REPORT FOR THUTUKA POWER STATION SOLAR PV PLANT HYDROLOGICAL ASSESSMENT

MPUMALANGA PROVINCE, SOUTH AFRICA

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Report Name	**REPORT FOR THUTUKA POWER STATION SOLAR PV PLANT HYDROLOGICAL ASSESSMENT**		
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This report titled Report For Thutuka Power Station Solar Pv Plant Hydrological Assessment was compiled by Mapoti Mahlangu. Mapoti Mahlanguis he is a registered with the South African Council for Natural Scientific Professions.

Foreword

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Executive Summary

MKMakafane (PTY) ltd (herein referred to as Makafane) was appointed by Eskom Hld SOC Ltd (client), under the provisional of high-definition survey services to Eskom Distribution, Generation and Transmission Divisions on an "as and when required" basis for the period of 3 years contract, to conduct the Hydrological Impact Assessment Study for the proposed Thuthuka Solar photovoltaic (PV) project (65 MW).

The project site is located in quaternary Catchment C11K in the Upper Vaal Water Management Area (WMA8). The project area is surrounded by small, non-perennial Rivers. The project area experiences a Mean Annual Precipitation (MAP) of 633 mm. The Mean Annual Evaporation (MAE) is approximately 1520 mm, which is more than double the MAP for the area, which indicates a region characterized by distinct dry and wet seasons (WRC, 2015) with a negative natural water balance. The runoff depth for Quaternary Catchment C11K was calculated to be approximately 59 mm. This runoff accounts for approximately 9% of the MAP for the area.

The simulated conceptual sizing of stormwater drains/channels were designed to accommodate storm flows resulting from the 1:50-year rainfall event. The proposed stormwater management plan should be used to guide conceptual designs for the Thuthuka stormwater infrastructure. If simulated specifications are implemented, the probability of the drains overtopping will be low should a 50-year flood event occur. This holds true provided the stormwater infrastructures are maintained throughout their operational life.

It was noted during the site visit that the dams are at full capacity and they sometimes spill. It is likely that in the rainy season they would overtop. The additional stormwater that is routed into the dams will also impact on the capacity of the dams. It is recommended that more water is pumped into the coolers or other processes in operations to recycle water and improve the storage capacity of the dams and reduce the potential impacts on downstream receptors that may be affected by the overtopping dams.

The 1:50-year floodline on the river sections were modelled for the streams in proximity to the study area. The results showed that most of the project area is not within the Floodline area. However, it seems Alternative Site 2 may intersect with the modelled Floodline extent. However, this could not be confirmed in the report as the boundary of the site was not available at the time of writing this report.

The following recommendations are made for this study:

- Stormwater management specifications for a 50-year design event stipulated in this report should be used as a guide to inform conceptual and detailed engineering designs by a professional engineer;
- It is recommended that the proposed earth drains with velocities over 3 m/s must be lined with rip-rap and grassed/vegetated to prevent erosion;
- Stormwater management infrastructure needs to be maintained throughout their operational life to ensure its effectiveness;
- It is recommended that more water is pumped into the coolers or other processes to recycle water and improve the storage capacity of the dams and reduce the potential impacts on downstream receptors that may be affected by the overtopping dams;
- It recommended that the site layout is overlain with the delineated floodline extent to ascertain whether Alternative site 2 interacts with the floodline; and

- It is recommended that no development takes place within the floodline area to protect the environment and the infrastructure and to ensure compliance with Legislation.

ABBREVIATIONS

DTM	: Digital Terrain Model
MAE	: Mean Annual Evaporation
MAP	: Mean Annual Precipitation
MAR	: Mean Annual Runoff
MIPI	: Midgley and Pitman
NWA	: National Water Act
PCSWMM	: Personal Computer Storm Water Management Model
PV	: Photo Voltaic
RM3	: Rational Method Alternative 3
SDF	: Standard Design Flood
WMA	: Water Management Area

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1. Introduction

MKMakafane (PTY) ltd (herein referred to as Makafane) was appointed by Eskom Hld SOC Ltd (client), under the provisional of high-definition survey services to Eskom Distribution, Generation and Transmission Divisions on an "as and when required" basis for the period of 3 years contract, to conduct the Hydrological Impact Assessment Study for the proposed Thuthuka Solar photovoltaic (PV) project (65 MW), which is situated within the boundary of Eskom-owned land near Thuthuka Power Station in the Gert Sibande District Municipality. The locality of the study area is presented in Figure 1.

2. Study Objectives and Scope of Work

The objectives of the hydrological assessment are:

a. Hydrology and Climate: to provide hydrology and climate analysis including catchment delineation and determination of upstream catchment areas;

b. Peak Flows: to calculate peak flows using the Rational Method Alternative 3 (RM3), Standard Design Flood (SDF) and the Midgley and Pitman (MIPI) for the delineated sub-catchments;

c. Stormwater management plan: to identify constraints and generate alternative development scenarios for the drainage system that addresses environmental concerns.

d. Floodline Delineation and Mapping: to simulate the 1:50-year floodline or inundation boundary in proximity to the study area.

e. Reporting: This report was compiled to present findings of the study as well as conclusions and recommendations of the stormwater management and Floodline studies.

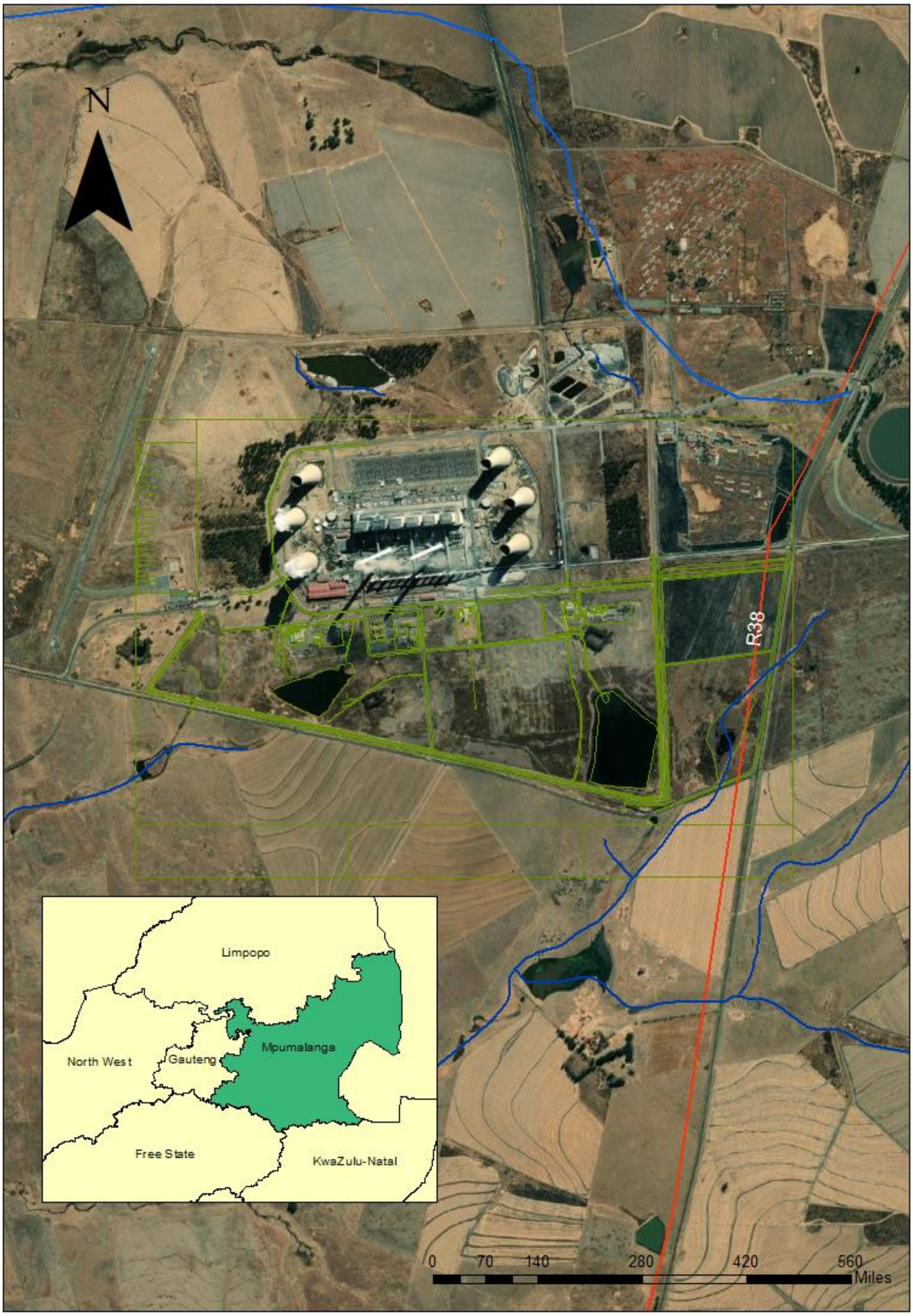


Figure 1: Locality Map of the Thuthuka PV Powerplant

3. Methodology

3.1 Baseline Hydrology and Climate

Climate data obtained from the database of the Water Resources of South Africa, 2012 study (WRC, 2015) was analysed to determine the Mean Annual Precipitation (MAP), Mean Annual Evaporation (MAE) and the Mean Annual Runoff (MAR) for the Thuthuka Power Station region and site. Historical rainfall-runoff data from 1920 to 2009 (89 years) was adequate to determine the mean hydro-meteorological parameters for the study area. These analyses were useful to provide insight into the general rainfall-runoff and evaporation dynamics at the site.

3.2 Design Rainfall and Peak Flows

Catchment delineation was undertaken in Global Mapper using Advanced Land Observing Satellite (ALOS) World 3D – 30m (AW3D30) global digital surface model (DSM) data (JAXA, 2015). This dataset is stored in a raster GeoTIFF format referenced to the Hartebeesthoek 94 Datum (WGS84 ellipsoid).

Widely used and recommended methods including the Rational Method Alternative 3 (RM3), Standard Design Flood (SDF) and the Midgley & Pitman (MIPI) were used to calculate the 1:50-year peak flows for the delineated sub-catchments (SANRAL, 2013). Design rainfall depths were determined using the Design Rainfall Programme for South Africa and the modified Hershfield equation as input to the RM3 and SDF methods, respectively.

3.3 Conceptual Stormwater Management Plan

Stormwater modelling was conducted in PCSWMM, a continuous modelling platform which assists in conceptual placement and sizing of storm water infrastructure including drains, storages and junctions. Routing of flows in the stormwater drains/channels was conducted using the dynamic wave method. Conceptual sizes of stormwater structures were determined and these will form the basis for conceptual and detailed engineering designs by the design engineer.

Stormwater management aims to fulfil several objectives which include the following:

- The need to protect the welfare and safety of people, and to protect property from flood hazards by safely routing and discharging stormwater from development sites;
- The opportunity to conserve water and make it available to the public for beneficial uses; and
- The responsibility to preserve the natural environment.

The 50-year design rainfall depth was used in the model for major systems typical of general commercial and industrial land uses as indicated in Table 1.

Table 1: Design flood frequencies for major systems

System Type	Land Use	Design Flood Recurrence Interval
	Residential	50 years
	Institutional (e.g. schools)	50 years

System Type	Land Use	Design Flood Recurrence Interval
Major	General commercial & industrial	50 years
	High value central business districts	50 – 100 years

Source: (CSIR, 2000)

3.4 Floodline Delineation

Hydraulic modelling was conducted in HEC-RAS 5.07 which allows pre-processing within the in-built RAS Mapper module. A Digital Terrain Model (DTM) was generated from the ALOS DSM for the area to make the topographic data compatible with RAS Mapper. The pre-processing involved generation of the channel geometry, including the river network, banks, flow paths and cross sections.

The HEC-RAS model simulates total energy of water by applying basic principles of mass, continuity and momentum as well as roughness factors between all cross sections (US Army Corps of Engineers, 1995). A height is calculated at each cross-section, which represents the level to which water will rise at that section, given the calculated initial peak flows for the 1:50-year event on all river sections.

Analyses are performed by first modelling flows at the sub-catchment outlet, and then moving upstream. Manning's Roughness Coefficients (n) for the channels and river banks were set at 0.03, representing natural channels without weeds, reeds and short grass on the banks (Chow, 1959).

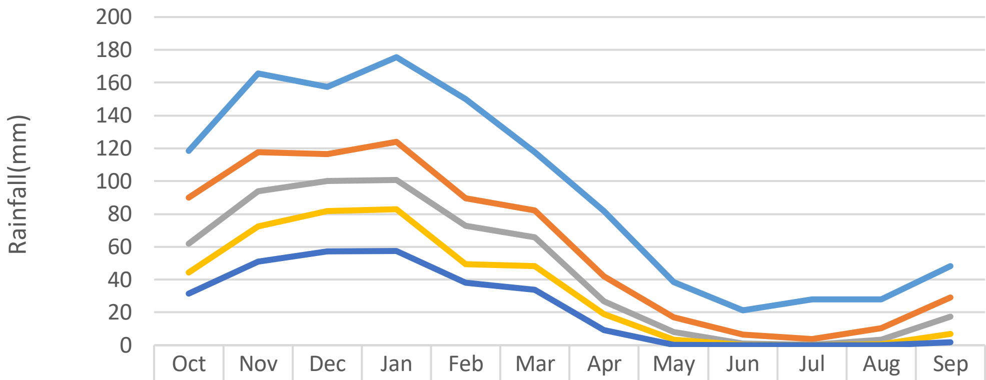
4. Catchment Characteristics

This section details an overview of the meteorological and hydrological conditions of the study area, from which the hydraulic modelling parameters were derived.

4.1 Hydrology and Climate

The project site is located in quaternary Catchment C11K in the Upper Vaal Water Management Area (WMA8) (see Figure 5). The study area is surrounded by small, non-perennial Rivers. The main River, in which the tributaries in the project site drain to is the Vaal River, which eventually joins the Orange River. The Orange River feeds into the Atlantic Ocean in a Westerly direction.

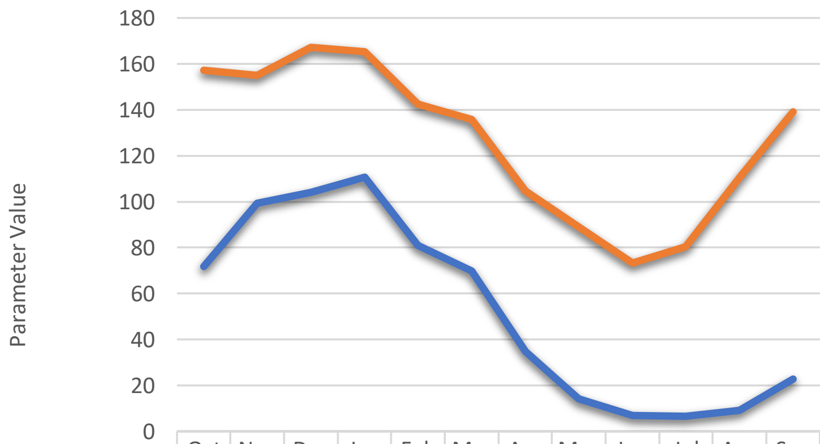
The project area experiences a Mean Annual Precipitation (MAP) of 633 mm and a Mean Annual Evaporation (MAE) of approximately 1 520 mm (WRC, 2015). Figure 2 shows that the peak rainfall is received during the month of January (90th percentile of 157 mm) with the drier season (from April to September) receiving rainfall not exceeding 100 mm per month, 90% of the time.



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
90 Percentile	119	166	157	176	150	118	82	39	21	28	28	48
70 Percentile	90	117	116	124	90	82	42	17	7	4	10	29
50 Percentile	62	94	100	101	73	66	27	8	1	0	3	17
30 Percentile	44	72	82	83	50	48	19	3	0	0	1	7
10 Percentile	32	51	57	57	38	34	9	0	0	0	0	2

Figure 2: Average Monthly Rainfall Distribution for Quaternary Catchment C11K

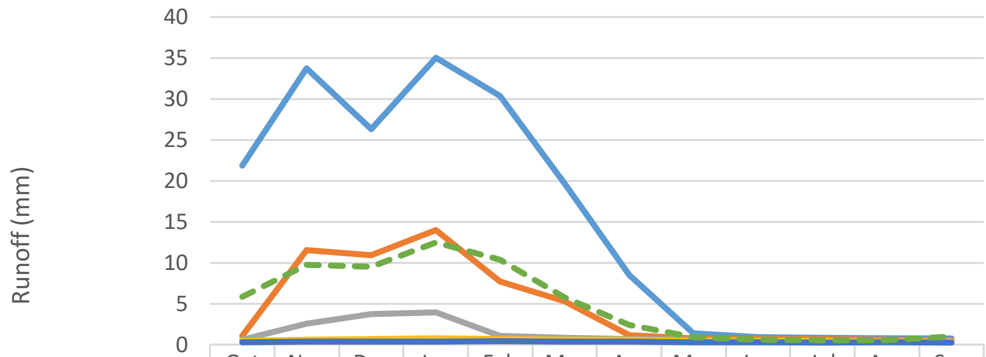
The MAE is 1520 mm, which is more than double the MAP for the area, which indicates a region characterized by distinct dry and wet seasons (WRC, 2015) with a negative natural water balance. The monthly distribution of potential evaporation and rainfall can be seen in Figure 3.



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Evaporation(mm)	157	155	167	165	143	136	105	89	73	80	110	139
Rainfall(mm)	72	99	104	111	81	70	35	14	7	7	9	23

Figure 3: Average Monthly Evaporation for Quaternary Catchment C11K

The runoff depth for Quaternary Catchment C11K was calculated to be approximately 59 mm. This runoff accounts for approximately 9% of the MAP for the area. The 90th and 10th percentiles of runoff during the wettest month of January are 35 mm and 0.4 mm, respectively (see Figure 4).



	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
90 Perecentile	21,9	33,8	26,3	35,0	30,4	19,7	8,5	1,4	0,9	0,9	0,8	0,8
70 Percentile	1,0	11,5	10,9	14,0	7,7	5,3	1,1	0,8	0,6	0,6	0,6	0,5
50 Percentile	0,6	2,5	3,7	3,9	1,1	0,8	0,7	0,6	0,5	0,5	0,5	0,4
30 Percentile	0,4	0,6	0,6	0,8	0,7	0,6	0,6	0,5	0,4	0,4	0,4	0,4
10 Percentile	0,3	0,4	0,4	0,4	0,4	0,4	0,3	0,3	0,3	0,2	0,2	0,2
Average	5,9	9,7	9,5	12,5	10,4	5,8	2,4	0,9	0,6	0,5	0,5	1,0

Figure 4: Average Monthly Runoff for Quaternary Catchment C11K

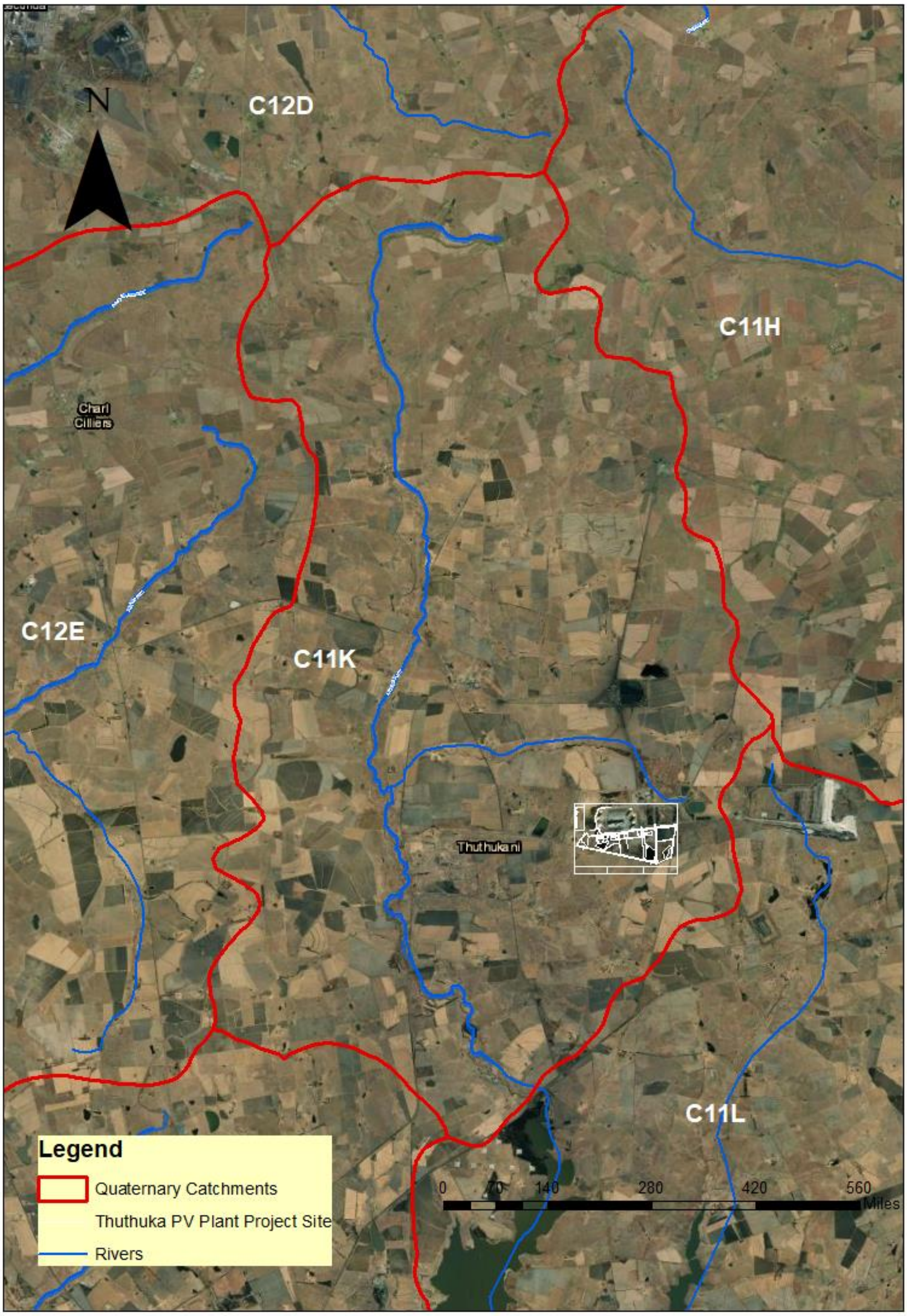


Figure 5: Quaternary Catchments in the region of the Thuthuka PV Plant Project Site

4.2 Design Rainfall Depths

Design Rainfall Depths for the 1:2-year to 1:100-year return periods were calculated using the Design Rainfall Software for South Africa (Smithers and Schulze, 2000). The rainfall station that was used is Niekerksvlei with SAWS Number 0441650_W, which is located approximately 5 km from the project site. The rainfall depths are presented in Table 2. The rainfall depths with durations equal to the time of concentration (Tc) of assessed catchments were used to calculate peak flows using the RM3 method. The recalibrated modified Hershfield equation was used to determine precipitation depths used in the SDF method (Alexander, 2002).

Table 2: 24-Hour Design Rainfall for the Thuthuka Power Station Region

Return Period						
Duration	**2year**	**5year**	**10year**	**20year**	**50year**	**100year**
5 m	8.4	11.2	13.3	15.4	22.5	25.7
10 m	12.2	16.4	19.3	22.4	33.2	37.8
15 m	15.2	20.4	24.1	27.9	41.6	47.4
30 m	19.3	25.9	30.7	35.5	52.3	59.7
45 m	22.2	29.8	35.3	40.8	59.7	68.2
1 h	24.6	33	38.9	45.1	65.7	75
1.5 h	28.2	37.9	44.8	51.9	75.1	85.8
2 h	31.2	41.9	49.5	57.3	82.6	94.3
4 h	36.6	49.1	58	67.1	98.2	112.1
6 h	40.2	53.9	63.7	73.7	108.7	124
8 h	42.9	57.6	68	78.7	116.7	133.3
10 h	45.2	60.6	71.6	82.9	123.4	140.9
12 h	47.1	63.2	74.7	86.4	129.2	147.4
16 h	50.3	67.5	79.8	92.3	138.8	158.4
20 h	52.9	71.1	84	97.2	146.7	167.5
24 h	55.2	74.1	87.5	101.3	153.5	175.3

5. Conceptual Stormwater Management Plan

5.1 Model Parameters

The model was driven by the 50-year design rainfall depths. Manning's roughness coefficients (n) used in the model for impervious and pervious areas ranged from 0.013 (float finish, concrete) to 0.035 for land cover characterised by brush and dense grass vegetation (McCuen, 1996). Dominant soils at the Thuthuka project site include Arcadia (over 57% abundance) as well as Rensburg, Swartland and Mispah soil forms. The soils are generally poorly drained and exhibit a very fine clay-loam texture such that low to moderate infiltration rates are expected. PCSWMM requires these criteria to incorporate infiltration into the analysis using various methods including the Green-Ampt infiltration method which was used in this study. The clay loam soils resulted in selection of a suction head of 208.8 mm, a saturated hydraulic conductivity of 2 mm/hour and an initial deficit of 0.267 being used for stormwater modelling of pervious surfaces.

5.2 Sub-catchment Characteristics

The layout of stormwater infrastructure for the Thuthuka project site included junctions, proposed and existing channels or drains and existing dams. The general layout is presented in Figure 6. Sub-catchments include S1 which is the laydown construction area where the proposed PV Plant substation, O & M building and the proposed connection point will be located. Sub-catchments S2 and S3 are within the Solar PV boundary and should represent the site where the solar panels will be installed. Modelled runoff depths, peak runoff rate and runoff associated runoff coefficients for delineated sub-catchments are presented in Table 3. As expected, higher runoff coefficients are observed due to a combination of less permeable soils and paved areas emanating from the proposed Solar PV development.

Table 3: Sub-catchment runoff depths, runoff rates and associated runoff coefficients

Subcatchment Name	**Description**	**Infiltration (mm)**	**Runoff Depth (mm)**	**Runoff Volume (ML)**	**Peak Runoff (m^3/s)**	**Runoff Coefficient**
S1	Laydown Area	39.98	75.6	1.83	0.39	0.651
S2	PV Site	22.37	92.51	34.98	8.29	0.797
S3	PV Site	48.87	66.9	1.6	0.3	0.576

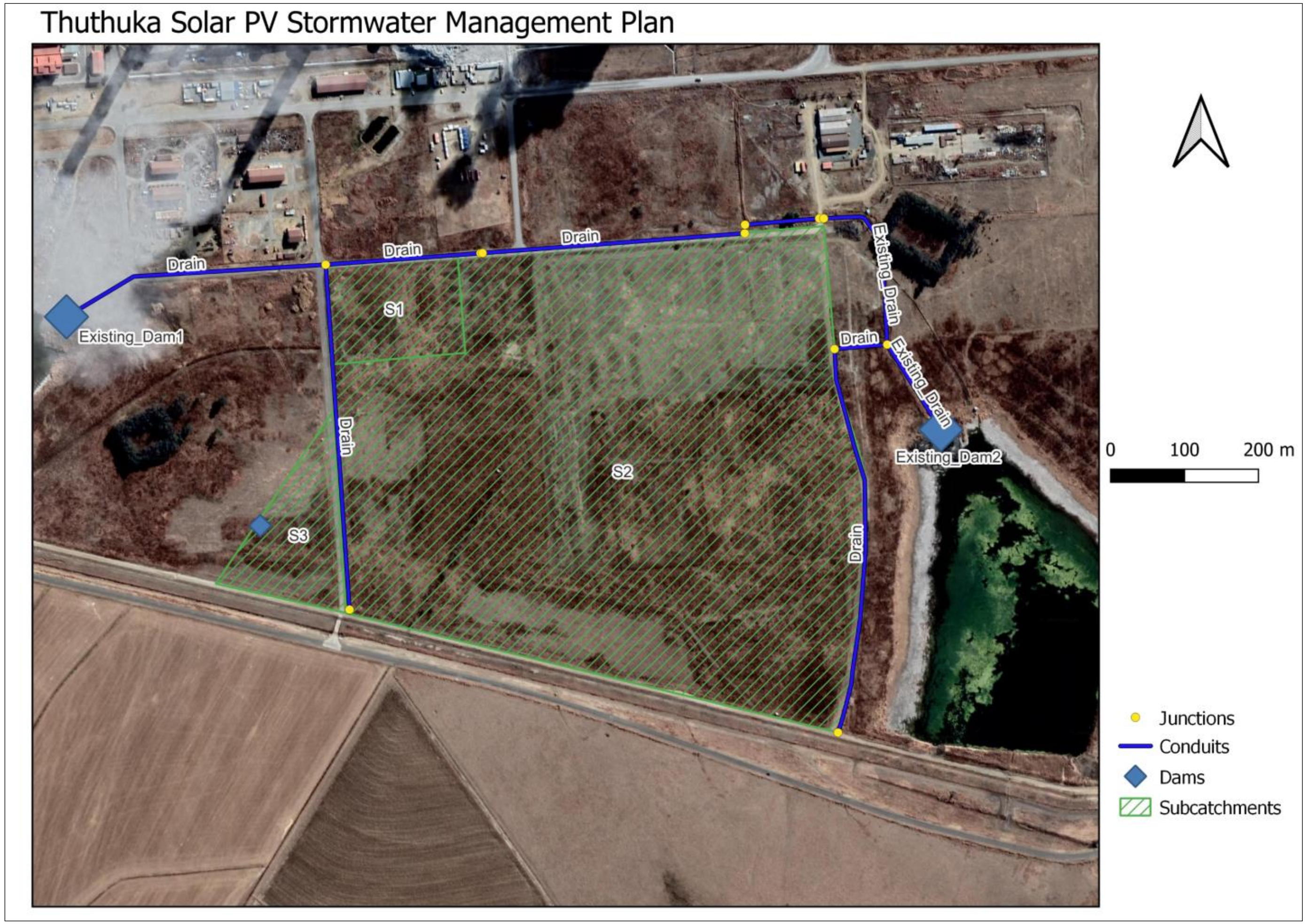


Figure 6: Conceptual Stormwater Management Plan for the Thuthuka project site

5.3 Stormwater Management Measures

Simulated conceptual sizing of stormwater drains/channels that can accommodate storm flows resulting from the 1:50-year rainfall event are described. The results show that some drains/channels are at risk of eroding since their maximum velocities are greater than 3 m/s. These earth drains should be lined with rip-rap and grassed/vegetated to minimise the occurrence of erosion should extreme rainfall events occur.

Characteristics and specifications of the drains/channels are indicated in Table 4. This information should be used to guide conceptual designs for the Thuthuka stormwater infrastructure. If simulated specifications are implemented, the probability of the drains overtopping will be low or least expected should 50-year flood events occur. This holds true provided the stormwater infrastructures are maintained throughout their operational life.

It was observed during the site visit that the dams are at full capacity and they sometimes spill. It is likely that in the rainy season they would overtop. The additional stormwater that is routed into the dams will also impact on the capacity of the dams. It is recommended that more water is pumped into the coolers or other processed to recycle water and improve the storage capacity of the dams and reduce the potential impacts on downstream receptors that may be affected by the overtopping dams.

Table 4: Characteristics and dimensions of optimised stormwater drains and culverts for the Thuthuka project site

Drain/ Culvert	Description	Cross-Section	Depth (m)	Bottom Width (m)	Left Slope	Right Slope	Slope (m/m)	Max (Flow) m^3/s	Max (Velocity) (m/s)
C1	Drain	TRAPEZOIDAL	1	1	1	1	0.0108	1.586	3.8
C2	Drain	TRAPEZOIDAL	1	1	1	1	0.0219	2.31	2.86
C3	Drain	TRAPEZOIDAL	1	1	1	1	0.012	1.887	4.15
C4	Drain	TRAPEZOIDAL	1	1	1	1	0.0253	2.272	5.7
C5	Drain	TRAPEZOIDAL	1	1	1	1	0.0194	2.272	5.18
C6	Existing Drain	TRAPEZOIDAL	1	2	2	2	0.0009	2.267	1.51
C7	Existing Culvert	CIRCULAR	1	0	0	0	0.0065	2.267	3.11
C8	Existing Drain	TRAPEZOIDAL	1	2	2	2	0.0125	2.264	3.77
C9	Existing Drain	TRAPEZOIDAL	1	2	2	2	0.0014	5.296	2.21
C10	Drain	TRAPEZOIDAL	1	1	1	1	0.0004	2.625	1.35
C11	Drain	TRAPEZOIDAL	1	1	1	1	0.0127	3.092	4.86

6. Floodline Modelling

The 1:50-year floodline on the river sections were analysed to evaluate the risks associated with the potential flooding or inundation of infrastructure and for the protection of water resources. In this study floodlines were modelled for the streams in proximity to the study area.

6.1 Peak Flows

Sub-catchments were delineated for the streams in proximity to the study area (Figure 7). Peak flows calculated using the RM3 and MIPI methods are of the same order of magnitude, hence the SDF flood peaks were considered an over-estimate for this site. The RM3 peak flows were used in HEC-RAS for hydraulic modelling as the Rational method is more suitable for smaller catchments (i.e., catchments <15 km^2) (SANRAL 2013). Catchment characteristics and calculated peak flows are presented in Table 5 and Table 6 below.

Table 5: Characteristics of the Delineated Sub-Catchment

Catchment	AREA	Longest Watercourse (L)	Distance to Centroid (Lc)	Elevation (mamsl)		Slope
	km^2	km	km	10%L	85%L	(m/m)
C1	3.6	1.34	0.99	1601	1620	0.0189
C2	9.8	2.77	1.55	1603	1628	0.0120

Table 6: Peak Flows for the Delineated Catchments

Catchment	Method					
	RM3		SDF		MIPI	
	1:50yr	1:100yr	1:50yr	1:100yr	1:50yr	1:100yr
	(m^3/s)					
C1	**41.94**	**57.63**	58.13	74.85	43.60	55.07
C2	**64.37**	**88.59**	155.08	196.39	73.24	92.51

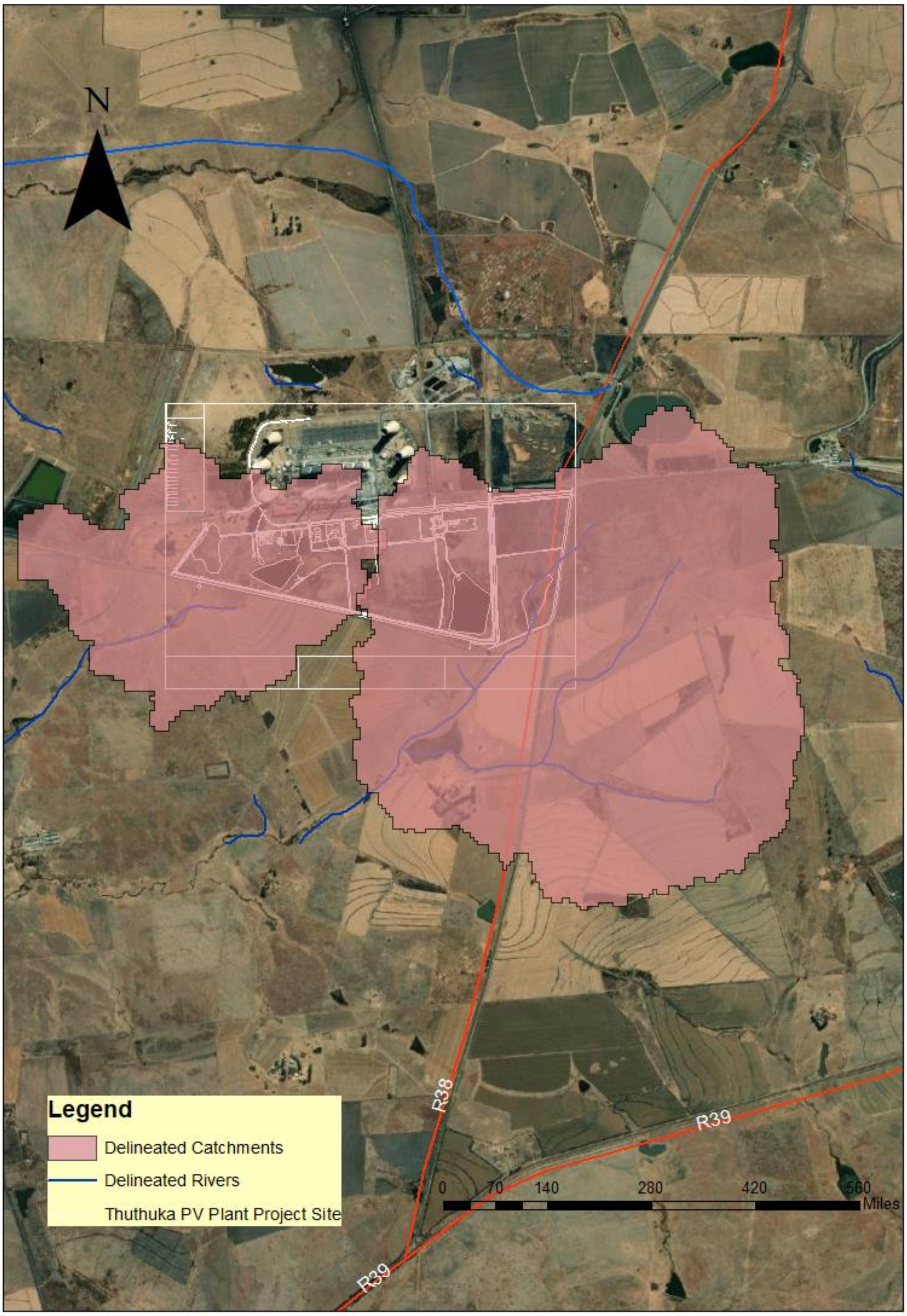


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Figure 7: Delineated Sub-Catchments in the Thuthuka Power Station Project Site

6.2 Inundation Mapping

The 1:50-year floodline for the nearby streams was calculated and the inundation boundary is presented in Figure 8. From the results, most of the project boundary is not within the Floodline area. However, it seems Alternative Site 2 may intersect with the modelled Floodline extent. A conclusion may be made when the Alternative Site 2 boundary is overlain with the Floodline delineation. This could not be concluded in the report as the final boundary of the site was not available at the time of writing this report. It is recommended that no development takes place within the Floodline area to protect the environment and the infrastructure and to ensure compliance with Legislation.

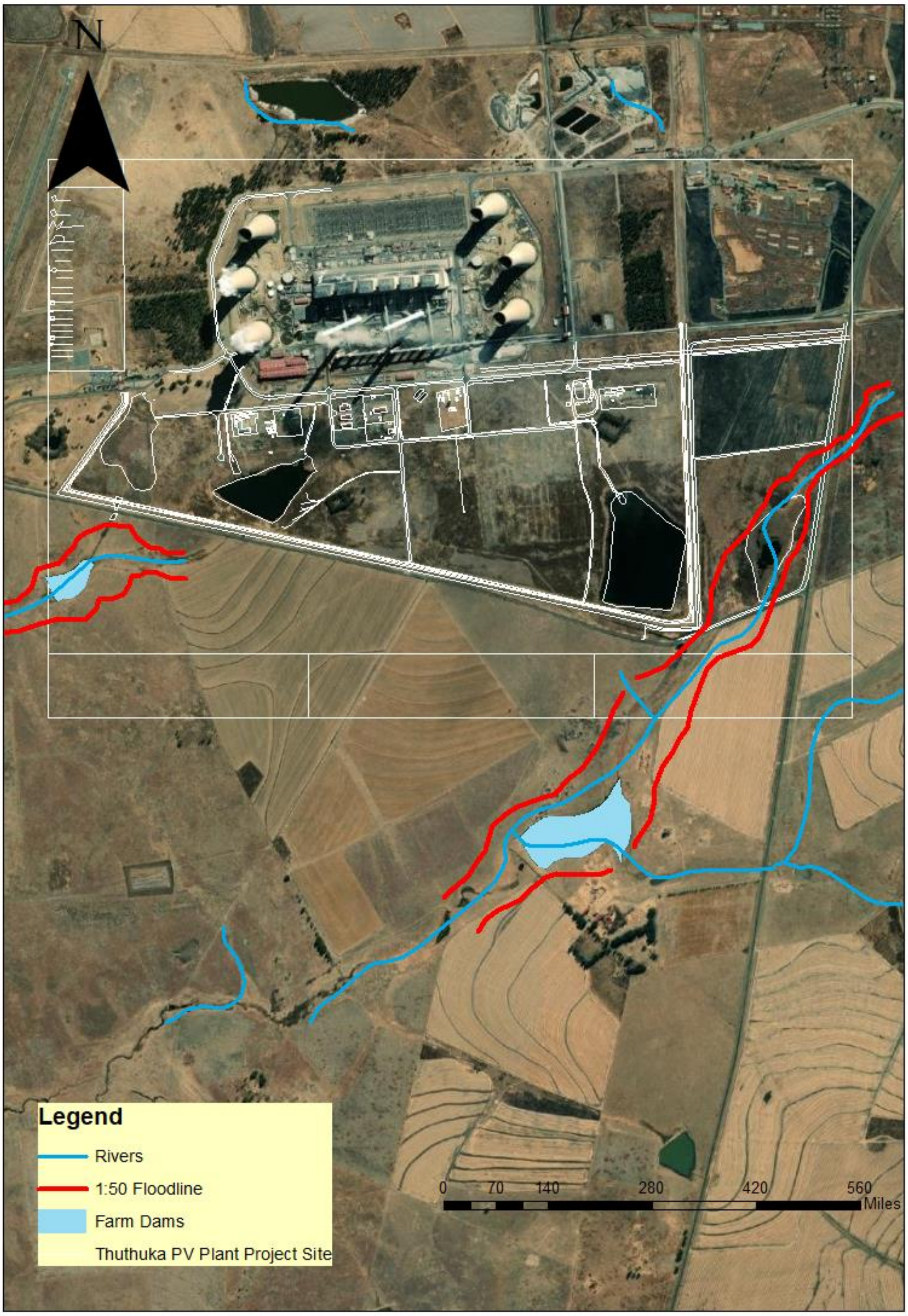

Figure 8: 1:50 Year Floodline at the Thuthuka PV Plant Project Site

7. Conclusion and Recommendations

This hydrological study was required for the Thuthuka Power Station PV Plant in the Gert Sibande District Municipality in the Mpumalanga Province. The assessment included a conceptual stormwater management plan and a Floodline delineation to identify flood risk in the project site and to mitigate impacts.

The conceptual stormwater management plan was designed to manage stormwater at the project site for the 1:50 year return period. The proposed stormwater infrastructure has been retrofitted into existing drains, culvert and dams in order to holistically manage storm flows on the Thuthuka PV project site and to minimise the footprint of environmental disturbance as much as practically possible.

The 1:50-year floodline for the nearby streams was modelled in Hec-RAS and the flood map produced. Most of the project boundary is not within the Floodline area. However, it seems Alternative Site 2 may intersect with the modelled Floodline extent. A conclusion may be made when the Alternative Site 2 boundary is overlain with the Floodline delineation. This could not be concluded in the report as the final boundary of the site was not available at the time of writing this report.

The following recommendations are made for this study:

- Stormwater management specifications for a 50-year design event stipulated in this report should be used as a guide to inform conceptual and detailed engineering designs by a professional engineer;
- It is recommended that the proposed earth drains with velocities over 3 m/s are lined with rip-rap and grassed/vegetated to prevent erosion;
- Stormwater management infrastructure needs to be maintained throughout their operational life to ensure effectiveness;
- It is recommended that more water is pumped into the coolers or other processed to recycle water and improve the storage capacity of the dams and reduce the potential impacts on downstream receptors that may be affected by the overtopping dams;
- It recommended that the site layout is overlain with the delineated floodline extent to ascertain whether Alternative site 2 interacts with the floodline; and
- It is recommended that no development takes place within the Floodline area to protect the environment and the infrastructure and to ensure compliance with Legislation.

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