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REPORT

Hartesbeespoort W&S Feasibility Study
Flood Lines Report

Report No : 17161-45-Rep-001

01/12/2017 17161

RECORD OF REVISIONS

Date	Revision	Author	Comments
01/12/2017	0	Temweka Chirwa	Issued for information.

EXECUTIVE SUMMARY

A feasibility study is underway for the Housing Development Agency (HDA) in developing the site at Portion 237 of Farm Hartebeesport 238 JR 772 JR for residential occupation. The site is in Jan Niemand Park and is bound by Stormvoel Road on the northern boundary, Derdepoort Road on the eastern boundary and a railway line on the southern boundary. There is no defined feature on the western boundary, but the closest developed area is Lindopark.

A storm water channel runs through the site for which a flood line analysis is needed. This report addresses the flood line determination study conducted for the 50-year and the 100-year flood intervals. The study included a site visit, hydrological calculations to determine the magnitudes of the floods, hydraulic modelling of the site characteristics and flood magnitudes. Results of the above mentioned exercises and recommendations have been presented in this report study.

From the study, it has been determined that for both the 50-year and 100-year floods, the channel is flooded, and the flow encroaches marginally onto the site.

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LIST OF ACRONYMS

ESRI	Environmental System Research Institute
HEC-RAS	Hydrologic Engineering Center River Analysis System
SAGA GIS	System for Automated Geoscientific Analyses – Geographical Information System
SANRAL	South African National Roads Agency Limited

1 INTRODUCTION

The Housing Development Agency (HDA) intends to develop a site as an inner-city project for integrated human settlement. Portion 237 of Farm Hartebeesport 238 JR 772 JR was identified as the site for this development. The site is in Jan Niemand Park and is bound by Stormvoel Road on the northern boundary, Derdepoort Road on the eastern boundary and a railway line on the southern boundary. There is no defined feature on the western boundary, but the closest developed area is Lindopark. A feasibility study is underway to determine the best direction in which the site should be developed.

There is a watercourse that runs along the eastern boundary of the site. It exists as a concrete lined storm water channel. A flood line analysis is needed to determine the buffer zone in which development cannot take place within.

This report addresses the Flood Line Determination study that has been conducted. The study included a site visit, hydrological calculations to determine the magnitudes of the floods, hydraulic modelling of the site characteristics and flood magnitudes. Results of the above mentioned exercises and recommendations have been presented in this report study.

2 BACKGROUND

The storm water channel under investigation was in Jan Niemand Park, Pretoria. The full length of the channel was 1.3km. It flows into the Moretele River, also known as the Pienaarsrivier. The storm water channel is concrete lined, and it starts north of the industrial area, it runs through open fields, and it crosses underneath two railway line bridges. On the same side there are man-made furrows that act to divert storm water into the concrete storm water. This is to protect the buildings downstream of the furrows.

3 FLOOD LINE DETERMINATION

3.1 BATTERY LIMITS

- The area of investigation was limited to Portion 237 of Farm Hartebeesport 238 JR 772 JR as shown in Figure 1. The hatched area indicates the storm water channel under investigation
- For modelling purposes, the storm water channel was analysed beyond the bound of the farm portion both on the upstream and downstream sides.
- The analysis of the storm water channel was limited to the channel at the section before joining up with the Moretele River approximately 500m downstream of the site.
- The man-made furrows on the northern extent of the site, to the south of existing buildings, have not been assessed because they do not occur naturally and are in place to prevent inundation of the previously mentioned buildings.
- The study excluded specifically excluded the delineation of wetlands as this is a study for a wetland specialist.

Figure 1: Extent of investigation battery limits

3.2 SITE VISIT

On the 7th November 2017 a site visit was conducted to assess the state of the storm water channel to improve knowledge of the site. The stream was looked at on both sides of Stormvoel Road as highlighted in Figure 2. The overall site boundary is also shown in Figure 2.

Figure 2: Extent of the whole channel

3.2.1 Objectives

The aim of the visit was to determine the type of watercourse servicing the site, whether natural or man-made; the features surrounding it as well as controls like weirs, or diversions that may exist in the watercourse.

3.2.2 Observations

On site, it was noted that the watercourse is a concrete trapezoidal channel with dimensions as depicted in Figure 3. The bottom width of the channel is 1m and its average height is 1.5m. The side slopes for the channel are 1.5V:1H.

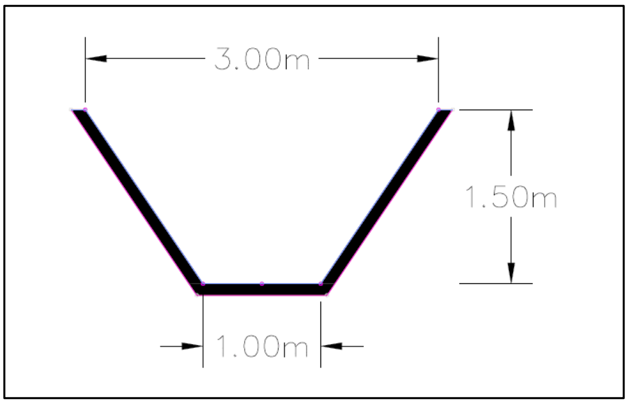

Figure 3: Cross section of Channel

From the northern end of the site, it was observed that the channel was overgrown with vegetation such as Blackwell switchgrass (*Panicum virgatum L.).* The vegetation in the channel affects the flow of the water, causing the water to back-up instead of running steadily. Plant life like Giant Reeds (*Arundo Donax*) and *Acacia Karroo* have grown around the channel and restricted access to the channel in some areas, see Figure 4.

Figure 4: Overgrown Channel and Vegetation Restricting Access

The site falls within the Marikana Thornveld of the Savanna Biome. This terrain is known for its open *Acacia Karroo* woodland which occur in valleys and slightly undulating plains, and some lowland hills (Mucina & Rutherford, 2006). Acacia trees are common to the area, and several were noticed on the site.

There is a culvert that conveys water under the Stormvoel Road. It is a box culvert with triple barrels, with the label *3600 1500 class C4* noted inside it. The label gives the dimensions of the culvert, that is 3.6m width and a height of 1.5m. The vegetation surrounding the channel made it difficult to picture (as shown in Figure 5) but google imagery from 2010 shows how the channel widens on the connection to the culverts, as seen in Figure 6.

Figure 5: Vegetation Overgrowth at Culvert Entrance

Figure 6: Triple barrel culvert by Stormvoel Road (Google Earth, 2010)

The southern end of the channel is fenced off as can be seen in Figure 6, however, over time the fence has be worn down and a hole was cut through that allows passage to the site.

Figure 7and Figure 8 shows the ruined condition of the channel with visible cracks and breakages in certain sections. The dimensions of the channel are assumed to remain constant despite, the possibility that the side walls may have moved over time.

Figure 7: South side of channel also overgrown

Figure 8: Cracks in Concrete

A railway lines crosses the channel at two locations. The line traverses above the channel on a bridge, and therefore does not impede the flow of water through the channel. The bridges are pictured in Figure 9.

Figure 9: Two Bridges for Railway Lines

3.3 METHODOLOGY

The method for determining the flood lines involves the following:

- Flood Hydrology – This entails determining the peak flow rate for a defined watercourse at a specific point. The peak flow rate, also termed the Flood, is determined for a specific recurrence interval. The 1 in 50 and 1 in 100-year floods are used for determining the flood lines. Rainfall information for the area and catchment characteristics are the main contributing factors to the magnitude of the Flood.
- Hydraulic Simulation – This entails determining the water profile of the Flood for a defined watercourse and a specific flood return period. Longitudinal and cross-sectional profiles are produced to indicate the water level in the watercourse for a Flood.
- Flood line Mapping – This entails plotting the area encroached by the Flood on a map as determined by the hydraulic simulation

3.4 HYDROLOGY

3.4.1 Catchment Characteristics

3.4.1.1 Description of the Study Area

The study area is a channel in the Jan Niemand Park area, Pretoria. The channel is a tributary to the Moretele River. However, for this investigation it will serve as the main stream, while Moretele River is beyond the scope of this investigation. The site has been assessed in its predevelopment state, which has no developed areas and storm water features apart from the storm water channel under investigation. This approach gives a conservative treatment to the assessment.

3.4.1.2 Catchment Delineation

The study area was delineated to determine the catchment area that contributes runoff to the storm water channel. Delineation was achieved by using Autodesk Civil 3D and the survey data provided by Trail Survey Pty (Ltd).

3.4.2 Flood Magnitude

The flood magnitudes were computed using the rational method as outlined in the document ***Drainage Manual, Fifth Edition (2006)*** as published by SANRAL (South African National Roads Agency Limited). The Rational Method is one of the best known and widely used methods of computing peak flows for small catchments. The method is based on the assumption that the flow rate is directly proportional to the size of the contributing catchment and the rainfall intensity (SANRAL, 2006).

The rational method requires the following inputs:

i. Catchment size
ii. The mean annual precipitation of the area
iii. Length of watercourse
iv. Slope of the area
v. Run-off coefficient

Point rainfall for the area

Table 1 gives some of this information about the site

Table 1: Catchment Information

	Hartebeesport 238 Portion 237
Catchment Area	1.55km^2
Mean Annual Precipitation (MAP)	654mm
Length of Watercourse	0.8km
Average Slope	2.5%
Point Rainfall (50 year)	90mm
Point Rainfall (100 year)	120mm

Appendix A presents the full calculations to determine the flood magnitudes. The following were applicable to the calculations:

- 90% of the site is classified as flat area and 10% is classified as hilly.
- 10% of the site is classified as permeable and 90% of the site as semi-permeable.
- 20% of the site is on light bush & farmland, while 80% is on grassland.
- The total runoff coefficient, C, for rural area is 0.3569 and 0.43 for the 50-year and 100-year floods respectively.
- The point rainfalls are 90mm and 120mm respectively with corresponding rainfall intensities of 83.47mm/hr and 111.30mm/hr.

The resulting peak flood for the 50-year return period was 12.83m^3/s while for the 100-year return period, it was 20.61m^3/s.

3.5 MODELLING

3.5.1 HEC-RAC Software

The modelling of the storm water channel to determine the floodlines was done in *HEC-RAS*. *HEC-RAS* is an acronym for the Hydrologic Engineering Center River Analysis System, software developed by the United States Army Corps of Engineers, was used to run the hydraulic modelling.

HEC-RAS is able to conduct steady flow water surface profile computations; one dimensional and two dimensional unsteady flow simulations; Quasi unsteady or fully unsteady flow movable boundary sediment transport computations; and water quality analysis.

In this study, we were looking at the steady flow water surface profiles of a single river reach, though the system is capable of analysis full networks of river reaches if necessary.

The basic computational procedure is based on the solution of the one dimensional energy equation. Energy losses are evaluated by friction using Manning's equation and contraction or expansion coefficient.

The effects of various obstructions such as bridges, culverts, dams, weirs, and other structures in the flood plain may also be considered in the computations. In this analysis, we considered the effects of the culverts and the bridges.

3.5.2 Geometric Data

Contours with five metre intervals were obtained from survey data for the study area. These contours provide the elevation of the cross-sections. Most contour mapping do not reflect elevations under water, and therefore stream slopes may not be representative using only mapping data. Thus, using *Autodesk Civil3D 2018* software the field measured dimensions were added to the geometry to ensure that the defined storm water channel would be analysed. The extracted geometry of the channel was then imported to HEC-RAS.

The channel geometry was exported from *Autodesk Civil 3D* to *HEC-RAS*. The complete data set comprised of the following:

- The concrete channel in the study area known as the reach.
- The cross-section details for the reach were spaced at 25m intervals Each cross-section is known as a river station.
- Figure 10 illustrates typical cross-section information that is utilized in the programme. The distance along the cross-section is referred to as ***station*** and its units are (m). Each station has a corresponding elevation which is a plot of the ground level in reference to the position along the station. The units for elevation are meters above mean sea level (m.a.m s.l) but are simply displayed as meters (m).

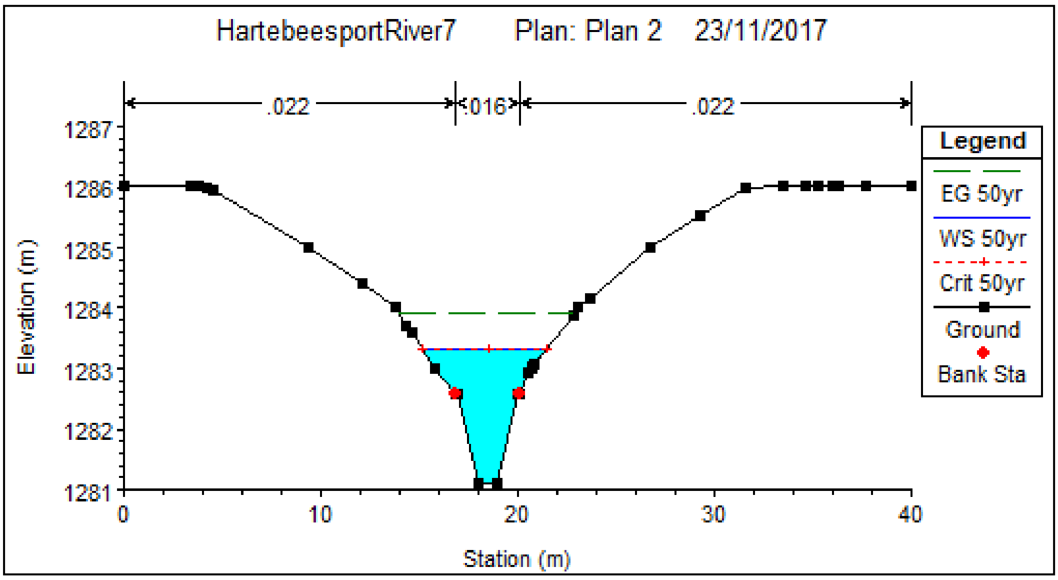

Figure 10: Typical Cross Section Detail.

The hydraulic computations utilize Manning's equation to generate the water surface profiles in the channel. The following is the general form of Manning's equation:

$$Q = \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}$$

where:

$Q=$ Flow rate in m^3/s

$n=$ Manning's roughness coefficient

$R=$ Hydraulic radius in m

$S=$ Average slope of the section of the stream (assuming that the average slope is equal to the frictional slope) in m/m

A Manning's "n" roughness coefficient value of 0.016 was assumed for all sections of the channel. This is the manning's n value for old concrete as revealed from past research. This value can only be used if the channel is cleaned out of overgrowth. Cleaning out the channel allows for the manning's n to be reduced from 0.022 to 0.016. On the banks of the channel, a manning's n value of 0.022 was used.

The layout of the channel with the obstructions as represented in HEC-RES is shown in Figure 11. Figure 12 shows the properties of the hydraulic structures as entered in HEC-RAS, using the culvert as an example.

The triple barrel concrete box culvert across the Stormvoel Road was modelled based on survey information. The culvert comprises of three 50m long culverts that span over 3.6m each and have a rise of 1.5m. In Figure 11, the culvert is situated between river stations 135 and 200.

The two railway bridges that pass over the channel were also modelled. They have lengths of 10m and 20m, raised a metre above the channel, depicted between river stations 400 and 500.

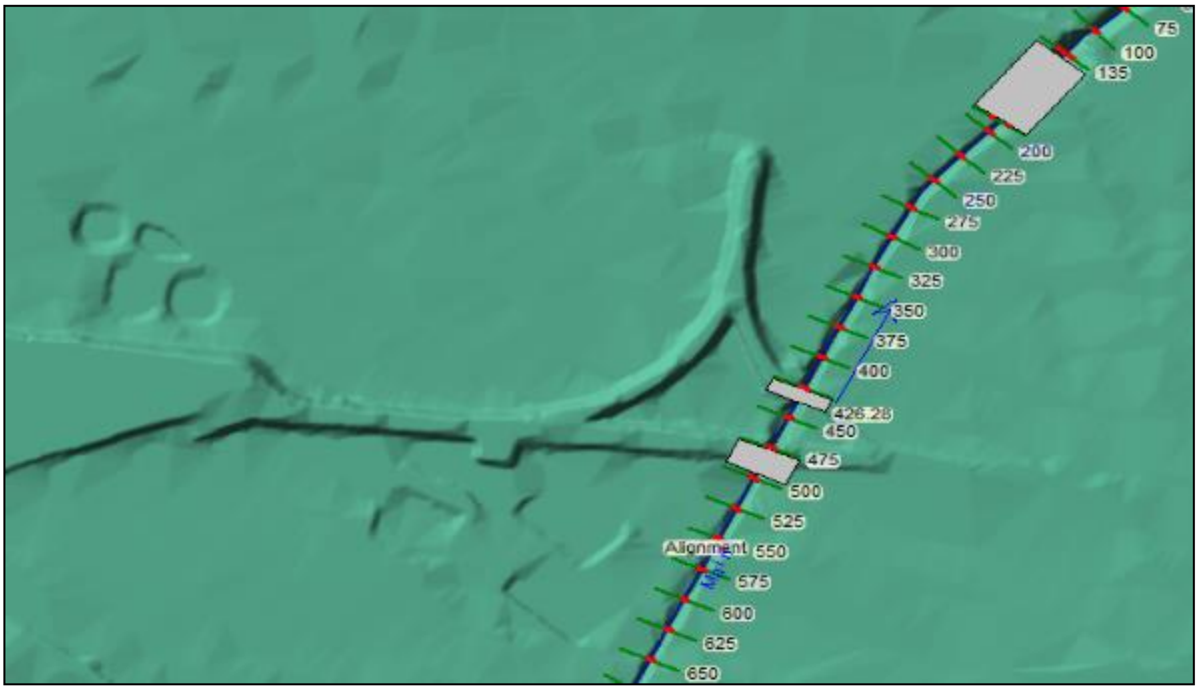

Figure 11: Layout of channel reach with obstructions, that is, culvert and bridges

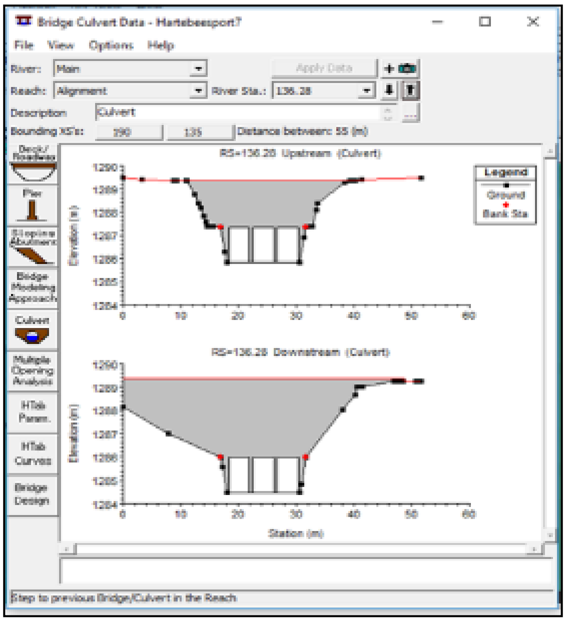

Figure 12: Cross-sections of the culvert

4 RESULTS

4.1 GEOMETRY DATA

The cross-sections in Figure 13, Figure 14 and Figure 15 illustrate different results that were determined for key river station positions. These positions are representative of the entire storm water channel. The cross-sections show the Energy Grade line (i.e EG 100), the Water Surface line (WS 100), the Critical Water Surface (Crit 100), the Bank Stations and the Ground level.

The EG line for the two profiles, shows the elevation of the energy head of water flowing in a pipe, conduit or channel (Sacremento State: Office of Water Programs, 2017). The energy grade line is the total head of water, comprising of elevation head and the velocity head.

The water surface elevation, shows the profile or the depth of the flowing water and the profile is known as the hydraulic grade line.

The critical WS elevation is the water surface elevation at the critical depth. Critical depth is the depth of the water surface when it has the lowest energy level for a particular flow rate (FishXing, 2006). Flows at a depth greater than critical depth are known as subcritical and are slow flowing, while flows at a depth lower than critical depth are referred to as supercritical and tend to be fast flowing (Edwards, 2013).

The bank stations mark the end of the channel and the start of the channel banks. This distinction allows to tailor the manning's n to the type of material that the banks are made of. In this study, the banks remain vegetated and therefore have a manning's n of 0.022, while the channel has a manning's n value of 0.016 as shown at the top of the cross-section figures. These values remain constant for all cross-sections along the storm water channel.

Figure 13 shows the cross-section at river station 190 which is the cross-section just upstream of the culvert. It has a wider cross-section to accommodate the transition to the culvert. For the 100-year profile, the EG elevation is 1287.46m, the WS elevation is 1287.38m while the critical WS elevation is 1286.61m. Considering the WS elevation and the critical WS elevation, the flow regime in the channel is subcritical at this position. The total velocity 1.31m/s. The maximum channel depth is 1.53m.

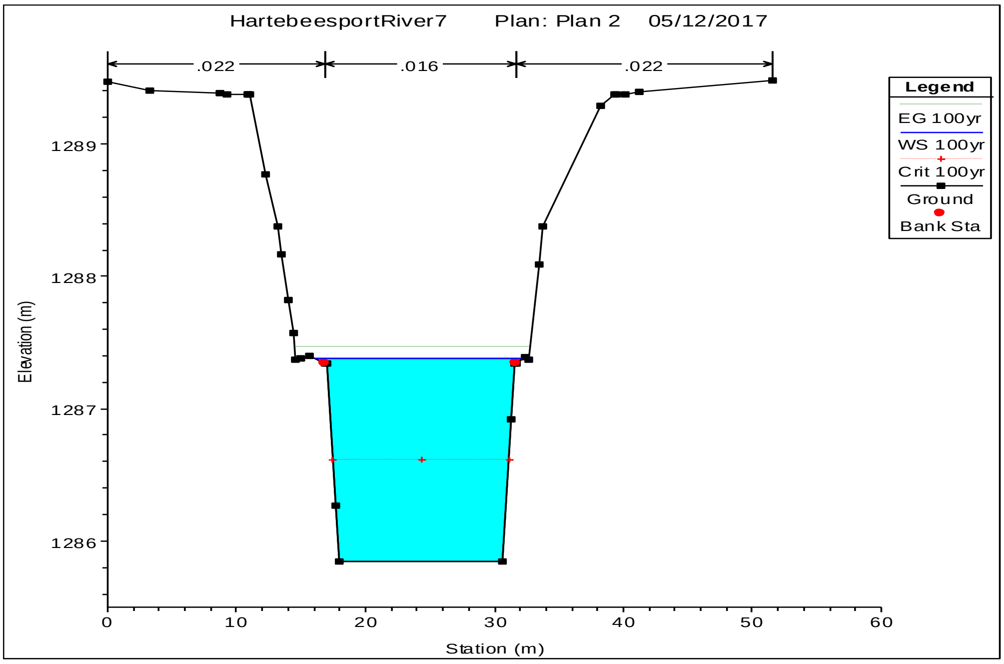

Figure 13: Cross-section of River Station 190, upstream of the culvert

Figure 14 and Figure 15 : These sections have been assessed at critical depth elevations. Thus, the WS elevation is equal to the critical WS elevation.

River station 250 depicted in Figure 14, is a cross-section in the middle of the site, with a typical shape of the channel. For the 100-year profile, the EG elevation is 1290.71m, the WS elevation has a value of 1289.88m. The total velocity 3.71m/s. The maximum channel depth is 2.54m.

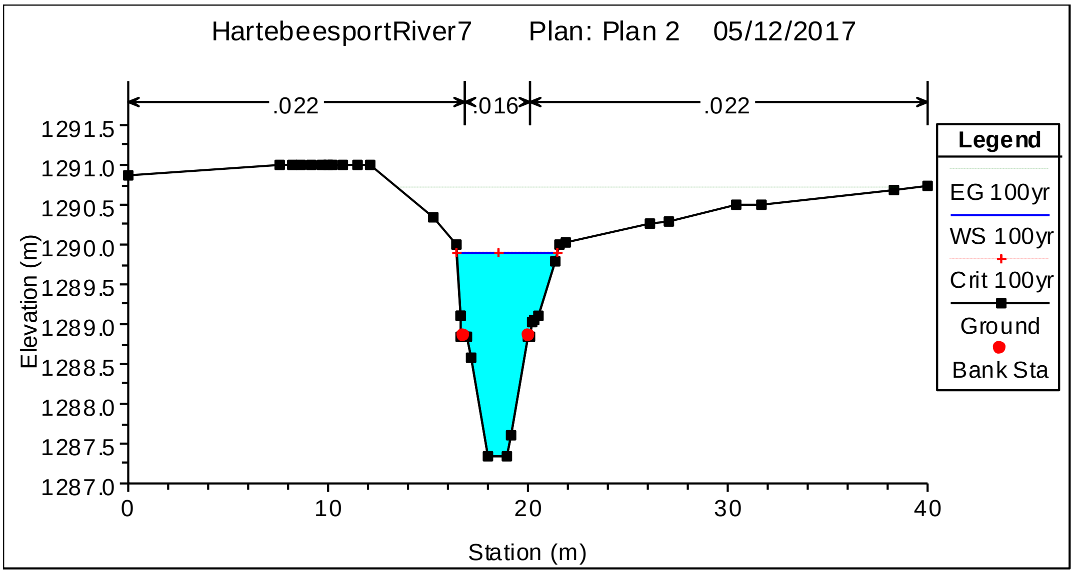

Figure 14: Cross-section of river station 250

River station 425 in Figure 15, is a cross-section downstream of the 10m long railway bridge. The river banks are distorted due to the elevated railway line that affects the contours in the survey. For the 100-year profile, the EG elevation is 1294.87m, the WS elevation is 1294.16m. The total velocity 3.37m/s. The maximum channel depth is 2.45m.

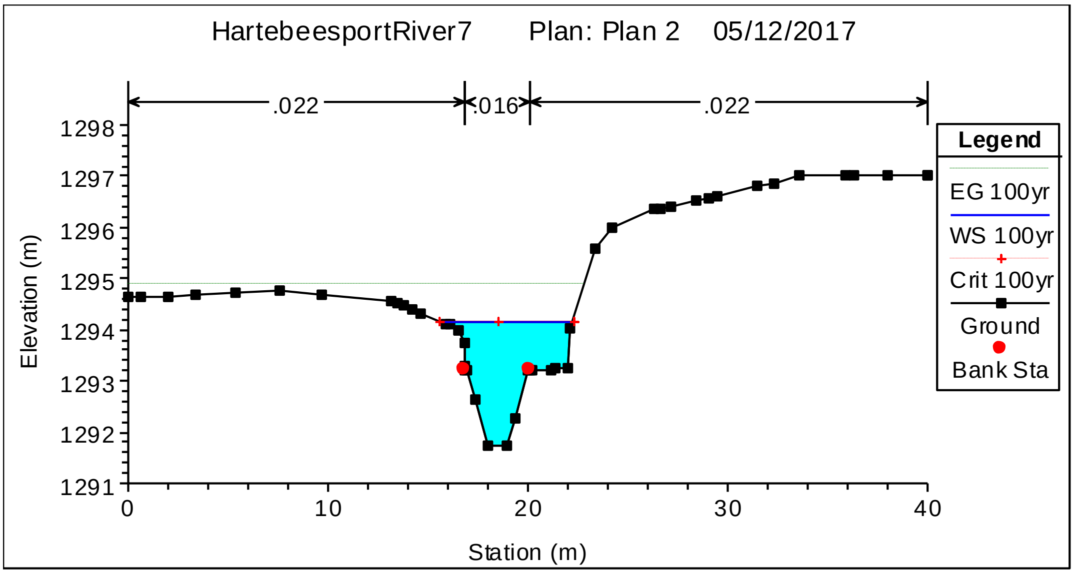

Figure 15: Cross-section of River Station 425, downstream of Bridge 1

4.2 LONG SECTION PROFILES

Figure 16 and Figure 17 depict the longitudinal profiles of the 50-year and 100-year. The profile views show the results of all cross-sections in one graphical output, showing the same elevation lines as the cross-section views. The profile can be used to identify irregularities or instability in the analysis, as these would show in the profile. The study area is in the station range 200m to 425m

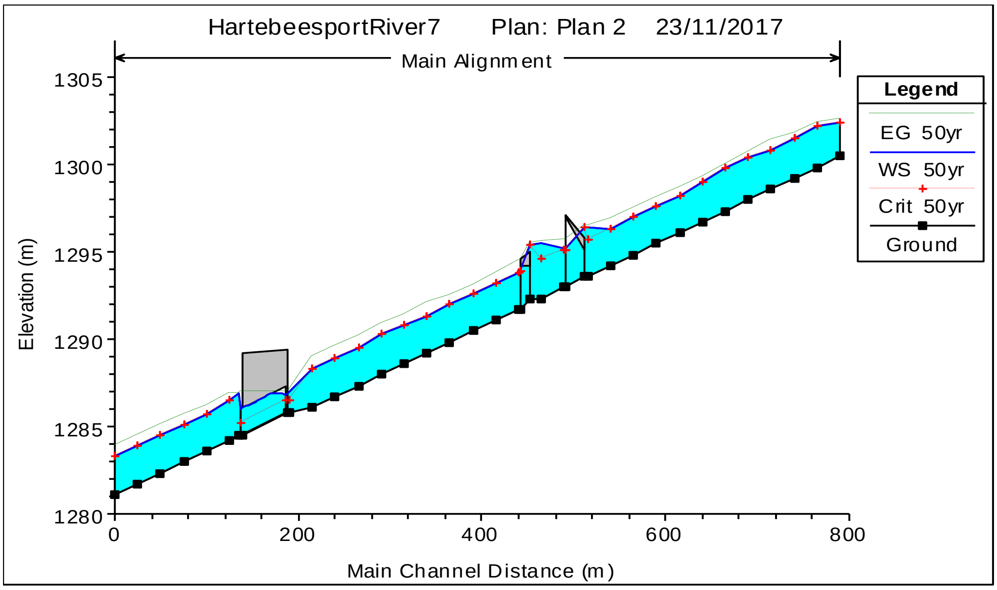

Figure 16: Longitudinal Section Profile of 50-year Flood

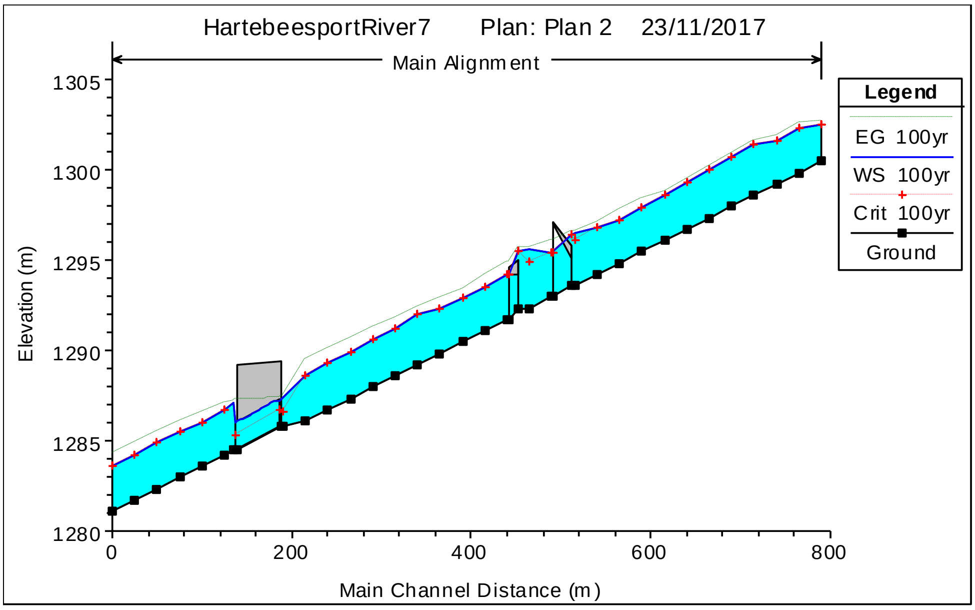

Figure 17: Longitudinal Section Profile of 100-year Flood

4.3 3D ILLUSTRATION OF FLOODLINES

HEC-RAS also has the option to view the 3D layout of the channel. Figure 18 illustrates the 3D representation of the floodplain.

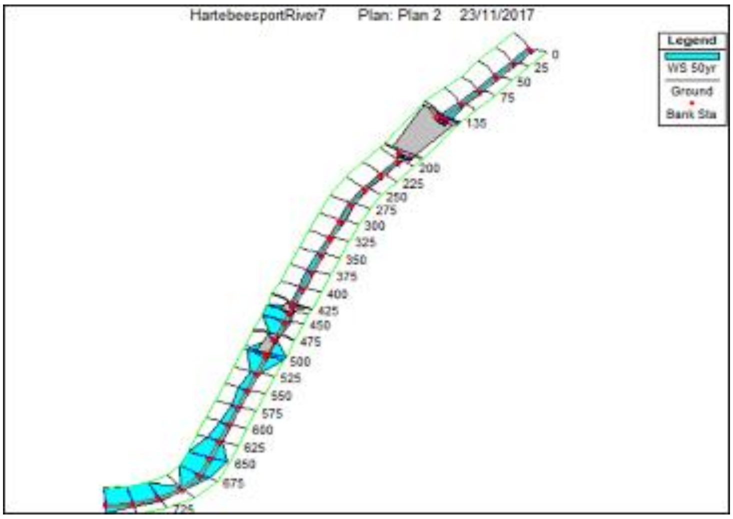

Figure 18: 3D Illustration of Results in HEC-RAS

4.4 MAPPING OF FLOODLINES

After assessing all the results in HEC-RAS, the floodlines were mapped. The survey data was exported to Civil 3D as a Geotiff file. A free and open-source software, SAGA GIS, was used to edit the spatial data to convert the Geotiff file into ESRI binary grid file that is compatible with HEC-RAS's mapper function. The imported data served as the terrain background on which the floodplains were mapped. The mapper generated the shapefiles for the 50-year and 100-year floods as shown in Figure 19.

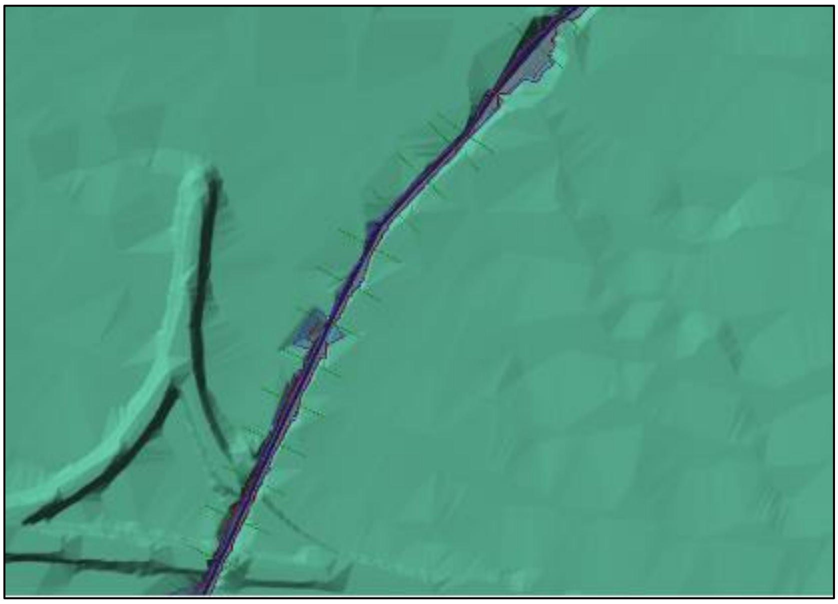

Figure 19: HEC-RAS RAS Mapper Floodlines

The floodline shapefiles were exported back to Civil 3D where the necessary maps were generated. The results are shown on Drawing No. 17161-73-01-01. The drawing shows the extent of the flooding due to that the 50-year and 100-year return period floods.

4.5 BUFFER ZONE

Furthermore, buffer lines have been established on both sides of the channel. These buffer lines are the extents of the floodlines. They indicate the recommended limits of spatial development on both sides of the site. The setting out information is tabulated in Table 2 and shown on Drawing No. 17161-73-02-01.

Table 2: Buffer line Coordinates

	Position	X-Coordinates	Y-Coordinates
East	A	-71106.5213	-2845450.3627
	B	-71171.3408	-2845521.3663
	C	-71197.7569	-2845584.2501
	D	-71265.2411	-2845710.5735
West	E	-71114.4938	-2845442.7896
	F	-71183.7718	-2845519.1566
	G	-71227.7578	-2845586.0435
	H	-71272.1686	-2845710.2405

5 LIMITATIONS

5.1 DATA LIMITATIONS

The contours of the survey data are not always able to consistently define the boundaries of the channel. In this case, it can be attributed to the small size of the channel. Obstructions such as the road and the railways also affect the representation of the storm water channel in the existing ground level contours.

As mentioned previously, most survey data are unable to capture ground elevation under water. This coupled with the large amounts of vegetation overgrowth in the channel, means that the contours are not representative of the true depth of the channel.

All this distorts the size of the channel if the existing ground level is used without modification. The cross-sections will not be uniform regarding depth along the channel, with some river stations appearing shallower than others.

In order to combat this problem, field data can be taken to supplement the information. In this study the measured dimensions of the channel were inserted to the existing ground surface. This ensured that the channel was well defined at all river stations and that the right elevation for the channel was used at the railway line crossings.

Another limitation faced occurred during the site visits. Access to observe the channel was restricted in many locations due to the vegetation overgrowth. Only a few measurements were able to be taken. Therefore, an assumption was made that the channel was equal in dimensions. This assumption was proven along the sections that were measured.

6 CONCLUSION

In conclusion, the flood lines of both the 1 in 50 year and 1 in 100 year floods do encroach on the site as shown in Drawing No. 17161-73-01-01. A buffer zone of 5m on average is needed from the channel to ensure the development is protected. The buffer zone is indicated on Drawing No. 17161-73-02-01

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APPENDIX A: Rational Method Calculation

Rational Method

Description of Catchment	Storm water Channel						
River details	Trapezoidal Concrete Channel						
Calculated by	TC			Date	17/11/2017		
Physical Characteristics							
Size of Catchment	1.55		Km²	Rainfall Region	Inland		
Longest Watercourse	0.8		km	Area Distribution factors			
Average Slope (overland)	0.025		m/m	Rural	Urban		Lakes
Average Slope (defined watercourse)	0.023		m/m	100	0		0
Dolomite area (%)	0		%				
Mean annual rainfall (MAR)	654		mm	r	0.4		-
Rural				Urban			
Surface slope	%	Factor	C_s	Description	%	Factor	C_2
Vleis and pans		0.03	0	Lawns			
Flat areas	10	0.08	0.072	sandy, flat		0.1	
Hilly	90	0.16	0.016	sandy, steep		0.2	
Steep		0.26	0	heavy soil, flat		0.17	
Total	100	-	0.088	heavy soil, steep		0.35	
Permeability	%	Factor	C_p	Residential areas			
Very		0.04	0	Houses		0.5	
Permeable	10	0.08	0.008	Flats		0.7	
Semi	90	0.16	0.144	Industry			
Impermeable		0.26	0	Light		0.8	
Total	100	-	0.152	Heavy		0.9	
Vegetation	%	Factor	C_v	Business			
Thick bush and plantation		0.04	0	City centre			
Light bush and farm-land	20	0.11	0.022	Suburban			
Grasslands	80	0.21	0.168	Streets		0.95	
No-Vegetation		0.28	0	Maximum flood		1	
Total	100	-	0.19	Total (C2)			
Time of Concentration			Notes:				
Overland flow	Defined Watercourse						
$T = 0.604\left(\frac{rL}{\sqrt{S_{av}}}\right)^{0.467}$	$T = \left(\frac{0.87L}{1000S_{av}}\right)^{0.385}$						
0.839504419 Hours	0.238687	Hours					
Run-off Coefficient							
Return period (years) T	2	5	10	20	50	100	Max
Run-coefficient, C_1					0.43	0.43	
C_{1D}					0.43	0.43	
F_t					0.83	1	
C_{1T}					0.3569	0.43	
C_T					0.3569	0.43	
Rainfall							
Return period (years) T	2	5	10	20	50	100	Max
Point rainfall					90	120	
Point intensity					83.473	111.29	
Area reduction					1	1	
Average Intensity					83.473	111.29	
Return period (years) T	2	5	10	20	50	100	Max
Peak flow (m³/s)					12.8269	20.605	

APPENDIX B: Drawings