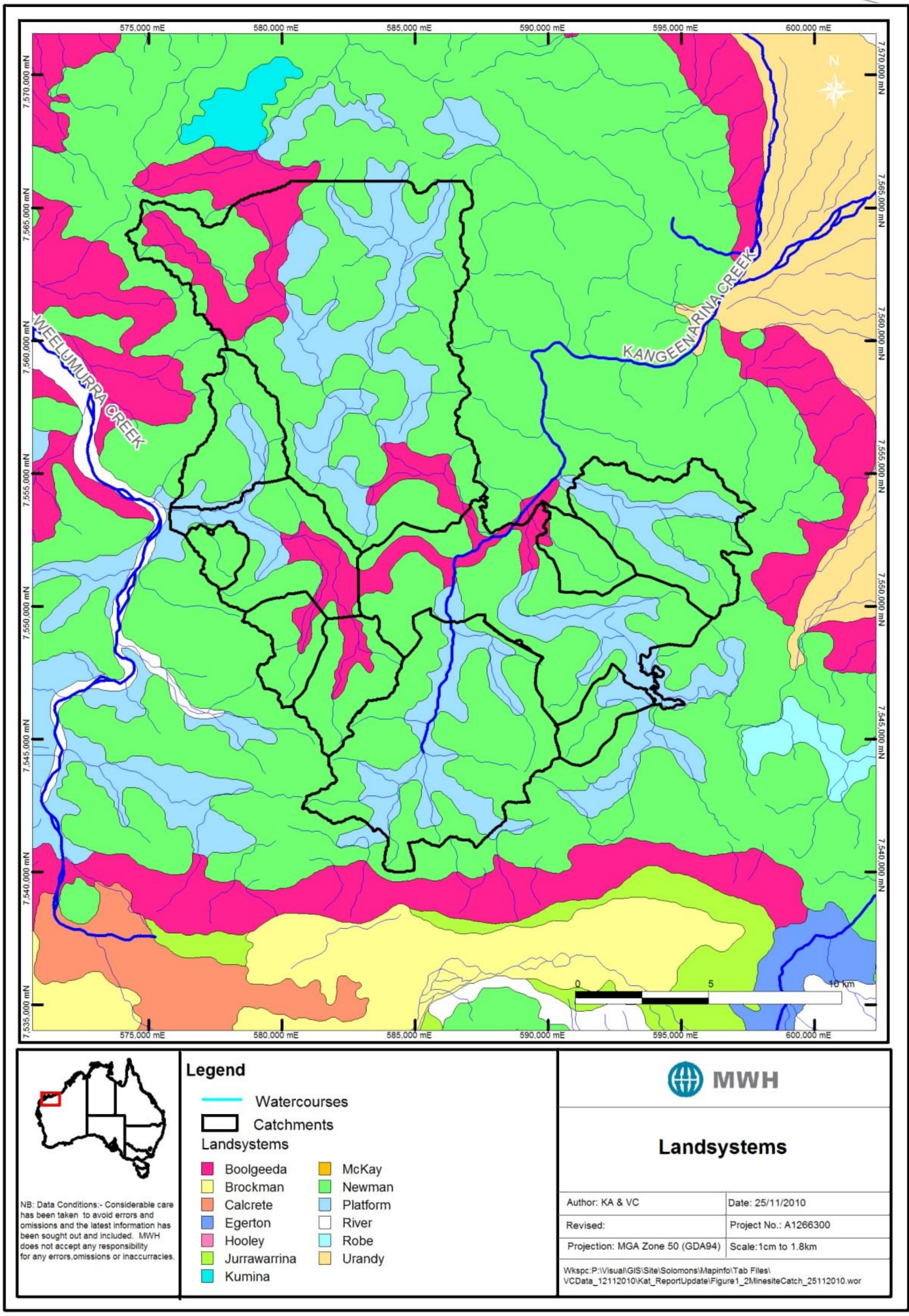


Figure 2.1: Land Systems of the Solomon Project Area

3. Regional Hydrology and Climate

3.1 Streamflow

Currently there are 9 operating streamflow gauging stations within the Fortescue River Basin, as listed in Table 3-1and shown in Figure 3-1. There are only two operating gauges within the upper Lower Fortescue River Catchment; Fortescue River at Gregory Gorge (Site 708002) and Fortescue River at Deep Reach (Site 708005). Deep Reach is approximately 13 km upstream of Gregory Gorge and does not have a stage versus discharge rating relationship, therefore the flow characteristics of Gregory Gorge gauging station approximately 95 Km downstream from the Solomons site are detailed below.

The monthly streamflow distributions and the total annual discharge plots for the Fortescue River at Gregory Gorge (Site 708002) gauging station are shown in Figure 3-2 and Figure 3-3, respectively. The distributions show February to be the dominant runoff month; March also has high runoff. On the other hand, streamflows are minimal between July and November. The large differences between the mean and median monthly data demonstrate the highly variable nature of the catchment streamflows.

The annual streamflow volumes in Lower Fortescue River watershed are highly variable, with flow typically only in response to large rainfall events. The largest annual flows recorded at Gregory Gorge were in 1975 (1,181,000 ML) and 2006 (1,141,000 ML).

Table 3-1: Steamflow Gauging Stations

Station No.	Station Name	River Name	Catchment Area (Km^2)	Latitude	Longitude	Date Opened	Operating Agency
708002	Gregory Gorge	Fortescue	14629.5	-21.56	116.92	31/05/1965	DOW (WA)
708003	Jimbegnyinoo Pool	Fortescue	18371.5	-21.33	116.16	30/10/1968	DOW (WA)
708011	Newman	Fortescue	2822.1	-23.4	119.79	7/01/1980	DOW (WA)
708005	Deep Reach	Fortescue	13865.6	-21.61	117.11	30/05/1965	DOW (WA)
708015	Bilanoo	Fortescue	18401.8	-21.29	116.14	9/12/1975	DOW (WA)
708001	Flat Rocks	Marillana Ck	1369.5	-22.72	118.97	13/08/1967	DOW (WA)
708016	Weeli Wolli Springs	Weeli Wolli	1444.7	-22.92	119.21	6/10/1997	DOW (WA)
708014	Tarina	Weeli Wolli Ck	1511.8	-22.88	119.23	8/05/1985	DOW (WA)
708013	Waterloo Bore	Weeli Wolli Ck	3990.8	-22.73	119.34	28/11/1984	DOW (WA)

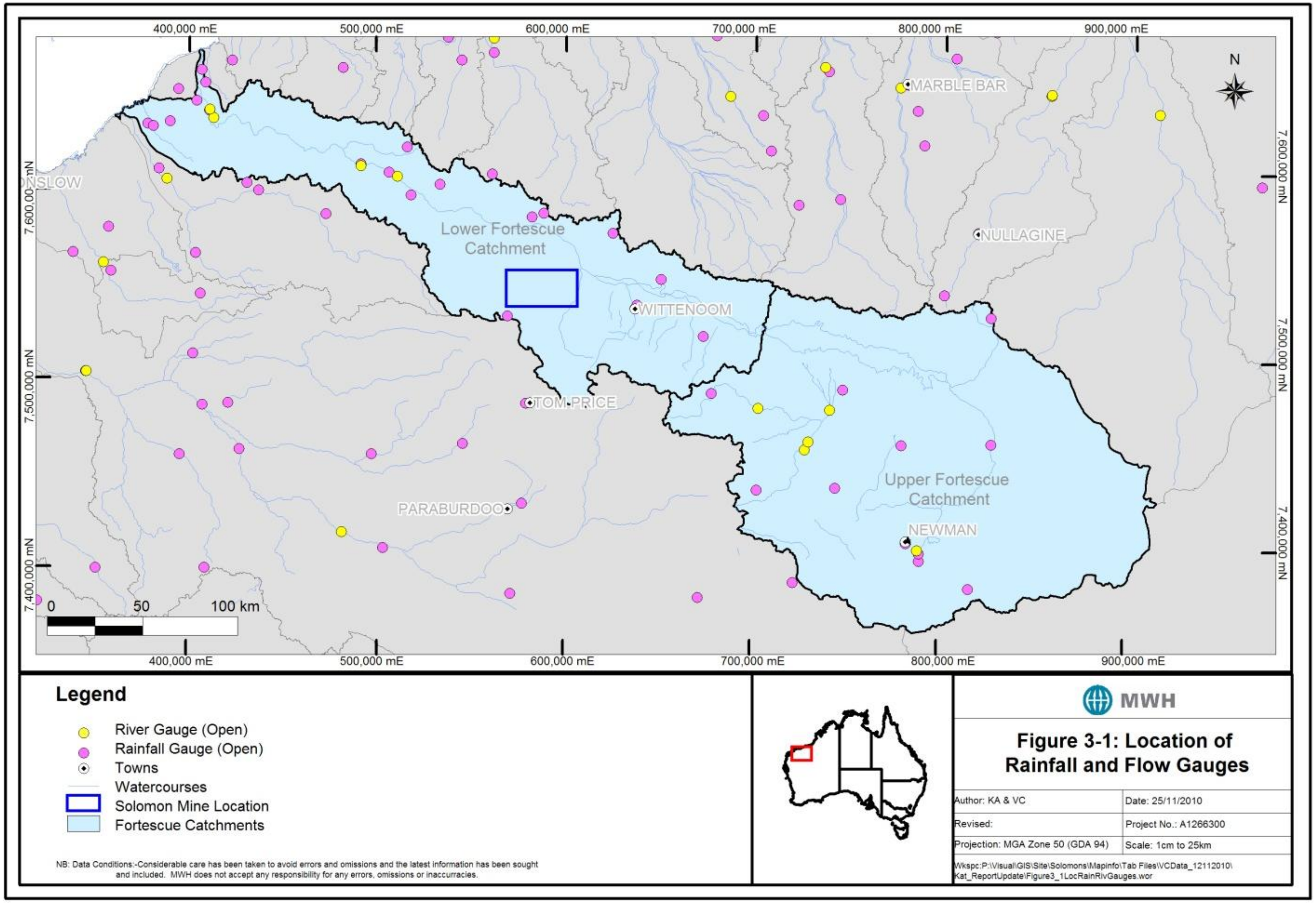


Figure 3-1: Rainfall and Flow Gauge Locations

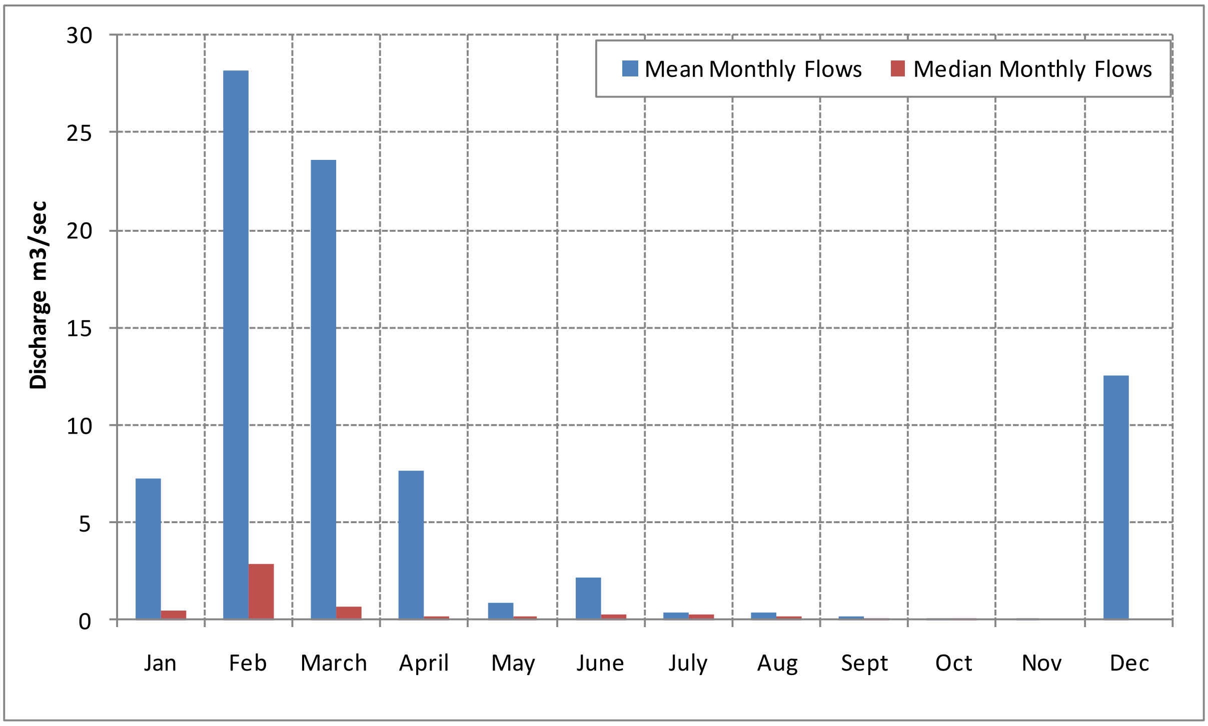


Figure 3-2: Average Monthly Flow Distribution (1969–2009), Fortescue River – Gregory Gorge (708002)

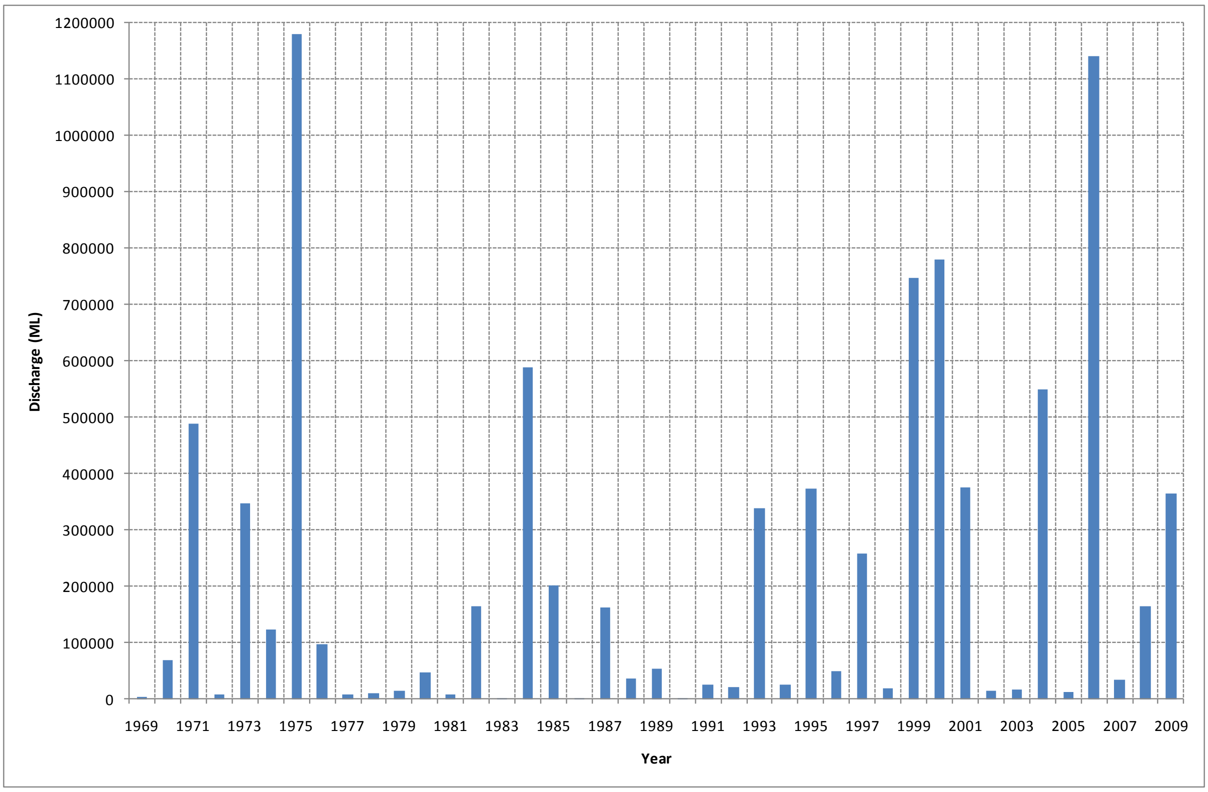


Figure 3-3: Annual Streamflow, Fortescue River – Gregory Gorge (708002)

3.2 Climate

The climate of the region is described as semi-arid to arid and is characterised by hot summers and warm winters. The region experiences a climate of extremes, where severe droughts and major floods can occur at close intervals.

Meteorological data are available from two Bureau of Meteorological Station (BOM) locations in proximity to the project area. Data is available from:

- Wittenoom (BOM No. 005026) data available 1949 to present. This meteorological station is located approximately 50 km northeast of the project area.

- Tom Price (BOM No. 005072) data available 1972 to present. This station is located approximately 53 km southwest of the project area.

A summary of long term meteorological data from Wittenoom and Tom Price is listed in Table 3-2.

Table 3-2: Climatic Data Summary (Wittenoom and Tom Price)

Month	*Wittenoom			*Tom Price		
	Mean Daily Maximum Temp (°C)	Mean Daily Minimum Temp (°C)	Mean Monthly Rainfall (mm)	Mean Daily Maximum Temp (°C)	Mean Daily Minimum Temp (°C)	Mean Monthly Rainfall (mm)
January	39.6	26.1	103	38.5	23	79.3
February	37.8	25.3	109.1	36.2	22.4	93.9
March	36.7	24.3	70.7	34.2	20.6	62.1
April	33.1	21.2	28.7	31.6	17.4	31
May	27.7	16.1	27.4	27.6	12	20.4
June	24.5	12.8	28.3	23.5	8	25.3
July	24.2	11.5	14.3	23	7.2	16.8
August	26.7	13.2	8.8	25.5	8.5	10.8
September	31.1	16.8	2.3	29.2	11.4	2.3
October	35.3	20.6	3.7	33.6	16	4.5
November	38	23.6	8.8	35.6	18.8	10.8
December	39.6	25.4	49.5	37.8	21.7	40.6
Annual	32	19.7	454.2	31.4	15.6	400.2

Notes:
*Periods for calculating statistical data vary between meteorological stations. Wittenoom (Temperature data 1951-2010 and Rainfall data 1950-2010). Tom Price (Temperature data 1997-2010 and Rainfall data 1972-2010).

Source: Bureau of Meteorology Climate Averages Station No. 005026 and 005072 respectively

Temperature variations in the region can be large, with the average daily maximum temperatures rising to 35 to 40^{0}C in summer and dropping to a minimum of 11^{0}C in winter.

Annual potential evaporation is 3,175 mm (mean daily average 8.7 mm). The excess of evaporation over rainfall, which is greater than a factor of ten, is typical for arid and semi arid areas in Australia (Figure 3-4).

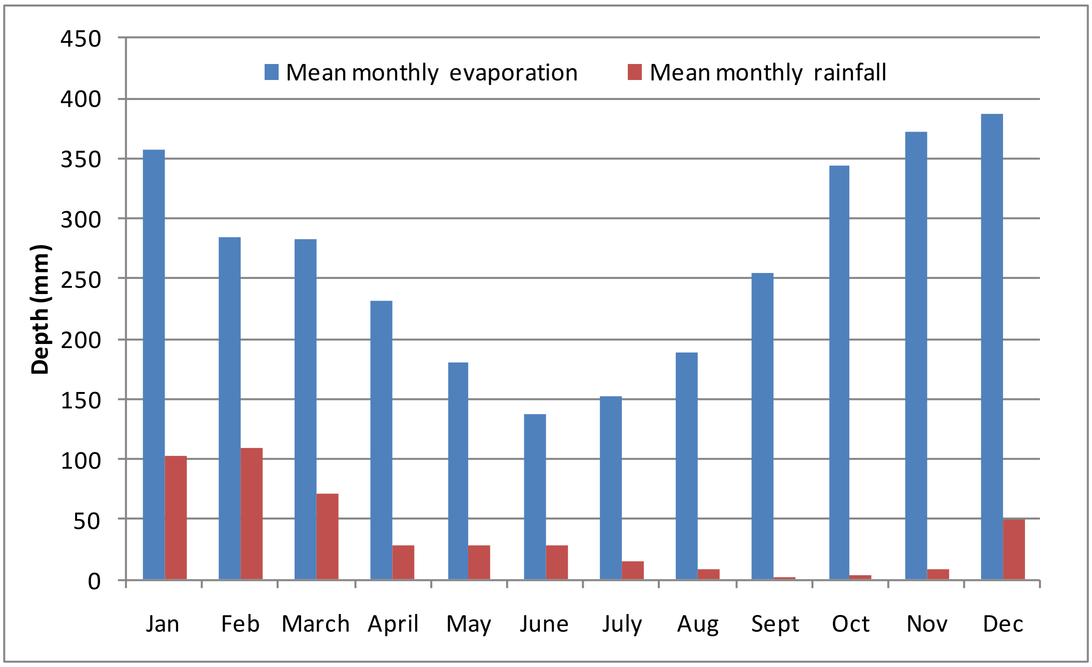


Figure 3-4: Mean monthly evaporation and rainfall at Wittenoom (005026)

Rain falls mainly in the summer months from January to March, and is unusual between July and October. Most of the summer rain comes from scattered thunderstorms, producing heavy localised falls in short periods. In addition, tropical lows that usually originate off the Pilbara coast can bring widespread rain to the region. A secondary peak in the monthly rainfall can occur in May as a result of rainfall caused by tropical cloud bands, which intermittently affect the area mostly in May and June. Rainfall in general is unreliable and highly variable, which predominantly relates to the random nature of localised thunderstorms and cyclonic lows passing through the region.

Annual rainfall totals in the region are also highly variable. Figure 3-5 displays the annual rainfall at Hamersley (005005). Table 3-3 details the mean and median annual rainfall and also the year of highest recorded rainfall for rain gauges in the local area. The contrast in recorded rainfall statistics is an indication of the highly variable temporal distribution in the region. Figure 3-1 shows the location of the rainfall gauges in proximity to the Project area.

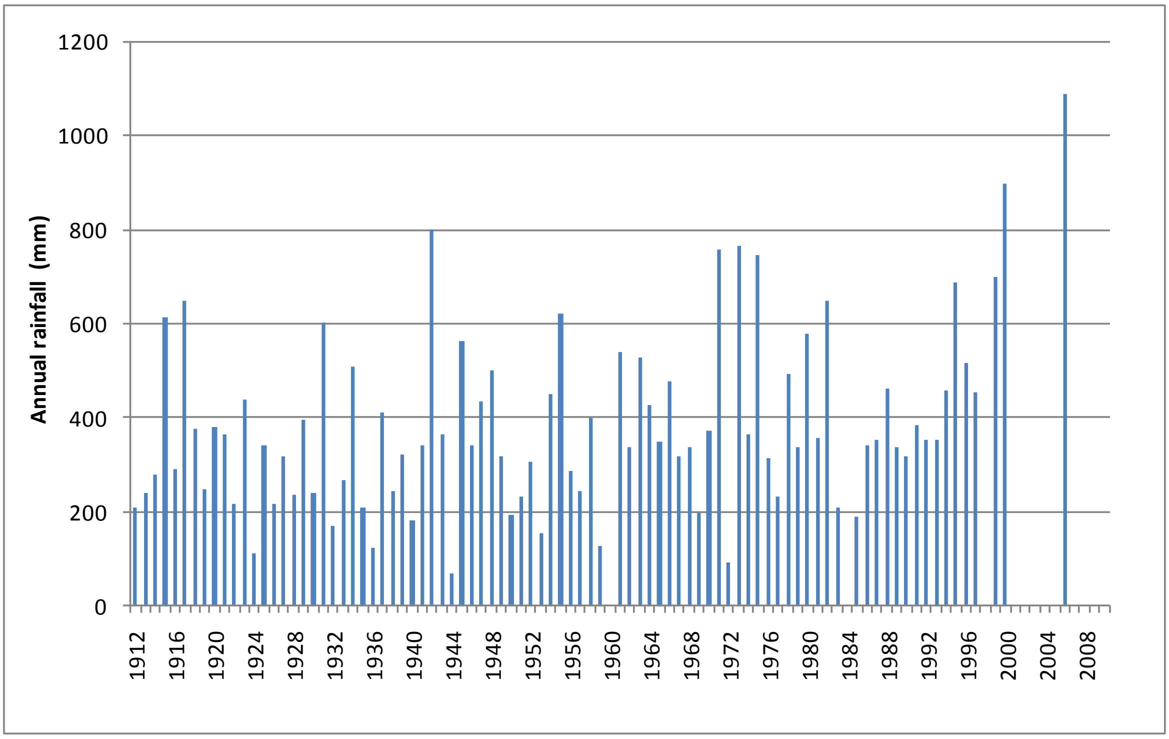


Figure 3-5: Annual Rainfall at Hamersley (005005) 1912 – 2010 *(missing data 1960, 1984, 1998, 2001-05, 2007-09)*

Table 3-3: Summary of Recorded Rain Data

Gauge ID	Location	Year Open	Approximate distance from site (km)	Mean annual Rainfall (mm)	Mean annual Rainfall (mm)	Maximum Annual		Operator
						Rainfall (mm)	Year	
005005	Hamersley	1912	13	386.4	349.4	1089.8*	2006	BOM
005001	Coolawanyah	1923	23	345.6	317.3	883.9*	2006	BOM
005014	Mount Florance	1886	25	372.8	340.2	926.7*	1999	BOM
005026	Wittenoom	1950	40	460.6	434	1344.6	1999	BOM
005055	Wittenoom Aero	1974	41	390.7	358.9	1043.4*	2006	BOM
005073	Hooley	1972	45	403.8	366.2	896.5*	2006	BOM
005015	Mulga Downs	1897	55	353.0	334.6	1125.1*	2006	BOM
505032	Millstream Borefield @ 13A	1977	75	386.5	401.6	736.8	2009	DOW
*Years of missing data								

3.2.1 Cyclones

The northwest West Australian coastline between Broome and Exmouth is the most cyclone-prone region of the Australian coastline, having the highest frequency of coastal crossings (75% between 1970-71 to 2007-2008). The cyclone season usually starts in mid December, peaks in February and ends in April (BOM). Major rainfall events have resulted from tropical cyclones within the Fortescue Basin in 1975, 1999, 2006 and 2009 which generated significant surface runoff and streamflows in the region. Table 3-4 summarises notable cyclones that have crossed the region in recent years.

Hamersley (005005; 1912 - 2010) and Collawanyah (005001; 1923 to 2010) rainfall stations both recorded their highest annual rainfall in 2006. This coincided with four tropical cyclones impacting the Pilbara coast between Onslow and Dampier. The most significant as detailed in Table 3-4 were Clare in January and Glenda in March. The resulting magnitude of the rainfall events recorded at Hamersly and Coolawanyah were between 2 and 5 year ARI following Clare and Glenda. This indicates recorded annual rainfall recorded in 2006 was an accumulation of several moderate events, not one significant rainfall event.

Table 3-4: Summary of Notable Cyclones Impacting Central Pilbara from 1975 to 2010

Tropical Cyclone	Description
Joan, 8 Dec 1975	Joan crossed the Pilbara coast just 50 km west of Port Hedland on 8 Dec as a Category 4 system. It brought heavy rainfall in the region causing significant flooding. Hamersley (005005) recorded a total of 401 mm of rain during the event (greater than a 100 Yr ARI event). Many tributaries of the Fortescue River such as the Weelumurra (flows past the western extent of Queens) Creek overflowed and caused severe flooding in the region.
Vance, 21-24 March 1999	Vance crossed the Pilbara coast near the town of Exmouth as a Category 5 cyclone on 22 March. Storm surge, a combination of very high seas and high tides caused severe erosion of the beachfront at Exmouth. The cyclone began to weaken as it moved further inland but rain from the decaying cyclone caused widespread flooding in the Central Pilbara. Hamersley (005005) recorded a cumulative (5days) total of 170 mm total of rain during the event
John, 12-16 Dec 1999	Forming on 12 Dec TC John intensified to category 5 on the 14th and crossed the Pilbara coast at Whim Creek 120 km northeast of Karratha on the 15th. Widespread rainfall caused significant flooding in the Pilbara region and mining operations were suspended at many sites. Rainfall station Hamersley (05005) reported a total of 113 mm for the duration of the activity.
Clare 9 Jan 2006	Clare was a Category 3 system when it crossed the Pilbara coast west of Dampier on 9 Jan. It brought heavy rainfall and some flooding in the region. Rainfall gauging station at Hamersley (005005) recorded a total of 138 mm of precipitation and Coolawanyah (005001) recorded a total of 168 mm during the event.
Glenda 30 March 2006	Glenda approached the Pilbara coast as a Category 4 storm and weakened to a Category 3 system when it crossed the coast at Onslow on 30 March. Rainfall stations Hamersley (005005) and Coolawanyah (005001) recoded rainfall totals of 120mm and 127mm respectively.
Tropical Low, February 2009	Significant impact was associated with a tropical low during February that caused heavy rain and flooding to the Pilbara. The low crossed the coast near Onslow and caused flooding along the Ashburton, Fortescue and nearby rivers.

4. Data Review and Site Visit

4.1 Hydrological Data

There are only two operating gauges within the upper Lower Fortescue River Catchment; Fortescue River at Gregory Gorge (Site 708002) and Fortescue River at Deep Reach (Site 708005) as discussed in Section 3.1. The two gauges are both approximately 80 to 98 Km downstream from the Solomons site.

On site water level monitoring instruments have been installed on Weelumurra Creek, Kangeenarina Creek and Zion with the intended purpose of these sensors is to measure water level in permanent pools. They will also record levels during floods and this can be used within a hydraulic model to estimate flood flows. Locations for further rainfall and flow gauging equipment have been identified to capture the rainfall variability within the local catchment and possible stream flows of the Kangeenarina Creek catchment.

4.2 Previous Hydrological Report

Task 2 of our proposal dated 9 July 2010 was to undertake a high level review of Golder and Associates December 2008 report ***Preliminary Flood Hydrology and Hydraulic Study – FMG Solomon Project.***

4.2.1 Summary

The hydrology and hydraulic work presented in the report is appropriate for the level of analysis required for a pre-feasibility investigation. The methods and software used are considered appropriate and the description of the results obtained and the parameters used are generally good.

The analysis of possible flood protection measures to minimise the impacts of flooding including inundation of pits is not particularly thorough. Only one flood management options seems to have been considered and it is not clear how this option would work in practice. A map showing the drainage channels, ore boundary and proposed embankments all together may have clarified the proposed solution.

4.2.2 Objectives

The primary objective of the work is to "*assess likely impacts on flood levels and to provide preliminary concepts on the protection required for the pits to minimise the imapacts of flooding*" A further aim of the analysis was to "*assess possible measures that would need to be implemented to allow mining to take place without risk of inundation of the pits during major storm events*"

The only flood management option investigated was the construction of an embankment longatudinally down the drainage channel to divert flows to one side of the embankmant. This would allow mining to occur on the dry side of the embankment. It is assumed that once the "dry side" has been mined, flows will be directed back into the pit to allow mining of the previous flood chanel. The description of how this would be acheived was not clear. No model results of simulated flows through the mined out pits were provided.

The main output of the analysis was to estimate the increase in velocity and depth resulting from constricting flood flows on one side of the channel.

4.2.3 Design Rainfall Estimation

Design rainfall depths are provided based on AUS-IFD Version 2.0 which uses data up to 2001. More up to date IDF tables may be obtained directly from BOM. Katrina – is this correct ???

It would have been useful to include at least an example of the temporal profile used in the design rainfall estimate.

4.2.4 RORB Model

The Valley of Queens - West End model has comparatively large sub-catchment areas, especially sub-catchment D. This leads to a relatively high Kc model coefficient compared to RORB models for other project catchments. This possibly results in the peak discharge from the Valley of Queens – West End of 3405 m^3/s for a catchment area of 1,234 km^2. This catchment area is over five times bigger than Serenity but peak flow is only 3 times greater.

Possibly dividing sub-catchment D up into smaller segments would have kept the Kc similar to other catchments.

It is assumed that no calibration of the RORB model is possible due to a lack of catchment rainfall and flow data.

For comparative purposes, flood estimates are also derived using the Pilbara Index Flood Method, based on flow records from a limited number of gauging stations in the Pilbara region and the Rational Method.

No details of parameters such as time of concentration or runoff coefficient are provided for these methods.

4.2.5 Design Hydrographs

The Serenity, Kings South and Queens 12 hour (rainfall) duration 50-year ARI hydrographs are quite different from all other durations at these sites. They are distinctly two-peaked. This obviously reflects the temporal rainfall pattern derived using Australian Rainfall and Runoff methods. 12-hour hydrographs for Queens – West End and Kings North do not display the same pattern.

The 12-hour 50-year ARI hydrograph for Serenity is also much ‘longer’ than the others and looks as though it peaks after about 12 to 13 hours. All other duration hydrographs peak relatively quickly

4.2.6 Hydraulic Modelling

The HEC-RAS model for assessing peak water levels is considered appropriate.

The runoff calculated from the hydrological/RORB analysis was applied to HEC-RAS open channel hydraulic models of the areas affected by each project pit.

A number of ‘conservative’ measures have been adopted:

- Manning’s n. A value of 0.045 has been used when it is stated that 0.03 may be more appropriate.
- Flood flow for lower cross sections are applied to upper cross sections

- Downstream boundary water level conditions for Valley of Queens. Mike ???

Peak water levels were modelled adjacent to the flood defence bund, a freeboard added and a minimum crest level defined at the upstream and downstream extents of the mine. The methodology and use of HEC-RAS for the bund assessment is reasonable.

4.3 GIS Data

Extensive GIS data were obtained from the Department of Water and Geoscience Australia. Coverage of the Fortescue and adjacent catchments included information such as regional elevation, cartography, infrastructure, utilities and hydrography.

Also obtained from the Department of Water were:

- A Water Resources Information Catalogue including GIS layers of the location of all rainfall, flow, water level and water quality stations throughout the State.

- A Geographic Data Atlas providing detailed GIS data on catchment and sub-catchment boundaries and drainage alignments.

GIS data relating to mine infrastructure, topographic contours, aerial photographs and LIDAR were provided by FMG.

All GIS data were transferred to Mapinfo to determine catchment boundaries, to develop catchment rainfall runoff models of the proposed mine areas, design mine drainage, and to assist in the assessment of the existing hydrology of the site.

4.4 Site Visit Observations

A site visit was made to the minesite as part of this investigation on 8th and 9th of September 2010. The proposed mine site was inspected. Assessments of the major drainage catchments feeding into the mine site were also undertaken.

4.4.1 Groundwater

Very little rain has fallen in the last year. The last large event was in 2006. [MWH to work out frequency of 2006 event at Solomons. Use surrounding regional long-term rainfall. Assist with extraction of rain data from Castle daily gauge if necessary.]

The 2006 cyclone increased groundwater levels and allowed dense stands of saplings to establish in stream beds in the Trinity and Zalamea areas.

Pressure transducers have been installed at (at least) three locations where permanent springs/water holes exist as shown in Figure 1. At the spring upstream of the Zion ore body in the Zalamea Creek the monitor has recorded a continuous reduction in levels within the pool since 2006. It is therefore assumed that until another extreme rainfall event occurs the water table will eventually drop to below the reach of the saplings and many of them will die off.

The upper level of the aquifer is generally coincides with the top of the CID.

The CID and surrounding bedrock has relatively high permeability and so the area of the aquifer that will be drawn down will extend some distance away from the pit boundary.

To minimize the extent of groundwater that will be drawn down and in particular the impact on groundwater levels and discharge at the springs in the Weelumurra Creek it is proposed to install a grout curtain at the lease boundary adjacent to the Tom Price Railway Road. Monitoring of water levels and flows at the springs is underway and will provide a baseline of information so that average flows and levels can be maintained once dewatering of the mine begins.

FMG have been in discussion with DoW regarding a regional (West Pilbara) strategy for enhancing water supply. The potential excess of water from the pit dewatering programme may be piped to DoW's Millstream bore field to augment supply to Karratha. The quantity of excess water will depend on ore processing requirements which are yet to be confirmed.

4.4.2 Geomorphology

The ranges where the Solomon Mine is located are a remnant of a much larger mountain system. This results in the main valleys having significantly larger hydraulic capacity than is required to drain the existing catchment area and excess sediment relative to runoff. The excess sediment has resulted in the valley floor filling up with sediment and given rise to very flat channel gradients.

The geomorphology and in particular, drainage direction is influenced by the slope of the CID and the underlying indurated conglomerate. These units are (generally) tilted to the northwest so are exposed at high elevations in the southwest and are buried beneath the existing landform to the northwest.

Although the tilted CID results in a generally northwest trending drainage system, more recent geological events (subsidence in the eastern area of the site?) have resulted in the formation of a relatively steep incised channel which now drains to the east. This results in a catchment divide occurring in the middle of a valley floor as indicated in Figure 1-2.

4.4.3 Surface water

The impact of the 2006 cyclone was evident in several places where flood debris had accumulated against the trunks of large trees. This evidence had been destroyed in places by more recent bushfires.

The locations of debris are shown in Figure 1. They were in the lower Zalamea Creek and were associated with distinct flood channels and relatively recent bed erosion. Within the stream beds of these other creeks there was a lack of flood debris and defined flood channels and bed erosion. There are several explanations for the difference in observed runoff between these two areas;

1. A rain shadow caused by the elevated Hamersley Range results in less rainfall in the Kangeenarina, King and Queens catchments.
2. The bed material within these catchments is predominantly silty with a low clay fraction. The assumption is that these materials have high permeability which results in a low storm rainfall – runoff ratio. If this is the case, rainfall will infiltrate into the creek bed material and recharge the CID aquifer and produce a lower than expected runoff hydrograph.
3. The channel slope in these areas is very flat resulting in low velocities and minimal debris and sediment transport.
4. A combination of both of these explanations.

4.4.4 Monitoring

Water level monitoring instruments have been installed at the locations shown in Figure 4-1. The intended purpose of these sensors is to measure water level in permanent pools. They will also record levels during floods and this can be used within a hydraulic model to estimate flood flows. Four piezometers have been installed in bores within the existing Solomon Mine drainage channels. It is thought that these will provide useful level information during a flood event.

Two other water level recording sites were identified and a description of location and proposed instrumentation provided. The first location is near the outlet of the South Kangeenarina Creek just upstream of its confluence with the main channel, also shown in Figure 4.2.

The second location is upstream of the confluence of the North West catchments and the main channel.

Tipping bucket recording rain gauges were proposed for four locations shown in Figure 4.2. These are;

1. Within the castle camp compound
2. In the lower Valley of the Kings catchment
3. In the lower Valley of the Queens catchment.
4. In the lower Kangeenaringa stream channel adjacent to the ore processing and transfer facility.

Information on instrument type and location were provided following the site visit.

The raingauges and water level meters will provide valuable information during the life of the mine and with any luck may record a large event before the end of the current hydrological project. In any case, the instruments will be operated for as long as possible and any new data can be used to update runoff and hydraulic models if required.

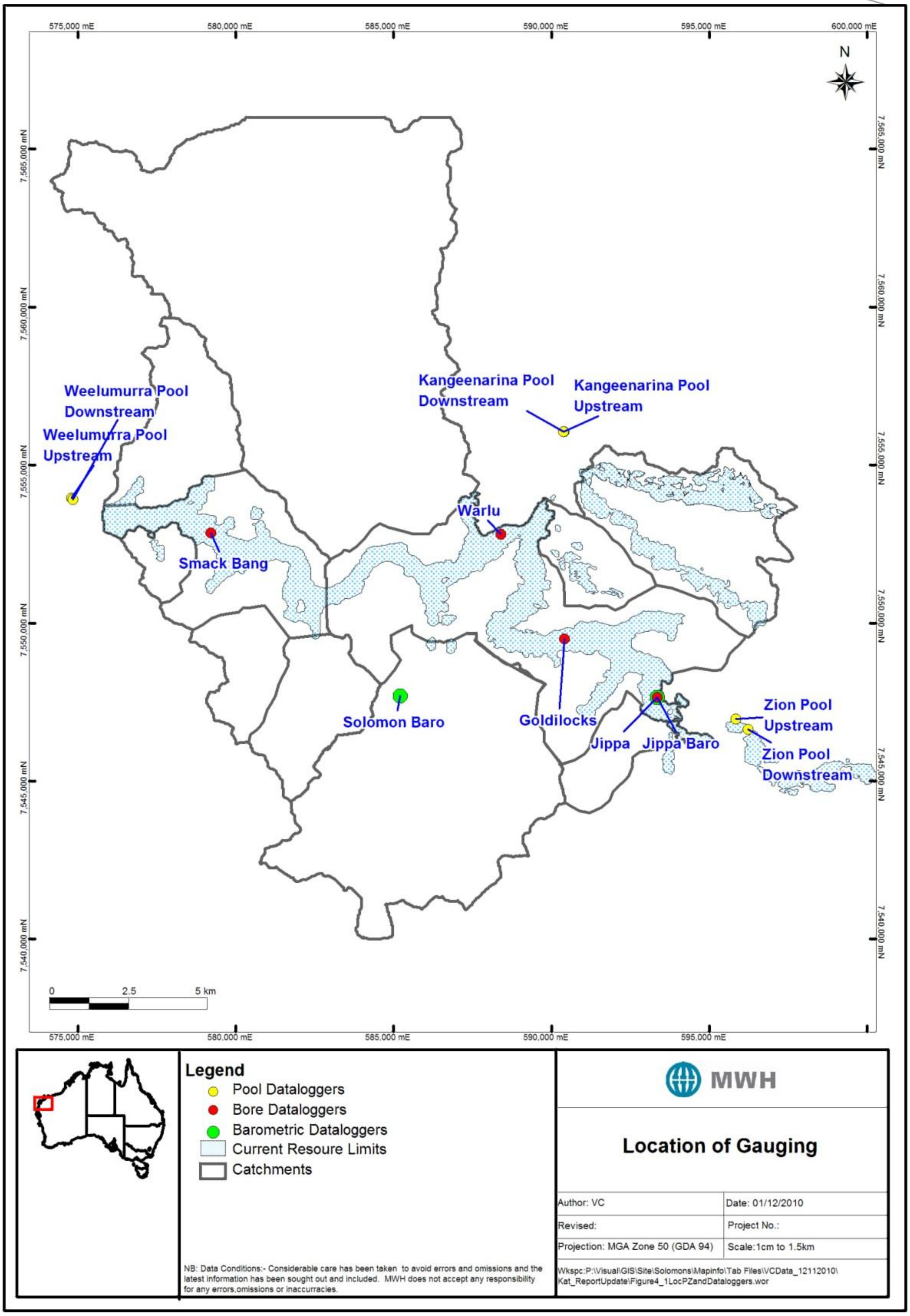


Figure 4-1: Location of Existing Hydrometric Gauges

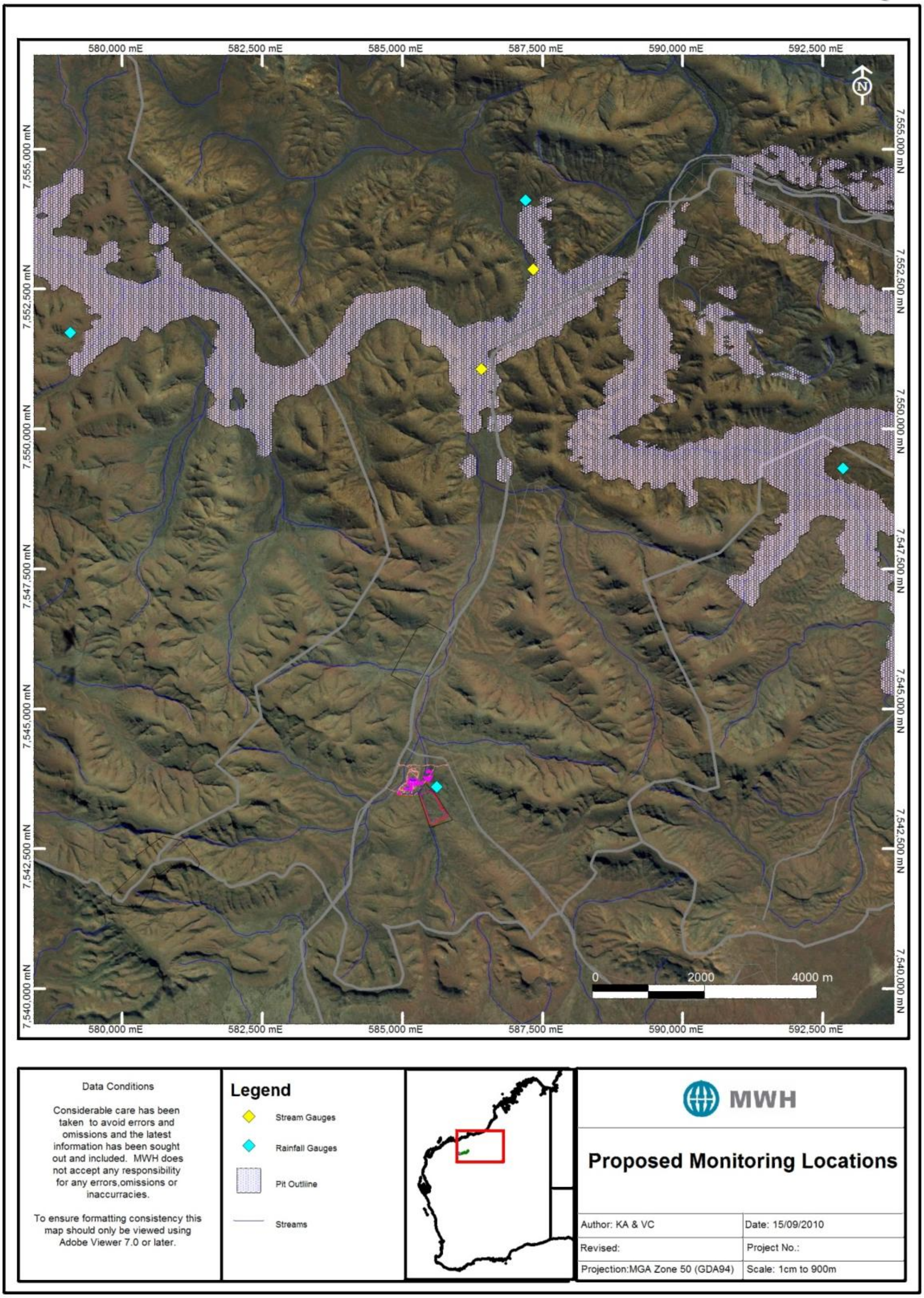


Figure 4-2: Location of Proposed Hydrometric Gauges

5. Catchment Hydrology

5.1 Introduction

As there are no flow records available for any of the drainage lines that drain across the proposed minesite, a rainfall-runoff model was developed to generate peak hydrographs for these catchments. This section describes the methods used to develop and check the design hydrographs. The simulated floods were then input to hydraulic model to test the preliminary effectiveness of the proposed flood mitigation measures in managing surface water flows and minimising runoff into the minesite area.

Design rainfall was obtained from BoM. Rainfall-runoff modelling was carried out using RORB modelling software to establish peak flow estimates. The resulting peak flows were compared to those calculated using regional and rational methods for K4 (South Kangeenarina Catchment). The rainfall-runoff model was then used to test various dam sizes and configurations.

5.2 Design Rainfall

In the absence of a long-term rainfall record at the site, the 100-year ARI design rainfall was obtained from BoM for the location 22.12S, 117.85 E at the Solomon 1 minesite.

5.2.1 Design Rainfall Totals

The design rainfall intensities (mm per hour) and depths (mm) for a range of events and durations are tabulated in Table 5-1 and Table 5-2 respectively.

Table 5-1: Solomon1 Design Rainfall Intensities from BoM (mm/hr)

Duration	5 Year ARI	10 Year ARI	20 Year ARI	50 Year ARI	100 Year ARI
30 minutes	65.3	76.6	90.9	110	125
1 hour	44.5	52.7	63.1	77.2	88.3
2 hours	28.9	34.8	42.3	52.7	61
3 hours	22.1	27	33.3	42	49.1
6 hours	13.8	17.4	21.8	28.3	33.6
12 hours	8.61	11	14	18.5	22.2
24 hours	5.32	6.79	8.66	11.4	13.7
48 hours	3.18	3.99	5.03	6.52	7.75
72 hours	2.27	2.84	3.57	4.62	5.48

Table 5-2: Solomon 1 Design Rainfall Depths from BoM (mm)

Duration	5 Year ARI	10 Year ARI	20 Year ARI	50 Year ARI	100 Year ARI
30 minutes	17.85	23.60	32.65	38.30	45.45
1 hour	23.80	31.60	44.50	52.70	63.10
2 hours	29.40	39.60	57.80	69.60	84.60
3 hours	32.40	44.10	66.30	81.00	99.90
6 hours	37.80	52.44	82.80	104.40	130.80
12 hours	45.12	63.24	103.32	132.00	168.00
24 hours	55.92	78.24	127.68	162.96	207.84
48 hours	69.12	96.00	152.64	191.52	241.44
72 hours	74.88	103.68	163.44	204.48	257.04

5.2.2 Temporal Distribution

Temporal patterns were required to convert design rainfall depth with a specific ARI to a design flood of the same frequency. Temporal patterns were obtained from the recommended profiles for Zone 7 (Western Australia – Indian Ocean) in ARR Volume 2.The patterns vary in relation to ARI, with different patterns for events of recurrence interval less than or equal to 30-years and greater than 30-years. Example temporal patterns for the 100-year 24-hour and 72-hour rainfall events are shown in Figure 5-1and Figure 5-2.

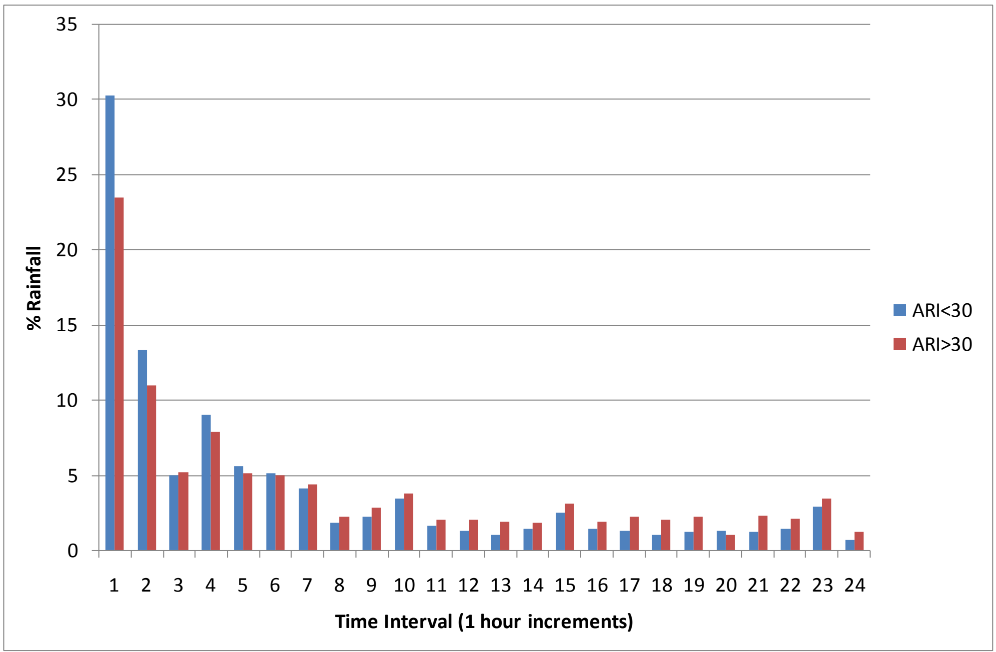


Figure 5-1:Temporal Patterns for Solomon - 24 hour duration

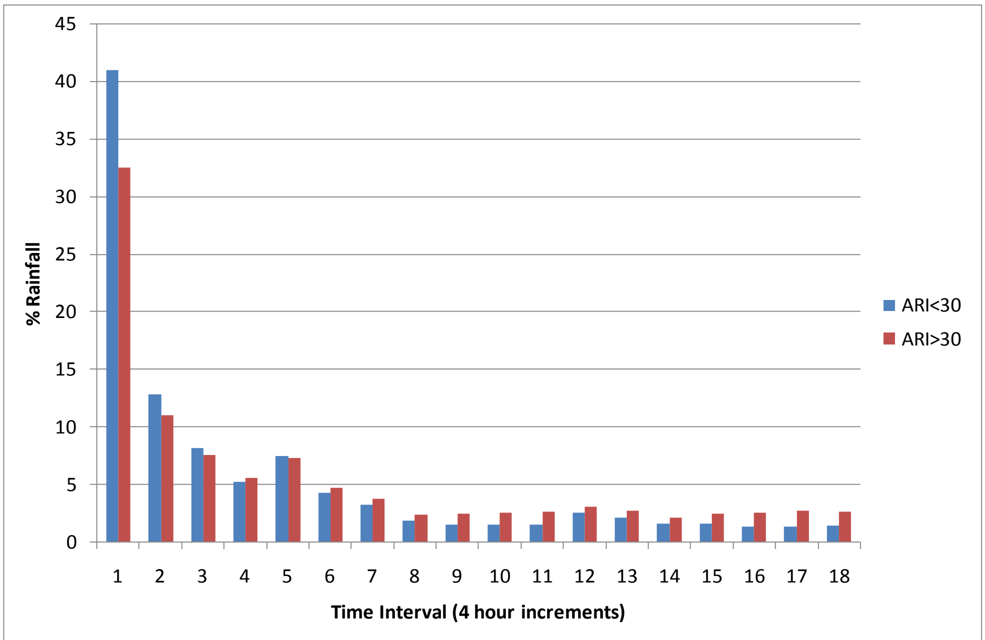


Figure 5-2: Temporal Patterns for Solomon - 72 hour duration

The temporal pattern which is adopted can have a major effect of the computed flow. The Zone 7 temporal patterns have a significant fraction of the rainfall occurring in the first time interval. It should be noted that these temporal patterns are very sensitive to the depth of the initial loss value used. In the absence of more detailed information, these temporal patterns have been adopted.

5.2.3 Critical Duration

The critical duration of a rainfall event is that which produces the highest peak flow. This duration will vary based on the size, layout and geology of the catchment. Hence a number of rainfall events with varying durations were derived to input to the rainfall-runoff model. The range of durations covered was 30 minutes to 72 hours.

5.3 Recorded Rainfall

The most recent significant floods within the project area occurred in 2006. The largest of these occurred in late February after a very wet start to the year.

Figure 3-1 shows the locations of raingauges in the Lower Fortescue Valley. The nearest open gauge to the Solomon project area is site 005005 (Hamersley) 13 km to the southwest. The Hamersley station is a daily gauge has been operating since 1912. It recorded 239mm over 4 days from Feb 27 2006. The closest automatic raingauge is at Millstream (005012), 105 km to the northwest. The Millstream gauge recorded 133mm during the same period.

5.4 Rainfall Runoff Model

An initial loss-continuing loss rainfall-runoff model was developed to estimate flood volumes and flows in the Project site. The model subtracted losses from rainfall to give rainfall-excess which was routed through the catchment and channel network to produce hydrographs. The model was used to determine design event peak flow hydrographs and investigate hydrological characteristics of the site.

The model was developed using RORB modelling software. RORB is an industry standard hydrological modelling package which has been widely used for hydrological design throughout Australia. RORB models can be set up with limited data, making it suitable for application **at** Solomons.

It was observed that generally the catchments within the project area are likely to show two kinds of runoff response. The slopes of the catchments are typically covered with Banded Iron Formation (BIF) and detrital material from the BIF. Runoff from these areas is likely to be similar or greater than typical Pilbara flows and loss values will therefore be similar to that described in ARR.

The floors of the valleys are predominantly alluvial and colluvial silts and sands overlaying CID. It is thought that infiltration in these areas will be higher than the ARR Pilbara average resulting in relatively high losses across the floodplain. To take the variation in losses into account, RORB was used to predominantly model rainfall runoff from the valley side slopes and the Infoworks hydraulic model was used to predominantly model the floodplain. Figure 5.3 displays the modelled RORB subcatchments.

The results of the combined RORB and Infoworks runoff modelling were compared with observed evidence of water levels and river bed scour during the 2006 floods. However due to the lack of event data (sub daily interval data) for the nearby Hamersley gauge the results of the comparison are considered unreliable.

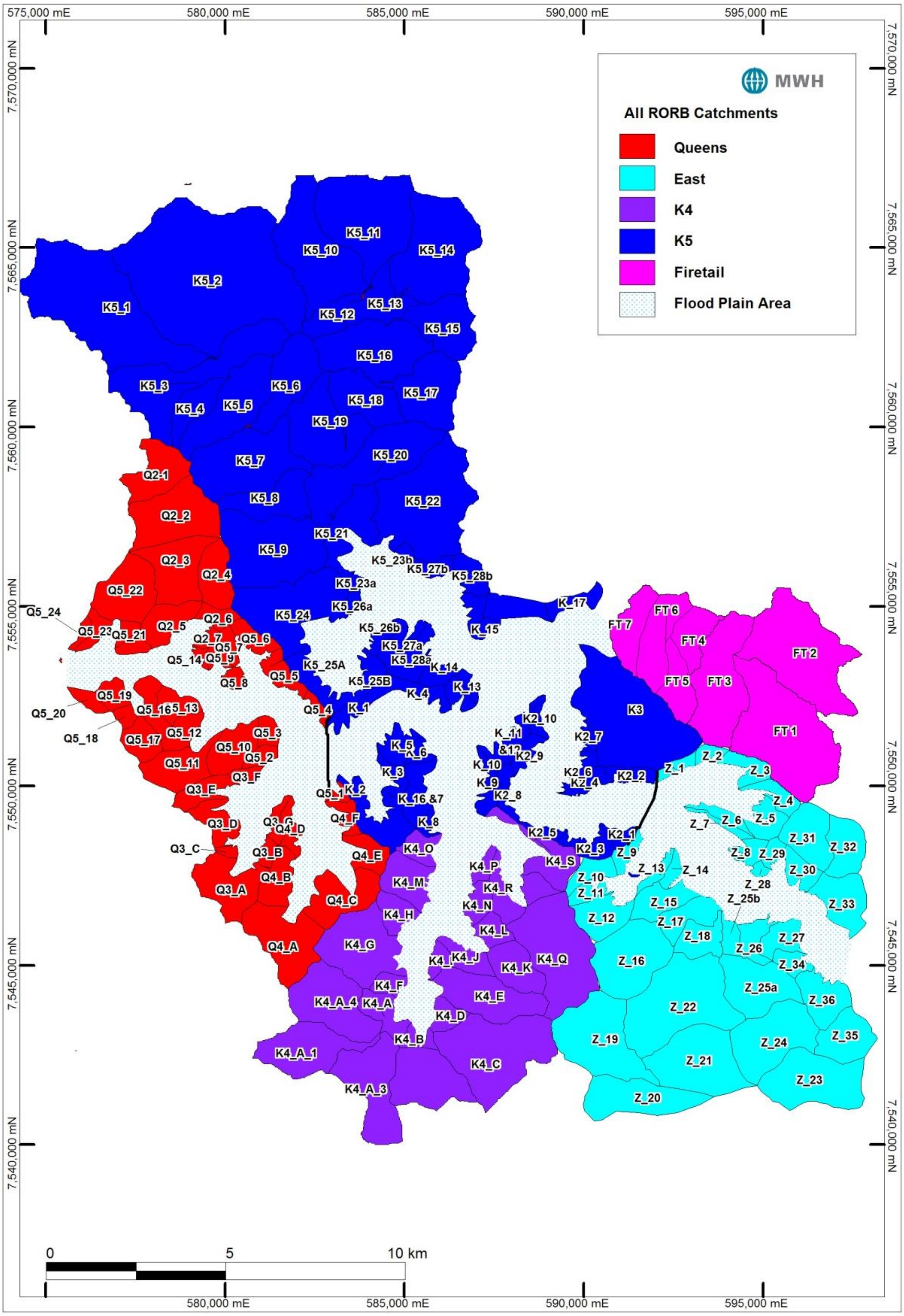


Figure 5-3: RORB Rainfall-Runoff Model modelled catchments

5.4.1 Model Loss Parameters

Where sufficient data are available, initial loss and continuing loss parameters can be derived using recorded catchment rainfall and runoff data. As no storm rainfall or flow data are yet available at the Solomon site several alternative methods were used to try and provide a rough reality check of rainfall runoff model results.

The Kangeenarina South Catchment (K4) was selected for these checks with the intention of then applying the adopted loss parameters to all modelled catchments.

The following is a description of the various methods used.

1. **Default ARR Values:** Guidance on appropriate default loss parameters for use in RORB is provided in Australian Rainfall and Runoff (Pilgrim, 1987). The design values of initial loss vary with rainfall zone, flood frequency and the degree of non linearity assumed in the catchment flood hydrograph model. The design values for the *Pilbara* rainfall zone are shown in Table 5.3.

Table 5.3: Initial loss and continuing loss values (from ARR)

ARI (years)	5	10	20	50	100
Pilbara – loam soils	40	52	47	32	22
Median continuing loss = 5 mm/hr					

*Non Linear Model (m = 0.8)

2. Loss parameters in the flood plain runoff model were increased to get a feel for the impact of suggested high infiltration rates in this part of the catchment. Default ARR loss parameters for the 100yr ARI flood were doubled and quadrupled to test the impact of these changes on flood flows and depths in the K4 catchment.

3. Comparison with peaks flow estimates from Regional and Rational Methods.

Regional methods have been derived for estimating peak flows in ungauged catchments in the Pilbara. Peak flows for the project area were estimated using the Index Flood (Regional) Method, as recommended in ARR. Estimates are based on catchment area and an average annual rainfall determined from regional isohyets provided in ARR.

Peak flows for the project area were also calculated using the Rational Method applicable to the Pilbara Region of Western Australia The rational method relates rainfall intensity for a given frequency, with the design flood magnitude of the same frequency, providing approximate peak flood flows.

A summary of the comparison between the methods described above estimated for the location at the boundary of the Trinity Pit within the K4 catchment is shown in Table 5.4

Table 5-4 Comparison of Peak Flood Estimation Methods at Lower K4 Catchment

Method	100 yr ARI (m^3/sec)
RORB/ Infoworks (ARR losses X2)	782
RORB/ Infoworks (ARR losses X4)	737
Rational Method	1059
Index Flood (Regional) Method	854

Losses adopted for the 100 year design flood were 22mm in the first hour and 5mm for every hour thereafter in the RORB catchments and 44mm in the first hour and 10mm thereafter for the floodplain catchments. As can be seen from the table above, increasing the losses applied on the floodplain from double to quadruple default ARR values did not reduce peak flows significantly.

It should be noted that the majority of gauging stations in the Pilbara Region, data from which the regional methods (Rational and Index Flood) have been derived, are poorly rated and have relatively short lengths of record. ARR recommends that flood estimates derived for these regions should be treated with caution, especially for higher average recurrence intervals and given that there is little data or the data are of poor quality. RORB and similar models should give better flood estimates than the Rational and Index Flood Methods (ARR).

5.4.2 Other Model Parameters

Published regional relationships to determine kc have been derived for Australia (ARR, 1987); for the Arid Interior/North West region of Western Australia, the following relationship is recommended and was adopted:

$$k_c = 1.06L^{0.87}S^{-0.46}$$

Where L is the mainstream length (km) measured from the catchment outlet to the most remote point on the catchment boundary and S is the equal area stream slope (m/km). A summary of the adopted model parameters are detailed in Table 5.5.

Table 5.5: Rainfall-Runoff Model Parameters

Parameter	Value	ARR Reference
IL – Initial Loss (mm)	22	Extrapolated from values in Table 3.3, ARR Vol.1, Book II, Section 3.
CL – Continuing Loss (mm/hr)	5	From Table 3.3, ARR Vol.1, Book II, Section 3.
Kc – Storativity	$k_c = 1.06L^{0.87}S^{-0.46}$	Based on RORB parameters calculated using Equation (3.29), ARR Vol.1, Book V, Section 3.
m – Non-linearity Parameter	0.8	From 3.4.4 part 1 (d) ii, ARR Vol.1, Book V, Section 3.

5.4.3 Design Flood Hydrographs

The design storm hyetographs for 5, 50 and 100 year ARIs and durations from 30 minutes hours to 48 hours were derived using the IFD data (Table 5.1) and ARR temporal patterns. These hyetographs were applied to the RORB model to obtain discharge hydrographs for the various catchments across the Project site using the parameters discussed above. The RORB results are provided in Appendix A.

As discussed, it is expected that generally the slopes of the catchments and the valley floor will show different runoff responses. The slopes of the catchments are typically covered with Banded Iron Formation (BIF) and detrital material from the BIF. Runoff from these areas is likely to be similar or greater than typical Pilbara flows and loss values will therefore be similar to that described in ARR. The floors of the valleys are predominantly alluvial and colluvial silts and sands overlaying CID. It is thought that infiltration in these areas will be higher than the ARR Pilbara average resulting in relatively high losses across the floodplain.

To take into account the variation of losses, RORB was used to predominately model rainfall from the valley side slopes and the hydraulic model was used to predominately model the valley floor. RORB flow hydrographs for the modelled valley slopes subcatchments are provided in Appendix A. The flow hydrographs derived using the RORB model for their critical duration were adopted for input into the hydraulic model. Information on the hydraulic modelling is detailed in Section 6.

The results shown in Tables 5.6 and Table 5-5 are the peak design flows from the combined RORB and hydraulic modelling for the 100 Year ARI design rainfall event.

Table 5-6 Peak flood and critical duration Kings and Firetail (Combined RORB and Hydraulic Modelling)

Catchment	Catchment Area (Km^2)	100 Year ARI	
		Peak Flow (m3/s)	Critical Duration (hr)
K2	12	68	24
K3	7	160 (RORB)	24
K4	52	782	24
K5	105	1121	24
FT1	23	451 (RORB)	24
Downstream FT & mining infrastructure	234	2168	24
Fortescue Plain	347	2987	24

Table 5-3 Peak flood and critical duration Queens (Combined RORB and Hydraulic Modelling)

Catchment	Catchment Area (Km^2)	100 Year ARI	
		Peak Flow (m3/s)	Critical Duration (hr)
Q2	12	130	24
Q3	8	82	24
Q4	11	104	24
Weelumurra Ck	55	523	24

6. Hydraulic Modelling

A combination of 2D and1D hydraulic modelling techniques were used to model six time stage scenarios based on the mine plan provided by FMG (Stages 0, 1, 2, 3, 4 and 5). All hydraulic modelling was undertaken in InfoWorks RS, a widely-used 1D/2D modelling package developed by Wallingford Software/ MWH Soft (see www.mwhsoft.com/products/). For each time stage, with the exception of Stage 0 which represents the pre-works site, two models were run, one 'do nothing' model, and another model including flood mitigation options relating to the pit extents of that stage. All the 'do nothing' models, Stage 0 and the Stage 1 model including flood mitigation options were purely 2D, while the models for Stages 2, 3, 4 and 5 with flood mitigation options included 1D elements linked to the 2D model.

6.1 2D Hydraulic Modelling Components

InfoWorks RS uses a TIN (triangular irregular network) mesh as the basis of its 2D modelling. Each vertices of the triangles in the TIN mesh are assigned an elevation using a ground model or DEM (digital elevation model). For the Solomon project area a 1m grid DEM was built using LIDAR data provided by FMG. This DEM was then imported into InfoWorks RS for use with the TIN. The coverage 2D TIN mesh, or 2D sim polygon, is shown in Figure 6.1 and has been drawn to this extent to encompass all the pits of the proposed mine and the majority of the valley floors of the catchments draining the site. At the moment the Fire Tail Valley pit and the tailings storage facility are not included in the model.

Input boundary conditions to the 2D model were flow-time point sources representing flows from the hillside catchments modelled in RORB and direct rainfall over the 2D area using loss adjusted rainfall data. The loss adjustments made to the rainfall applied in InfoWorks were as follows: an initial loss of 44mm and a continuing loss of 10mm/hr, double the values recommended in ARR for this region. Output boundary conditions were normal boundaries at two outflow points onto the Fortescue floodplain in east and one outflow into the Weelumurra Creek. An evaporation rate of 10mm/day was also applied to the 2D sim polygon.

Bed resistance (mannings n) was modelled as constant at 0.05 across 2D sim polygon. This was selected as a conservative value for preliminary phase modelling. Based on an assessment of land cover data is available for the site three types of land cover each with their own roughness value dominate the site. The mannings n value 0.05 is the lowest of the three roughness values at the site and is likely to result in higher flows but lower depths.

A number of structures have been incorporated into the model depending on the pit extent/pit stage (all of these structures are shown in Figure 6.3. The proposed mine pits were modelled using mesh polygons and porous polygons of the same extent. The mesh polygons allow an artificial ground level to be specified so were used to lower the ground within the pit extents by a given amount. The porous polygons of zero porosity and 1m height were used to model basic 1m protection bunds around the pits. For Stage 5, the mesh polygon and porous polygon extents are shown in Figure 6.2.

Walls and dams have also been incorporated into the 2D model by the use of lines/boundaries in the 2D TIN mesh that water cannot move across. The walls in the model have been used to deflect flow away or around pits, while the dams have been used restrict flow from large catchments before it reaches the pit. The dams in the model are drain by a single culvert in their bases.

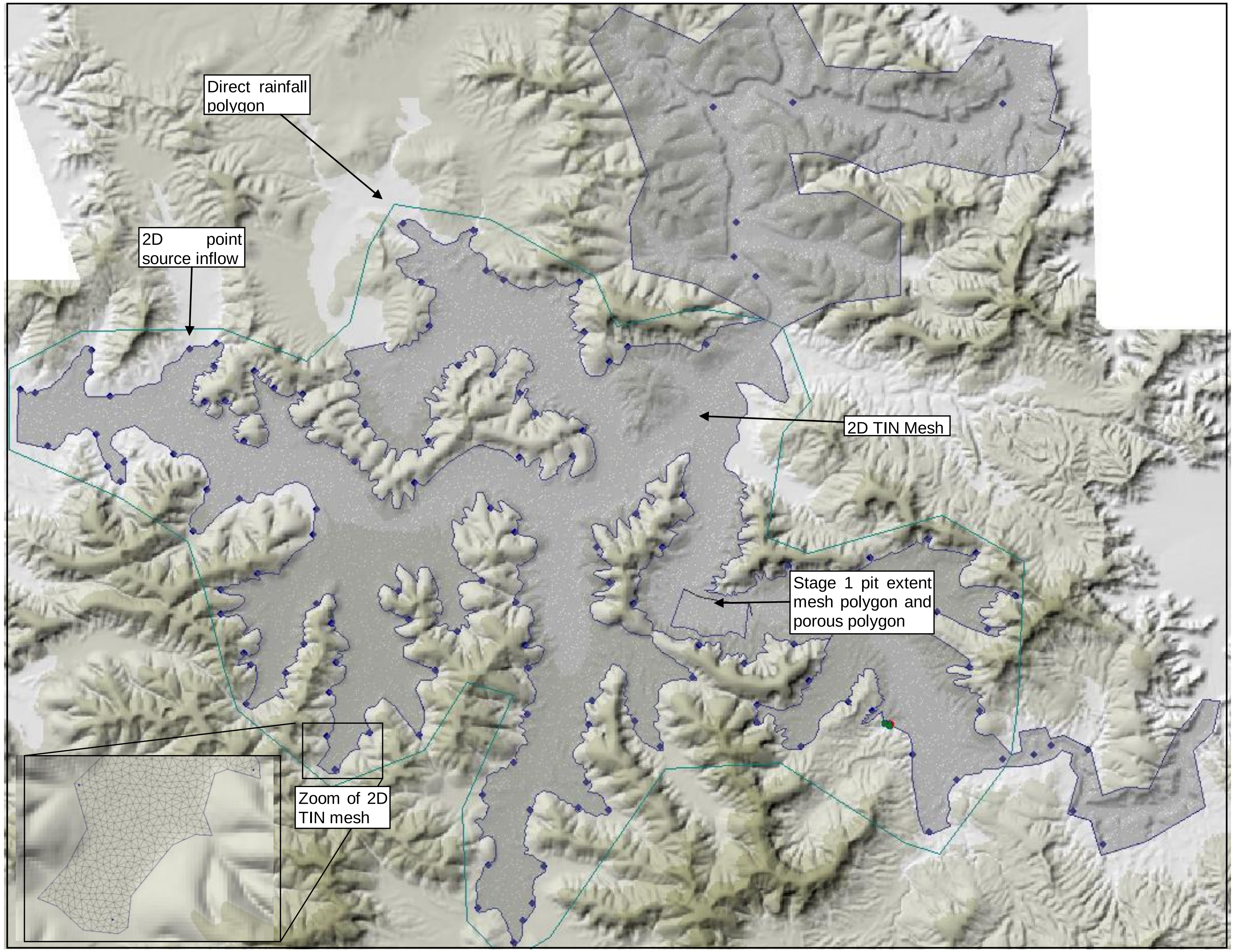


Figure 6.1: Components of the 2D Hydraulic Model (no 1D elements)

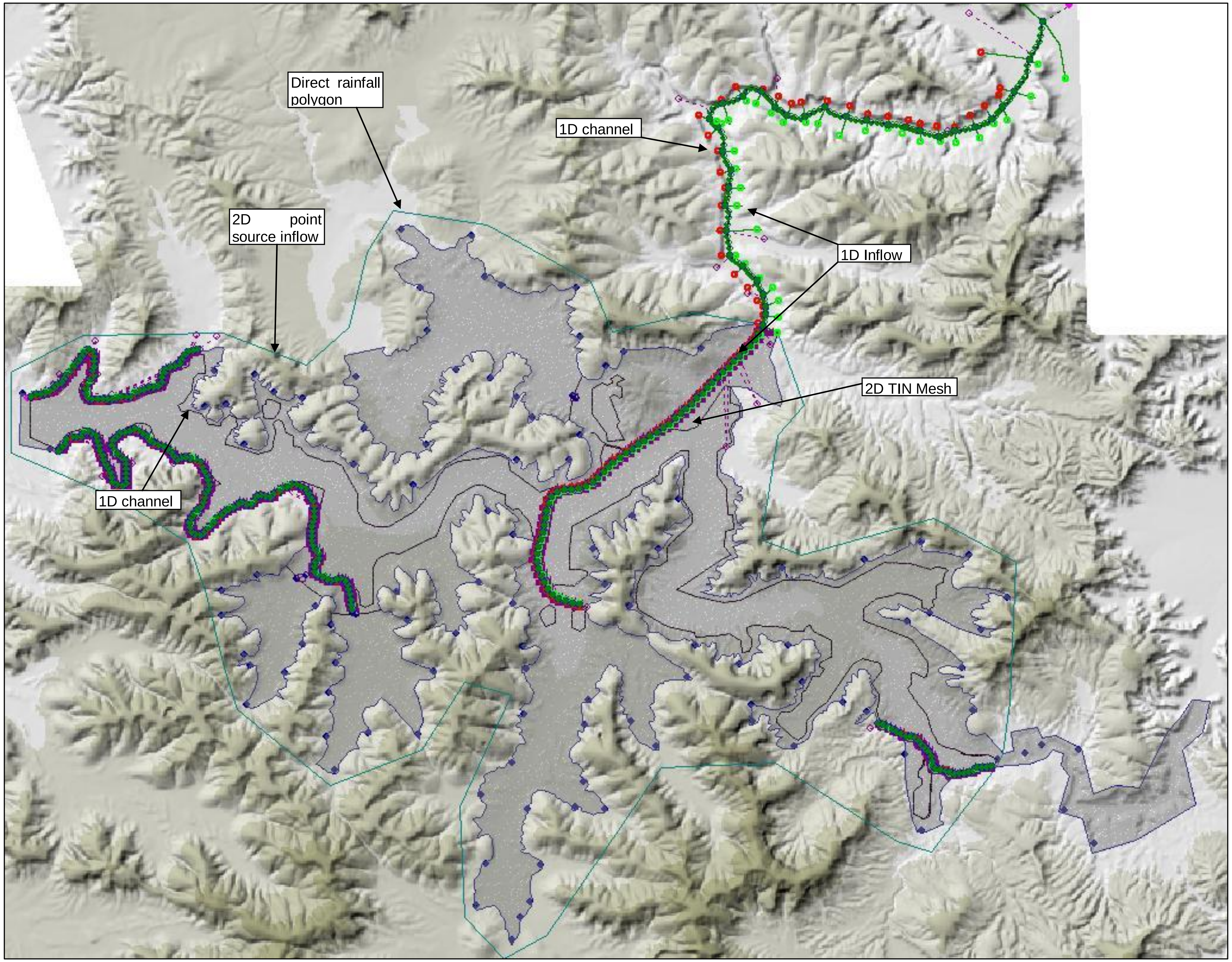


Figure 6.2 Components of the combined 1D & 2D hydraulic model.

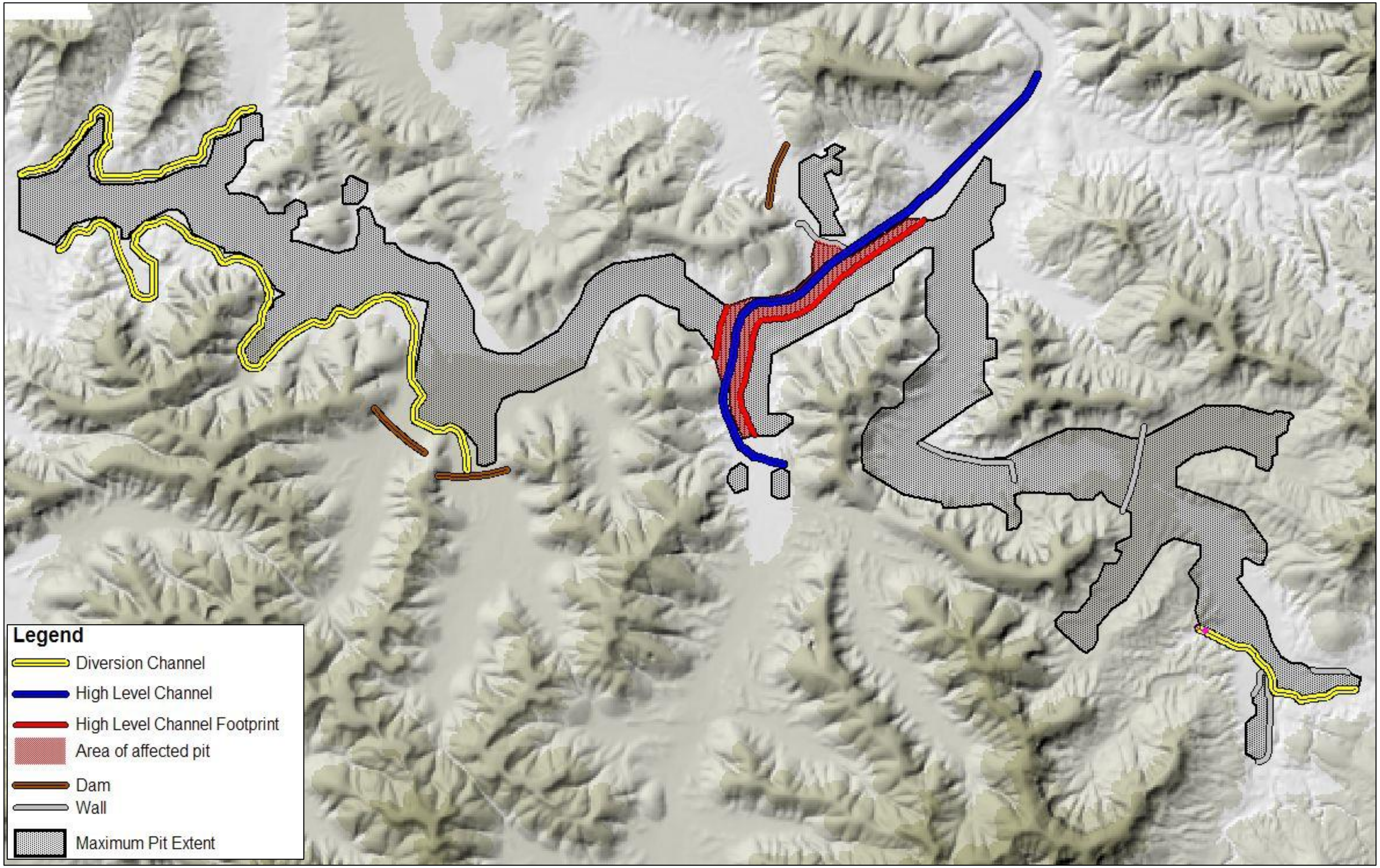


Figure 6.3: Footprint of Flood Management Options

6.2 1D Hydraulic Modelling Components

Four 1D channels have been incorporated into the hydraulic modelling as possible options for flow diversion around the proposed mine pits (as shown in Figure 6.1 and Figure 6.2). Three of these channels are basic ditch channels that generally run along the side of the 2D sim polygon intercepting flow that would otherwise run into the pits. The fourth channel is the large “high level” channel which has been proposed as an option for conveying flow originating from K4 catchment (South Kangeenareena Catchment) across the Valley of the Kings to the main stream that runs out to the Fortescue flood plain past the Fire Tail Valley. All the 1D channels are linked to the 2D sim polygon at least along one side by spill units which allow water to move from the channels into the 2D sim polygon when water depth in the channel exceeds the bank level. Similarly water can flow into the channels from the 2D sim polygon. Where the 1D channels ran along the side of the 2D sim polygon a number of 2D point source inflows are converted to 1D lateral inflows, where the flow modelled in RORB is run into the 1D channel rather than the 2D sim polygon.

7. Flood Management Options

Rainfall-runoff and hydraulic models of the mine site were used to assess the impact of each option. See Section 1.3 for an explanation of catchment and option names used.

Table 7-1 lists the options and the stage in the current mine plan that they need to be implemented. A detailed description of each option is included in the section below. The locations of the options are shown in Figure 7-1 for Stage 5 of the mine plan.

For each option the impact of not implementing the option was also assessed. The potential impacts of “doing nothing” are the cost of pumping out flood water and the operational downtime this may cause. Only the cost of pumping water out of the pit has been estimated at this stage. The cost of disruption to the mining operation due to pit inundation and post flood pit clean up has not been considered at this stage.

A summary of estimated capital costs and the time and cost to pump water from pits for the 100 year event for all options is provided in Table 7-15.

Table 7-1: Potential Flood Management Options

Catchment ID	Option Name	Description	Time Horizon (Stage)
		Valley of the Kings	
K1	K1 Bund and Diversion Channel	Temporary bund and diversion channel to direct flows from small catchment south toward Zalamea Creek during early stage of mine life.	1 to 3
K2	K2 Bund and Diversion Channel	Diversion of flows from small catchment around south extent of pit to direct flow into Zalamea Creek	2 to End
K3	K3 Bund and Diversion Channel	Diversion of flows from TSF catchment away from pit boundary and to minimise impact on ore processing area to the north	2 to End
K4	K4 Land Bridge	Land Bridge from outlet of South Kangeenarina catchment to north side of Trinity to downstream of Firetail catchment. Mine plan will need to be modified to delay mining a slice of ore beneath the land bridge until the end of the operation. The bridge will also provide a transport link between the South Kangeenarina and Queens areas to the processing area adjacent to Firetail.	2 to End
K5	K5 Detention Dam	Detention dam to contain flood water from large 120km^2 North West catchment	2 to End
		Valley of the Queens	
Q1	Q1 Bund and Diversion Channel	Diversion of flows past the southern end of the Queens pit.	3 to End
Q2	Q2 Bund	Diversion of flows past the northern end of the	3 to End

Catchment ID	Option Name	Description	Time Horizon (Stage)
	and Diversion Channel	Queens pit.	
Q3	Q3 Detention Dam	Detain floodwaters from the catchment to the south of Queens pit to attenuate flows.	5 to End
Q4	Q4 Detention Dam	Detain floodwaters from the catchment to the south of Queens pit to attenuate flows.	4 to End
Q5	Q5 Drainage Channel	Relatively low capacity drainage channel to transfer water to downstream of the mine from the two small southern detention dams (Q3 and Q4). The channel would also intercept some hillside runoff that would otherwise flow into the pit.	5 to End
	Do Nothing (Status Quo)	For all options there is the alternative of letting floodwater flow directly into the pit and gravitate down-slope to a pit floor sump area. Water would be pumped out after the storm event.	All stages

In each of the options, a larger magnitude event than a 100 year ARI event may cause overtopping of channels and cause damage to the option so that it fails. This is a residual risk over and above the design standard.

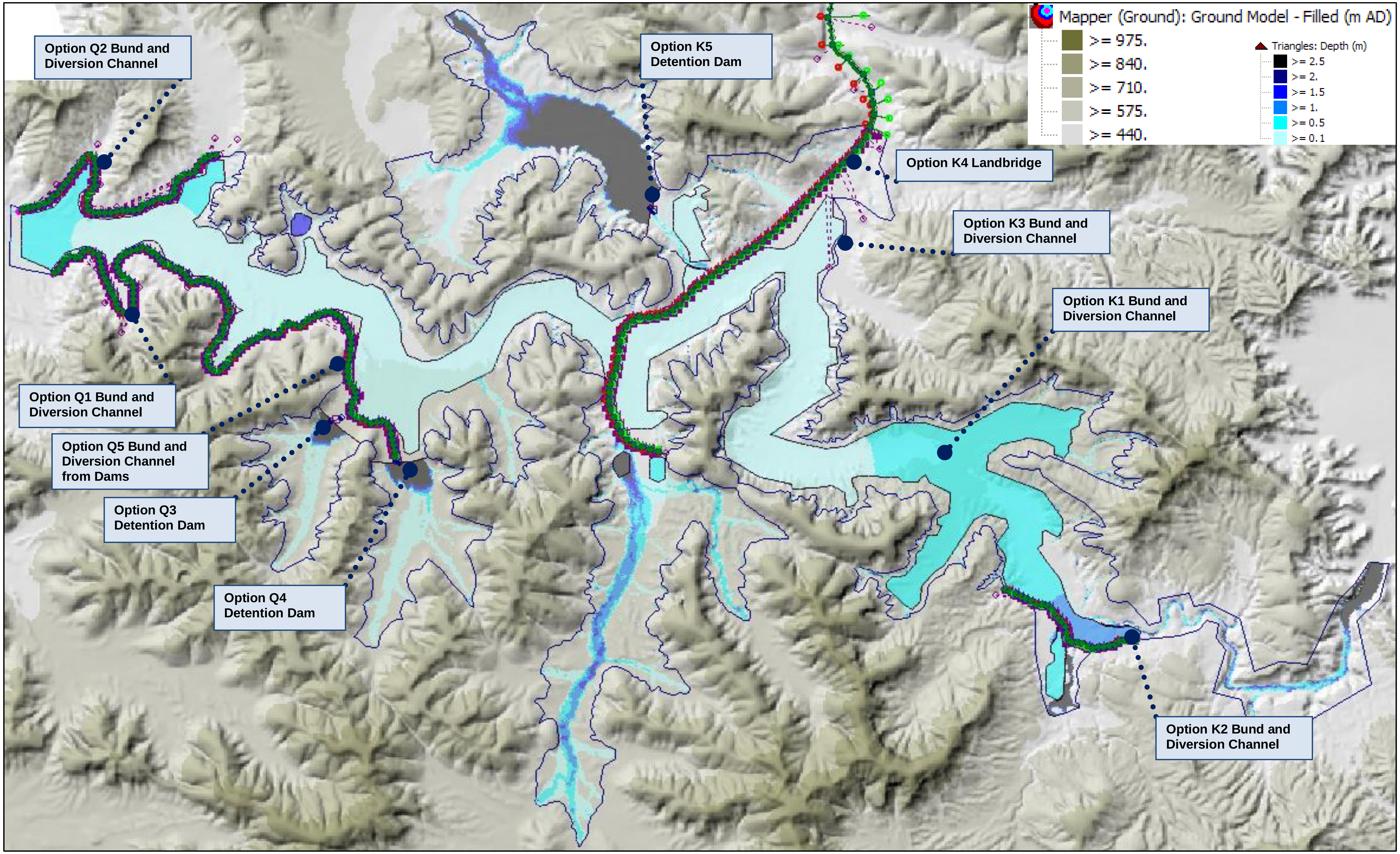


Figure 7-1: Locations of Proposed Flood Management Options

7.1 K1 Bund and Diversion

The objective of the K1 Bund and Diversion Option is to divert flows that would otherwise discharge into the Stage 1 and Stage 2 Kings open pit. It consists of a 1m to 2m bund across the valley floor divide between the headwaters of the Zalamea and Kangeenarina catchments. Figure 7.1 shows the location of the option. Under the current mine plan the option would be required at the start of mining during Stage 1 but would be removed with the pit development during Stage 3 (year 6 to 10) when the Kings Pit would cut through the catchment boundary.

The benefit of the bund is to divert flood runoff away from the pit development and direct it towards the east over a shallow valley divide. This would require relatively straightforward earthworks and would not be a major disturbance to wider mine activities and transport routes.

The 100 year ARI runoff that would be diverted away from the pit development is approximately $30m^3/s$. The corresponding increase in flows towards the east due to the diversion bund would therefore be $30m^3/s$ in the 100 year ARI event.

The general dimensions of the bund earthworks are approximately 1 to 2m in average height, 800m length, with a 3m crest width and trapezoidal cross section shape with 3 horizontal to 1 vertical side slopes.

The terrain over which the alignment is placed is generally typical valley floor topography. The profile of the ground indicates a maximum height of 2.5m to crest level. The construction material would be the surrounding valley floor soils and this would be bulldozed into the bund dimensions and compacted with tracked or wheeled machinery. Compaction of the materials would be carried out in 500mm lifts.

The typical bund cross section assumed for volume estimation is trapezoidal with a 4m crest width and side slopes of 1 vertical to 3 horizontal. The estimated volume of earthworks for the bund is $15,000m^3$.

The assumed cost rate of the bund earthworks is estimated to be between $7 and $10 per bulk cubic metre based on Pilbara rates obtained in 2008 for embankment construction. The assumed rate for this study is $10 per bulk cubic metre (BCM). The cost of the bund is in the order of $150,000.

The bund will be most important for Stages 1 and 2 and will be removed as part of the development of Stage 3.

In combination with the diversion bund, a channel on the north side of the Stage 1 pit would be developed to pass $18\text{-}20m^3/s$ in a 100 year ARI event. The dimensions would be 1,500m length, 4m base width, 2 horizontal to 1 vertical, with depth 2m.

The estimated volume of cut earthworks for the 1500m long channel is $24,000m^3$ plus overburden cut to maintain a 1 in 200 gradient. Most of the overburden cut would be excavated as part of the pit development works. For estimation, the channel excavation volume is assumed to be around $50,000m^3$.

The cost of the diversion channel is estimated to be $250,000 at $5 per cubic metre excavation with cut spoil disposed alongside the channel. This gives a channel rate of $160-200/m length.

Estimated capital costs and the potential pumping costs incurred by not implementing the option are summarised in Table 7-2. Costs associated with disruption, work safety, delays to ore delivery, other damage and clean up costs are not included.

Table 7-2: Option K1 Cost Summary

Option	Capital cost of option	Volume of water into pit with "do nothing" option during 100 yr ARI event m^3 (A)	Cost to pump out (A) at 20cents /kW hour	Average annual volume of runoff into pit with "do nothing" option m^3 (B)	Cost to pump out (B) at 20cents /kW hour
K1 Bund & Channel	$400,000	800,000	$58,133	477,855	$34,724

The Option K1 channel will only be useful during Stage 1. After Stage 1 the pit is developed along the valley floor in both directions and the diversion would need to be extended 5km around the pit boundary. This would pass flows from the outcrop formation around the pit, and cost an estimated $850,000 for earthworks. Every year that the diversion bunds and channels are in operation will results in less annual runoff entering the pits and being pumped out.

7.2 Option K2 Bund and Diversion Channel

The objective of the K2 Bund and Diversion Option is to divert flows that would otherwise discharge into the eastern end of the Stage 2 Kings open pit. It consists of a 1m to 2m bund in combination with a large diversion channel to carry flows from the southern catchments around the pit and into Zalamea Creek to the east. Figure 7-1 shows the location of the option. Under the current mine plan the option would be required at the start of mining Stage 2 and remain in place.

The benefit of the bund and channel is to divert runoff away from the pit and direct it east toward Zalamea Creek. (100 year ARI flood peak is estimated to be $1000m^3/s$) This would maintain the flow regime in the creek downstream of the mine to a large extent.

The existing 100 year ARI runoff that would be carried by Zalamea Creek is approximately $1225m^3/s$. The diversion channel would carry $1000m^3/s$ of this flow around the southern pit boundary and be diverted back into the Zalamea Creek. $70m^3/s$ would come from the upstream bund area at K1 and the remaining $155m^3/s$ would come from the outcrops to the north of the pit. This flow would be diverted via a smaller channel around the northern pit boundary

The dimensions of the bund earthworks are approximately 1 to 2m in average height, 3.5km length, with a 4m crest width and trapezoidal cross section shape with 3 horizontal to 1 vertical side slopes. The construction material would be the channel excavation materials and this would be bulldozed into the bund dimensions and compacted with tracked or wheeled machinery. Compaction of the materials would be carried out in 500mm lifts.

The estimated volume of earthworks for the bund is $42,000m^3$. The assumed rate for this study is $10 per bulk cubic metre (BCM). The cost of the bund is in the order of $420,000.

In combination with the bund, the channel would be developed to pass $1000m^3/s$ in a 100 year ARI event. The dimensions would be 3.5km length, 150m base width, 2 horizontal to 1 vertical, with depth 2m. The average channel gradient is 1 in 146.

The estimated volume of cut earthworks for the channel is 1.1 million m^3 plus overburden cut to maintain a 1 in 146 gradient. Most of the overburden cut would be excavated as part of the pit development works. For estimation, the channel excavation volume is assumed to be around 1.5 million m^3.

The cost of the diversion channel is estimated to be $7.5 million at $5 per cubic metre excavation with cut spoil disposed alongside the channel or used as mine backfill. This gives a channel rate of $2,200/m length.

The channel and bund will be most important for Stage 2 mine development and would be environmentally beneficial for the following Stages and after mine closure as it will maintain the flow regime in the Zalamea Creek.

The impact of not implementing the K2 Option (adopting a “do nothing” approach) would be to allow flood runoff to enter the pit and then pump it back out.

The depth of pit inundation will depend on the volume of the area of the pit at the time of the event. The Stage 2 pit surface area is small (1.4km^2) and the 100 year ARI runoff past the pit is large at 1000m^3/s – this combination would result in relatively deep inundation within the pit.

Estimated capital costs and the potential pumping costs incurred by not implementing the option are summarised in Table 7-3. Costs associated with disruption, work safety, delays to ore delivery, other damage and clean up costs are not included.

Table 7-3: Option K2 Cost Summary

Option	Capital cost of option	Volume of water into pit with “do nothing” option during 100 yr ARI event m^3 (A)	Cost to pump out (A) at 20cents /kW hour	Average annual volume of runoff into pit with “do nothing” option m^3 (B)	Cost to pump out (B) at 20cents /kW hour
K2 Bund & Channel	$7,900,000	5,500,000	$399,667	n/a	n/a

7.3 K3 Bund and Diversion Channel

The objective of the K3 Bunding and Diversion Option is to divert flows from the tailings facility catchment that would otherwise discharge into the Stage 3 Kings pit. It consists of a 1m to 2m bund in combination with a diversion channel to carry flows around the east edge of the pit and into Kangeenarina Creek to the north. Figure 7-1 shows the location of the option. Under the current mine plan the option would be required at the start of mining Stage 3 and remain in place thereafter.

The benefit of the bund and channel is to divert runoff away from the pit and direct it north towards Kangeenarina Creek. (100 year ARI flood is estimated to be 30-50m^3/s)

The general dimensions of the bund earthworks are approximately 1 to 2m in average height, 1500m length, with a 4m crest width and trapezoidal cross section shape with 3 horizontal to 1 vertical side slopes. The estimated volume of earthworks for the bund is 21,000m^3.

The assumed rate for this study is $10 per bulk cubic metre (BCM). The cost of the bund is in the order of $210,000 (assumed rate is $10 per bulk cubic metre).

In combination with the diversion bund a channel on the east side of the Stage 3 pit would be developed to pass 30 to 50m^3/s in a 100 year ARI event. The dimensions would be 1,500m length, 10m base width, 2 horizontal to 1 vertical, with depth 2m.

The estimated volume of cut earthworks for the 1500m long channel is 36,000m^3 plus overburden cut to maintain a 1 in 200 gradient. Most of the overburden cut would be excavated as part of the pit development works. For estimation, the channel excavation volume is assumed to be around 70,000m^3.The cost of the diversion channel is estimated to be $360,000 at $5 per cubic metre excavation with cut spoil disposed alongside the channel. This gives a channel rate of $250/m length.

The channel will be most useful during Stage 3. After Stage 3 the pit is developed along the valley floor in both directions and the diversion would pass flows from the outcrop formation around the pit, and limit pit inflows. Every year that the diversion bunds and channels are in operation will mean less annual runoff entering the pits and being pumped out.

The impact of not implementing the K3 Option (adopting a "do nothing" approach) would be to allow flood runoff to enter the pit and then pump it back out. The depth of pit inundation will depend on the area of the pit at the time of the event. The Stage 3 pit surface area is very large (15.5km^2) and the 100 year ARI runoff past the pit is small (30 - 50m^3/s). Accordingly, flows from the Tailings Facility catchment would not be very deep or be a large volume to pump out.

Estimated capital costs and the potential pumping costs incurred by not implementing the option are summarised in Table 7-4. Costs associated with disruption, work safety, delays to ore delivery, other damage and clean up costs are not included.

Table 7-4: Option K3 Cost Summary

Option	Capital cost of option	Volume of water into pit with "do nothing" option during 100 yr ARI event m^3 (A)	Cost to pump out (A) at 20cents /kW hour	Average annual volume of runoff into pit with "do nothing" option m^3 (B)	Cost to pump out (B) at 20cents /kW hour
K3 Bund & Channel	$570,000	1,100,000	$79,933	139,374	$10,128

7.4 K4 Land Bridge

The objective of the K4 Landbridge Option is to control flows through the Trinity area that would otherwise spill into the Stage 2, 3, 4 and 5 Kings pit. Figure 7.1 shows the location of the option. The concept of the landbridge is delay mining of the northern side of the existing Kangeenarina Creek in the trinity area so that flood flows can pass around the mine. Under the current mine plan the option would be required at the start of Stage 2 and would be mined at the end of the Solomon operation.

The benefit of the K4 Landbridge is to control flood runoff from the main Kangeenarina Creek catchment through the Trinity area and direct it north past the processing area. It would maintain the flow regime in the Kangeenarina Creek downstream of the mine to a large extent. It would also provide a transport link between the Valley of the Queens pit and the ore processing area.

The landbridge will also provide a channel for floodwater detained behind the proposed K5 Detention Dam to discharge (at a greatly attenuated rate) back into the Kangeenarina Creek. If the K5 Detention Dam is not in place, the landbridge width would increase by approximately 125%.

The existing Kangeenarina Creek 100 year ARI flood flow close to the proposed processing area is approximately 750 - 800m^3/s. The combination of the K4 Landbridge and K5 Detention Dam options will manage most of this flow around the Kings pit. Peak flows downstream of the landbridge will be reduced but the volume of flood water discharged past the mine will not be significantly affected.

The K4 Landbridge would be designed to pass 900m^3/s in a 100 year ARI event. The average channel gradient on the landbridge is 1 in 175. The total dimensions would be 8.1km in length, 150m base width, 2 horizontal to 1 vertical, with depth 2m. Sections of the landbridge could be staged through Stages 2, 3 and 4.

The estimated volume of cut earthworks for the channel is 2.4 million m^3 plus a small overburden cut to maintain a 1 in 175 gradient. Most of the overburden cut would be required in any case to take the underlying ore in the final stages of the mining operation. The landbridge alignment would most likely be on the true left bank of the Kangeenarina Creek valley. For estimation, the channel excavation volume is assumed to be around 2.0 million m^3.

The cost of the diversion channel is estimated to be $10 million at $5 per cubic metre excavation with cut spoil disposed alongside the channel or as mine backfill. This gives a channel rate of $1,250/m length.

The landbridge will be most important for Stage 2 when the pit intersects the Trinity area. The K4 Landbridge at Stage 2 does not need to be long, and a modification in the pit outline into Kangeenarina Creek valley could delay the need for the landbridge until Stage 3.

The impact of not implementing the K4 Landbridge option (adopting a “do nothing” approach) would be to allow flood runoff to enter the pit and then pump it back out. The Kangeenarina Creek catchment to the south of the pit is quite large and would provide a large pit inflow volume.

The depth of pit inundation will depend on the area of the pit at the time of the event. The Stage 2 pit surface area is approximately 6km^2 and the 100 year ARI runoff past the pit is large at 900m^3/s – this combination would cause deep water ponding in the lower parts of the pits that have been mined out in earlier stages.

Clearly parts of the ore body would be inaccessible while the landbridge was in service. At the end of the mine life the landbridge would be decommissioned and the ore below the landbridge mined out.

Estimated capital costs and the potential pumping costs incurred by not implementing the option are summarised in

Table 7-5. Costs associated with disruption, work safety, delays to ore delivery, other damage and clean up costs are not included.

Table 7-5: Option K4 Cost Summary

Option	Capital cost of option	Volume of water into pit with "do nothing" option during 100 yr ARI event m^3 (A)	Cost to pump out (A) at 20cents /kW hour	Average annual volume of runoff into pit with "do nothing" option m^3 (B)	Cost to pump out (B) at 20cents /kW hour
K4 Landbridge	$10,000,000	12,000,000	$872,000	1,095,085	$79,576

7.5 K5 Detention Dam

The objective of the K5 Detention Dam option is to temporarily detain flood flows from the large catchment to the northwest of Trinity and then release the detained water at a greatly reduced, manageable rate. There are several options for transmitting attenuated flows from the dam to downstream of the mine. If the K4 Landbridge is adopted it will also provide a channel for water released from the K5 dam.

Detained water would be released through the dam via a low level outlet culvert. It appears that the dam would need to be completed at the start of Stage 2 under the current mine plan, or at the start of Stage 3 if the pit into Kangeenarina Creek valley can be delayed or modified to allow a substantial part of the existing channel to remain in place. Figure 7.1 shows the location of the option.

The benefit of the K5 Detention Dam is to control flood runoff from the northwest (K5) catchment and provide flood protection to the pit. It also significantly reduces the required width of the K4 Landbridge option.

The existing 100 year ARI peak runoff from the northwest catchment is approximately 1100m^3/s. The dam would reduce the peak discharge around the mine to approximately 30 to 60m^3/s.

A zoned-embankment dam has been preliminarily designed to the 100 year ARI flood standard to estimate the embankment dimensions. The site of the dam has been chosen for its relative topographic constriction and will naturally require further investigation into the foundations and other dam aspects. The height of the dam is calculated to be 17m to the crest, the crest width is 10m, and the longitudinal length at crest level is 820m. The side slopes of the dam are 1 vertical to 3 horizontal. The volume of the dam is estimated to be 600,000m^3. The profile of the dam is shown in Figure 7-2.

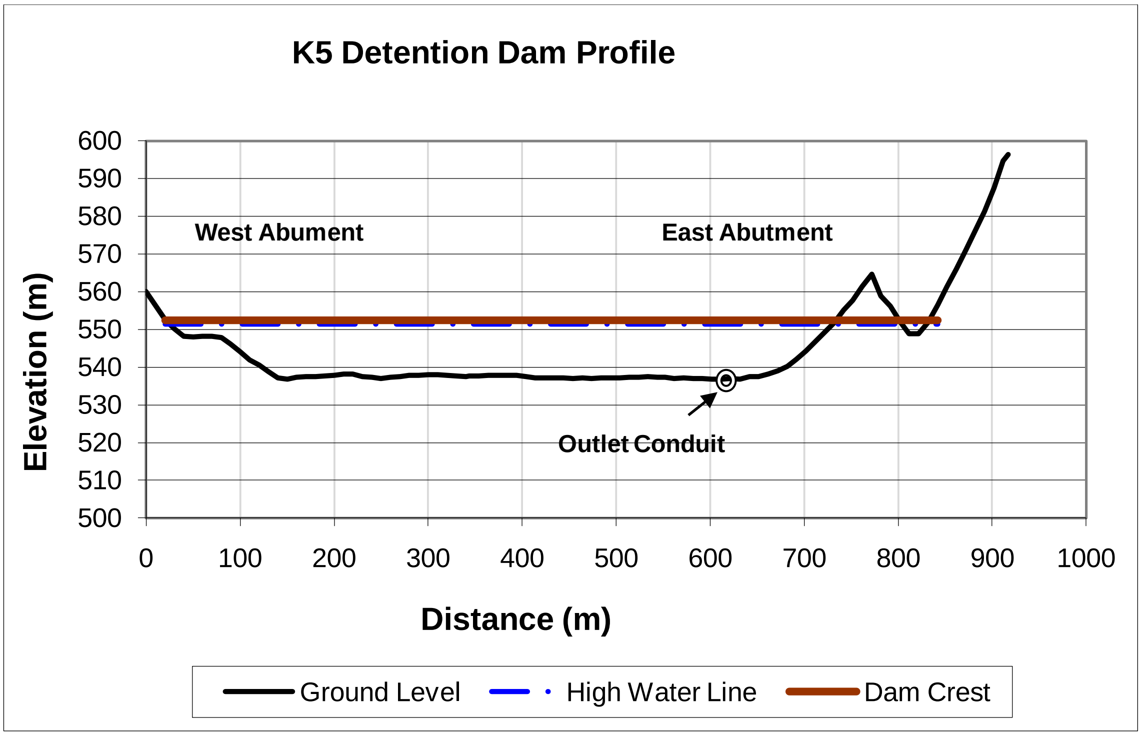


Figure 7-2: K5 Detention Dam Profile

The dam configuration will need further design to determine the spillway capacity and location. Further design would also refine the outlet capacity and overall dam dimensions. At present, the lake formed by a 100 year ARI event would be drained over two weeks.

The depth of pit inundation will depend on the area of the pit at the time of the event. The Stage 2 pit surface area is quite large (6.1km^2) but the non-throttled 100 year ARI runoff past the pit is large at 1400m^3/s. This combination would result in deep ponding in the lower parts of the pits that have been worked out in earlier stages.

Estimated capital costs and the potential pumping costs incurred by not implementing the option are summarised in Table 7-7. Costs associated with disruption, work safety, delays to ore delivery, other damage and clean up costs are not included.

Table 7-6: K5 Detention Dam Costs

Item	Description	Unit	Estimated Quantity	Unit Price	Item Price
1	Mobilization and Prep Work	LS	1	$ 500,000	$ 500,000
2	Dam Foundation Excavation/Preparation	BCM	68163	$ 2.50	$ 170,407
3	Zone 1 - Embankment	BCM	588316	$ 7.00	$ 4,118,215
4	Zone 2 - Granular Filter	BCM	13900	$ 30.00	$ 416,994
6	Upstream Soil Cement Plating	BCM	8853	$ 84.00	$ 743,615
8	Outlet Works/Primary Spillway	LS	1	$ 400,000	$ 400,000
9	Emergency Spillway (site grading)	LS	1	$ 1,000,000	$ 1,000,000
	Cost of Dam Construction				**$ 7,349,231**
	Site Investigation, Final Design and Specifications (20% of Base Construction Cost)				$ 1,469,846
	Permitting and Mitigation (1% of Construction Cost)				$ 73,492
	Engineering (10% of Construction Cost)				$ 734,923
	Contingency Concept Design Phase(40% of Construction Cost)				$ 3,000,000
	Project Total Cost				**$ 13,000,000**

Table 7-7: Option K5 Cost Summary

Option	Capital cost of option	Volume of water into pit with “do nothing” option during 100 yr ARI event m^3 (A)	Cost to pump out (A) at 20cents /kW hour	Average annual volume of runoff into pit with “do nothing” option m^3 (B)	Cost to pump out (B) at 20cents /kW hour
K5 Detention Dam	$13,000,000	18,500,000	$1,344,333	2,090,617	$151,918

7.6 Q1 Bund and Diversion

The objective of the Q1 Bund and Diversion Option is to divert flows that would otherwise discharge into the Valley of Queens pit, during Stage 3, 4 and 5. It consists of a 1m to 2m bund in combination with a diversion channel to carry flows from the southern catchments around the southern pit edge and to the west. Figure 7.1 shows the location of the option. Under the current mine plan the option would be required at the start of mining Stage 4 but would be partly required in Stage 3.

The capacity of the channel has been designed based on the assumption that the two detention dams Q3 and Q4 are in place to attenuate flood flows from these catchments. The benefit of the bund and channel is to divert up to 140m^3/s of 100 year ARI flood runoff around the pit and direct it west into Weelumurra Creek.

The dimensions of the bund earthworks are approximately 1 to 2m in average height, 9.4km in length, with a 4m crest width and trapezoidal cross section shape with 3 horizontal to 1 vertical side slopes. The construction material would be the channel excavation materials and this would be bulldozed into the bund dimensions and compacted with tracked or wheeled machinery. Compaction of the materials would be carried out in 500mm lifts.

The estimated volume of earthworks for the bund is 140,000m^3. The assumed rate for this study is $10 per bulk cubic metre (BCM). The cost of the bund is in the order of $1.4million.

In combination with the bund, the channel would be developed to pass up to 140m^3/s in a 100 year ARI event. The channel is considered in two parts: upper-middle section and lower section.

The dimensions for the upper-middle section of the channel are 5.8km length, 20m base width, 2 horizontal to 1 vertical, with depth 2m. The average channel gradient is 1 in 215. The estimated volume of cut earthworks for the channel is 260,000m^3 plus overburden cut to maintain the 1 in 215 gradient. Some of the overburden cut would be excavated as part of the pit development works. For estimation, the channel excavation volume is assumed to be around 500,000m^3.

The cost of the upper-middle section of the diversion channel is estimated to be $2.5million at $5 per cubic metre excavation with cut spoil disposed alongside the channel or in the mine. This gives a channel rate of $450/m length.

The dimensions for the lower section of the channel are 3.6km length, 45m base width, 2 horizontal to 1 vertical, with depth 2m. The average channel gradient is 1 in 500. The estimated volume of cut earthworks for the channel is 350,000m^3 plus overburden cut to maintain the 1 in 500 gradient. Some of the overburden cut would be excavated as part of the pit development works. For estimation, the channel excavation volume is assumed to be around 600,000m^3.

The cost of the lower section of the diversion channel is estimated to be $3million at $5 per cubic metre excavation with cut spoil disposed alongside the channel or in the mine. This gives a channel rate of $850/m length.

The total cost of the Q1 channel for the full 9.4km length is $5.5 million, and the excavation volume is estimated to be 1.1million m^3. The associated bund cost is $1.4 million giving the channel and bund a cost of around $6.9 million.

The impact of not implementing the Q1 Bund and Diversion option (adopting a “do nothing” approach) would be to allow flood runoff to enter the pit, direct it toward low points in the mine and then pump it back out. In this case, the catchments to the south of the Valley of Queens pit are moderately large and would provide a moderately large pit inflow volume. The depth of pit inundation will depend on the area of the pit at the time of the event.

Estimated capital costs and the potential pumping costs incurred by not implementing the option are summarised in Table 7-8. Costs associated with disruption, work safety, delays to ore delivery, other damage and clean up costs are not included.

Table 7-8: Option Q1 Cost Summary

Option	Capital cost of option	Volume of water into pit with "do nothing" option during 100 yr ARI event m^3 (A)	Cost to pump out (A) at 20cents /kW hour	Average annual volume of runoff into pit with "do nothing" option m^3 (B)	Cost to pump out (B) at 20cents /kW hour
Q1 Bund and Diversion	$6,900,000	270,000	$196,200	19,911	$1,447

7.7 Q2 Bund and Diversion

The objective of the Q2 Bunding and Diversion Option is to divert flows that would otherwise discharge into the Valley of Queens pit, during Stage 3, 4 and 5. It consists of a 1m to 2m bund in combination with a diversion channel to carry flows from the northern catchments around the northern pit edge and then west to Weelumurra Creek. Figure 7.1 shows the location of the option. Under the current mine plan the option would be required at the start of mining Stage 4 but would be partly required in Stage 3 at the western downstream end.

The benefit of the bund and channel is to divert up to $200m^3/s$ of 100 year ARI flood runoff around the pit.

The dimensions of the bund earthworks are approximately 1 to 2m in average height, 5.4km length, with a 4m crest width and trapezoidal cross section shape with 3 horizontal to 1 vertical side slopes. The construction material would be the channel excavation materials and this would be bulldozed into the bund dimensions and compacted with tracked or wheeled machinery. Compaction of the materials would be carried out in 500mm lifts. The estimated volume of earthworks for the bund is $76{,}000m^3$. The cost of the bund is in the order of $760,000 (assumed rate for this study is $10 per bulk cubic metre).

In combination with the bund, the channel would be developed to pass up to $200m^3/s$ in a 100 year ARI event.

The dimensions for the channel are 5.4km length, 45m base width, 2 horizontal to 1 vertical, with depth 2m. The average channel gradient is 1 in 266. The estimated volume of cut earthworks for the channel is $500{,}000m^3$ plus overburden cut to maintain the 1 in 266 gradient. Some of the overburden cut would be excavated as part of the pit development works. For estimation, the total channel excavation volume is assumed to be around $800{,}000m^3$.

The estimated cost of the diversion channel is estimated to be $4million at $5 per cubic metre excavation with cut spoil disposed alongside the channel or in the mine. This gives a channel rate of $750/m length. The total estimated cost of the Q2 channel and bund is $4.8million.

The impact of not implementing the Q2 Bund and Diversion option (adopting a "do nothing" approach) would be to allow flood runoff to enter the pit, direct it toward low points in the mine and then pump it back out. In this case, the catchments to the north of the Valley of Queens pit are moderately large and would provide a moderately large pit inflow volume.

Estimated capital costs and the potential pumping costs incurred by not implementing the option are summarised in Table 7-9. Costs associated with disruption, work safety, delays to ore delivery, other damage and clean up costs are not included.

Table 7-9: Option Q2 Cost Summary

Option	Capital cost of option	Volume of water into pit with "do nothing" option during 100 yr ARI event m^3 (A)	Cost to pump out (A) at 20cents /kW hour	Average annual volume of runoff into pit with "do nothing" option m^3 (B)	Cost to pump out (B) at 20cents /kW hour
Q2 Bund and Diversion	4,800,000	2,800,000	$203,467	298,600	$21,698

7.8 Q3 Detention Dam

The objective of the Q3 Detention Dam Option is to temporarily detain flood flows from the moderately large catchment to the south of the Queens pit and then release the detained water at a greatly reduced, manageable rate into a low capacity channel (Q5 Bund and Diversion Channel Option). The Q5 Channel would then convey the attenuated flow west around the Valley of Queens pits where it would then flow into the Weelumurra Creek.

Water would be released from the dam via a low level outlet culvert. It appears that the dam would need to be completed at the start of Stage 4 under the current mine plan. Figure 7.1 shows the location of the option.

The existing 100 year ARI peak runoff from the southern catchment is approximately 80-90m^3/s. The dam would reduce the peak discharge through the mine to approximately 10 to 20m^3/s.

A zoned-embankment dam has been preliminarily designed to the 100 year ARI flood event standard to estimate the embankment dimensions. The site of the dam has been chosen for its relative topographic constriction and will naturally require further design investigation into the foundations and other dam aspects. The height of the dam is calculated to be 8.5m to the crest, the crest width is 10m, and the longitudinal length at crest level is 690m. The side slopes of the dam are 1 vertical to 3 horizontal. The volume of the dam embankment is estimated to be 200,000m^3.

The profile of the dam is shown in Figure 7-3 and a summary of costs in Table 7-10.The dam configuration will need further design to determine the spillway capacity and location. Further design would also refine the outlet capacity and overall dam dimensions. At present, the lake formed by a 100 year ARI event would be drained down over two weeks.

The impact of not implementing the Q3 Detention Dam Option (adopting a "do nothing" approach) would be to allow flood runoff to enter the pit, direct it toward low points in the mine and then pump it back out.

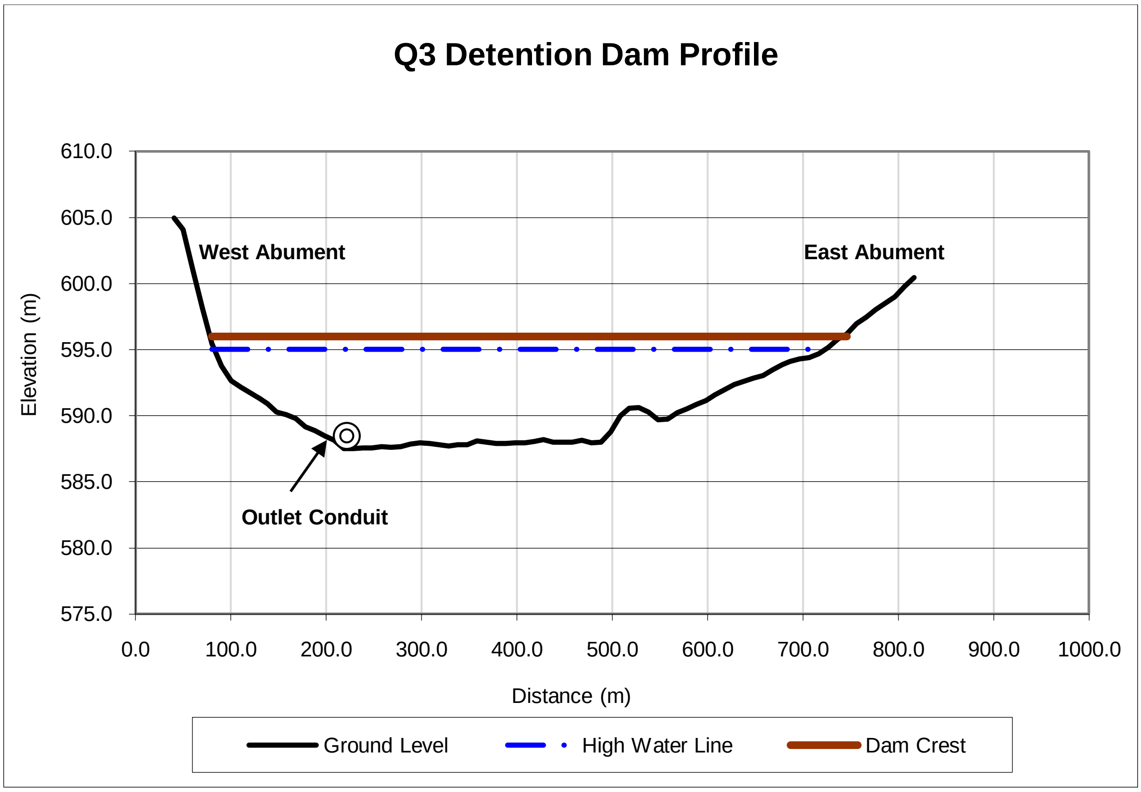


Figure 7-3: Q3 Detention Dam Profile

Table 7-10: Q3 Detention Dam Costs

Item	Description	Unit	Estimated Quantity	Unit Price	Item Price
1	Mobilization and Prep Work	LS	1	$ 400,000	$ 400,000
2	Dam Foundation Excavation/Preparation	BCM	34616	$ 2.50	$ 86,539
3	Zone 1 - Embankment	BCM	189096	$ 7.00	$ 1,323,673
4	Zone 2 - Granular Filter	BCM	8057	$ 30.00	$ 241,700
6	Upstream Soil Cement Plating	BCM	3748	$ 84.00	$ 314,845
8	Outlet Works/Primary Spillway	LS	1	$ 400,000	$ 400,000
9	Emergency Spillway (site grading)	LS	1	$ 1,000,000	$ 1,000,000
	Cost of Dam Construction				**$ 3,766,757**

Site Investigation, Final Design and Specifications (20% of Base Construction Cost)	$ 753,351
Permitting and Mitigation (1% of Construction Cost)	$ 37,668
Engineering (10% of Construction Cost)	$ 376,676
Contingency Concept Phase (40% of Construction Cost)	$ 1,500,000
Project Total Cost	**$ 6,500,000**

Estimated capital costs and the potential pumping costs incurred by not implementing the option are summarised in Table 7-11. Costs associated with disruption, work safety, delays to ore delivery, other damage and clean up costs are not included.

Table 7-11: Option Q3 Cost Summary

Option	Capital cost of option	Volume of water into pit with "do nothing" option during 100 yr ARI event m^3 (A)	Cost to pump out (A) at 20cents /kW hour	Average annual volume of runoff into pit with "do nothing" option m^3 (B)	Cost to pump out (B) at 20cents /kW hour
Q3 Detention Dam	$6,500,000	600,000	$43,600	159,285	$11,575

7.9 Q4 Detention Dam

The objective of the Q4 Detention Dam Option is to temporarily detain flood flows from the moderately large catchment to the south of the Queens pit and then release the detained water at a greatly reduced, manageable rate into a low capacity channel (Q5 Bund and Diversion Channel Option). The Q5 Channel would then convey the attenuated flow west around the Valley of Queens pits where it would then flow into the Weelumurra Creek.

Water would be released from the dam via a low level outlet culvert. It appears that the dam would need to be completed at the start of Stage 4 under the current mine plan. Figure 7.1 shows the location of the option.

The existing 100 year ARI peak runoff from the north west catchment is approximately 100 - 120m^3/s. The dam would reduce the peak discharge through the mine to approximately 10 to 20m^3/s.

The zoned-embankment dam has been preliminarily designed to the 100 year ARI flood event standard to estimate the embankment dimensions. The site of the dam has been chosen for its relative constriction and is subject to further design investigation into the foundations and other dam aspects. The height of the dam is calculated to be 8.9m to the crest, the crest width is 10m, the longitudinal length at crest level is 743m. The side slopes of the dam are 1 vertical to 3 horizontal. The volume of the dam is estimated to be 245,000m^3.

The profile of the dam is shown Figure 7-4 and estimated costs in

Table 7-12.

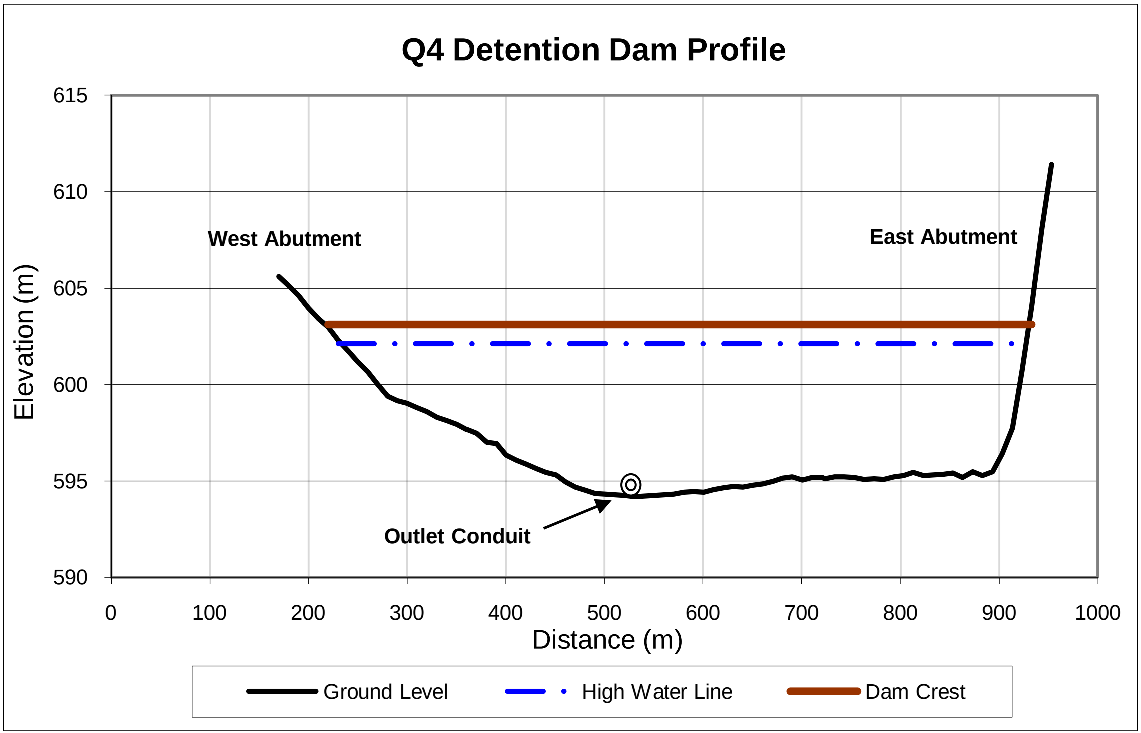


Figure 7-4: Q4 Detention Dam Profile

Table 7-12: Q4 Detention Dam Costs

Item	Description	Unit	Estimated Quantity	Unit Price	Item Price
1	Mobilization and Prep Work	LS	1	$ 500,000	$ 500,000
2	Dam Foundation Excavation/Preparation	BCM	41231	$ 2.50	$ 103,076
3	Zone 1 - Embankment	BCM	236696	$ 7.00	$ 1,656,875
4	Zone 2 - Granular Filter	BCM	9349	$ 30.00	$ 280,467
6	Upstream Soil Cement Plating	BCM	4659	$ 84.00	$ 391,381
8	Outlet Works/Primary Spillway	LS	1	$ 400,000	$ 400,000
9	Emergency Spillway (site grading)	LS	1	$ 1,000,000	$ 1,000,000
	Cost of Dam Construction				**$ 4,331,799**

Site Investigation, Final Design and Specifications (20% of Base Construction Cost)	$ 866,360
Permitting and Mitigation (1% of Construction Cost)	$ 43,318
Engineering (10% of Construction Cost)	$ 433,180
Contingency Concept Design Phase (40% of Construction Cost)	$ 1,700,000
Project Total Cost	**$ 7,300,000**

The dam configuration will need further design to determine the spillway capacity and location. Further design would also refine the outlet capacity and overall dam dimensions. At present, the lake formed by a 100 year ARI event would be drained down over two weeks.

The impact of not implementing the Q4 Detention Dam Option (adopting a "do nothing" approach) would be to allow flood runoff to enter the pit, direct it toward low points in the mine and then pump it back out.

Estimated capital costs and the potential pumping costs incurred by not implementing the option are summarised in Table 7-13. Costs associated with disruption, work safety, delays to ore delivery, other damage and clean up costs are not included.

Table 7-13: Option Q4 Cost Summary

Option	Capital cost of option	Volume of water into pit with "do nothing" option during 100 yr ARI event m^3 (A)	Cost to pump out (A) at 20cents /kW hour	Average annual volume of runoff into pit with "do nothing" option m^3 (B)	Cost to pump out (B) at 20cents /kW hour
Q4 Detention Dam	$7,300,000	1,000,000	$72,667	238,928	$17,362

7.10 Q5 Bund and Diversion Channel

The objective of the Q5 Bunding and Diversion Option is to convey attenuated flows from the two proposed detention dams – Q3 and Q4 during Stage 3, 4 and 5. It consists of a 1m to 2m bund in combination with a diversion channel to carry flows from the dams around the southern pit edge and to the west. Figure 7.1 shows the location of the option. Under the current mine plan the option would be required at the start of mining Stage 4.

The benefit of the channel is that in combination with the Q3 and Q4 detention dams it allows flood water that would otherwise discharge into the Queens pit to be controlled and discharged downstream of the mine into Weelumurra Creek.

The dimensions of the bund earthworks are approximately 1 to 2m in average height, 3.4km in length, with a 4m crest width and trapezoidal cross section shape with 3 horizontal to 1 vertical side slopes. The construction material would be the channel excavation materials and this would be bulldozed into the bund dimensions and compacted with tracked or wheeled machinery. Compaction of the materials would be carried out in 500mm lifts.

The estimated volume of earthworks for the bund is 48,000m^3. The cost of the bund is in the order of $480,000 (assumed rate for this study is $10 per bulk cubic metre).

In combination with the bund, the channel would be developed to pass up to 40m^3/s released from the Q3 and Q4 detention dams. The channel is upstream of the option Q1 bund and channel.

The dimensions for the channel are 3.4km length, 5m base width, 2 horizontal to 1 vertical, with depth 1.5m. The average channel gradient is 1 in 114. The estimated volume of cut earthworks for the channel is 36,000m^3 plus overburden cut to maintain the 1 in 114 gradient. Some of the overburden cut would be excavated as part of the pit development works. The channel excavation volume is estimated to be around 100,000m^3.

The cost of the diversion channel is estimated to be $500,000 at $5 per cubic metre excavation with cut spoil disposed alongside the channel or in the mine. This gives a channel rate of $150/m length. The total cost of the Q5 bund and channel is estimated at $1million.

Estimated capital costs and the potential pumping costs incurred by not implementing the option are summarised in Table 7-14. Costs associated with disruption, work safety, delays to ore delivery, other damage and clean up costs are not included.

Table 7-14: Option Q5 Cost Summary

Option	Capital cost of option	Volume of water into pit with “do nothing” option during 100 yr ARI event m^3 (A)	Cost to pump out (A) at 20cents /kW hour	Average annual volume of runoff into pit with “do nothing” option m^3 (B)	Cost to pump out (B) at 20cents /kW hour
Q5 Bund and Channel	$1,500,000	1,300,000	$94,467	497,766	$36,171

7.11 Do Nothing Case

For each of the options described above the alternative is to not implement the option and adopt a default “do nothing” approach. “Do nothing” in this case means implementing standard minesite stormwater management practices including safety bunding around all pits. In this assessment it has been assumed that during a major flood the impact of local stormwater management practices and safety bunding will not make a significant difference to floodwater discharge into the pits.

The depth of the surface water runoff pond in the pit will depend on the volume of the void at the time of the event. Early development stages would have small, shallow pit voids which have the potential to be inundated to relatively high depths.

Table 7-15: Summary of Estimated Capital Cost and Pumping Costs (per Option)

Option	Description	Capital cost of option ($)	Volume of water into pit with "do nothing" option during 100 yr ARI event m^3 (A)	Time to Pump Out (A) at 24,000m^3/day (Days)	Cost to pump out (A) at 20cents per kHhr ($)	Average annual volume of runoff into pit with "do nothing" option m^3 (B)	Time to Pump Out (B) at 24,000m3/day (Days)	Cost to Pump Out (B) at 20cents per kWhour ($)	Ratio B/C	Rank
K1	Diversion channel and bund	400,000	800,000	33	58,133	477,855	20	34,724	0.145	1
K2	Diversion channel and bund	7,900,000	5,500,000	229	399,667		-	0	0.051	6
K3	Diversion channel and bund	570,000	1,100,000	46	79,933	139,374	6	10,128	0.140	2
K4	Landbridge and channel	10,000,000	12,000,000	500	872,000	1,095,085	46	79,576	0.087	4
K5	Detention Dam	13,000,000	18,500,000	771	1,344,333	2,090,617	87	151,918	0.103	3
Q1	Diversion channel and bund	6,900,000	2,700,000	113	196,200	19,911	1	1,447	0.028	8
Q2	Diversion channel and bund	4,800,000	2,800,000	117	203,467	298,600	12	21,698	0.042	7
Q3	Detention Dam	6,500,000	600,000	25	43,600	159,285	7	11,575	0.007	10
Q4	Detention Dam	7,300,000	1,000,000	42	72,667	238,928	10	17,362	0.010	9
Q5	Diversion channel and bund	1,500,000	1,300,000	54	94,467	497,766	21	36,171	0.063	5

8. Flood Management Options for Current Mine Plan (Stages 1 to 5)

8.1 Introduction

In this section the flood management options described in Section 7 and listed in Table 7-1 are combined for each stage of the current mine plan.

The current mine plan is divided into five stages. The pre-mining stage has also been included for reference. The modelled stages are:

- Stage 0: Base case – pre-development
- Stage 1: Year 1
- Stage 2: Years 2 - 5
- Stage 3: Years 6 - 10
- Stage 4: Years 11 - 15
- Stage 5: Years 16 – 20 or end of mine.

Rainfall runoff and hydraulic models described in Sections 5 and 6 were used to simulate the impact of the 100 year ARI flood on the mining operation for each stage for the “do nothing” option and with the proposed flood management options in place. The objective of the proposed options is to minimise the volume of flood water discharged to the pits during the design flood event and on an annual basis and so reduce the costs associated with disruption to the mine operation and pumping out of water.

The flood management options proposed here do not totally exclude flows from pits but seek to manage the larger sources of runoff volumes. Therefore even with the flood management options in place, some flows will discharge into the pits and this will need to be managed and pumped out.

8.2 Stage 0: Base Case

Figure 8-1 is a plan of the existing terrain with a 100 year ARI flood event modelled showing the predicted flood water extent and depths during peak channel discharge.

An outline of the boundary between the RORB modelled catchments and the floodplain area modelled in the 2D hydraulic model is shown on each map.

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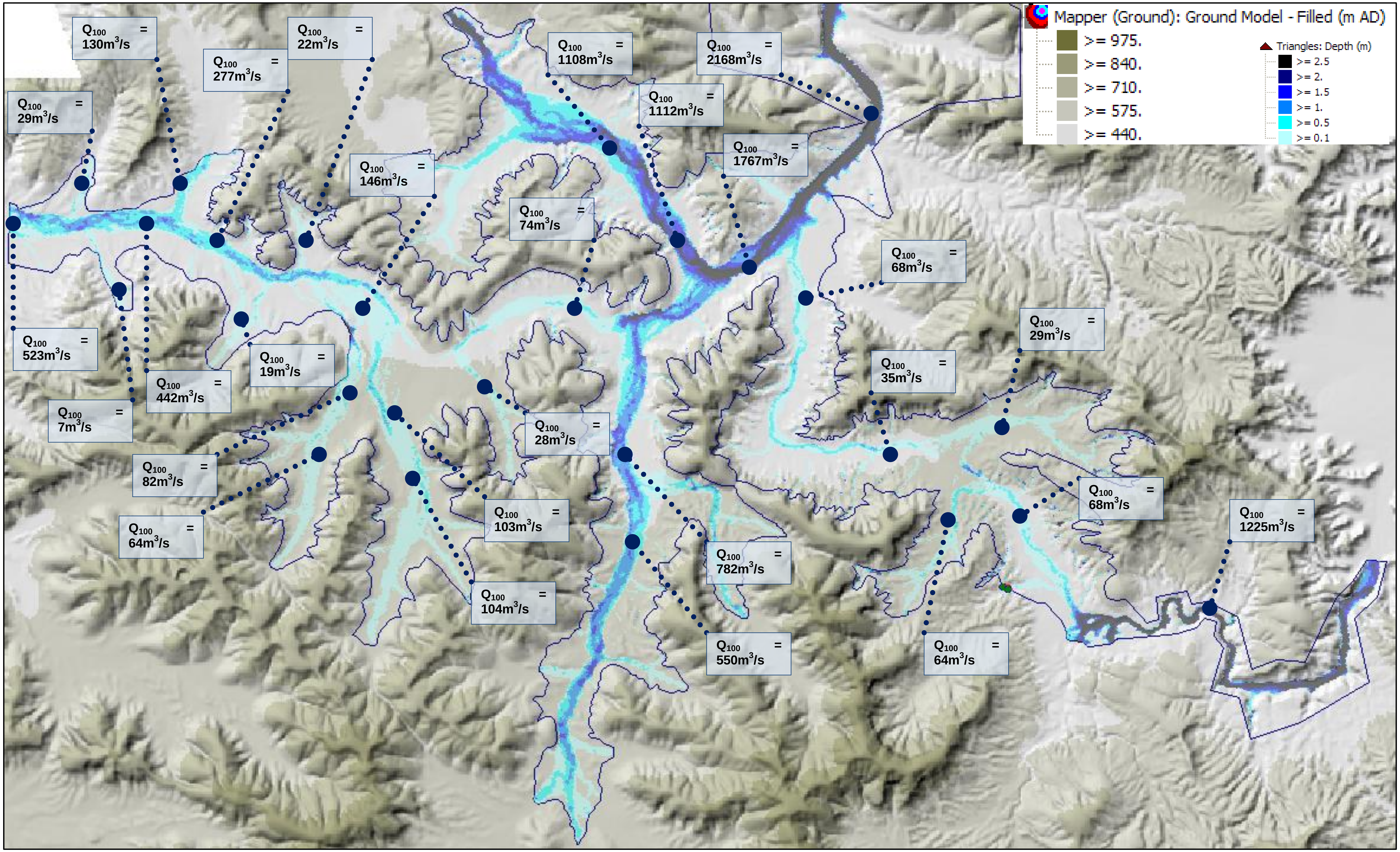

Figure 8-1: 100 Year ARI Flood; Stage 0 Base Case

8.3 Stage 1: Year 1

Figure 8-3 shows the extent of the modelled 100 year ARI flood and the impact on Stage 1 of the mine without flood management infrastructure.

Figure 8-4 shows the 100 year ARI flood and the impact on Stage 1 of the mine with proposed flood management options implemented.

The flood management options for Stage 1 include:

- **K1 Bund and Diversion Option:** a bund in the K2 pit diverting runoff towards the east, and away from K2 pit and a bund and channel around the north side of pit K2

The volume of surface water runoff that enters all of the pits up to and including the Stage is shown in the chart below (Figure 8.2). The reduction in flood volume due to the options into the pit is shown in the Figure 8.3 and Figure 8.4.

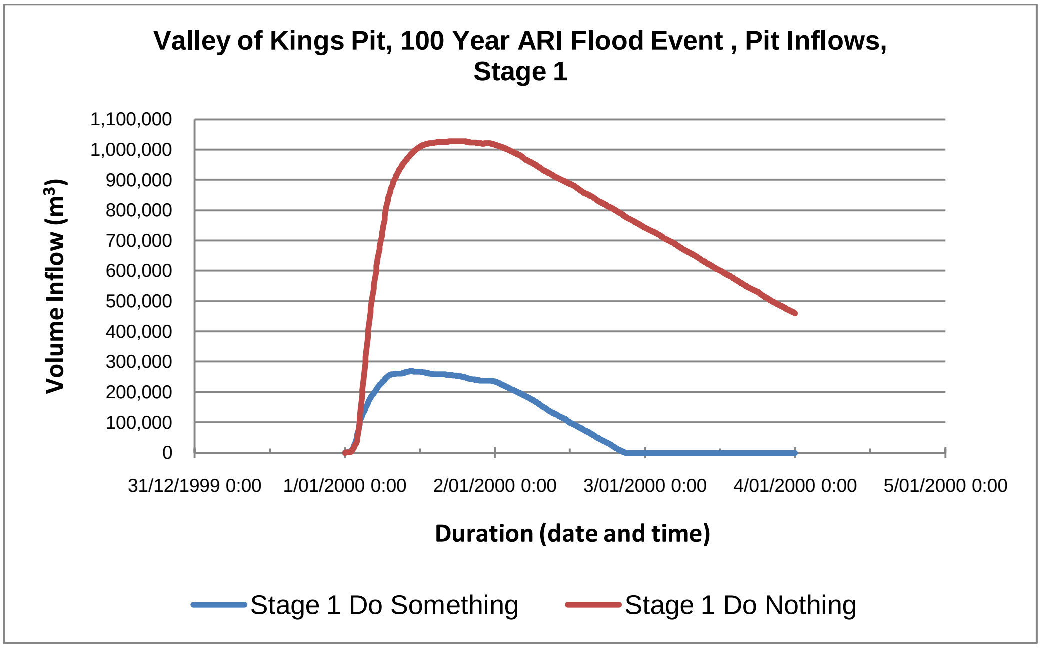

Figure 8-2: Stage 1 Pit Flood Volumes

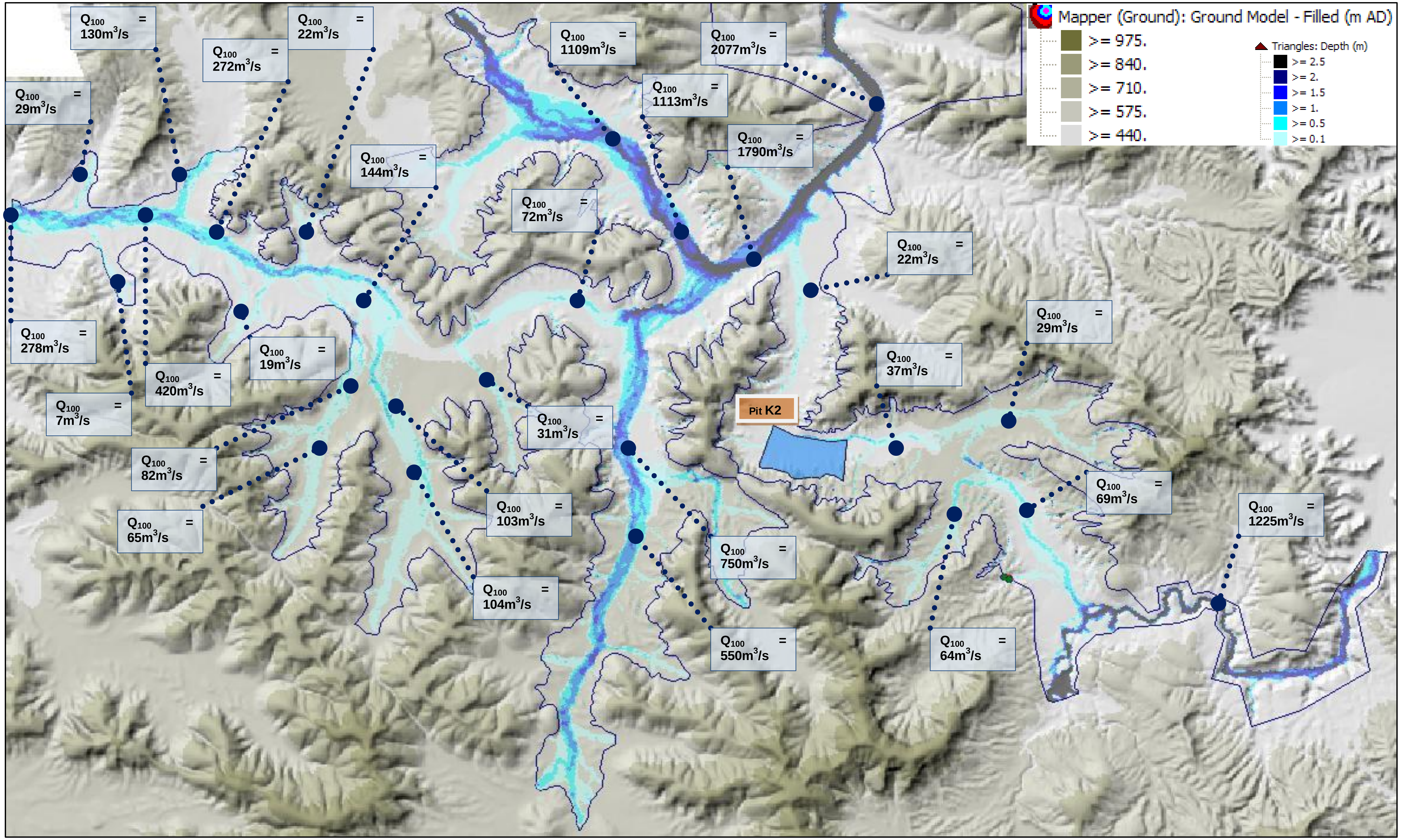

Figure 8-3: 100 Year ARI Flood; Stage 1; Planned Mine with no Flood Management

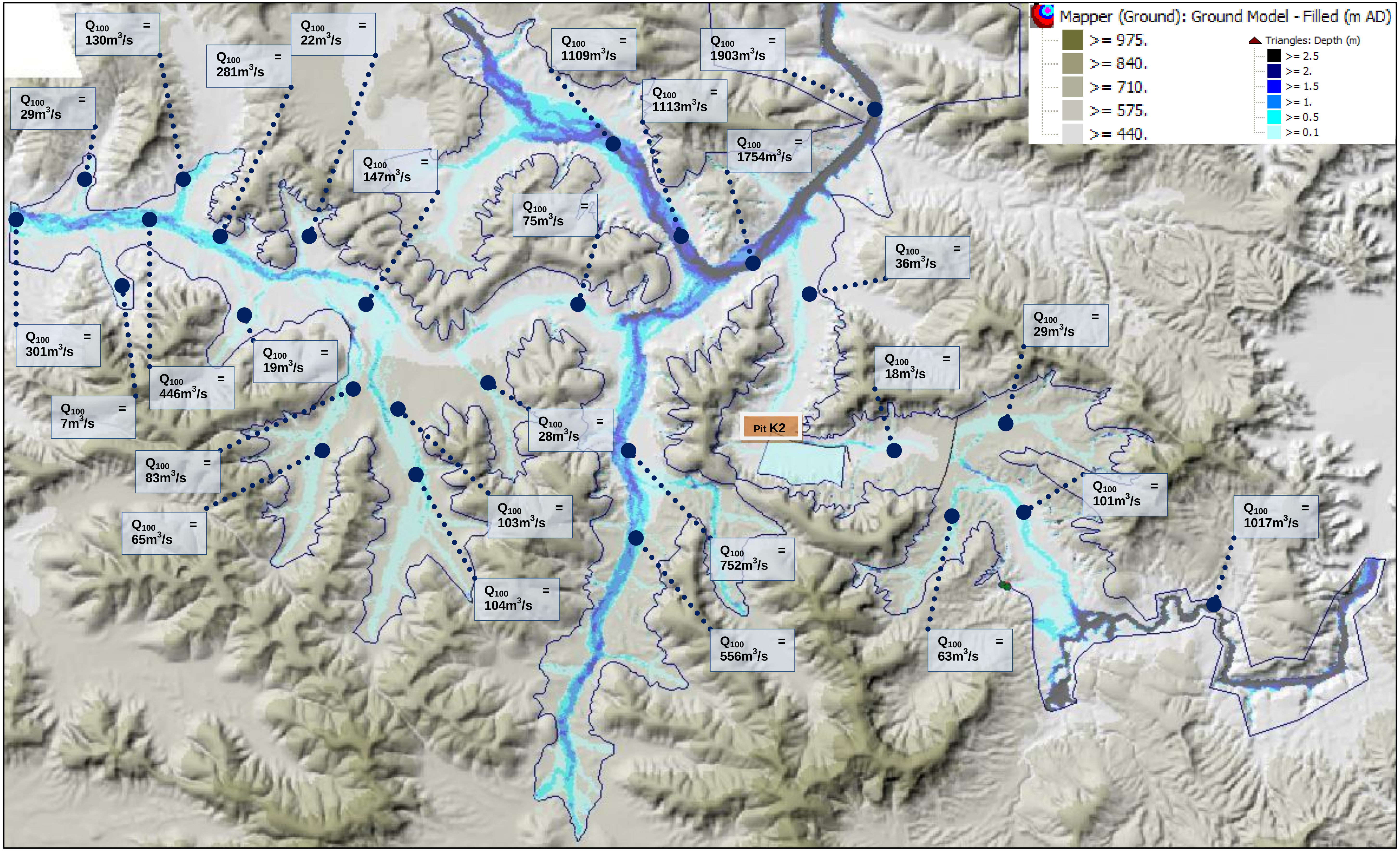

Figure 8-4: 100 Year ARI Flood; Stage 1; Planned Mine with Proposed Flood Management Options

8.4 Stage 2: Years 2 – 5

Figure 8-6 shows the extent of the modelled 100 year ARI flood and the impact on Stage 2 of the mine without flood management infrastructure. Figure 8-7 shows the 100 year ARI flood and the impact on Stage 2 of the mine with proposed flood management options implemented.

The figures show peak discharges at points of interest along the channels. The volume of surface water runoff that enters each of the pits is noted in Figure 8.5.

The flood management options for Stage 2 include:

- **K1 Bund and Diversion Option:** a bund in K2 diverting runoff towards the east, and away from K2 pit
- **K2 Bund and Diversion Option:** a bund and channel around the north and south sides of pit K1
- **K4 Landbridge Option:** a diversion channel and landbridge on Kangeenarina Creek across the Trinity area
- **K5 Detention Dam:** detention dam from catchment K5

The volume of rainfall and surface water runoff that enters all of the pits up to and including the Stage is shown in Figure 8.6. The reduction in flood volume into the pit due to the flood management options is shown in Figure 8.7.

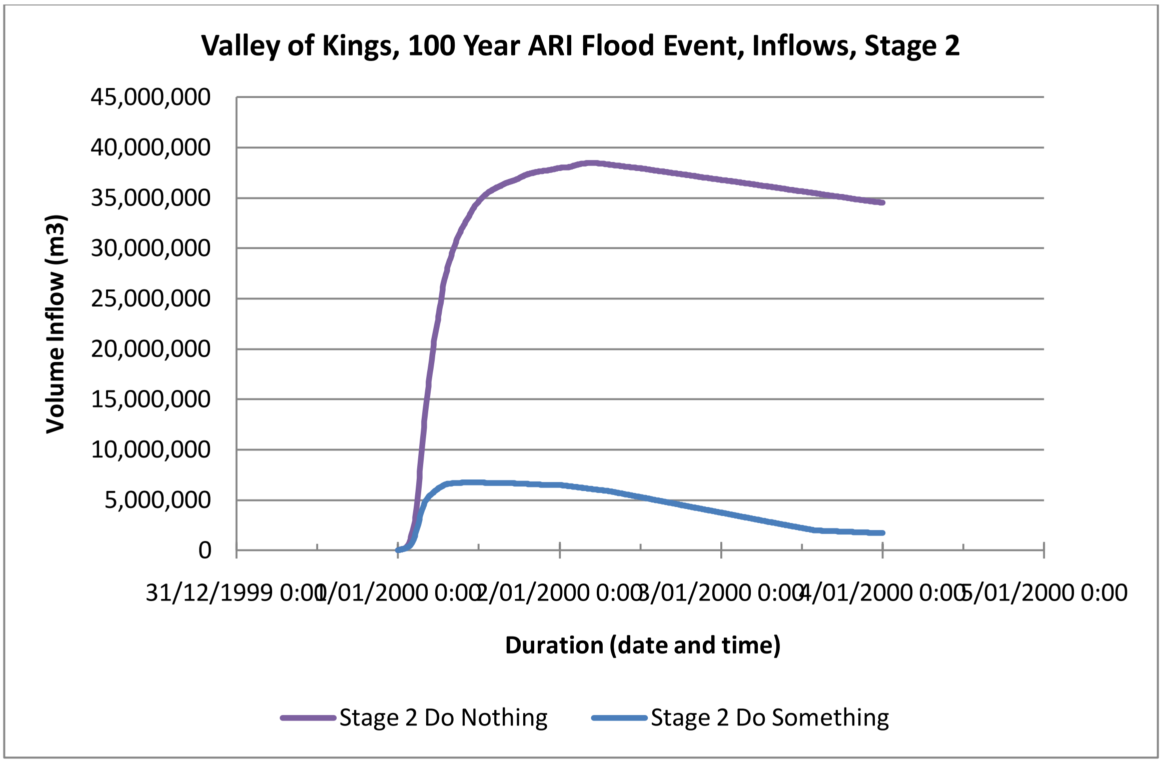

Figure 8-5: Stage 2 Pit Flood Volumes

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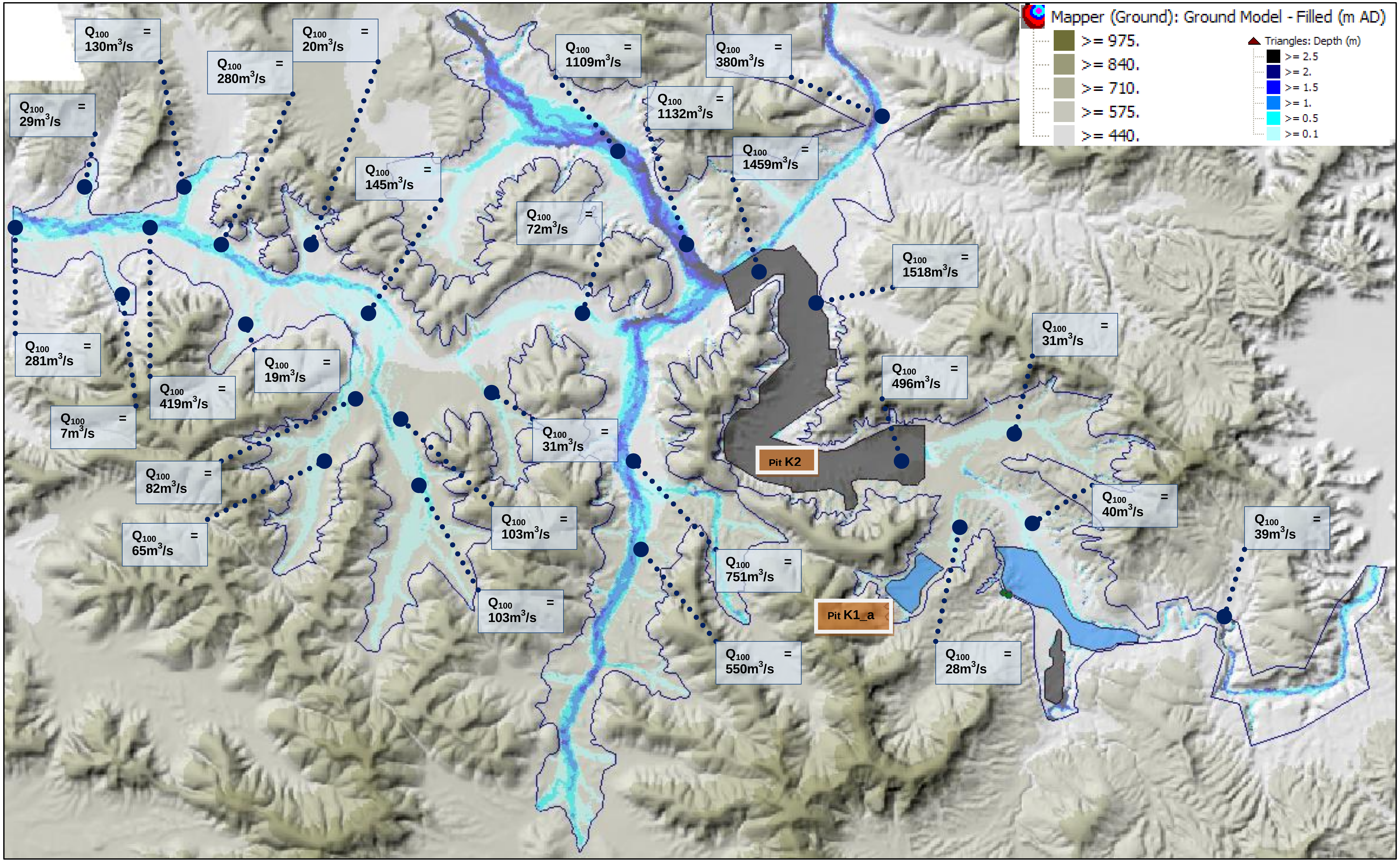

Figure 8-6: 100 Year ARI Flood; Stage 2; Planned Mine with No Flood Management

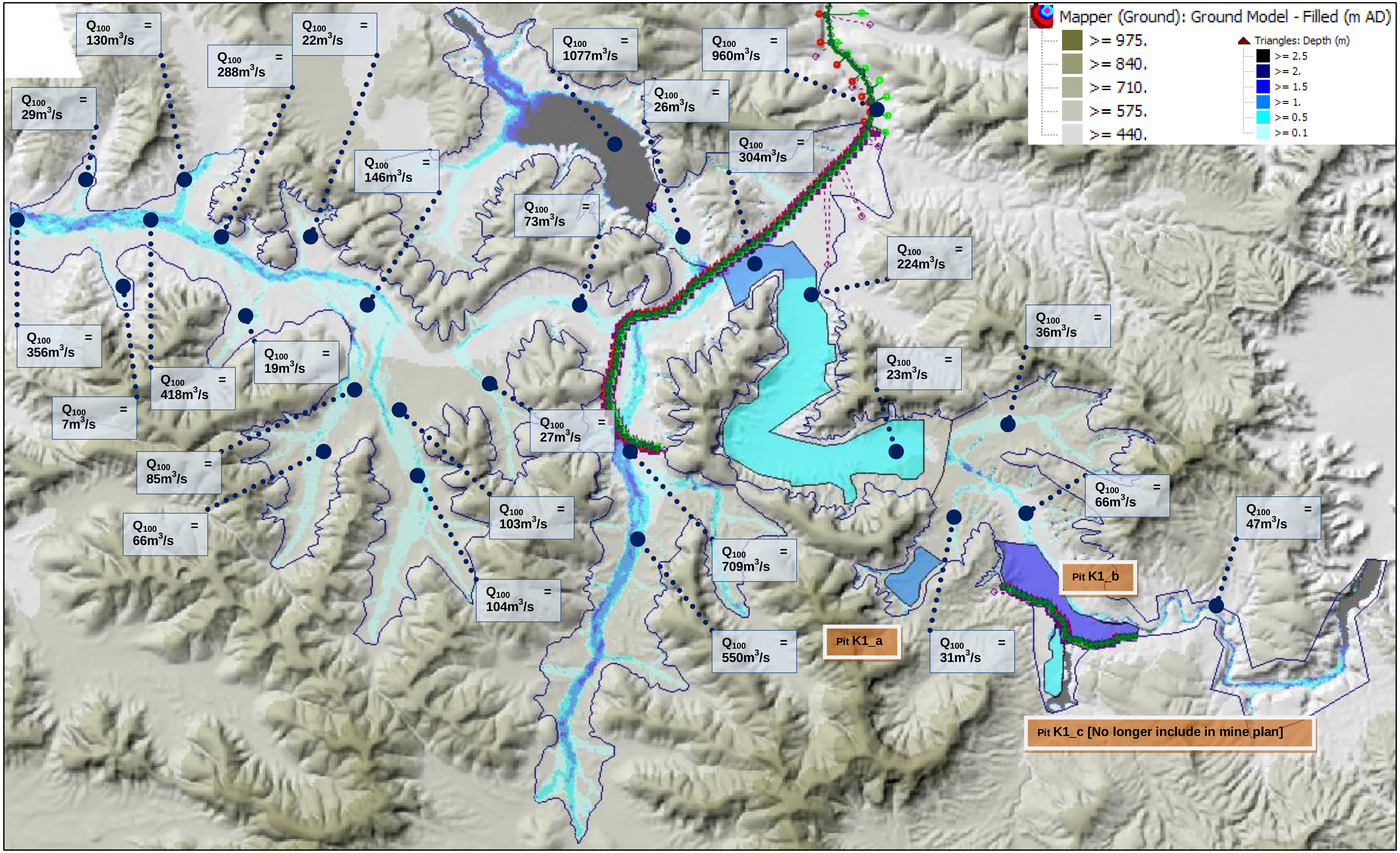

Figure 8-7: 100 Year ARI Flood; Stage 2; Planned Mine with Proposed Flood Management Options

8.5 Stage 3: Years 6 – 10

Figure 8-9 shows the extent of the modelled 100 year ARI flood and the impact on Stage 3 of the mine without flood management infrastructure.

Figure 8-10 shows the 100 year ARI flood and the impact on Stage 3 of the mine with proposed flood management options implemented. The figures show peak discharges at points of interest along the channels. The volume of rainfall and surface water runoff that enters each of the pits is noted Figure 8.8.

The flood management options for Stage 3 include:

- **K2 Bund and Diversion Option:** a bund and channel around the north and south sides of pit K1
- **K3 Bund and Diversion Option:** a bund a diversion to divert flows from the TSF catchment away from the Kings pit
- **K4 Landbridge Option:** an extension upstream of the diversion channel and landbridge across the Trinity area
- **K5 Detention Dam:** detention dam from catchment K5
- **Q1 Bund and Diversion:** Bund and diversion channel to convey floodwater around the southern side of the Queens pit
- **Q2 Bund and Diversion:** Bund and diversion channel to convey floodwater around the northern side of the Queens pit.

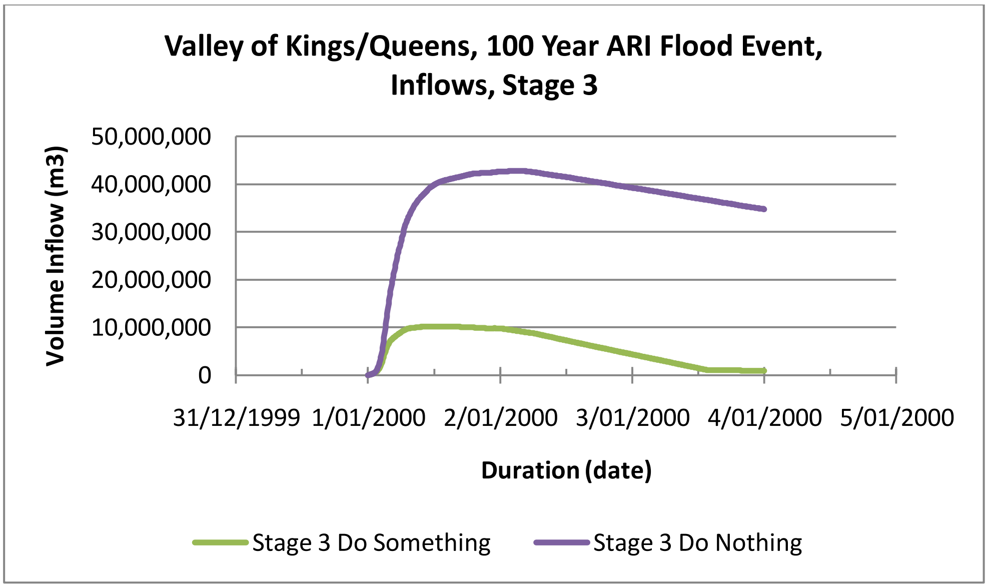

Figure 8-8: Stage 3 Pit Flood Volumes

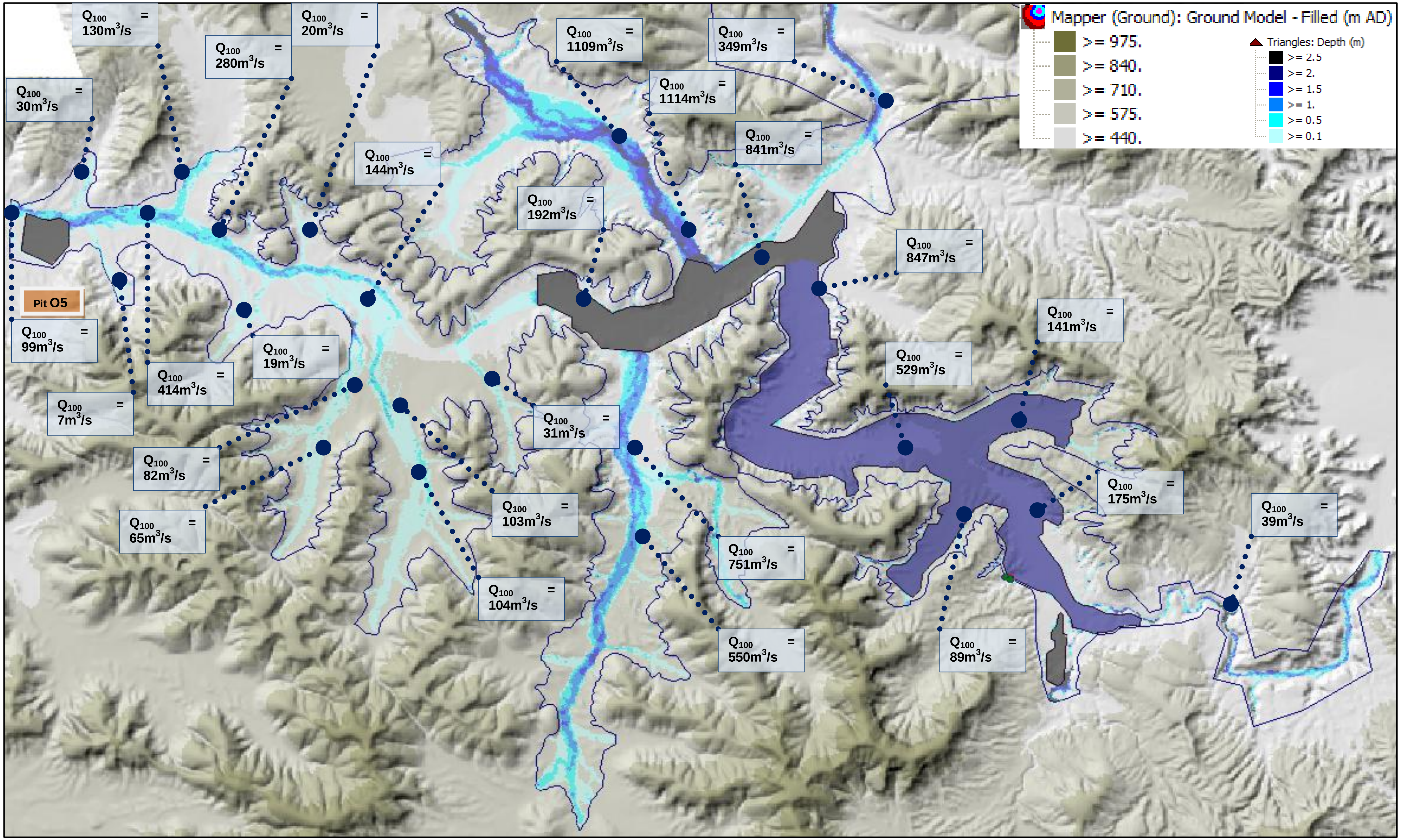

Figure 8-9: 100 Year ARI Flood; Stage 3; Planned Mine with No Flood Management

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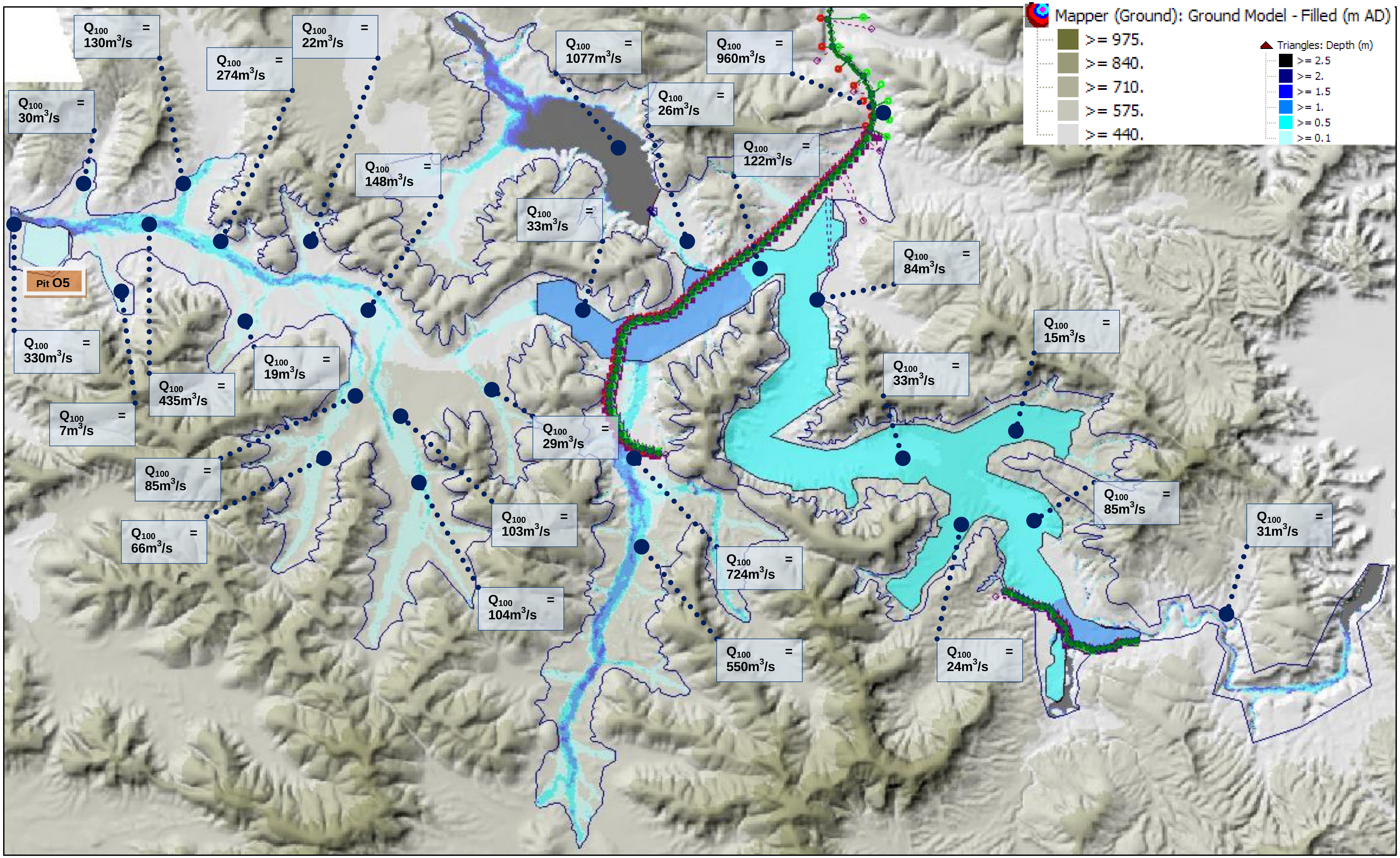


Figure 8-10: 100 Year ARI Flood; Stage 3; Planned Mine with Proposed Flood Management Options

8.6 Stage 4: Years 11 – 15

Figure 8-12 shows the extent of the modelled 100 year ARI flood and the impact on Stage 4 of the mine without flood management infrastructure. Figure 8-13 shows the 100 year ARI flood and the impact on Stage 4 of the mine with proposed flood management options implemented.

The figures show peak discharges at points of interest along the channels. The volume of surface water runoff that enters each of the pits is noted in Figure 8.11.

The flood management options for Stage 4 include:

- **K2 Bund and Diversion Option:** a bund and channel around the north and south sides of pit K1
- **K3 Bund and Diversion Option:** a bund a diversion to divert flows from the TSF catchment away from the Kings pit
- **K4 Landbridge Option:** an extension upstream of the diversion channel and landbridge across the Trinity area
- **K5 Detention Dam:** detention dam from catchment K5
- **Q1 Bund and Diversion:** Bund and diversion channel to convey floodwater around the southern side of the Queens pit
- **Q2 Bund and Diversion:** Bund and diversion channel to convey floodwater around the northern side of the Queens pit.
- **Q3 and Q4 Detention Dam Options:** detention dams at Q3 and Q4 catchments
- **Q5 Drainage Channel Option:** channel to convey attenuated water from Q3 and Q4 dams

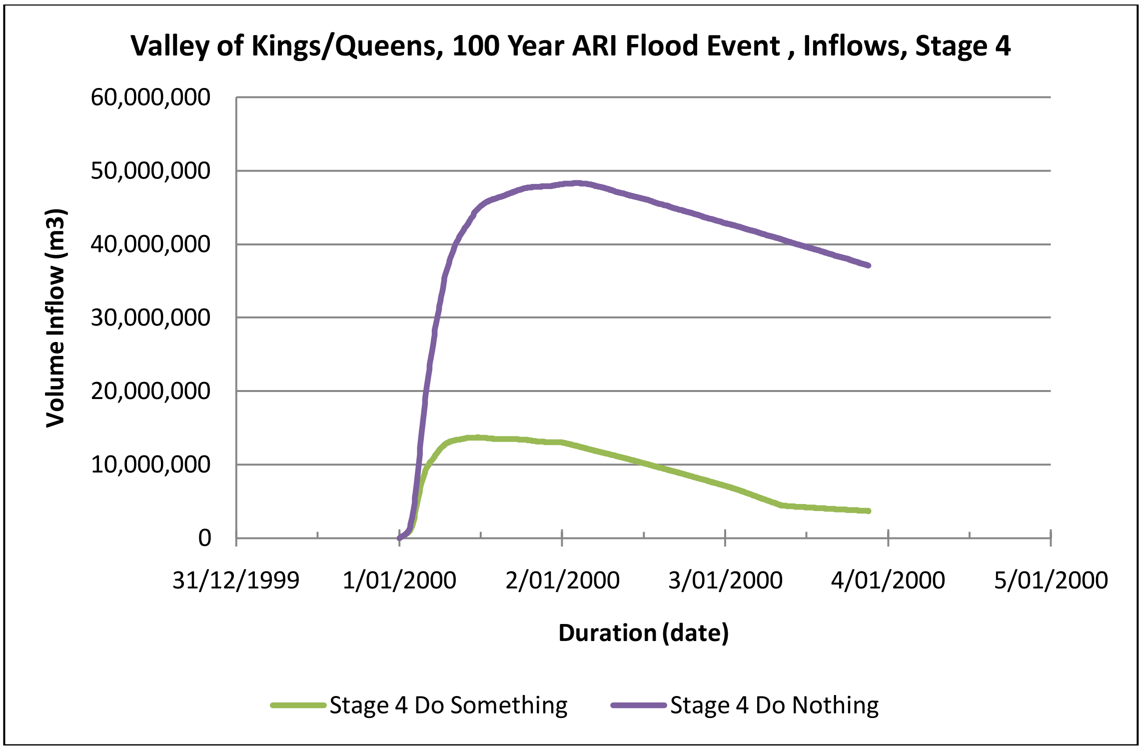


Figure 8-11: Stage 4 Pit Flood Volumes

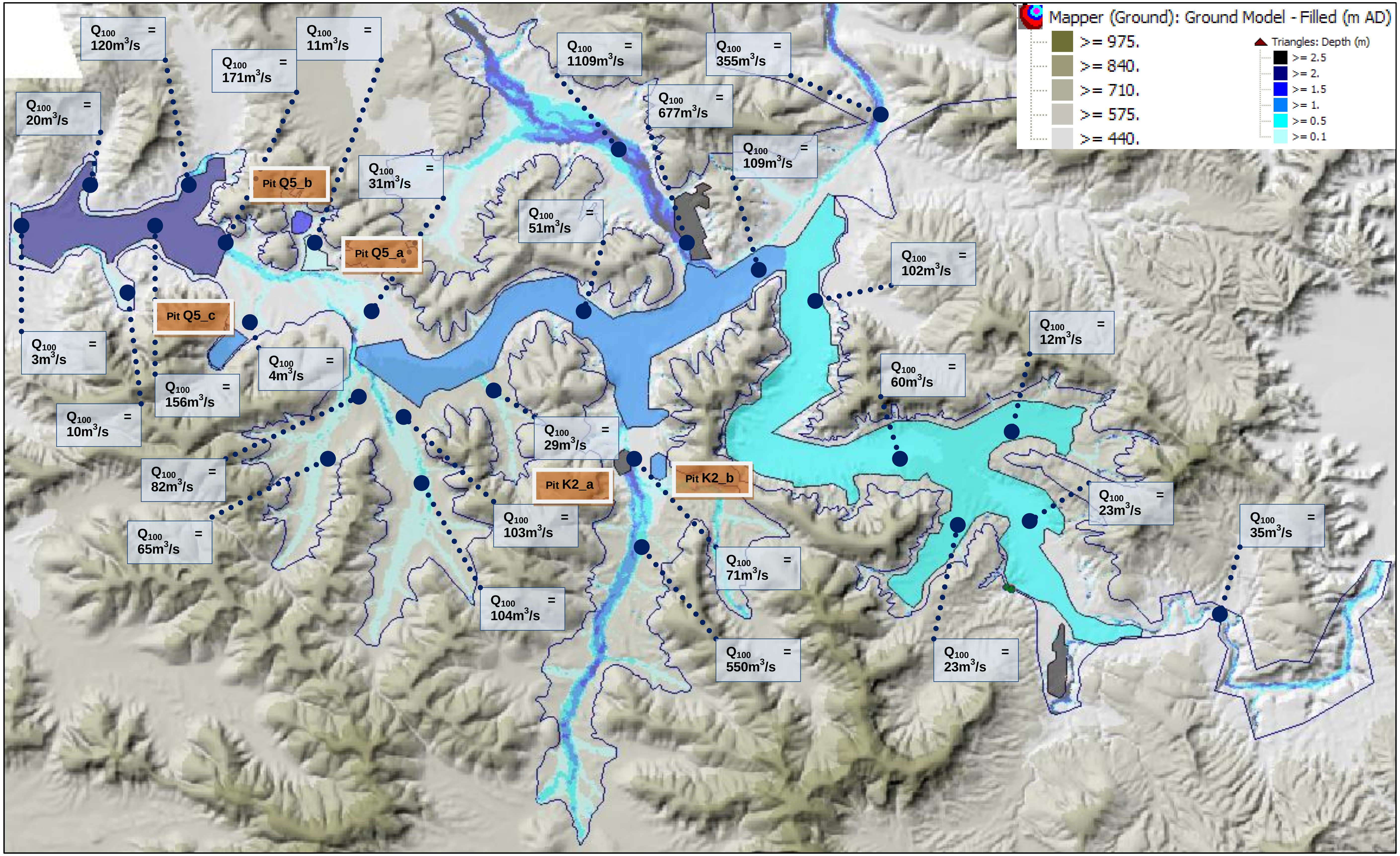


Figure 8-12: 100 Year ARI Flood; Stage 4; Planned Mine with No Flood Management

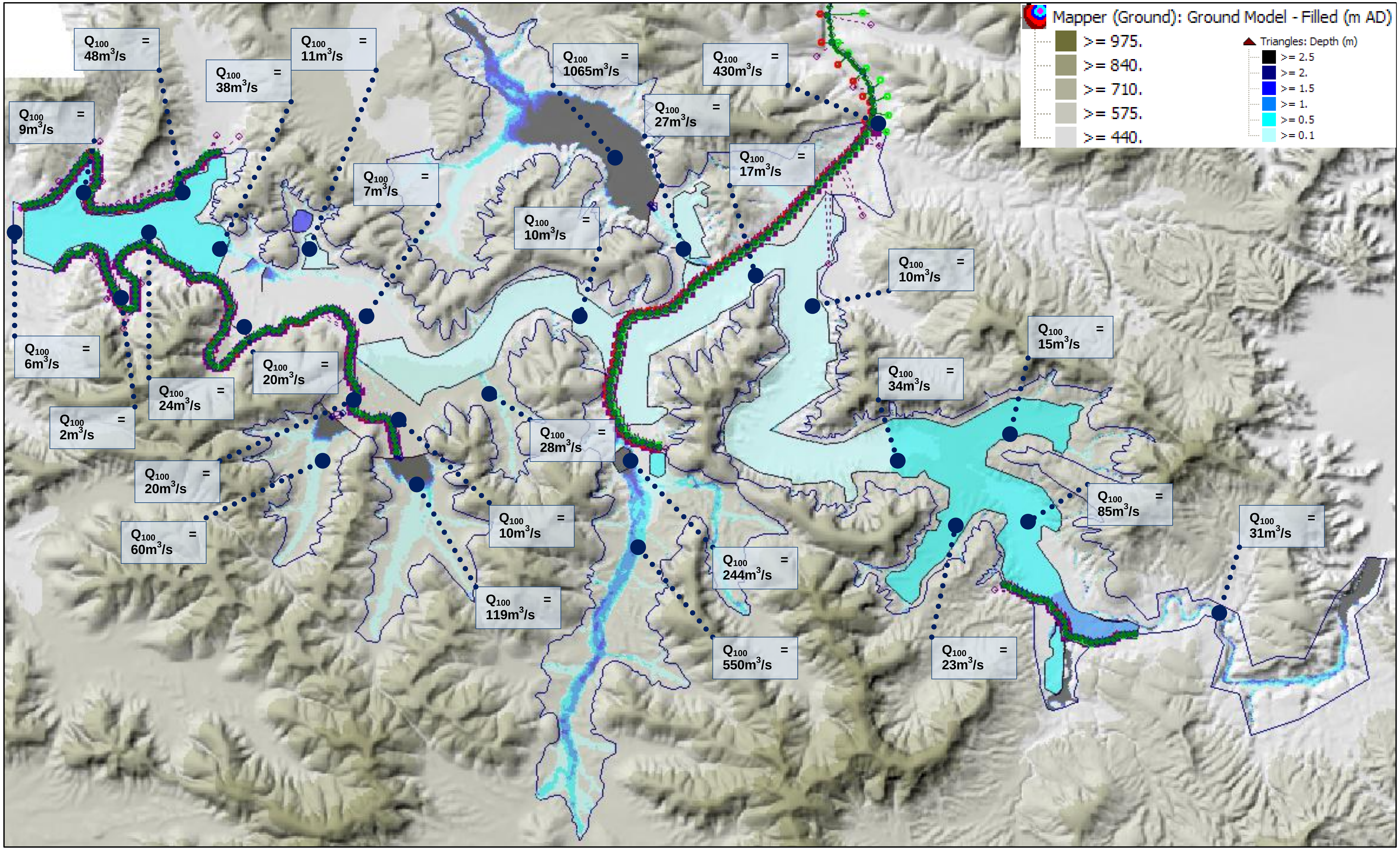


Figure 8-13: 100 Year ARI Flood; Stage 4; Planned Mine with Proposed Flood Management Options

8.7 Stage 5: Years 16 – 20 or end of mine.

Figure 8-15 shows the extent of the modelled 100 year ARI flood and the impact on Stage 5 of the mine without flood management infrastructure. Figure 8-16 shows the 100 year ARI flood and the impact on Stage 5 of the mine with proposed flood management options implemented.

The figures show peak discharges at points of interest along the channels. The volume of rainfall and surface water runoff that enters each of the pits is noted in Figure 8.14.

The flood management options for Stage 5 include:

- **K2 Bund and Diversion Option:** a bund and channel around the north and south sides of pit K1
- **K3 Bund and Diversion Option:** a bund a diversion to divert flows from the TSF catchment away from the Kings pit
- **K4 Landbridge Option:** diversion channel and landbridge across the Trinity area to taken as the "goodbye cut" at the end of mining
- **K5 Detention Dam:** detention dam from catchment K5
- **Q1 Bund and Diversion:** Bund and diversion channel to convey floodwater around the southern side of the Queens pit
- **Q2 Bund and Diversion:** Bund and diversion channel to convey floodwater around the northern side of the Queens pit.
- **Q3 and Q4 Detention Dam Options:** detention dams at Q3 and Q4 catchments
- **Q5 Drainage Channel Option:** channel to convey attenuated water from Q3 and Q4 dams

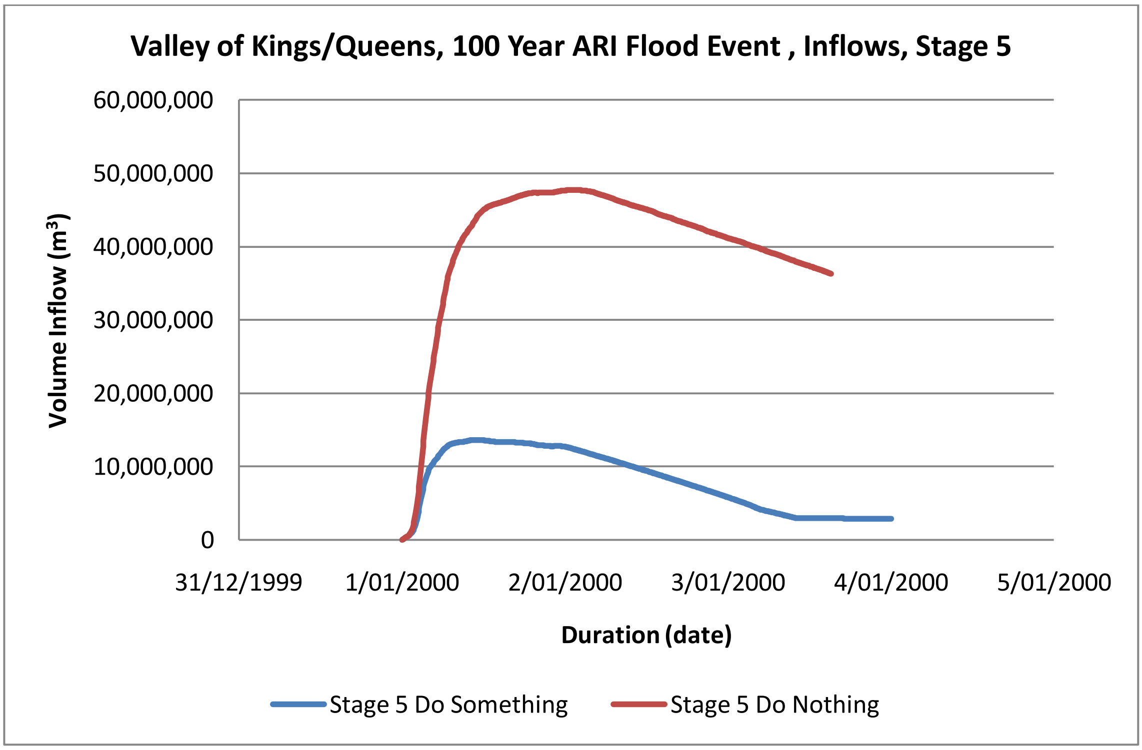


Figure 8-14: Stage 5 Pit Flood Volumes

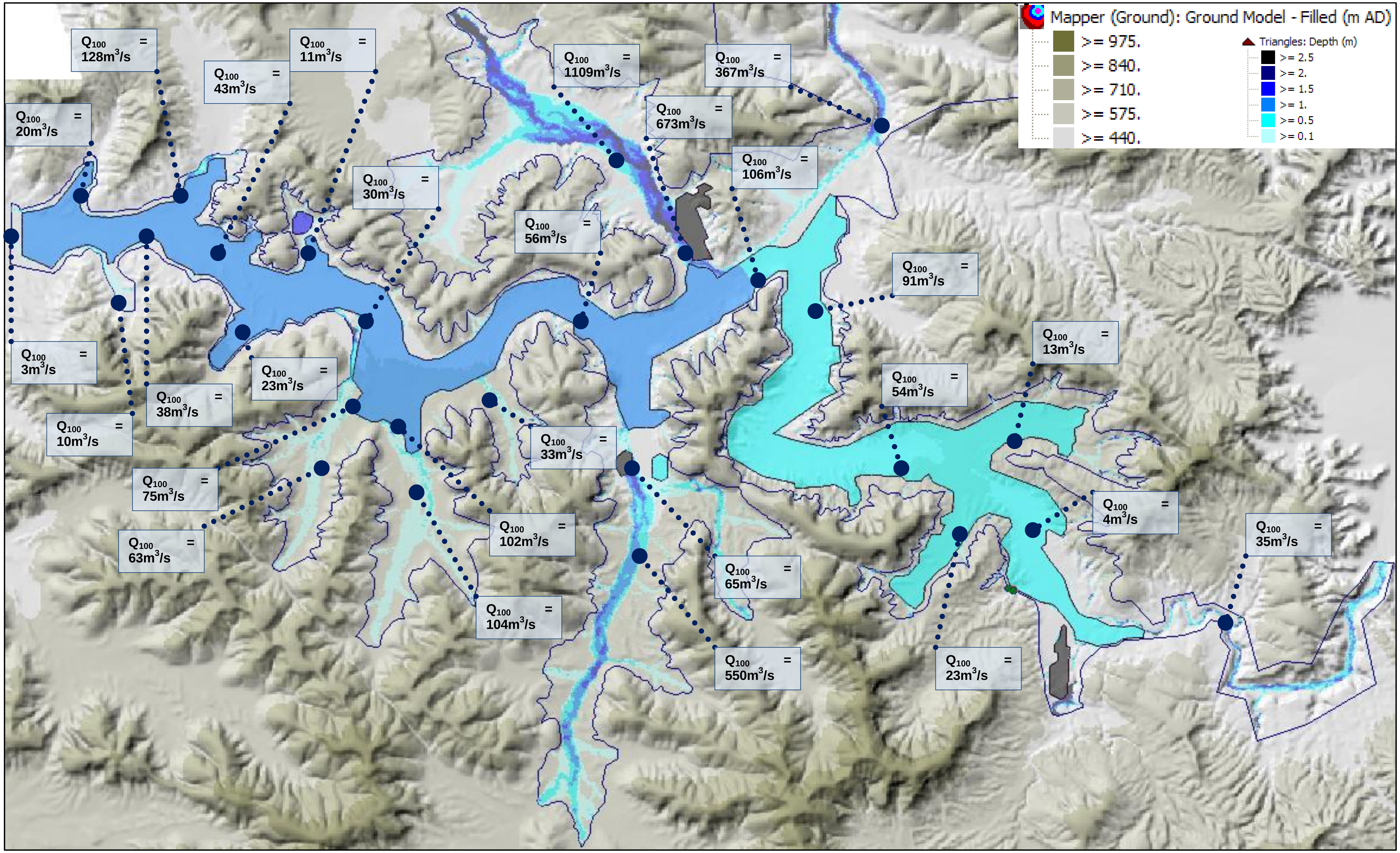


Figure 8-15: 100 Year ARI Flood; Stage 5; Planned Mine with No Flood Management

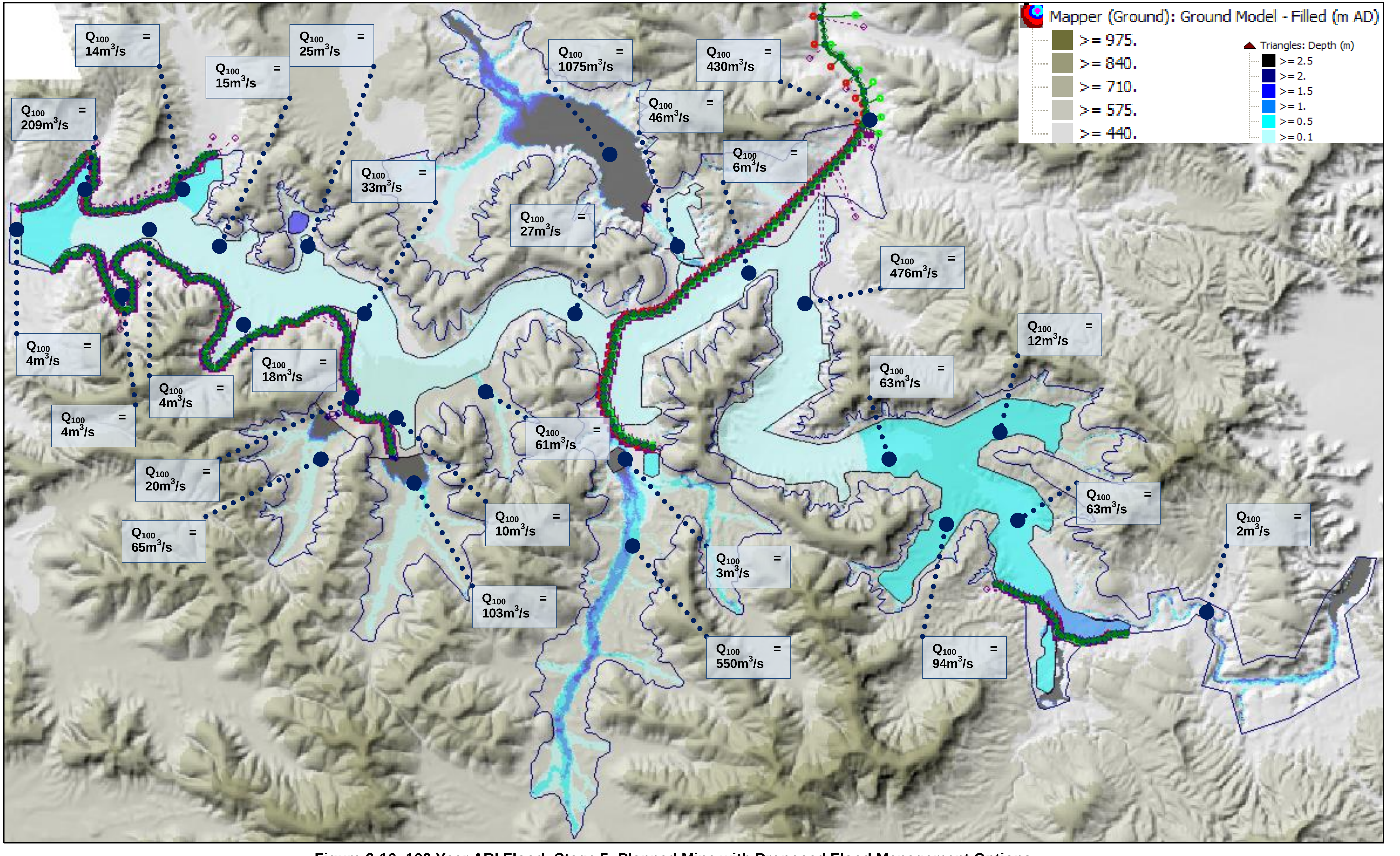


Figure 8-16: 100 Year ARI Flood; Stage 5; Planned Mine with Proposed Flood Management Options

Table 8-1: Summary of Estimated Capital Costs and Pumping Costs (Per Stage)

Stage	100 year ARI runoff volume into pit (m^3)	Cost to pump out ($) at 20cents/kW hour	Time to pump out following 100 year ARI event (days) at 24,000 m^3/day	Capital cost of surface water management options for each stage	Accumulated capital cost of surface water management options
1 (Year 1)	1,000,000	$72,667	42	$400,000	$400,000
2 (Years 2-5)	38,350,000	$2,786,767	1,598	$30,900,000	$31,300,000
3 (Years 6-10)	44,850,000	$3,259,100	1,869	$570,000	$31,870,000
4 (Years 11-15)	52,520,000	$3,816,453	2,188	$27,000,000	$58,870,000
5 (Years 16-20)	45,080,000	$3,275,813	1,878		$58,870,000
Total		$13,210,800		$58,870,000	

A more detailed table of flood inflows into each part of the mine and estimated inundation depths for each stage is included in Table 8-2.

Pit identification follows the Kings and Queens pit stage notation used throughout this report. Some smaller pits are shown on the current mine plan and these are noted as sub-pits, for example “K1_a” is a sub-pit of the K1 stage pit that is separate from the main excavation and are shown in the Figures in Section 8.

The pit areas are measured from the current mine stages plan in GIS. The “working pit” area is the pit under development during the Stage. The “excavated pit void” is a pit void that is excavated to final depth during an earlier Stage and is connected to the working pit.

Runoff volume into pits is calculated from a 2D hydraulic model of the mine at each of the 5 Stages with no flood protection works around the pits. It is assumed that the nominal bunds and channels around the pits in the “do nothing” case are overwhelmed or are ineffective during the 100 year ARI rainfall event. These cases are intended to show the worst cases of pit inundation. The model calculates volume from direct rainfall on the pit area plus overland runoff that crosses the pit perimeters.

It is assumed that flood water that enters the working pit would be directed through the working pit area towards the lowest level in the pit which could be the neighbouring excavated pit void, or part of the actual working pit. The depth of flood water is assessed against the working pit area or part of the working pit area, or against the adjacent excavated pit void. The pits are assumed to be vertically walled and horizontally based.

“Into pit void” assumes the working pit area has been completed and the pit is an “excavated pit void”.

“In working pit” implies that the pit does not have an adjacent excavated pit void to catch flood water, and flood volumes must be contained within the working pit void.

The time and cost to pump out is estimated based on the following assumptions:

1. Unit cost of energy = 20 cents/kW.hour

2. Pit depth 70m (pumping lift)

3. Pump out rate 1000m^3/hour (24,000m^3/day) – nominally chosen.

The table below summarises the impacts of the “do nothing” approach in terms of pit inundation depth, energy cost to pump out, and duration to pump out pits after a 100 year ARI rainfall event. FMG mine planners would provide refinements to the costs and add other costs (disruption, working safety, delays to ore delivery, other damage costs, etc) to go with this table and to assess the “do nothing” approach.

Table 8-2: Do Nothing Summary of 100 Year ARI Rainfall Inflows

Stage	Pit Location/ Identification	Total Pit Area (km^2)	Working Pit Area (km^2)	Excavated Pit Void Area (km^2)	100 Year ARI Runoff Volume into Pit (m^3)	Depth in Working Pit Area (m)	Depth in 1/2 Working Pit Area (m)	Depth in 1/4 Working Pit Area (m)	Depth in Excavated Pit Void (m)	Likelihood of 100 Year ARI Event during the Stage (%)	Cost to Pump Out ($) at 20cents/kW hour	Time to Pump Out (days) at 24,000m^3/day
Year 1												
1	K2	1.00	1.00	0.00	1,000,000	1	2	4	in working pit	1%	$72,667	42
Years 2-5												
2	K2	6.14	5.14	1.00	30,000,000	6	12	23	29.9	4%	$2,180,000	1250
2	K1_a	0.44	0.44	0.00	500,000	1	2	5	in working pit	4%	$36,333	21
2	K1_b	1.41	1.41	0.00	1,500,000	1	2	4	in working pit	4%	$109,000	63
2	K1_c	0.31	0.31	0.00	6,350,000	21	41	82	in working pit	4%	$461,433	265
Years 6-10												
3	K2	15.36	7.36	7.99	33,000,000	4	9	18	4.1	5%	$2,398,000	1375
3	K1_a	0.44	0.00	0.44	500,000	into pit void	into pit void	into pit void	1.1	5%	$36,333	21
3	K1_b	1.41	0.00	1.41	1,500,000	into pit void	into pit void	into pit void	1.1	5%	$109,000	63
3	K1_c	0.31	0.00	0.31	6,350,000	into pit void	into pit void	into pit void	20.6	5%	$461,433	265
3	Q5	0.84	0.53	0.31	3,500,000	7	13	26	11	5%	$254,333	146
Years 11-15												
4	K2	19.30	3.95	15.36	29,000,000	7	15	29	1.9	5%	$2,107,333	1208
4	K2_a	0.10	0.10	0.00	6,800,000	72	143	286	in working pit	5%	$494,133	283
4	K2_b	0.12	0.12	0.00	1,000,000	9	17	34	in working pit	5%	$72,667	42
4	K1_a	0.44	0.00	0.44	500,000	into pit void	into pit void	into pit void	1.1	5%	$36,333	21
4	K1_b	1.41	0.00	1.41	1,500,000	into pit void	into pit void	into pit void	1.1	5%	$109,000	63
4	K1_c	0.31	0.00	0.31	6,350,000	into pit void	into pit void	into pit void	20.6	5%	$461,433	265
4	Q5	3.90	3.06	0.84	6,800,000	2	4	9	8.1	5%	$494,133	283
4	Q5_a	0.22	0.22	0.00	20,000	0.1	0.2	0.4	in working pit	5%	$1,453	1
4	Q5_b	0.12	0.12	0.00	200,000	2	3	7	in working pit	5%	$14,533	8
4	Q5_c	0.25	0.25	0.00	350,000	1	3	6	in working pit	5%	$25,433	15
Years 16-20												
5	K2	27.05	3.38	23.67	22,460,000	7	13	27	1	5%	$1,632,093	936
5	K2_a	0.10	0.00	0.10	6,800,000	into pit void	into pit void	into pit void	72	5%	$494,133	283
5	K2_b	0.12	0.00	0.12	100,000	into pit void	into pit void	into pit void	1	5%	$7,267	4
5	K1_a	0.44	0.00	0.44	500,000	into pit void	into pit void	into pit void	1	5%	$36,333	21
5	K1_b	1.41	0.00	1.41	1,500,000	into pit void	into pit void	into pit void	1	5%	$109,000	63
5	K1_c	0.31	0.00	0.31	6,350,000	into pit void	into pit void	into pit void	21	5%	$461,433	265
5	Q5	3.90	3.06	0.84	6,800,000	2	4	9	8	5%	$494,133	283
5	Q5_a	0.22	0.00	0.22	20,000	into pit void	into pit void	into pit void	0	5%	$1,453	1
5	Q5_b	0.12	0.12	0.00	200,000	2	3	7	in working pit	5%	$14,533	8
5	Q5_c	0.25	0.00	0.25	350,000	into pit void	into pit void	into pit void	1	5%	$25,433	15

- Notes: 1. Runoff volume into pit is based on a 24 hour duration, 100 year ARI rainfall event. Calculated from 2D hydraulic model, assuming surface water is free to follow ground slopes over pit perimeter, with minimal flood protection.
- 2. Internal pit benching and development of mine during stages is unknown and is simplified into three configurations of low level flood volumes (full working area, ½ and ¼ working areas)
- 3. Excavated pit void refers to pits excavated during previous stages. 4. Evaporation of 9mm/day from the pit volume is not included in the time to pump out the pit void

9. Decision Analysis and Preferred Options

A more detailed description of the proposed decision making process for selecting flood management options is given in Appendix B.

Before beginning a formal decision making process the possible options described in this report need to be reviewed by FMG for fatal flaws.

The remaining options are then short listed by undertaken with a relatively informal MCA, performed by the project team. The short-listed most promising options then can be taken forward for more detailed consideration.

The second stage is a more formal assessment of the short-listed options judged against various criteria which need to be met to achieve a good solution. The widely used Multi-criteria Assessment (MCA) approach is used for this second stage assessment. The process is outlined below.

The individual attribute scores for a particular scheme-option are combined by forming a weighted sum to derive an overall score for each scheme-option. The contribution that each attribute gives to the sum of scores for an option is weighted to reflect the decision makers' beliefs about the relative importance of the different attributes. The resulting scheme-option scores indicate preferences between the scheme-options, providing a means of ranking them and hence identification of the most promising scheme-option

10. Potential Environmental Impacts of Flood Management Options

10.1 Introduction

The Department of Water has a number of objectives for managing water in the Pilbara region. The Pilbara regional water plan sets out objectives for all water users across the region and the mining guideline builds on the regional objectives, with a specific focus on managing water in mining projects (DoW,2009b).

A few of the more relevant objectives to this project are listed below:

- Plan for, and manage the effects of the highly variable climate;
- Ensure that mining activity does not adversely affect the quality and quantity of public and private drinking water supplies;
- Minimise the adverse effects of the abstraction and release of water on environmental, social and cultural values;
- Use a monitoring and evaluation process to adaptively manage the effects of abstractions and releases on the water regime, both at mining sites and in the catchment in general; and
- Ensure that the cumulative effects of individual mining operations are considered and managed.

The proposed mine site is located in the Hamersley Ranges within the upper section of the Lower Fortescue River catchment. Kangeeenarina Creek is the main drainage system through the Valley of Kings, flowing in a north easterly direction towards the Fortescue River plains. The Valley of the Queens drains in a westerly direction towards the Weelumurra Creek. Weelumurra Creek flows in a northly direction along the western boundary of the Queens Pit and converges with the Fortescue River approximately 35km downstream of the project area. The Zalamea Creek catchment encompassing the eastern section of the Kings drains in a north easterly direction towards the poorly defined Southern Branch of the Fortescue River.

The combined area of the catchments likely to be impacted by the proposed mine is approximately 342 km^2 this represents 1.7% of the Lower Fortescue Catchment. Table 10.1 details other catchment area comparisons. The percentage of the Millstream Catchment (Fortescue River) is 2.5%. Please note this comparison is solely a catchment area comparison.

Table 10.1: Comparison of Impacted Catchment Areas

Catchment	River	Catchment Area (km^2)	Proposed Solomons Mine	
			Mine Catchment Area (km^2)	Percentage of Catchment (%)
Millstream @ Deep Reach Pool (708005)	Fortescue River	13,866	342	2.5
Millstream @ Gregory Gorge (708002)	Fortescue River	14,630	342	2.4
Lower Fortescue Catchment	Fortescue River	19,890	342	1.7
Fortescue Catchment	Fortescue River	49, 710	342	0.7

10.2 Potential Hydrological & Environmental Impacts

Potential impacts on surface water hydrology resulting from the proposed mining operation are:

- Modification or interruption of exiting natural drainage channels and or flows
  - Surface water flow patterns are likely to be modified by the valley pits, diversion channels, roads, railway and other associated infrastructure.
  - Capturing, retaining flows and releasing slowly
  - Catchment area upstream proposed detention dams will be inundated.
  - Discharge of excess water from mine dewatering and flood waters.
- Increased sediment runoff and scour
  - Disturbed ground and stockpiled materials may increase sediment runoff
  - Discharging/pumping water from the open pits may have elevated and sediment loads
  - Increased flow velocities from flood management infrastructure (channels, culverts) may cause localised scour and increased sediment load.
- Diminishing water quality of discharge downstream.
  - Evaporation of accumulated surface water within the pit will likely increase the salinity concentration. This may result in lower quality water being discharged to the downstream environment.
- Potential contaminant discharge into the drainage system from hydrocarbons and hazardous storage;

10.2.1 Modification of Existing Natural Drainage Channels and Flow Volumes

The proposed valley pits and associated mine infrastructure such as access roads, mine processing plant, waste-rock dumps, flood protection bunds and diversion channels will potentially alter the existing natural drainage patterns of the mine and associated catchments.

The proposed flood management structures of a land bridge, earth bunds and diversion channels will divert flows back into the natural drainage systems downstream of the mine. Thus, the modification of existing natural channels and drainage patterns will be isolated to the associated mine catchments. The proposed diversion structures will assist in minimising the reduction of downstream flows.

The large pit area and proposed detention dams have the potential to reduce surface water flows due to losses to the groundwater system and evaporation. A minimal volume of attenuated surface water will infiltrate through to the groundwater system. It is expected that infiltration and evaporation losses will only slightly reduce the volume of surface water flows.

10.2.2 Inundation associated with Damming

There are three proposed detention dams designed to attenuate flow. Flows will be detained, released and diverted downstream.

Detention dams are proposed to manage and attenuate flows from the K5, Q4 and Q 3 catchments. The detention of water for short periods after rainfall events will inundated areas of the catchments that previously would not have been inundated. The area and length of time the three catchments are likely to be inundated is tabulated in Table 10.2. The dam outflows were calculated as a single culvert with cross-sectional area of 0.75m^2; therefore in reality detention times should be lower.

Table 10.2 Area of Inundation from Proposed Detention Dams

Catchment	Approximate Area of Catchment Km^2	Peak Volume of water (ML) (100 Yr ARI design rainfall event)	Approximate Area of inundation (Km^2) (100 Yr ARI design rainfall event)	Approximate Length of Inundation (Hrs)
K5	105	27,860	2.7	300 (12.5 days)
Q3	8	998	0.2	55
Q4	11	1897	0.4	70

Where floodwaters are impounded, outlet structures should be sized to ensure that the period of inundation will not cause adverse effects on vegetation.

10.2.3 Potential Increased Sediment Runoff

Increased sediment runoff may result where ground disturbance has occurred as a result of the proposed mining operation. Areas that are prone to elevated sediment runoff are downstream of waste rock dumps, stockpile areas and water pumped from the pits during flood events or dewatering.

Large areas of the Pilbara are predisposed to soil erosion because of their susceptible, often fine textured soils, land degradation (removal of vegetation that exposes the fragile soil structure) and the highly intense rainfall that is experienced (WRC,1997). During a large rainfall event, the background mobilisation of natural sediments within the Fortescue catchment is expected to be high. An aerial photo taken after Cyclone George (Figure 10-1), March 2007 (a 6-7 year ARI event) of the Port Hedland coast shows that the waters in the floodplain were carrying significant natural sediment loads, causing red discolouration of the flood water over a wide area.

It is expected that the volume of potential sediment, transported from the mine operation will have a minimal impact in comparison to the high sediment loading from the natural surrounding environment in large rainfall events.

The proposed flood management methods (detailed in Sections 7 and 8) of ‘do nothing’ or a combination of bunds, diversion channels, detention dams and land bridges will effect sediment loading of runoff events.

Detention dams proposed at K5, Q3 and Q4 would effectively act as a low level sediment treatment pond. Flows are attenuated and released slowly, allowing time for sediment to fall out of solution. Other proposed flood management structures will divert flood waters away from areas (open pits, stockpiling and waste rock dumps) that are prone to increasing sediment concentrations in surface water flows.

The proposed ‘do nothing scenario’ permits flow to runoff naturally through the catchment and into the pit. The water volume will be removed by pumping, and will likely contain high levels of sediments. This water should be treated in large settling ponds prior to discharge (if being discharged to the downstream environment) to decrease the sediment concentration from the disturbed pit bed. Stormwater runoff from the stockpile and waste rock areas should also be treated through the use of settling ponds to reduce sediment concentrations before discharge. The treated discharge should be directed back into the existing draining channel downstream.

Figure 10-1: Floodwaters after Cyclone George (March 2007) Port Hedland Coast

10.3 Water Management Areas and Significant Pools

It is important that sensitive water management areas are not adversely affected.

The Fortescue River and its pools are connected to and interact with the underlying alluvial aquifer. The direction of interaction changes seasonally in response to flooding, evaporation from pools or transpiration of groundwater by riparian vegetation. Permanent pools have demonstrated long-term connectivity to the groundwater and are expected to be maintained by groundwater discharge during drought periods. Because of this, these pools provide critical habitat and are an important refuge for native flora and fauna (DOW, 2010b)

10.3.1 Millsteam Aquifer and National Park

Both the Millstream Aquifer and National Park are located within the Lower Fortescue Catchment. The Millstream aquifer provides water to the West Pilbara Water Supply Scheme, operated by the Water Corporation. As well as being a vital water source for the scheme, the Millstream aquifer supports the groundwater-dependent vegetation and biologically rich river pools and wetlands of the Millstream Chichester National Park. The river pools and wetlands are listed on the Register of the National Estate and in the Directory of Important Wetlands. Millstream is also of great cultural importance to the Yindjibarndi people (DOW, 2010).

A list of some of the key pools of the system are:

- Pools along the Fortescue River including Deep Reach, Crossing, Palm and Livistona pools
- Off-channel pools and wetlands including Chinderwarriner Pool and the Millstream Delta, Woodley Creek, Peters Creek and Palm Creek.

The closest proposed mining area to the Millstream Chichester National Park is the Valley of Queens. The western boundary of the Valley of the Queens (Weelumurra Creek) is approximately 95 km upstream from the Millstream National Park.

The pools and wetlands of the Millstream system are sustained by discharge from the Millstream aquifer and intermittent seasonal flow from the Fortescue River. (DOW, 2009)
Recharge to the alluvial Millstream aquifer results mainly from direct infiltration through the riverbed during periods of flow in the Fortesuce River and streams draining into the system. The volume of recharge is controlled by the duration, depth and frequency of flow and the storage available in the aquifer (DoW, 2010b).

The mean annual flow of the Fortescue River recorded at Gregory Gorge (708002), located 20km downstream from Deep Reach Pool is 208 GL per annum. Maximum annual flows were recorded in 1975 and 2006 with 1,181 GL and 1,141 GL recorded respectively. Between 1968 and 2010 there have been 9 years where annual flows have been less than 10 GL (approximately 5% of the mean annual flow). It is not expected that the Solomons mining project will decrease contributing runoff into the Fortescue River to impact on the recharge of the Millstream aquifer.

11. Recommendations

Recommendations will be made following feedback from FMG on this interim report.

There is a lack of data to calibrate the rainfall-runoff and hydraulic models used to test the impact of the identified flood management options. The current programme of installing raingauges and level sensors within the project area will hopefully provide this much need information.

12. References

DoW, 2010, *Millstream aquifer – determination of a long-term reliable allocation*, Department of Water, Allocation Planning Series, Report No. 42, June 2010.

DOW, 2010b, *Lower Fortescue River – Ecological Values & Issues*, Department of Water, Environmental Water Report, Series Report No. 15, September 2010.

DOW, 2010c, *Millstream Water Reserve Drinking Water Source Protection Plan, West Pilbara Water Supply*, Water Resource Protection Series, Report WRP 116, Department of Water, June 2010

DOW, 2009, *Millstream Status Report – A Review of Management & Consolidation of Current Understanding,* Department of Water, Report Series No.9, September 2009.

Department of Mines and Petroleum, Environment Notes on Mining, *Care and Maintenance*, September 2009

Department of Mines and Petroleum, *Mining Proposals in Western Australia*, February 2006.

Department of Water, 2009b *Pilbara Water in Mining Guidelines*, Report No.34, September 2009

Institution of Engineers, Australia. 1998 - Australian Rainfall and Runoff, A Guide To Flood Estimation, Editor-in-chief D H Pilgrim. (Volume 1).

Institution of Engineers, Australia. 1998 - Australian Rainfall and Runoff, A Guide To Flood Estimation, Editor-in-chief D H Pilgrim. (Volume 2).

Water and Rivers Commission, Water Quality Guidelines No. 5, Mining and Mineral Processing, *Minesite water quality monitoring,* 2000

Water and Rivers Commission, Water Quality Guidelines No. 6, Mining and Mineral Processing, *Minesite stormwater,* 2000

Water and Rivers Commission, *The State of the Northern Rivers*, Publication No. WRAP 10, December 1997

Appendix A: RORB Results

Catchment	Area (Km2)	5 Year ARI		50 Year ARI		100 Year ARI	
		Peak flow (m3/sec)	Critical Duration (Hrs)	Peak flow (m3/sec)	Critical Duration (Hrs)	Peak flow (m3/sec)	Critical Duration (Hrs)
K1							
RORB Subcatchments							
K1	32.7	119.4	12	431.9	3	710.7	1
K2							
RORB Subcatchments							
K2_1	0.4	1.9	1	12.8	1	17.9	1
K2_2	0.5	3.3	1	18.2	1	29.6	1
K2_3	0.7	4.0	1	26.8	1	37.2	1
K2_4	0.5	3.1	1	18.4	1	28.2	1
K2_5	0.3	1.8	1	10.5	1	16.6	1
K2_6	0.4	2.4	1	14.4	1	21.8	1
K2_7	0.3	1.5	1	9.3	1	13.5	1
K2_8	0.5	2.9	1	17.8	1	26.6	1
K2_9	0.5	3.0	1	17.1	1	26.8	1
K2_10	0.3	1.8	1	11.1	1	16.7	1
K 4							
RORB Subcatchments							
K4_A (and upstream)	10.8	44.4	6	232.7	1	415.5	1
K4_B	3.3	15.1	6	95.8	1	145.7	1
K4_C	5.9	25.1	6	156.4	1	243.6	1
K4_D	0.7	3.2	6	20.3	1	32.9	1
K4_E	2.9	11.5	6	65.7	1	112.4	1
K4_F	0.5	2.4	6	14.9	1	24.0	1
K4_G	3.6	15.6	6	97.6	1	148.6	1
K4_H	0.9	4.2	6	26.6	1	42.3	1
K4_I	0.5	2.3	6	14.1	1	23.5	1
K4_J	0.8	4.2	6	25.8	1	42.6	1
K4_K	1.6	6.8	6	43.0	1	64.5	1
K4_L	0.7	3.3	6	20.6	1	32.5	1
K4_M	1.6	7.6	6	47.6	1	75.9	1
K4_N	0.7	3.0	6	22.0	1	27.8	1
K4_O	0.7	3.5	6	18.6	1	36.1	1
K4_P	0.4	1.8	6	10.6	1	18.7	1
K4_Q	5.7	22.7	6	135.9	1	227.5	1
K4_R	0.9	4.6	6	27.5	1	47.4	1
K4_S	1.5	7.2	6	44.7	1	73.0	1
K5							
RORB Subcatchments							
K5_21 (and upstream)	89.9	177.4	9	665.3	6	999.7	6
K5_22	6.5	17.7	12	61.4	18	90.3	3
K5_23a	0.2	0.8	12	3.0	1	5.5	1
K5_23b	0.2	0.7	12	2.8	1	5.2	1
K5_24	4.5	12.9	12	43.2	3	65.6	1
K5_25A	0.9	3.5	12	16.2	1	30.2	1
K5_25B	0.9	3.5	12	15.2	1	27.9	1
K5_26a	0.2	0.9	12	4.2	1	7.8	1
K5_26b	0.4	1.6	12	8.2	1	15.5	1
K5_27a	0.8	2.8	12	9.8	1	16.5	1
K5_27b	0.6	2.2	12	10.3	1	19.2	1
K5_28	0.8	2.9	12	13.0	1	24.0	1
K5_29a	0.8	2.2	12	9.9	1	18.3	1
K5_29b	0.6	2.8	12	9.5	1	16.1	1

Catchment	Area (Km2)	5 Year ARI Peak flow (m3/sec)	5 Year ARI Critical Duration (Hrs)	50 Year ARI Peak flow (m3/sec)	50 Year ARI Critical Duration (Hrs)	100 Year ARI Peak flow (m3/sec)	100 Year ARI Critical Duration (Hrs)
Ridges between K4 & K5							
RORB Subcatchments							
K_1	0.7	3.8	6	24.4	1	38.1	1
K_2	1.8	8.3	6	55.0	1	78.3	1
K_3	0.5	2.7	6	17.8	1	26.9	1
K_4	0.7	4.0	6	24.6	1	40.0	1
K_5	0.8	3.2	6	20.6	1	32.0	1
K_6	0.3	1.5	6	10.0	1	14.3	1
K_7	2.1	10.6	6	69.8	1	104.1	1
K_8	0.2	1.0	6	6.7	1	9.8	1
K_9	0.4	2.2	6	14.2	1	21.7	1
K_10	0.2	1.2	6	7.8	1	12.4	1
K_11	0.9	4.7	6	30.4	1	46.8	1
K_12	0.5	2.4	6	15.9	1	23.1	1
K_13	0.3	1.3	6	8.4	1	12.6	1
K_14	0.5	2.7	6	18.0	1	27.0	1
K_15	0.3	1.5	6	9.6	1	14.3	1
K_16	2.1	10.2	6	67.9	1	98.9	1
K_17	0.6	3.0	6	19.9	1	29.8	1
Zalamea Creek							
RORB Subcatchments							
1	0.4	1.8	12	11.2	1	18.6	1
2	0.3	1.4	12	8.9	1	14.4	1
3	0.8	3.2	12	19.3	1	30.8	1
4	0.7	2.9	12	17.7	1	27.6	1
5	0.8	3.7	12	22.6	1	35.7	1
6	0.4	2.0	12	12.4	1	20.0	1
7	0.3	1.3	12	7.8	1	12.1	1
8	0.5	2.1	12	12.5	1	20.2	1
9	0.4	1.9	12	11.6	1	17.9	1
10	0.7	2.9	12	17.3	1	28.5	1
11	0.5	1.8	12	10.7	1	18.5	1
12	1.4	5.6	12	28.8	1	52.5	1
13	0.3	7.0	12	42.4	1	72.9	1
14	0.3	1.4	12	8.7	1	13.8	1
15	1.2	5.0	12	22.7	1	40.4	1
25 (and upstream)	32.7	119.4	12	431.9	3	710.7	1
26	0.8	3.1	12	13.9	1	24.7	1
27	0.9	3.7	12	22.1	1	36.5	1
28	0.2	0.7	12	4.1	1	6.5	1
29	0.4	1.5	12	9.0	1	14.9	1
30	0.8	3.0	12	15.9	1	28.7	1
33 (and upstream)	5.2	21.1	12	97.6	1	171.4	1
34	0.5	2.1	12	12.7	1	21.2	1
36	1.6	13.2	12	65.6	1	118.8	1
Outlet (Trib of Sth Fortescue)	67.5	228.2	12	838.8	3	1271.6	1
Firetail	23	76.9	6	288.4	1	454.5	1

Catchment	Area (Km2)	5 Year ARI		50 Year ARI		100 Year ARI	
		Peak flow (m3/sec)	Critical Duration (Hrs)	Peak flow (m3/sec)	Critical Duration (Hrs)	Peak flow (m3/sec)	Critical Duration (Hrs)
Queens							
RORB Subcatchments							
Q2_5 (and upstream)	10.6	36.8	12	131.3	1	210.2	1
Q2_6	0.5	2.4	6	12.3	1	22.2	1
Q2_7	0.3	1.1	6	6.8	1	10.3	1
Q3_A	2.3	9.4	6	43.3	1	76.2	1
Q3_B	0.3	1.2	6	7.5	1	12.5	1
Q3_C	0.2	0.7	6	3.7	1	6.5	1
Q3_D	1.0	3.9	9	23.5	1	39.9	1
Q3_E	0.9	3.6	6	16.3	1	28.4	1
Q3_F	0.3	1.2	6	6.2	1	11.2	1
Q3_G	0.4	1.6	9	9.9	1	16.2	1
Q4_A	4.2	12.0	6	50.1	1	86.6	1
Q4_B	1.2	4.7	6	24.1	1	43.6	1
Q4_C	2.1	8.4	6	40.6	1	72.1	1
Q4_D	0.6	2.3	9	14.0	1	22.4	1
Q4_E	0.8	3.3	6	18.4	1	32.4	1
Q4_F	0.5	2.0	6	11.4	1	19.7	1
Q5_1	0.2	0.8	9	5.1	1	8.4	1
Q5_2	0.4	1.7	6	7.1	1	12.3	1
Q5_3	0.5	1.8	6	8.2	1	14.4	1
Q5_4	0.3	1.2	6	7.3	1	11.5	1
Q5_5	0.7	3.1	9	19.0	1	29.4	1
Q5_6	0.7	2.7	9	16.3	1	27.2	1
Q5_7	0.4	1.5	6	7.7	1	14.0	1
Q5_8	0.3	1.3	9	8.2	1	13.0	1
Q5_9	0.3	1.4	6	9.0	1	13.9	1
Q5_10	1.4	5.8	6	25.8	1	45.0	1
Q5_11	1.8	7.0	6	28.1	1	47.4	1
Q5_12	0.8	3.2	6	15.7	1	28.1	1
Q5_13	0.8	3.1	6	17.7	1	30.8	1
Q5_14	0.2	0.9	6	5.4	1	8.2	1
Q5_15	0.4	1.5	6	7.5	1	13.4	1
Q5_16	0.8	3.3	6	13.6	1	23.5	1
Q5_17	1.0	3.8	6	15.3	1	26.3	1
Q5_18	0.3	1.2	6	5.8	1	10.3	1
Q5_19	0.6	2.4	6	11.3	1	19.9	1
Q5_20	0.4	1.6	6	6.5	1	11.1	1
Q5_21	0.3	1.1	6	5.6	1	9.9	1
Q5_22	2.5	9.3	12	35.9	1	58.4	1
Q5_23	0.5	2.0	6	9.4	1	16.6	1
Q5_24	0.2	0.9	6	3.6	1	6.1	1
Weelumurra Creek Converge	54.6	158.3	12	585.5	6	818.8	3
Combined Kings Coarse RORB Model							
RORB Subcatchments							
K5	105	318.6	12	1026.6	18	1601.5	3
K4	52	180.6	12	578.8	3	931.4	4.5
K2	12	45.6	12	146.2	3	251.6	3
K3	7	26.4	12	85.4	3	160.3	1
CID Process Plant	211.4	622.6	12	2207.4	18	3439.0	3
Firetail	23	75.9	12	243.4	3	376.2	4.5
Downstream Firetail	234	702.0	12	2470.1	18	3832.2	3
Fortescue Floodplain (approx 13km DS from minesite)	347	995.7	12	3476.6	24	5128.7	3

Appendix B: Multi-criteria analysis methodology

A number of flood management options have been identified and their effectiveness in reducing the volume of water entering the pit is being evaluated in order that the most cost effective option can be identified. A formalised method of decision making, known as Multi-criteria Analysis (MCA) is being used to assess the various options.

Decision Making

Formal methods of decision making, where there are competing factors and significant uncertainty, as in this case here, offer robust defensible means of selecting the best solutions. The methods recognise that the best solution is generally a compromise between achieving the greatest benefit with the resources and funds available. They provide the essential rationale and traceability of the decisions that are eventually made.

The Multi-criteria Analysis method has the advantage that it allows options to be assessed on the basis of both tangible benefits and intangible benefits and risks without the need for extensive analysis and data. The methods are applied in two stages, initially, to short-list the most promising options, following by a more detailed analysis of the short-listed options only. The goal is to identify and make recommendations as to the overall best compromise scheme.

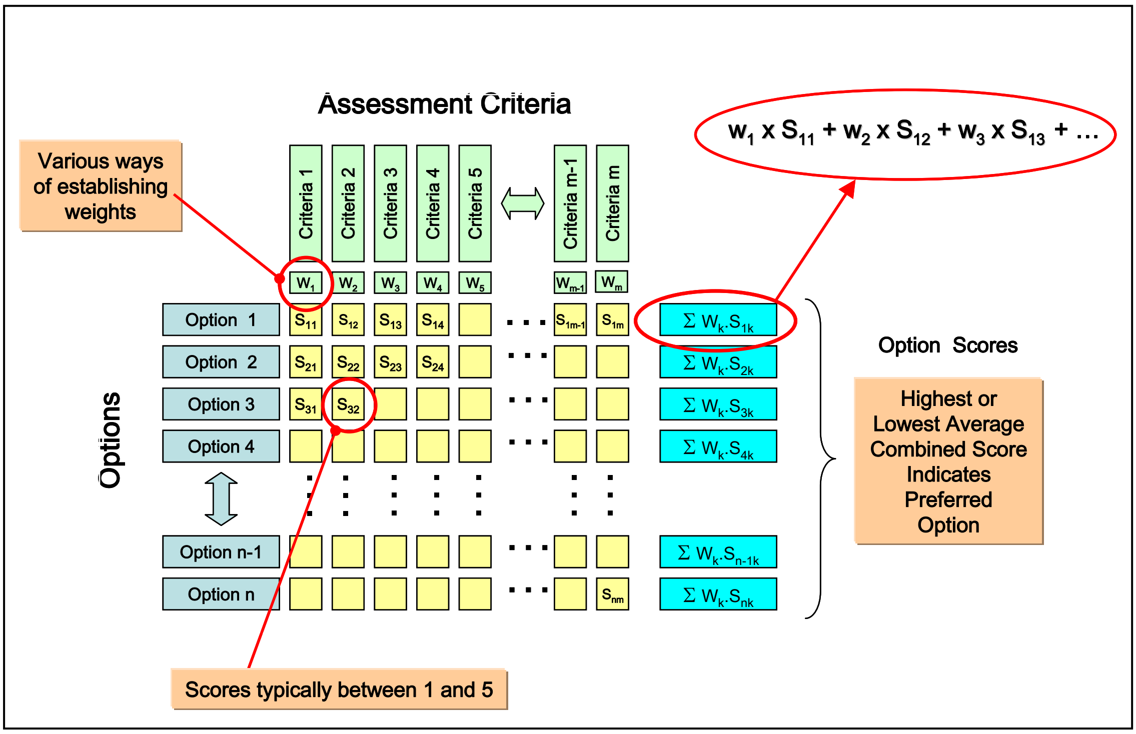
Multi-Criteria Analysis

Multi-criteria analysis is a formal method of decision making. Decisions are guided by rating the alternative solutions to a problem (options). This is achieved by assigning scores to the options for each of a set of chosen criteria or attributes of the ‘ideal’ solution. Attributes are typically chosen to cover all issues of concern, (e.g. triple or quadruple bottom line issues), and can cover both tangible (e.g. cost) and intangible (e.g. sustainability) factors. The option scores are combined in some way (usually a weighted sum) to rank the options. The contribution that each attribute gives to the sum of scores for an option is weighted to reflect the decision maker’s beliefs about the relative importance of the different criteria.

The scores may be seen as surrogates for measures of value for the criteria, allowing the effects of diverse criteria, with different units, to be combined. The weights represent beliefs about what is important in a particular situation or to a particular group of individuals.

A schematic representation of the MCA method is illustrated in Figure A1. In this figure the options are shown listed down the left hand side. The criteria are listed across the top. The scores for each option against each criterion are shown as the boxes containing the “S” terms forming a two-dimensional matrix of each option against each criterion. The weight applied to each criterion is represented by the boxes with the “w” terms. Preferences between the options are obtained by forming the weighted sum of scores for a particular option as depicted on the right hand side of the Figure.

Figure A1. Schematic of Multi-criteria Analysis Method



Scoring of options and Weighting of Criteria

Each of the options will be scored against each of the criterion on a five point scale from1 to 5, where the higher the score the better the option was considered to be with respect to a particular criterion.

Criterion weights were determined through discussion, using an interactive graphical tool, which allowed the relative importance of the criteria to be explored using a sliding scale of values from 1 to 10 (Figure A2). These criterion values were then adjusted to sum to 1 (Table A1). Scaling the weights to one is used to make it easier to investigate alternative weighting schemes and perform sensitivity analysis.

Figure A2. Graphical Representation of the Weighting of Attributes

Weights - Graphical Method

Attribute Refs:	C1		C3	C4	C5	C6	C7		C9	C10	C11	C12	C13	C14		C16	C17			
10													1							
9																				
8	1				1															
7				1										1		1				
6																	1			
5						1	1		1		1									
4																				
3			1							1										
2												1								
1																				
0		1						1							1			1	1	1
Attributes	Capital Expenditure	Earth Moving & Disposal	Operational Expenditure	Loss of Production / downtime - Pit Flooding	Un-recovered resources	Sheetflow Effects	Loss of Flow to d/s Basin	Loss of groundwater recharge	Ponding Effects	Sediment Aggregation / degradation	Direct Impact on Fauna & Flora	Visual Impacts	Impact on Human Safety	Requirements Sequencing Mining	Benefits of Strategy	Long Term Reliability	Technical Difficulty / Buildability	Collects Local Run-off		
Weight:	8		3	7	8	5	5		5	3	5	2	10	7		7	6			

Sum: 81