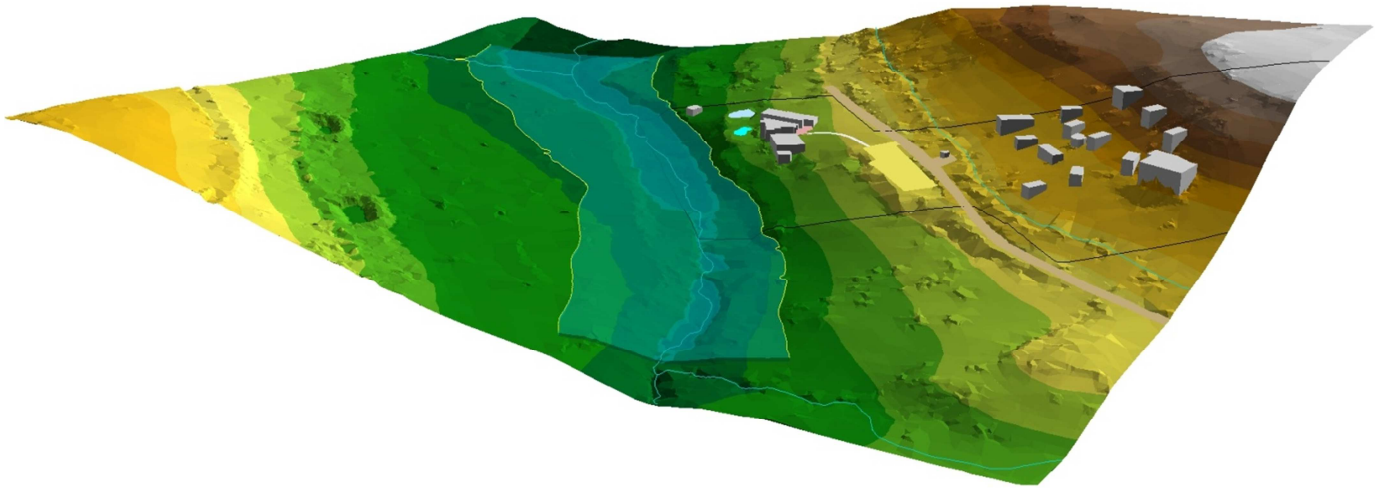


# 100-YEAR FLOOD LINES FOR THE MAGALIES RIVER AT THE MAGALIES RIVER LODGE ON PORTION 77 OF THE FARM KRUITFONTEIN 511 JQ, MOGALE CITY LOCAL MUNICIPALITY, GAUTENG PROVINCE, RSA



Compiled by

**Garfield Krige**

*Pr.Sci.Nat. Aquatic Science (Reg. No. 400068/10)*  
and

**Al Zylstra**

*Pr.Eng. (Reg. No. 730493)*

of

**African Environmental Development  
PO Box 1588  
Rant en Dal 1751**

**Tel: 083 657 0560  
Fax: 086 670 5102  
E-mail: [info@aed.co.za](mailto:info@aed.co.za)**

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**Cover Image:** A 3-D DTM of the terrain surrounding the study area, showing the 100-year floodplain of the Magalies River, at, upstream, and immediately downstream from study area, i.e. Portion 77 of the farm Kruitfontein 511 JQ

**Prepared for:**



**Eco Assessments Ecological and Environmental Consultants**

Box 441037  
Linden 2104  
Tel: +27 11 783 3428  
Email: mark@ecoassessments.co.za

**Prepared by:**



**African Environmental Development**

PO Box 1588, Rant-en-Dal, 1751  
129 Malmani Rd, Sterkfontein Country  
Estates, Krugersdorp, RSA 1739  
Tel: +27 83 657 0560  
Email: info@aed.co.za

**On behalf of the:**



**Magalies River Lodge**

-25.98802, 27.5468  
Magaliesburg 1791  
Tel: +27 71 605 3531 or  
+27 83 326 4819  
Email: stay@magaliesriverlodge.co.za

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## List of Acronyms and Abbreviations

Item	Description
~	Approximately (e.g. ~10 m wide = "approximately 10 m wide")
>	Greater than
<	Less than
Ø	Diameter (referring to a pipe or cylinder)
3-D or 3D	Three dimensional
AED	African Environmental Development
□	Centreline
CAD	Computer Aided Drawing
CSIR	South African Council of Science & Industrial Research
DTM	Digital Terrain Model
DEM	Digital Elevation Model
DWS	Department of Water & Sanitation
FR Number	Froude Number
GIS	Geographic Information Service
HRU	Hydrological Research Unit (a division of the Civil Engineering Department of the University of the Witwatersrand in South Africa)
LiDAR	Light Detection and Ranging, a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth. Usually done from an aeroplane, but more recently also using a drone when smaller areas are to be surveyed
mamsl	Metres above mean sea level (elevation)
MAP	Mean annual precipitation (rainfall, measured in millimetres)
MAR	Mean annual run-off (the amount of the annual rainfall that reaches a watercourse, measured in millimetres)
MCLM	Mogale City Local Municipality
N	North
$\eta$	Mannings roughness coefficient
$P_e$	Probability
RI	Return interval (pertaining to floods, e.g. RI of 100-years)
RI's	Plural of RI (Return Intervals)
S	South
SG	Surveyor General (e.g. SG Diagram)
TC	Time of Concentration (time for a storm to reach its maximum rate of rainfall)



# 100-YEAR FLOOD LINES FOR THE MAGALIES RIVER AT THE MAGALIES RIVER LODGE ON PORTION 77 OF THE FARM KRUITFONTEIN 511 JQ, MOGALE CITY LOCAL MUNICIPALITY, GAUTENG PROVINCE, RSA

## 1 Introduction and Background

*African Environmental Development (AED)* was commissioned by **Eco Assessments CC**, to develop the 100-year flood lines for the Magalies River at the Magalies River Lodge on the northeastern bank (right-hand bank) of the Magalies River, Magaliesburg, Mogale City Local Municipality (MCLM), Gauteng Province, Republic of South Africa (hereafter referred to as the "*study area*"). The goal of this study was to model the 100-year flood lines at, and in close proximity to the lodge. The request for the 100-year flood lines originates from the MCLM Division Biodiversity Management. This report is a brief description of the methodology used, the assumptions made and a discussion of the resultant 100-year flood lines of this watercourse.

### 1.1 Study Area

The Magalies River Lodge locates on Portion 77 of the farm Kruitfontein 511 IQ. The centreline (□) of the Magalies River is also the western boundary of Portion 77, hence the request for determining the 100-year flood lines of this reach of. The study area falls within the area of jurisdiction of the MCLM in Gauteng Province near Magaliesburg, immediately northeast of the Magalies River. The river flows generally in a north-northwesterly direction at the study area. The Magalies River is an upper tributary of the Crocodile River. The confluence of these two rivers occurs within the Hartbeespoort.

### 1.2 The Catchment of the Magalies River

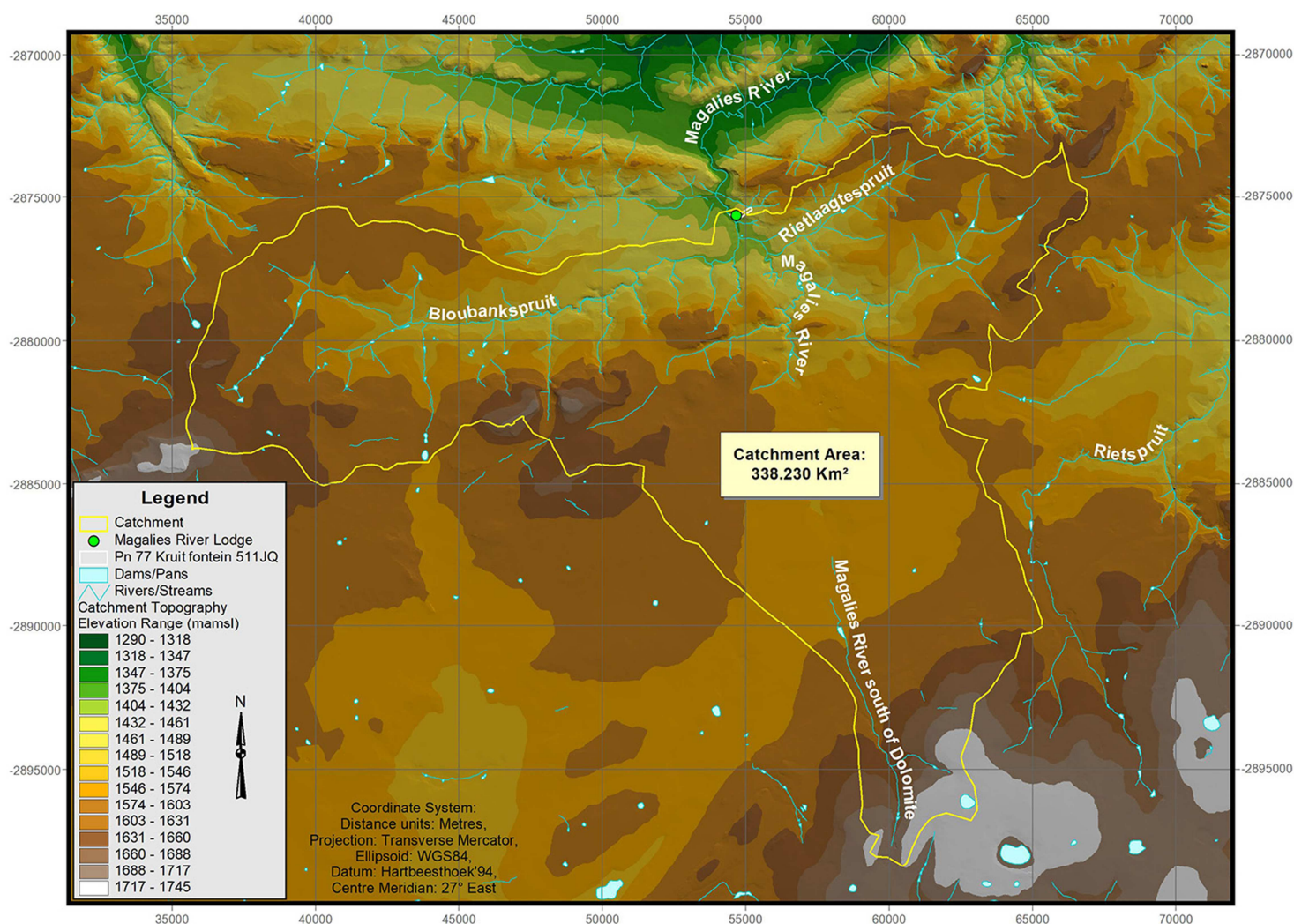
The study area falls within a single quaternary catchment, Quaternary Catchment A21F, i.e. the entire catchment of the Magalies River from its origin up the point where it enters the Hartbeespoort Dam. This catchment has a mean annual precipitation (MAP) of 677.28 mm/a, of which 25.0 mm/a reaches surface



watercourses as mean annual run-off (MAR) (*Middleton & Bailey, 2005*) (*Bailey & Pitman, 2012*). It locates within Veld Zone 4, the "Grasslands of the interior plateau" in terms of the Midgley-classification (*Midgley, 1972*).

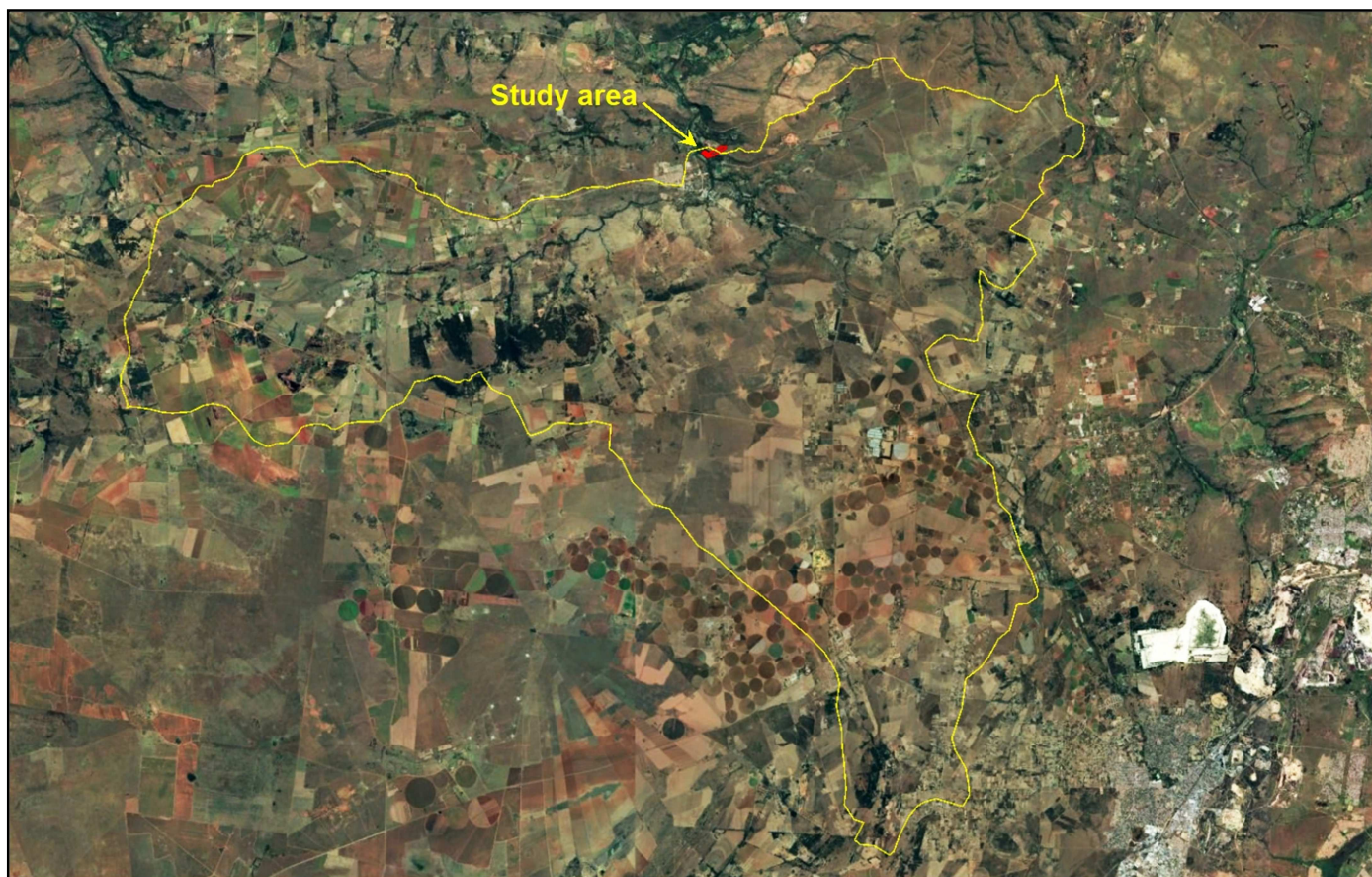
At the study area, the Magalies River's catchment has a distinctly unusual shape, mostly due to the presence of the Daspoort ridge, deflecting the course of the Magalies River's tributaries through a comparatively narrow gorge immediately downstream from the study area. The geography has resulted in a three-pointed star-shaped catchment with 3 primary tributaries, the actual Magalies River, the Bloubankspruit and the Rietlaagtespruit. Referring to **Figure 1**, it will be observed that the Bloubankspruit drains the western point of the star, with the Rietlaagtespruit draining the eastern point. The Magalies River drains the southern point, which in itself is an unusual catchment, as it portrays two distinct watercourse reaches, separated by a more-or-less featureless area approximately 9 Km wide, where there is no visible surface watercourse. The reason for this area lacking surface water is the geology underlying the surface being dolomite of the Malmani Sub-Group, Chuniespoort Group of the Transvaal Supergroup. The dolomitic area is almost 12 Km wide between the two reaches of the Magalies River. Dolomite in this area is a karstic formation and the upper reach of the Magalies River simply disappears (water filters into the porous ground) shortly after it reaches the edge of the dolomite. It then flows via the Steenkoppie dolomitic aquifer and re-appears at the Maloney's Eye in the upper reach of the "true" Magalies River. Although the area underlain by dolomite is mostly devoid of surface water, during a 100-year storm, surface water will flow across the land towards the northern part of the Magalies River and thus this part of the catchment must be taken into account when determining maximum flooding conditions.

Almost the entire catchment comprises of rural (undeveloped) surfaces, with only a tiny fraction being urban areas, such as the town of Magaliesburg, as can be seen in **Figure 2**. Also clearly visible in **Figure 2** are the many centre pivot irrigation circles that indicates the part of the catchment underlain by dolomite. Please refer to **Figure 1** for details of the catchment of the river and to **Figure 2**, an aerial image, for more detail on the physical character of this catchment.



**Figure 1:** The catchment of the Magalies River up to (and including) the study area. The catchment has a somewhat unusual shape, when compared to a "normal" elongated river catchment. (Topography created using 5-m contour lines obtained from the Surveyor General office)





**Figure 2:** The catchment of the Magalies River on an aerial image, showing the characteristics of the catchment. As can be seen, almost the entire area within the yellow line is rural, with hardly any urbanisation present. The part of the catchment underlain by dolomite is identified by the many centre pivot irrigation circles, clearly visible on this satellite image (*Aerial Imagery: Google Earth, 2020*)

### 1.3 Elevation Information Used

The contour lines used in the flood model at the study area were produced using the DEM obtained from MCLM. 0.50-m contour lines were produced from this DEM. The DEM was produced using LiDAR surveying techniques. Generally speaking, AED considers LiDAR a very good technique for surveying elevations at, and around wetlands and watercourses, where it is not always possible for surveyors on foot to gain access. Furthermore, being very narrow laser beams, a LiDAR survey can penetrate all but the densest of vegetation, providing true ground elevations under tree covers. Trees and dense vegetation are often associated with rivers and wetlands. This is particularly true for the reach of the Magalies River at the study



area. The river is totally hidden by the dense tree cover, as demonstrated in **Figures 4 and 5**.

#### 1.4 Background to Flood Lines, Floodplains and Areas of Inundation

Note: Although this section mostly refers to a 100-year flood, it is true for floods with any return interval (RI).

A 100-year flood is a flood event that has a 1% probability of occurring in any given year. The 100-year flood is thus also referred to as the 1% flood, since its annual exceedance probability is 1%, or as having a return interval (RI) of 100-years. The 100-year flood is generally expressed as a flow rate,  $Q$  in  $m^3/s$ . Based on the expected 100-year flood's flow rate in a given stream or river, the flood's water level can be mapped as an area of inundation. The resulting floodplain map is referred to as the 100-year floodplain, which may be very important in how close to the stream buildings or other activities are allowed.

A common misconception exists that a 100-year flood is likely to occur only once every 100 years. In fact, statistically, there is an approximately **63.4 %** chance of a 100-year floods occurring in any given 100-year period. The **Probability ( $P_e$ )** of one of a specifically sized flood occurring during any return interval, exceeding the specifically sized flood severity, can be expressed as:

$$P_e = 1 - \left[ 1 - \left( \frac{1}{T} \right) \right]^n$$

...where  $P_e$  is the probability,  $T$  is the return interval of a given storm (e.g. 100-year, 50-year, 20-year, etc.), and  $n$  is the number of years. The exceedance probability  $P_e$  is also described as the natural, inherent, or hydraulic risk of failure when, e.g. referring to dams, bridges, etc. However, ultimately, the expected value of the number of 100-year floods occurring in any 100-year period is 1. In other words, 100-year floods have a 1% chance of occurring in any given year ( $P_e = 0.01$ ), 10-year floods have a 10% chance of occurring in any given year ( $P_e = 0.1$ ), 50-year floods have a 2% chance of occurring in any given year ( $P_e = 0.02$ ), etc. The percent chance of an  $x$ -year flood occurring in a single year can be calculated by dividing 100 by  $x$ .



## 1.5 Legal Considerations

In terms of Section 144 of the **National Water Act** of 1998 (Act 36 of 1998), a flood line, representing the highest elevation that would probably be reached during a storm with a return interval of 100 years, must be indicated on all plans for the establishment of townships. The term, “*establishment of townships*” includes the subdivision of stands or farm portions in existing townships, if the 100-year flood lines are not already indicated on these plans, or when the land-use category of a particular portion of land is changed.

The purpose of this section of the act is to inform developers/landowners or residents/occupants/tenants/land-users of the dangers of flooding.

The earlier version of the **National Building Regulations and Building Standards Act** (Act 103 of 1977) refers to the 50-year flood lines. The newer version refers to areas that are *prone to flooding*. Due to this discrepancy between different legislations, most municipalities require both the 50- and 100-year flood lines to be indicated on plans, even though the National Water Act supersedes the National Building Regulations and Building Standards Act.

According to the Constitution of South Africa no legislation can supersede another. National, Provincial and Local Legislation (By-Laws) are all on the same level and must be adhered to. Similarly, older and newer legislation pertaining to the same entity are also on the same level.

In this instance, however, MCLM only requested that the 100-year flood lines be indicated on a map of the Magalies River Lodge. The 100-year flood lines are anyhow the safer of the two flood line sets.

## 2 Design Storms and Flood Line Modelling

### 2.1 Methodology Flood Lines

The determination of flood lines is done in two steps, **1)** modelling a succession of “*design storms*”, each of them with a specific duration (1 hour, 2 hours, 24-hours,



etc.), producing a particular discharge in  $\text{m}^3/\text{s}$  and, **2)** routing the highest discharge produced in Step 1 through cross sections across representative reaches of the river/streams at the study area, which then assigns an elevation on each side of the centreline ( $\square$ ) of the stream to which floodwaters would rise at that particular cross section.

The first part of the process comprises the modelling of a succession of “design storms” with statistical RIs of 50- and 100-years and durations ranging from 1 to 24 hours, falling over the catchment at the study area during single rainfall events with a RI of 100-years.

Where a catchment is smaller than approximately ( $\sim$ ) 50  $\text{Km}^2$ , design storms are derived using a deterministic approach, as opposed to the purely statistical methods used for larger catchments (i.e. catchments larger than  $\sim 100 \text{ Km}^2$ ). This is done as a result of the difficulty of extrapolating the frequency analyses of peak discharges and experience envelope diagrams for small areas, as the range of enveloped values becomes extremely wide as the catchment area decreases. Another reason is the problem of attempting to assign recurrence intervals to these small experience envelopes. Hence, for catchments under  $\sim 50 \text{ Km}^2$ , the acceptable procedure is to employ the original Rational Method ( $Q = CIA$ ), an Empirical Method, and the Amended Rational Method, as researched, designed and published in Reports No. 1/72, ‘Design Flood Determination in South Africa’, 1972 and 1/74, ‘A Simple Procedure for Synthesizing Direct Runoff Hydrographs’ 1974, produced by a joint venture between the CSIR and the Hydrological Research Unit (HRU) (a division of the Department of Civil Engineering at the University of the Witwatersrand). The discharge is then derived using a weighting system that depends on the surface area of the catchment.

Where a catchment is larger than  $\sim 100 \text{ Km}^2$ , the standard statistical unit hydrograph Hydrological Research Unit model, as described by Bauer & Midgley (Bauer & Midgley, 1974), is used. Storms with durations of 1 to 24 hours are synthesised, using modelling techniques described in Report No 1/72 “Design Flood Determination in South Africa” (Midgley, 1972) and Report No 1/74 “A Simple Procedure for Synthesizing Direct Run-off Hydrographs” (Bauer & Midgley, 1974),





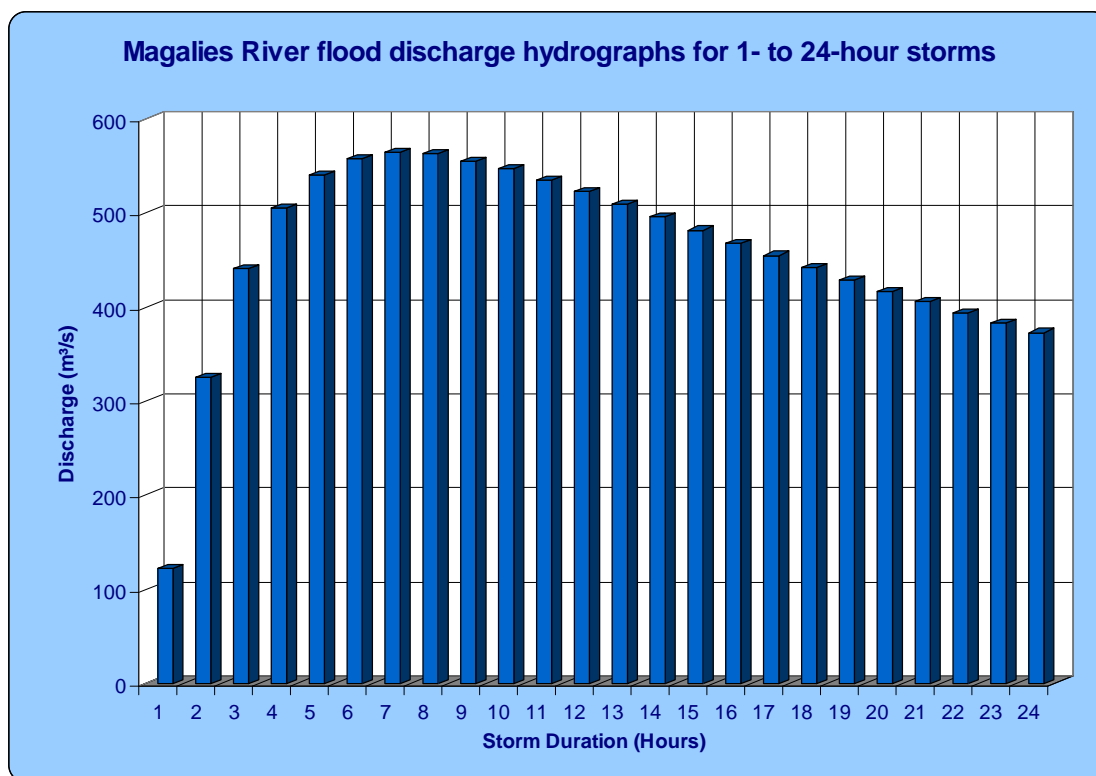
both documents produced by a joint venture of the Hydrological Research Unit, a division of the Department of Civil Engineering of the University of the Witwatersrand and the CSIR and using software developed by AED. Using the modelling techniques described by these documents, direct run-off hydrographs are then derived for the different storm durations. The hydrographs that produced the highest discharge is selected.

In instances where the catchment falls in the transition zone between ~50- and ~100-Km<sup>2</sup>, the discharge is modelled using both the Rational Method suite and the HRU method described in the paragraph above. The highest discharge is then selected.

With a catchment of 338.23 Km<sup>2</sup>, the flood discharge by the Magalies River at the study area was derived using the standard statistical unit-hydrograph HRU model (for larger catchments), as its catchment is significantly larger than 100 Km<sup>2</sup>.

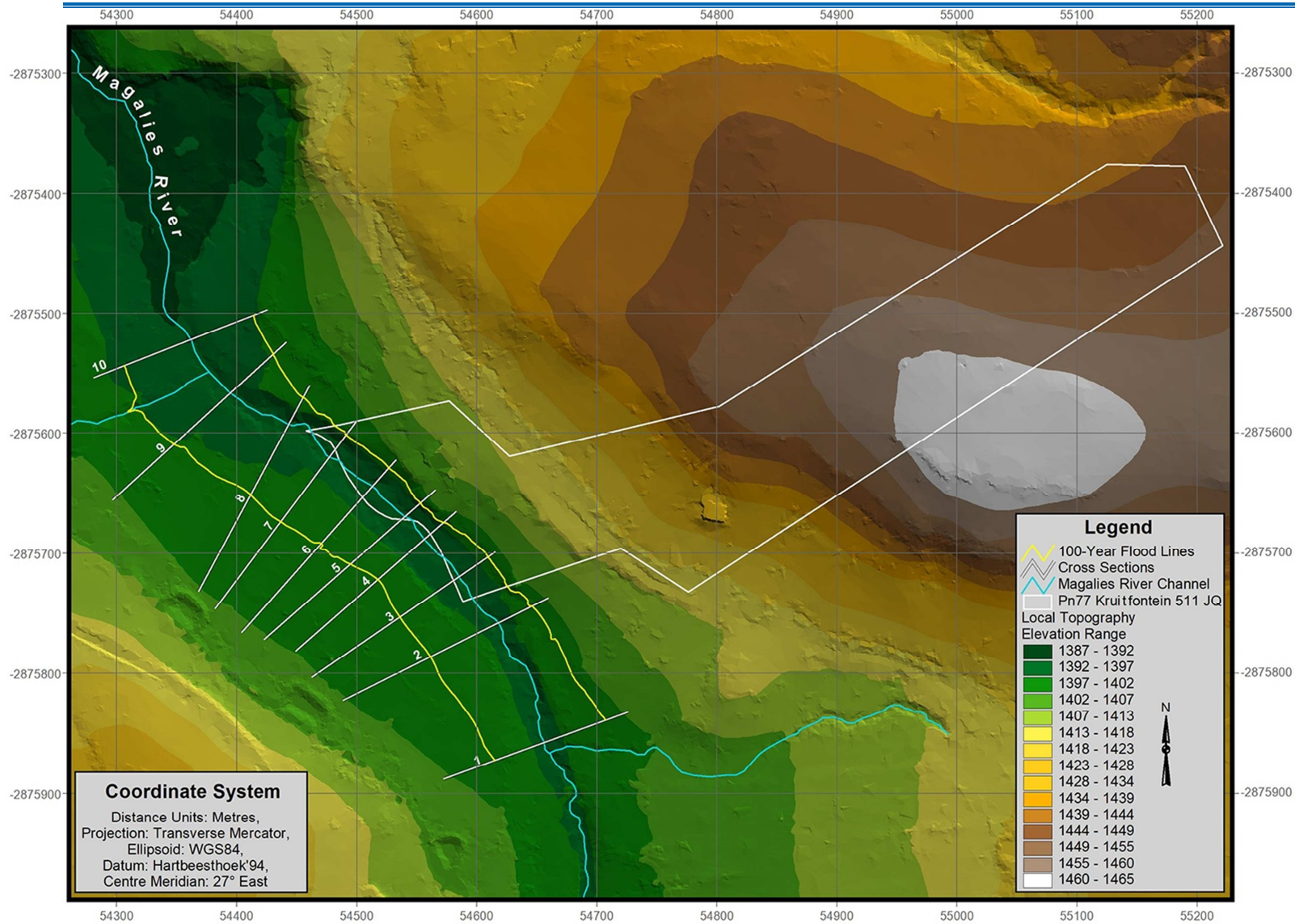
The mean annual precipitation (MAP) of the Magalies River was sourced from the Water Research Commission 2012 study (Bailie & Pitman, 2012). The average MAP for quaternary catchment A21F is 677.28 mm/a.

**Graph 1** summarises the results of the flood models for the 100-year flooding events in the Magalies River.



**Graph 1:** The hydrographs for a 100-year flood in the Magalies River at the study area. A storm of 7 hours in duration will produce the highest peak flow rate (of 563.70 m³/s)

The results of the flood model are discussed in the following section (Section 2.2), while the results are shown in **Figures 3 to 7** on the following pages.



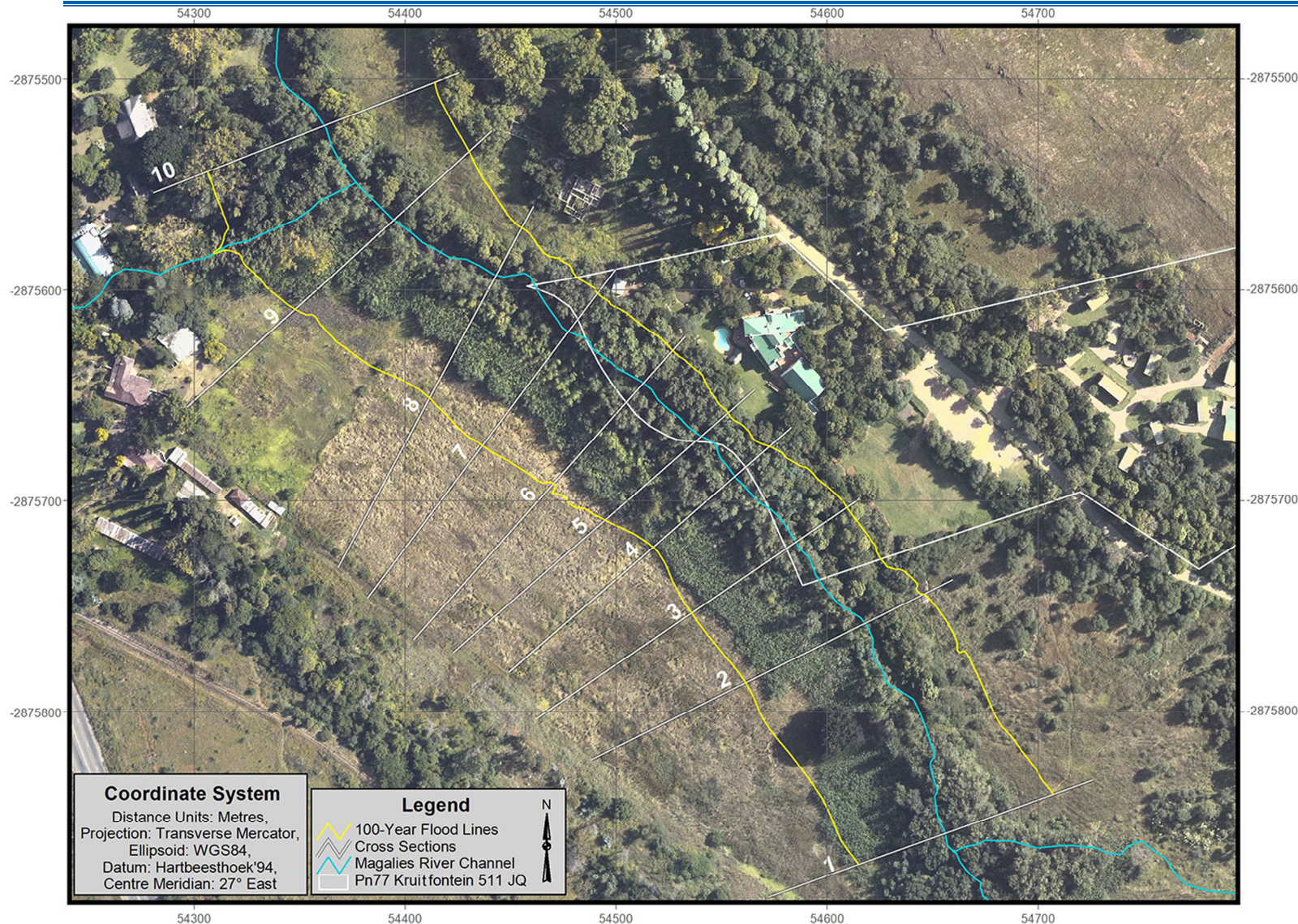




**Figure 4:** The 100-year flood lines at the study area on a backdrop of a rectified aerial image, sourced from the office of the Surveyor General. The image was produced during a 2016 survey.

Also shown are the 10 cross-sections used in this model.



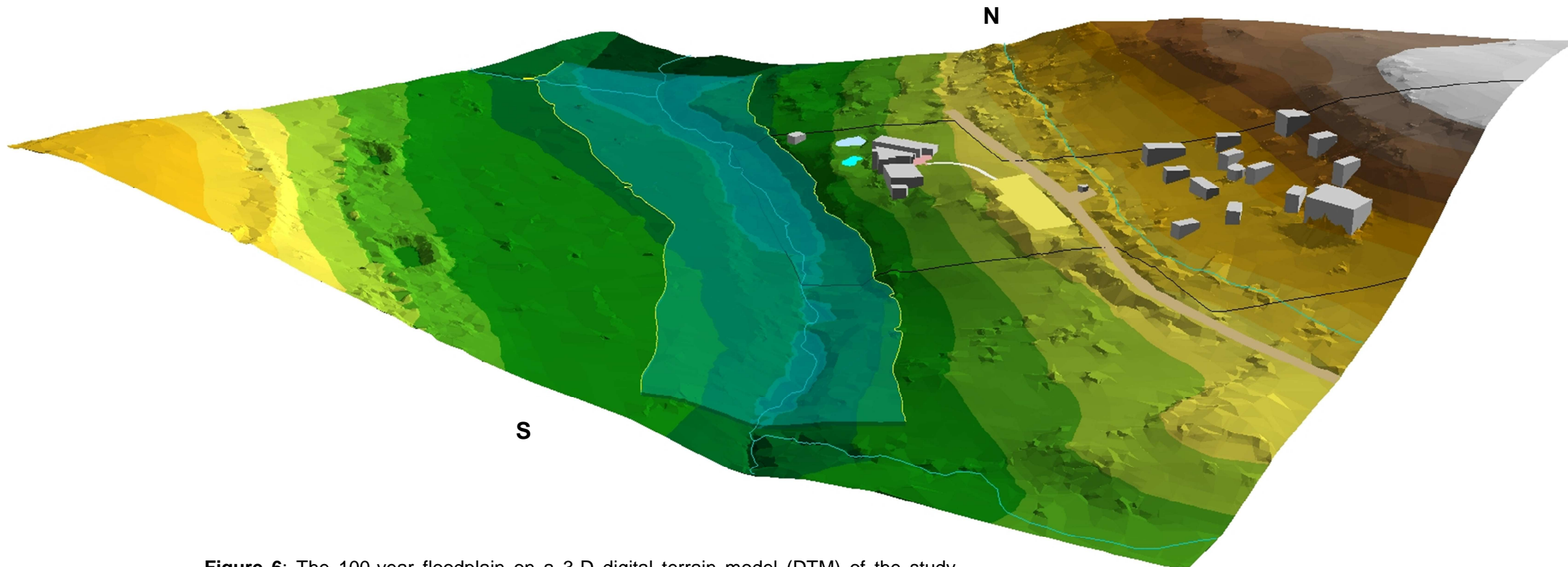


**Figure 5:** The 100-year flood lines at the study area on a backdrop of a rectified aerial image, sourced from the MCLM. The image was produced during a 2009 survey (the same time as the LiDAR survey).

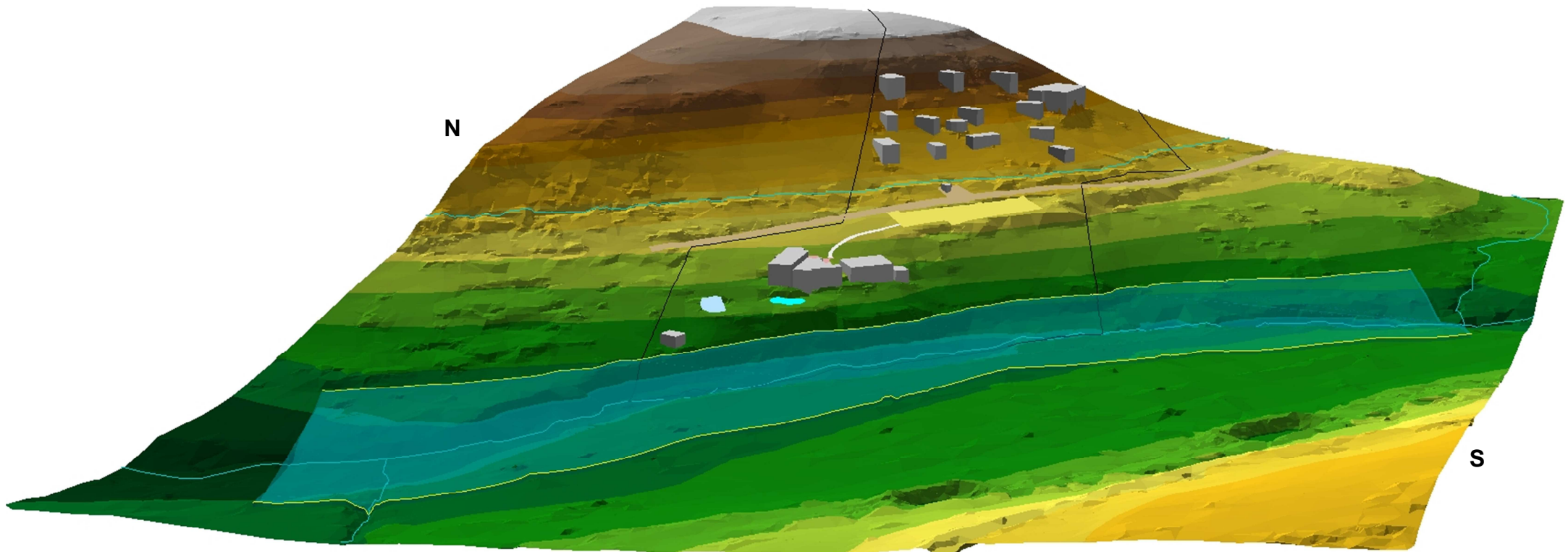
This figure is a closer view of the study area.

Also shown are the 10 cross-sections used in this model.

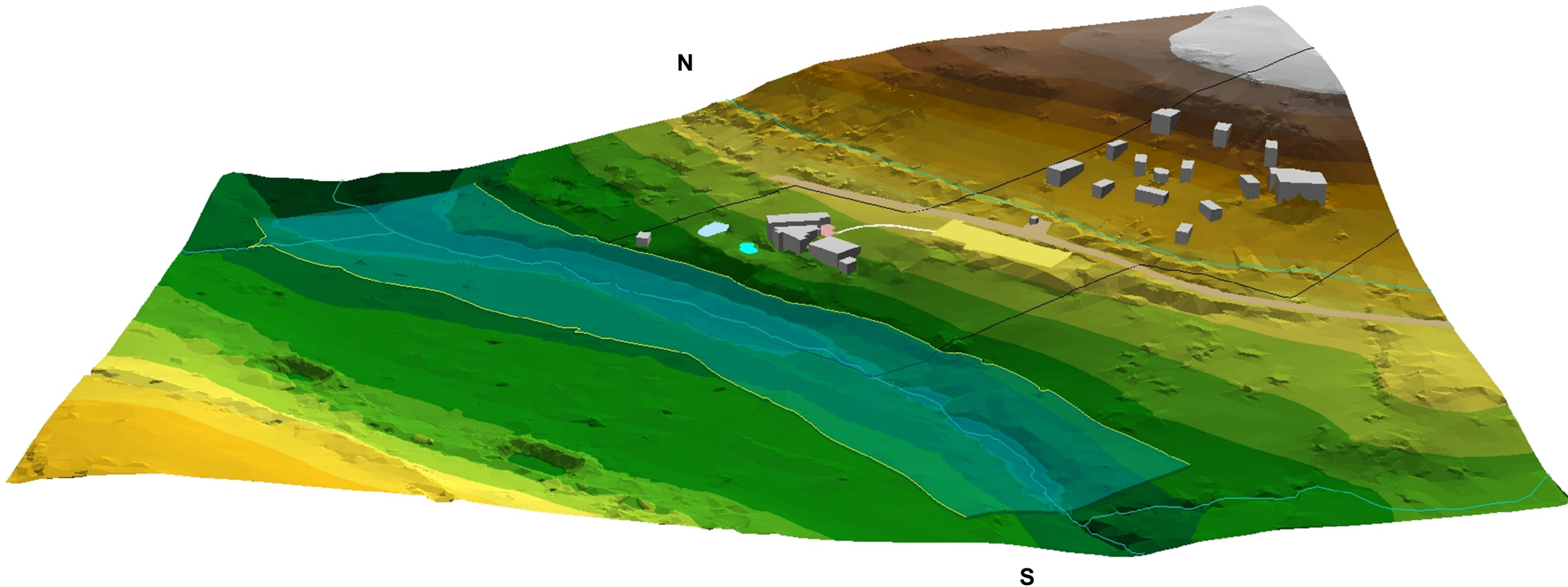




**Figure 6:** The 100-year floodplain on a 3-D digital terrain model (DTM) of the study area. In this image it is apparent that, due to the steep slope of the right-hand river bank, the largest part of the 100-year floodplain is on the left-hand side of the river's □. Please note that a 1.5x vertical exaggeration factor was used to increase the sense of depth, i.e. everything appears 1½ times deeper or higher than in reality (Topography produced using MCLM 2009 LiDAR data)



**Figure 7:** The 100-year floodplain on a 3-D digital terrain model (DTM) of the study area. Please note that a 1.5x vertical exaggeration factor was used to increase the sense of depth, i.e. everything appears 1½ times deeper or higher than in reality (Topography produced using MCLM 2009 LiDAR data)

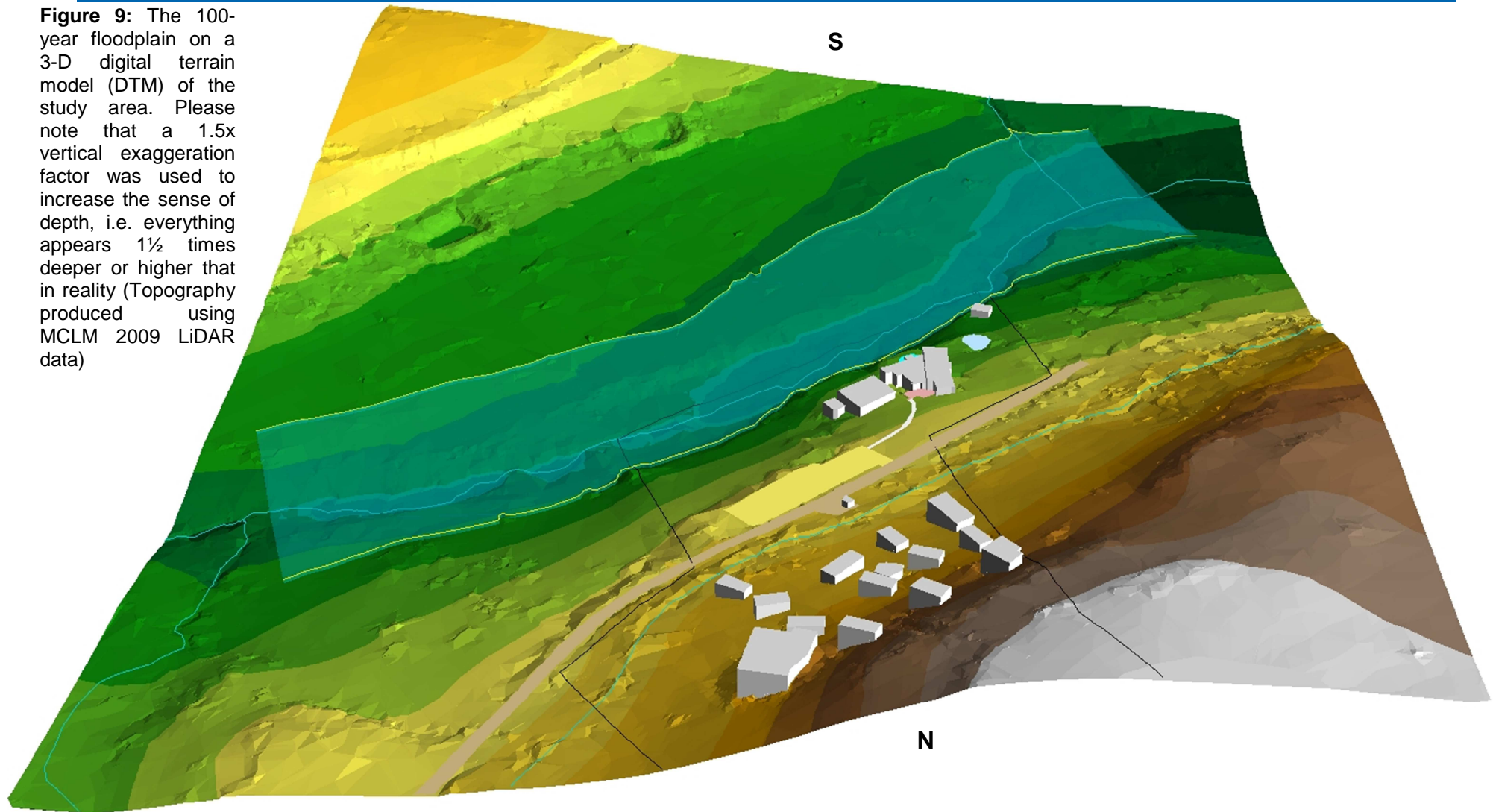


**Figure 8:** The 100-year floodplain on a 3-D digital terrain model (DTM) of the study area. Please note that a 1.5x vertical exaggeration factor was used to increase the sense of depth, i.e. everything appears 1½ times deeper or higher than in reality (Topography produced using MCLM 2009 LiDAR data)





**Figure 9:** The 100-year floodplain on a 3-D digital terrain model (DTM) of the study area. Please note that a 1.5x vertical exaggeration factor was used to increase the sense of depth, i.e. everything appears 1½ times deeper or higher than in reality (Topography produced using MCLM 2009 LiDAR data)



## 2.2 Results

In the second part of the process, the discharge (flow) in  $\text{m}^3/\text{s}$ , produced by the design storm that produced the highest discharge, was routed through cross sections across representative sections of the watercourse, using Mannings theory for Open Channel Flow (*Chow, 1959*) and using software developed by AED. Ten cross sections were plotted across representative reaches of the Magalies River (shown in **Figures 3 to 5**).

Due to the dense tree growth along and across the Magalies River at the study area, particularly high Mannings Roughness Coefficient values ( $\eta$ ) were used in this flood model. D-values ranging between 0.1 (at, and immediately adjacent to the river channel) and 0.06 to 0.055 (further away from the river's □ and up the sides of the river channel) were used. Only when the elevations reached areas above the steep slopes of the river channel, i.e. the true terrestrial zone, did we use a D-value of 0.05, as even this zone alongside the river had comparatively thick vegetation growth. Refer to **Photos 1 to 3** for more detail of the vegetation within the 100-year floodplain.



**Photo 1:** This photo shows the dense vegetation in close proximity to the Magalies River low-flow stream channel (Photo: Garfield Krige, 02/10/2020)





**Photo 2:** At and immediately downstream from the study area the Magalies River low-flow stream channel is almost blocked with dense vegetation and fallen trees (Photo: Garfield Krige, 02/10/2020)



**Photo 3:** At the Magalies River Lodge the slope of the river channel is particularly steep. At the same time, there is a much gentler slope on the other side of the river; hence the largest part of the 100-year floodplain is on the other side (western side) of the river (Photo: Garfield Krige, 02/10/2020)

The flood lines resulting from this project are shown in **Figures 3 to 7**.



## 2.3 Discharge off storms with RIs of 1- to 100-year falling over the catchment of the No-Name Stream at the study area

**Graph 1** summarises the *RI* vs. *Discharge* relationship for the Magalies River catchment at the study area. The graph also contain its regression line (trend line) formula,

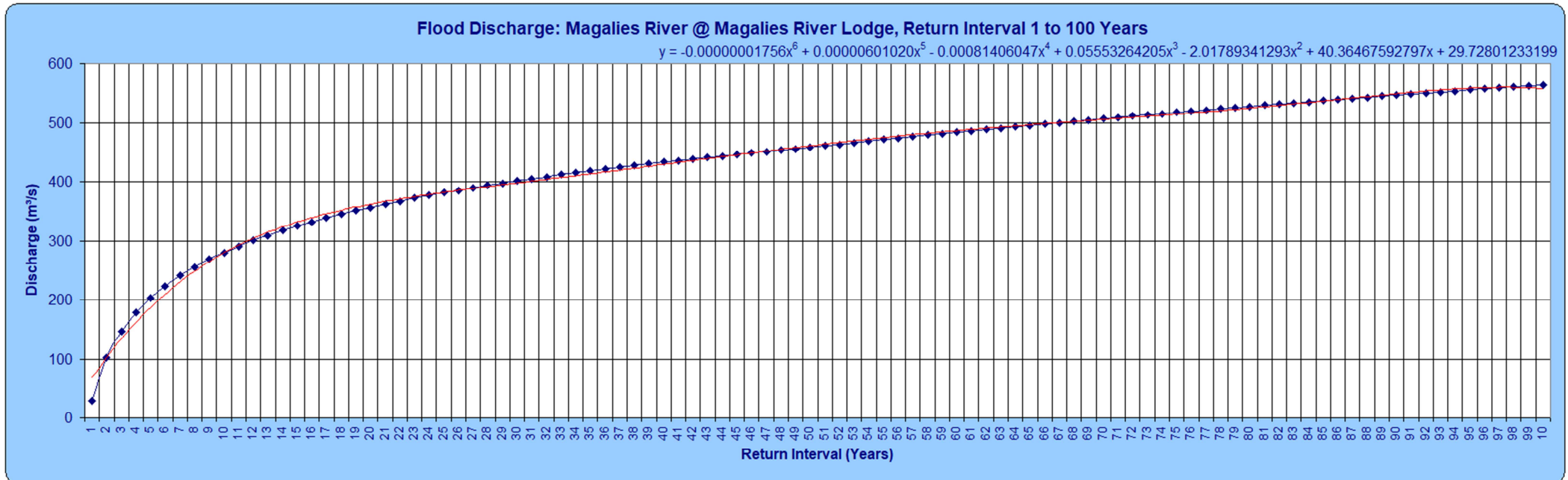
$$y = -0.00000001756x^6 + 0.00000601020x^5 - 0.00081406047x^4 + 0.05553264205x^3 - 2.01789341293x^2 + 40.36467592797x + 29.72801233199$$

...where *x* is the return interval in years (what you have) and *y* is the discharge in m<sup>3</sup>/s (what you want). Obviously, one does not have to use all those decimal places in the formula to attain a representative result.

The discharge can either be read off the graph directly, or the formula can be used to determine the discharge for a particular RI more accurately.

It must be noted that the graph and formula is specific to this particular catchment (the Magalies River at the Magalies River Lodge) and cannot be used anywhere else.

It must be furthermore also noted that this formula is only accurate for *x*-values (years) from 1 to 100. It rapidly becomes totally inaccurate when an *x*-value of 100-years is exceeded. Thus, this formula cannot be used to predict the discharge of floods with RIs of >100-years. When RIs of >100-years are required, AED uses a different approach to determine the discharge.



**Graph 2:** The discharge off storms with RIs ranging from 1- to 100-years, falling over the catchment of the Magalies River at the study area. Interestingly, the regression line (trend line) of a polynomial formula gets closer than that of a logarithmic formula



## 2.4 Comments relating to the Flood Lines

### 2.4.1 Extent of the flood lines at the study area

Referring to **Figures 3** to **7**, it is observed that, in spite of the comparatively large flow in the river during a 100-year flood, the water will not reach any of the permanent infrastructure ("permanent infrastructure" exclude the timber decks closer to the river) at the lodge. This is due to the steep slope on the lodge's side of the river and the gentler slope on the opposite side of the river. This results in a larger percentage of the 100-year floodplain being on the opposite side of the river. This is best observed in **Figure 6**, which is a 3D view, looking downstream along the river channel.

The 2-level timber deck will fall within the 100-year floodplain, but as it is not a permanent structure and it rests on poles and not walls, it will not impede the flow of the river during a 100-year flood. The decks are shown in **Photo 4**.



**Photo 4:** The two timber decks at the study area are within the 100-year floodplain, but due to their timber legs, will not impede the flow of the river during a 100-year flood. This deck is entirely covered by the tree canopy, making it impossible to indicate them on the drawings, but they locate on the right-hand side of the river between **Cross Sections 5** and **6** and almost opposite the main building of the lodge (refer to **Figure 3**) (Photo: Garfield Krige, 02/10/2020)



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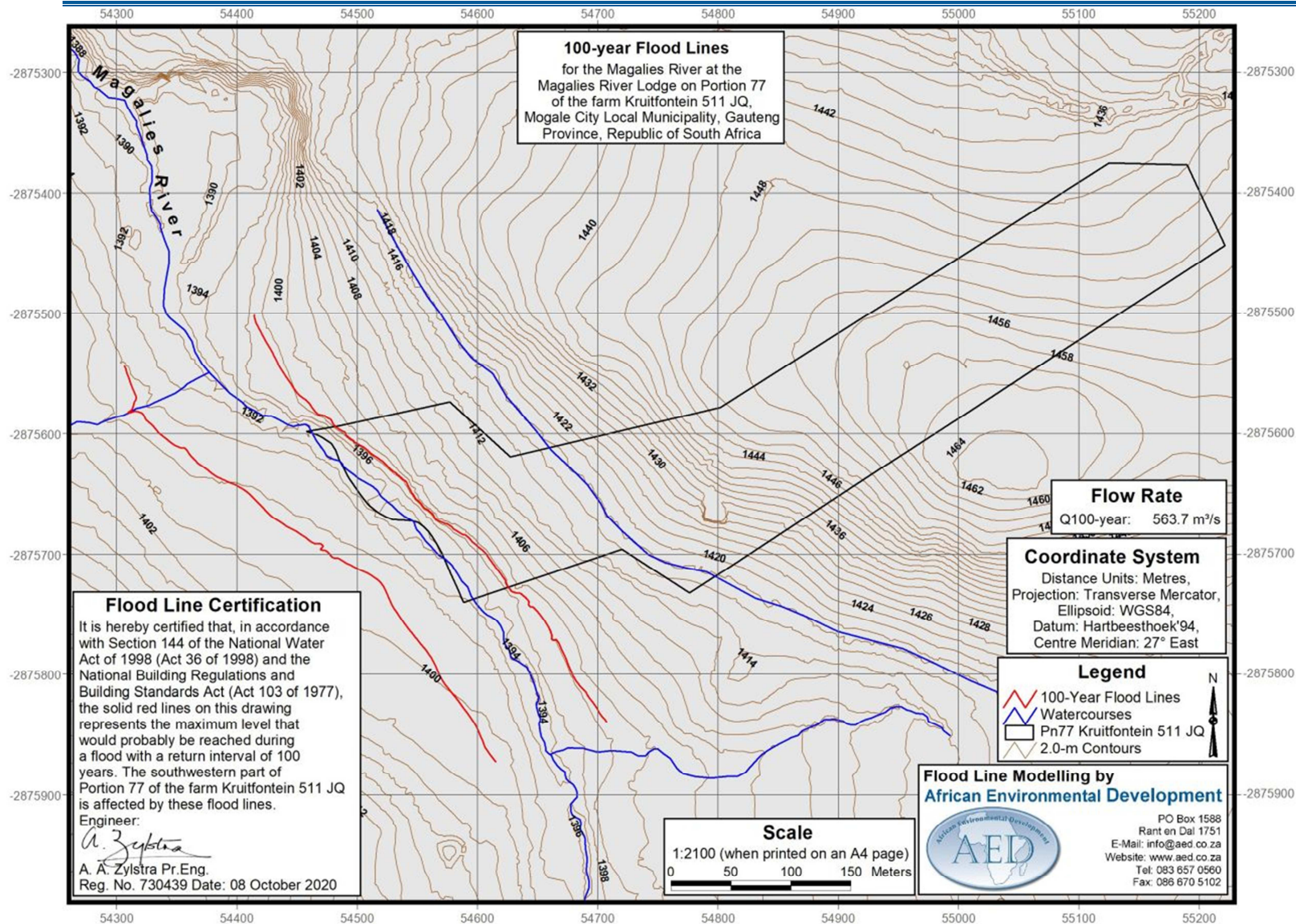
### 2.4.2 Accuracy of the LiDAR survey

A LiDAR survey from the air is orders of magnitude better than a survey by "hand" or by most any other surveying technique, particularly for surveying riverine and swampy/marshy areas where the terrain is often inaccessible to a surveyor on foot. Additionally, riverbanks are renowned for dense vegetation/trees and a survey by hand is impossible under a tree canopy or in swampy/marshy areas. Thus, AED always prefers to use LiDAR-surveyed contour lines when doing flood line work.

### 2.4.3 Coordinate System used in this report

All drawings were produced using the following parameters: **Distance Units**: Metres, **Projection**: Transverse Mercator, **Datum**: Hartbeesthoek'94, **Ellipsoid**: WGS84, with the **Centre Meridian** (or the longitude of origin - LO) of 27°. AED uses positive east and north, thus distances south of the equator and east of the 27° meridian will have positive values.





**Figure 10:** The 100-year flood lines (solid red lines) for the Magalies River.

This is a copy of the higher-resolution certified drawing attached to this document in **Appendix 1**

Topography produced using MCLM 2009 LiDAR data. All our work was done using 0.50-m contour lines. However, as the contour lines would "flow together" at the scale of an A4 page, this drawing shows 2-m contour lines only





### 3 Certification of Methods Used

#### 100-Year Flood Lines:

***Magalies River at the Magalies River Lodge, on Portion 77 of the farm  
Kruitfontein 511 JQ, Magaliesburg, Mogale City Local Municipality, Gauteng  
Province, RSA***

08/10/2020

TO WHOM IT MAY CONCERN,

This is to certify that the 100-year flood discharge for the above-mentioned watercourse at the above site was derived using Unit Hydrograph methods described in the *Report No 1/74 "A Simple Procedure for Synthesizing Direct Runoff Hydrographs"* of the *Hydrological Research Unit*, a division of the Department of Civil Engineering of the University of the Witwatersrand and using software developed by AED.

The 100-year return interval storms were synthesized from direct run-off hydrographs developed using methods described in *Report No. 1/72 "Design Flood Determination in South Africa"* of the same unit and also using software developed by AED.

Both Reports 1/72 and 1/74 were developed by a joint venture between the CSIR and the University of the Witwatersrand and are considered to be accurate methods, particularly for use under South African rainfall conditions.

The flood flow rate, determined in terms of paragraph 1, was routed through cross-sections plotted across the watercourse, using Mannings theory for open channel flow and using software developed by AED. This produced the flood elevations for the 100-year return interval storms, as indicated in the accompanying CAD files.

The 0.50-m contour lines used for this project were produced by AED using the input DEM data obtained from MCLM, who conducted the survey in 2009. The DEM was produced by a LiDAR survey. The accuracy of flood lines is directly related to the accuracy of these contour lines. AED believes that the original DEM is of an acceptable quality and adequate for the purposes of modelling flood lines.

  
A. A. Zylstra  
Pr. Eng. (Reg. No. 730493)



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## **Appendix 1: CAD Files and Certified Drawing**



**Please double-click on the above icon to open the zipped folder containing the CAD file in DXF, Shape File and KMZ file formats, as well as an image of the certified drawings in jpeg file format**