Report

PROPOSED BRONKHORSTSPRUIT DEVELOPMENT

ISO 9001 - FS 64925
ISO 14001 - EMS 550121
OHSAS 18001 - OHS 550122

FLOODLINE ASSESSMENT
KP 302-00307/09

Knight Piésold (Pty) Ltd.

Reg. No. 1995/012742/07
Est. 1921
Head Office : Knight Piesold House
4 De la Rey Road,
Rivonia, 2128
P.O.Box 221, Rivonia 2128, South Africa
Telephone: +27(11) 806-7111
Facsimile: +27(11) 806-7100
www.knightpiesold.com

CONTACT:
Edwin Lille
(elille@knightpiesold.com)

Knight Piésold
CONSULTING

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Author	Eugeshin Naidoo Civil Engineer		November 2016
Document Reviewer	Edwin Lille, Pr.Eng. Senior Engineer		November 2016
Approved by	Edwin Lille, Pr.Eng. Senior Engineer		November 2016

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(elille@knightpiesold.com)

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1 - INTRODUCTION

1.1 SUBJECT

Knight Piésold was requested by I-CAT International Consulting and Trading (Pty) Ltd. to determine the floodlines for the Bronkhorstspruit development. The total footprint area of the proposed development is approximately 6.27 hectares (ha). The Bronkhorstspruit River was found to flow adjacent to the proposed development site (as shown in Figure 1.1 below); the floodline assessment was carried out for this watercourse.

The site falls within the B20D quaternary catchment, and the Olifants Water Management Area (WMA). Section 144 of the South African National Water Act, 1998 (Act No. 36 of 1998) (NWA) (South Africa, 1998) which deals with residential/commercial developments was considered in the study. The act states that no residential/commercial development may be undertaken within the floodlines indicating the maximum level likely to be reached by floodwaters, on average, once in every 100 years.

This report accordingly addresses the floodline assessment undertaken for the proposed development.

1.2 TERMS OF REFERENCE

Knight Piésold was commissioned by I-CAT International Consulting and Trading (Pty) Ltd. to undertake the floodline assessment (1 in 50 year and 1 in 100 year recurrence interval) for the proposed development adjacent to the Bronkhorstspruit River.

1.3 SOURCES OF INFORMATION

The approximate locality plan of proposed development extents was received from I-CAT International Consulting and Trading (Pty) Ltd. in October 2016.

The survey data obtained from the I-CAT International Consulting and Trading (Pty) Ltd. was undertaken by means of a Lidar survey to produce 0.5m contours. The accuracy and confidence in the floodline investigation depends on the level of detail of the generated digital contours. The survey data received adequately captured all the hydraulically relevant features, including the defined channel in which the watercourse flows. The contours were used to develop a Digital Elevation Model (DEM) of the proposed site and this information was accordingly applied in the development of the HEC-RAS river flow model.

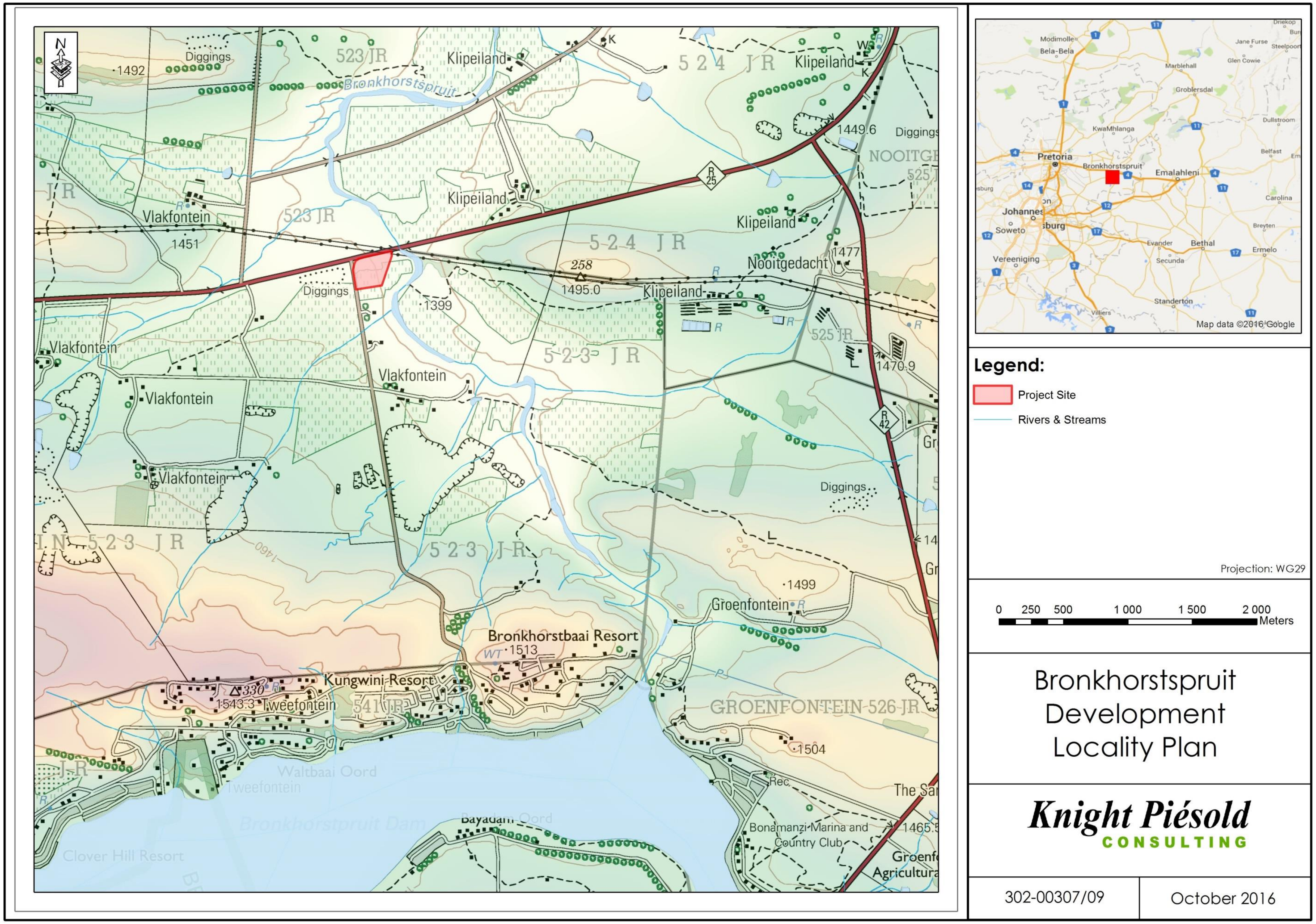

Figure 1.1: The proposed Bronkhorstspruit Development locality

1.4 STUDY METHODOLOGY

The following section describes the methodology employed in the floodline assessment.

1.4.1 Flood Hydrology

Rainfall data was obtained from TR102, Southern African Rainfall Report (Department of Environment Affairs, 1983). The point precipitation was determined utilising the Depth-Area-Duration-Frequency relationships as per the Hydraulic Research Unit of the University of the Witwatersrand's (HRU) report 2/78 (Midgley and Pitman, 1978).

In order to produce peak runoff input, five (5) methods were used to determine design flood peaks for the delineated catchment based on their applicability to the catchment area. These methods are the Alternative Rational Method, Unit Hydrograph Method, Standard Design Flood (SDF) Method, the Regional Maximum Flood (RMF) Method also referred to as the Empirical Method and the Statistical (Log Pearson 3 Method).

The rainfall depths with durations corresponding to the Time of Concentration (T_c) for any sub catchment were used to calculate peak flows for the combined catchment. The underlying assumption is that the largest possible peak flow is obtained when the storm rainfall event has duration equal to the time required for the whole catchment to contribute runoff at the outlet. A short description of the above-mentioned methods is given below.

Alternative Rational Method

The rational method was developed in the mid-19th century and still remains one of the most widely used methods for the calculation of peak flows for small catchments (< 15 km^2). The formula indicates that Q = CIA, where I is the rainfall intensity, A is the upstream runoff area and C is the runoff coefficient. Q is the peak flood flow. The point precipitation is determined using Depth-Area-Duration-Frequency relationships, HRU Report 2/78 (Midgley and Pitman, 1978). This alternative method is an adaptation of the traditional rational method. The main differences are in the calculation of the point precipitation as well as the unlimited catchment area applicability. The alternative method uses the modified recalibrated Hershfield equation as proposed for storm durations of up to 6 hours, and the Department of Water Affairs' technical report TR102 for duration of 1 to 7 days.

Standard Design Flood Method

The standard design flood (SDF) method was developed specifically to address the uncertainty in flood prediction under South African conditions (Alexander, 2002). The runoff coefficient (C) is replaced by a calibrated value based on the subdivision of South Africa into 26 regions or Water Management Areas (WMA's). The design methodology is slightly different to that of the Rational Method as it looks at the probability of a peak flood event occurring at any one of a series of similarly sized catchments in a wider region, while other methods focus on point probabilities. There is no limitation of the catchment size to which this method is applicable.

Unit Hydrograph Method

Unit hydrographs are applicable to catchments of between 15 and 5000 km^2. By using the concept of a unit hydrograph, the constant unique physical parameters of a catchment are established in the typical form of a hydrograph, and the size and duration may be further determined by considering the intensity and duration of rainfall. A unit hydrograph is a characteristic of a specific catchment, and is defined in metric terms as the hydrograph of one millimetre of run-off following rainfall of unit duration with uniform spatial and time distribution over the catchment. The duration of the hydrograph is thus proportional to the duration of the rainfall and the volume of the hydrograph is proportional to the intensity of the rainfall.

Empirical Method

The Regional Maximum Flood (RMF) is an empirically established upper limit of flood peaks that can be reasonably expected at a given site. The proposed method for the estimation of RMF is a revised and updated version of Departmental technical report TR 105 published in 1980. The method is based on maximum flood peaks recorded since 1856 at more than 500 sites in Southern Africa. The relative flood peak magnitude is expressed by the Francou-Rodier regional coefficient K. Eight maximum flood peak regions were delimited by a joint consideration of K, maximum observed 3 day rainfall and catchment characteristics. The respective K envelope lines (K.) were established by taking onto account the number and quality of data. The RMF can be instantly calculated if the geographic position of the site and its effective catchment area are known. Owing to its consistency the RMF compares favourably with results obtained by other methods. It is also shown that flood peaks in the 50 to 200 year recurrence interval can be estimated from RMF.

Statistical Method

Statistical methods are based on the fitting of probability distributions functions (in this case the Log Pearson 3 Distribution) to measured values of maximum annual flood peaks. The accuracy of these methods depends a great deal on the reliability of the measured values, particularly the accuracy with which flow rates are measured, and on the length of the historical record.

1.4.2 Floodline Delineation

A steady flow HEC-RAS flood analysis model (one dimensional hydraulic model) was developed for the watercourse within the study area. Floodlines on river sections are analysed to evaluate risks associated with potential flooding of infrastructure and protection of natural resources. Legislation guides the minimum requirements for placement of infrastructure in relation to a natural watercourse.

Section 144 of the NWA which deals with residential developments was considered in the study. The act states that no residential establishment may take place within the floodlines indicating the maximum level likely to be reached by floodwaters, on average, once in every 100 years. Therefore the 1 in 100-year recurrence interval floodline was estimated for the proposed development. Figure 1.2 depicts the methodology applied to complete the floodline analysis.

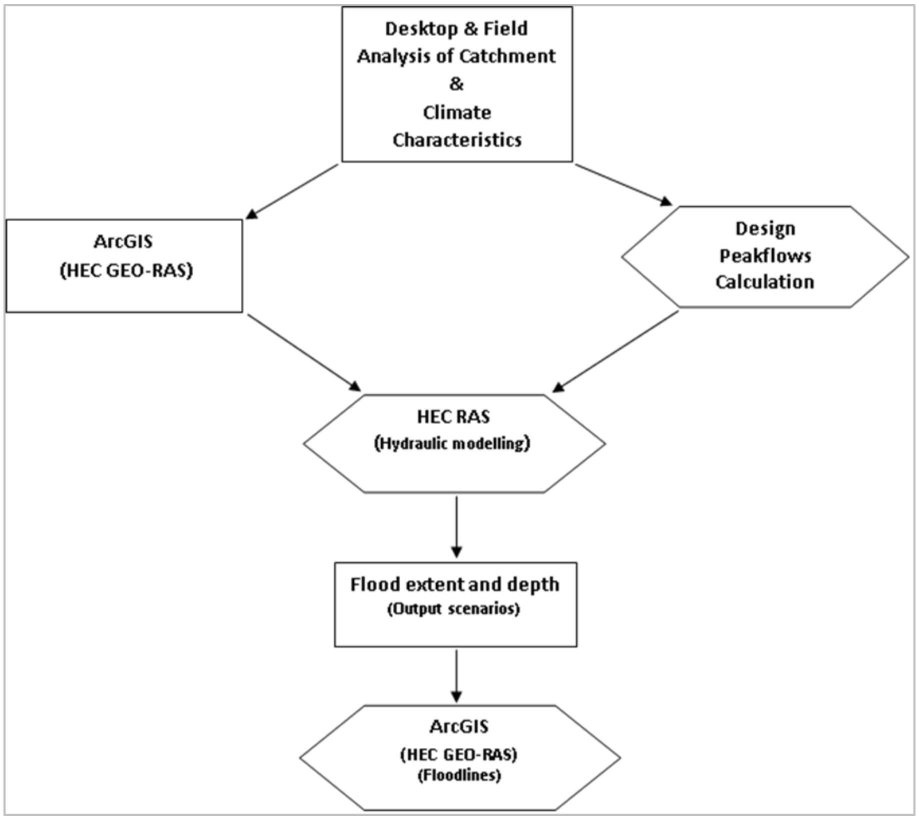

Figure 1.2: Summary of the study methodology

The approach adopted in the study can be summarised as follows:

- A desktop evaluation was carried to assess the site specific hydrological conditions of the stream, which will influence the floodline determination;
- The catchment area (inclusive of sub-catchments) was delineated using the combined survey and GIS dataset;
- The time of concentrations were calculated using various equations including the Defined Watercourse Formula and the Bransby–Williams Formula;
- A flood peak analysis was undertaken to determine the different recurrence interval flood peaks for the identified stream;
- The flood peaks and the survey data of the study area were then used as inputs to the HEC-RAS backwater program to determine the water surface elevations for the 1 in 50 year and 1 in 100 year floods peaks.

The river sections were modelled in HEC-RAS (US Army Corps of Engineers, 1995) by defining cross sections at various intervals along the stream. These cross sections were created in ArcView 10.1 (ESRI, 2012) and exported into HEC-RAS. The positions of the cross sections were determined by any anticipated changes in flow regime, such as at river bends.

HEC-RAS (US Army Corps of Engineers, 1995) models total energy of water by applying basic principles of mass, continuity and momentum, as well as applying Manning's equation for roughness between all cross sections. A flow height is calculated at each cross section which represents the level at which water will rise at that section, given a sustained peak flow. This was calculated for the 1 in 50 year and 1 in 100 year peak flood flows on all river sections. The flows in the analysis were performed by modelling the most downstream position in the river section first, and progressively moving upstream.

2 - FLOOD HYDROLOGY

The following sections describe the flood hydrology:

2.1 STORM RAINFALL

A long record of rainfall is required to reliably assess statistical characteristics of the local rainfall. The rainfall depths used within this study were extracted from the closest weather station to the study site, obtained from the Department of Water Affairs' technical report TR102 for duration of 1 to 7 days. The selection of the Bronkhorstspruit (Municipal) Station (514408) is based on the fact that this is the closest station to the study area (approximately 7 km away) with a reliable record. The daily rainfall record covers 70 year period, with a calculated Mean Annual Precipitation (MAP) of 625 mm.

The 24-hour storm rainfall depth for the 2-year, 10-year, 20-year, 50-year and 100-year recurrence interval events, at the Bronkhorstspruit (Municipal) Station (514408) was abstracted. The depths are presented in Table 2.1.

Table 2.1: Rainfall (mm) depth for the various recurrence intervals

Recurrence Interval (Years)	1 in 2 year	1 in 10 year	1 in 20 year	1 in 50 year	1 in 100 year
24 hour Rainfall depth (mm)	64.4	77.7	123.2	151.0	173.2

2.2 CATCHMENT PARAMETERS

Various standard methods, as described by Alexander (2001a) were used in the determination of catchment parameters relevant to the determination of flood peaks in the watercourse under consideration. Figure 2.1 shows the accepted catchment area and all assumed hydrological parameters are summarised in Table 2.2.

Table 2.2: Catchment Parameters used in the flood peak calculations

Parameter	Value at Downstream End
Size of catchment (km^2)	1265.4
Longest water course length (km)	62.5
Length to catchment centroid along longest river course (km)	29.6
Mean Annual Rainfall (mm)	625
Average river course slope:	
(10-85 Method) (%)	0.3
SDF Basin No	1
Veld Type Distribution (HRU 1/72)	4

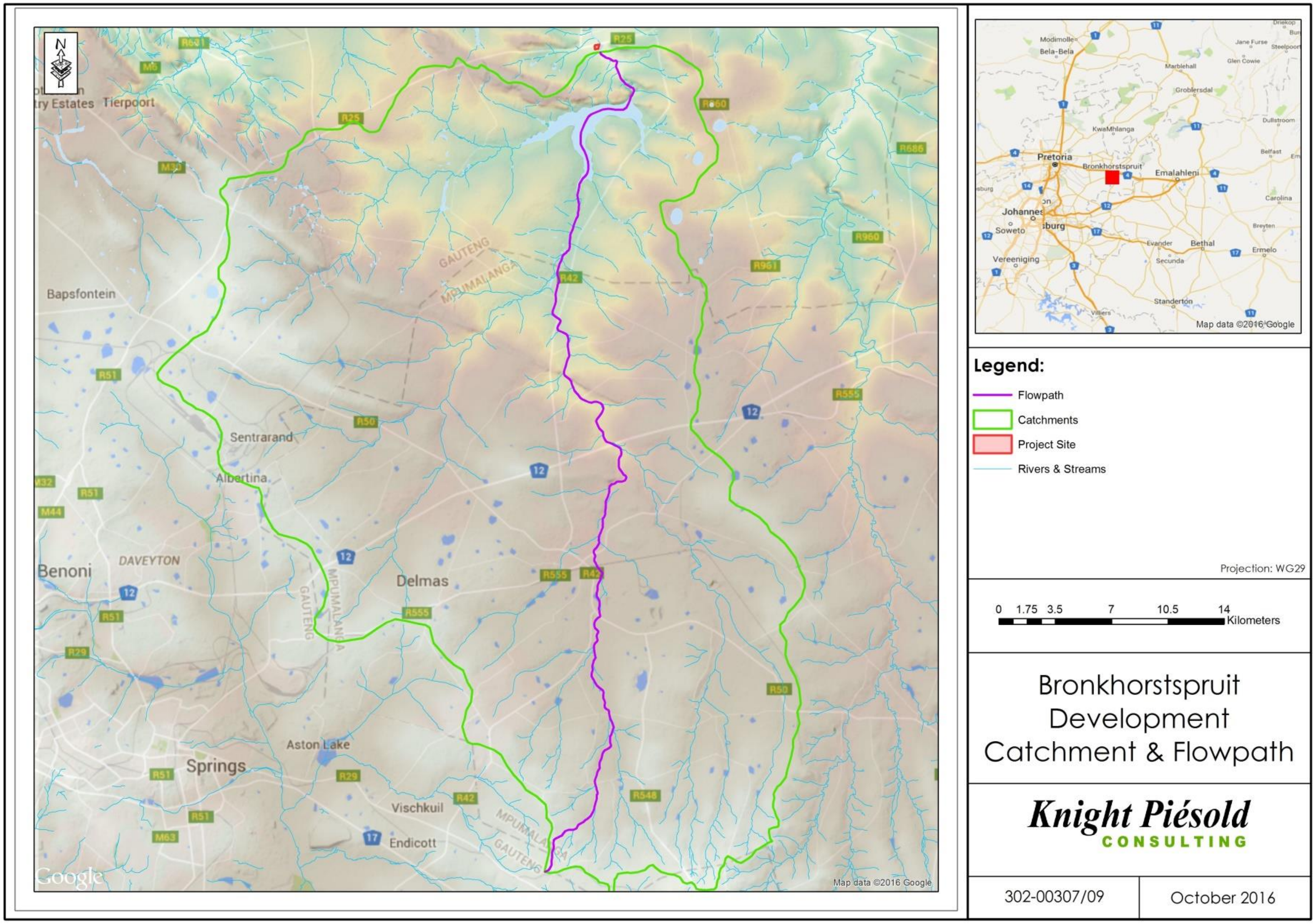

Figure 2.1: Delineated catchment and longest watercourse for the Bronkhorstspruit River up to the proposed development site

2.3 FLOOD PEAK CALCULATION

Peak flows for the 1 in 50 year and 1 in 100 year storm events were calculated for the delineated catchment for the pre-development scenario. Calculations were based on current conditions at the project site which were verified during the site visit.

Based on the desktop evaluation of the delineated catchment it was determined that the Bronkhorstspruit Dam (details are shown in Table 2.3 below) located approximately 4km upstream of the site, will potentially have a substantial influence on the flood water levels adjacent to the proposed development (behaving as the hydraulic control within the river). Therefore the attenuation caused by the Dam was considered in the calculations as the Dam would store a portion of the storm volume before discharging into the Bronkhorstspruit River; however this is dependent on the capacity of the dam as well as the catchment area.

Table 2.3: Bronkhorstspruit Dam characteristics

Bronkhorstspruit Dam characteristics	
Crest Length (m)	152.4
Effective Spillway Crest Length (m)	72.6
Water Surface Area at FSL (ha)	873
Storage Capacity at FSL (m^3)	57.913×10^6
Maximum Spillway Discharge (m^3/s)	1340
Dam Category	3

The degree of flood attenuation in the Dam, and therefore the potential benefit to be derived from the flood routing was assessed by estimating the flood volume likely to be associated with the specific flood event. If the flood volume is large relative to the volume available surcharge storage, i.e. the volume between the spillway crest and non-spill crest levels, flood routing would be unnecessary. Görgens et al (1990) developed a quick guide formula to determine the necessity or otherwise of flood routing as shown below:

$$\frac{Q_{out}}{Q_{in}} = 0.99 - 5.56\left(\frac{A_r}{A_c}\right)$$

Where:

- A_r is the area of the dam at FSL
- A_c is the area of the catchment commanded by the Dam

When this equation was applied the results indicated that the area of the dam is as low as 1% of the area of the catchment, attenuation, i.e. ($1-Q_{out}/Q_{in}$), could be as low as 5%. It was therefore decided that flood routing would not be required as the attenuation would be negligible. It was therefore assumed that the Dam is at its Full Supply Level (FSL) and that the 1 in 50 year and 1 in 100 year storm events were routed through the Dam without any attenuation (the full flood peaks were used in the calculations).

2.3.1 Flood Peaks

Peak flood flows for the 1 in 50 year and 1 in 100 year recurrence interval storm events were estimated for the delineated catchment using the abovementioned methods. Calculations were based on current conditions at the project site.

The statistical method was carried out using the Bronkhorstspruit Flow Gauge (B2H003), this gauge provided 35 years (period between 1982 and 2016) of usable data. The flow gauge corresponded to a total catchment area of 1574 km^2. It is recommended that a statistical analysis be carried out on a record preferably longer than half of the design return period, and should include both wet and dry periods. A Log Pearson 3 probability distribution function was fitted to measured values of maximum annual flood peaks. The results show that the peak flows obtained from the statistical analysis were dramatically lower than those calculated using the empirical and deterministic methods. Upon further investigation of the rating curve obtained from Department of Water Affairs for the Bronkhorstspruit Flow Gauge, it appears that the flow gauge is limited to a maximum flow of 104 m^3/s; this indicates that flow meter cannot measure flows greater than this. For these reasons the estimated statistical peak flows were not used in the HECRAS (US Army Corps of Engineers, 1995) analysis.

The estimated peak flows are presented in Table 2.4 for the 1 in 50 year and 1 in 100 year recurrence intervals.

The RMF Method peak flows were selected for use in the HECRAS (US Army Corps of Engineers, 1995) floodline simulation model.

Table 2.4: Summary of the peak flows estimated for the study

	Recurrence Interval	
	1 in 50 year	1 in 100 year
Method	m^3/s	
Alternative Rational Method	640	771
Unit hydrograph Method	604	840
Standard Design Flood Method	1035	1311
RMF	954	1198
Statistical Method	123	147
Selected Peak Flows	**954**	**1198**

3 - FLOODLINE DELINEATION

3.1 FIELDWORK AND SITE ASSESSMENT

A desktop assessment was initially carried out to identify the influential hydrological and man-made structures that could impact the flow along the watercourse. This assisted in the development of factors that could potentially influence the level of flooding expected for the proposed site. A bridge was identified just downstream of the proposed development site, under the R25 as shown in Figure 1.1.

A site visit was carried out on the 18th of October 2016 to measure the bridge dimensions as well as to determine the current drainage conditions through the bridge. The measured dimensions are shown in Table 3.1 below. Table 3.2 shows photographs and observations made during the site visit. The R25 Bridge was incorporated into the floodline analysis.

Table 3.1: R25 Bridge dimensions

Bridge Dimensions	
Height (m)	5
Width (m)	15
Number of Barrels (No.)	3
Bridge Length (m)	15
Deck Height (m)	1.5

Table 3.2: Photographs and description of the R25 Bridge

Photographs	Description
	• Photograph taken of the bridge on the upstream side. • The bridge was found to be free of by debris with reeds growing on the banks. • Low water levels were found in the bridge during the site visit.

	• Photograph taken of the bridge on the upstream side, looking downstream. • The left and right barrels of the bridge do not have well defined flow paths. This indicates that the central barrel carries the flow under normal flow conditions. During high flow conditions the adjacent barrels carry the flow as well. • The bridge is concrete with the base being bare earth.
	• Photograph taken of the upstream reach of the river from the bridge. • The river is well characterised by a well-defined channel with dense vegetation on the banks.
	• Photograph taken of the bridge on the upstream side, looking downstream. • The photo shows the well-defined channel located in the central barrel of the bridge.

3.2 FLOODLINE RESULTS

The Bridge was incorporated into the HECRAS model and its full capacity was used in the analysis. Manning's roughness coefficients for the river were estimated to be 0.035 for the channel and 0.04 for the river banks. The Manning's n coefficients were estimated by comparing the vegetation and nature of the channel surfaces to published data (Barnes, 1967; Chow, 1959; Hicks and Mason, 1991).

The 1 in 50 year and 1 in 100 year recurrence interval floodline results are shown in Figure 3.1.

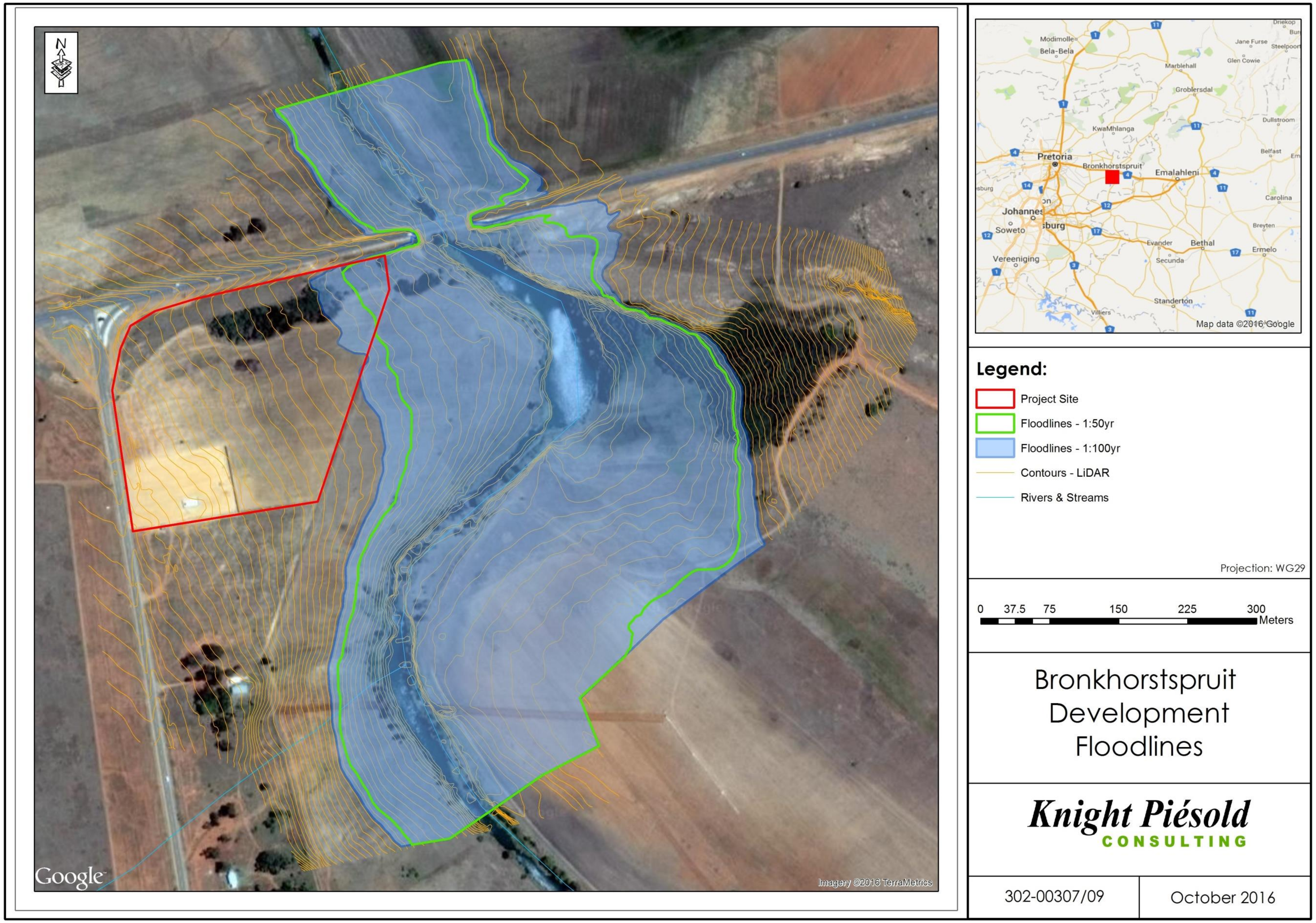

Figure 3.1: 1 in 50 year and 1 in 100 year floodline extents

4 - CONCLUSIONS

A HECRAS model was developed to calculate the 1 in 50 year and the 1 in 100 year recurrence interval floodline extents. The HECRAS model was developed using the survey data obtained from I-CAT International Consulting and Trading (Pty) Ltd. The results indicate the extent at which the proposed development site will be inundated during the 1 in 50 year and 1 in 100 year flood recurrence interval event, specifically the north-eastern portion of the proposed development.

5 - RECOMMENDATIONS

It is recommended that the small portion of the site which may be inundated during the 1 in 50 year and the 1 in 100 year floodline is not developed, and the proposed development on the site is restricted to areas outside the 1 in 100 year floodline.

6 - REFERENCES

- *Department of Water and Sanitation. (1998). Section 144 of the South African National Water Act (Act No. 36). South Africa.*
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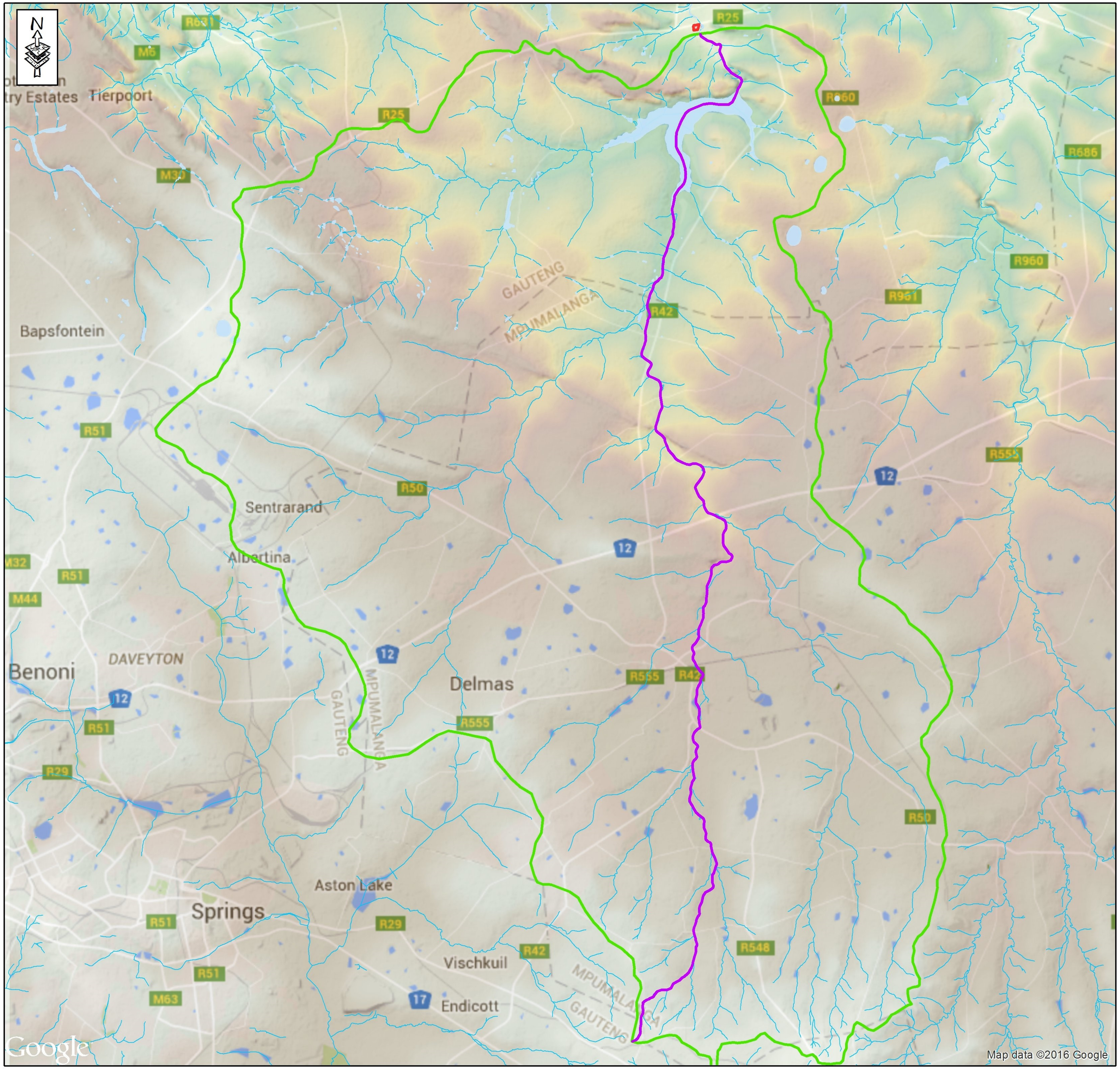
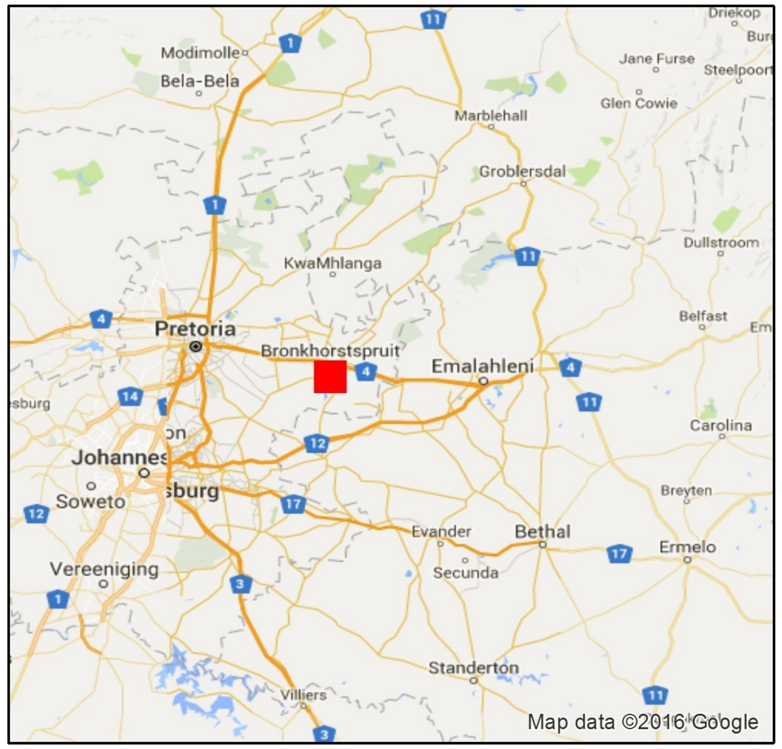
A

Catchment Area Map





Legend:

- Flowpath
- Catchments
- Project Site
- Rivers & Streams

Projection: WG29

0 1.75 3.5 7 10.5 14 Kilometers

Bronkhorstspruit Development Catchment & Flowpath

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302-00307/09

October 2016

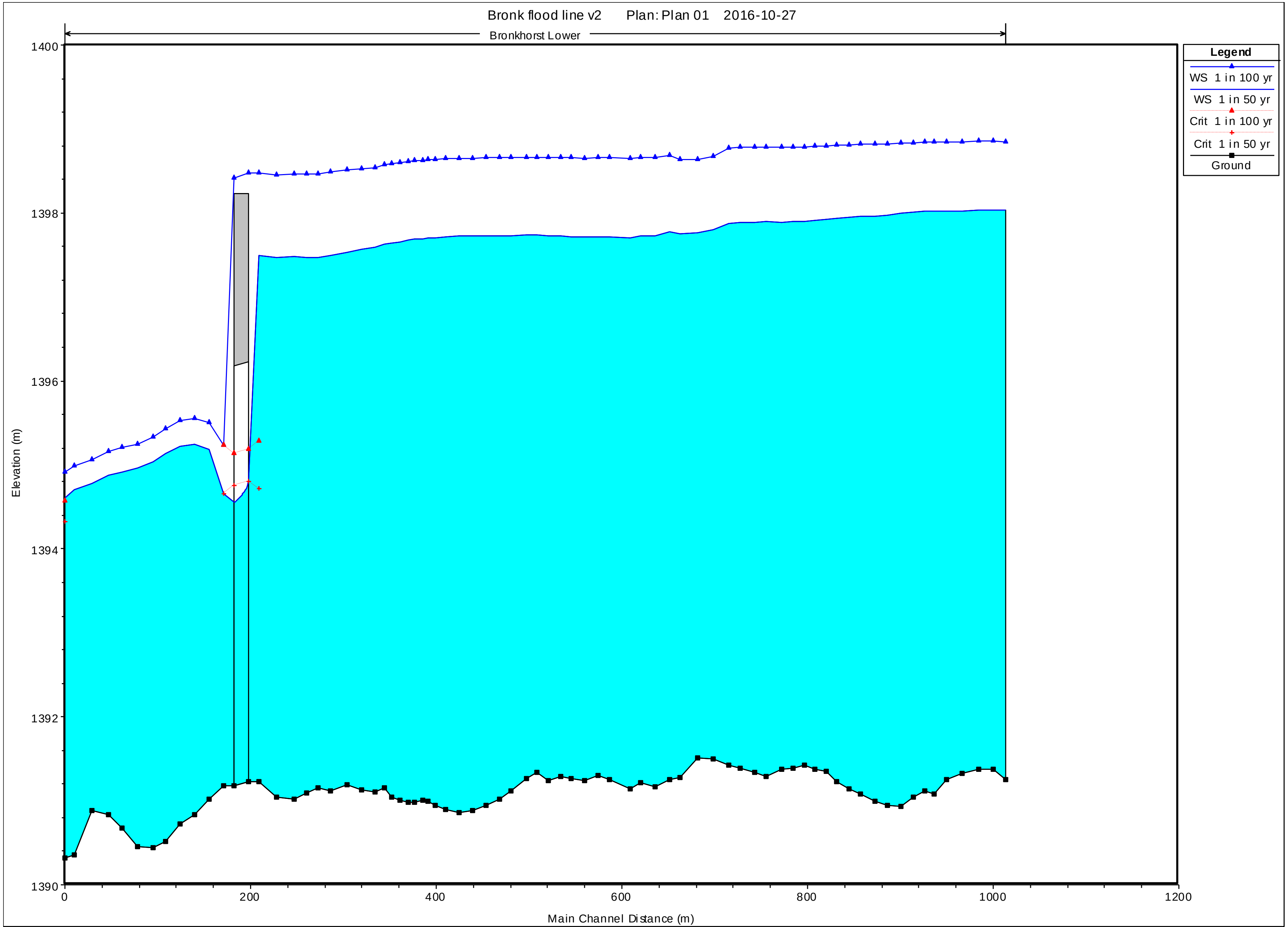
B

Hydraulic Model Output and Long Section

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
Lower	1030	1 in 50 yr	954.39	1391.25	1398.04		1398.23	0.000714	2.71	595.27	188.44	0.33
Lower	1030	1 in 100 yr	1198.38	1391.25	1398.85		1399.02	0.000567	2.6	748.06	188.44	0.3
Lower	1017	1 in 50 yr	954.39	1391.38	1398.04		1398.22	0.000731	2.72	634.88	229.92	0.34
Lower	1017	1 in 100 yr	1198.38	1391.38	1398.86		1399.01	0.000536	2.52	828.61	239.38	0.29
Lower	1001	1 in 50 yr	954.39	1391.38	1398.03		1398.2	0.000745	2.73	637.93	231.61	0.34
Lower	1001	1 in 100 yr	1198.38	1391.38	1398.86		1399	0.000546	2.53	834.04	244.55	0.3
Lower	983	1 in 50 yr	954.39	1391.33	1398.02		1398.19	0.00069	2.65	659.64	238.17	0.33
Lower	983	1 in 100 yr	1198.38	1391.33	1398.85		1398.99	0.000509	2.46	861.64	250.78	0.29
Lower	966	1 in 50 yr	954.39	1391.25	1398.02		1398.17	0.000593	2.46	698.27	249.42	0.3
Lower	966	1 in 100 yr	1198.38	1391.25	1398.85		1398.98	0.00044	2.3	908.89	259.6	0.27
Lower	953	1 in 50 yr	954.39	1391.08	1398.03		1398.16	0.000518	2.34	726.09	249.58	0.29
Lower	953	1 in 100 yr	1198.38	1391.08	1398.85		1398.97	0.000398	2.21	936.31	260.24	0.26
Lower	943	1 in 50 yr	954.39	1391.12	1398.02		1398.16	0.000505	2.3	734.18	253.32	0.28
Lower	943	1 in 100 yr	1198.38	1391.12	1398.85		1398.96	0.000388	2.18	948.02	264.36	0.25
Lower	931	1 in 50 yr	954.39	1391.05	1398.01		1398.15	0.000502	2.3	728.76	255.35	0.28
Lower	931	1 in 100 yr	1198.38	1391.05	1398.84		1398.96	0.000385	2.17	945.81	266.94	0.25
Lower	917	1 in 50 yr	954.39	1390.93	1398		1398.14	0.000465	2.24	735.61	259.89	0.27
Lower	917	1 in 100 yr	1198.38	1390.93	1398.83		1398.95	0.000358	2.12	956.42	269.06	0.24
Lower	903	1 in 50 yr	954.39	1390.94	1397.98		1398.13	0.00049	2.29	722.23	265.53	0.28
Lower	903	1 in 100 yr	1198.38	1390.94	1398.82		1398.95	0.000368	2.15	949.19	273.1	0.25
Lower	889	1 in 50 yr	954.39	1391	1397.97		1398.13	0.000532	2.36	720.11	284.14	0.29
Lower	889	1 in 100 yr	1198.38	1391	1398.82		1398.94	0.00038	2.16	965.78	291.82	0.25
Lower	874	1 in 50 yr	954.39	1391.08	1397.96		1398.12	0.000544	2.37	724.21	294.74	0.29
Lower	874	1 in 100 yr	1198.38	1391.08	1398.82		1398.93	0.000381	2.15	980.81	303.87	0.25
Lower	861	1 in 50 yr	954.39	1391.14	1397.95		1398.11	0.00055	2.35	722.55	299.9	0.29
Lower	861	1 in 100 yr	1198.38	1391.14	1398.81		1398.93	0.000382	2.13	984.6	309.8	0.25
Lower	848	1 in 50 yr	954.39	1391.23	1397.94		1398.1	0.000595	2.44	711.54	300.48	0.3
Lower	848	1 in 100 yr	1198.38	1391.23	1398.8		1398.92	0.000403	2.18	976.59	311.18	0.26
Lower	836	1 in 50 yr	954.39	1391.35	1397.93		1398.1	0.00064	2.51	704.23	302.16	0.32
Lower	836	1 in 100 yr	1198.38	1391.35	1398.8		1398.92	0.000421	2.21	972.51	312.72	0.26
Lower	824	1 in 50 yr	954.39	1391.37	1397.91		1398.09	0.000736	2.68	680.7	295.22	0.34
Lower	824	1 in 100 yr	1198.38	1391.37	1398.79		1398.91	0.00047	2.34	945.55	306.42	0.28
Lower	813	1 in 50 yr	954.39	1391.43	1397.89		1398.08	0.000801	2.79	673.12	304.31	0.35
Lower	813	1 in 100 yr	1198.38	1391.43	1398.79		1398.91	0.000484	2.36	949.61	315.25	0.28
Lower	801	1 in 50 yr	954.39	1391.39	1397.89		1398.06	0.00087	2.91	677.29	307.81	0.37
Lower	801	1 in 100 yr	1198.38	1391.39	1398.79		1398.9	0.000506	2.42	957.4	318.85	0.29
Lower	788	1 in 50 yr	954.39	1391.38	1397.89		1398.05	0.000768	2.72	702.08	307.69	0.34
Lower	788	1 in 100 yr	1198.38	1391.38	1398.79		1398.89	0.000461	2.3	985.56	323.51	0.27
Lower	772	1 in 50 yr	954.39	1391.29	1397.89		1398.03	0.000794	2.82	713.3	304.64	0.35
Lower	772	1 in 100 yr	1198.38	1391.29	1398.79		1398.88	0.000473	2.37	997.05	324.99	0.28
Lower	760	1 in 50 yr	954.39	1391.34	1397.89		1398.02	0.000861	2.9	708.82	305.83	0.36
Lower	760	1 in 100 yr	1198.38	1391.34	1398.78		1398.87	0.000492	2.39	987.62	318.64	0.28
Lower	744	1 in 50 yr	954.39	1391.39	1397.89		1398	0.000815	2.77	724.03	307.12	0.35
Lower	744	1 in 100 yr	1198.38	1391.39	1398.78		1398.86	0.000469	2.29	1006.33	322.26	0.27
Lower	731	1 in 50 yr	954.39	1391.42	1397.88		1397.99	0.000744	2.68	739.26	306.79	0.34
Lower	731	1 in 100 yr	1198.38	1391.42	1398.77		1398.86	0.000443	2.26	1029.26	330.52	0.27
Lower	715	1 in 50 yr	954.39	1391.5	1397.8		1397.97	0.000765	2.67	568.49	162.5	0.34
Lower	715	1 in 100 yr	1198.38	1391.5	1398.68		1398.84	0.000618	2.62	715.58	175.56	0.31
Lower	698	1 in 50 yr	954.39	1391.51	1397.76		1397.96	0.000938	2.93	528.45	157.01	0.38
Lower	698	1 in 100 yr	1198.38	1391.51	1398.64		1398.83	0.00074	2.85	672.88	172.35	0.34
Lower	680	1 in 50 yr	954.39	1391.28	1397.76		1397.93	0.000878	2.92	558.21	169.83	0.37
Lower	680	1 in 100 yr	1198.38	1391.28	1398.64		1398.81	0.000681	2.8	718.76	191.89	0.33

Lower	668	1 in 50 yr	954.39	1391.25	1397.77		1397.91	0.00097	3.09	674.94	298.41	0.39
Lower	668	1 in 100 yr	1198.38	1391.25	1398.68		1398.78	0.000556	2.55	973.6	341.43	0.3
Lower	652	1 in 50 yr	954.39	1391.17	1397.73		1397.9	0.00081	2.82	690.34	303.48	0.35
Lower	652	1 in 100 yr	1198.38	1391.17	1398.66		1398.77	0.000478	2.37	1000.56	347.18	0.28
Lower	637	1 in 50 yr	954.39	1391.22	1397.73		1397.88	0.000774	2.75	714.05	314.24	0.35
Lower	637	1 in 100 yr	1198.38	1391.22	1398.66		1398.76	0.000457	2.31	1037.12	363.49	0.27
Lower	626	1 in 50 yr	954.39	1391.14	1397.71		1397.87	0.000804	2.82	703.24	316.92	0.35
Lower	626	1 in 100 yr	1198.38	1391.14	1398.65		1398.75	0.000464	2.34	1035.46	370.26	0.27
Lower	603	1 in 50 yr	954.39	1391.25	1397.72		1397.84	0.00072	2.64	757.76	331.26	0.33
Lower	603	1 in 100 yr	1198.38	1391.25	1398.66		1398.74	0.000423	2.22	1099.95	384.91	0.26
Lower	591	1 in 50 yr	954.39	1391.3	1397.72		1397.83	0.000671	2.54	783.1	333.6	0.32
Lower	591	1 in 100 yr	1198.38	1391.3	1398.66		1398.73	0.000403	2.16	1128.94	390.84	0.25
Lower	576	1 in 50 yr	954.39	1391.24	1397.72		1397.82	0.000574	2.36	822.3	338.81	0.3
Lower	576	1 in 100 yr	1198.38	1391.24	1398.65		1398.72	0.000357	2.04	1173.07	396.87	0.24
Lower	562	1 in 50 yr	954.39	1391.27	1397.72		1397.8	0.000488	2.18	877.5	348.93	0.27
Lower	562	1 in 100 yr	1198.38	1391.27	1398.66		1398.72	0.000312	1.91	1234.1	404.41	0.22
Lower	550	1 in 50 yr	954.39	1391.29	1397.73		1397.79	0.000401	1.97	947.93	359.78	0.25
Lower	550	1 in 100 yr	1198.38	1391.29	1398.66		1398.71	0.000264	1.75	1314.7	416.45	0.21
Lower	537	1 in 50 yr	954.39	1391.24	1397.73		1397.78	0.000308	1.72	1044.67	379.34	0.22
Lower	537	1 in 100 yr	1198.38	1391.24	1398.66		1398.71	0.000207	1.55	1424.1	428.51	0.18
Lower	525	1 in 50 yr	954.39	1391.34	1397.74		1397.78	0.000227	1.48	1181.6	404.9	0.19
Lower	525	1 in 100 yr	1198.38	1391.34	1398.67		1398.7	0.000159	1.35	1581.06	451.5	0.16
Lower	514	1 in 50 yr	954.39	1391.26	1397.74		1397.77	0.000191	1.36	1227.99	394.05	0.17
Lower	514	1 in 100 yr	1198.38	1391.26	1398.67		1398.7	0.000138	1.27	1614.15	426.88	0.15
Lower	497	1 in 50 yr	954.39	1391.12	1397.73		1397.77	0.000164	1.28	1257.8	387.73	0.16
Lower	497	1 in 100 yr	1198.38	1391.12	1398.66		1398.7	0.000129	1.24	1642.43	443.18	0.14
Lower	485	1 in 50 yr	954.39	1391.02	1397.73		1397.77	0.000146	1.21	1285.6	389.04	0.15
Lower	485	1 in 100 yr	1198.38	1391.02	1398.66		1398.69	0.000117	1.18	1671.75	443.91	0.14
Lower	470	1 in 50 yr	954.39	1390.94	1397.73		1397.77	0.000121	1.11	1319.08	380.04	0.14
Lower	470	1 in 100 yr	1198.38	1390.94	1398.66		1398.69	0.0001	1.11	1694.92	432.7	0.13
Lower	456	1 in 50 yr	954.39	1390.88	1397.73		1397.76	0.000115	1.09	1313.15	374.83	0.13
Lower	456	1 in 100 yr	1198.38	1390.88	1398.65		1398.69	0.000096	1.09	1682.67	423.21	0.13
Lower	441	1 in 50 yr	954.39	1390.86	1397.72		1397.76	0.000118	1.11	1287.56	369.61	0.14
Lower	441	1 in 100 yr	1198.38	1390.86	1398.65		1398.69	0.000099	1.11	1653.46	418.54	0.13
Lower	426	1 in 50 yr	954.39	1390.9	1397.71		1397.76	0.000139	1.19	1211.44	359.55	0.15
Lower	426	1 in 100 yr	1198.38	1390.9	1398.64		1398.69	0.000114	1.18	1569.23	409.53	0.14
Lower	416	1 in 50 yr	954.39	1390.94	1397.7		1397.76	0.000168	1.31	1132.09	345.95	0.16
Lower	416	1 in 100 yr	1198.38	1390.94	1398.64		1398.68	0.000136	1.28	1478.92	398.64	0.15
Lower	408	1 in 50 yr	954.39	1390.99	1397.7		1397.76	0.000191	1.38	1083.3	336.66	0.17
Lower	408	1 in 100 yr	1198.38	1390.99	1398.63		1398.68	0.000152	1.35	1420.7	386.67	0.16
Lower	402	1 in 50 yr	954.39	1391.01	1397.7		1397.75	0.000196	1.39	1067.92	327.75	0.17
Lower	402	1 in 100 yr	1198.38	1391.01	1398.63		1398.68	0.000155	1.36	1393.8	370.85	0.16
Lower	393	1 in 50 yr	954.39	1390.98	1397.69		1397.75	0.000223	1.5	1000.67	306.86	0.19
Lower	393	1 in 100 yr	1198.38	1390.98	1398.62		1398.68	0.000176	1.45	1305.13	345.14	0.17

Lower	387	1 in 50 yr	954.39	1390.98	1397.67		1397.75	0.000255	1.6	934.18	287.15	0.2
Lower	387	1 in 100 yr	1198.38	1390.98	1398.61		1398.68	0.000202	1.56	1218.8	321.83	0.18
Lower	377	1 in 50 yr	954.39	1391.01	1397.66		1397.75	0.000284	1.68	883.9	272.29	0.21
Lower	377	1 in 100 yr	1198.38	1391.01	1398.6		1398.68	0.000225	1.64	1152.97	304.02	0.19
Lower	369	1 in 50 yr	954.39	1391.05	1397.64		1397.74	0.000312	1.75	829.19	252.4	0.22
Lower	369	1 in 100 yr	1198.38	1391.05	1398.58		1398.67	0.00025	1.72	1080.58	281.49	0.2
Lower	360	1 in 50 yr	954.39	1391.15	1397.63		1397.74	0.000327	1.79	797.94	242.89	0.23
Lower	360	1 in 100 yr	1198.38	1391.15	1398.57		1398.67	0.000266	1.77	1042.6	276.14	0.21
Lower	351	1 in 50 yr	954.39	1391.11	1397.59		1397.73	0.000429	2.02	718.17	238.49	0.26
Lower	351	1 in 100 yr	1198.38	1391.11	1398.54		1398.66	0.000335	1.96	963.01	282.77	0.23
Lower	336	1 in 50 yr	954.39	1391.13	1397.56		1397.72	0.000542	2.27	685.53	248.95	0.29
Lower	336	1 in 100 yr	1198.38	1391.13	1398.53		1398.66	0.000402	2.15	954.53	314.4	0.25
Lower	320	1 in 50 yr	954.39	1391.19	1397.53		1397.71	0.000653	2.49	663.61	263.95	0.32
Lower	320	1 in 100 yr	1198.38	1391.19	1398.52		1398.65	0.000446	2.26	954.18	330.44	0.27
Lower	303	1 in 50 yr	954.39	1391.12	1397.5		1397.7	0.000755	2.61	628.1	252.7	0.34
Lower	303	1 in 100 yr	1198.38	1391.12	1398.49		1398.64	0.000511	2.38	909.08	322.55	0.29
Lower	289	1 in 50 yr	954.39	1391.16	1397.47		1397.69	0.000808	2.74	596.13	230.61	0.35
Lower	289	1 in 100 yr	1198.38	1391.16	1398.47		1398.63	0.000568	2.54	871.23	320.23	0.3
Lower	277	1 in 50 yr	954.39	1391.09	1397.47		1397.67	0.000748	2.63	614	231.48	0.34
Lower	277	1 in 100 yr	1198.38	1391.09	1398.46		1398.62	0.000546	2.48	887.22	324.33	0.3
Lower	263	1 in 50 yr	954.39	1391.02	1397.48		1397.65	0.000688	2.53	636.93	228.3	0.32
Lower	263	1 in 100 yr	1198.38	1391.02	1398.46		1398.61	0.000528	2.44	908.98	327.09	0.29
Lower	244	1 in 50 yr	954.39	1391.04	1397.46		1397.64	0.000724	2.62	622.95	218.62	0.33
Lower	244	1 in 100 yr	1198.38	1391.04	1398.45		1398.6	0.000575	2.57	894.7	322.72	0.3
Lower	225	1 in 50 yr	954.39	1391.23	1397.49	1394.72	1397.61	0.000675	2.52	688.74	235.2	0.32
Lower	225	1 in 100 yr	1198.38	1391.23	1398.48	1395.29	1398.58	0.000528	2.46	966.66	325.75	0.29
Lower	200		Culvert									
Lower	188	1 in 50 yr	954.39	1391.18	1394.66	1394.66	1396.39	0.009467	6.38	164.93	140.41	1.09
Lower	188	1 in 100 yr	1198.38	1391.18	1395.24	1395.24	1397.24	0.008953	6.88	192.25	193.66	1.09
Lower	172	1 in 50 yr	954.39	1391.02	1395.18		1395.7	0.004152	4.64	355.06	192	0.74
Lower	172	1 in 100 yr	1198.38	1391.02	1395.5		1396.08	0.004377	5.02	419.51	212.96	0.77
Lower	157	1 in 50 yr	954.39	1390.84	1395.25		1395.6	0.002788	4	409.2	190.35	0.61
Lower	157	1 in 100 yr	1198.38	1390.84	1395.56		1395.97	0.003168	4.46	471.04	211.46	0.66
Lower	141	1 in 50 yr	954.39	1390.72	1395.22		1395.55	0.002812	4.1	411.11	187.86	0.62
Lower	141	1 in 100 yr	1198.38	1390.72	1395.53		1395.92	0.003073	4.49	470.95	199.41	0.66
Lower	125	1 in 50 yr	954.39	1390.52	1395.13		1395.5	0.003135	4.32	393.17	183.42	0.65
Lower	125	1 in 100 yr	1198.38	1390.52	1395.43		1395.86	0.003498	4.76	448.56	195.81	0.7
Lower	111	1 in 50 yr	954.39	1390.44	1395.04		1395.45	0.00347	4.57	381.82	187.03	0.69
Lower	111	1 in 100 yr	1198.38	1390.44	1395.33		1395.8	0.003815	4.99	437.06	198.28	0.73
Lower	95	1 in 50 yr	954.39	1390.46	1394.96		1395.39	0.003747	4.65	375.05	191.93	0.71
Lower	95	1 in 100 yr	1198.38	1390.46	1395.25		1395.74	0.004013	5.02	432.23	201.94	0.74
Lower	78	1 in 50 yr	954.39	1390.67	1394.92		1395.31	0.003742	4.52	381.82	196.88	0.71
Lower	78	1 in 100 yr	1198.38	1390.67	1395.21		1395.66	0.003991	4.88	439.94	207.11	0.74
Lower	63	1 in 50 yr	954.39	1390.84	1394.87		1395.25	0.003848	4.44	384.29	201.71	0.71
Lower	63	1 in 100 yr	1198.38	1390.84	1395.16		1395.6	0.00407	4.78	443.36	212.24	0.74
Lower	46	1 in 50 yr	954.39	1390.88	1394.78		1395.18	0.004313	4.64	372.08	202.86	0.75
Lower	46	1 in 100 yr	1198.38	1390.88	1395.07		1395.52	0.004466	4.95	431.3	211.83	0.77
Lower	27	1 in 50 yr	954.39	1390.36	1394.7		1395.1	0.003684	4.59	390.47	209.2	0.71
Lower	27	1 in 100 yr	1198.38	1390.36	1394.99		1395.44	0.003925	4.95	451.08	220.32	0.74
Lower	17	1 in 50 yr	954.39	1390.32	1394.61	1394.32	1395.06	0.004006	4.74	380.24	213.89	0.73
Lower	17	1 in 100 yr	1198.38	1390.32	1394.91	1394.57	1395.4	0.004	4.95	446.15	221.56	0.74

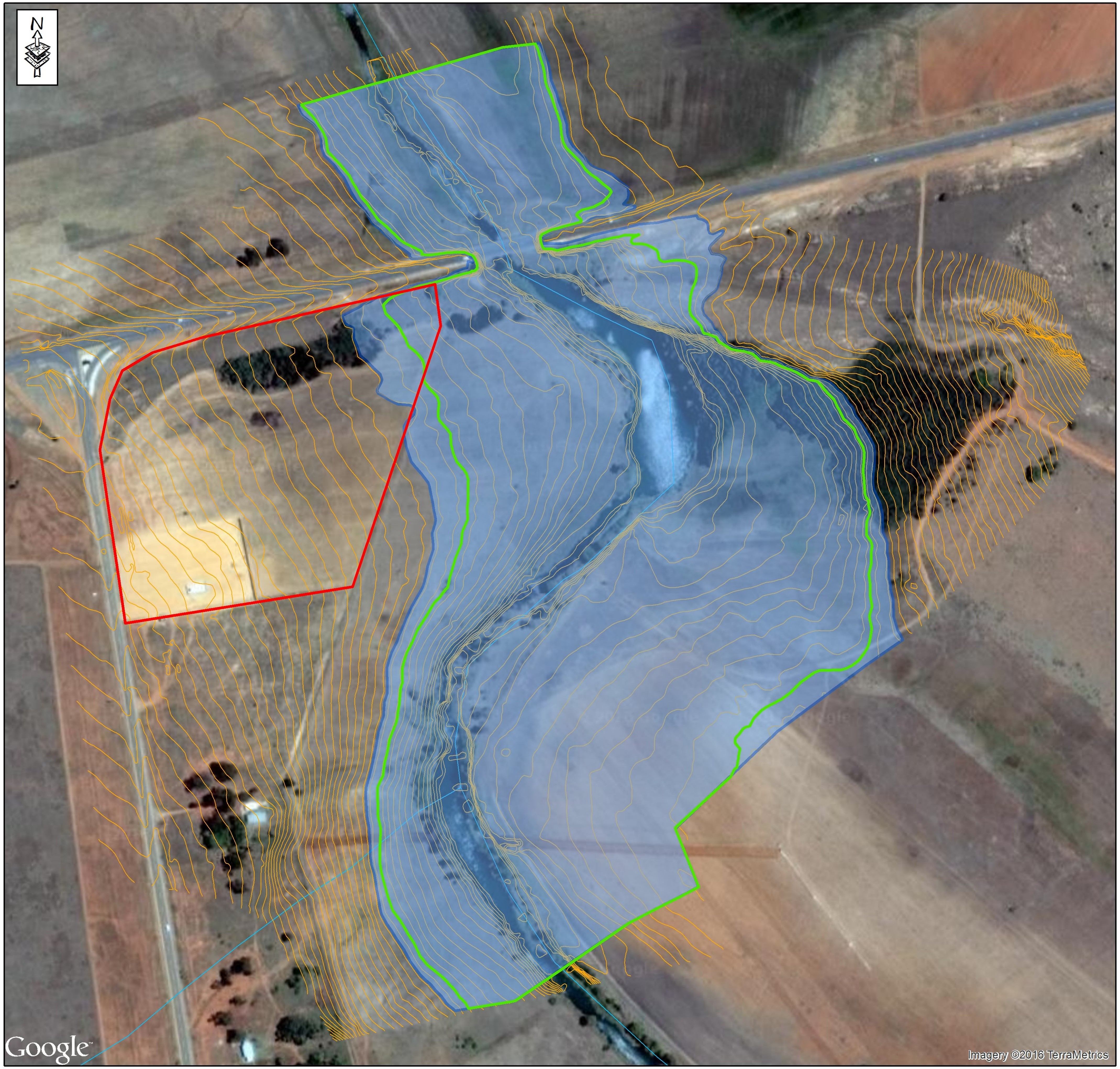


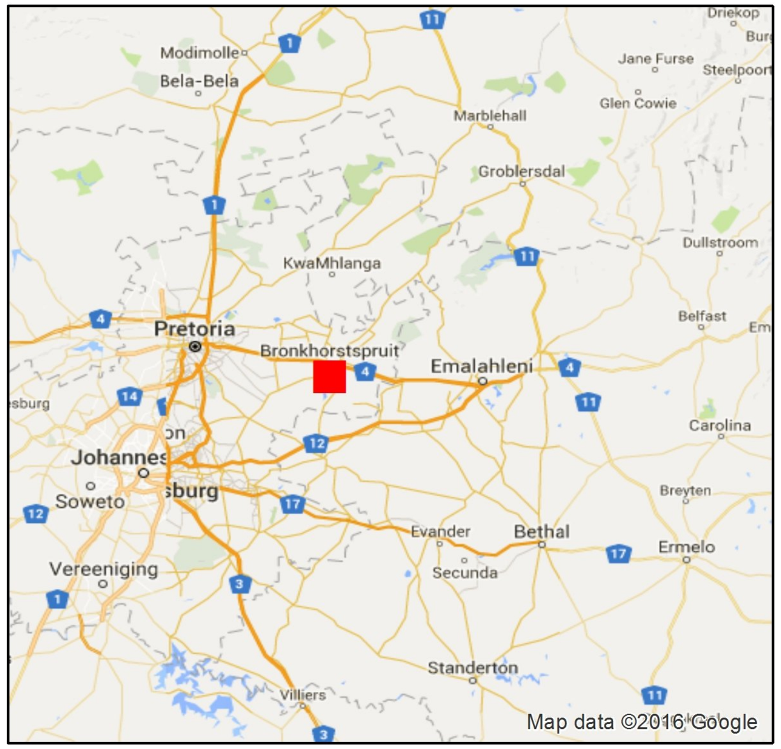
Bronk flood line v2 Plan: Plan 01 2016-10-27
Bronkhorst Lower
Legend
WS 1 in 100 yr
WS 1 in 50 yr
Crit 1 in 100 yr
Crit 1 in 50 yr
Ground
Elevation (m)
1400
1398
1396
1394
1392
1390
0
200
400
600
800
1000
1200
Main Channel Distance (m)

Knight Piésold

C

Inundation Maps





Legend:

- Project Site
- Floodlines - 1:50yr
- Floodlines - 1:100yr
- Contours - LiDAR
- Rivers & Streams

Projection: WG29

0 37.5 75 150 225 300 Meters

Bronkhorstspruit Development Floodlines

Knight Piésold CONSULTING

302-00307/09	October 2016