Report No: P WMA
19/G10/00/2413/6

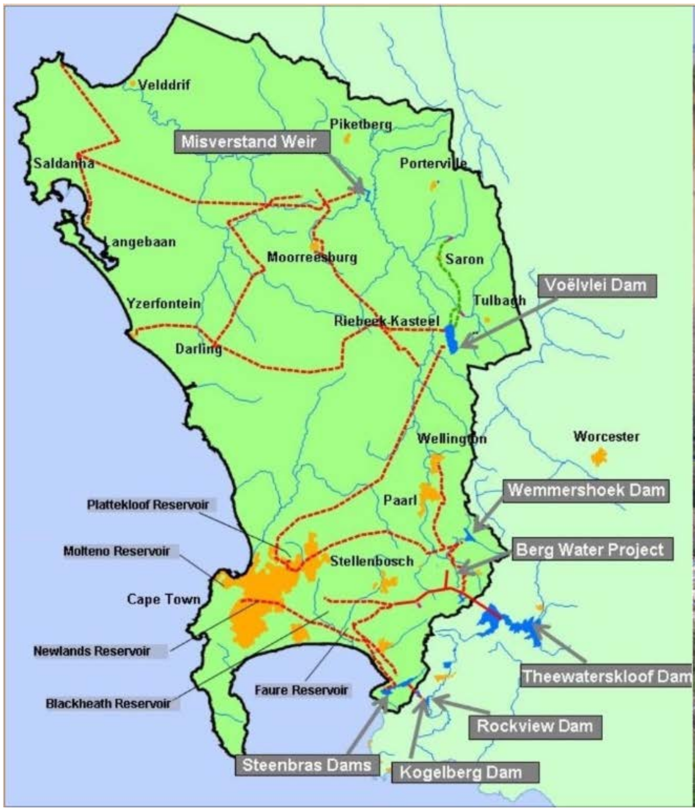
Department of Water Affairs
Directorate: Options Analysis

PRE-FEASIBILITY AND FEASIBILITY STUDIES FOR AUGMENTATION OF THE WESTERN CAPE WATER SUPPLY SYSTEM BY MEANS OF FURTHER SURFACE WATER DEVELOPMENTS

REPORT No.3 – VOLUME 2
Breede-Berg (Michell's Pass) Water Transfer Scheme

APPENDIX No.11

Diversion Weirs Design for the Berg River-Voëlvlei Augmentation Scheme, and the Breede-Berg (Michell's Pass) Water Transfer Scheme




December 2012

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1	**ECOLOGICAL WATER REQUIREMENT ASSESSMENTS**	Vol 1	PWMA19 G10/00/2413/1	**Riverine Environmental Water Requirements**
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2	**PRELIMINARY ASSESSMENT OF OPTIONS**		PWMA19 G10/00/2413/4	Appendix 1: Scheme Yield Assessments and Diversion Functions
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PWMA19 G10/00/2413/7

WESTERN CAPE FUTURE SCHEMES FEASIBILITY STUDY

Hydraulic Design of the proposed Berg River Abstraction Works at Voëlvlei Dam

May 2012

Submitted to:

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1. Introduction

ASP Technology (Pty) Ltd was appointed during 2011 to carry out the hydraulic design of the proposed river abstraction works on the Berg River at Voëlvlei Dam. A possible site for the abstraction works was identified on the left bank at a bend in the Berg River during the pre-feasibility study. A topographical survey of the site and geological information were obtained from Aurecon during this study.

2. Scope of work

The work involved the following:

a) Field work to obtain sediment samples for grading analysis
b) Flood hydrology
c) Analysis of the river hydraulics to determine the most suitable site
d) Design of the hydraulic components of the abstraction works at feasibility level of detail

3. Site visit

Field work was carried out during April 2012 to obtain river bed sediment for grading analysis, required for mathematical modelling of the fluvial morphology The results of the grading analysis with photographs at the sampling locations are included in Appendix A. Figure A-1, Appendix A, shows the positions where the samples were taken. The grading analysis is based on sieve and hydrometer tests.

Table 3.1 shows a summary of the sediment fractions obtained from the grading analysis. The average d_{50} value is 0.4 mm (sand) if data from sites 001 to 006 are used. The sample at site 007 was affected by bedrock and was therefore not used. Bed rock was visible on the left bank of the river bend during the field visit.

Table 3.1 Summary of sediment grading results

		Unit	Sample 001	Sample 002	Sample 003	Sample 004	Sample 005	Sample 006	Sample 007	Average d_{50}* Used (CCHE)
Class 1	0-20%	mm	0.01	0.031	0.18	0.06	0.14	0.075	19.00	0.083
Class 2	20-40%	mm	0.05	0.07	0.37	0.33	0.40	0.26	30.00	0.247
Class 3	40-60%	mm	0.13	0.15	0.54	0.50	0.64	0.42	39.00	0.397
Class 4	60-80%	mm	0.23	0.30	0.84	0.80	1.00	0.65	42.00	0.637
Class 5	80-100%	mm	0.44	0.54	1.50	1.70	2.20	1.20	47.00	1.263

Note: * Median diameter

Figure 3-1 shows a satellite image of the river bend on the Berg River where the abstraction works is proposed. The abstraction works has to be on the left bank (outside of the bank) to make best use of secondary currents during floods to scour the intake area and to keep coarse sediment away from the intakes. From the proposed abstraction works the water would be pumped to Voëlvlei Dam.

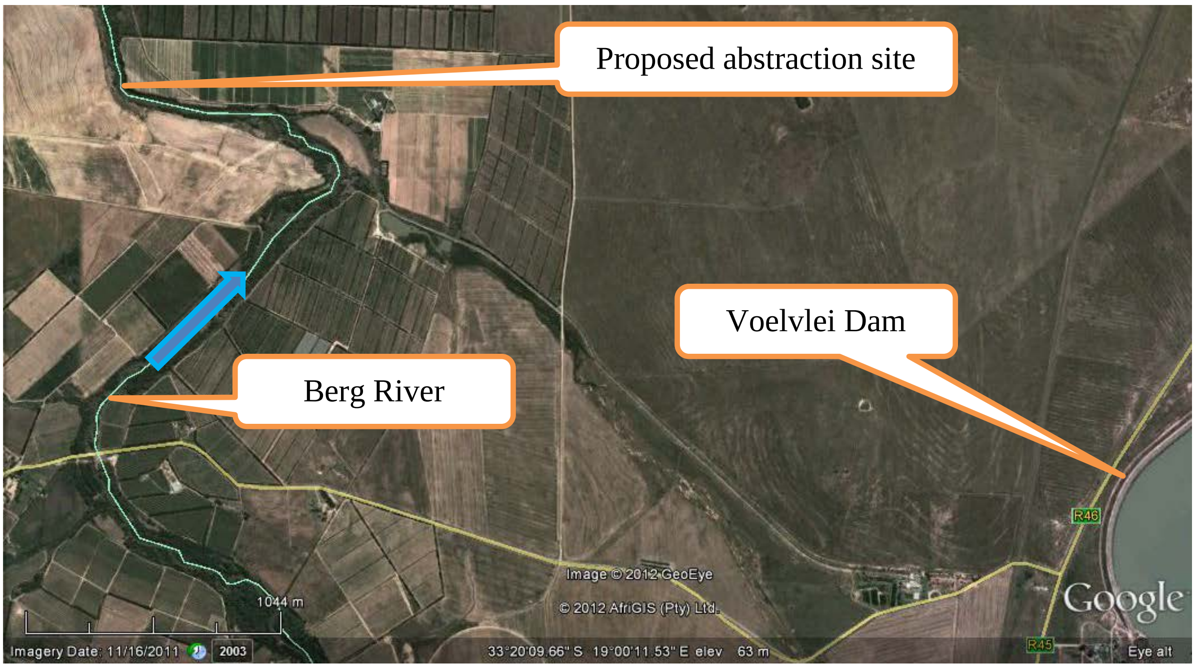


Figure 3-1 Satellite image of the Berg River near Voëlvlei Dam

4. Flood hydrology

A flood hydrology assessment was needed at the site to determine water levels, sediment transport and scour required to position and design the abstraction works.

Floods peak data were obtained from the Department of Water Affairs gauging station G1H013 at Drieheuvels, for the period 1964 to 2011. The catchment area at the gauging station is 2934 km^2, while the proposed site has a catchment area of 2059 km^2. The observed flood peaks were scaled to the site by using the square root of the catchment ratio. Based on TR137 (1988) the largest flood on record occurred on 18 Mei 1954 at gauging station G1M07 (Old Number) near Wellington with a flood peak of 2130 m^3/s. This was not a localized flood since at G1H002, at Vier en twintig River station, the flood peaked at 771 m^3/s on a tributary of the Berg River. The flood peak at Drieheuvels gauging station was 819 m^3/s with a gauge plate reading of 6.5 m. The Drieheuvels peak flood was also considered in the probabilistic analysis.

Dams result in flood attenuation and must be accounted for during the hydrological analysis. Berg River dam has an estimated attenuation factor of 10-15 % at the site, but was not taken into account during this design. The flood hydrology of the specific site should be verified during the detail design.

Table 4.1 shows the flood peaks at the site used in a probabilistic flood analysis. Table 4.2 and Figure 4-1 show the results of the probabilistic analysis. The proposed distribution that gives conservatively high flood peaks during major floods is the LPIII distribution. The 100 year flood based on this distribution is about 1168 m^3/s.

Table 4.1 Observed flood peaks scaled to the site

Year	Flood peak (m^3/s)	Year	Flood peak (m^3/s)
1964 / 1965	70	1994 / 1995	149
1965 / 1966	127	1995 / 1996	446
1966 / 1967	373	1996 / 1997	286
1967 / 1968	171	1997 / 1998	158
1968 / 1969	113	1998 / 1999	202
1969 / 1970	85	1999 / 2000	111
1970 / 1971	123	2000 / 2001	490
1971 / 1972	46	2001 / 2002	183
1972 / 1973	155	2002 / 2003	112
1973 / 1974	310	2003 / 2004	126
1974 / 1975	171	2004 / 2005	171
1975 / 1976	280	2005 / 2006	183
1976 / 1977	580	2006 / 2007	820
1977 / 1978	81	2007 / 2008	557
1978 / 1979	151	2008 / 2009	309
1979 / 1980	124	2009 / 2010	184
1980 / 1981	497	2010 / 2011	140
1981 / 1982	97		
1982 / 1983	407		
1983 / 1984	703		
1984 / 1985	329		
1985 / 1986	284		
1986 / 1987	249		
1987 / 1988	152		
1988 / 1989	263		
1989 / 1990	346		
1990 / 1991	542		
1991 / 1992	528		
1992 / 1993	811		
1993 / 1994	533		

Table 4.2 Probabilistic analysis results

Exceed. Prob.	Recurrence interval (years)	LN	LPIII	GEV_{MM*}	GEV_{PWM**}	Proposed
		Q (m^3/s)	Q (m^3/s)	Q (m^3/s)	Q (m^3/s)	Q (m^3/s)
0.5	2	225	223	251	235	**223**
0.2	5	404	403	427	404	**403**
0.1	10	549	551	544	532	**551**
0.05	20	708	715	655	670	**715**
0.02	50	941	959	800	873	**959**
0.01	**100**	**1138**	**1168**	**908**	**1045**	**1168**
0.005	200	1355	1400	1016	1235	1400
0.002	500	1673	1745	1158	1519	1745
0.001	1000	1940	2038	1265	1762	2038
0.0005	2000	2230	2361	1372	2032	2361
0.0002	5000	2655	2838	1514	2436	2838
0.0001	10000	3007	3240	1621	2781	3240

Note: *MM = Method of Moment; **PWM = Probability Weighted Moment

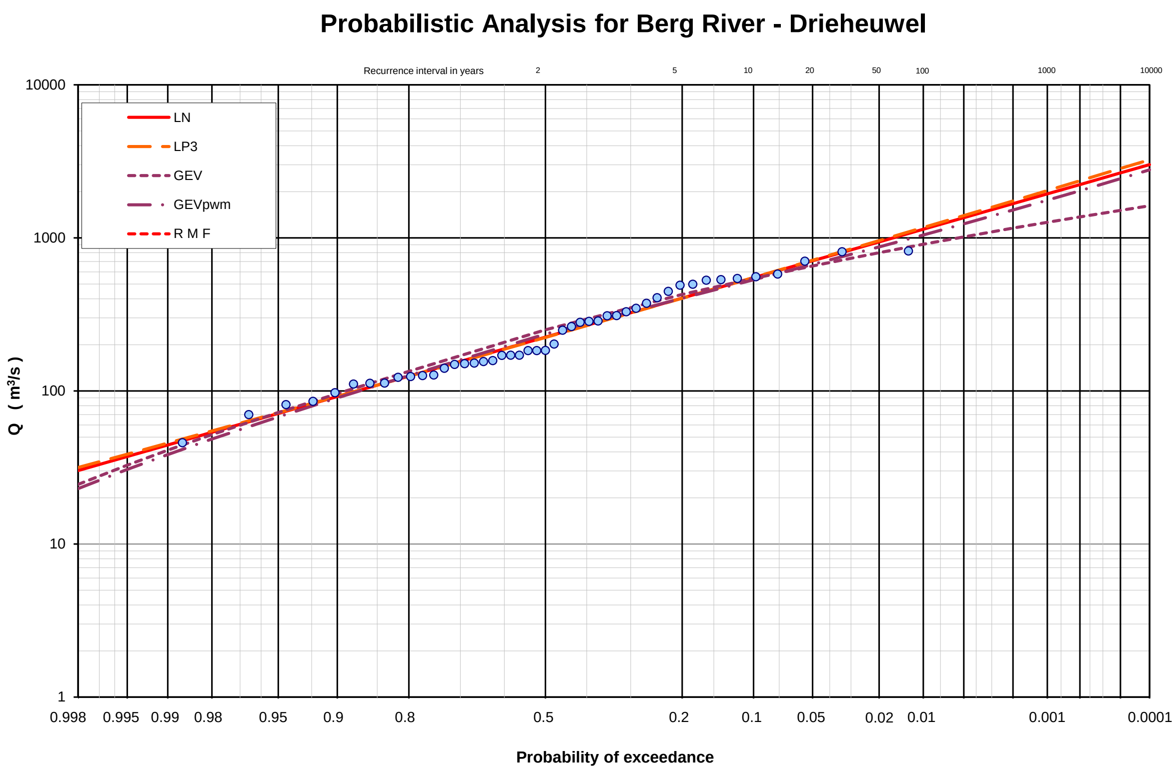


Figure 4-1 Probabilistic results plotted graphically

A deterministic method, the unit hydrograph method was also used. Table 4.3 shows the flood peaks determined with this method.

Table 4.3 Flood peaks based on the unit hydrograph method

Flood recurrence interval (years)	Flood peak (m^3/s)
2	376
10	560
100	1493

For design purposes a 100 year flood peak of 1500 m^3/s was used in this study. The abstraction works is designed for the Q_{100} flood with freeboard.

5. Hydraulics of the proposed abstraction works site

A two dimensional fully hydrodynamic model was used to simulate the flow patterns and sediment dynamics in the Berg River to aid in the design of the abstraction works.

Figure 5-1 shows the model bathymetry (masl) which was set up based on the survey data. The survey data consists of a LIDAR survey and three cross sections through the river which had to be combined in this study. Based on the geotechnical report the possible weir location is as indicated in Figure 5-1 based on a proposed site from the pre-feasibility study. The left bank is quite steep, while the right bank floodplain is wide. The main channel bed is relatively low compared to the floodplain levels at the proposed site. The average river bed gradient is hydraulically small at 1:1282.

In the mathematical modelling the following assumptions were made:

- Main channel hydraulic roughness Manning n = 0.045 s/m$^{0.333}$
- Floodplain roughness Manning n = 0.060 s/m$^{0.333}$
- Tailwater levels (Table 5.1) based on normal flow calculations and applied at the downstream end of the model, about 80 m from the abstraction works site, and at coordinates X : -1831.591, Y : -3689108.659 .

Table 5.1 Tailwater levels used in hydrodynamic modelling

Discharge (m^3/s)	Water level (masl)
0.00	44.90
0.29	45.40
1.69	45.90
4.69	46.40
9.18	46.90
15.41	47.40
23.74	47.90
34.14	48.40
46.68	48.90
60.31	49.40
75.39	49.90
91.95	50.40
160.13	50.90
216.24	51.40
271.27	51.90
338.10	52.40
548.05	52.90
674.65	53.40
807.26	53.90
1029.34	54.40
1281.24	54.90
1600.00	55.40
1950.00	55.90
2400.00	56.40
2900.00	56.90

Note: The lowest bed level at the position where the tailwater stage-discharge relationship was calculated is 44.90 masl.

Figure 5-2 shows the simulation results for a 2 year flood. The highest flow velocity is at the outside of the bend (left bank) where the abstraction works is proposed. This bend effect will therefore limit abstraction of coarse sediment. The flow stays mainly in the main river channel during this flood. The flood width at the site is much narrower than at the upstream bend. The flow depth at the site is about 7.6 m.

Figure 5-3 indicates that the flow velocity during the 2 year flood at the proposed site is about 2.11 m/s. The flow velocities at the upstream bend are much smaller in comparison.

Figures 5-4 and 5-5 indicate the same as Figures 5-2 and 5-3, for the 10 year flood. During the 100 year flood the right floodplain flow is wide, but the velocities at the left bank remain high.

The proposed site on the left bank seems to be ideally located. The flow depth is about 10.39 m during the 100 year flood and the flow velocity about 2 m/s. The velocity is smaller than during the 2 year flood because of the wide floodplain flow during the 100 year flood. The right bank floodplain is under water, but the flow velocities are small and the flow depth shallow, and it should be possible to construct a weir/embankment on the floodplain without significantly increasing the major flood levels upstream.

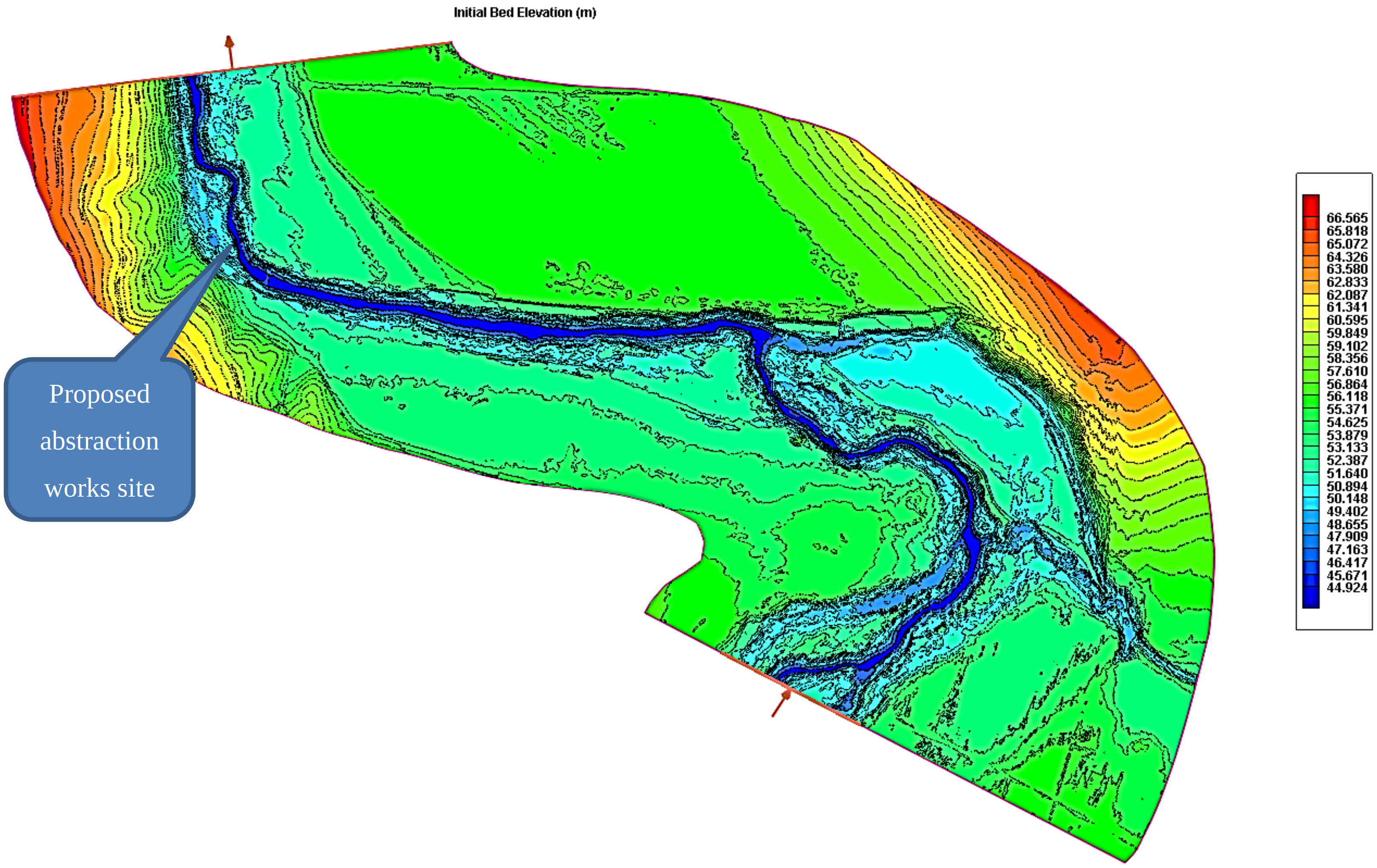


Figure 5-1 2D model bathymetry of Berg River Abstraction works at Voëlvlei Dam (elevations based on survey data as masl)

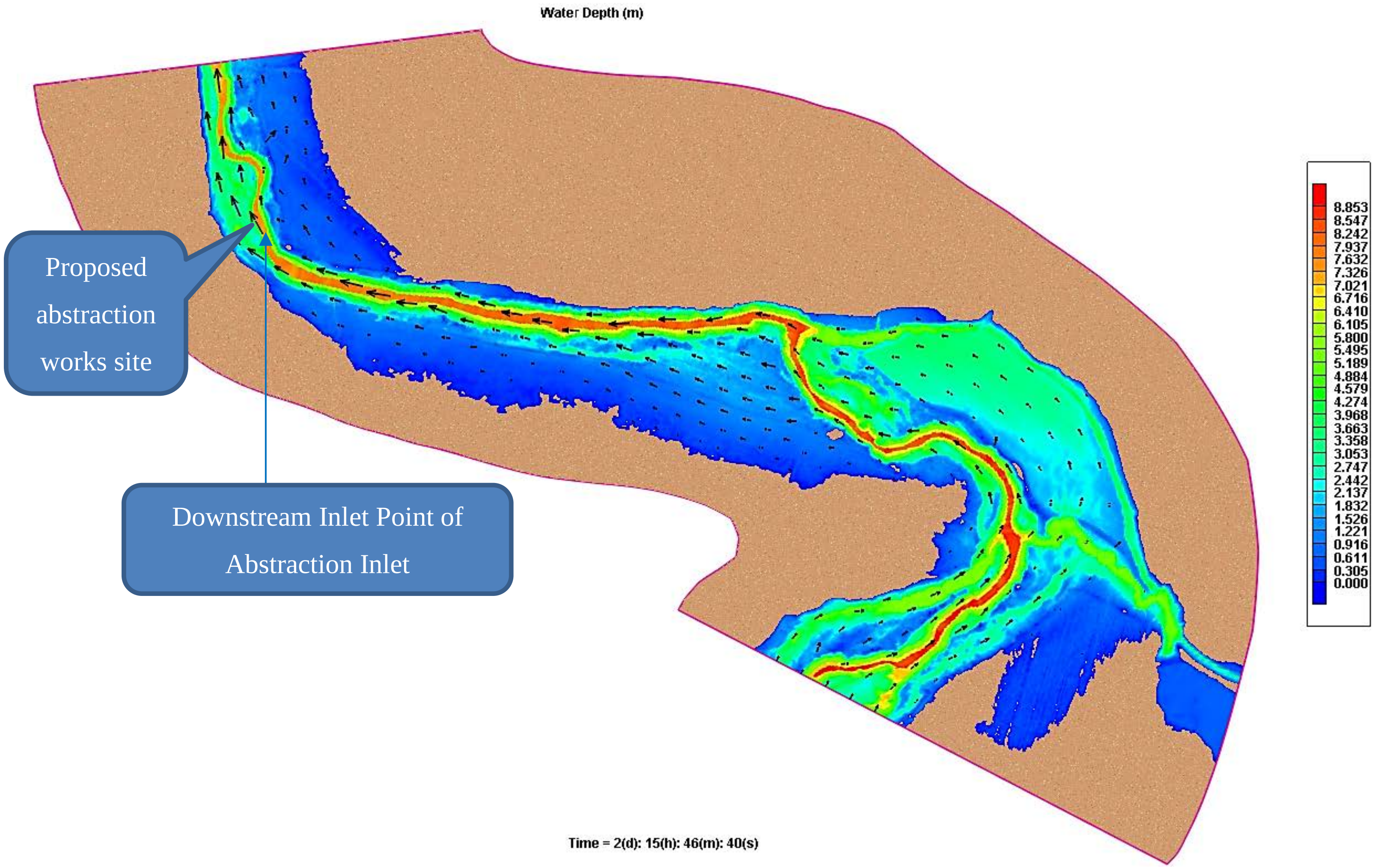


Figure 5-2 2 Year Flood Water Depth (m) with Velocity Vectors

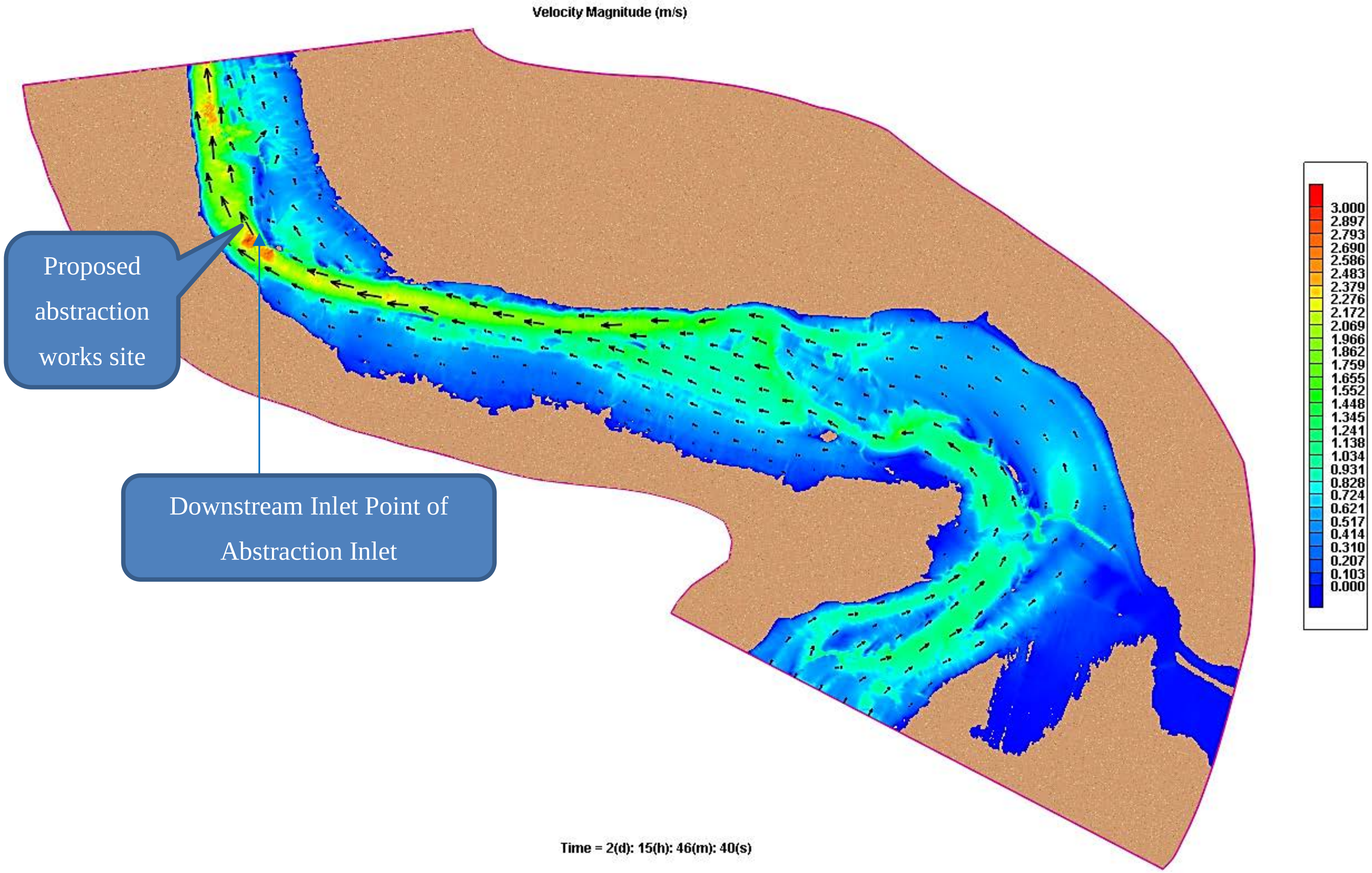


Figure 5-3 2 Year Flood Velocity Magnitude (m/s) with velocity vectors

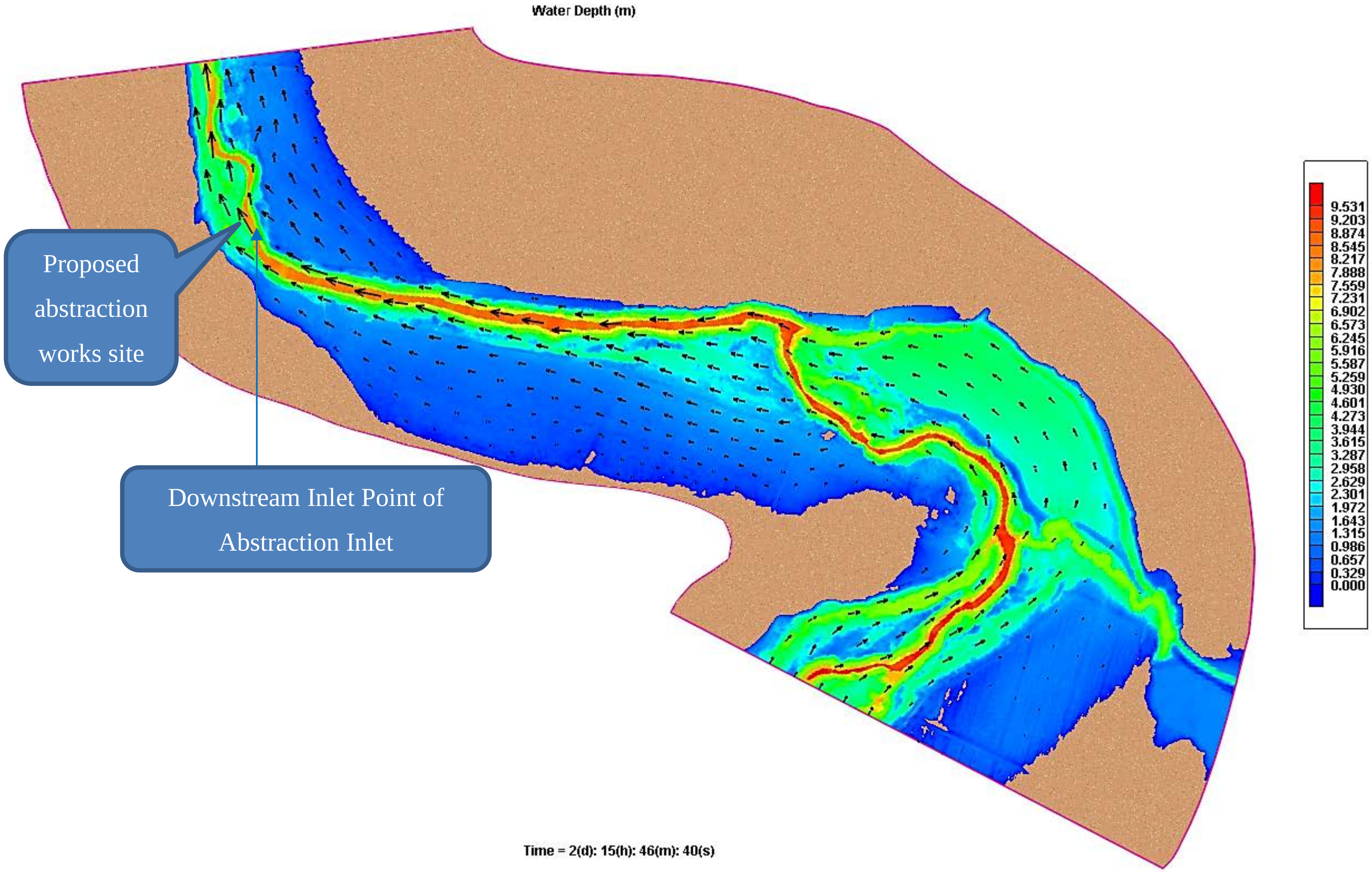


Figure 5-4 10 Year Flood (Water Depth)

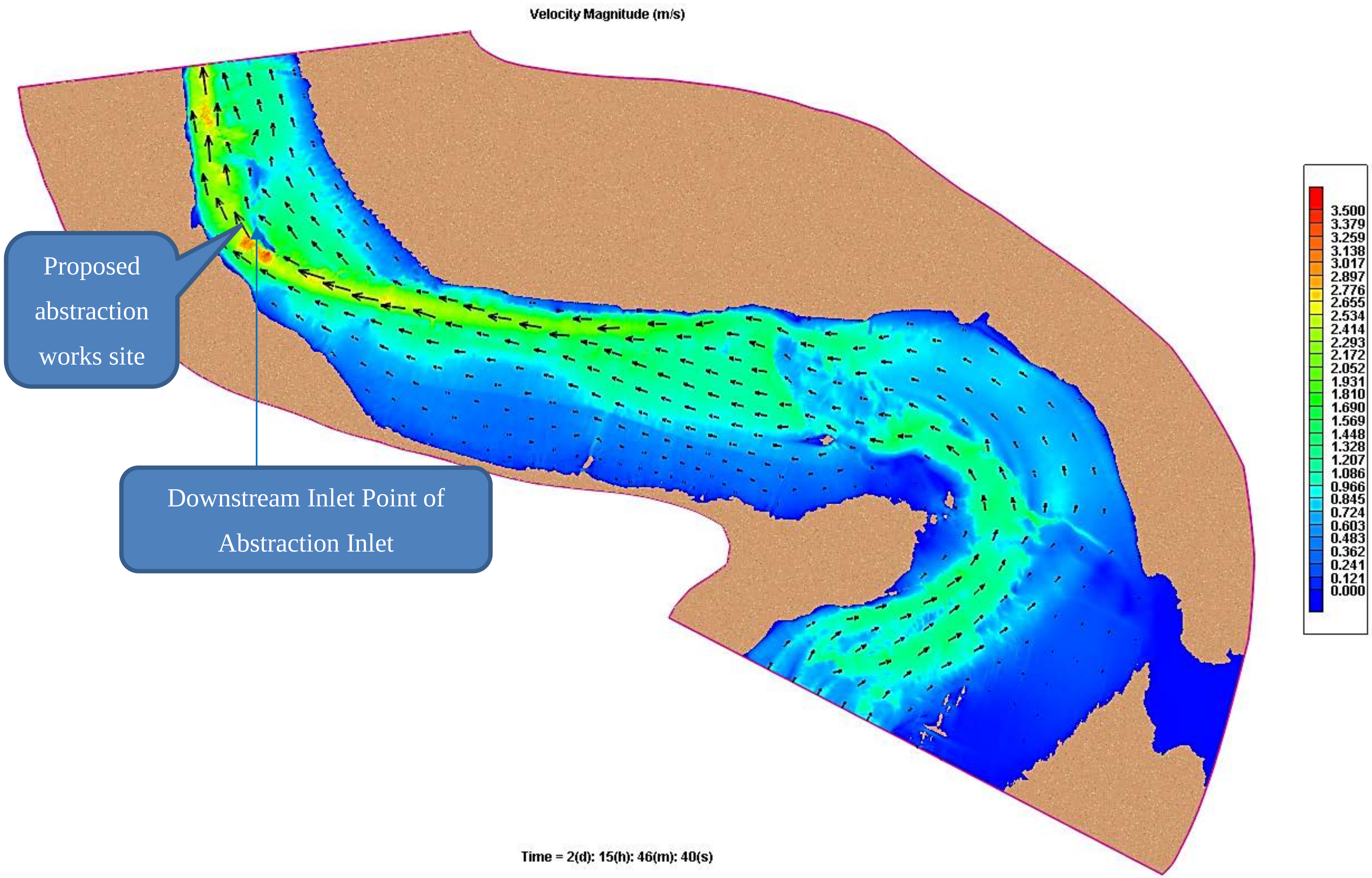


Figure 5-5 10 Year Flood (Velocity Magnitude)

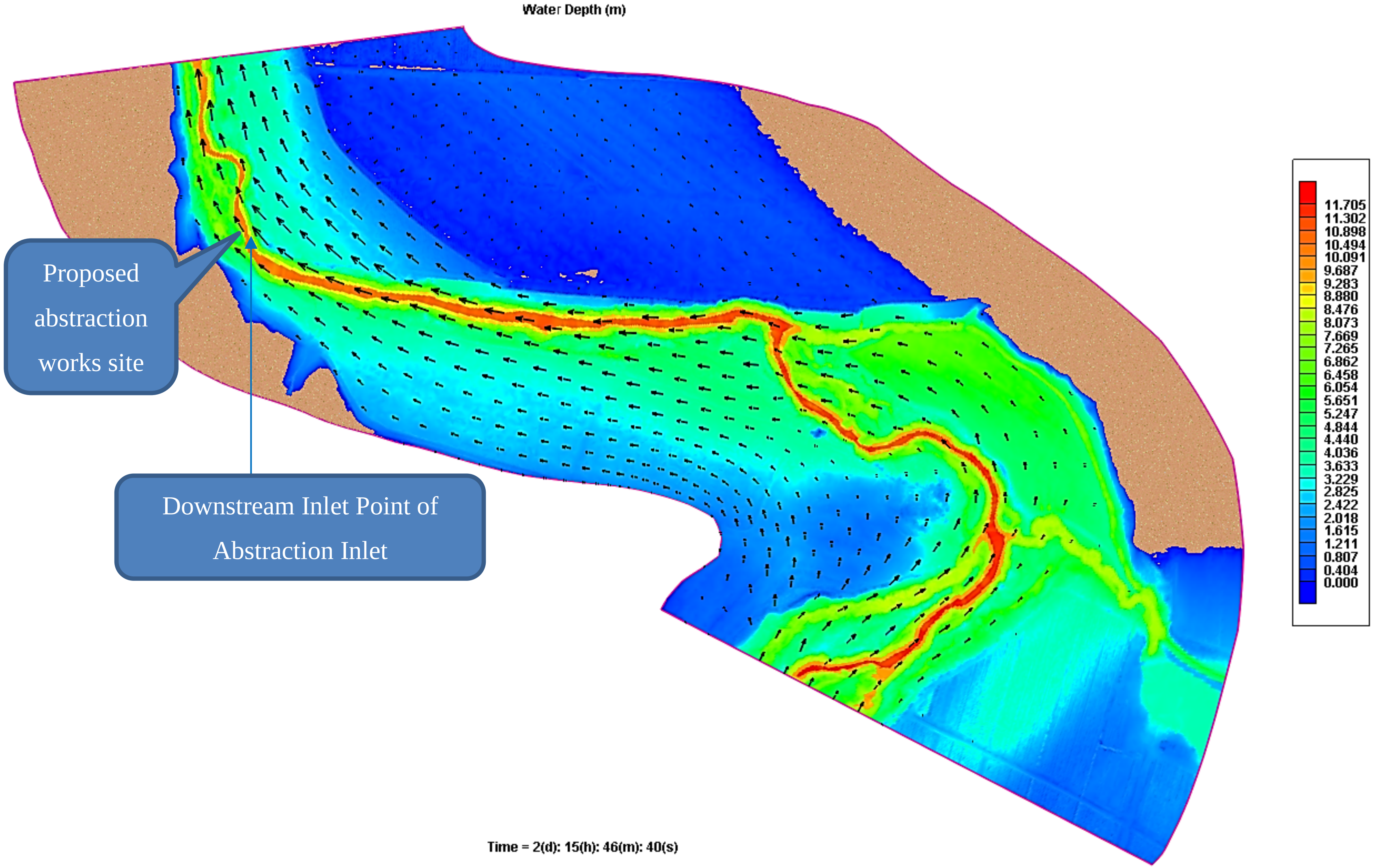


Figure 5-6 100 Year Flood Water Depth (m) with Velocity Vectors

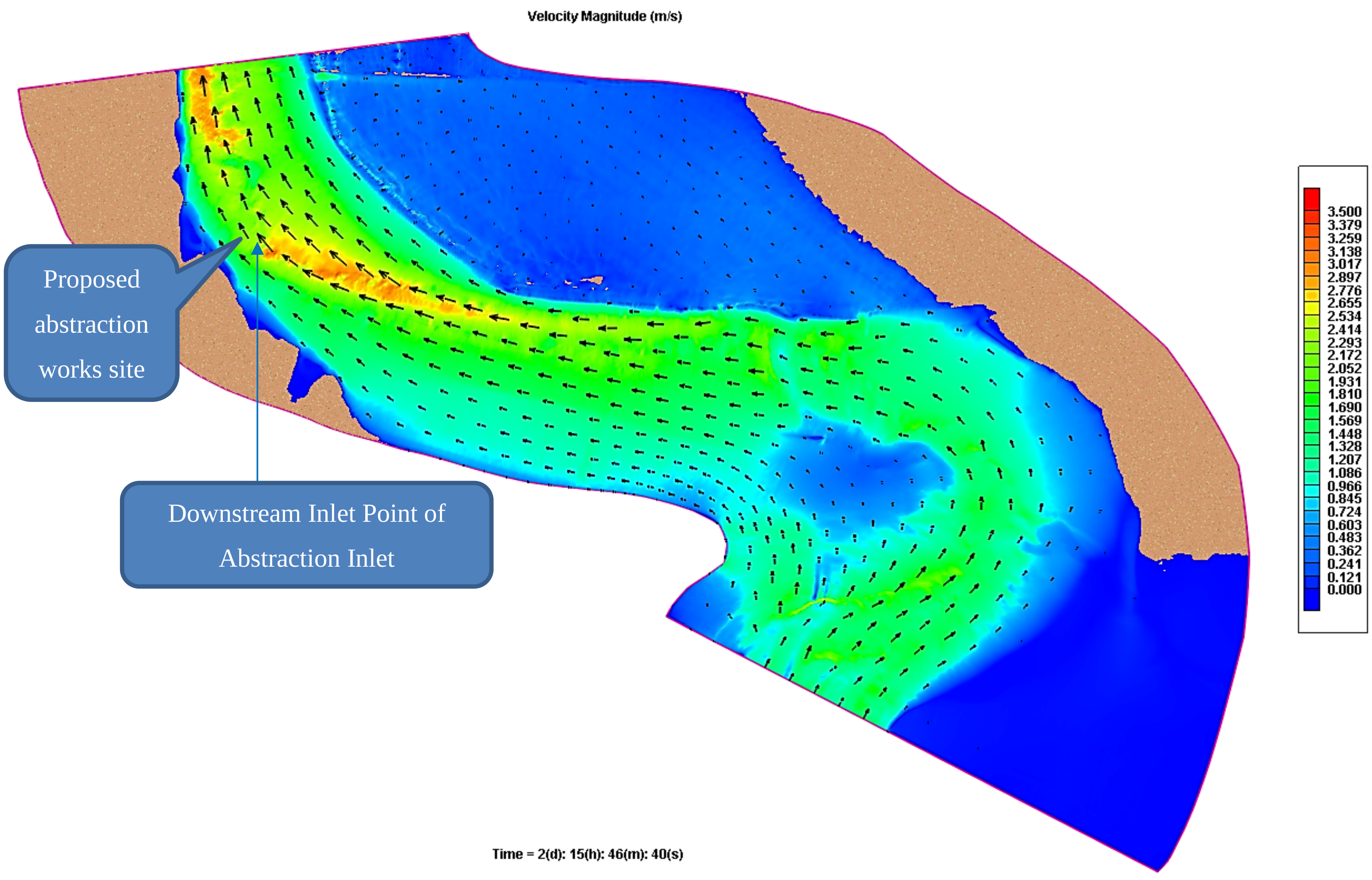


Figure 5-7 100 Year Flood Velocity Magnitude (m/s) with Velocity Vectors

Figures 5-9 to 5-11 show the bed erosion and scour as bed change from the original survey, following the 2 year, 10 year and 100 year flood hydrographs respectively. The flood hydrographs used in the simulations are shown graphically in Figure 5-8.

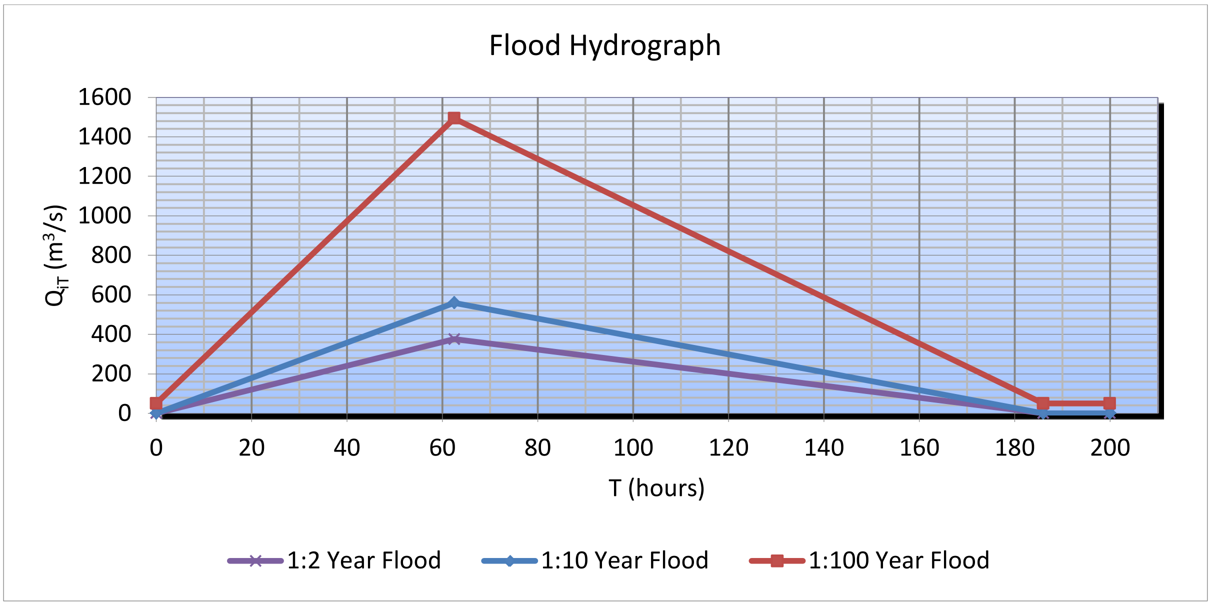


Figure 5-8 Flood hydrographs

During the 2 year flood when the flow is more confined to the main channel, scour in the order of 3.5 m is possible at the site and during the 100 year flood about 4.7 m.

Scour was simulated at the outside of the bend in the river. No bed rock was specified in the model.

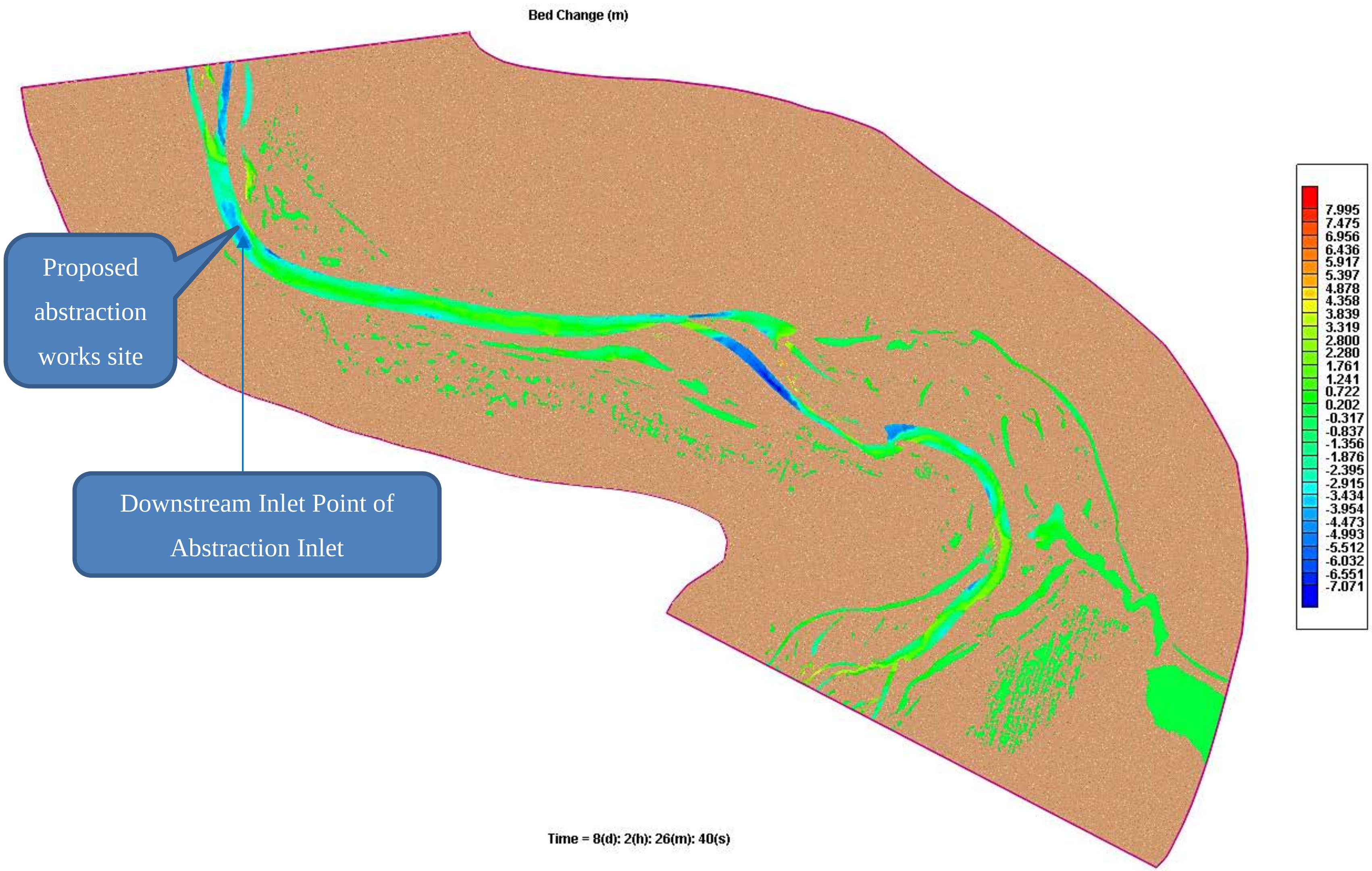


Figure 5-9 2 Year Flood (Bed Change)

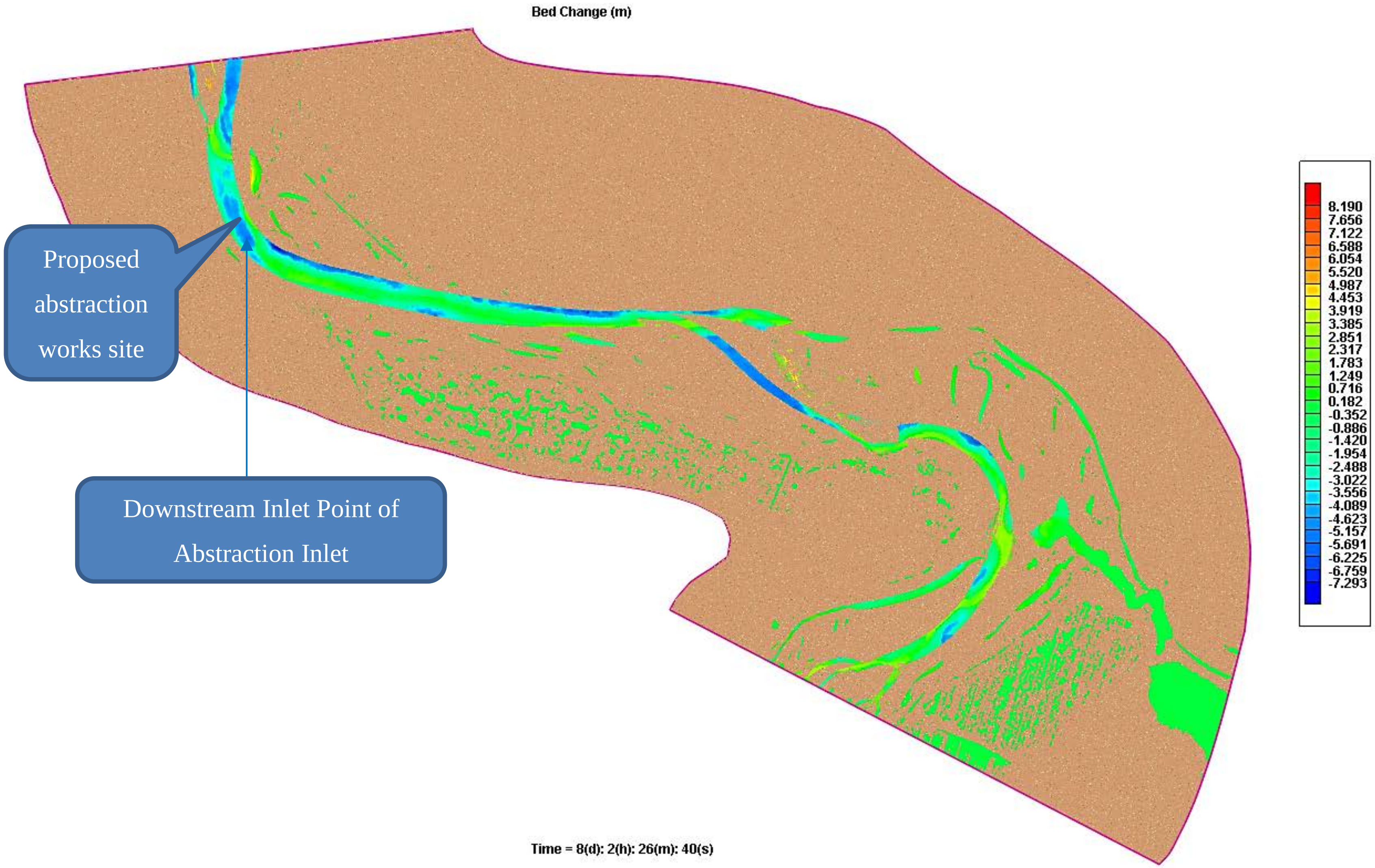


Figure 5-10 10 Year Flood (Bed Change)

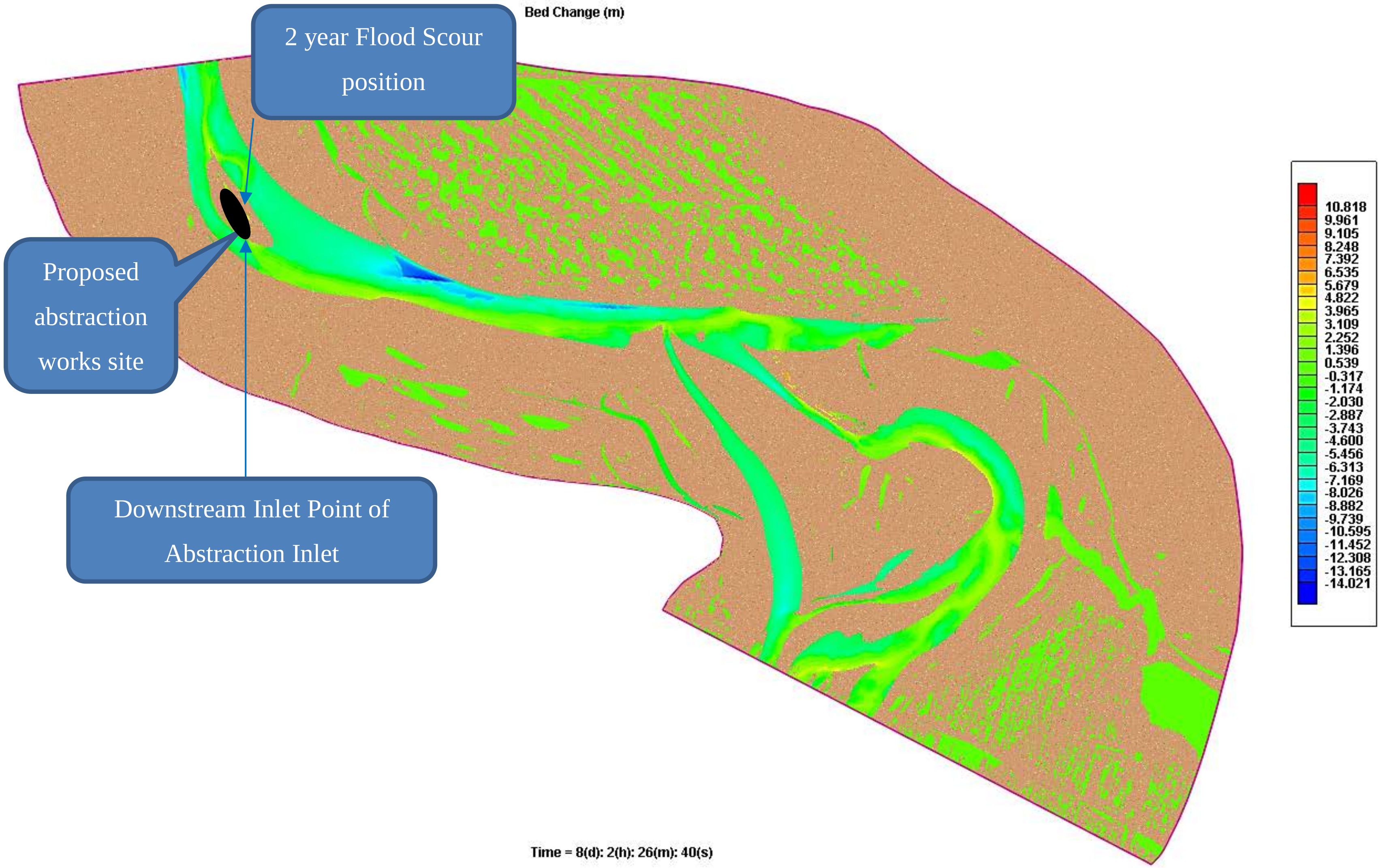


Figure 5-11 100 Year Flood (Bed Change)

6. Abstraction works design

The design of the abstraction works is based on research of the following references: Brink et al. (2006). Sediment Control at River Abstraction Works in South Africa. SA Water Research Commission.; Basson (2006). Considerations for the Design of River Abstraction Works in South Africa. SA Water Research Commission; Basson, G.R. (2012). Mathematical modelling of sediment transport and deposition in reservoirs – Guidelines and case studies. ICOLD Bulletin; and Msadala et al. (2011). Sediment yield prediction for South Africa – 2010 Edition. SA Water Research Commission.

The proposed design of the abstraction works will ensure a low maintenance and robust design, with a high assurance of supply. Drawings of the proposed design are enclosed in Appendix B. The civil engineering components of the abstraction works were designed for a peak abstraction discharge of 6 m^3/s.

A proposed layout of the abstraction works is shown in Figure 6-1 on the river, with Figure 6-2 providing more details of the structure and weir on the river. The proposed abstraction works has the following components:

- Crump weir
- Earth embankment on the right bank floodplain
- Boulder trap with radial gate which could be opened to flush sediments
- Gravel trap with two canals and dividing wall, with radial gates downstream for flushing. The gravel trap right bank side wall is at the 100 year flood level with freeboard. An underwater opening in this wall of the gravel trap allows the water from the river to be diverted, while keeping floating debris outside and away from the trashracks.
- Trashracks leading to hoppers with jet pumps downstream of the gravel trap
- Pump intakes to pump water to Voëlvlei Dam in a dry well design.

This proposed layout had to be optimized to limit the weir height and impact of the weir on flood levels. The downstream ends of the boulder and gravel traps were raised 0.3 m above the lowest river bed level of 44.92 masl for free flow flushing under low flow conditions.

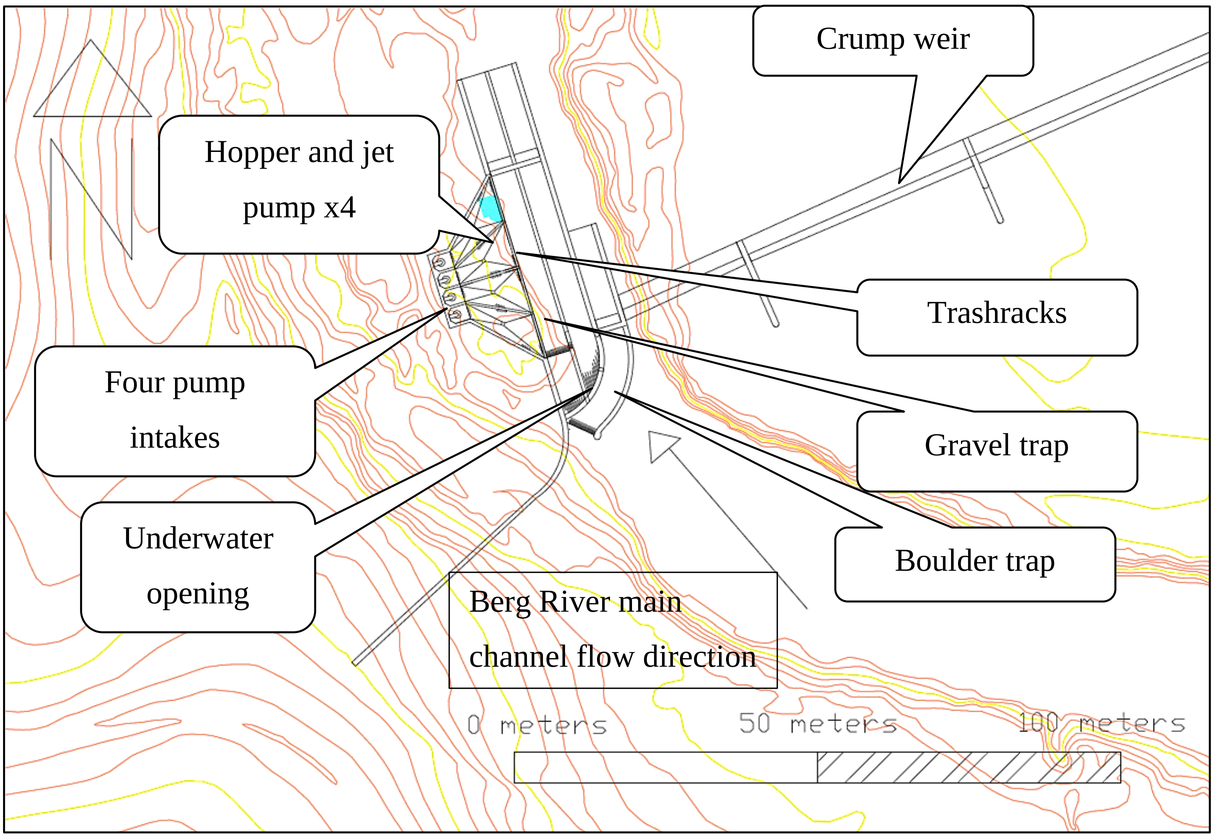


Figure 6-1 Plan View of Proposed Abstraction Works layout

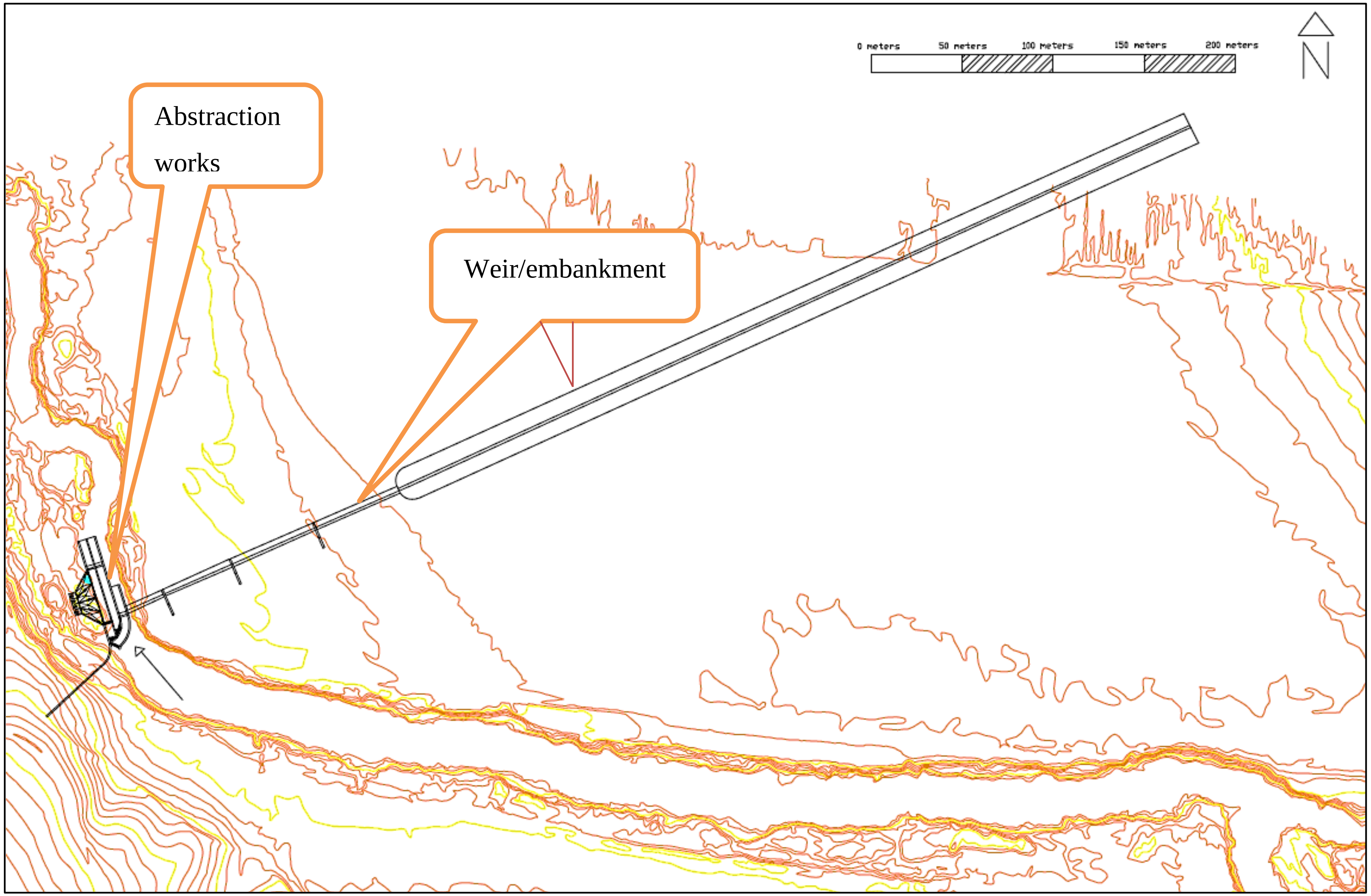


Figure 6-2 Plan View of proposed Abstraction Works on the Berg River

This design is not the most reliable design because of the use of the jet pumps which rely on the main pumps and a high head. Normally the preferred solution would be longer sand trap canals downstream of the trashracks which would also act as pump canals and these canals can be flushed under gravity. To ensure effective flushing of these canals during small floods, the weir is typically higher than with a hopper design. The specific reach on the Berg River has a small gradient which leads to regular floodplain flooding. A high weir would therefore cause additional damming during floods and therefore it was decided to use a design with a hopper to keep the weir as low as possible. A gravel trap canal which can be flushed was however added, in addition to a boulder trap. It should be noted that in case the hopper fills with sand if the jet pumps does fail, the main pumps are designed to pump coarse sediment, typically particles of up to 80 mm in diameter.

The pumps are protected from debris by a trashrack with 40 mm openings (10 x 50 mm flat bars, vertical, at 50 mm centre to centre spacing). The gravel trap layout and intake is skew to the river flood flow direction (in plan) to enhance the development of secondary flow currents against the structure, which will ensure local scour to keep the intakes open, and will also transport the coarse sediment away from the intakes during a flood. The top of the trashracks extends to the 100 year flood level and can be cleaned during floods by using a platform above the 100 year flood level. River water passes through a submerged opening (with soffit at the Minimum Operating level (MOL)) into the gravel trap and therefore floating debris should not pose problems at the trashrack during floods.

A gravel trap is placed upstream of the hopper to remove coarse sediment through two 4 m wide by 4.0 m high radial gates located at its downstream end. The gates should be large to pass flood flow. The gravel trap has a steep bed slope (varying from 1:20 to 1:30 in the two canals) to scour cobbles and boulders. Under normal flow conditions the gravel trap is submerged. Flushing of sediment deposited in the gravel trap should be carried out from time to time as required during small to medium floods. Flushing durations are expected to be less than 30 minutes.

The hoppers and jet pumps are located on the left bank side of the gravel trap. The hoppers are steep with side slopes of 2:1 (V:H) and the jet pumps are located at the centre of each hopper. The discharge required to drive each jet pump would be about 20 *l*/s. The jet pump must be able to pump coarse sediment about 80 mm in diameter. The hopper and gravel trap will mainly trap coarse sediment such as sand, and most of the silt and all the clay would be pumped to the off-channel dam.

A boulder trap and gate is proposed between the weir and the gravel trap, with the purpose to scour sediment at the submerged opening during small floods when the river bend secondary flow effect is not well developed.

A weir is required to provide sufficient head for flushing of the gravel and boulder traps, and to ensure sufficient depth for the pumps during low flow conditions. A 3 m high (average low notch height) weir has been designed with a 21 m long low notch next to the boulder trap. The crest level of the low notch is 47.9 masl while the lowest bed level is 44.923 masl. The total weir length is 160 m, consisting of four notches (refer to Figure 6-3). The weir will be founded on solid rock, and therefore no energy dissipation structure has been added.

Figure 6-3 shows the river bed cross section at the abstraction site. The low notch is located at the left bank side of the weir against the boulder trap, to ensure low flows near the intakes.

A section of the weir is shown in Appendix B.

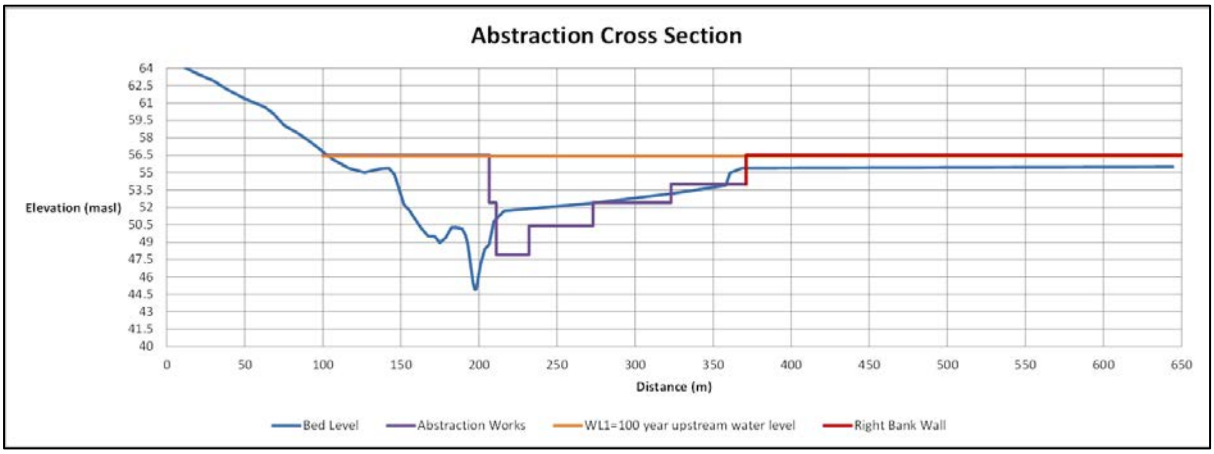


Figure 6-3 Cross section of the proposed weir and abstraction works

The top of the structure should be at 56.514 masl (11.6 m above the river bed), which is the Q_{100} year flood (1500 m^3/s) with freeboard as determined from the hydrodynamic model simulations with the abstraction works in place. Access to the structure is obtained by road. With this design no spillage will occurs on the left bank during medium and large floods.

The pump switchgear should be above the Q_{100} flood level on the left bank at or above 56.514 masl (when the top of the structure is at Q_{100} flood level), which includes freeboard for wave action due to turbulence, the bend effect and the backwater caused by the abstraction works. The power-cables and control-cables should be protected against floods and other possible damage, by means of appropriate pipe sleeves.

A canoe chute should be designed at the weir as part of the detail design since the location of the site is on the route of the annual Berg River canoe marathon.

The fishway design at the weir could be a vertical slotted fishway or a rock-ramp type spillway. If the latter is selected the design would be similar to the one shown in Figure 6-4. The typical characteristics of the rock-ramp fishway are as follows:

a) The longitudinal slope of the fishway is 1:10, thereby ensuring a design stream power of 150 W/m^3.

b) The fishway has a "u" shaped main channel of 0.9 m width, with steps (broad crested weirs) every 2 m. The left hand side of the fishway is located 0.1 m above the fishway weir crests and has a triangular shape. This left hand side shallow splash zone for eels is 0.6 m wide.

c) The fishway could be designed for a discharge of 0.1 m^3/s, and will operate for a range of river flows.

d) The upstream entrance to the fishway is controlled by rectangular orifice. During floods this opening would be under water to limit possible debris entrainment.

e) The surface of the fishway should be formed by boulders/rocks using a grouted stone pitching technique. The fishway structure has a concrete base. Gabion boxes or Reno mattresses should not be used, because they will be scoured and damaged during floods.

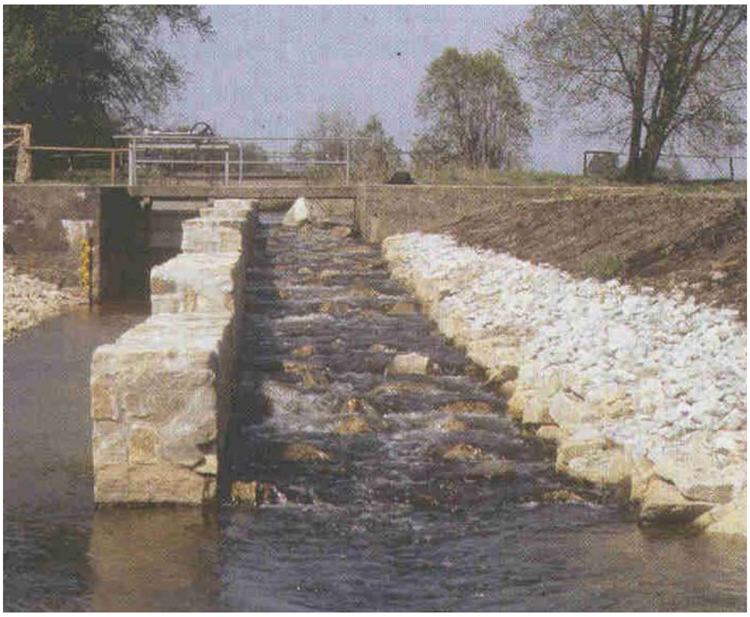


Figure 6-4 Rock-ramp type fishway

Damming caused by the proposed abstraction works and weir is limited as indicated in Figure 6-5. The water level at during the 100 year flood upstream of the weir would be 56.296 masl, compared to the current scenario water level of 55.64 masl. Figure 6-6 shows the floodlines for the 100 year flood.

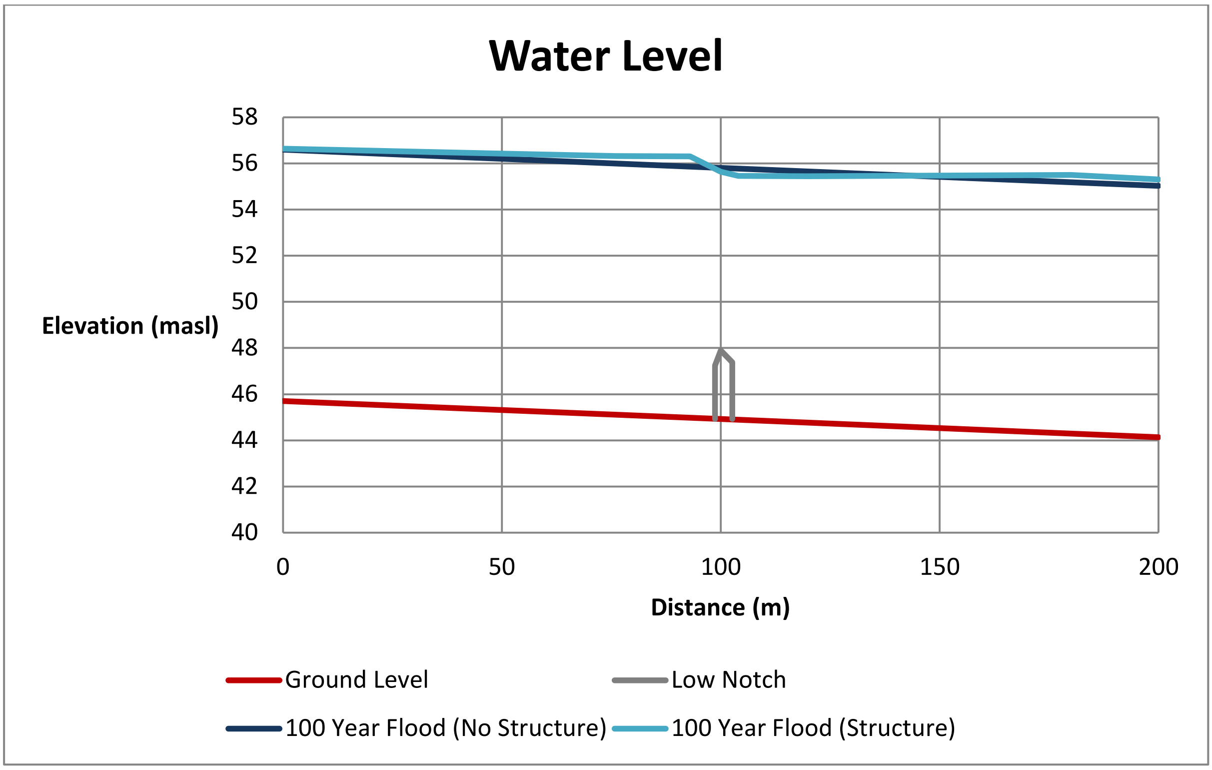


Figure 6-5 Longitudinal section of simulated water levels

Some of the key characteristics of the proposed design are summarized in Table 6.1.

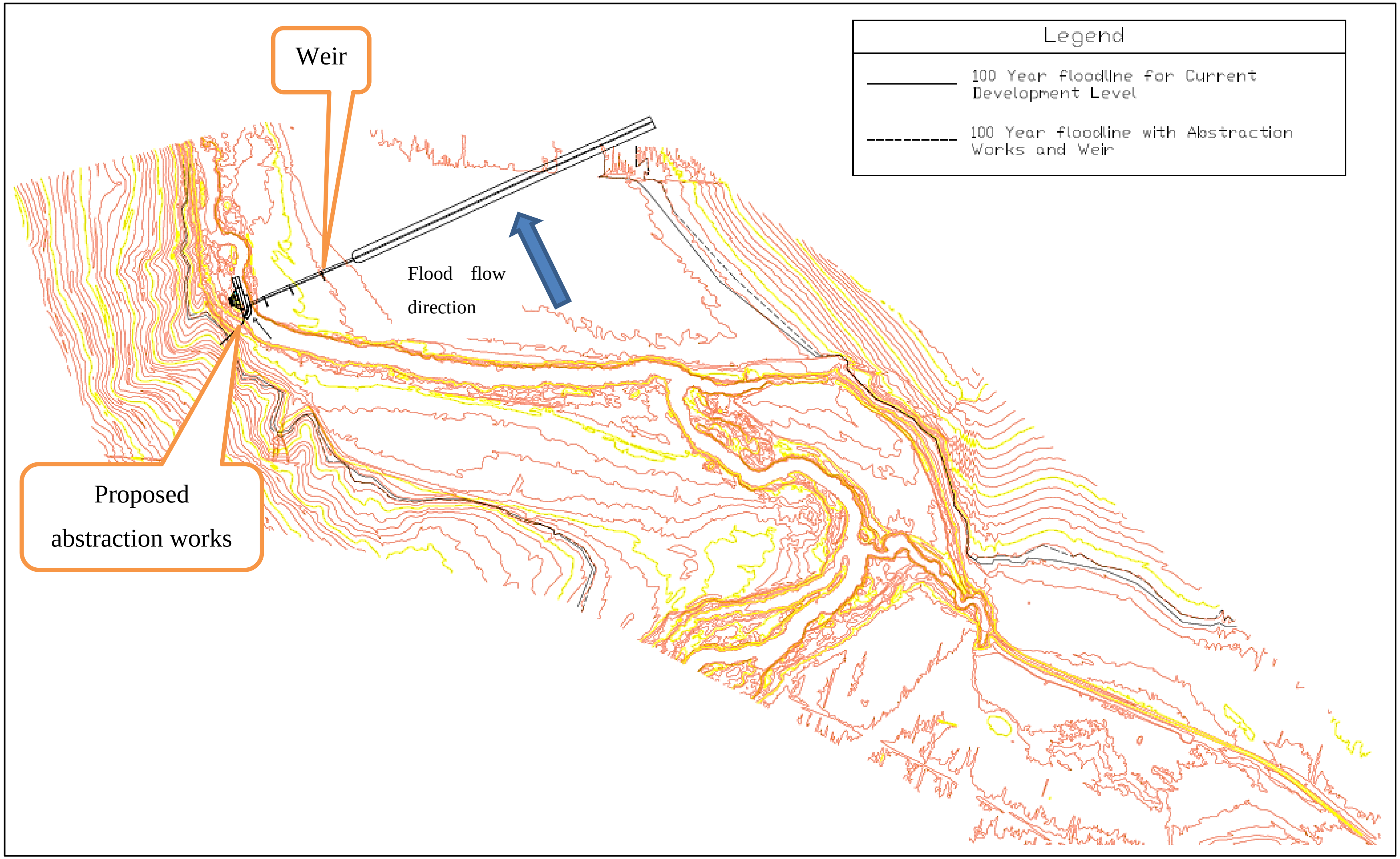


Figure 6-6 100 year floodlines

Table 6.1 Key characteristics of the proposed abstraction works

Design Summary			Units
Crump Weir			
	Low Notch Length	20	m
	2nd Notch Length	40	m
	3rd Notch Length	50	m
	4th Notch Length	50	m
	Low Notch Crest Elevation = MOL	47.9	masl
	2nd Notch Crest Elevation	50.4	masl
	3rd Notch Crest Elevation	52.4	masl
	4th Notch Crest Elevation	54.0	masl
	Lowest River Bed Elevation at site	44.92	masl
	Low Notch Height Above River Bed	2.98	m
	Discharge Capacity Low Notch only	71	m^3/s
Abstraction Inlet between boulder and gravel traps			
	Opening Length	15.4	m
	Opening Height	0.85	m
	Opening Invert Level	47.113	masl
Trashrack			
	Trashrack Length	30	m
	Trashrack minimum Height required	0.774	m
	Trashrack Invert Level	47.127	masl
Pump Canals			
# Pump Canals		4	
Pump Canal Width		2.6	m
# Duty Pumps		3	
# Standby Pumps		1	
Total Duty Pump Capacity		6	m^3/s
Total Standby Pump Capacity		2	m^3/s

Table 6.1 Key characteristics of the proposed abstraction works (continued)

Design Summary			Units
Hopper			
	Hopper Invert Level	35.123	masl
Volume	100Qduty minimum required	600	m^3
	200Qduty maximum required	1200	m^3
	Provided Volume	970	m^3
Sediment Traps			
	Boulder trap Width	4	m
	Gravel trap Canal Width	4	m
Flood Levels 50 m upstream of the weir site			
	Q_2 Flood Level Without Abstraction Works	53.050	masl
	Q_{10} Flood Level Without Abstraction Works	53.608	masl
	Q_{100} Flood Level Without Abstraction Works	55.770	masl
	Q_2 Flood Level With Abstraction Works	53.942	masl
	Q_{10} Flood Level With Abstraction Works	54.831	masl
	Q_{100} Flood Level With Abstraction Works	56.415	masl
	Q_{100} Flood with freeboard = top of structure	56.514	masl

7. Low lift pumping system

Three duty and one standby pump could be used at the river abstraction works with a dry well. The total duty pump discharge capacity is 6 m^3/s. One pump intake is placed in a pumping bay. The pumping bays have dividing walls between them.

Flushing of the pump bays can be done by installation of water jets underneath the pump intakes. The jet exit velocities should be 4 m/s and the jet should point towards the hopper.

During the detail design consideration could be given to installing fine screen with 40 x 40 mm openings at the entrance to each pump canal, which can be raised for cleaning. Stop logs could also be placed at the location of the fine screens to block off the pump intake canals if required.

8. Proposed operation of the abstraction works

The proposed abstraction works should be self-scouring during floods larger than the Q_5 flood and secondary currents will keep the intakes open. The gravel trap opening is under water and generally debris would not reach the trashracks.

The gravel trap could be flushed during small floods or at the end of large floods. The gates are normally closed and should not be opened during large floods. The tailwater level should be low enough so that free outflow conditions occur for maximum flushing efficiency of the sediment.

The boulder trap should be flushed before the gravel trap is flushed to prevent coarse sediment from entering the gravel trap. The boulder trap and gravel trap should not be flushed continuously because this will impact on the low flow ecology due to elevated base flow sediment concentrations. Gravel and boulder trap flushing would be for short periods only and during small floods or at the end of large floods.

Flushing of the boulder trap by using the radial gate should only be done to clean the gravel trap and therefore the intake area and not the sediment upstream of weir. Equilibrium sedimentation to say within 0.5 m of the weir crest is expected to occur but will not impact on the operation of the abstraction works.

Flushing of the pump bays would be possible by submerged jets underneath the pumps that would re-entrain fine sediments and transport it towards the hopper.

It is important that the pipeline between the river abstraction works and Voëlvlei Dam is operated at a high flow velocity, or flushed from time to time at a velocity > 2 m/s or cleaned mechanically from time to time to remove silt deposition which could affect the hydraulic roughness and friction losses.

9. Conclusions and Recommendations

This study proposes a robust abstraction works design, with a high assurance of supply, relatively low in maintenance. A boulder trap, gravel trap and hoppers with jet pumps are proposed. The two traps could be flushed under gravity to remove sediment and can handle coarse sediment. Flushing of sediment will have a low impact on the river ecology because it is done during small floods or at the end of large floods, never under low flow conditions and therefore the base flow water quality is not affected. The estimated flushing duration for the traps is less than 30 minutes each.

The submerged intake is self-scouring during floods due to the orientation of the structure and local flow conditions in the river. A weir is required to create sufficient head to flush sediment from the gravel and boulder traps and to obtain the required depth at the pumps during low flow periods. The proposed weir height is 3 m at the low notch. The trashracks would generally remain debris free, but could be cleaned during floods.

It is recommended that the top of the abstraction works is constructed high enough to be accessible during the Q_{100} flood. The top of the structure and switchgear should therefore be at or above elevation 56.514 masl.

Four pump bays are located at the four hoppers. These pumps should be able to pump coarse sediment. Three duty and one standby pumps were considered in the design, but different layout are possible and will not impact on the basic layout of the abstraction works. The trashrack is designed for 6.0 m^3/s.

A rock-ramp type fishway or vertical slotted fishway is proposed. The rock-ramp type has a gradient of 1:10 (V:H), with a 0.9 m wide “u” shaped main channel and weirs every 2.5 m, and a shallower triangular shaped splash zone, 0.6 m wide, located on one side of the main channel. Grouted stone (boulders/rocks) pitching is specified to create a natural rough surface texture.

A canoe chute should be designed at the weir as part of the detail design since the location of the site is on the route of the annual Berg River canoe marathon.

For the detail design phase the following is recommended:

- The mathematical modelling in this report is based on only 3 cross section surveys underwater. A comprehensive survey should be carried out underwater to tie in with the LIDAR survey.
- The topographical survey on land and underwater has to be extended downstream of the site for at least 500 m to improve the hydraulic analysis reliability. The survey elevation should extend to above the 100 year flood level.
- A water level recorder (pressure sensor and logger) should be installed at the site to obtain a stage-discharge relationship from low flows to floods. Water levels should use the same datum as the survey and be indicated as masl. The downstream water levels affect the flushing of sediment and the weir has to be high enough to maximize flushing efficiency under small flood conditions. An Acoustic Doppler Current Profiler should be used on site to measure the flows from time to time in order to correlate the flows with the nearest gauging station.
- A hydraulic physical model study is proposed of the abstraction works, weir and embankment, at a scale of 1:25 to allow simulation of floods up to the 100 year event and to minimize scale effects. The efficiency of flushing of the boulder and gravel traps with the correct tailwater levels for different floods has to be tested in the model. Self scouring of the intake area during floods also has to be determined with movable bed model tests. From the above tests the final weir height and MOL has to be determined.

10. References

Brink, C, Basson, G.R. and Denys, F. (2006). Sediment Control at River Abstraction Works in South Africa. SA Water Research Commission.

Basson, G.R. (2006). Considerations for the Design of River Abstraction Works in South Africa. SA Water Research Commission.

Basson, G.R. (2012). Mathematical modelling of sediment transport and deposition in reservoirs – Guidelines and case studies. ICOLD Bulletin.

Msadala, V., Gibson, L., Le Roux, J., Rooseboom, A. and Basson, G.R. Sediment yield prediction for South Africa – 2010 Edition (2011). SA Water Research Commission Publication.

TR138. (1988). Regional maximum flood determination in southern Africa. Technical Report, Department of Water Affairs.

APPENDIX A

Sediment grading analysis data based on sampling carried out on 5 April 2012

Site visit sample coordinates

Description	South Coordinates			East Coordinates		
	Degrees	Minutes	Seconds	Degrees	Minutes	Seconds
Measuring Point 001	33°	19'	45.26"S	18°	58'	0.30"E
Measuring Point 002	33°	19'	44.80"S	18°	58'	56.95"E
Measuring Point 003	33°	19'	44.70"S	18°	58'	55.14"E
Measuring Point 004	33°	19'	44.23"S	18°	58'	53.48"E
Measuring Point 005	33°	19'	44.01"S	18°	58'	51.30"E
Measuring Point 006	33°	19'	43.56"S	18°	58'	49.32"E
Measuring Point 007	33°	19'	41.49"S	18°	58'	48.89"E
Abstraction Works Site	33°	19'	42.14"S	18°	58'	48.82"E

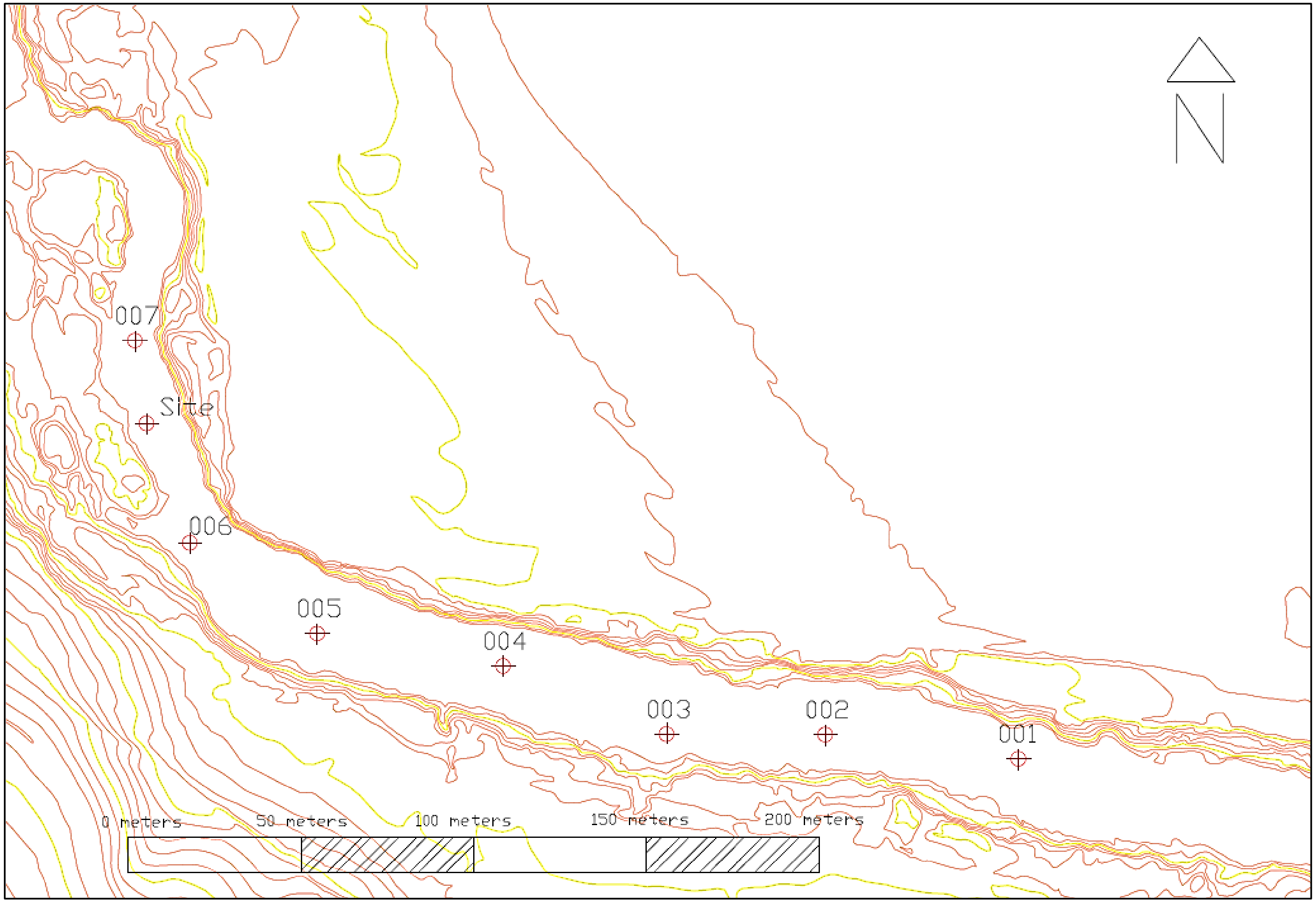


Figure A-1 Sediment sampling locations

Sediment grading analysis: Sieve and hydrometer methods

ASTM Metode

Monster nommer	Berg River Abstraction Works 001
Datum	2012/04/18
Houer nommer	1
Nat massa	76
Droë massa	76

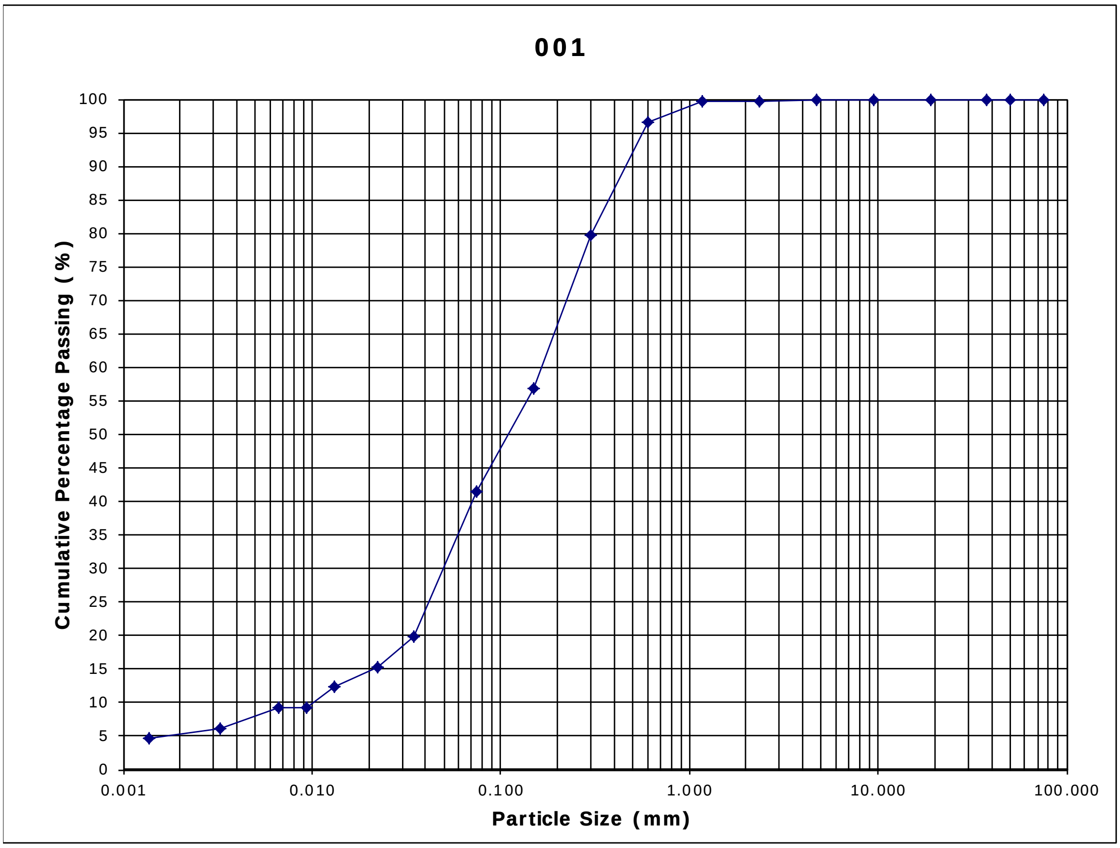
	Lugdroog	Oonddroog
Totale massa	775	775.00
Massa in fles	65	65.00

Sif toets	
Sif grootte (mm)	Massa (g)
2.36-1.18	0
1.18-0.60	2
0.60-0.30	11
0.30-0.150	15
0.150-0.075	10
<0.075	27.00

Sif analiese			
Sif grootte (mm)	Agterblywende massa (g)	% op sif	% groter 100.00
75.00	0	0.00	100.00
50.00	0	0.00	100.00
37.50	0	0.00	100.00
19.00	0	0.00	100.00
9.50	0	0.00	100.00
4.75	0	0.00	100.00
2.36	2	0.26	99.74
<2.36	773.00	99.74	0.00

Hidrometer lesings			
Tyd (min)	Werklik Lesing	Temp C	Gekor lesing
2	18	21	13.00
5	15	21	10.00
15	13	21	8.00
30	11	21	6.00
60	11	21	6.00
250	9	21	4.00
1440	8	21	3.00

Eenhede	% Konsentrasie	Diameter (D)
mm	100.00	75
mm	100.00	50
mm	100.00	37.5
mm	100.00	19
mm	100.00	9.5
mm	100.00	4.75
mm	99.74	2.36
mm	99.74	1.18
mm	96.67	0.6
mm	79.79	0.3
mm	56.78	0.15
mm	41.43	0.075
mm	19.95	0.0348
mm	15.34	0.0224
mm	12.28	0.0131
mm	9.21	0.0094
mm	9.21	0.0066
mm	6.14	0.0033
mm	4.60	0.0014



ASTM Metode

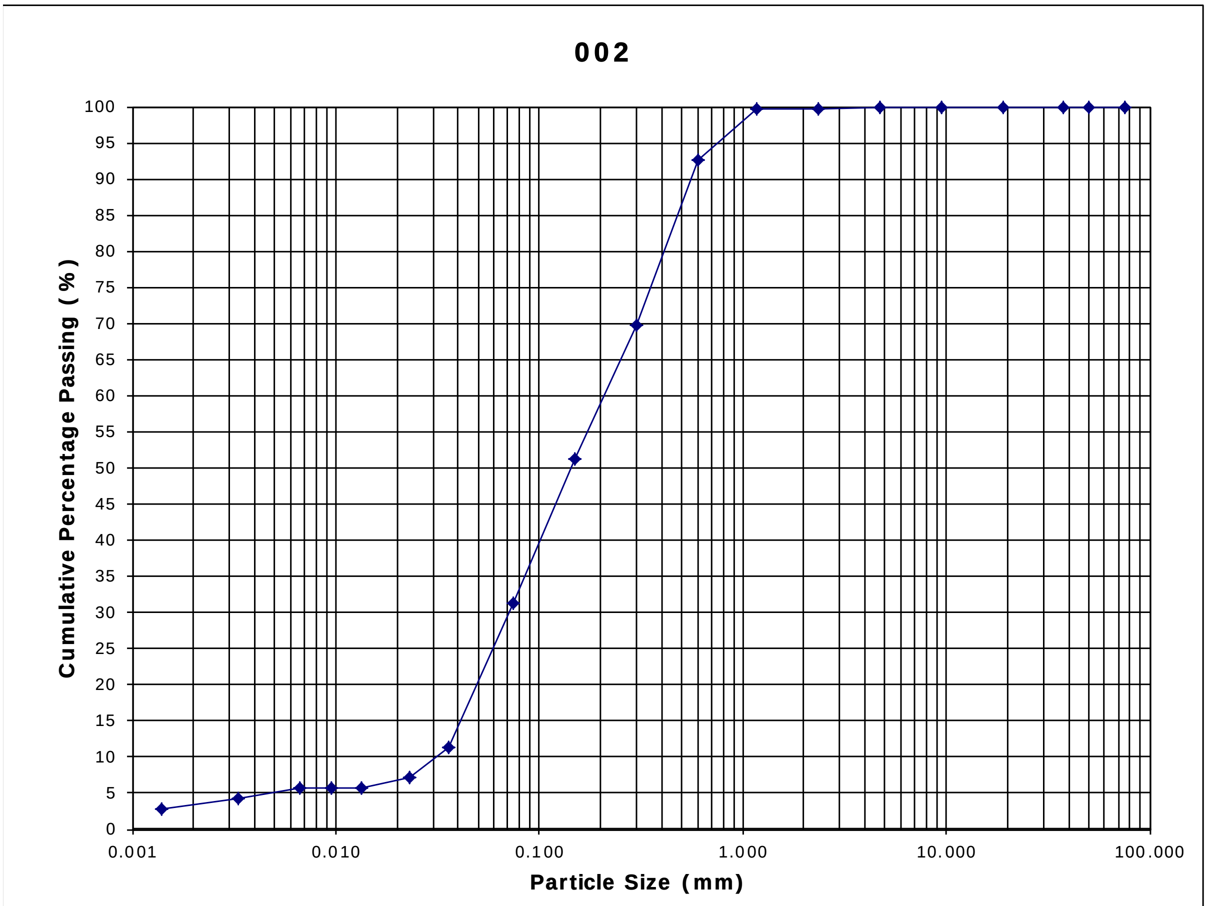
Monster nommer	Berg River Abstraction Works 002	
Datum	2012/04/18	
Houer nommer	3	
Nat massa	86	
Droë massa	86	
	Lugdroog	Oonddroog
Totale massa	748	748.00
Massa in fles	70	70.00

Sif toets	
Sif grootte (mm)	Massa (g)
2.36-1.18	0
1.18-0.60	5
0.60-0.30	16
0.30-0.150	13
0.150-0.075	14
<0.075	22.00

Sif analiese			
Sif grootte (mm)	Agterblywende massa (g)	% op sif	% groter
			100.00
75.00	0	0.00	100.00
50.00	0	0.00	100.00
37.50	0	0.00	100.00
19.00	0	0.00	100.00
9.50	0	0.00	100.00
4.75	0	0.00	100.00
2.36	2	0.27	99.73
<2.36	746.00	99.73	0.00

Hidrometer lesings			
Tyd (min)	Werklik Lesing	Temp C	Gekor lesing
2	13	21	8.00
5	10	21	5.00
15	9	21	4.00
30	9	21	4.00
60	9	21	4.00
250	8	21	3.00
1440	7	21	2.00

Eenhede	% Konsentrasie	Diameter (D)
mm	100.00	75
mm	100.00	50
mm	100.00	37.5
mm	100.00	19
mm	100.00	9.5
mm	100.00	4.75
mm	99.73	2.36
mm	99.73	1.18
mm	92.61	0.6
mm	69.81	0.3
mm	51.29	0.15
mm	31.34	0.075
mm	11.40	0.0359
mm	7.12	0.0231
mm	5.70	0.0134
mm	5.70	0.0095
mm	5.70	0.0067
mm	4.27	0.0033
mm	2.85	0.0014



ASTM Metode

Monster nommer	Berg River Abstraction Works 003	
Datum	2012/04/18	
Houer nommer	4	
Nat massa	94	
Droë massa	93	
	Lugdroog	Oonddroog
Totale massa	827	818.20
Massa in fles	70	69.26

Sif toets	
Sif grootte (mm)	Massa (g)
2.36-1.18	9
1.18-0.60	22
0.60-0.30	24
0.30-0.150	9
0.150-0.075	2
<0.075	3.26

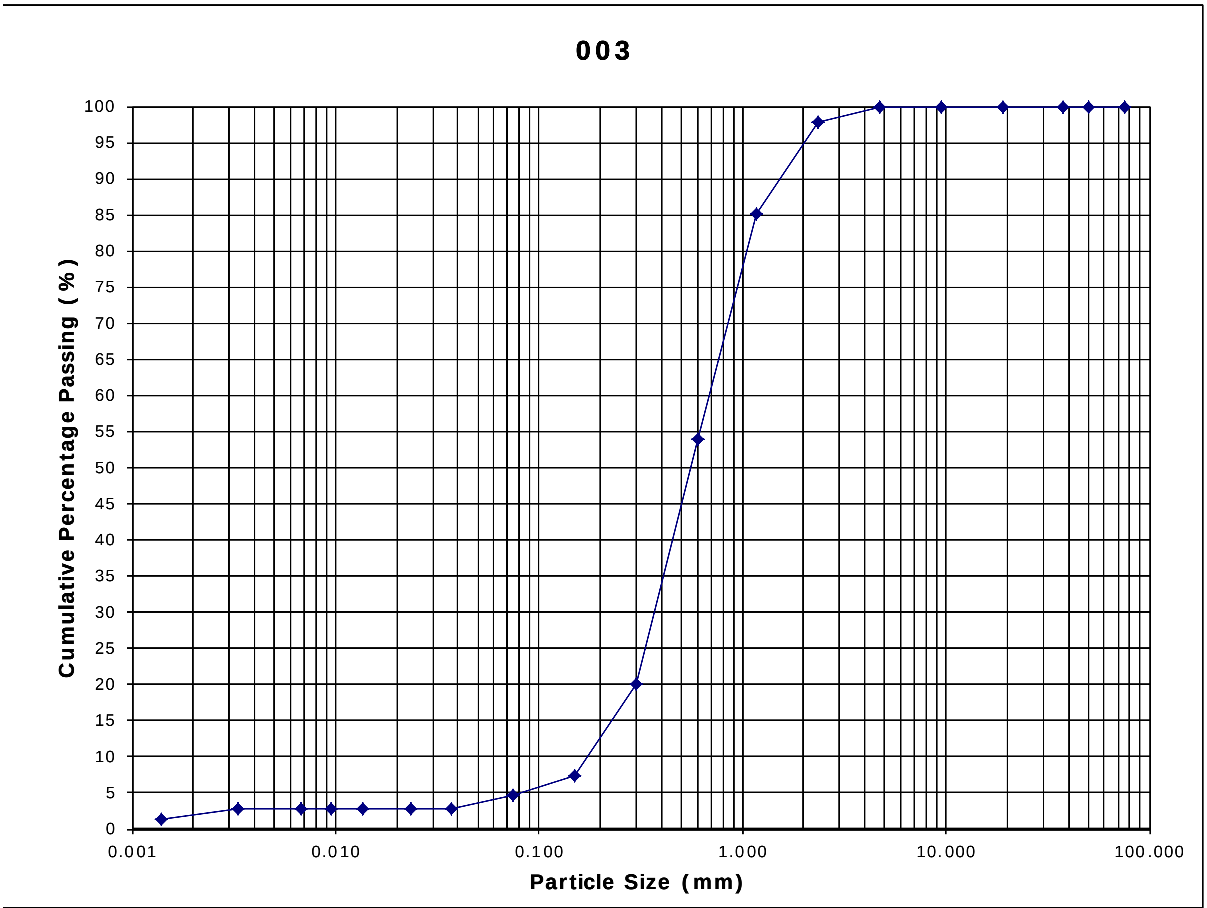
Sif analiese

Sif grootte (mm)	Agterblywende massa (g)	% op sif	% groter
			100.00
75.00	0	0.00	100.00
50.00	0	0.00	100.00
37.50	0	0.00	100.00
19.00	0	0.00	100.00
9.50	0	0.00	100.00
4.75	0	0.00	100.00
2.36	18	2.20	97.80
<2.36	800.20	97.80	0.00

Hidrometer lesings

Tyd (min)	Werklik Lesing	Temp C	Gekor lesing
2	7	21	2.00
5	7	21	2.00
15	7	21	2.00
30	7	21	2.00
60	7	21	2.00
250	7	21	2.00
1440	6	21	1.00

Eenhede	% Konsentrasie	Diameter (D)
mm	100.00	75
mm	100.00	50
mm	100.00	37.5
mm	100.00	19
mm	100.00	9.5
mm	100.00	4.75
mm	97.80	2.36
mm	85.09	1.18
mm	54.02	0.6
mm	20.13	0.3
mm	7.42	0.15
mm	4.60	0.075
mm	2.82	0.0372
mm	2.82	0.0235
mm	2.82	0.0136
mm	2.82	0.0096
mm	2.82	0.0068
mm	2.82	0.0033
mm	1.41	0.0014



ASTM Metode

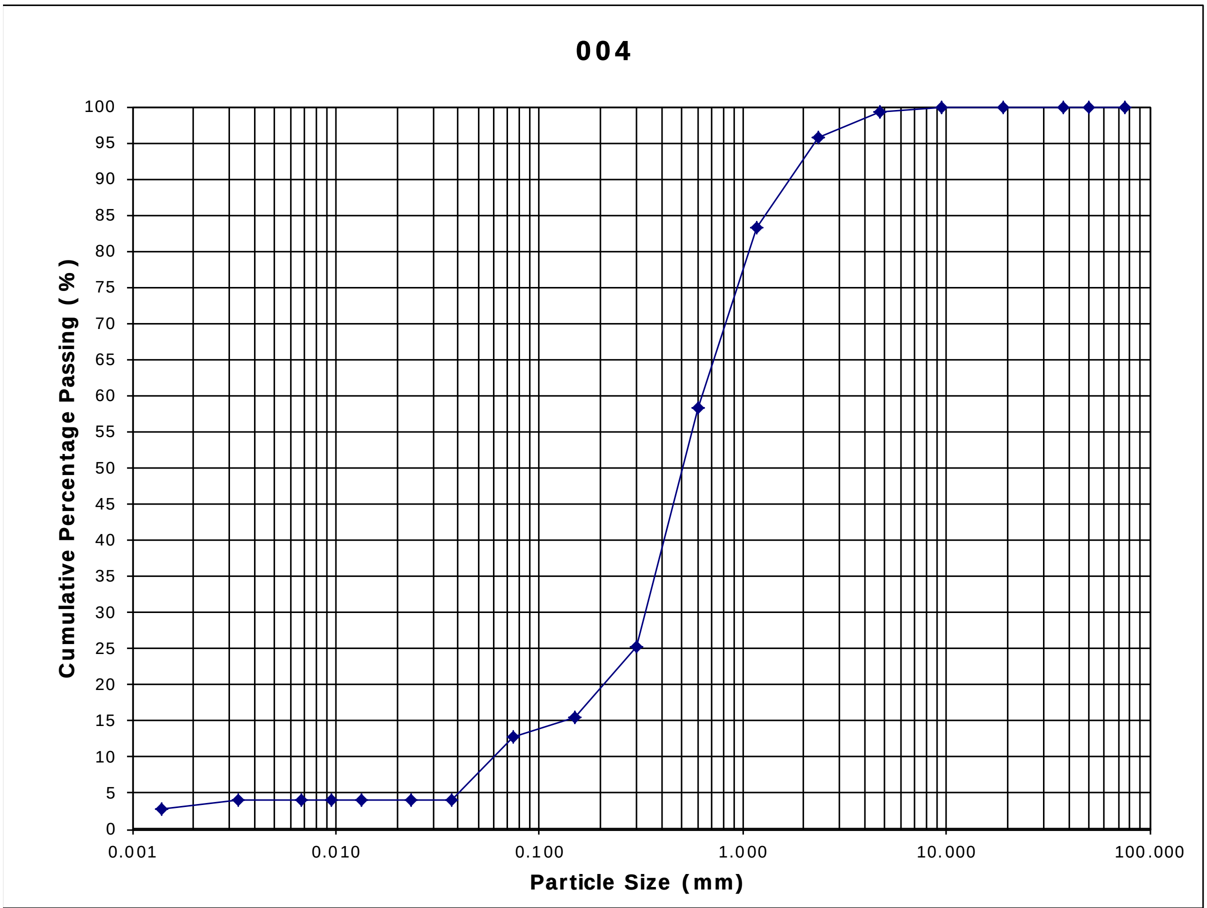
Monster nommer	Berg River Abstraction Works 004	
Datum	2012/04/18	
Houer nommer	5	
Nat massa	91	
Droë massa	90	
	Lugdroog	Oonddroog
Totale massa	821	811.98
Massa in fles	70	69.23

Sif toets	
Sif grootte (mm)	Massa (g)
2.36-1.18	9
1.18-0.60	18
0.60-0.30	24
0.30-0.150	7
0.150-0.075	2
<0.075	9.23

Sif analiese			
Sif grootte (mm)	Agterblywende massa (g)	% op sif	% groter 100.00
75.00	0	0.00	100.00
50.00	0	0.00	100.00
37.50	0	0.00	100.00
19.00	0	0.00	100.00
9.50	0	0.00	100.00
4.75	6	0.74	99.26
2.36	29	3.57	95.69
<2.36	776.98	95.69	0.00

Hidrometer lesings			
Tyd (min)	Werklik Lesing	Temp C	Gekor lesing
2	8	21	3.00
5	8	21	3.00
15	8	21	3.00
30	8	21	3.00
60	8	21	3.00
250	8	21	3.00
1440	7	21	2.00

Eenhede	% Konsentrasie	Diameter (D)
mm	100.00	75
mm	100.00	50
mm	100.00	37.5
mm	100.00	19
mm	100.00	9.5
mm	99.26	4.75
mm	95.69	2.36
mm	83.25	1.18
mm	58.37	0.6
mm	25.20	0.3
mm	15.52	0.15
mm	12.76	0.075
mm	4.15	0.0369
mm	4.15	0.0233
mm	4.15	0.0135
mm	4.15	0.0095
mm	4.15	0.0067
mm	4.15	0.0033
mm	2.76	0.0014



ASTM Metode

Monster nommer	Berg River Abstraction Works 005
Datum	2012/04/18
Houer nommer	6
Nat massa	79
Droë massa	79

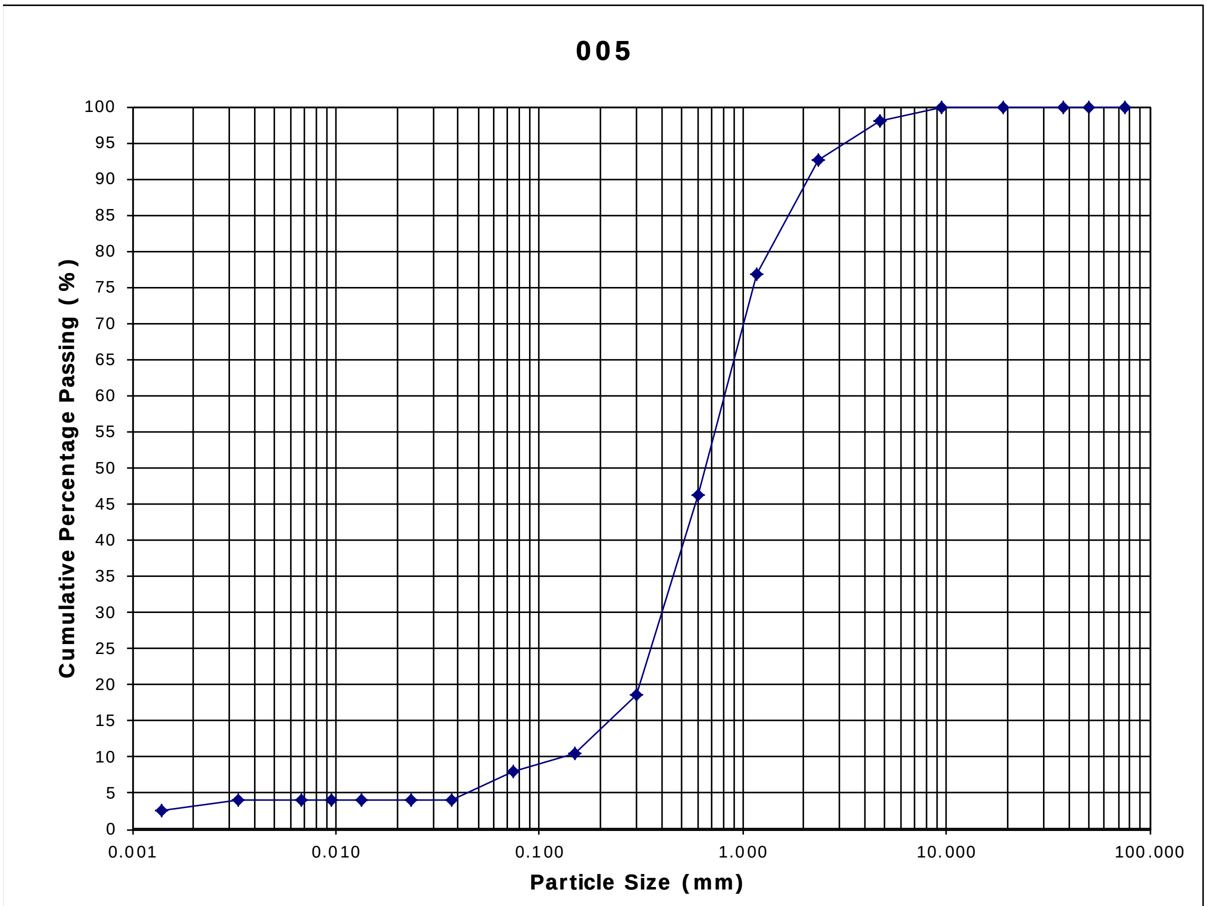
	Lugdroog	Oonddroog
Totale massa	1217	1217.00
Massa in fles	70	70.00

Sif toets	
Sif grootte (mm)	Massa (g)
2.36-1.18	12
1.18-0.60	23
0.60-0.30	21
0.30-0.150	6
0.150-0.075	2
<0.075	6.00

Sif analiese			
Sif grootte (mm)	Agterblywende massa (g)	% op sif	% groter 100.00
75.00	0	0.00	100.00
50.00	0	0.00	100.00
37.50	0	0.00	100.00
19.00	0	0.00	100.00
9.50	0	0.00	100.00
4.75	24	1.97	98.03
2.36	66	5.42	92.60
<2.36	1127.00	92.60	0.00

Eenhede	% Konsentrasie	Diameter (D)
mm	100.00	75
mm	100.00	50
mm	100.00	37.5
mm	100.00	19
mm	100.00	9.5
mm	98.03	4.75
mm	92.60	2.36
mm	76.73	1.18
mm	46.30	0.6
mm	18.52	0.3
mm	10.58	0.15
mm	7.94	0.075
mm	3.97	0.0369
mm	3.97	0.0233
mm	3.97	0.0135
mm	3.97	0.0095
mm	3.97	0.0067
mm	3.97	0.0033
mm	2.65	0.0014

Hidrometer lesings			
Tyd (min)	Werklik Lesing	Temp C	Gekor lesing
2	8	21	3.00
5	8	21	3.00
15	8	21	3.00
30	8	21	3.00
60	8	21	3.00
250	8	21	3.00
1440	7	21	2.00



ASTM Metode

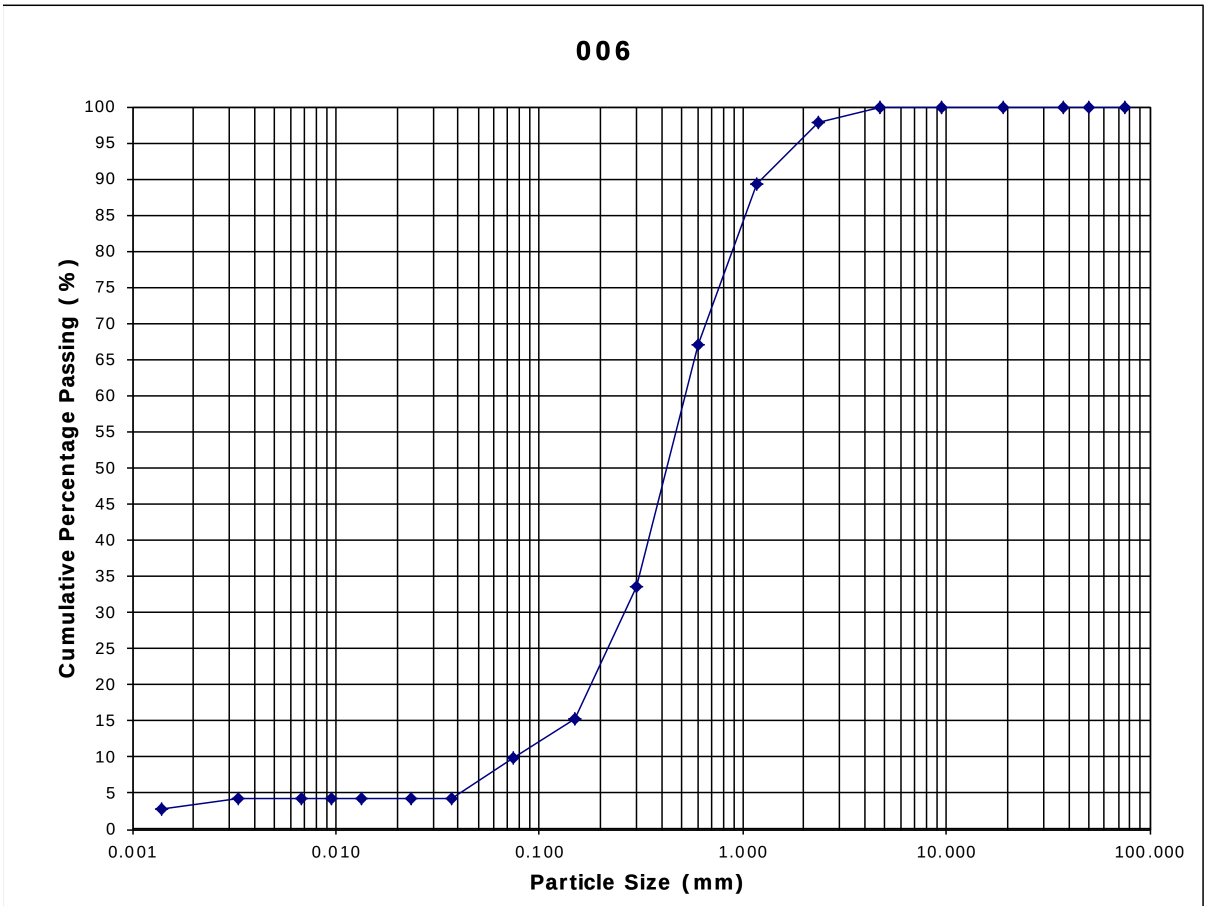
Monster nommer	Berg River Abstraction Works 006	
Datum	2012/04/18	
Houer nommer	7	
Nat massa	84	
Droë massa	84	
	Lugdroog	Oonddroog
Totale massa	1212	1212.00
Massa in fles	70	70.00

Sif analiese			
Sif grootte (mm)	Agterblywende massa (g)	% op sif	% groter 100.00
75.00	0	0.00	100.00
50.00	0	0.00	100.00
37.50	0	0.00	100.00
19.00	0	0.00	100.00
9.50	0	0.00	100.00
4.75	2	0.17	99.83
2.36	25	2.06	97.77
<2.36	1185.00	97.77	0.00

Hidrometer lesings			
Tyd (min)	Werklik Lesing	Temp C	Gekor lesing
2	8	21	3.00
5	8	21	3.00
15	8	21	3.00
30	8	21	3.00
60	8	21	3.00
250	8	21	3.00
1440	7	21	2.00

Sif toets	
Sif grootte (mm)	Massa (g)
2.36-1.18	6
1.18-0.60	16
0.60-0.30	24
0.30-0.150	13
0.150-0.075	4
<0.075	7.00

Eenhede	% Konsentrasie	Diameter (D)
mm	100.00	75
mm	100.00	50
mm	100.00	37.5
mm	100.00	19
mm	100.00	9.5
mm	99.83	4.75
mm	97.77	2.36
mm	89.39	1.18
mm	67.04	0.6
mm	33.52	0.3
mm	15.36	0.15
mm	9.78	0.075
mm	4.19	0.0369
mm	4.19	0.0233
mm	4.19	0.0135
mm	4.19	0.0095
mm	4.19	0.0067
mm	4.19	0.0033
mm	2.79	0.0014



ASTM Metode

Monster nommer	Berg River Abstraction Works 006
Datum	2012/04/18
Posisie nommer	7
Nat massa	84
Droë massa	84

Eenhede	% Konsentrasie	Diameter (D)
mm	100.00	75
mm	100.00	50
mm	42.00	37.5
mm	25.00	26.5
mm	9.00	19
mm	2.00	13.2
mm	1.00	9.5
mm	1.00	4.75
mm	0.00	2.36
mm	0.00	0.3
mm	0.00	0.15
mm	0.00	0.075
mm	0.00	0.0000
mm	0.00	0.0000
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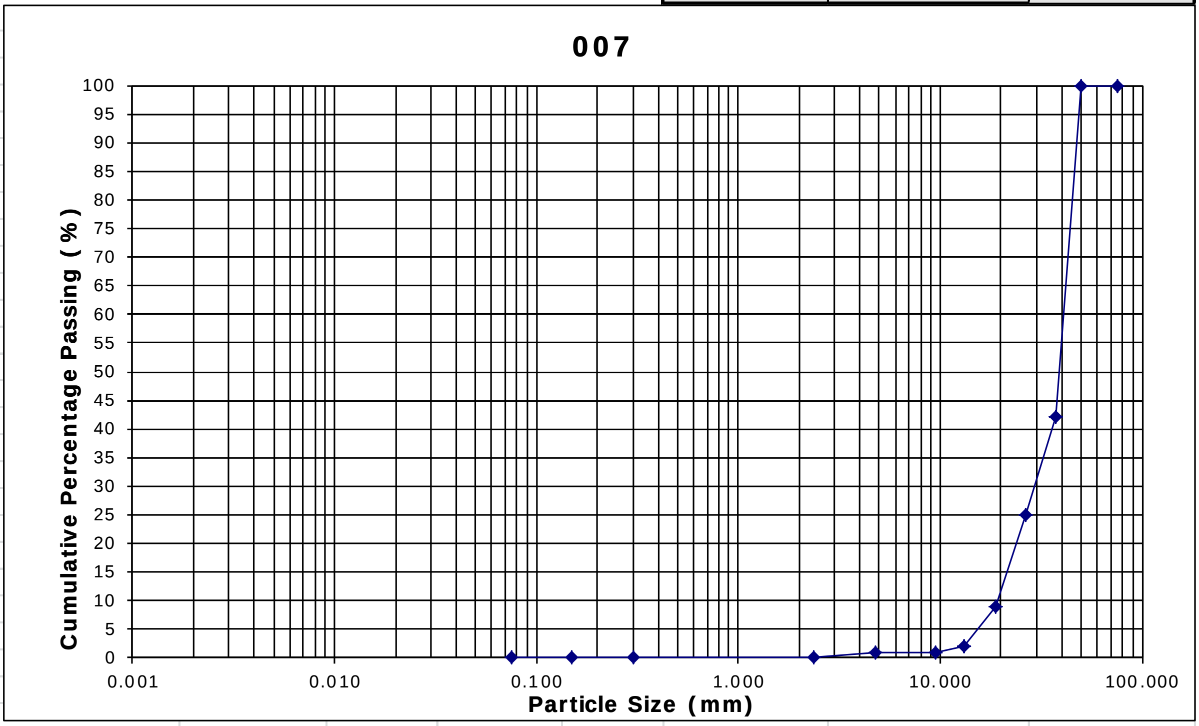
mm	0.00	0.0000
mm	0.00	0.0000
mm	0.00	0.0000
mm	0.00	0.0000



Sampling point photographs

Figure A-2 Measuring Point 001 Left Bank View

Figure A-3 Measuring Point 001 Downstream View

Figure A-4 Measuring Point 001 Right Bank View

Figure A-5 Measuring Point 001 Upstream View

Measuring Point 002

Figure A-6 Measuring Point 002 Left Bank View

Figure A-7 Measuring Point 002 Downstream View

Figure A-8 Measuring Point 002 Right Bank View

Measuring Point 003

Figure A-9 Measuring Point 003 Left Bank View

Figure A-10 Measuring Point 003 Downstream View

Figure A-11 Measuring Point 003 Right Bank View

Measuring Point 004

Figure A-12 Measuring Point 004 Left Bank View

Figure A-13 Measuring Point 004 Downstream View

Figure A-14 Measuring Point 004 Right Bank View

Measuring Point 005

Figure A-15 Measuring Point 005 Left Bank View

Figure A-16 Measuring Point 005 Downstream View

Figure A-17 Measuring Point 005 Right Bank View

Measuring Point 006: From the centre of the river to the left bank, there was no sediment on the river bed. Sediment sample was taken from the right bank side.

Figure A-18 Measuring Point 006 Left Bank View

Figure A-19 Measuring Point 006 Downstream View

Figure A-20 Measuring Point 006 Right Bank View

Measuring Point 007

Figure A-21 Measuring Point 007 Left Bank View

Figure A-22 Measuring Point 007 Downstream View

Figure A-23 Measuring Point 007 Right Bank View

Downstream of Measuring Point 007

Figure A-24 Thickly Bushed Downstream View (Access very difficult)

Figure A-25 Upstream View for placement of Abstraction Works

Abstraction Work Site

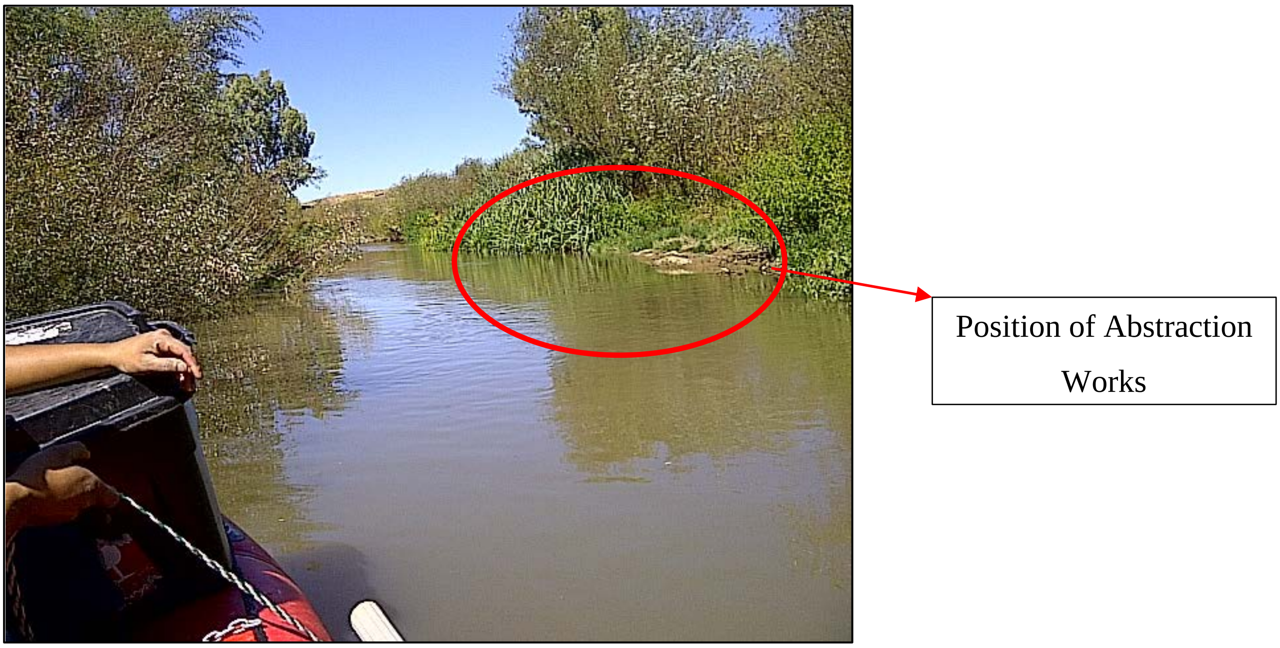


Figure A-26 Bed rock and position of Abstraction Works

Figure A-27 Left Bank Elevation Viewed for Abstraction Works Position

Figure A-28 Bed rock at Abstraction Works Position

Figure A-29 Left Bank of River Consists of Bed Rock at Abstraction Works Position

Table A.1 Sediment grading fractions of seven sites

		Unit	Sample 001	Sample 002	Sample 003	Sample 004	Sample 005	Sample 006	Sample 007	Average d_{50} used*
Class 1	0-20%	mm	0.01	0.031	0.18	0.06	0.14	0.075	19	0.083
Class 2	20-40%	mm	0.05	0.07	0.37	0.33	0.40	0.26	30.00	0.247
Class 3	40-60%	mm	0.13	0.15	0.54	0.50	0.64	0.42	39.00	0.397
Class 4	60-80%	mm	0.23	0.30	0.84	0.80	1.00	0.65	42.00	0.637
Class 5	80-100%	mm	0.44	0.54	1.50	1.70	2.20	1.20	47.00	1.263

Note:* Used in numerical model. Average of samples 001 to 006. Sample 007 not representative.

APPENDIX B

Proposed abstraction works design drawings

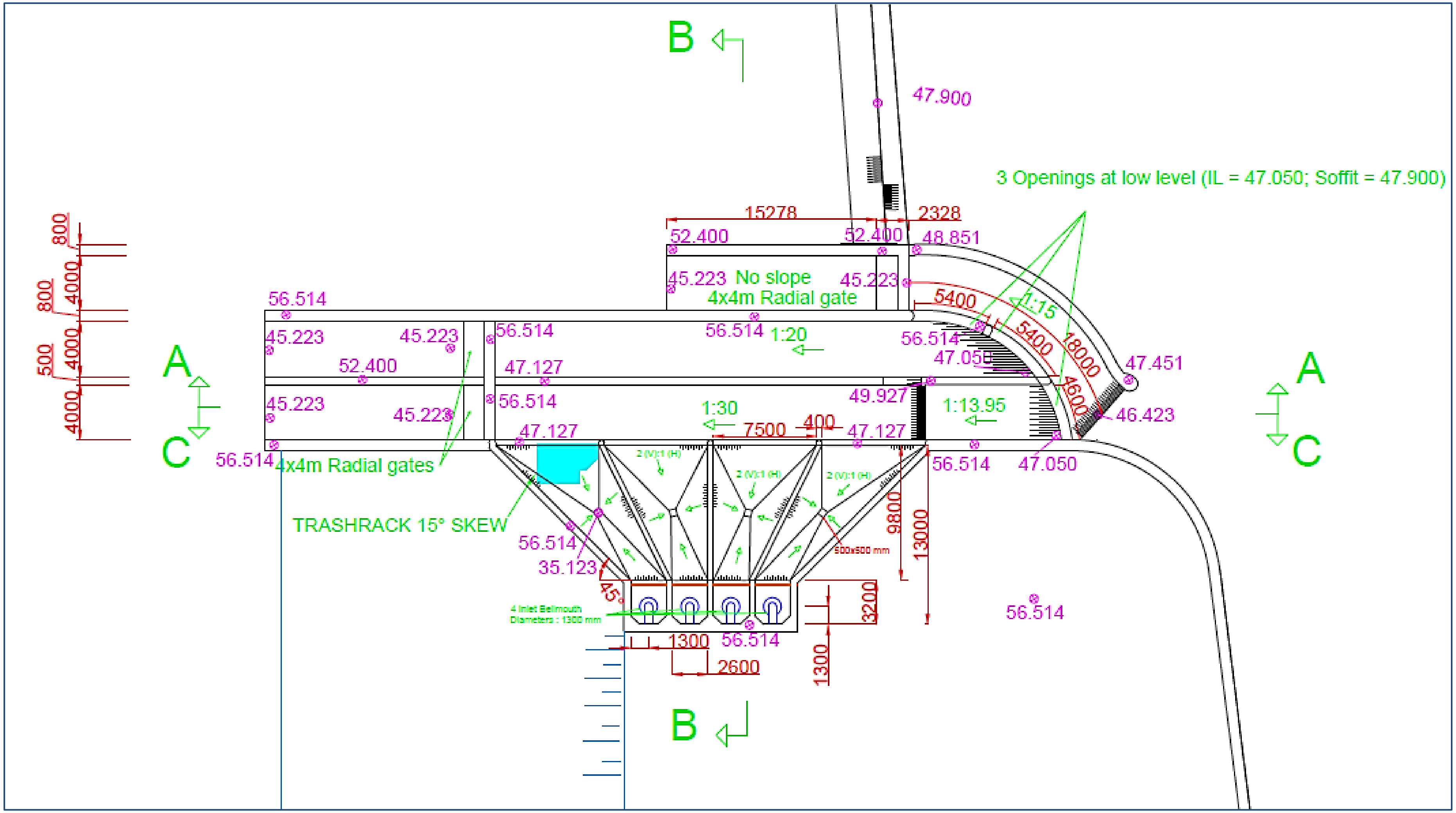


Figure B-1 Plan View - Berg River Abstraction Works

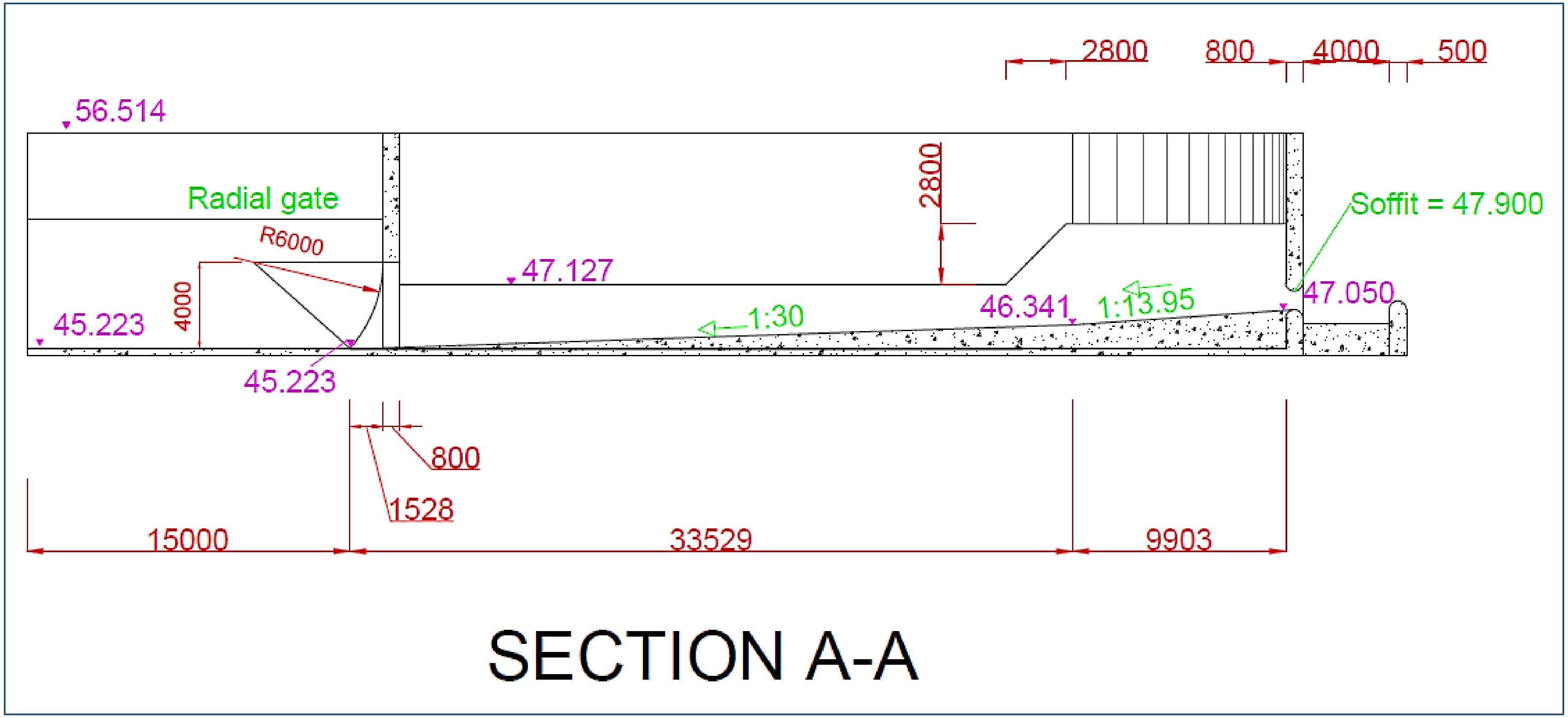


Figure B-2 Section A-A - Berg River Abstraction Works

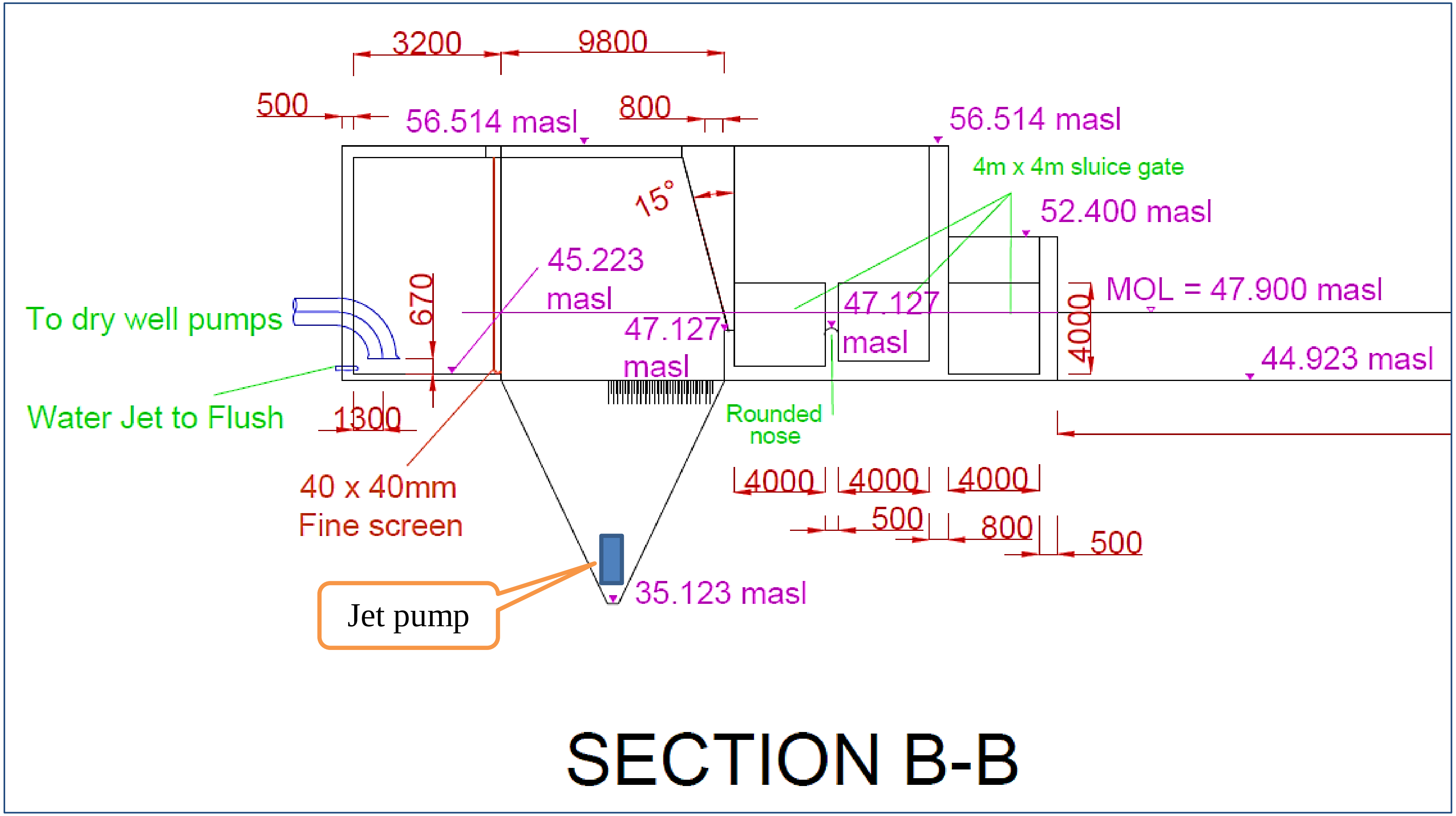


Figure B-3 Section B-B - Berg River Abstraction Works

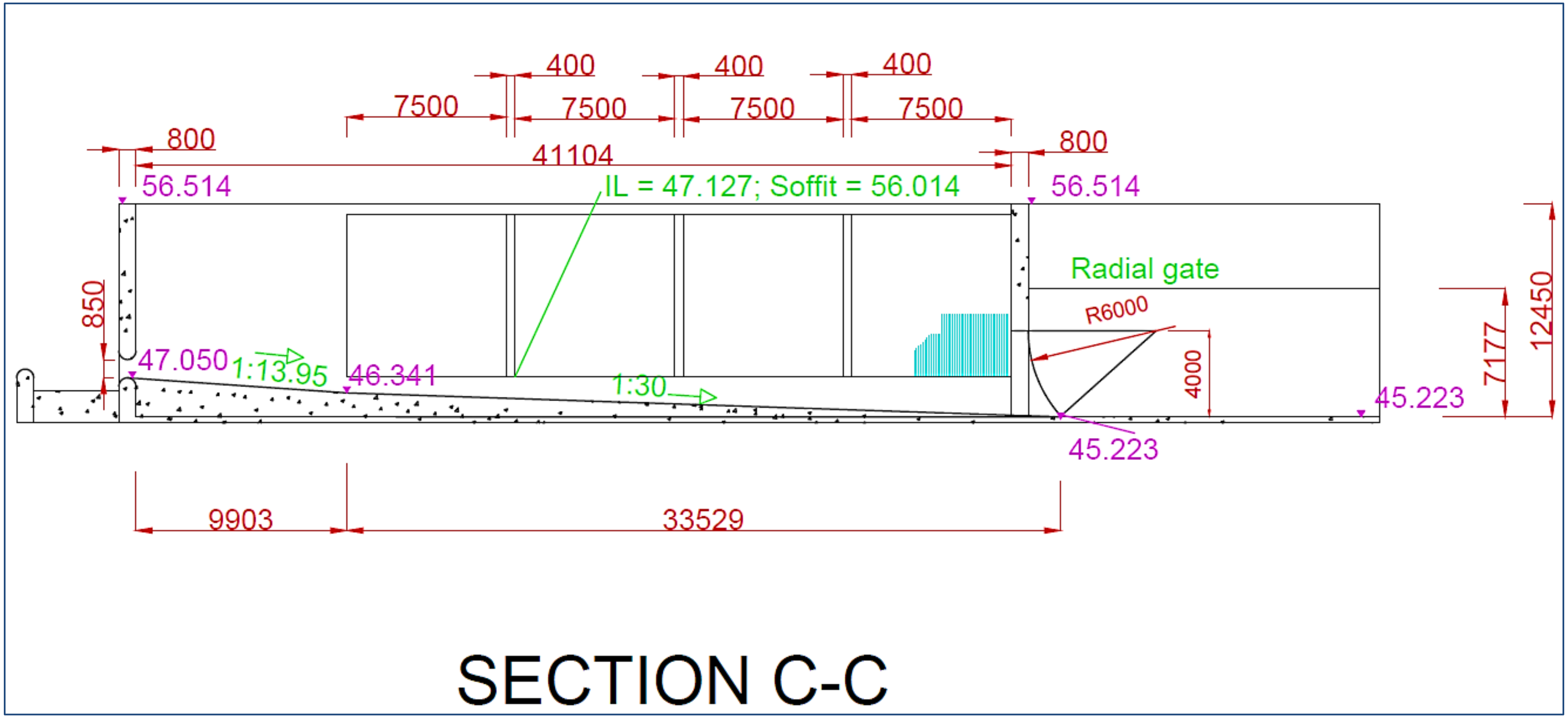


Figure B-4 Section C-C - Berg River Abstraction

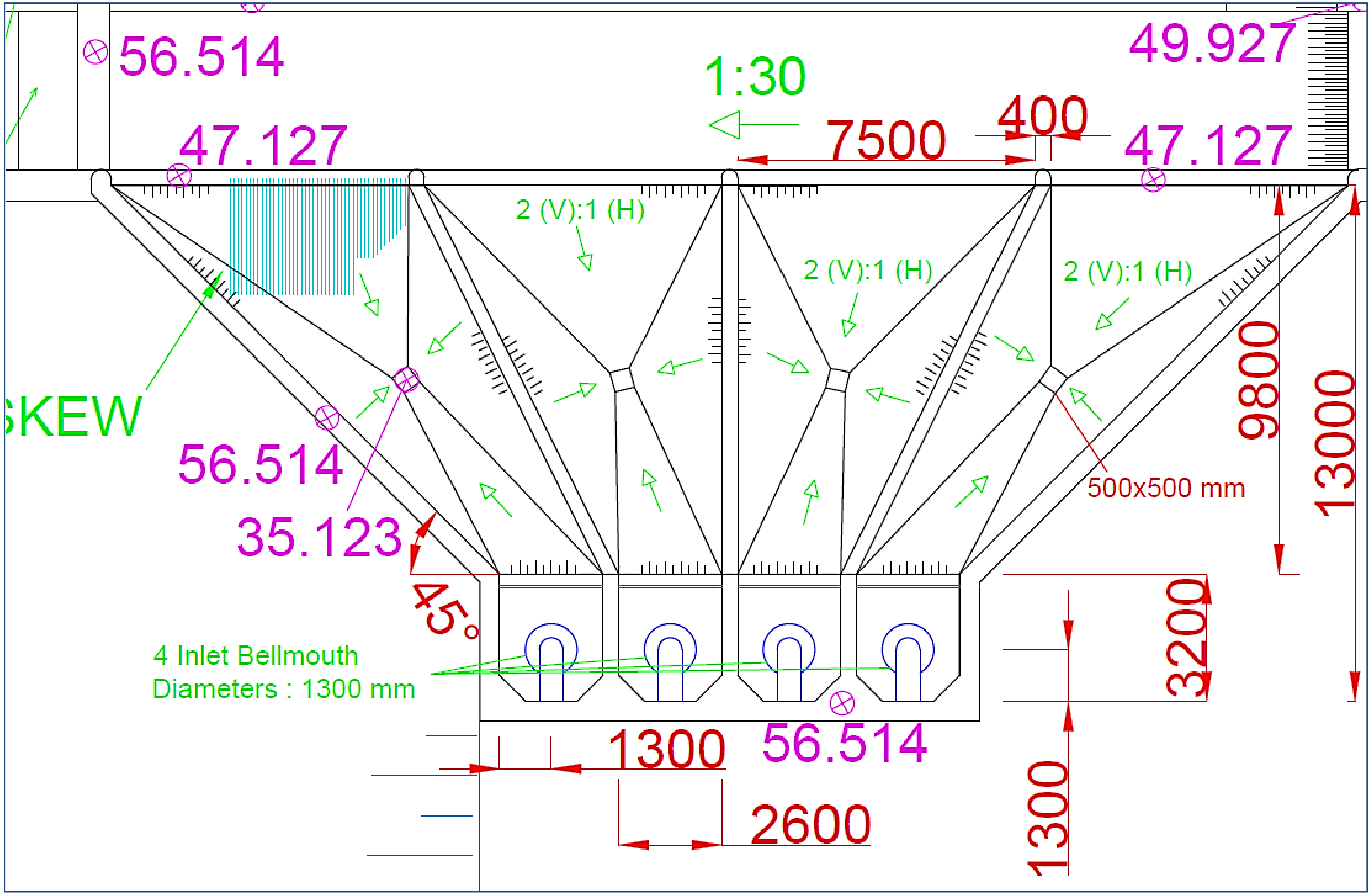


Figure B-5 Detail Plan View - Abstraction Hopper

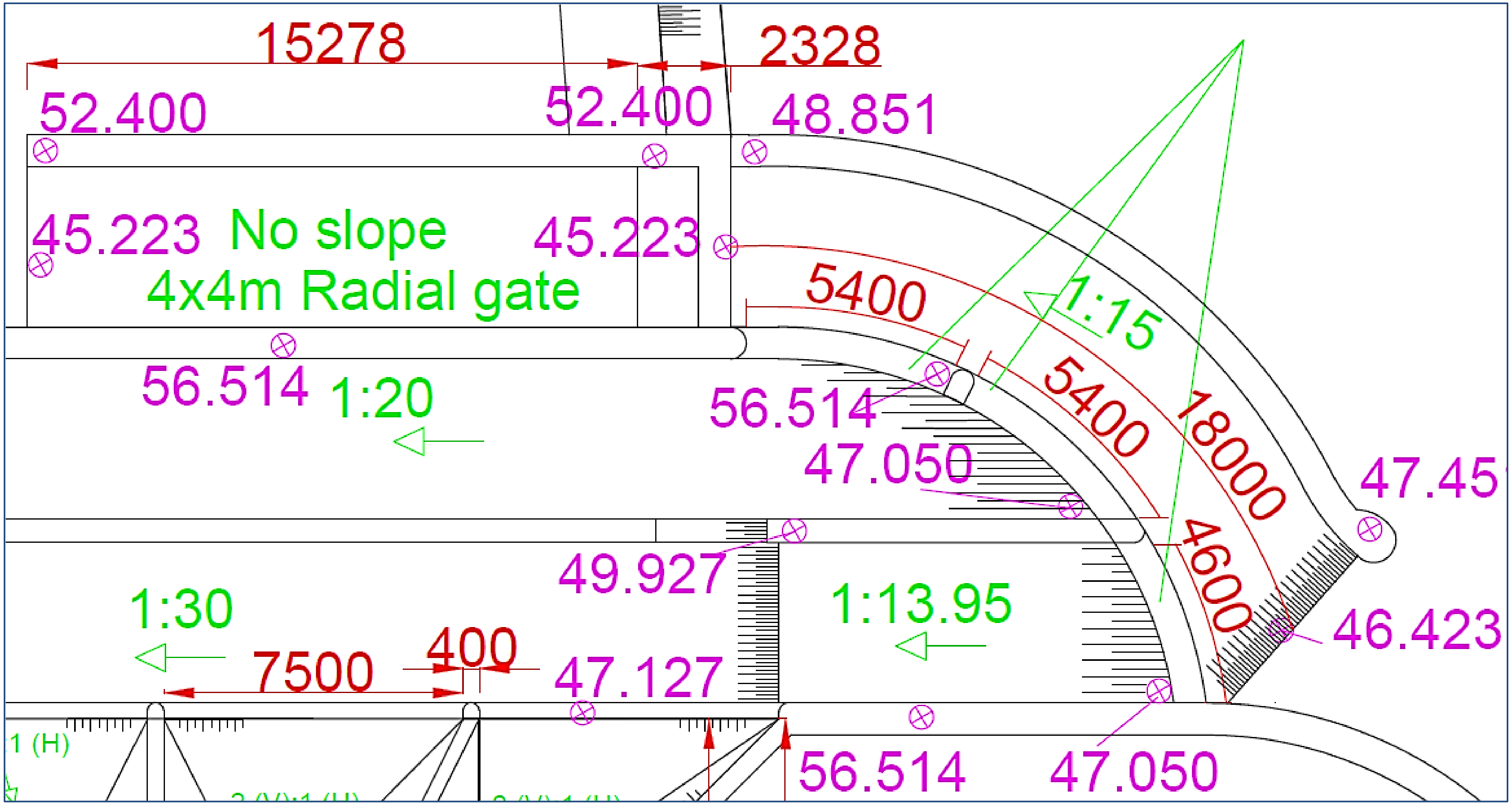


Figure B-6 Detail Plan View - Abstraction Works Intake

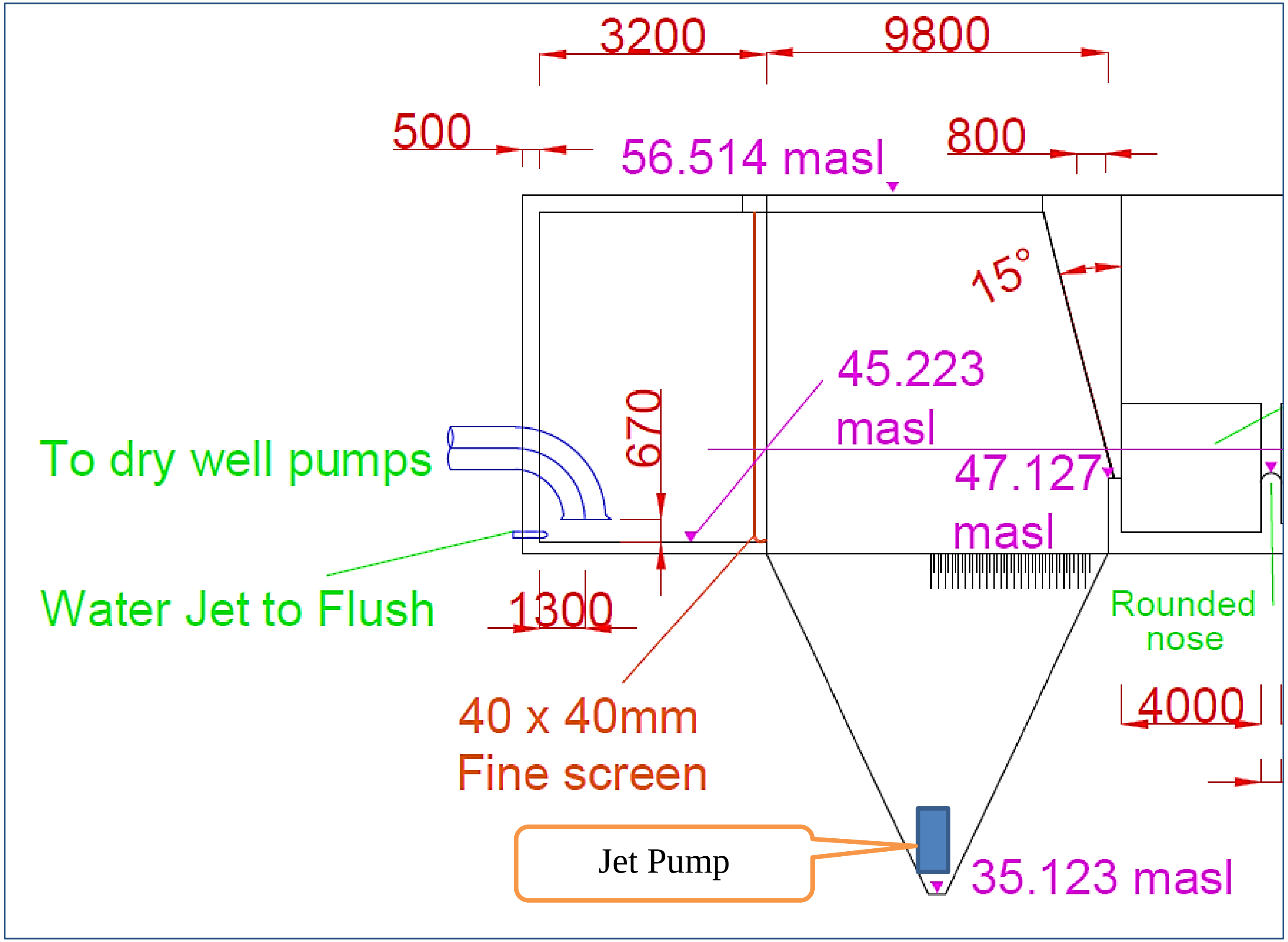


Figure B-7 Elevation - Abstraction Works Hopper and Pump Canal

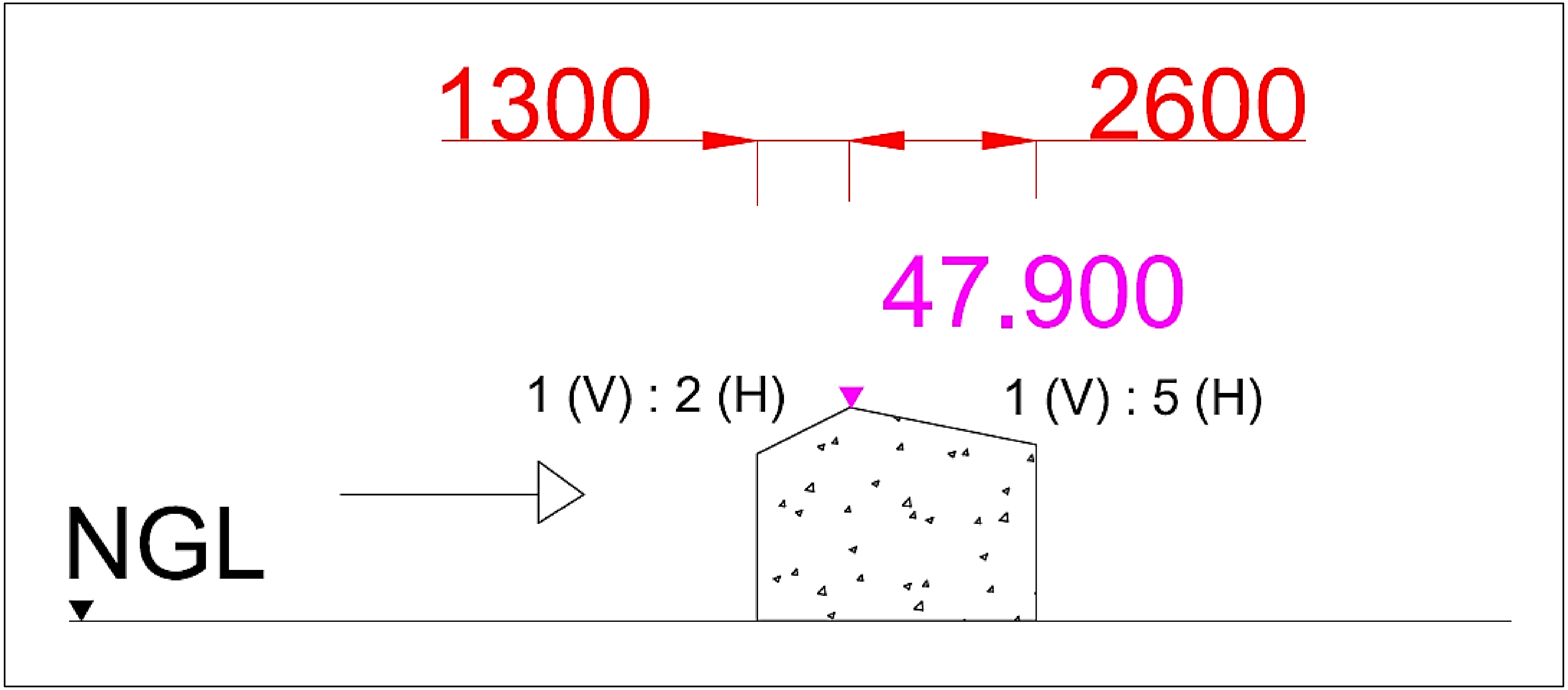


Figure B-8 Section of the Low Notch of the Crump weir

WESTERN CAPE FUTURE SCHEMES FEASIBILITY STUDY

Hydraulic Design of the Proposed Mitchell's Pass River Abstraction Works

September 2012

Submitted to:

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Cape Town
7441

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1. Introduction

ASP Technology (Pty) Ltd was appointed during 2011 to carry out the feasibility study hydraulic design of the proposed river abstraction works on the Mitchell's Pass River near Ceres. A possible site for the abstraction works was identified on the left bank at the existing DWA gauging weir H1H006 during the pre-feasibility study. A topographical survey of the site was obtained from Aurecon during this study.

2. Scope of work

The work involved the following:

a) Flood hydrology
b) Analysis of the river hydraulics to determine the most suitable abstraction works design
c) Design of the hydraulic components of the abstraction works at feasibility level of detail

3. Flood hydrology

A flood hydrology assessment was needed at the site to determine water levels for the design of the abstraction works.

Flood peak data were obtained from the Department of Water Affairs gauging station H1H006 at Ceres ($33^0$25'18"S, $19^0$16'06"E) for the period 1950 to 2011. The catchment area at the gauging station is 753 km^2. Based on TR137 (1988) the largest flood on record at this station occurred on 3 August 1955 at gauging station H1H006 (Old Number) with a flood peak of 1140 m^3/s and a gauge plate reading of 7.7 m. However, 70% of the recorded data at this station exceeded the relevant rating tables. For instance, from the recorded data, the maximum flow on the day of the highest recorded peak was limited to a recorded value of 139 m^3/s due to the rating table capacity. In view of this, the water surface elevations versus discharge relationship for floods at the site was obtained from a one-dimensional model

(HEC-RAS) simulation. The HEC-RAS cross sectional discharge against water level data for floods was then used to extend the DWA rating curves, and were used to calculate the estimated discharges based on the actual recorded water levels at the gauging station.

Table 3.1 shows the flood peaks at the site used in a probabilistic flood analysis. Table 3.2 and Figure 3-1 show the results of the probabilistic analysis. The proposed distribution that gives conservatively high flood peaks during major floods is the average of the Log Normal and GEV_{mm} distributions. The 100 year flood based on this distribution is 1140 m^3/s.

Table 3.1 Observed flood peaks after rating table interpolation

Year	Flood peak (m^3/s)	Year	Flood peak (m^3/s)
1950 / 1951	272	1981 / 1982	231
1951 / 1952	208	1982 / 1983	-
1952 / 1953	218	1983 / 1984	50
1953 / 1954	202	1984 / 1985	530
1954 / 1955	336	1985 / 1986	637
1955 / 1956	1140	1986 / 1987	473
1956 / 1957	245	1987 / 1988	358
1957 / 1958	866	1988 / 1989	372
1958 / 1959	269	1989 / 1990	354
1959 / 1960	273	1990 / 1991	408
1960 / 1961	267	1991 / 1992	398
1961 / 1962	-	1992 / 1993	343
1962 / 1963	240	1993 / 1994	480
1963 / 1964	487	1994 / 1995	537
1964 / 1965	236	1995 / 1996	155
1965 / 1966	164	1996 / 1997	37
1966 / 1967	287	1997 / 1998	443
1967 / 1968	788	1998 / 1999	333
1968 / 1969	286	1999 / 2000	249
1969 / 1970	207	2000 / 2001	205
1970 / 1971	206	2001 / 2002	415

1971 / 1972	410	2002 / 2003	438
1972 / 1973	111	2003 / 2004	145
1973 / 1974	468	2004 / 2005	248
1974 / 1975	355	2005 / 2006	495
1975 / 1976	113	2006 / 2007	264
1976 / 1977	473	2007 / 2008	514
1977 / 1978	580	2008 / 2009	456
1978 / 1979	170	2009 / 2010	664
1979 / 1980	290	2010 / 2011	387
1980 / 1981	127	2011 / 2012	373

Table 3.2 Probabilistic analysis results

Exceed. Prob.	**Recurrence interval (years)**	**LN**	**LPIII**	**GEV_{MM*}**	**GEV_{PWM**}**	**Proposed**
		Q (m^3/s)	**Q (m^3/s)**	**Q (m^3/s)**	**Q (m^3/s)**	**Q (m^3/s)**
0.5	2	314	365	329	335	322
0.2	5	525	519	497	500	511
0.1	10	687	582	613	608	649
0.05	20	858	622	727	712	790
0.02	50	1101	653	880	845	985
0.01	**100**	**1301**	**668**	**999**	**944**	**1140**
0.005	200	1515	677	1120	1043	1303
0.002	500	1822	685	1286	1172	1531
0.001	1000	2074	688	1415	1270	1713
0.0005	2000	2344	691	1548	1367	1905
0.0002	5000	2729	693	1729	1494	2172
0.0001	10000	3044	693	1871	1590	2387

Note: *MM = Method of Moment; **PWM = Probability Weighted Moment

Statistical Analysis for Mitchell's Pass (H1H006)

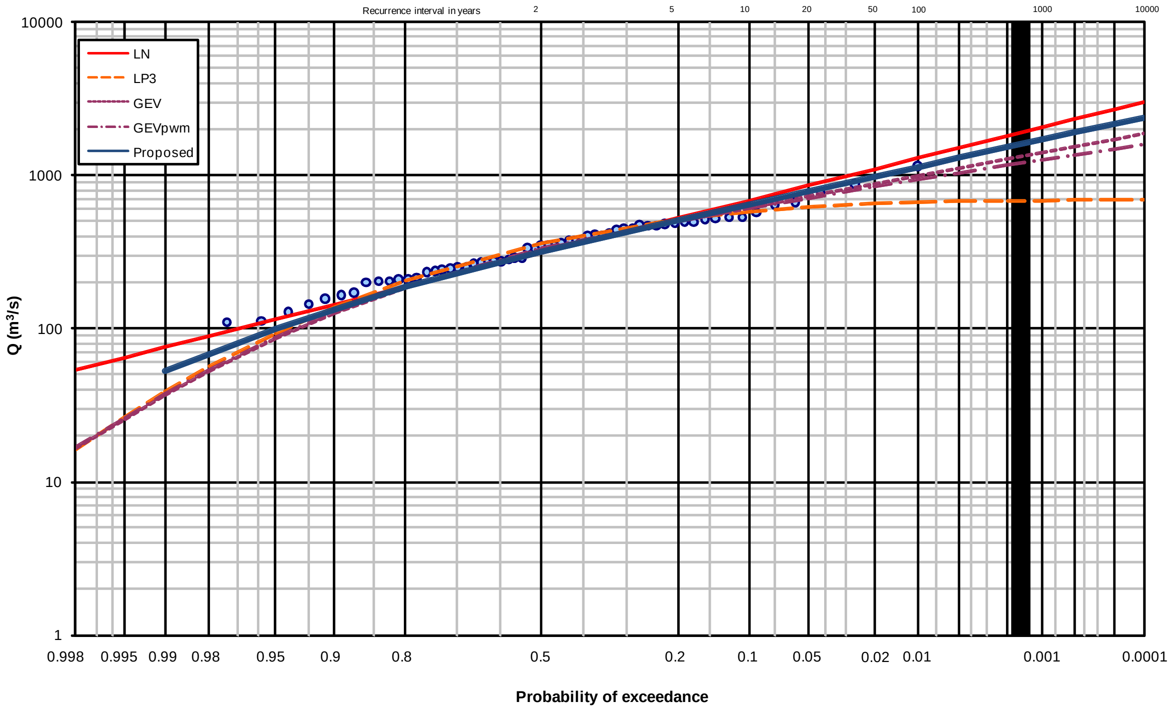

Figure 4-1 Probabilistic results plotted graphically

For design purposes a 100 year flood peak of 1140 m^3/s was used in this study. The abstraction works is designed for the Q_{100} flood with the applicable freeboard.

5. Hydraulics of the proposed abstraction works site

A one dimensional hydraulic model was used to simulate the steady flow patterns in the Mitchell's Pass River to aid in the feasibility study design of the abstraction works.

Figure 5-1 shows the model cross sections locations based on the survey data.

In the mathematical modelling the following assumptions were made:

- Main channel hydraulic roughness Manning n = 0.045 s/m$^{0.333}$
- Floodplain roughness Manning n = 0.060 s/m$^{0.333}$
- The downstream boundary condition was based on the normal depth criteria in terms of the average energy slope of 0.003 (m/m).

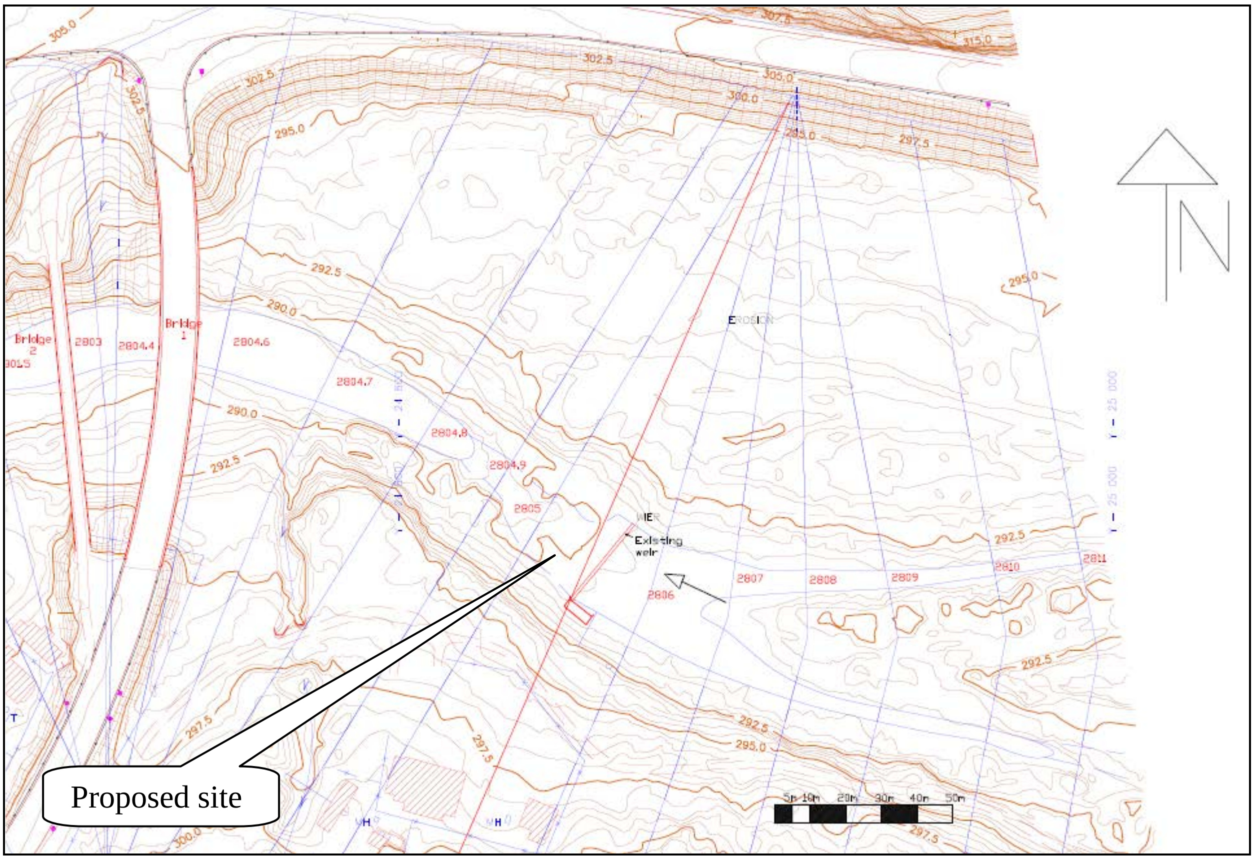

Figure 5-1 Plan View of the MPR Proposed Abstraction Works Site

Figure 5-2 shows the water level results at the site during the 100 year flood based on the one-dimensional model results.

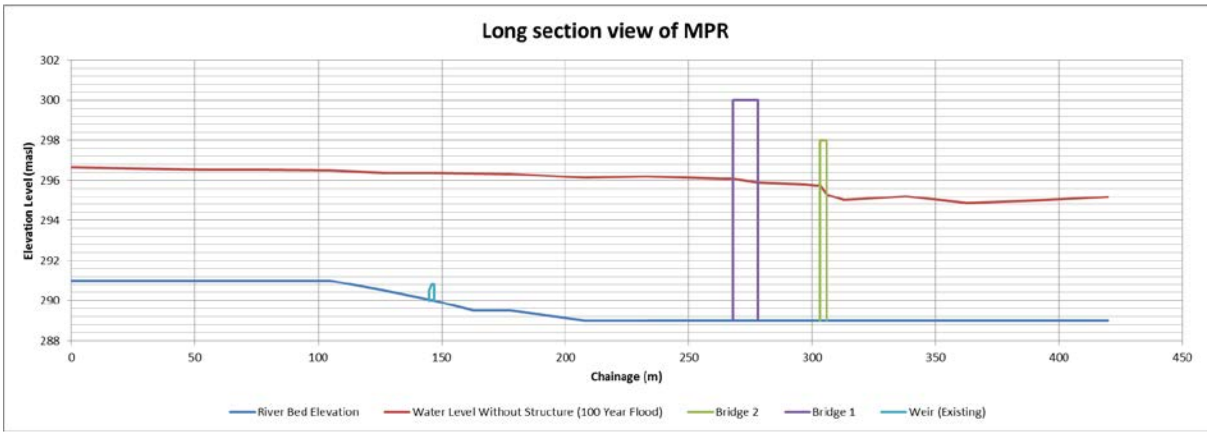

Figure 5-2 Long section view with water level Eetents at 100 year flood

The proposed abstraction works site is located near the position of the existing DWA weir at chainage 147 m in Figure 5-2. The flow depth is 6.49 m, at bed elevation of 291 masl, during the 100 year flood and the flow velocity is 2.4 m/s. The bridges downstream of the site cause local damming upstream.

6. Abstraction works design

The design of the abstraction works is based on the research by: Brink et al. (2006): Sediment Control at River Abstraction Works in South Africa. Basson (2006): Considerations for the Design of River Abstraction Works in South Africa and Basson (2011).

The proposed design of the abstraction works will ensure a low maintenance and robust design, with a high assurance of supply. Drawings of the proposed design are enclosed in Appendix A. The civil engineering components of the abstraction works were designed for a peak diversion discharge of 5 m^3/s.

A proposed layout of the abstraction works is shown in Figures 6-1 and 6-2 on the river, with Figure 6-3 providing a cross-section of the structure and weir on the river. The proposed abstraction works has the following components:

- A weir across the river.
- Boulder trap with radial gate which could be opened to flush sediments.
- Gravel trap with two canals and dividing wall, with radial gates downstream for flushing. The gravel trap on the left bank side wall is at the 100 year flood level with freeboard. An underwater opening in this wall of the gravel trap allows the water from the river to be diverted, while keeping floating debris outside and away from the trashracks.
- Trashracks leading to the sand trap canals.

This proposed layout had to be optimized to limit the weir height and the impact of the weir on flood levels. The downstream ends of the boulder and gravel traps were designed at the same elevation as the lowest river bed level of 290 masl for free flow flushing under low flow conditions (See Appendix A).

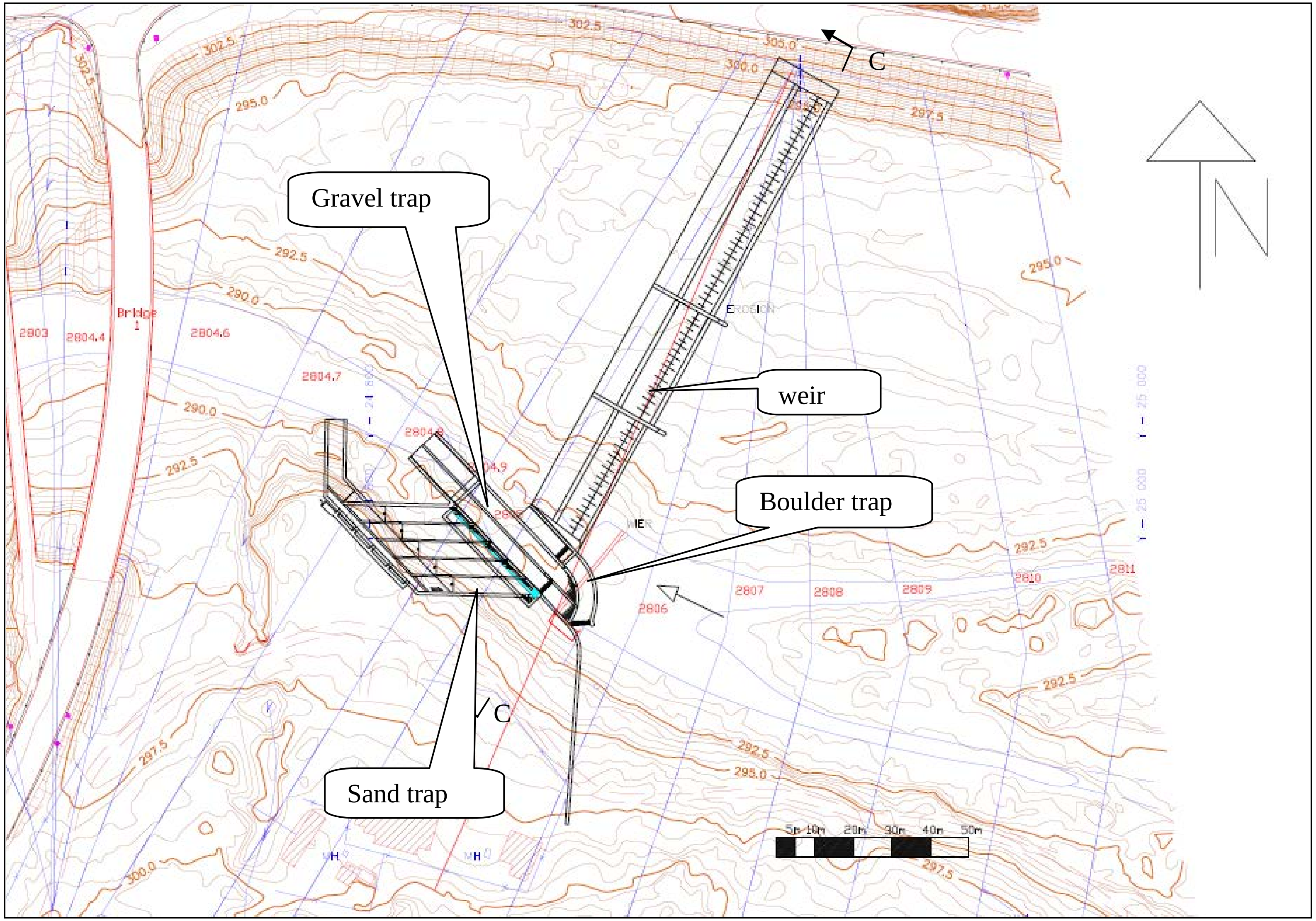

Figure 6-1 Plan View of proposed Abstraction Works site

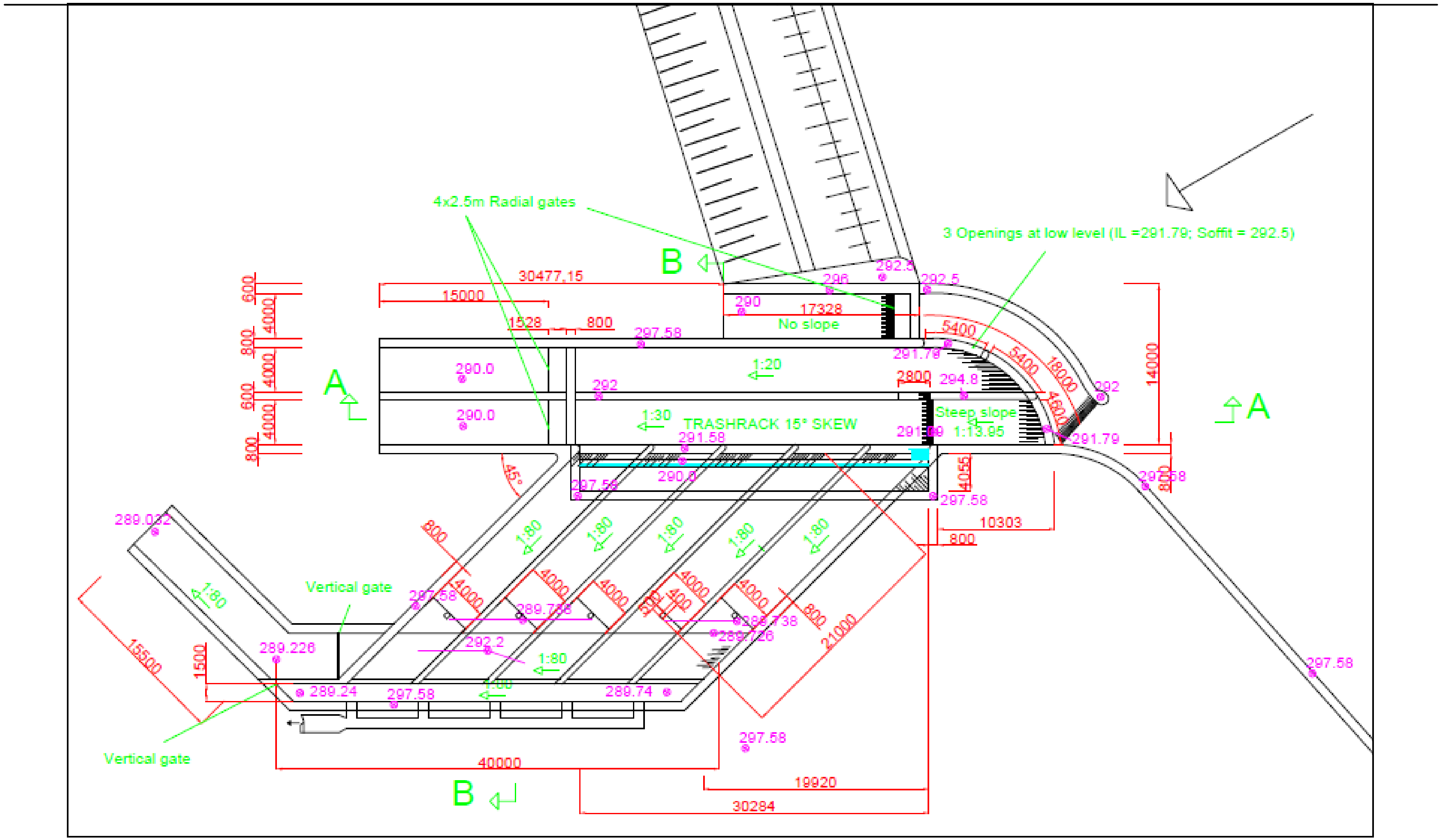

Figure 6-2 Plan View of proposed Abstraction Works– see Appendix A

The design has 5 sand trap canals downstream of the trashracks and these canals can be flushed under gravity. The sand trap canals are protected from debris by a trashrack with 40 mm openings (10 x 50 mm flat bars, vertical, at 50 mm centre to centre spacing). The sand trap was designed to trap sand of 0.3 mm and larger particles. The gravel trap layout and intake is skew to the river flood flow direction (in plan) to enhance the development of secondary flow currents against the structure, which will ensure local scour to keep the intakes open, and will also transport the coarse sediment away from the intakes during a flood. The top of the trashracks extends to the 100 year flood level (297.36 masl) and can be cleaned during floods by using a platform above the 100 year flood level (297.58 masl). River water passes through a submerged opening (with soffit at the Minimum Operating level (MOL)) into the gravel trap and therefore floating debris should not pose problems at the trashrack during floods. The MOL is at the crest level of the low notch of the weir.

A boulder trap is placed upstream of the trashracks to remove coarse sediment. Two 4 m wide by 2.5m high radial gates are located at the downstream end of the graveltraps and one at the boulder trap. The gates should be large to pass flood flow. The gravel trap canals have steep bed slopes of 1:20 and 1:30 at the upstream and downstream sections respectively in the two canals. Under normal flow conditions the gravel and boulder traps are submerged. Flushing of sediment deposited in the boulder and gravel traps canals should be carried out from time to time as required during small to medium floods. Flushing durations are expected to be less than 30 minutes.

A weir is required to provide sufficient head for flushing of the gravel and boulder traps, and to ensure sufficient depth to divert the flow during low flow conditions. A 2.5 m high (average low notch height) weir has been designed with a 33.08 m long low notch next to the boulder trap. The crest level of the low notch is 292.5 masl while the lowest bed level is 290.0 masl. The total weir length is 132.19 m, consisting of three notches (refer to Figure 6-2). The weir will probably not be founded on solid rock, and therefore an energy dissipation structure is required in the form of a roller bucket (Appendix B).

Figure 6-3 shows the river bed cross section at the abstraction site. The low notch is located at the left bank side of the weir against the boulder trap, to ensure low flows near the intakes.

A section of the weir is shown in Appendix B.

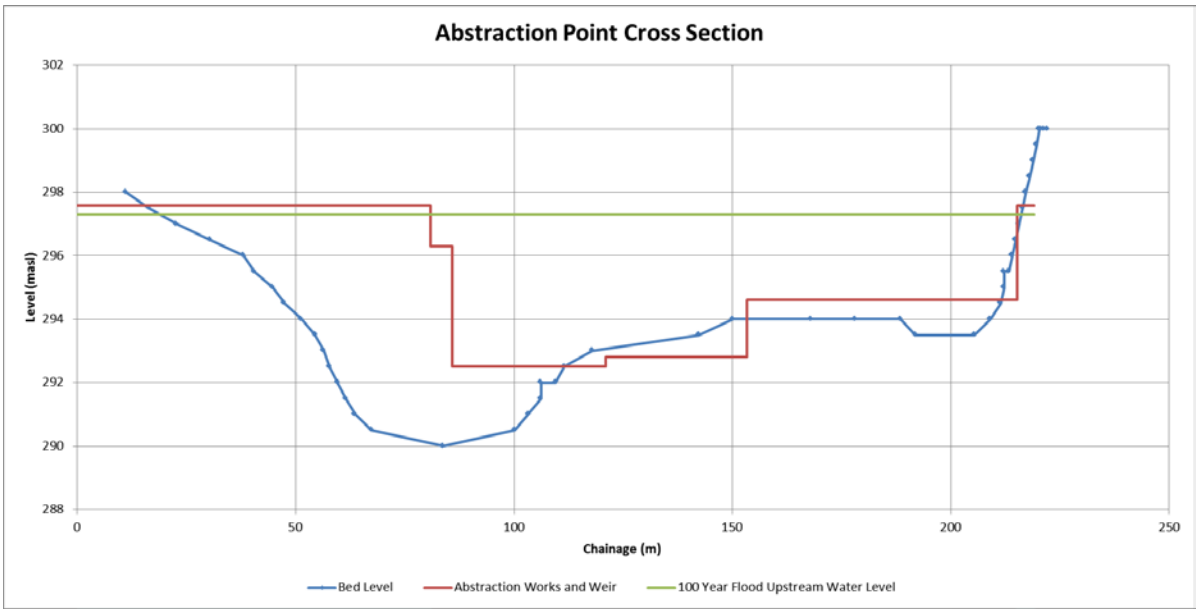

Figure 6-3 Cross section of the proposed weir and abstraction works (Section A-A on figure 6-2)

The top of the structure should be at 297.58 masl (7.58 m above the river bed), which is the Q_{100} year flood (1140 m^3/s) with freeboard as determined from the hydraulic mathematical model simulations with the abstraction works in place. Access to the structure is obtained by road. With this design no spillage will occur on the left bank during medium and large floods.

A fishway design at the weir could be a vertical slotted fishway or a rock-ramp type spillway. If the latter is selected the design would be similar to the one shown in Figure 6-4. The typical characteristics of the rock-ramp fishway are as follows:

a) The longitudinal slope of the fishway is 1:10, thereby ensuring a design stream power of 150 W/m^3.
b) The fishway has a "u" shaped main channel of 0.9 m width, with steps (broad crested weirs) every 2 m. The left hand side of the fishway is located 0.1 m above the fishway

weir crests and has a triangular shape. This left hand side shallow splash zone is 0.6 m wide.

c) The fishway could be designed for a discharge of 0.1 m^3/s, and will operate for a range of river flows.

d) The upstream entrance to the fishway is controlled by rectangular orifice. During floods this opening would be under water to limit possible debris entrainment.

e) The surface of the fishway should be formed by boulders/rocks using a grouted stone pitching technique. The fishway structure has a concrete base. Gabion boxes or Reno mattresses should not be used, because they will be scoured and damaged during floods.

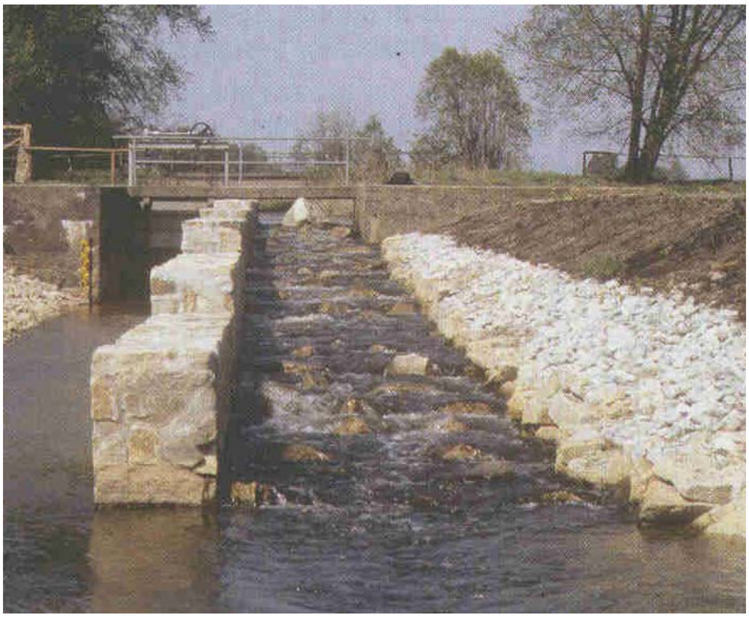

Figure 6-4 Rock-ramp type fishway

Damming caused by the proposed abstraction works and weir is indicated in Figure 6-5. The water level during the 100 year flood upstream of the weir would be 297.36 masl, compared to the current scenario water level of 296.49 masl, a difference of 0.87 masl. The results show that the proposed weir and abstraction works will cause limited local damming during the 100 year flood.

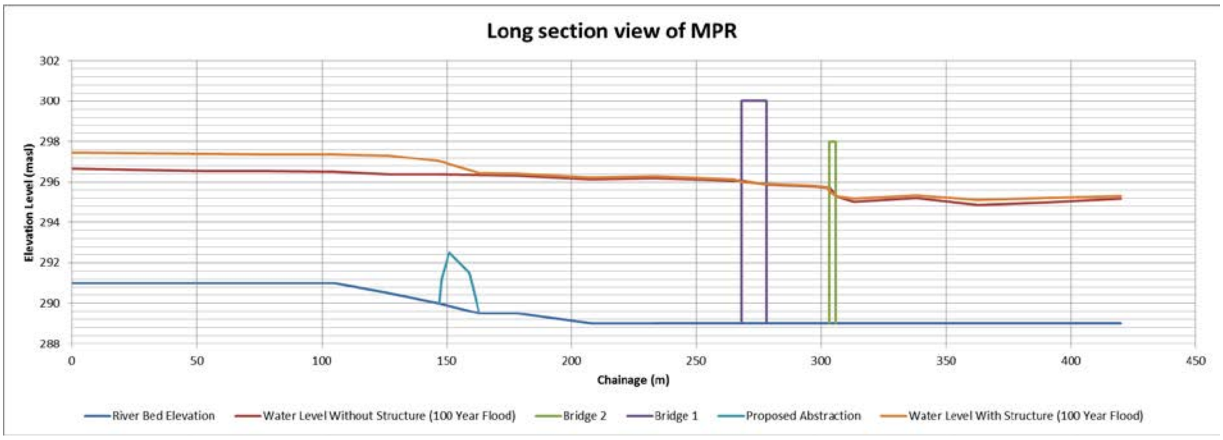

Figure 6-5 Longitudinal section of the simulated water levels

Some of the key characteristics of the proposed design are summarized in Table 6.1.

Table 6.1 Key characteristics of the proposed abstraction works

Design Summary			Units
Crump Weir			
	Low Notch Length	33.08	m
	2nd Notch Length	31.32	m
	3rd Notch Length	62.79	m
	Low Notch Crest Elevation = MOL	292.5	masl
	2nd Notch Crest Elevation	292.8	masl
	3rd Notch Crest Elevation	294.6	masl
	Lowest River Bed Elevation at site	289	masl
	Low Notch Height Above River Bed	2.5	m
	Discharge Capacity Low Notch only	10.76	m^3/s
Abstraction Inlet - boulder and gravel trap			
	Opening Length	15.4	m
	Opening Height	0.705	m
	Opening Invert Level	291.79	masl
Trashrack			
	Trashrack height	6.0	m
	Number of Removable Trashracks	5	
	Trashrack Invert Level	291.58	masl
Sand trap			
# Canals		5	
Canal Width		4.0	m
Total Diversion Capacity		5	m^3/s

Table 6.1 Key characteristics of the proposed abstraction works (continued)

Sediment Traps			
	Boulder trap Width	4	m
	Gravel trap Canal Width	4	m
Flood Levels 50 m upstream of the weir site			
	Q_2 Flood Level Without Abstraction Works	294.94	masl
	Q_{10} Flood Level Without Abstraction Works	295.58	masl
	Q_{100} Flood Level Without Abstraction Works	296.49	masl
	Q_2 Flood Level With Abstraction Works	295.14	masl
	Q_{10} Flood Level With Abstraction Works	296.16	masl
	Q_{100} Flood Level With Abstraction Works	297.36	masl
	Q_{100} Flood with freeboard = top of structure	297.58	masl

7. Proposed operation of the abstraction works

The intake area of the proposed abstraction works should be self-scouring during floods larger than the Q_5 flood and secondary currents will keep the intakes open. The gravel trap opening is under water and generally floating debris would not reach the trashracks.

The gravel trap could be flushed during small floods or at the end of large floods. The gates are normally closed and should not be opened during large floods. The tailwater level should be low enough so that free outflow conditions occur for maximum flushing efficiency of the sediment.

The boulder trap should be flushed before the gravel trap is flushed to prevent coarse sediment from entering the gravel trap. The boulder trap and gravel trap should not be flushed continuously because this will impact on the low flow ecology due to elevated base flow sediment concentrations. Gravel and boulder trap flushing would be for short periods only and during small floods or at the end of large floods.

Flushing of the boulder trap by using the radial gate should only be done to clean the gravel trap intake area and not the sediment upstream of weir. Equilibrium sedimentation to say the weir crest is expected to occur but will not impact on the operation of the abstraction works.

The 5 sand trap canals can be flushed one at a time by vertical gates located downstream of each canal. Flushing should be done during floods.

The diversion discharge will be controlled by automatic valve on the pipeline downstream of the sand trap.

8. Conclusions and Recommendations

This study proposes a robust abstraction works design, with a high assurance of supply, relatively low in maintenance. The works is designed for a diversion of 5.0 m^3/s. A boulder trap, gravel trap and sand traps are proposed for sediment exclusion. The traps could be flushed under gravity to remove sediment and can handle coarse sediment. Flushing of sediment will have a low impact on the river ecology because it is done during small floods or at the end of large floods, never under low flow conditions and therefore the base flow water quality is not affected. The estimated flushing duration for the trap canals are about 20 minutes each.

The submerged intake at the river is self-scouring during floods due to the orientation of the structure and local flow conditions in the river. A weir is required to create sufficient head to flush sediment from the gravel and boulder traps and to divert the flow under small flood conditions. The proposed weir height is 2.5 m at the low notch. The trashracks would generally remain debris free, but could be cleaned during floods. If the weir is not founded on rock and energy dissipater in the form of a roller bucket is required. The weir crest with the roller bucket should preferable by an ogee, or else a Crump.

It is recommended that the top of the abstraction works is constructed high enough to be accessible during the Q_{100} flood. The top of the structure should therefore be at or above elevation 297.58 masl.

A rock-ramp type fishway or vertical slotted fishway is proposed. The rock-ramp type has a gradient of 1:10 (V:H), with a 0.9 m wide "u" shaped main channel and weirs every 2.5 m, and a shallower triangular shaped splash zone, 0.6 m wide, located on one side of the main channel. Grouted stone (boulders/rocks) pitching is specified to create a natural rough surface texture.

For the detail design phase the following is recommended:

- The mathematical modelling in this report is based on a one dimensional model. The hydraulics and sediment dynamics should be investigated by a two-dimensional fully hydrodynamic model.
- The sediment diversion ratio should be investigated in more detail.

- A hydraulic physical model study is proposed of the abstraction works, weir and embankment, at a scale of 1:25 to allow simulation of floods up to the 100 year event and to minimize scale effects. The efficiency of flushing of the boulder, gravel and sand traps with the actual tailwater levels for different floods has to be tested in the model. Self scouring of the intake area during floods also has to be determined with movable bed model tests. From the above tests the final structure and weir heights has to be determined.

9. References

Brink, C, Basson, G.R. and Denys, F. (2006). Sediment Control at River Abstraction Works in South Africa. SA Water Research Commission.

Basson, G.R. (2006). Considerations for the Design of River Abstraction Works in South Africa. SA Water Research Commission.

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TR137. (1988). Regional maximum flood determination in Southern Africa. Technical Report, Department of Water Affairs.

APPENDIX A

Proposed abstraction works design drawings

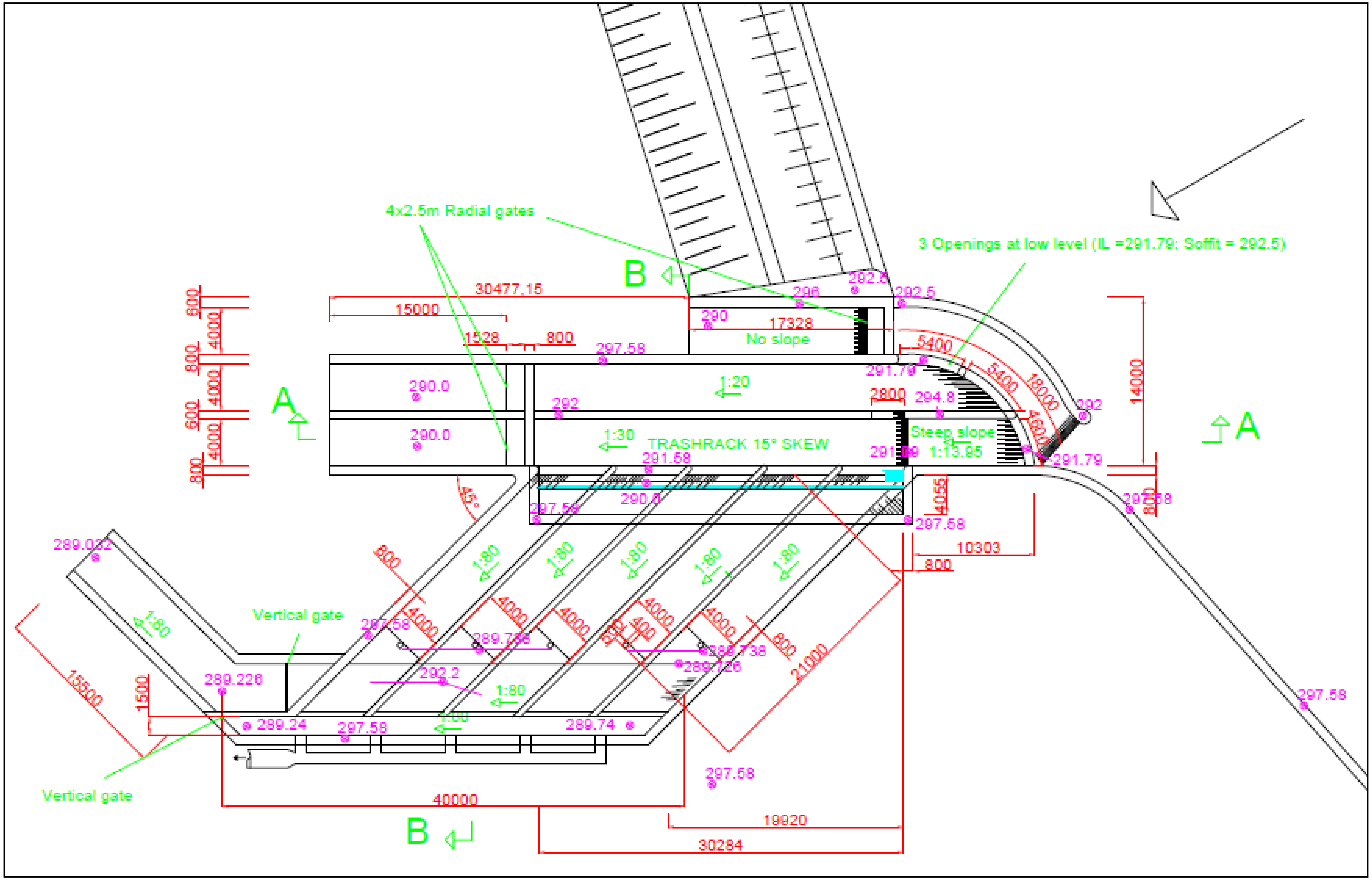

Figure A-1 Plan View of MPR Abstraction Works

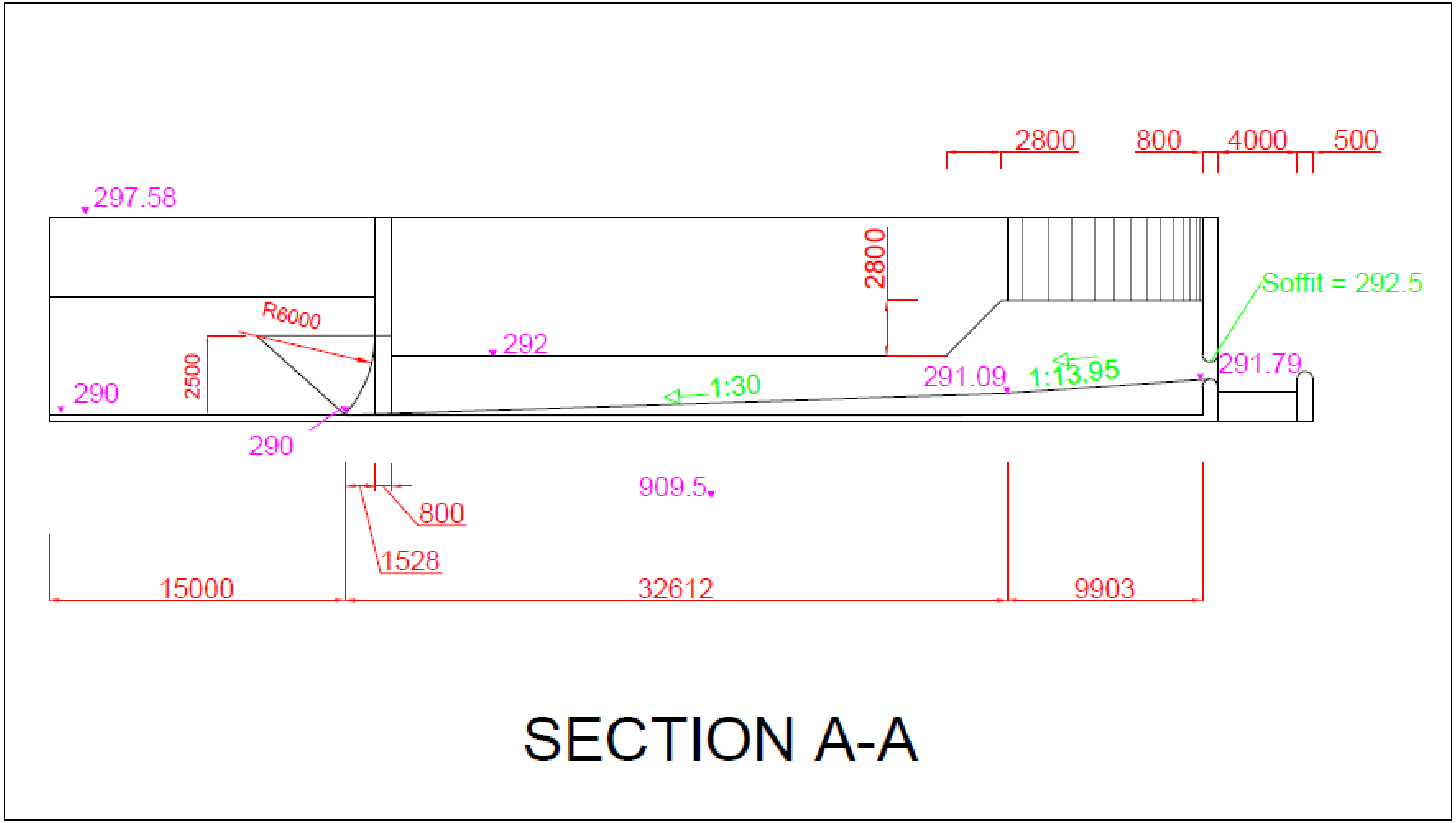

Figure A-2 Section A-A MPR Abstraction Works

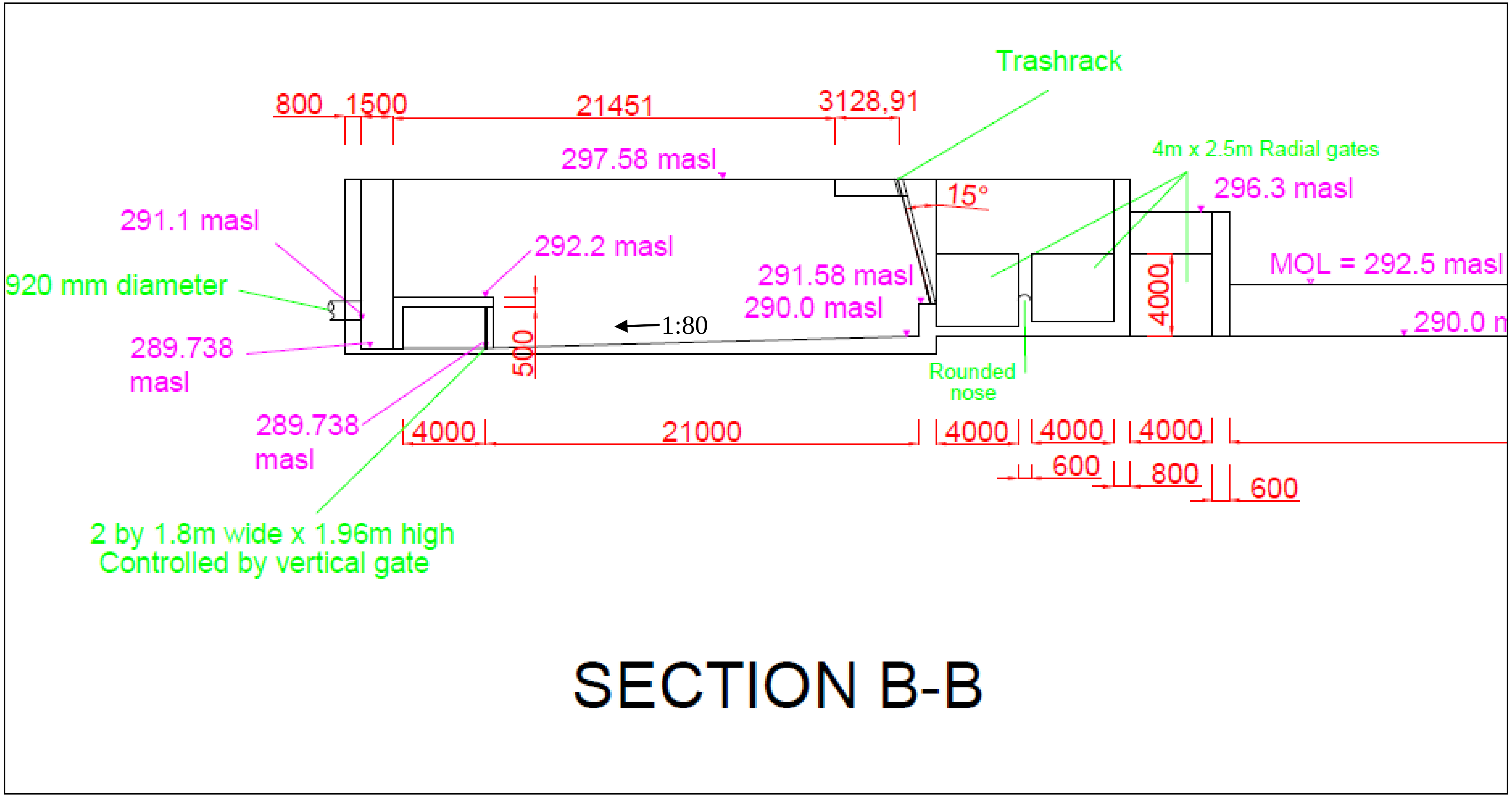

Figure A-3 Section B-B MPR Abstraction Works

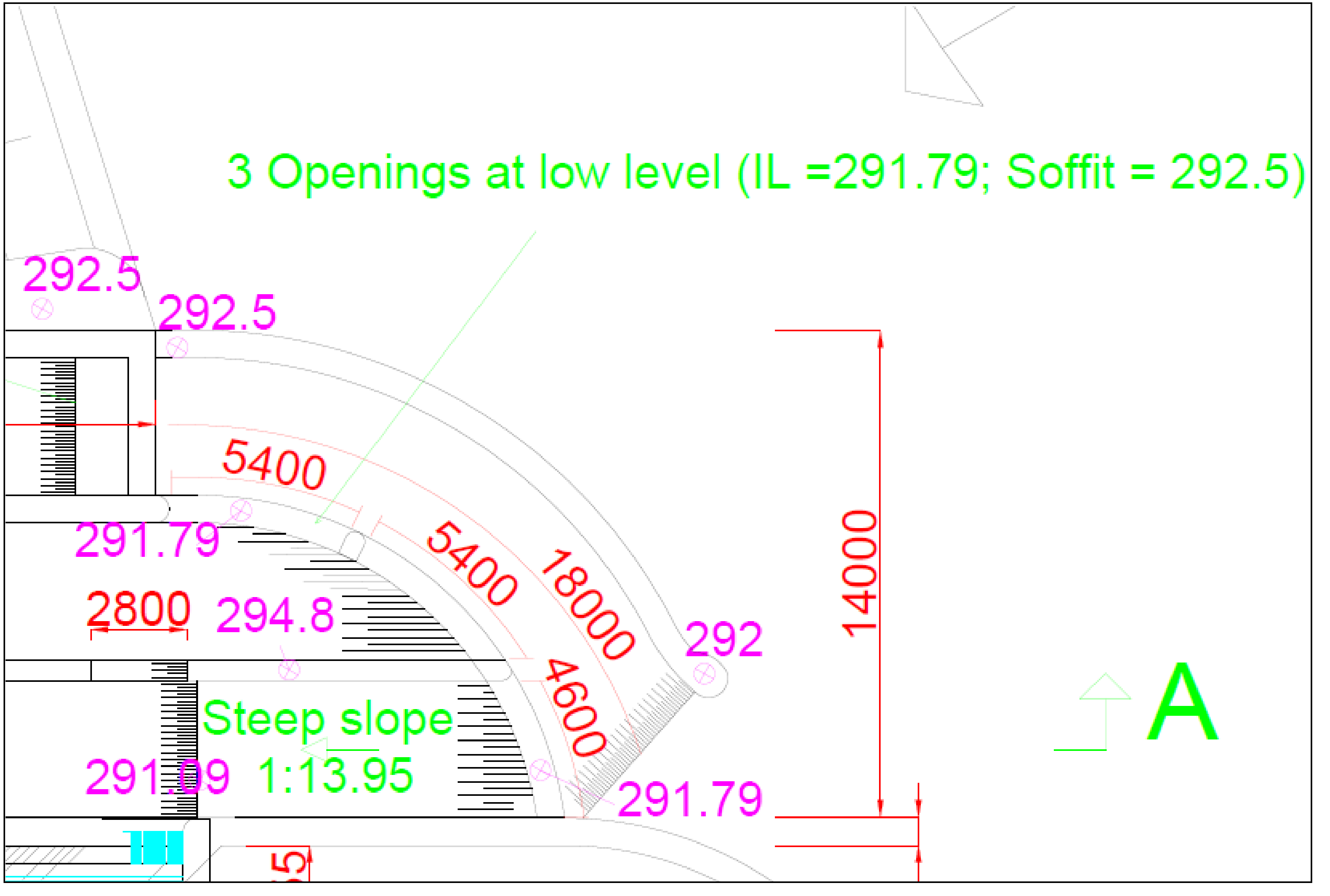

Figure A-4 Detail Plan View: Abstraction Works Intake

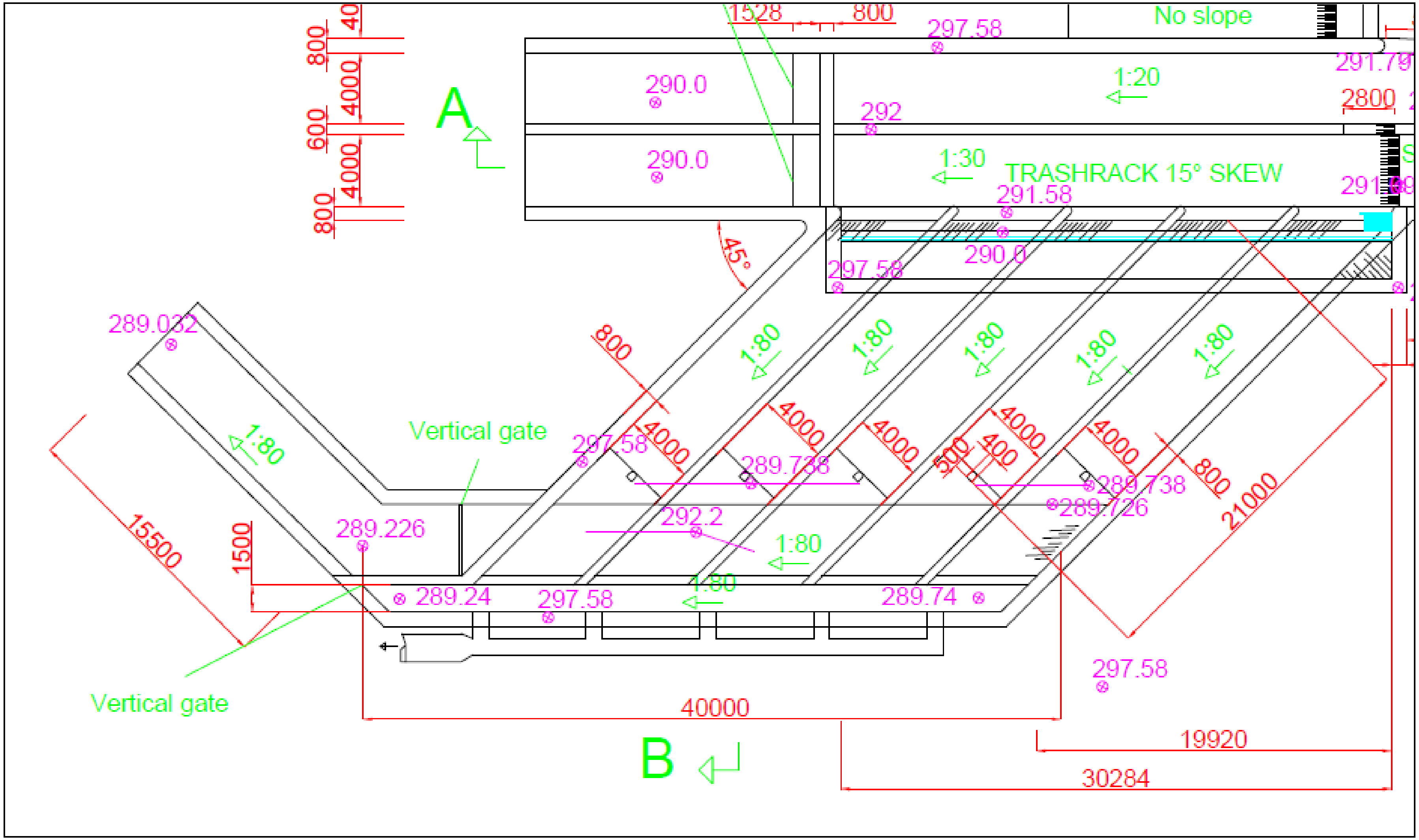

Figure A-5 Detail Plan View: Abstraction Sand Traps

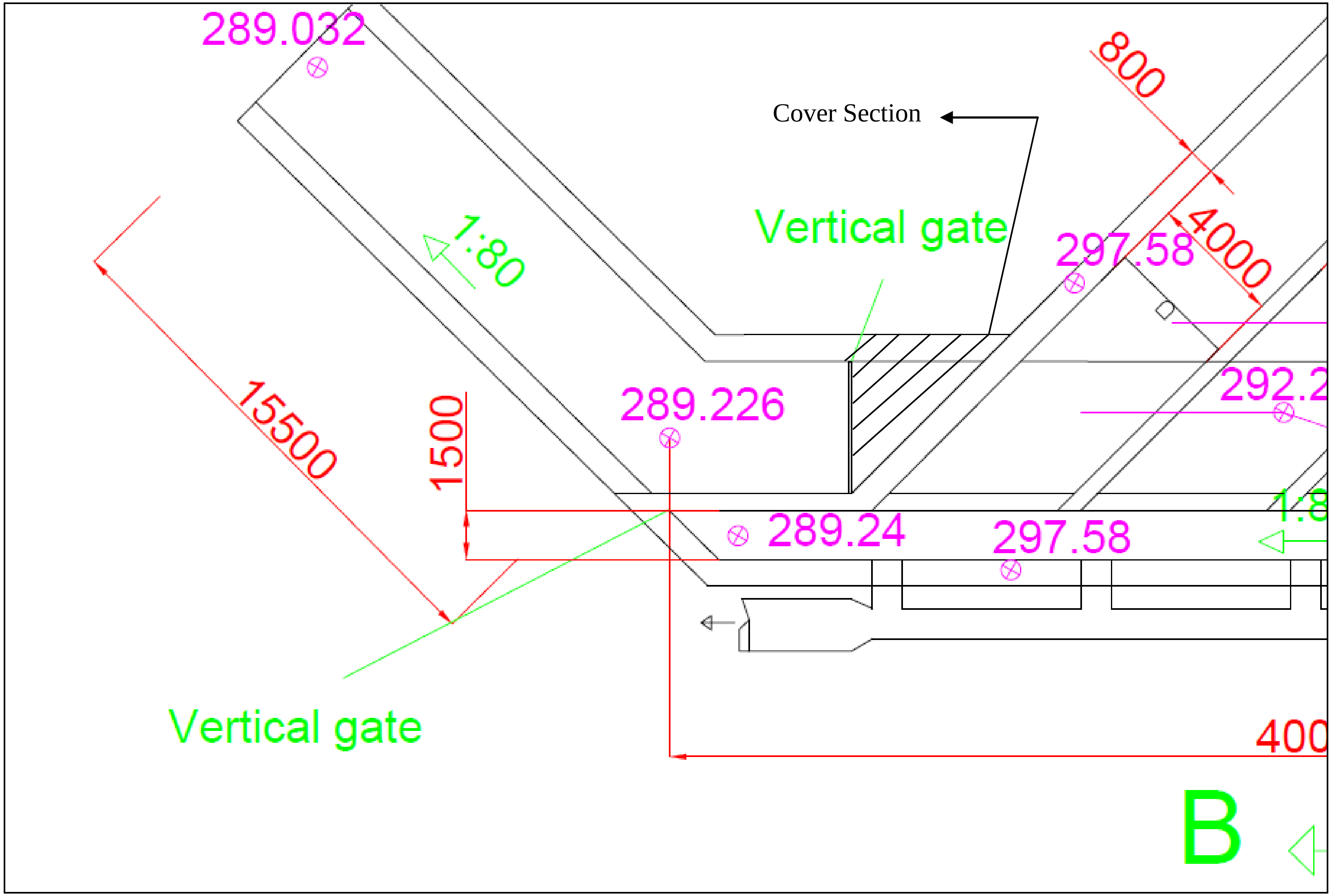

Figure A-6 Detail Plan View: Abstraction Works Water Transport Section

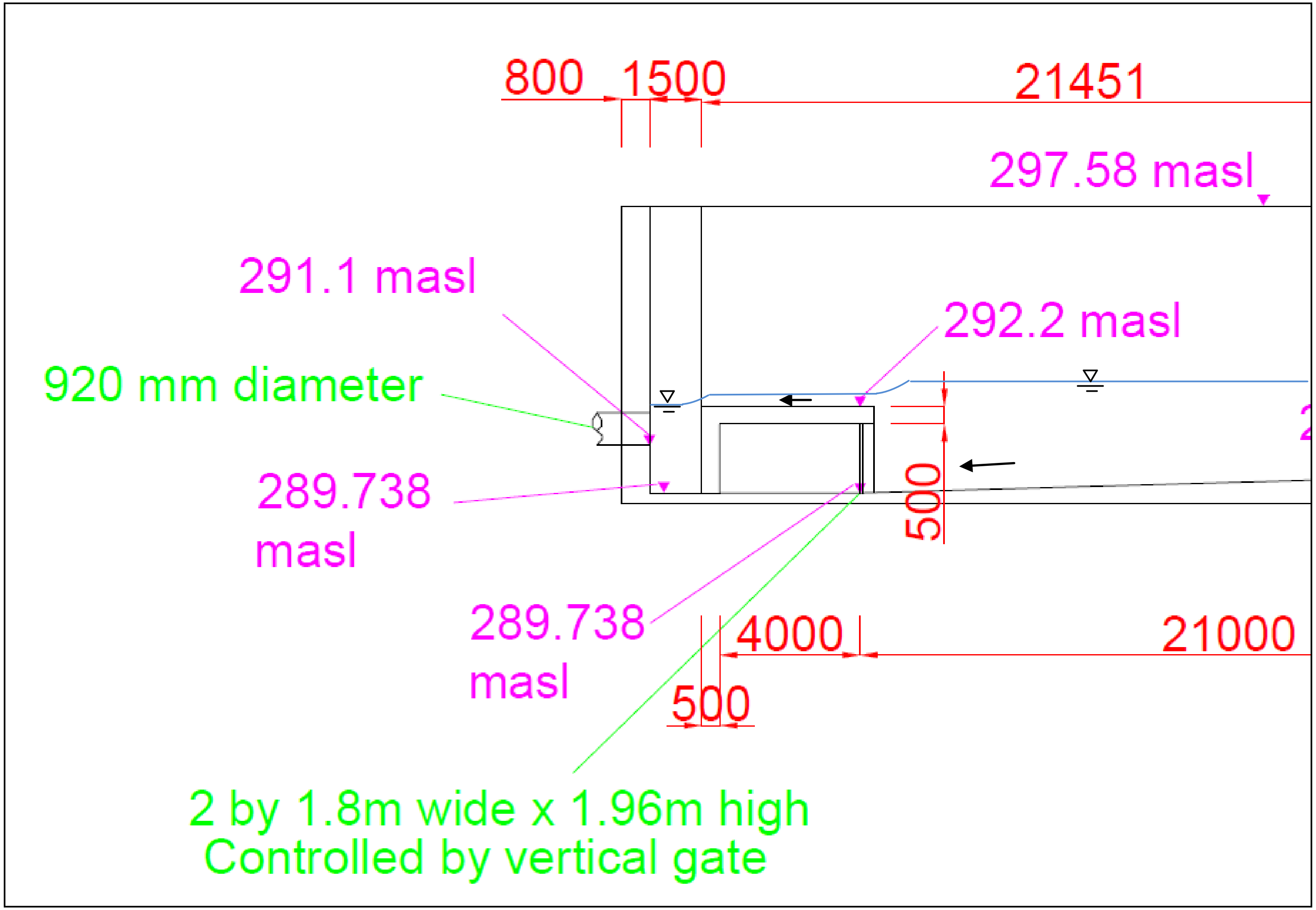

Figure A-7 Detail Plan View: Sand Trap Split Section

APPENDIX B

Proposed Weir Design

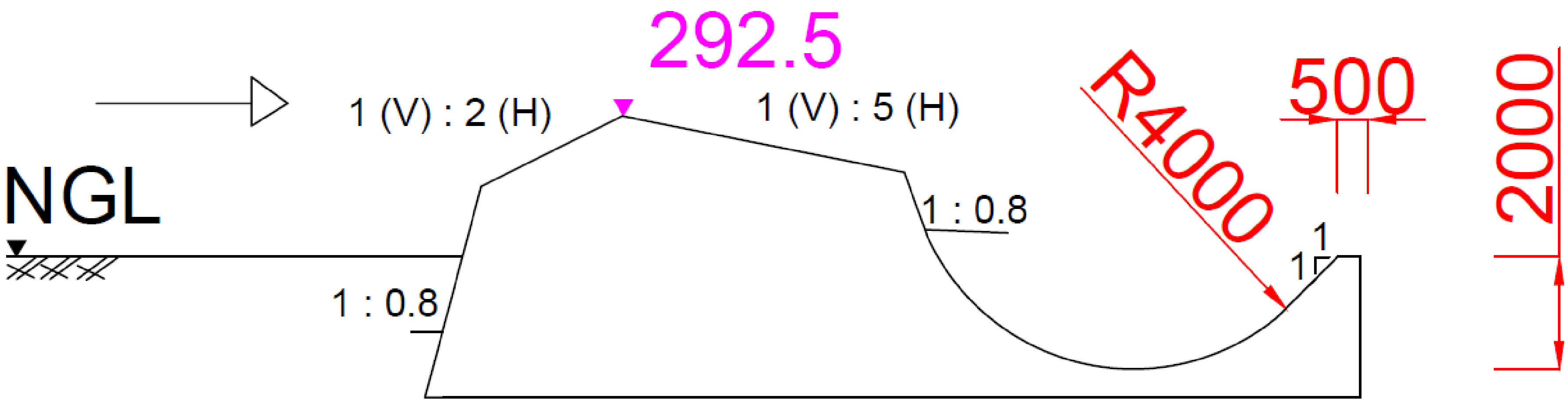

Figure B-1 Section of the Low Notch of the Crump Weir