Lower Incomati Flood Risk Management: Pre-Feasibility and Flood Disaster Mitigation Report

Project Name: Lower Incomati Flood Risk Management

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Disclaimer

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List of Acronyms

Acronym	Long-Form
AMSL	Above Mean Sea Level
ANE	National Roads Administration of Mozambique
ARA-Sul	Administração Regional de Águas do Sul
BCR	Benefit Cost Ratio
CBA	Cost Benefit Analysis
CMF	Catchment Management Forum
CRIDF	Climate Resilient Infrastructure Development Facility
DEM	Digital Elevation Model
DFID	Department of International Development
EDM	Electricidade de Mocambique
ERR	Economic Rate of Return
ESA	European Space Agency
EST	Eastern Standard Time
EU	European Union
EU MSSDP	European Union Maragra Smallholder Sugarcane Development Project
FAO	Food and Agricultural Organisation
GBP	Gross Domestic Product
GIS	Geographical Information System
GLCN	Global Land Cover Network
GTS	Global Telecommunications Systems
Ha	Hectares

IIMA	Interim Incomati Maputo Agreement
INAM	National Meteorology Institute
INGC	National Institute for Disaster Management
MCP	Miller Cum Planter
LCCS	Land Cover Classification System
MoU	Memorandum of Understanding
NOAA	National Oceanic and Atmospheric Administration
NPV	Net Present Value
PRIMA	Progressive Realisation of the IncoMaputo Agreement
RP	Return Period
TPTC	Tri-Partite Technical Committee
UNEP	United Nations Environment Programme
USD	United States Dollar
WASH	Water. Sanitation and Hygiene
WHO	World Health Organisation

Abstract

The purpose of the Lower Incomati Flood Risk Management Project is to determine a holistic approach to flood risk management working with ARA-Sul, the Sugar Estates Illovo and Tongaat Hulett with the focus on reducing flood vulnerability for the poorer communities (outgrowers) while showing economic viability for all parties.

Prior to this project the two main sugar estates in the Lower Incomati carried out a localised approach to flood avoidance by constructing flood bunds within their estates. Due to the complexity of the Lower Incomati river connectivity within a floodplain it was difficult for the Sugar Estates to objectively determine the potential increased flooding impacts of their flood bund construction around the surrounding areas.

The methodology and approach to this project included:

- Developing a 2D hydraulic model of the Lower Incomati that would objectively present the current impact of flooding for flood events ranging from the 1 in 5 year to the 1 in 20 year and to also show the impact of flood risk management scenarios that could be used by the key stakeholders.
- The evolution of the stakeholder engagement to have increased influence within the Incomati basin. This originally commenced with Illovo and Tongaat with ARA-Sul chairing the meeting to the expansion of the steering group to include ANE (Roads Department) and the Manhiça Municipality Infrastructure Department and other important decision makers as the project progressed.
- Providing a quantitative financial analysis approach including indicative costing of the flood risk management options, determining the flood risk management benefits and producing average benefit cost ratios. This created a focus on the holistic economic impacts on preferred flood risk management approach that will benefit all parties including the poorer communities (outgrowers) and the Sugar Estates.

The project commenced in August 2014 and was completed in August 2015. One of the key successes was the willingness for the Sugar Estates, ARA-Sul and other key stakeholders to work together on developing the hydraulic model to improve the accuracy and confidence in the results, sharing data and signing a Memorandum of Understanding (MoU) on the project. Five stakeholder events were held during the course of this Phase 1 of the project and the influence of the events has grown with more decision makers attending to enable influencing and change.

The outcome of the project is that the public and private partnership between stakeholders and the results of the hydraulic modelling and economic and financial analysis show that the preferred flood risk management options have economic benefit with high Benefit Cost Ratios (BCRs) for all parties including the poorer communities/ outgrowers. The overall solution to flood risk management that will have a shared benefit for everyone in the Lower Incomati is to have a transition from a flood avoidance approach to a holistic flood risk management approach with agreed preferred infrastructure development.

Executive Summary

In August 2014, the Climate Resilient Infrastructure Development Facility (CRIDF) commenced the project of Flood Modelling and Vulnerability Assessment of Lower Incomati Smallholder Developments in Mozambique. This project looks at making recommendations for flood risk management and warning responses for the Lower Incomati Catchment Management Forum (also known as UGBI), chaired by ARA-Sul, and stakeholders in the Lower Incomati. The stakeholders are Illovo Sugar and Tongaat-Hulett's small out-grower farmers and extension services, and CRIDF's client is ARA-Sul.

The project has been divided into three phases, each one to fulfil the following overall objectives:

- Phase 1: development of preliminary recommendations for management responses that minimise the impacts of various flood magnitudes in the Lower Incomati Catchment.
- Phase 2: development of a flood early warning and low flow monitoring system which can be used for both low flow management and flood warning in the Lower Incomati system;
- Phase 3: development of recommendations for the operation of large storage infrastructure in the Incomati basin to both minimise flood and drought risks.

The report presented herein, constitutes the final deliverable of Phase 1 presenting a Flood Disaster Management Plan which integrates a report of the required and collected data, a flood risk assessment of the Lower Incomati study area and the analysis of possible structural solutions to reduce and manage flood risk in the study area.

Several stakeholder events have taken place since September 2014 alternatively at each of the Sugar Estates with ARA-Sul chairing the meetings and CRIDF supporting the process. The project focus has been on a public and private partnership approach to flood risk management and supporting the poorer communities. As the project has progressed, there has been a very successful collaborative approach to understanding the holistic flood risk and approaches to reduce the impacts.

The study area spans an area of approximately 4,500 km^2, where two sugar estates Tongaat Hulett and Illovo operate and have their irrigation fields and flood protection dykes. The contributing catchment area as inflow for the study area is approximately 38,240 km^2.

The methodology applied to carry out a flood risk assessment was the following:

- Determine the flow peaks at different return periods;
- Determine the flooding extent, water depth and velocity at the key areas of interest for different return periods;
- Determine flood hazard and vulnerability to floods;
- Combine flood hazard and vulnerability to calculate and map flood risk in the study area.

An extreme event analysis was carried out where three different methodologies were applied and compared to obtain estimations of peak flow discharges for different return periods. The return periods considered are 1 in 5, 10 and 20 years. It was found that the most appropriate inflow hydrographs for the current study are the estimates produced by the Standard Design Flood method.

The purpose of the hydraulic modelling in this study was to produce the results regarding different flood parameters to be used in the generation of flood maps. Two models using MIKE software were built, a one-dimensional MIKE 11 model and a two-dimensional model MIKE 21. The estimated flood flows at the various return periods were routed through the hydraulic models of the study area under the present physical structure of the floodplain area. The models were finally used in testing of different structural interventions for flood management in the study area.

The estimated flood extent for the 1 in 5, 10 and 20 year flood event return periods was determined and detailed maps are presented in Appendix A. It is concluded that particularly regarding the flood protection dykes, Tongaat Hulett at Xinavane dykes are likely to fail already at a 1 in 5 year flood event as opposed to the Illovo (Maragra) protection dykes, with the Maragra Miller Cum Planter (MCP) areas being well protected from flooding for up to the 1 in 10 year return period flood event. The location of the failing dykes for both sugar estates and for each return period can be seen in detail as a collection of maps in Appendix A.

The measure of hazard/danger is obtained when combining current velocity with water depth information. These maps are tools to provide information about flood hazards and to implement the necessary preventive and preparedness measures by presenting areas which could be flooded according to different probabilities. A debris factor for different depths and velocities is directly related to the dominant land use was applied to increase hazard. The result has been a classification and mapping of different hazard degrees to people of a flood event:

- Low – Caution; “Flood zone with shallow flowing water or deep standing water”
- Moderate - Dangerous for some (i.e. children); “Danger: Flood zone with deep or fast flowing water”
- Significant - Dangerous for most people; “Danger: flood zone with deep fast flowing water”
- Extreme - Dangerous for all; “Extreme danger: flood zone with deep fast flowing water”

Regarding flood hazard, the detailed maps in Appendix B present which areas are affected particularly by Significant and Extreme flood hazard which incur in the worst damage and higher socio-economic impacts. Particular attention has been given to identifying and listing the outgrowers of each sugar estate which are expected to be affected.

Regarding flood vulnerability, the areas where outgrowers’ fields are situated are the most vulnerable whereas the MCP large scale areas are at a much lower risk, mostly due to permanent employment status, insurance cover, and access to potable water, electricity and credit; in addition the latter have been found to be better protected by flood protection dykes. This is shown in Appendix C.

The focus community of this project are people working and living off outgrower schemes on the Lower Incomati in the region where Tongaat-Hulett and Illovo sugar estates operate. As a result of the flood risk assessment, it has been concluded that in summary, although measures have been taken to reduce the impact of floods on crops situated in the flood plains particularly flood levees around the large scale MCP fields and some outgrower areas, many of the outgrower schemes are located in the most hazardous and high risk areas, and the higher risk outgrowers have been identified and listed. The flood risk map is presented in Appendix D.

Different modelling scenarios were agreed upon with the stakeholders, which consisted of different structural intervention measures directed towards an improved management of the risk of flooding in the study area. The models were adjusted to test each of the options which are:

- S1 Additional protection wall around the 1,000Ha developed in close proximity to existing Maragra, and new dykes at Martins and Taninga;
- S2 Impact of dredging a section of the Incomati River from the river diversion upstream of the factory to about 5 km beyond Taninga on flooding risk for downstream areas;
- S3 Impact of the new berms or dykes being installed along the Tsatsimbe or Cuenga River for flood protection by Xinavane;
- S1S3 Combination of the additional Maragra protection dykes and the new Xinavane protection dyke;
- S4 Testing of different configurations for the hydraulic structure at Tsatsimbe River bifurcation, such as reduction of number of culverts and restoration of original river embankment.

Based on the results of the modelling, it has been found that the new dyke walls to be put in place by both sugar estates do not have a negative mutual impact but their degree of effectiveness varies. From the hydraulic modelling results dredging of the channel section by the Xinavane fields, will cause an increase of flow going down the main Incomati channel which results in higher water levels and a potential increase in flooding, however this measure is part of Tongaat Hulett's irrigation operations and is not intended as a flood management measure.

Testing of embankment behaviour at the Incomati - Tsatsimbe bifurcation carried out by raising the embankment crest level and removing the culvert structure altogether was found to have the highest reduction of flood impact on outgrower areas. A further scenario combined the latter with the implementation of a dyke upstream of Magude town and the 2D model results showed this added protection structure would reduce flood impacts in the outgrower areas. Finally, regarding the hydraulic structure at Incomati - Tsatsimbe bifurcation, it is suggested that for improved flood risk management, an option where an operational structure (valves, gates) which would allow for complete interruption of flow through the structure when there is a forecast of 1 in 5 year magnitude, should be investigated in detail outside the current pre-feasibility study.

It should be noted that the scenarios S1 and S4 related to potential structural interventions reduced flooding in the highest risk areas and greatly improved the situation for the outgrowers who are at the highest risk and most vulnerable. From the hydraulic modelling the S2 and S3 options did not improve the flood risk management situation in any marked way for the outgrowers. Scenario S1 which targeted specific outgrower areas up until the 1 in 5 year flood event proved to be effective, as well as Scenario S4, which presented the most promise in resolving the problem extensively by carrying out structural interventions at the Tsatsimbe bifurcation that could reduce a major area of flooding for Tongaat Hulett areas as well as the downstream Illovo areas. However, there are other areas where vulnerable communities are located which could be negatively affected by these interventions such as the inhabitants of the Josina Machel area surrounding the Lagoa Chuali, and also areas upstream of the model domain where Tongaat-Hulett has established and is planning to establish other outgrower fields which have not been examined under the scope of this project.

It must be noted that current 2D hydraulic model used for this project utilises a coarse Digital Elevation Model (DEM) with GPS survey data blended in to improve the accuracy. The hydraulic model has been used to find out the relative effects of comparing scenarios, and which flood options are effective to help inform flood risk management decision making. The current hydraulic model does not have the level of DEM accuracy to determine flood embankment crest levels for detail design or construction purposes.

The estimated population of the entire Lower Incomati Basin is roughly 492,000. This entire population is seen as relevant when looking at the economic impact of flooding in the Basin. The estimated population of the Flood Model study area is, however, roughly 245,000, about 60% of which are believed to be located in smaller villages or rural settlements across the Incomati flood plain. Over the last two decades, populations in the central areas have grown (particularly towns and localities involved in sugar outgrower associations and labour recruitment), whereas that in rural areas dominated by subsistence and smallholder agriculture, population has declined. Moreover, although the percentage of female headed households in the Basin has declined over the same time, it remains high at around 47%. Employment and income levels in the Basin also remain low (although the sugar industry has resulted in large improvements in the last few decades).

At a macroeconomic level, the Lower Incomati produces about 80% of the sugar in Mozambique, resulting in a significant contribution to exports and national GDP. At a more local level, the economic importance of sugar is also substantial, providing a secure and stable market for cane producing smallholders and through employment generation, both of which increase the monetary income of the Basin population. The knock-on effects of sugar related monetary incomes on the local economy have been evident in increased trade in towns, areas close to cane-cutter hostels, and rural settlements where workers live.

The total economic cost of a flood event can be understood in terms of the immediate impact directly attributable to the flood damage, plus the secondary (knock-on impacts) throughout the economy as a result of decreased production, spending and consumption.

The immediate impacts can be further defined into direct, indirect (or flow-effects), and relief costs:

Based on these cost categories, the World Bank estimated that the 2000 flood event had a total immediate economic cost (including direct, flow and relief costs) on Mozambique of about USD 550 million. When these secondary knock-on effects are also taken into consideration, the World Bank estimates that Mozambique's GDP is cut by 5.6% on average when a major water shock occurs, equating to an annual reduction in Mozambique's GDP by 1.1%. Despite the significant economic cost of flood events, Mozambique remains among the countries in southern Africa with the least developed water infrastructure and storage capacity, and the water resources sector continues to be chronically underfinanced.

The costs of floods to the rural poor are often largely hidden in Mozambique as a large portion of this population remains outside of the monetary economy. A quantitative analysis, which can explicitly take into account these 'hidden' costs, is therefore required to inform considered flood management investment decisions. Cost-Benefit Analysis (CBA) has been chosen as the most appropriate methodology. CBA assesses the net economic value of a proposed investment by weighing up all relevant impacts (financial, socio-economic, environmental, etc.) by using money as a common unit of analysis.

Based on this framework, the direct, indirect (flow) and relief costs of a one-in-five year return period flood event is quantified and monetised for each sub-sector. Where it is not possible or practical to quantify/monetise certain costs, these are considered qualitatively in as much detail as possible. Overall this informs an estimate of the total economic cost of a one-in-five year event on the Lower Incomati Basin, and defines the ‘base scenario’. The preliminary analysis in this report finds that as a ‘base scenario’, a one-in-five year flood event costs the Lower Incomati Basin approximately **USD 24.6 million**. This number should be considered as a coarse estimate, with the understanding that many impacts could not be quantified and valued and are hence excluded from the quantitative estimate, and that the quantitative estimates are based on uncertain assumptions and questionable data, and should hence be seen as indicative at best.

Table 1 below provides a summary of the CBA results and alludes to the potential prioritisation of investments. In terms of NPV, the S1 investment is preferable to the S4e investment. This preference is, however, due to the fact that S1 is a significantly larger investment. The BCR and ERR performance indicators are independent of investment size, showing the relative ‘bang for buck’ of the investments. Based on the BCR and ERR indicators, Table 1 shows that the S4e investment is preferable. This result fluctuates however as the CBA assumptions are varied, implying that one investment is not clearly preferable over the other. Moreover, it is recognised that these two particular investments are independent unrelated interventions and are not mutually-exclusive.

Table 1S1 versus S4e CBA Performance Indicators

Performance indicator	S1 (10%)	S4e (10%)	Comparison
NPV	USD 1,972,909	USD 1,155,587	S1 > S4e
BCR	2.13	2.84	S4e > S1
ERR	33%	45%	S4e > S1

A sensitivity analysis of both the S1 and S4e investments shows that the positive results and economic viability of both are robust and resilient to changes in key assumptions and input variables.

The use of CBA for flood risk management in general assists in ensuring that private sector investments, which dominate the area in terms of flood prevention infrastructure, are aligned to the CRIDF principles of climate resilience and pro-poor development. It also serves to ensure that an investment will results in a net positive impact on society as a whole, and highlight where the distribution of impacts is an issue and compensation mechanisms may be required. Lastly, in line with CRIDF’s objective to leverage private sector investment in water resource management, the analysis contained in this report, and its extension to further analyses, provides a means for CRIDF and private sector stakeholders to align objectives and share risk.

The aim of the next phase of the project would be to expand this project to a transboundary, climate resilient, with evolution of stakeholder influence with an early flood warning system for the Incomati basin.

1 Introduction

1.1 Background

The Climate Resilient Infrastructure Development Facility (CRIDF) is the water infrastructure programme for southern Africa of the UK government's Department for International Development (DFID). CRIDF prepares small-scale water infrastructure projects and facilitates access to finance for their implementation. Through these projects CRIDF aims at ensuring impoverished communities in countries of the SADC region benefit from climate-resilient water infrastructure, while promoting and strengthening cooperation between stakeholders in shared river basins.

In August 2014, CRIDF initiated a project to carry out the Flood Modelling and Vulnerability Assessment of Lower Incomati Smallholder Developments in Mozambique. This project was developed due to the increasing incidence of extreme flooding events on the Lower Incomati River which have been negatively impacting the smallholder sugar cane growers who operate on the floodplains, as well as the existing large-scale Sugar Estates. It is possible that flood intensities will increase as climate change takes effect.

Two large Estates, the downstream Maragra Scheme managed by Illovo Sugar, and the upstream Xinavane Scheme managed by Tongaat-Hulett, have separately pursued flood protection works over a number of decades – which primarily involves heightening the dykes and the diversion of water. Unfortunately, by interfering with the natural run of the river without an overall view or understanding of the flood hydrodynamics of the floodplain system, these works may have increased the risk of flooding in certain areas and negatively affected natural functioning of the wetland system and increased inundation periods.

In addition, as expressed in consultation with the Lower Incomati Catchment Management Forum (CMF), chaired by ARA-Sul, management of low flow conditions and releases from the Corumana Dam to satisfy demands from water users is also challenging.

This Project thus looks at making recommendations for flood management and warning responses for the CMF, and stakeholders in the Lower Incomati. The stakeholders are Illovo Sugar and Tongaat-Hulett's small out-grower farmers and extension services and CRIDF's client is ARA-Sul.

1.2 Objectives

The project has been divided into three phases, each one to fulfil the following overall objectives:

- Phase 1: development of preliminary recommendations for management responses that minimise the impacts of various flood magnitudes in the lower Incomati Catchment. These management responses should include both preliminary recommendations for the design and placing of flood protection works, as well as the operation of that infrastructure under different flood magnitudes.
- Phase 2: development of a flood early warning and low flow monitoring system which can be used for both low flow management and flood warning in the lower Incomati system;

- Phase 3: development of recommendations for the operation of large storage infrastructure in the Incomati basin to both minimise flood and drought risks.

While detailed tasks for both Phases 2 and 3 will be established at a later stage of the project, it is anticipated that Phase 2 will include accessing the near real time flow monitoring data from the South African Incomati CMA, providing near real time data from suitable flow monitoring sites inside Mozambique, the potential upgrading of flow monitoring sites inside Mozambique, to provide recommendations for the operation of the Corumana Dam based on near real time flows in the Sabie River inside South Africa. The later element may be expanded to cover other planned infrastructure inside Mozambique, and inside South Africa and Swaziland, consistent with existing transboundary commitments between these countries. In this event, activities should be coordinated through the Tri-partite Technical Committee (TPTC).

The specific objectives of Phase 1 consist in the production of the following outcomes:

- Determination of flood risk by using a suitable 2-dimensional flood model to determine the degrees of exposure of the floodplain area to various magnitudes of flood hazard and to produce flood risk maps based on these analyses; and by working with the stakeholders to determine the vulnerabilities of the different stakeholders and areas of the floodplain to flood damage from various frequencies and magnitudes of floods.
- Make recommendations for flood risk reduction strategies and infrastructure and test them using the established models to determine are feasible.
- Influence stakeholder engagement during the project duration
- Carry out an economic/ financial assessment flood risk management strategies.
- Final Pre-Feasibility Disaster Mitigation Report,

The report presented herein, constitutes the Final Pre-Feasibility Disaster Mitigation Report which integrates a report of the flood risk assessment of the Lower Incomati study area and the analysis of possible structural and non-structural solutions to reduce and manage flood risk in the study area, the economic and cost benefit analysis assessment of the flood risk management strategies and the recommendations for the follow on activities.

1.3 Flood Risk Management Framework

Being the downstream country to different main river basins in southern Africa, Mozambique is highly vulnerable to flood disasters amongst several other natural disasters, and is annually hit by flooding with different degrees of severity. It has had the need to receive international assistance several occasions in the past decade. Therefore, the need for a legal framework for disaster response was of great importance for the country.

During the last decade, huge steps have been taken in order to create such legal, institutional and policy frameworks, the defining moment being the operationalization of the National Disaster Management Institute (INGC). Added to this, in June 2014, the Mozambican Government adopted the Law on Disaster Management

(Lei de Gestão das Calamidades, nº 15/2014) which represents great improvement in terms of the national legislation.

This law establishes the legal principles and mechanisms necessary for the management of disasters such as floods and making provision for measures and strategies on the following:

- Prevention and mitigation measures;
- Early warning systems;
- Disaster management systems;
- Request and contracting of goods and services;
- Special protection of zones and people.

Finally, it mentions the need to define and classify disaster risk zones as well as the rights of local inhabitants to receive due attention from the government from the implementation of mitigation measures to emergency evacuation procedures.

1.4 Purposes for Planning

Flood risk management and decision making involve the determination of where is the greater risk in order to set up priorities for measures. Planning is required in order to select the best options and range of measures to reduce flood risk like spatial planning and control of development (avoidance), asset system management (defences, flood storage areas, managing the pathways of rivers, estuaries and coasts), flood preparation (flood detection, forecasting, emergency planning) and flood incident management and response (flood warning, actions of emergency services, healthcare providers and flood risk management authorities, public, community support organizations), and recovery (insurance, local authorities, reconstruction).

The Flood Management Plan will assist the stakeholders in reducing its risk from flood hazards by:

- Identifying and mapping risk and all the associated components such as exposure of currently existing key infrastructure and vulnerability of the communities;
- Generate risk assessment data that can be used for planning future development in the areas of interest; and
- Proposal of strategies for risk reduction and management.

1.5 Who will benefit from this report?

The planning area for this plan is the downstream stretch of the Lower Incomati River and the ultimate beneficiaries of mitigation efforts are: the residents and businesses of the main focus areas as well as the Province because key provincial infrastructure is encompassed in the study area; and the country, as main road and railway connections between provinces are located at the focus area.

Flood protection and mitigation interventions protect those who live in, work in, and visit the focus area of this plan. Although this plan does not establish mandates for ARA-Sul and the Sugar Estates, or the Provincial

Government, it does provide a planning framework for the foreseeable flood hazard that may impact the study area. By establishing this plan, ARA-Sul, the Sugar Estates and the Provincial and Local Administration will be in a position to better prioritize, decide and fund local interventions for flood hazard risk reduction projects.

1.6 How to use this report

This flood disaster mitigation report is organized into the following main components: the Flood Risk Assessment, and the Flood Management Strategies.

A Flood risk assessment can be undertaken over a large area or for a particular site to:

- Identify whether and the degree to which flood risk is an issue;
- Identify flood zones;
- Inform decisions in relation to zoning and planning applications; and
- Develop appropriate flood risk management measures for development sited in flood risk areas.

A range of scales are relevant to the planning process: regional (regional planning guidelines), strategic (for city or county development plans or local area plans); and site specific (for master plans and individual site planning application). In the case of this study, the need for a detailed assessment was identified and carried out.

A risk assessment needs to consider the situation both as it is now and also how it might change in the future. In the case of this project, such consideration included changes in local hydraulic structures and construction of flood protection interventions within the areas of focus.

The key outputs integrating this disaster mitigation report are the following:

- Maps which include geographical features, satellite imagery of the area and identifies the catchment and watercourses;
- Clear identification of the structures which influence local hydraulics. This will include bridges, dykes, culverts, embankments, etc;
- Impact of flooding: maps indicating maximum water depths, speed of flow and flooded areas;
- Maps of vulnerability and flood risk zones;
- Flood alleviation measures already in place and their performance;
- Testing and evaluation of structural flood management interventions;
- A comprehensive economic analysis of the project;
- A high-level socio-economic assessment of the project area and intervention is required to inform whether further investment in the project is justified from the perspective of promoting pro-poor, climate resilient water infrastructure that promotes better management of shared resources;

- An economic analysis which provides an understanding of the economic cost of flooding on the Basin, and the economic implications of flood management infrastructure interventions, aims to support the decision making of stakeholders; and
- The recommendations for the next activities on the project.

1.7 Stakeholder Influence

Several stakeholder events have taken place since September 2014 which have been most alternatively at each of the Sugar Estates with ARA-Sul chairing the meetings and CRIDF supporting the process. The project focus has been on a public and private partnership approach to flood risk management and supporting the poorer communities. As the project has progressed, there has been a very successful collaborative approach to understanding the holistic flood risk and approaches to reduce the impacts.

The key stakeholder events are summarised below:

- 11th September 2014: Venue Illovo: initial stakeholder event with initial calibration findings from the 2D hydraulic modelling with a very coarse Digital Elevation Model (DEM) and satellite imagery of the March 2014 event.
- 4th November 2014: Venue Illovo: further findings from March 2014 calibration using a slightly more accurate DEM, commencement of CRIDF GPS survey
- 17th February 2015 Venue Tongaat: : findings from a revised March 2014 calibration which included the CRIDF GPS survey and further information from both Sugar Estates, MoU signed by all parties. Flood risk management options determined from Sugar Estates
- 8th May 2015 Venue Illovo: GPS survey from Tongaat and Illovo incorporated into the hydraulic model. Accurate calibration results with agreement from all parties. Design event hydrology analysis revised. Design event simulations presented. Flood risk management options agreed, Manhiça Municipality Infrastructure department member, and ANE attended the event and also presented road schemes in the Lower Incomati.
- 23rd July 2015 Venue Tongaat. Presentation of the flood risk management option results with agreement in results, presentation on the economic analysis findings. Funding for LiDAR (highly accurate DEM) for project area agreed with contributions from Illovo, Tongaat and DFID. ARA-Sul to be custodians of data. Manhiça Municipality Head of Infrastructure and ANE team attended the event. Initial discussions carried out on aspects to include Phase 2 and Phase 3 project components from all parties.

2 The Lower Incomati Floodplains

The Incomati River basin is shared by three countries, Mozambique (33%), Swaziland (5%) and South Africa (62%). Mozambique is the downstream state and 85% of average annual runoff is generated in its upstream neighbours. The study area is located in the Lower Incomati River catchment, constituting the catchment that drains to the lower reach of the Incomati River downstream of the South African border at Ressano Garcia. Sub-catchments include the Mazimechopes, Uaneteze and Massintonto sub-catchments, which extend into South Africa, as well as the lower part of the Sabie River catchment, downstream of the South Africa Mozambique border.

From the upstream part the basin has extensive uses for irrigation amongst others, having large water infrastructure in place the main examples being Maguga Dam in Swaziland and Driekoppies in South Africa (Komati affluent basin).

The main economic activity in the Lower Incomati catchment is commercial farming in Mozambique (sugarcane). Corumana Dam, which is located on the Sabie River immediately downstream of South Africa, is the only major dam in this catchment and is used for supplying water to downstream irrigators and for hydropower generation. The upper Massintonto and Uanetze catchments in South Africa are located in the Kruger National Park and are managed by the South African Department of Water Affairs (DWA). In Mozambique, the DNA has the overall responsibility for the management of the lower Incomati catchment, assisted by the regional authority ARA-Sul, who is also responsible for the operation and maintenance of Corumana Dam.

The study area spans an area of approximately 4500 km^2, where two sugar estates Tongaat Hulett and Illovo operate and have their irrigation fields and flood protection dykes as shown in Figure 2-1. It is also where the main urban centres are located, namely the towns of Manhiça, Magude and Xinavane. From Magude downstream, the Incomati River is split into different branches, mainly the main Incomati, the Tsatsimbe/Cuenga and the Incoluane, and the floodplain is sectioned by the national road N1 and other secondary main arteries and the national railway line of Ressano Garcia. The contributing catchment area as inflow for the study area is approximately 38,237 km2.

This area has been hard hit by flooding due to on the one hand incoming very high flows from the upstream catchment area, and also, due to the negative impacts of transport infrastructure and also flood protection dykes which the sugar estates have been putting in place over the years. The local community and smallholder farm owners have been hit the hardest, also because these constitute the most vulnerable stakeholders. In addition, due to climate change, the return periods of worse flood events have been decreasing. Therefore there is an urgent need for a flood management plan to be put in place for the coming years.

Both Illovo Sugar and Tongaat-Hulett have acknowledged the need to reassess their current flood management strategies in response to recent flood events, and also that a change in the flood management current paradigm needs to take place, by shifting the approach from continuous building of uncoordinated flood defence dykes on the floodplain, to managing flood risk. It has also been agreed that a combination of flood risk mapping, flood management strategies and an early warning system is the best way to manage flood occurrence in the floodplain, decrease negative social and economic impacts and increase resilience.

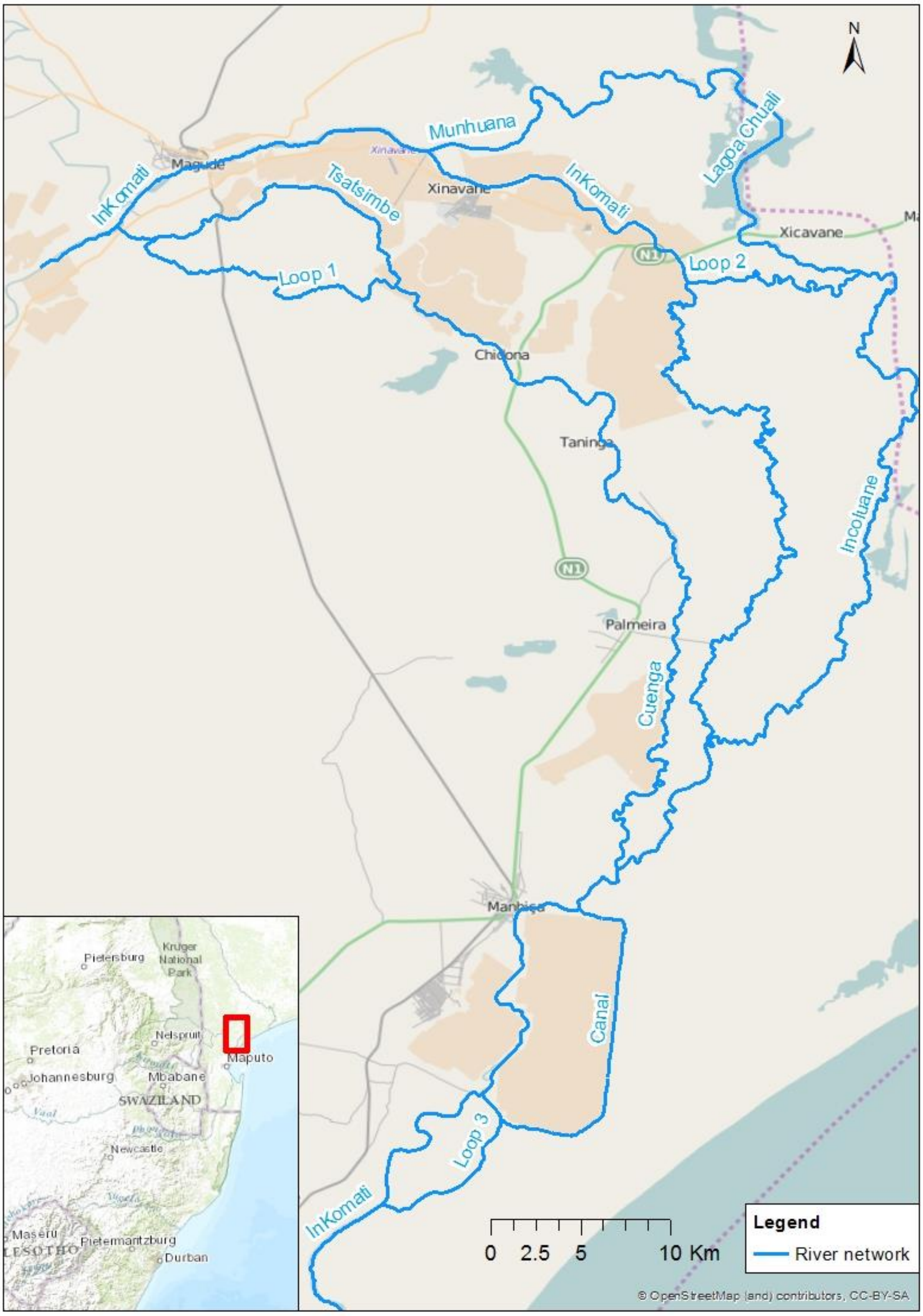


Figure 2-1 Map of the study area displaying the main urban centres, transportation services such as national road N1, the main river network and water bodies in blue, and sugar cane plantations in darker beige

Following the above reasoning, ARA-Sul is a key stakeholder of this project as the government water sector institution with the mandate to monitor and control incoming flood waters, together with the Sugar Estates and smallholder farmers.

3 Literature Review and Data Collection

Given the focus on the development of recommendations for flood management responses for the lower Incomati flood prone study area, and given the transboundary nature of the Incomati catchment, a lot of work has been carried out by different institutions from flood assessments to monitoring and information management systems.

The objective of the literature review and data collection was to determine the existing flood information for the area. The key perspective of these reports and associated response recommendations is to shift the approaches to flood risk avoidance, (which may potentially increase losses for large floods and will have greater impacts on floodplain ecology) to flood management which aims at reduced losses in the longer term, while minimising the ecological impacts. In many cases the impacts of disasters in impoverished areas is dramatic enough to erode the community resources to a degree where they are no longer able to sustain themselves. This can plunge them into a poverty cycle that leads to the collapse of the social and economic fabric supporting these communities leaving many people hopeless and destitute depending on outside intervention. The reduction of impacts related to such disaster events thus can save lives, prevent considerable hardship and reduce economic losses in the affected communities.

3.1 Data Sources

3.1.1 The PRIMA Project

The Governments of the Republics of Mozambique, The Republic of South Africa and the Kingdom of Swaziland have been working together on the management of their shared water resources and on carrying out studies of common interest through the Tripartite Permanent Technical Committee (TPTC), which was established in 1983. An Interim IncoMaputo Agreement (IIMA) was signed by the three governments in 2002 (TPTC, 2002) and it was agreed that a Comprehensive Agreement will follow, which would enable the countries to more effectively utilise, develop and protect the shared waters of the Incomati and Maputo River Basins.

The TPTC identified twelve projects to be implemented under the Progressive Realisation of the IncoMaputo Agreement (PRIMA), financed by the Government of Netherlands. This resulted in a substantial amount of work being done under the PRIMA such as hydraulic models and reports on disaster management and operating rules for the Incomati system.

All relevant information has been collected, namely:

- GIS shapefiles of the runoff and rainfall stations in the PRIMA project study area, most data outside of the Mozambican border;
- List of Mozambican runoff, rainfall, evaporation and water quality measuring stations;
- Flow data for stations X3H015 and X2H036 from 1982 to 2014;
- PRIMA MIKE 11 model setup.

3.1.2 ARA-Sul

ARA-Sul, Administração Regional de Águas do Sul, is the regional water management board responsible for the activities related to water resources in the Limpopo and Incomati River Basins in Mozambique and it is one of the entities of the PRIMA project. ARA-Sul has as a mandate to collect and manage water resources data and is hence a key stakeholder in this project.

The following list comprises the data provided by ARA-Sul:

- Nkomati Model Mike 11;
- Flood forecasting Maps for the Incomati Basin. Draft. March 2014. ARA-Sul;
- Evaluation of the hydrologic and hydraulic flood situation in Mozambique 1977-2013. First Phase Report. Final version. October 2013. Consultec and Salomon;
- Information for the operation of Corumana Dam. UGBI. March 2010. SWECO and Consultec;
- Final Report – Incomati River Basin Mozambique. Flood Risk Analysis Project. March 2004. SMEC ;
- Plan for the Incomati River Basin Draft Report, January 2003 /First National Water Development Project /National Water Resources Development/ NDF 197-5 / SWECO in association with Consultec, Impacto and BKS;
- Setup and calibration of the MIKE 11 Model for Limpopo and Incomati river Basins. Draft Final;
- Report, July 2002. (NDF 197 – MNWDP. Telemetry Flood Control and Integrated Management System for the Limpopo and Incomati basins);
- Legal framework for dissemination of hydrological information, circulation and decision on emergency periods;
- List of hydrometric stations on Lower Incomati;
- List of pluviometric stations on Lower Incomati.
- Topographical maps 1:250,000 (CENACARTA)
- Topographical maps 1:50,000 (CENACARTA)
- Corumana dam description (from "4 dams project"/DNA)

3.1.3 Instituto Hidrográfico da Marinha

The Hydrography Institute was created by the Portuguese Navy, consisting of its laboratory for marine sciences. It produces tide forecasts and has a long term database for different points for Portuguese speaking countries including Mozambique. The tidal time series for the Port of Maputo were obtained for 2 years between 2013 and 2015.

3.1.4 Illovo

Illovo is a part of a Multi-National Corporation producing raw and refined sugar for local, regional and world markets from sugar cane supplied by its agricultural operations and independent outgrowers. Illovo is the largest shareholder of one of the key infrastructure developments in the study area, the Maragra Açúcar SA estate, where raw sugar is produced, 60% of which according to Illovo is sold for local consumption and industrial markets and the balance exported to preferential markets in the EU.

Figure 3-1 Illovo sugar estate in Maragra Estate (taken from www.illovosugar.co.za).

Illovo is as a key project stakeholder, and data collected from its operations include the following:

- Daily maximum river water levels for the four gauging stations in the study area for 2014;
- Incomati river levels from 1952 to 2012 for Magude station;
- Field visit photography and video footage of the flood damage to the Maragra fields from August 2014;
- GIS shapefiles of the Maragra and small grower fields;
- All the surveyed top of dyke levels;
- Google Earth delineation and survey of main roads and railway tracks affecting the hydraulic behaviour in the floodplains;
- Topographical survey carried out in March 2015 of the selected roads, railways, Illovo dykes and hydraulic structures.

3.1.5 Tongaat Hulett

Tongaat Hulett grows sugarcane and maize and further processes it to produce different refined carbohydrate products. The Mozambique sugar operations comprise the sugar mills and estates of Mafambisee and Xinavane, the latter being the second key infrastructure development in the project area. According to Tongaat Hulett, sugar production capacity at the Xinavane mill is more than 240 000 tons in a 32-week crushing season. Tongaat Hulett land cooperates with private growers and community-based schemes in its surroundings.

Figure 3-2 Tongaat-Hulett sugar estate in Xinavane (taken from www.tongaat.co.za).

Tongaat Hulett is a critical project stakeholder and has contributed with the following data:

- GIS shapefiles of the Tongaat Hulett fields including small grower fields;
- Data obtained regarding the outgrower schemes, Google Earth identification of their location and description of functioning of these schemes;
- Topographical survey carried out in the Xinavane Estate.

3.2 Topographical Data

CRIDF carried out a topographical survey in order to generate important data for the main rivers and hydraulic structures in the study area. An appraisal of the river network and structures through an observation of satellite imagery provided by Google Earth was carried out and is presented below.

The main structures identified are presented in the following figures.

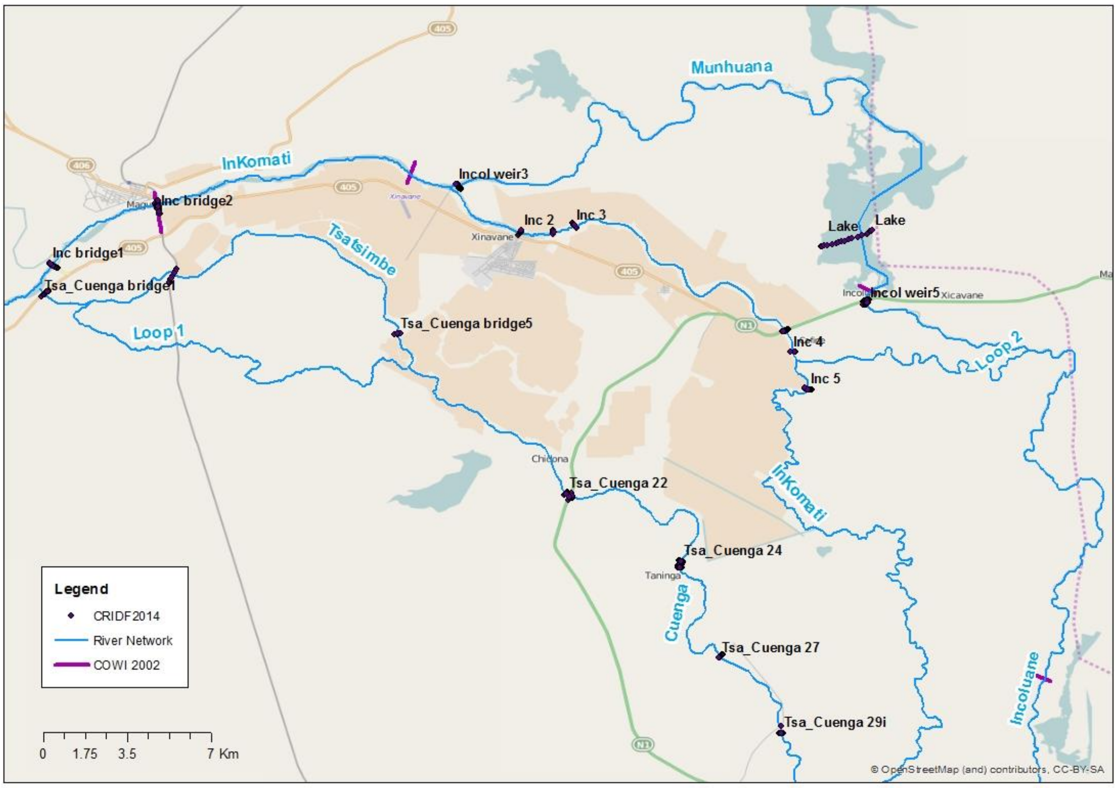


Figure 3-3 Northern section of the study area, where Xinavane Estate is located presenting the survey by CRIDF.

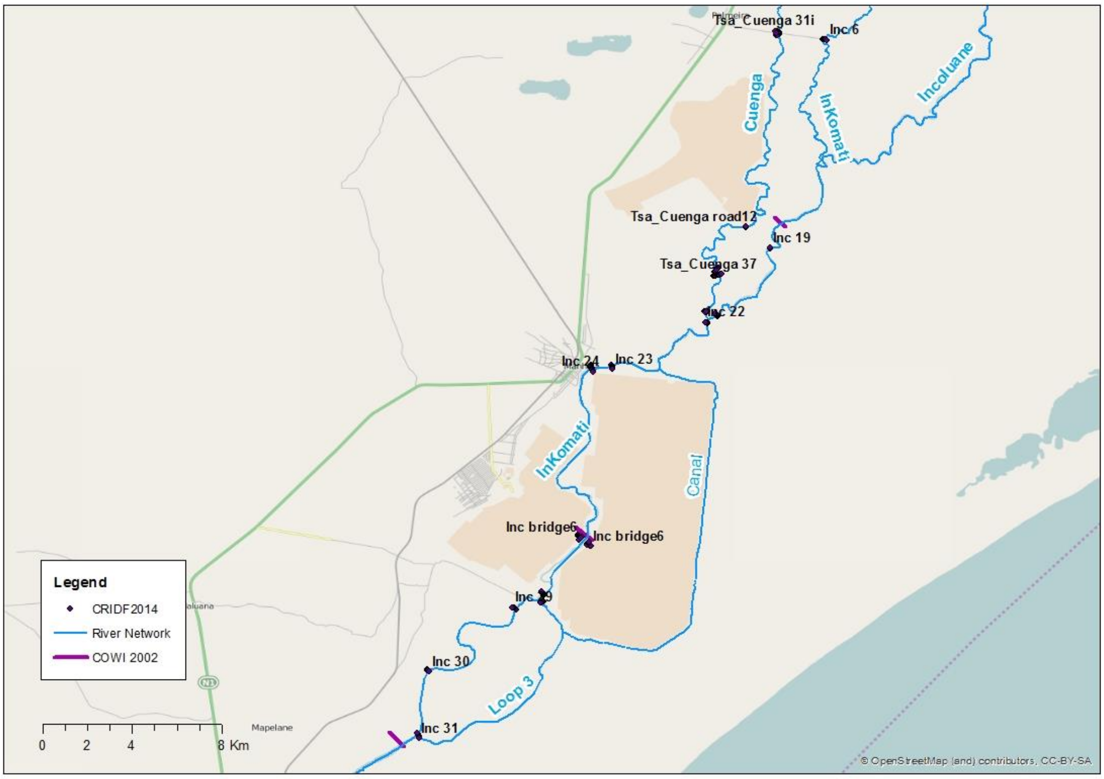


Figure 3-4 South section of the study area, where Maragra Estate is located presenting the survey by CRIDF.

The nomenclature of the structures is as follows: river name abbreviation, type of structure, order number from upstream to downstream. The location of the structures is presented in the table below in UTM and Decimal Degrees coordinate systems.

It was requested that each surveyed cross-section should also be accompanied by the observation of vegetation and soil cover in order to determine resistance to flow. Finally, topographical information regarding area and depth of the lakes to properly portray storage area in the model, was also requested and one cross-section obtained to allow for its conceptual representation.

Due to budget and time constraints not all the above depicted locations were surveyed, and priority was given to bridges and cross-sections of the main river channel close to the bridges. Where possible, the topographical survey of a certain section would always include the associated flood plain. The dimensions of the bridges were also surveyed. Also in order to refine the previous list, a comparison was done by CRIDF with the survey the consulting company Royal Haskoning-DHV will carry out over the course of their project for Tongaat-Hulett. In addition, a column specifying the cross-section width in metres was added, which was estimated through observation of the available Google Earth satellite imagery. However this analysis had its limitations and the widths would need to be supported and/or readjusted according to the experience on the ground when conducting the survey.

Name	UTM X	UTM Y	DD X	DD Y	Priority	Width
Inc 19	490428.816732	7199075.49454	32.904899	32.904899	X	150
Inc 21	486289.002448	7192667.4738	32.863701	32.863701	X	150
Inc 22	485964.374707	7192311.67191	32.86047	32.86047	X	150
Inc 23	482078.907668	7190434.39785	32.82182	32.82182	X	150
Inc 24	480958.58597	7190091.68328	32.810676	32.810676	X	200
Inc 28	479251.247307	7180120.20044	32.793547	32.793547	X	200
Inc 29	478445.836507	7179851.73007	32.785529	32.785529	X	150
Inc 30	474770.895157	7176873.46356	32.748906	32.748906	X	150
Inc 31	474335.669202	7174136.71457	32.744522	32.744522	X	200
Tsatsi_Cuenga 22	480759.681091	7219582.90182	32.809115	32.809115	X	150
Tsatsi_Cuenga 23	481084.402936	7219426.05954	32.812335	32.812335	X	100
Tsatsi_Cuenga 24	485074.934651	7216789.77793	32.851897	32.851897	X	200
Tsatsi_Cuenga 25	485069.501171	7216437.77399	32.851839	32.851839	X	200
Tsatsi_Cuenga 27	486522.097359	7212898.24646	32.866219	32.866219	X	250
Tsatsi_Cuenga 29	488861.414115	7209765.91818	32.889413	32.889413	X	200
Tsatsi_Cuenga 31	488865.859764	7205495.9274	32.889422	32.889422	X	250
Tsatsi_Cuenga 32	488800.005494	7205167.0445	32.888766	32.888766	X	200
Tsatsi_Cuenga 34	487626.329515	7196672.72836	32.877032	32.877032	X	150
Tsatsi_Cuenga 36	486299.614536	7194843.66355	32.863828	32.863828	X	250
Tsatsi_Cuenga 37	486504.724737	7194422.5534	32.865863	32.865863	X	150
Tsatsi_Cuenga 38	485887.468369	7192863.51778	32.859711	32.859711	X	100

Name	UTM X	UTM Y	DD X	DD Y	Priority	Width
Inc 2	478887.635987	7230455.71916	32.79071	32.79071	X	340
Inc 3	481057.933023	7230691.97648	32.812227	32.812227	X	260
Inc 4	489317.180928	7225450.83055	32.89406	32.89406	X	260
Inc 5	489843.206028	7224098.59203	32.899267	32.899267	X	300
Inc 7	490488.672256	7199553.66384	32.905498	32.905498	X	150
Loop 3 1	479531.200284	7179495.72157	32.796323	32.796323	X	150
Loop 3 3	474666.176421	7173692.12616	32.747804	32.747804	X	150

Regarding the structures, priority should be given to bridges and weirs; therefore the list of locations has been reduced to the following:

Name	UTM X	UTM Y	DD X	DD Y	Width
Inc railway bridge	461255.784366	7229072.99877	32.615886	-25.053502	300
Inc bridge 2	465276.789399	7231601.30487	32.655814	-25.030767	700
Incol weir 3	476624.215252	7232395.1891	32.768305	-25.023816	350
Incol bridge 4	492090.585021	7227639.19068	32.921576	-25.066927	200
Incol weir 5	492064.268318	7227477.79096	32.921315	-25.068384	250
Inc bridge 6	480916.36996	7182688.41618	32.810151	-25.472765	700
Tsatsi_Cuenga bridge 1	460966.454237	7227872.48674	32.612984	-25.064336	330
Tsatsi_Cuenga bridge 3	465863.482404	7228707.30533	32.661557	-25.056916	200
Tsatsi_Cuenga bridge 5	474346.245641	7226232.46133	32.745612	-25.079434	100
Tsatsi_Cuenga bridge 7	480882.217974	7219493.20396	32.81033	-25.140392	100
Inc weir 1	480253.890345	7230454.64164	32.804254	-25.041392	200
Inc bridge 3	489003.130095	7226374.71819	32.890953	-25.078327	300

3.3 Meteorological Data

Meteorological data is of utmost importance for Phases 2 and 3 of this project as an Early Flood Warning System is highly dependent on rainfall and weather forecasts. It is important to gather historical data as well as real-time and forecasted data in order to implement such a system. The types of data that should be collected are: precipitation, potential evaporation, and temperature. The spatial and temporal resolution varies with data type and data source.

The relevant weather stations for the study area have been identified, and the data should be collected from the national meteorology institute – INAM.

Regarding freely available satellite data will be obtained from the National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Centre. The African Rainfall Estimation Algorithm Version 2 (2012) uses input data used for operational rainfall estimates are from 4 sources; 1) Daily Global Telecommunications Systems (GTS) rain gauge data for up to 1000 stations 2) AM SU microwave satellite precipitation estimates up to 4 times per d ay 3) SSM /I satellite rainfall estimates up to 4 times per day 4) GPI cloud-top IR temperature precipitation estimates on a half-hour basis. The three satellite estimates are first combined linearly using predetermined weighting coefficients, then are merged with station data to determine the final African rainfall. Daily binary and graphical output files are produced at approximately 3pm EST with a resolution of 0.1° and spatial extent from 40°S-40°N and 20°W-55°E. Additional data sets of 10 -day, monthly, and seasonal rainfall totals are created by accumulating daily data.

3.4 Flow and Water Level Data

Flow data has been collected from the following sources: ARA-Sul, the ICMA, and Illovo. The following Figure 3-5, presents the existing hydrometric gauges in the study area.

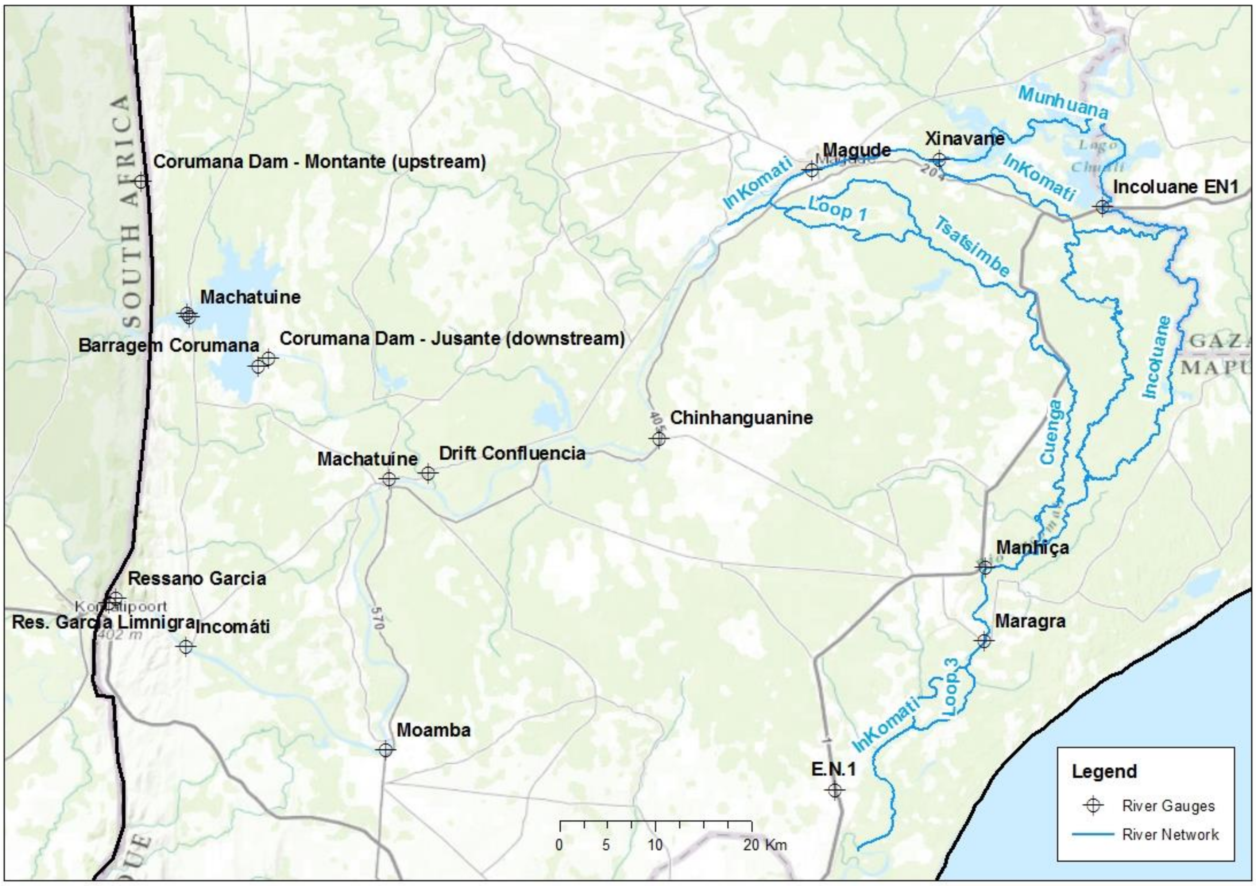


Figure 3-5 Map of the study area, displaying the river network simulated in the hydraulic model and the available river gauging stations.

From the stations shown above, ARA-Sul relies on Corumana dam station and Magude station for early warning as well as information from the South African DWS. The gauging stations have different record lengths and they are not real time enabled.

For this study the most relevant stations are on the one hand Ressano Garcia at the South African border to account for the inflow from the Incomati River, and Corumana Dam releases to account for the contribution from the Sabie River. No flow routing was done.

On the other hand ARA-Sul's stations Magude and Manhiça can be used for model calibration.

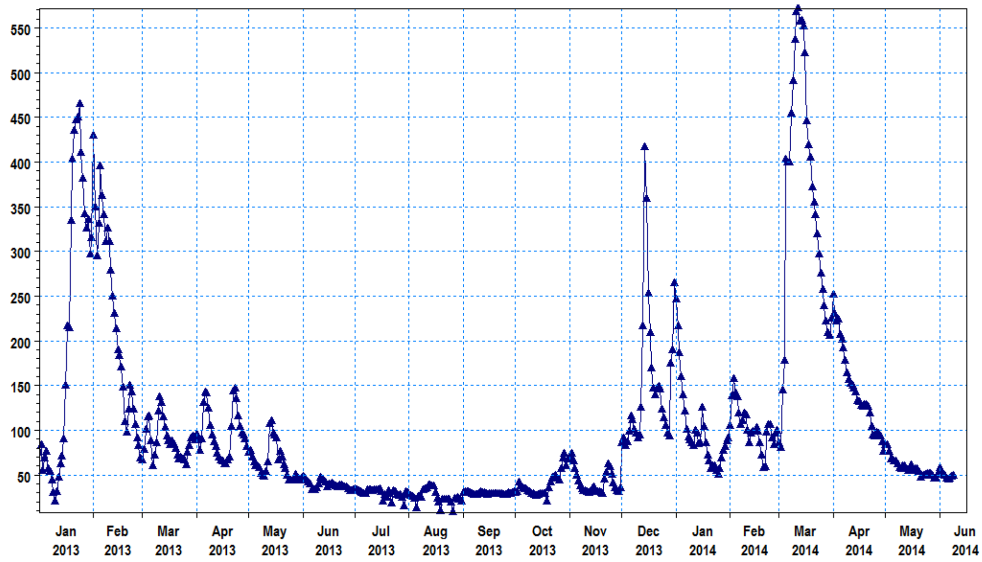


Figure 3-6 Observed discharge at Ressano Garcia station combined with Corumana dam releases (m3/s).

In terms of downstream water level data, tidal data was obtained from the website of the hydrographic institute of the Portuguese Navy, for the years of 2013 and 2014 in order to capture the impact of the tide on the flooding dynamics of the study area.

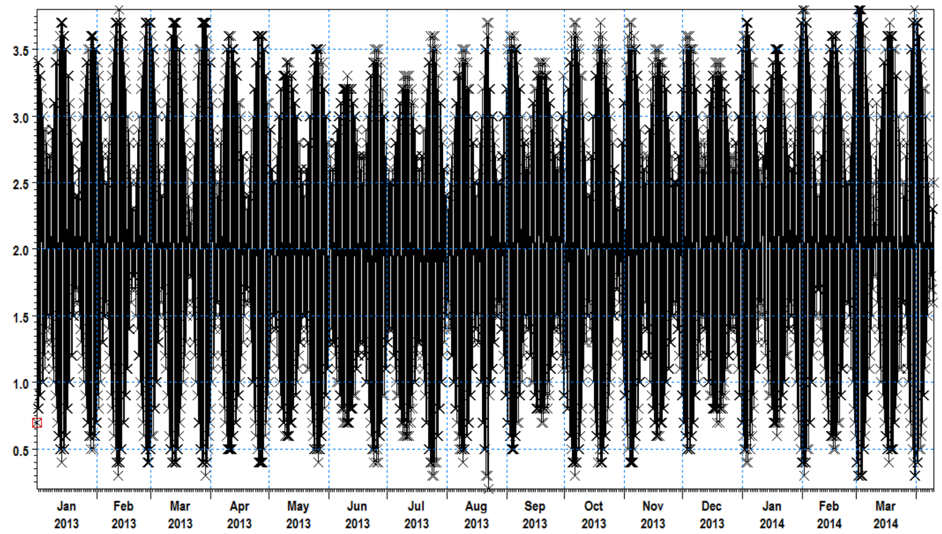


Figure 3-7 Tidal data at Porto of Maputo (AMSL) obtained from Instituto Hidrográfico da Marinha.

3.5 Land Cover Information

The Food and Agriculture Organization of the United Nations (FAO) and the United Nations Environment Programme (UNEP) launched the Global Land Cover Network (GLCN) with the objective to improve the availability of global information on land cover and its dynamics.

Globcover is currently the most recent (2005) and detailed (300 m) global dataset on land cover. The Globcover was published in 2008 as result of an initiative launched in 2004 by the European Space Agency (ESA). As part of its activities, GLCN has promoted the re-processing of the Globcover archive at national extent for the entire African continent (excluding areas not covered by the source data). The resulted data sets are vector based (.shp), coded using Land Cover Classification System (LCCS) classes, and topologically corrected to be used in the GLCN's Advanced Database Gateway software, which allows the data set to be further analysed, for example breaking down the LCCS classes in their classifiers for user-defined aggregations. This database was accessed and the data downloaded for the study area.

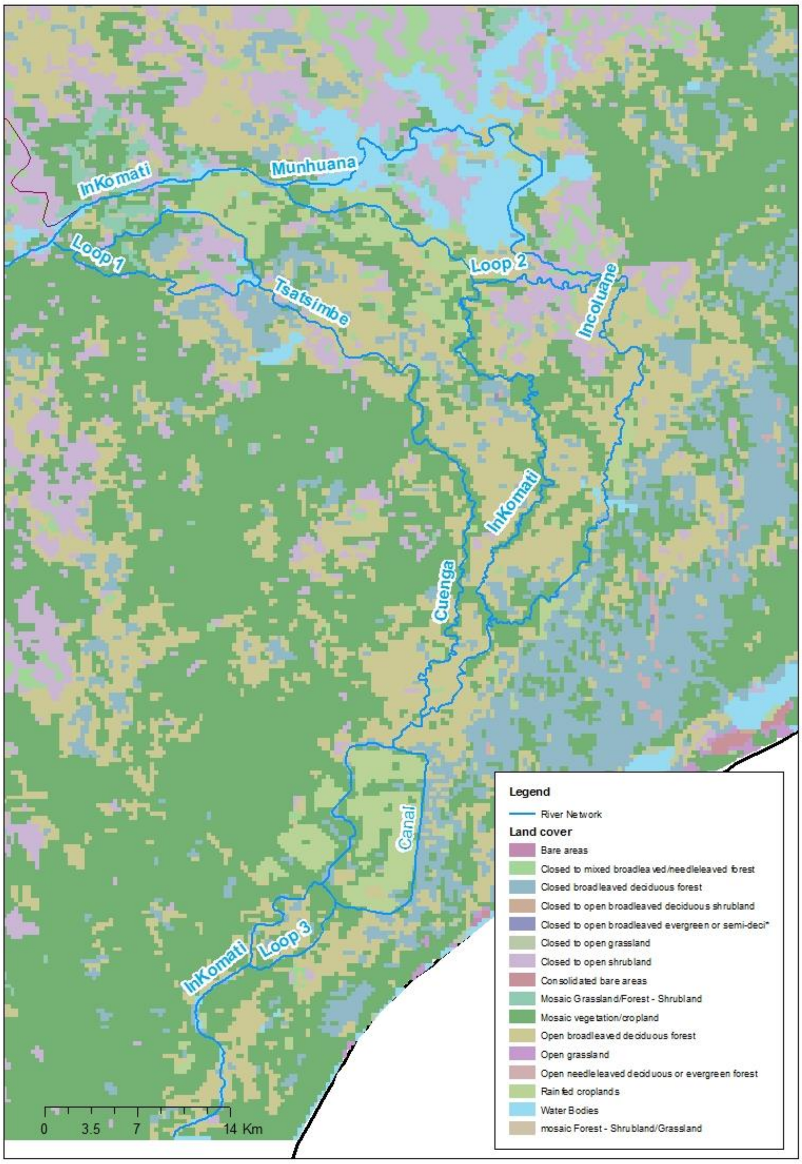


Figure 3-8 Land cover information for the study area (GLCN, 2005).

3.6 Flood Control Structures

The main flood control structures in the study area are the existing Corumana dam on the Sabie River used for flood control and flood protection dykes downstream.

Regarding Corumana dam, it is equipped with a bottom discharge outlet with capacity of 620 m^3/s at Maximum Storage Level through a conduit which is 240 m long, 7.5 m in diameter. This dam has allowed storage of considerable flood volumes, allowing the reservoir to have a dampening effect on flood peak flows downstream. This flood mitigating effect of the dam can be increased if the dam is equipped with gates. This is the reason Corumana dam is currently undergoing complimenting construction works with the installation of gates and this will increase storage volume from 720 Mm3 to 1200 Mm^3.

However the largest flood peaks arrive due to precipitation occurring in a number of the contributing tributary river basins of the Incomati River itself, which are the Komati (South Africa and Swaziland) and the Crocodile (South Africa). Currently there is no dam which can allow attenuation of these inflows, but construction of the new Moamba-Major dam has been initiated. This new dam is expected to have a total capacity of 850 Mm^3.

Once dam works are completed, consistent operational rules of both dams will have to be put in place. Together with an appropriate flood forecasting model, fed with also consistent information, it is expected that flooding in the study area will be reduced considerably.

However, dams do not avoid floods yet they allow the reduction of the inundation extent downstream hence reducing the negative social and economic impacts as well. Flood defence dykes are a very much used and effective structural mitigation measure to prevent localised areas from being flooded. In the study area dykes have been put up by the Sugar Estates at Xinavane and Maragra to protect the fields.

The main danger regarding making use of dykes is the fact that dykes should not be built on both river banks for the same river section. The river needs space to expand during a flood event and one side of the floodplain should be allowed to be flooded in order to form temporary storage for flood waters, leading to a reduction in the flood peak.

Dykes on both sides of the river lead to a reduction in the flow area which leads to higher water levels and also higher velocities of flow. The increase in flow velocity in turn leads to an increase in transport capacity of sediment loads by the river which generates risk of erosion and negative impacts on the river bed, river banks and bridge foundations.

3.7 Flood Management

In Mozambique there are several institutions which have a role to play before, during and after a flood event.

The key institutions are the meteorological institute INAM, the water sector DNA and ARA-Sul, the emergency operations centre CENOE which is part of the INGC, and the Local Government. The Local Government consists of the District's Administration, the District's Technical Council for Disaster Management and the Administrative Post. The downstream warning recipients are the floodplain inhabitants.

On an annual basis, INAM carries out a seasonal forecast and DNA/ARA-Sul perform the hydrological forecast and contingency plans. Meetings with the INGC and the rest of the water sector and relevant partners are organized to plan activities, budgets and mobilization of resources. These resources include technicians, data, IT and their respective update. Bulletins are put together by each basin management unit and each institution's interventions are coordinated.

During an emergency, when ARA-Sul receives a high rainfall event report from INAM, it carries out the hydrological modelling, and an initial assessment of the repercussions of the possible flood. It also issues a pre-warning to CENOE in Maputo and the Local Governments. At the same time, ARA-Sul sends the data to DNA so that the Technical Director Issues confirmation of the possible flood event based on comparison with data received from the South African DWS. After the confirmation takes place, a final warning is sent to CENOE which then issues the final warning to Local Administration and the Media namely the radio.

3.8 Vulnerability Data

To determine the vulnerability status the following data was collected:

- Inspection of Google Earth imagery combined with other spatial shapefile data collected for the area;
- Land use categorisation with regards to flood vulnerability;
- Data from the out-grower schemes held by the sugar estates;

One of the important aspects of the mobilisation of the CRIDF team was to keep alongside those working on the EU (European Union) supported projects for Maragra and Xinavane. The intention is primarily to agree the modalities of working with the small scale out-growers and other stakeholders to ensure that there is no confusion of publication of messages. As a part of these EU supported projects, community surveys were conducted, therefore the project team provided the EU team with a flood vulnerability specific survey which they would try to implement and combine with their own work. The results from the EU project's survey were obtained and used to determine the social and economic vulnerability of the different stakeholders and communities in the study area.

3.8.1 Existing Communication Infrastructure

The main transport network in the study area consists of the national road EN1 which does the connection of the main urban centres; these being the towns of Magude, Xinavane, and Manhiça with the capital Maputo.

Adding to this network there is a series of secondary roads and railway tracks across the floodplains which were considered in this study as it was found they affect the hydraulic behaviour of the floodplain areas. These consist mostly of the Beira, Palmeira, Calanga and Machubo roads, as well as the Xinavane and Magude railway tracks.

3.8.2 Demographic Information

District profiles for Manhiça and Magude were obtained from the webpage of the National Institute of Statistics (INE). The latest information regarding population, well-being, social-demographic, education, health, is from year 2013.

4 Satellite Data Acquisition

4.1 DEM Data

In order to carry out a detailed hydraulic analysis of flooding in the study area, it was necessary to obtain the most detailed topographical information possible, within budget and accuracy requirements. Since a two dimensional model was built, a digital elevation model (DEM) of the river and floodplains is necessary.

Initially satellite freely available datasets were obtained and their appropriateness investigated. The NASA Shuttle Radar Topographic Mission (SRTM) has provided digital elevation data for over 80% of the globe. This data is currently distributed free of charge by USGS and is available for download from the National Map Seamless Data Distribution System, or the USGS ftp site. Another Digital Elevation Model with 30 m resolution is available on-line produced by the ASTER Project. This is a Japan-US cooperative Earth-observing project aimed at contributing to the solution of global environment and resources problems. ASTER, the Advanced Spaceborne Thermal Emission and Reflection Radiometer, the first in a series of satellites planned in the NASA-initiated international EOS Project, was launched in December 1999 aboard the Terra platform.

The later available free satellite digital elevation models have been obtained for the study area. However, the quality was deemed to be insufficient to carry out a detailed hydraulic two dimensional analysis. Therefore, satellite DEM was purchased However, it is expected that the DEM will have to be ‘ground truthed’ through land based surveys of the critical flood prone areas.

The chosen product was NEXTMap World 30 Digital (Intermap Technologies®), this Digital Surface Model (DSM) is 30-meter DSM provides the most accurate worldwide elevation product on the market to date. It has been aligned and adjusted using high-resolution worldwide LiDAR (25-centimeter vertical accuracy) producing a significant improvement from the original 30-meter ASTER Global DEM and SRTM 30- and 90-meter products available today. The aggregation and merging process of other elevation datasets has enabled Intermap to remove many of the artefact’s “spikes and wells” characteristic of the latest release of ASTER and SRTM data. Additionally, NEXTMap World 30 is void filled and adjusted for vertical and horizontal shifts that occur in ASTER and SRTM global DSM offerings. Figure 4-1 shows the study area relief map of the NEXTMap DEM.

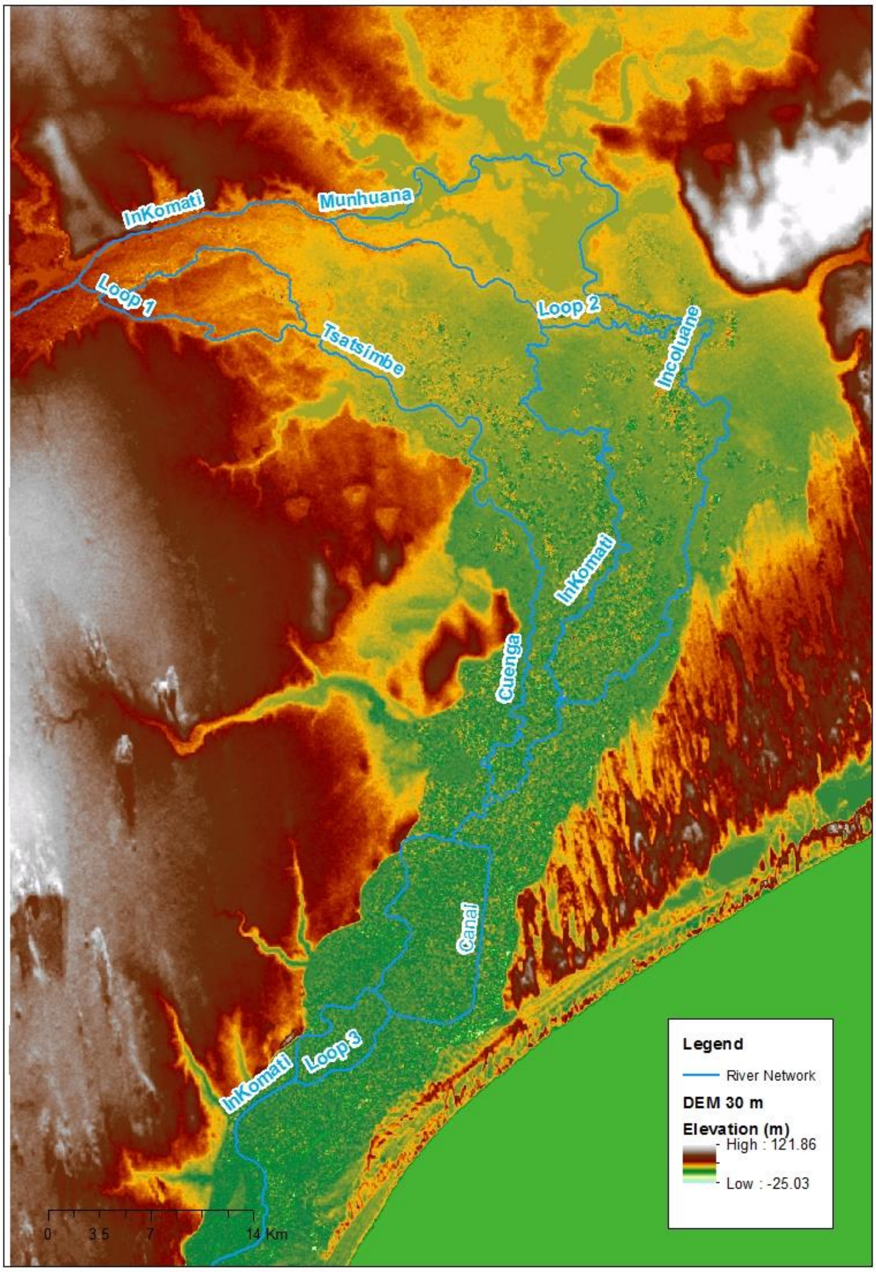


Figure 4-1 NEXTMap World 30 meter digital elevation model obtained for the study area

4.2 Post-processing and Bias Correction

The 30 x 30 m satellite digital elevation model was found to suffer from a large amount of erroneous values and noise particularly on the flattest floodplain areas towards the centre and south of the domain. Therefore, the final DEM dataset applied in this study was the result of several post-processing procedures.

Initially, using all the topographical surveys the project team obtained which were listed in the previous chapter, a bias correction process was carried out where an average difference I elevation between the observed points and the raster DEM cells was calculated (see Figure 4-2 and Figure 4-3 below). As a result, an average value of 4.5 m mas subtracted from the raster cell values.

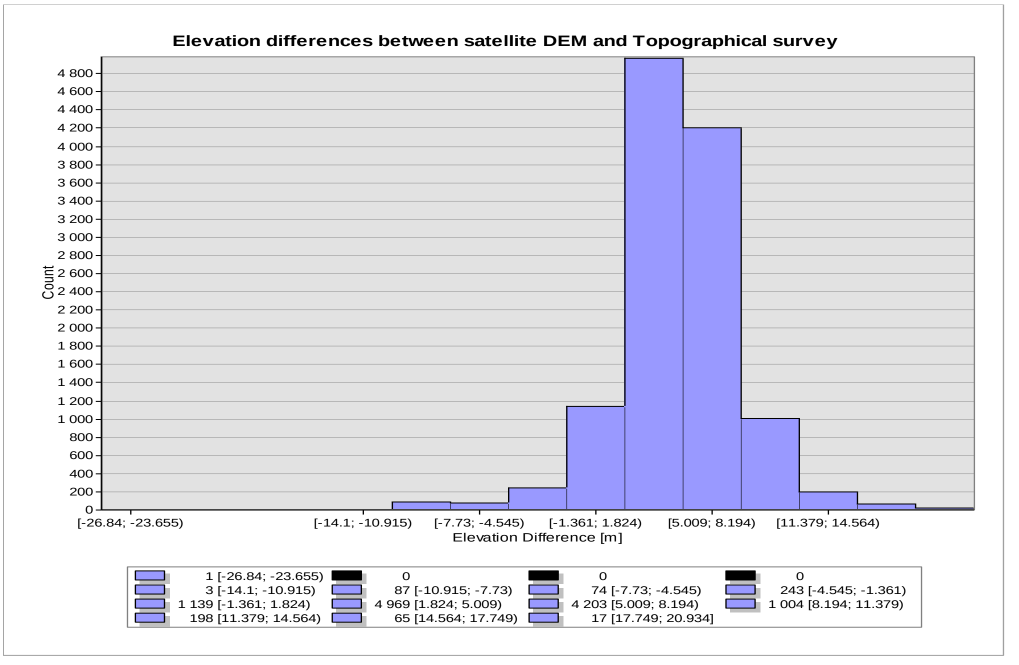


Figure 4-2 Bias correction analysis results (average value of 4.76 m)

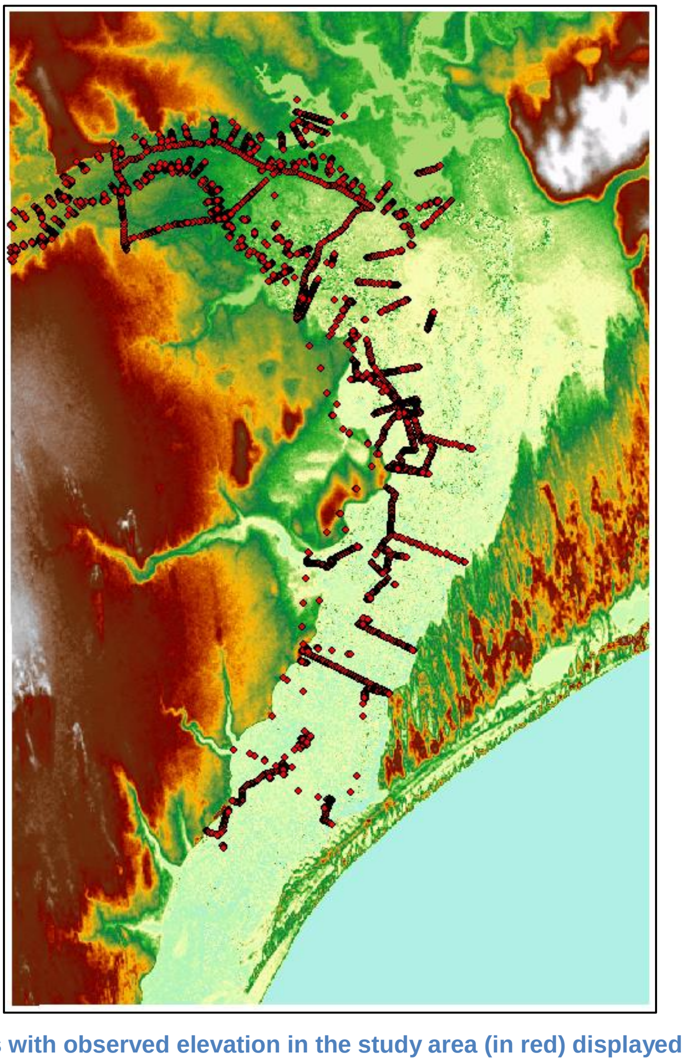


Figure 4-3 Points with observed elevation in the study area (in red) displayed over the DEM.

4.3 Imagery of Past Flood Events

Satellite imagery is also used in assessing and studying flooding dynamics and flood extent. Therefore, low resolution satellite imagery for the study area was collected from MODIS and medium resolution from LandSat.

The MODIS satellites operated by NASA started operation in 1999 with the launch of the Terra satellite and was followed by the launch of the Aqua satellite in 2002. The sensors are equipped with 36 bands in different wavelengths and with different spatial resolutions (250, 500 and 1000 m). The two MODIS satellites each deliver one image per day of any location around the globe. This high temporal resolution makes it very attractive for monitoring programs.

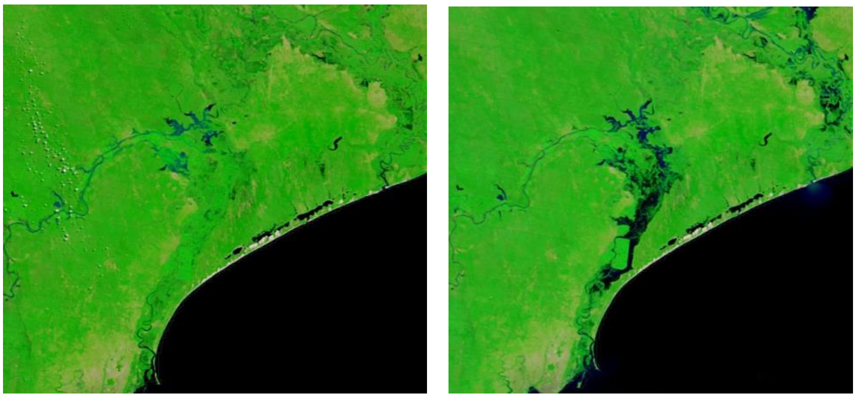


Figure 4-4 Sequence of images from MODIS during the March 2014 floods in the Lower Incomati.

The Landsat Project is the longest-running enterprise for acquisition of moderate resolution imagery of the Earth from space. The Landsat 1 satellite was launched in 1972; the most recent, Landsat 8, was launched in 2013. The instruments on the Landsat satellites have acquired millions of images. These images form a unique resource for applications in agriculture, geology, forestry, regional planning, education, mapping, and global change research. Landsat data are available since 1973 which means that event can be tracked more than 30 years back in time and the high number of spectral bands means that Landsat is the preferred solution for discriminating vegetation, geology and land cover types. Finally, the spatial extent of Landsat scenes makes them easy to work with as they cover large areas. A single Landsat scene covers app. 185 x 185 km.

5 Flood Risk Assessment

Flood risk is a combination of the flood hazard threat, exposure and vulnerability, as exemplified in Figure 5-1 below. The following subchapters present the methodology carried out to estimate these three parameters. The flood risk assessment corresponds to a calculation of the flood risk which results from the intersection of both the composite hazard zones and the composite vulnerability areas.

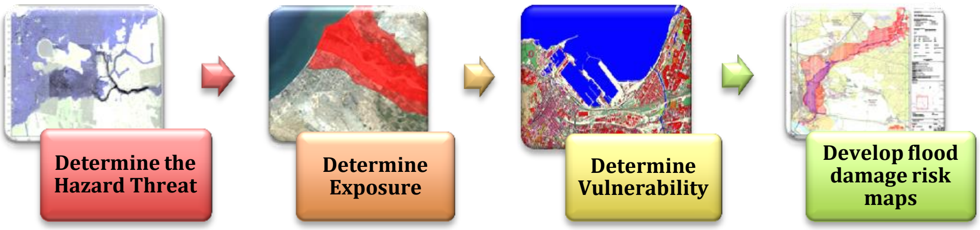


Figure 5-1 Flood Damage Risk Mapping Procedure.

5.1 Exposure Determination

Exposure is a consequence of the intersection between human activities from an agricultural, commercial, industrial or domestic perspective and flood hazard threat. Unfortunately the majority of communities in many areas around the globe tend to congregate around water resources such as rivers where the water is used to support various activities. While there are obvious benefits associated with these development patterns, they often place communities at risk of being impacted by various flooding activities.

The process undertaken to determine exposure is as follows:

- Google Earth satellite information was used to identify human activities and key structures which are near main river network in the study area;
- A detailed spatial classification of land use was carried out;
- The information from the flood hazard analysis will then be used to further identify community exposure by overlaying flood hazard extent onto satellite imagery showing exposure;

5.1.1 Classification of Land Use Categories and Key Areas

A classification system has been developed using the first two levels of the USGS land use categories as a guideline (Anderson et al, 1976). The first and second levels of the USGS land use are more generalised and are widely used as the standard categorization for land use and land cover (Table 5-1). The third level has been designed to mimic the conditions of the areas.

Spatial land use coverage was obtained for the area of interest; however the resolution thereof was very coarse and contained broad categories. Therefore, it was decided to rather use aerial imagery to, more accurately, manually create various land use categories according to the guidelines in Table 5-1 overleaf. Most of the agricultural coverage was supplied by the respective Illovo and Tongaat Hulett sugar estates. Other farm areas that were visible in the aerial photography were also included.

For the purpose of this project, two additional categories were included for the agriculture section, namely 'Large scale' and 'outgrowers'. The spatial coverage for these two sub-categories was also supplied by the sugar estates. 'Large scale' refer to MCP Grower (Miller Cum Planter) which means the "Milling company's own fields". It must be noted that naturally occurring land use types seen in Table 5-1 was not included in the classifications, as these do not contribute to human vulnerability.

Table 5-1 Categories used for classification of land cover

First Level	Second Level	Third Level
Built Up	Residential	Formal Low Density
		Formal Medium Density
		Formal High Density
		Informal Low Density
		Informal Medium Density
		Informal High Density
	Transportation	Railway
		Airport
		National Road
		Bridge
	Commercial	Market place
		Shopping complex
	Services	Army
		Hospital
		Police
		Church
		School
		University
	Industrial	-
Agricultural Land	Cropland and Pasture	Cropland
		Pasture
	Orchards, Groves, Vineyards, Nurseries and Ornamental Horticultural Area	Orchards
		Groves
		Vineyards
		Nurseries
		Ornamental Horticultural Area
	Outgrowers	-
	Large Scale	-
Forest Land	Deciduous Forest Land	-
	Evergreen Forest Land	-
	Mixed Forest Land	-
	Deciduous Forest Land	-

First Level	Second Level	Third Level
Water	Streams and Canals	Streams
		Canals
	Lakes and Reservoirs	Lakes
		Reservoirs
		Bays
		Estuaries
Barren Land	Dry Salt Flats	-
	Beaches	-
	Sandy Areas other than Beaches	-
	Bare Exposed Rock	-
	Strip Mines Quarries, and Gravel Pits	Strip Mines Quarries
		Gravel Pits
	Transitional Areas	-
	Mixed Barren Land	-

To better define low, medium and high population density the assumption made is the following: low density used for farm land areas where settlements were identified; medium and high density used for smaller versus larger rural urban centres (for example Palmeira versus Manhiça). The following Figure 5-2 depicts the final land use classification of the study area.

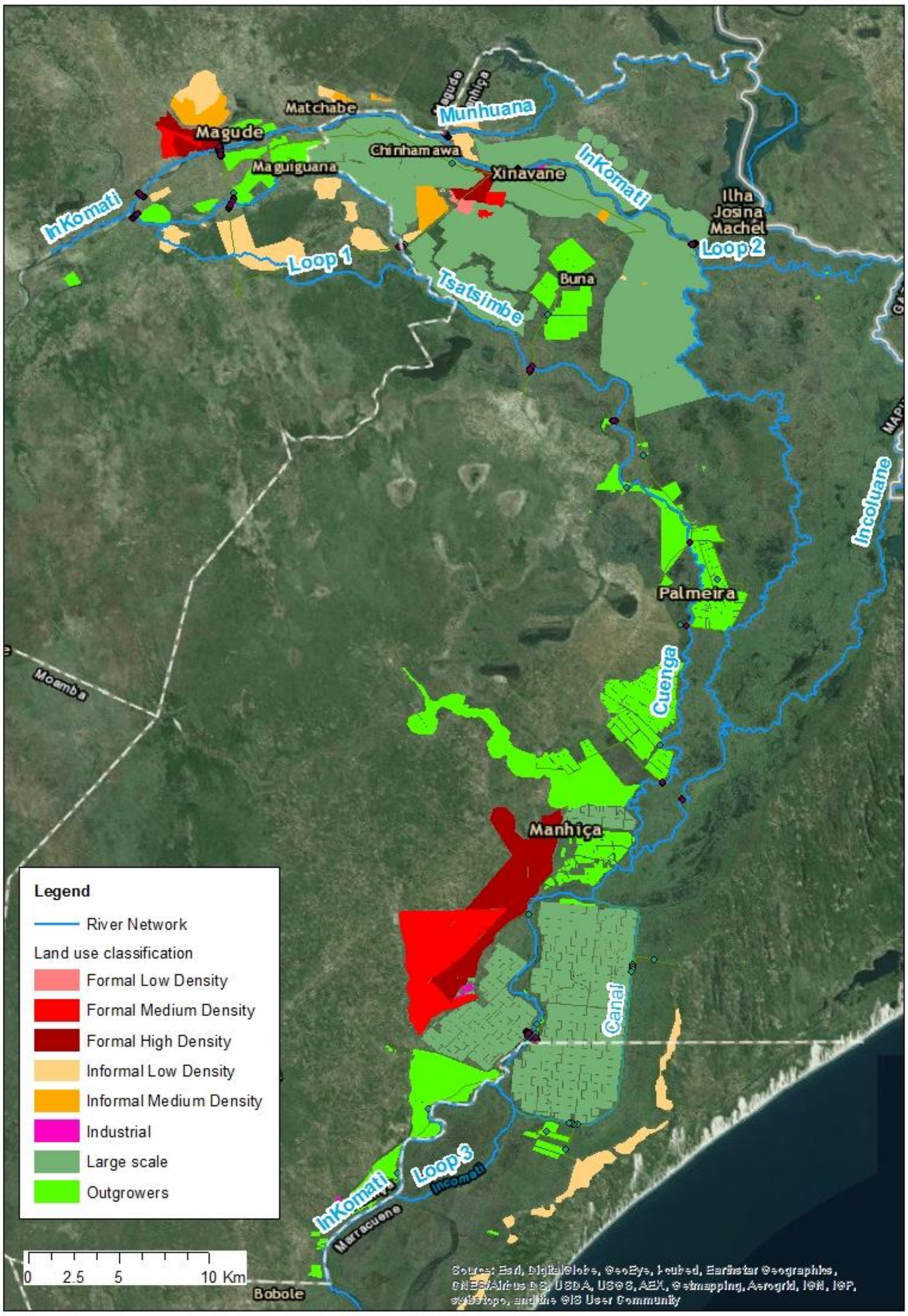


Figure 5-2 Land use classification of the study area.

5.2 Flood Hazard Analysis

A flood hazard analysis is a detailed flood plain assessment providing information about the flood extent, water depths or water level, flow velocity and flood hazard/danger level. The measure of hazard/danger is obtained when combining current velocity with water depth estimates. To determine these parameters there are two main steps taken to generate the required information:

- Determine the flow peaks at different return periods;
- Determine the flooding extent at the key areas of interest.

An extreme event analysis was carried out where three different methodologies were applied and compared to obtain estimations of peak flow discharges for different return periods for the study area. The return periods considered are 1 in 5, 10 and 20 years.

The purpose of the hydraulic modelling in this study was to produce the results regarding different flood parameters to be used in the generation of flood maps. Two models using MIKE software were built, a one-dimensional (1D) MIKE 11 model and a two-dimensional (2D) model MIKE 21. The estimated flood flows at the various return periods were routed through the hydraulic models of the study area under present physical structure of the floodplain area. The models enabled the determination of flood extent and depth, flow velocity and duration of inundation.

5.2.1 Extreme event analysis

The objective of an extreme value analysis is to find the design flow needed for planning purposes regarding probable flooding extent. The design flow in this case, is defined as the flow which has a return period of a certain number of years, this is the same as saying with a certain risk these flows will not be exceeded, which can be expressed as:

$$\mathrm{R} = 1 - (1 - 1/\mathrm{T})^{\mathrm{N}}$$

where R is the risk of exceedance of flow during a period of N years, with a return period of T. For the current study, the following return periods are chosen: 5, 10, and 20 years.

There are different statistical techniques that can be used to determine flood return periods using recorded flood flow volumes available and additionally, other standard techniques such as the Standard Design Flood (SDF) or the Regional Maximum Flood (RMF) methods.

All three techniques were applied and the results investigated to determine which approach would be most adequate for the study area.

Regarding using observed flow records, the longest record available was used from the Ressano Garcia Station on the Incomati river by the Mozambique border, station X2H036 according to the South African records, station E23 according to Mozambican records as shown in Figure 5-3.

The statistical analysis considers the maximum annual values of each year with records and the use of different probabilistic distributions whose parameters are adjusted to the data. This analysis requires the following choices be made: which distribution function is used, and method of estimation of parameters and quartiles.

The input time series utilized consisted of spanning 20 years of data and below in Figure 5-4 is a plot of the time series. There is a two year data gap for years 2000/2001 corresponding to the 2000 large flood event. In addition, other flood events are not fully captured.

Therefore, the annual maximum discharge time series was generated and estimates obtained from DWS for the 2000 and 2001 maximum discharge values added to it, for consistency purposes, and to ensure a correct picture of maximum values is obtained. Finally, the maximum values were confirmed by ARA-Sul.

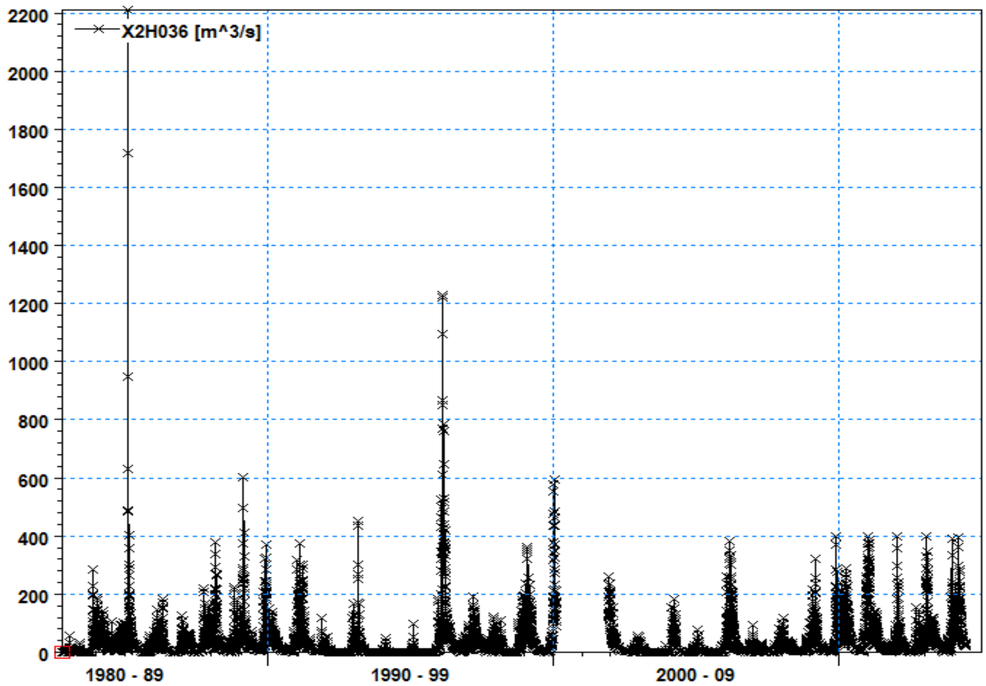


Figure 5-3 Discharge time series obtained from measured flow at X2H036 gauging station Ressano Garcia (m3/s).

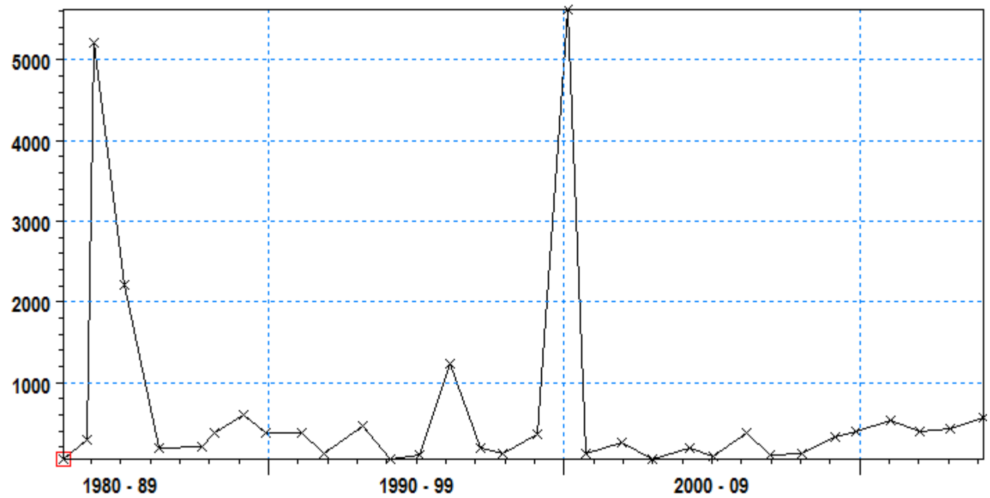


Figure 5-4 Annual maximum discharge time series obtained based on Ressano Garcia gauging station and flood flow peak estimates from DWS and ARA-Sul (m3/s).

The most typically applied probabilistic models were tested and the Log-Pearson III model proved to have a better fit in the estimation by the adjustment method of L-Moments, with Chi-squared test with a level of significance of 1.721% and the Kolmogorov-Smirnov test of 25.0 %.

For the Regional Maximum Flood method (Kovacs Z., 1988), the basin area value used was 38,237 km^2 and the flood peaks for the considered return periods calculated.

Regarding the Standard Design Flood method, the South African National Roads Agency Drainage Manual (SA NRA, 2013) was followed, and the flood peaks estimated. The following basin characteristics were used in the calculation:

Table 5-2 Calculated basin characteristics.

Basin characteristics			
Catchment area	A	38,237	km2
Length of main watercourse	L	934.32	km
Slope of main watercourse	S	1.96	m/km
Time of concentration - Bransby Williams method	Tc	141.57	h
Drainage basin zone	B	5	-

The following table presents a comparison of the flood peaks obtained.

Table 5-3 Comparison of flood peaks calculated through the different methods considered appropriate for the study.

Peak flood flow in m3/s	Standard Design Flood	Regional Maximum Flood1	Extreme Value Analysis
Q100	6,047	12,905	9592
Q50	4,743	10,950	5486
Q20	3,198	-	2535
Q10	2,169	-	1362
Q5	946	-	695

The simple triangular shape hydrograph was constructed for the time series, where duration for the rising limb is equal to time of concentration, and the duration for the falling limb is equal to 2 times the basin time of concentration. The results for all three methods are presented in the following Figure 5-5 to Figure 5-7.

It is considered that the most appropriate inflow hydrographs for the current study are the estimates produced by the SDF method.

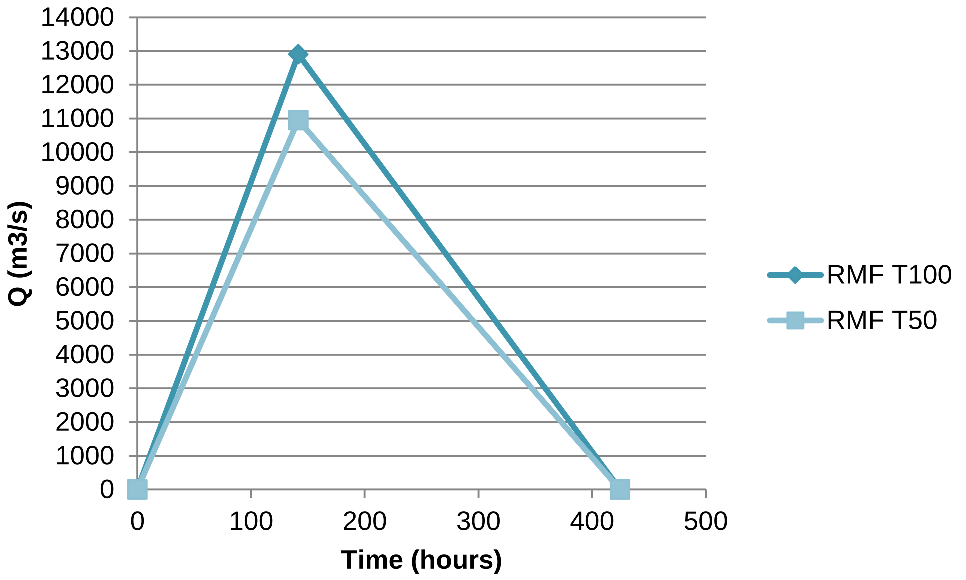


Figure 5-5 Design flow hydrographs obtained from applying the Regional Maximum Flood methodology.

[1] Method not applied to return periods below 1 in 50 years.

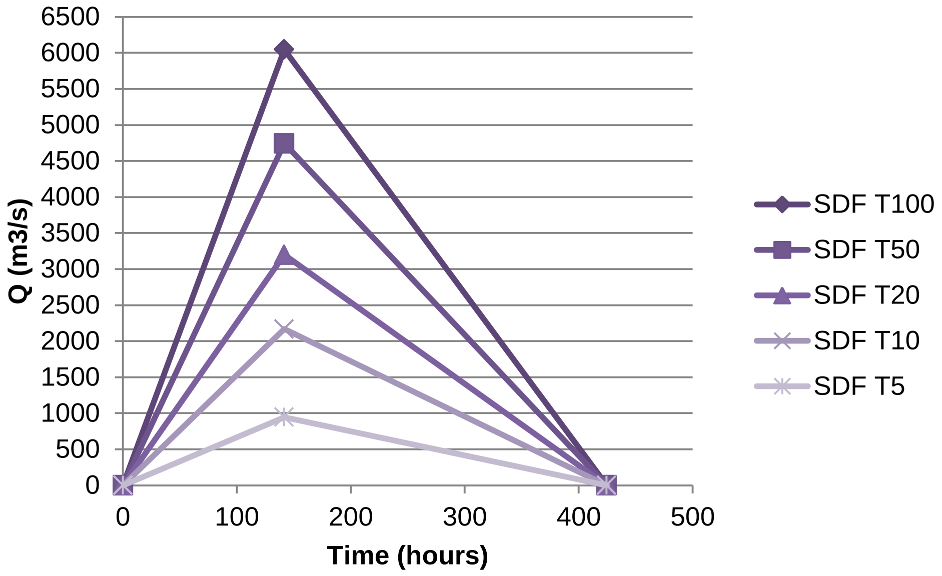


Figure 5-6 Design flow hydrographs obtained from applying the Standard Design Flood methodology.

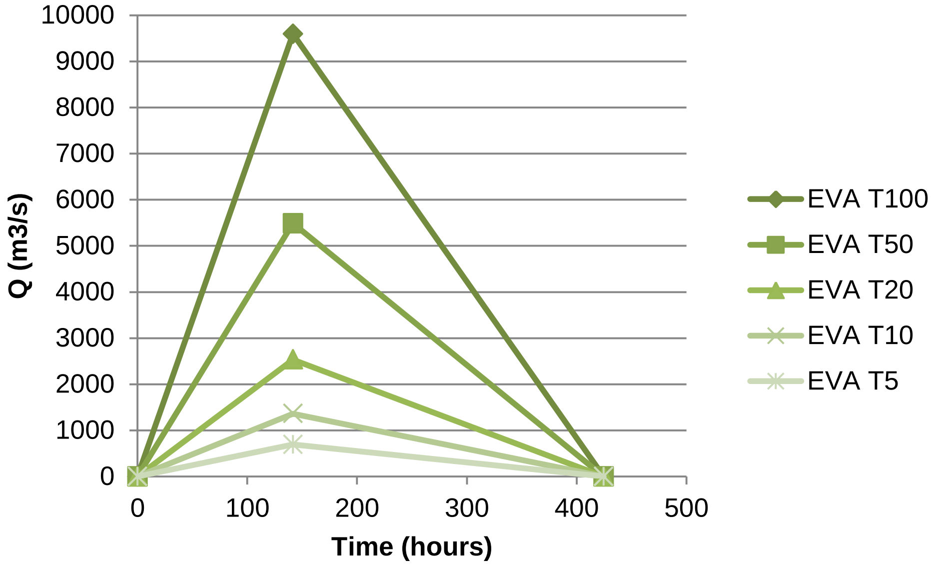


Figure 5-7 Design flow hydrographs obtained from applying an Extreme Value Analysis methodology.

In addition, the events of years 2012, 2013 and 2014 are compared to the SDF analysis, in order to ascertain the return period of the recent flood events in the study area. For this purpose, water level measurements obtained from ARA-Sul for Magude station E43 together with the station's rating curve were used to obtain the corresponding flow discharge values. This comparison is presented in the following Figure 5-8. According to the comparison below, the events of the last 3 years correspond to a 1 in 5 year event.

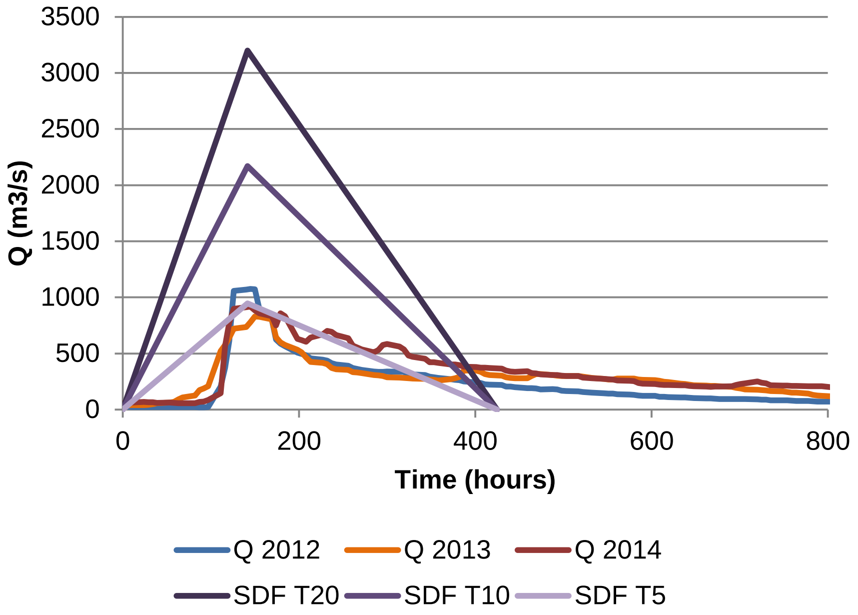


Figure 5-8 Comparison between SDF design flows with Magude station E43 flood events.

The following table presents a comparison of the respective flow volumes depicted in the previous Figure 5-8

Table 5-4 Comparison of flow volumes for the last three floods and the 1 in 5 yr return period event.

Flood event	2012	2013	2014	5 yr RP
Flow Volume (m3)	537,661,886	542,868,197	710,627,248	723,315,227

5.2.2 The MIKE 11 Model

MIKE 11 is the hydraulic river modelling model software produced by DHI. MIKE was used as the tool for simulating the hydraulics, water quality and sediment transport in estuaries, rivers, irrigation systems and other inland waters. The Hydrodynamic module of MIKE 11 uses an implicit finite-difference scheme to calculate unsteady flow described by the Saint-Venant equations of conservation of mass and momentum. The scheme is independent of the wave approximation chosen (kinematic, diffusive, or dynamic wave). A computational grid of Q-points and h-points is used as illustrated in **Error! Reference source not found.** overleaf. The topography of the river network is defined using cross-sections, and the bed resistance calculation can be done using the Chezy or Manning equations. Cross-sections constitute h-points, between which a Q-point is introduced. MIKE 11 handles looped as well as dendritic systems, backwater effects, flows in flood plains, and a wide range of control structures such as pumps, weirs, or controllable gates. Appendix G contains the information on the Hydraulic Model Configuration.

5.2.3 The MIKE 21 Model

MIKE 21 is the 2D hydraulic modelling system for free-surface flows, applicable to the simulation of hydraulic and environmental phenomena in inland river areas, lakes, estuaries, bays, coastal areas and seas. The hydrodynamic model in the MIKE 21 Flow Model (MIKE 21 HD) is a general numerical system for the simulation of water levels and flow. It simulates unsteady two-dimensional flows in one layer fluids (vertically homogeneous) and has been applied in a large number of studies. The Saint Venant equations of conservation of mass and momentum vertically integrated are solved describing the flow and water level variations inside the model domain. The most important model inputs are the topography and roughness conditions of the model area. The boundary conditions required can be either time varying flux or water level information. MIKE 21 allows the simulation of structures such as culverts and weirs which can be incorporated for example to simulate road under passes. If more complex structures such as Dam operations have to be included, this can be done in MIKE 11.

5.2.3.1 Model 2D Grid

The model grid was built using the satellite 30 by 30 m resolution DEM, which was initially converted into a 60 by 60 metre grid. The satellite topography was subject to a filtering process in the areas where a lot of noise was detected, particularly on the downstream floodplain areas. Topographical information provided by the sugar estates regarding elevation of dyke walls was introduced in the model grid, and the cross-sectional survey information from MIKE 11 was also used to include the river bed detailed topography in the two dimensional model grid. Finally, the main roads and railway lines were also approximately introduced in the model grid by raising the corresponding cells in the satellite DEM. The result is displayed in Figure 5-9 below.

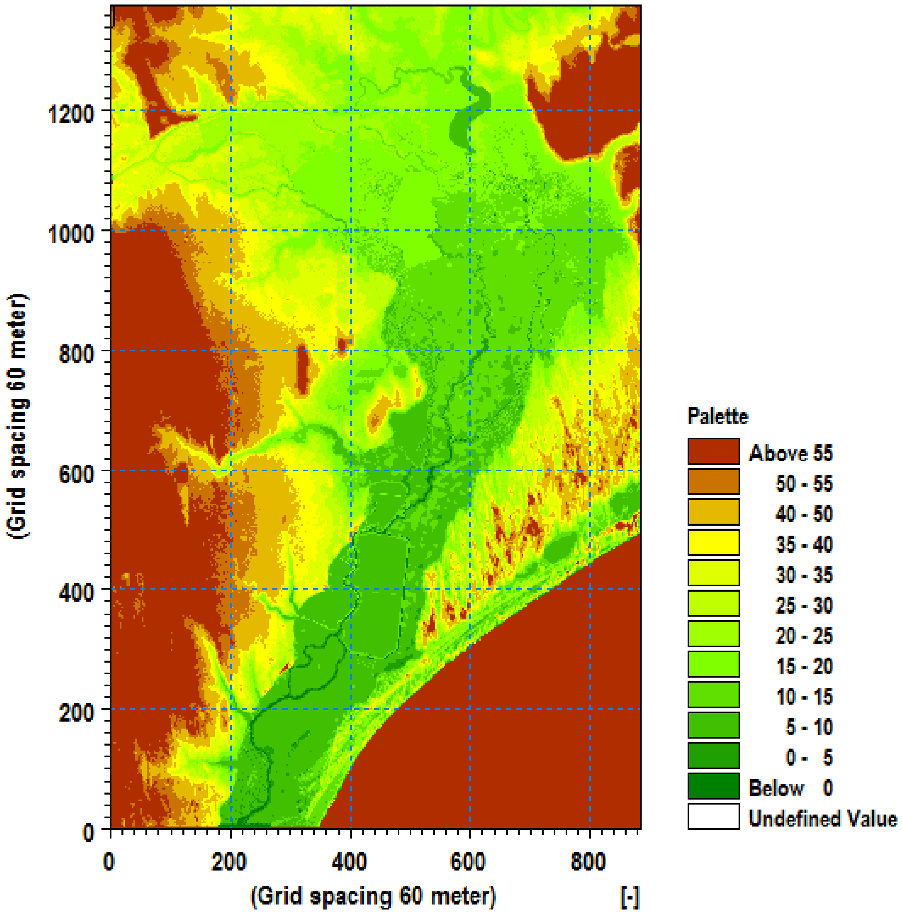


Figure 5-9 Model grid representing ground elevation in metres for the study area.

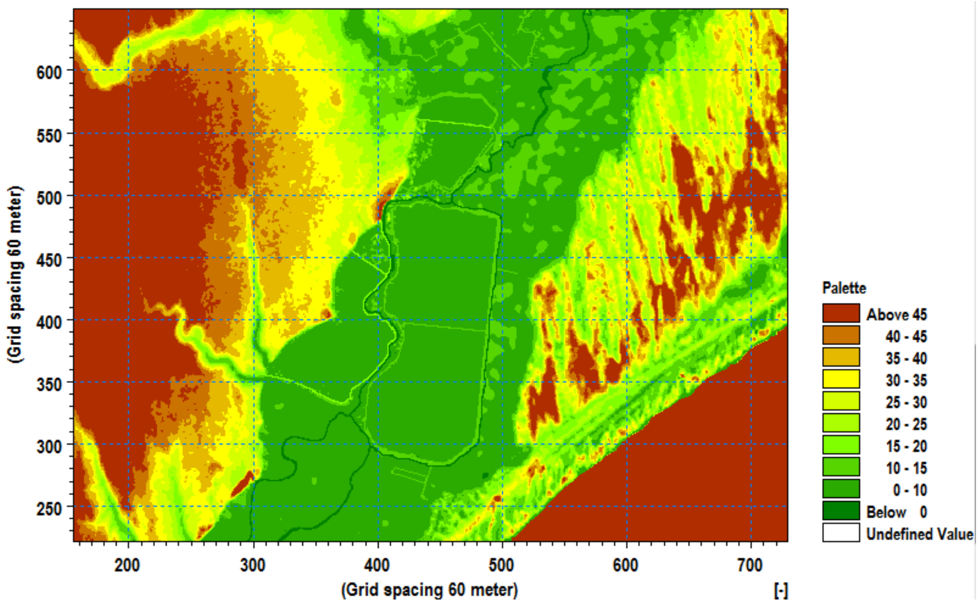


Figure 5-10 Detail of the Maragra area of the floodplain topography.

5.2.3.2 Resistance

The effect of bed resistance in the 2D hydraulic model is once more represented by varying the Manning number. For the 2D model, a spatially distributed Manning number was utilized based on the land cover information collected, as well as the MIKE 11 Manning values used for the main river network channels presented in the previous chapter.

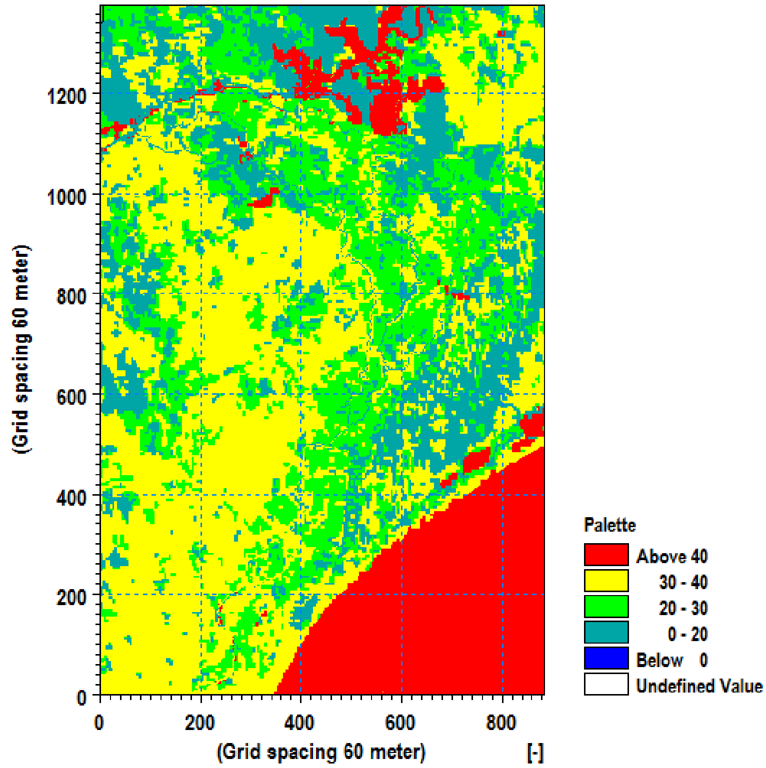


Figure 5-11 Spatially distributed Manning number M (m1/3/s) representing bed resistance in the study area.

5.2.3.3 Boundary Conditions

The 2D hydraulic model has one upstream inflow boundary and a downstream water level boundary. The upstream inflow time series correspond to the design flow time series built for each return period, whereas the downstream water level corresponds to the tidal variation estimated at the port of Maputo and presented in the previous chapters.

5.2.3.4 Model Calibration

The 2D hydraulic model was calibrated using satellite imagery of last year's flooding events. As can be seen in Figure 5-12 below, the most problematic area is the lake and Incoluane river area which was heavily flooded, but has only been conceptually introduced in the model. Similarly, the downstream area after the Maragra fields was also heavily flooded which is not being captured by the model appropriately.

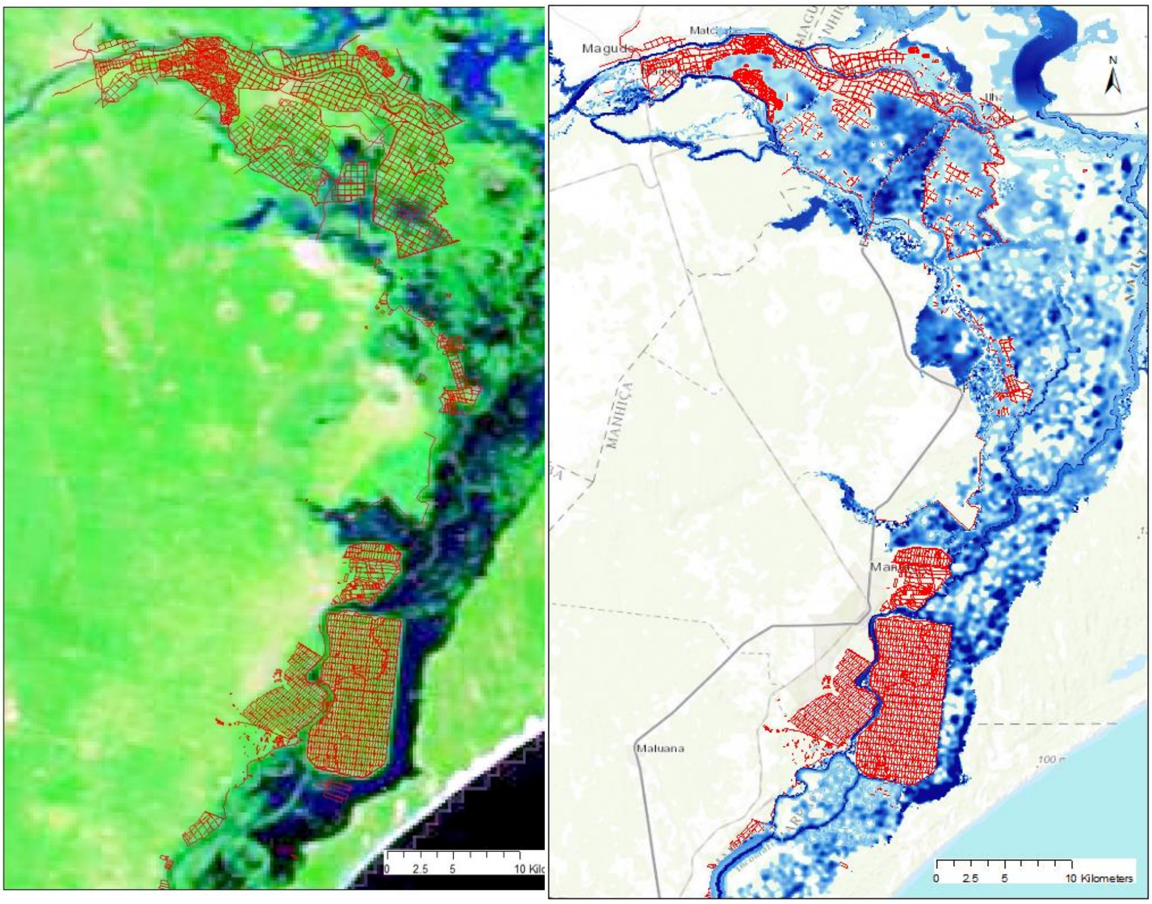


Figure 5-12 Calibration of the MIKE 21 model using flood extent of the 17th of March 2014 past flood event; the image on the left is a satellite image from the MODIS mission, and the image on the right displays the simulated flood extent, the lines in red represent the sugar estates' fields and infrastructure.

Finally, the flooding occurring at the top corresponds to a very low water depth of around 0.2 m which appears not to be displayed on the satellite imagery however, due to the non-existence of flood dykes in the upper Xinavane fields section, this amount of flooding is most likely to have occurred.

Calibration of the hydraulic model is directly related to the DEM data and even though improvements were carried out during the processing of the DEM, the best obtained approximation does not capture the satellite image exactly. It is necessary to consider however, the sensitivity of the satellite image itself as it is unknown to what depth of water does the dark blue colour correspond to.

5.2.4 Simulation Scenarios

After discussion with CRIDF and the stakeholders, including ARA-Sul, it was concluded that the most relevant return periods to be examined are the 1 in 5, 10 and 20 years extreme events.

As a part of this report, the baseline conditions for the study area are simulated. Therefore, this has resulted in the execution of three model runs in total.

5.2.5 Flood Hazard Calculation

Throughout this report the most important technical and modelling aspects leading up to the calculation of flood hazard have been presented in detail.

The measure of hazard/danger is obtained when combining current velocity with water depth information. These maps are tools to provide information about flood hazards and to implement the necessary preventive and preparedness measures by presenting areas which could be flooded according to different probabilities. In the case of this study the following return periods were considered: events with a high probability of occurrence as once in 5 and 10; and events with a medium probability of occurrence as once in 20 years.

The target group and use for the results presented can be national, regional or local land-use planning, flood managers, emergency services, forest services (watershed management), or public at large. Then depending on who will be the specific target for a particular map, the flood parameters and display must be adjusted.

The utilized hazard rating expression is based on consideration to the direct risks of people exposed to floodwaters (Surendran et al., 2008):

$$\mathrm{HR} = \mathrm{D} \times (\mathrm{v} + \mathrm{n}) + \mathrm{DF}$$

where, HR is flood hazard rating, D is depth of flooding (m), v is velocity of floodwaters (m/s), and DF is the debris factor (0, 0.5, 1 depending on probability that debris will lead to a hazard), n is a constant of 0.5.

It is suggested by this methodology that the debris factor for different depths and velocities is directly related to the dominant land use:

Table 5-5 Guidance on debris factors for different flood depths, velocities and dominant land uses (Surendran et al., 2008)

Depths (D)	Pasture/Arable	Woodland	Urban
0 to 0.25 m	0	0	0
0.25 to 0.75 m	0	0.5	1
D>0.75 m and\or v>2	0.5	1	1

Since the study area is mostly made up of sugar cane plantations, the “Pasture/Arable” factors were applied. In terms of flood hazard classification, the following definition is used.

Table 5-6 Hazard to people definition according to hazard rating thresholds (Surendran, 2008).

HR	Hazard degree	Description
< 0.75	Low	Caution - “Flood zone with shallow flowing water or deep standing water”
0.75 - 1.25	Moderate	Dangerous for some (i.e. children) - “Danger: Flood zone with deep or fast flowing water”
1.25 - 2.0	Significant	Dangerous for most people - “Danger: flood zone with deep fast flowing water”
>2.0	Extreme	Dangerous for all - “Extreme danger: flood zone with deep fast flowing water”

5.3 Flood Vulnerability Analysis

Vulnerability is essentially the resilience of a community to withstand the potential impacts of a specific hazard. Vulnerability is complex and multi-faceted essentially being the product of the combination of environmental, economic, social, institutional, technical and physical aspects. The quantification of vulnerability thus requires the measurement and assessment into a large matrix of interacting elements within an area.

Vulnerability thus requires the collection of information that enables a combined assessment of the physical, economic, social and environmental components into a single framework which can determine the vulnerability of an area to flood threats.

Areas that are more vulnerable are essentially more prone to impacts associated with specific hazards and thus are more likely to experience damages relating to hazards. Each element of vulnerability thus needs to be assessed independently initially and then these elements need to be combined into a specific scoring. It is thus necessary to map out the various components associated with vulnerability. The key components to map are as follows:

Physical vulnerability: Unlike exposure physical vulnerability is a function of structures' or persons' ability to withstand a hazard. Structural elements are thus a key component in determining physical vulnerability. A shack construction is less likely to withstand the impact of a flood versus a solid brick or concrete construction. A mapping classification of structures in an area is necessary to assess physical vulnerability.

Social vulnerability is a function of many factors but the main component is essentially poverty. The more poor a community generally the less socially organised it is, the recovery mechanisms are not in place (e.g. insurance), people are generally in a worse condition physically (sick or undernourished) etc. Other factors that influence social vulnerability are access to medical care and disaster response centres etc. A combination of census information, accessibility mapping and structural classification can assist with social vulnerability mapping.

Economic vulnerability is a function of economic exposure in specific areas. Expensive real estate, industry, and commercial buildings are more prone to economic impacts than poorer areas. These elements are usually easier to map and determine from a combination of census information and structural mapping. Finally a combination of these elements needs to be mapped to determine overall vulnerability this is usually done through a process such as multi criteria decision analysis or alternative methodology. Appendix H contains the detail on the flood vulnerability factors and analysis.

5.3.1 Multi Criteria Decision Analysis

The relevance of the variables which are important in determining Hazard and Exposure to the occurrence of floods can be physically and mathematically determined. However, the determination of the relevance of variables relating to vulnerability is more complex. This relevance was attributed based on the project team's experience and the results can be observed in the following table.

Table 5-7 Results from the vulnerability assessment in the Lower Incomati.

	Indicator	ID	Weighting (%)	Final weight
Physical Vulnerability	House Density	hh_a	5	40
	Road type	roads	2	
	Distance to closest road	road access	10	
	Road sizes	lanes	3	
	Place of Safety	safety	10	
	Rescue Services	rescue	10	
	Access to potable water	pot water	15	
	Type of sanitation	sanit	15	
	Access to health care	health	5	
	Access to assembly points	assemb	5	
	Access to electricity	elect	20	
Social Vulnerability	Literacy	lit	20	40
	Education	educ	20	
	Income	income	20	
	Employment status	employ	20	
	Household size	hh	5	
	Flood experience	flood	5	
	Mortality rates	mort	5	
	Water source	water	5	
Economic Vulnerability	Property value	pro_val	35	20
	Property type and purpose	pro_type	35	
	Savings	save	10	
	Banking access	bank	10	
	Access to credit	credit	10	

Regarding the physical vulnerability indicators, access to electricity (most important factor) was assigned a weight of 20 %, where potable water and type of sanitation were also given high weights of 15 %. These were followed by (in order of importance) by access roads, access to a place of safety and access to a place of rescue.

In terms of social vulnerability, the highest scores were given to literacy, education, income and employment status, all with equal weightings of 20 %., followed by household size, flood experience, mortality rates and water source all with 5 %.

Regarding economic vulnerability the highest weightings were allocated to property value and property type and purpose, each with 35 %.; followed by savings, banking access and access to credit with 10% each.

The approach taken to determine the overall vulnerability status was as follows:

- A weighted overlay using only the indicators from physical vulnerability was performed, using the weights defined in the 'Weighting' column (**Error! Reference source not found.**), producing an overall physical vulnerability layer.
- A weighted overlay using only the indicators from social vulnerability was performed, using the weights defined in the 'Weighting' column (**Error! Reference source not found.**), producing an overall social vulnerability layer.
- A weighted overlay using only the indicators from economic vulnerability was performed, using the weights defined in the 'Weighting' column (**Error! Reference source not found.**), producing an overall economic vulnerability layer.
- To produce an overall vulnerability layer, the physical, social and economic layers were assigned the final weights (**Error! Reference source not found.**), resulting in an overall vulnerability layer.

In order to calculate the physical, social and economic vulnerability and subsequently, total vulnerability to floods in the study areas, the Model Builder feature in ArcGIS was utilized. This feature allows building models using the toolboxes available in ArcGIS and multiple grids as input.

Weighted Overlay was the tool applied in the study which is widely used in sustainability and vulnerability analysis where multi criteria decision problem solving is necessary. In an overlay analysis it is necessary to identify the problem and build the suitable model to find the solution. This could require the model to be broken into different sub-models.

The inputs for the Weighted Overlay tool are the indicators/criteria presented previously in raster format. Since the input criteria layers will be in different numbering systems with different ranges, to combine them in a single analysis, each cell for each criterion must be reclassified into a common preference scale. The scale used for this analysis was 1 to 5 as shown from Table 5-5 to **Error! Reference source not found.**. A value of 1 means the lowest vulnerability and 5 the highest. Departing from the land classification polygons that were created, grids were prepared for each of the indicators/criteria. Values were assigned relative to each other within the grid and should also have the same meaning between the grids. For example, if a location for one criterion is assigned a value of 5, it will have the same influence on the phenomenon as a 5 in a second criterion.

Each of the criteria in the weighted overlay analysis is attributed a weight which represents the criterion's importance in determining the most vulnerable areas. All weights in the analysis must add up to 1, or 100%. For instance, as a final weight it has been decided that physical and social factors are more likely to increase a community's vulnerability to flood events rather than the economic factor, thus a 40% weight was assigned to both physical and social vulnerability and 20% was assigned to economic vulnerability.

5.4 Flood Risk Determination

Flood risk determination is the culmination of all previous methodological steps. Firstly, each hazard zone layer was overlaid with all other hazard zone layers in order to generate one composite flood hazard coverage. The 5, 10 and 20 year flood hazard layers were combined through the use of a weighted sum procedure. The flood hazard layer with highest probability of occurrence (5 year return period) was given a higher score, whereas the lowest (20 year return period) was given the lowest score. In the overlay procedure an area's final flood hazard score will be the combination of the different flood hazard layers it is affected by. Therefore, the resulting polygons will have a hazard score equal to a summation of the probability of occurrence for each hazard layer.

Finally, the vulnerability layer will be multiplied by the hazard score for each polygon which will allow for the calculation of the overall flood risk. The results from the flood risk determination are presented in a collection of maps on Appendix D.

6 Results and Discussion

The purpose of this section is to discuss individual analyses of the key outputs from the work carried out and described in the previous sections, culminating with the calculation and mapping of flood risk in the Lower Incomati region.

6.1 Flood Extent Determination

Flood extent for 5, 10 and 20 year return periods was determined using MIKE 21 software (as described in section 5). These different extents are evident in the map below (Figure 6-1) as expected, the 20 year return period extends over a greater area than the 10 and 5 year ones, where the later extends the least across the floodplain.

Parts of the Xinavane area are expected to be affected by floods from all return periods, primarily due to a significant proportion of the large scale fields being situated within the flood plain and unprotected by a dyke. The Tongaat Hulett sugar cane mill is elevated high enough to avoid the flood waters from any of the three return periods. The town of Magude is also out of the simulated flood extent.

The Illovo Sugar mill at Manhiça is also out of the flood plain and far enough from the Incomati River to avoid any flood threat from even the 20 year return period. The formal residential areas scattered around the town of Manhiça are also out of the flood extent, making this town unlikely to directly experience a flood of up to 20 year return period.

Regarding dyke failure, it has been found that Tongaat's dykes are more likely to fail already at a 1 in 5 year flood event. In the case of Illovo, that for the 1 in 10 flood event sector B's dykes are likely to fail, and sector A in the case of the 1 in 20 event; the west part of sector A, sector D and E are well protected up to the 1 in 20y event. The location of the failing dykes for both sugar estates and for each return period can be seen in detail as a collection of maps in Appendix A.

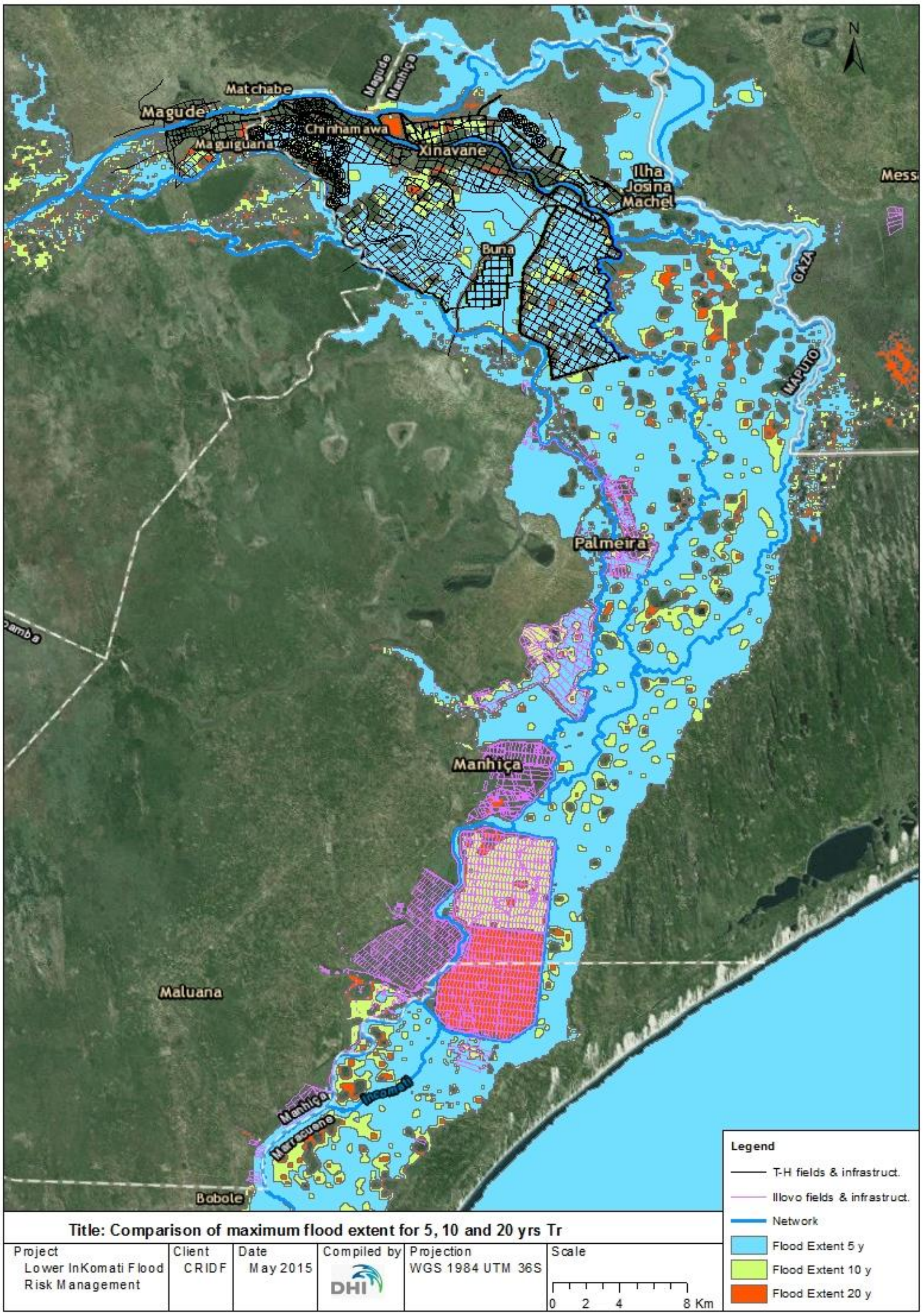


Figure 6-1 Flood extent of the Lower Incomati for the 1 in 5, 10 and 20 year return periods.

6.2 Flood Hazard Estimation

The maximum water depth and water velocity for each return period was used to calculate the flood hazard caused by the 1 in 5 (Figure 6-2), 10 (Figure 6-3) and 20 (Figure 6-4) year flood return period events.

The flood hazard results for the three return periods considered are presented in a collection of maps presented in Appendix B. These are based fully on the hydraulic calculations, namely water level and velocity of the 2D hydrodynamic model, along with the design inflow time series for three different return periods estimated.

One can clearly see from these three hazard maps that the extreme hazard is along the main river channel, where the water depth is at its deepest and the velocity is at its fastest.

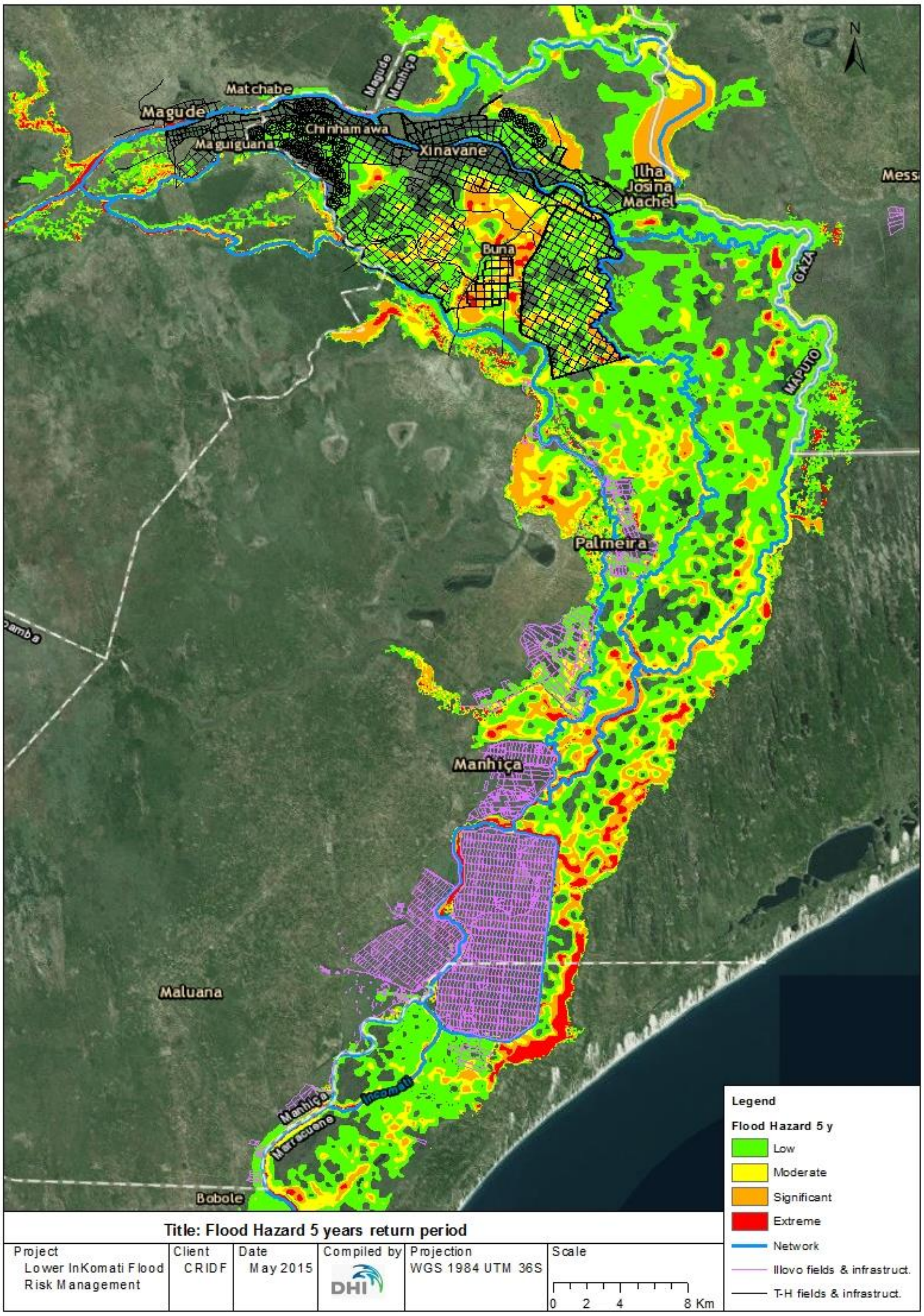


Figure 6-2 Flood hazard estimation for the 1 in 5 year return period.

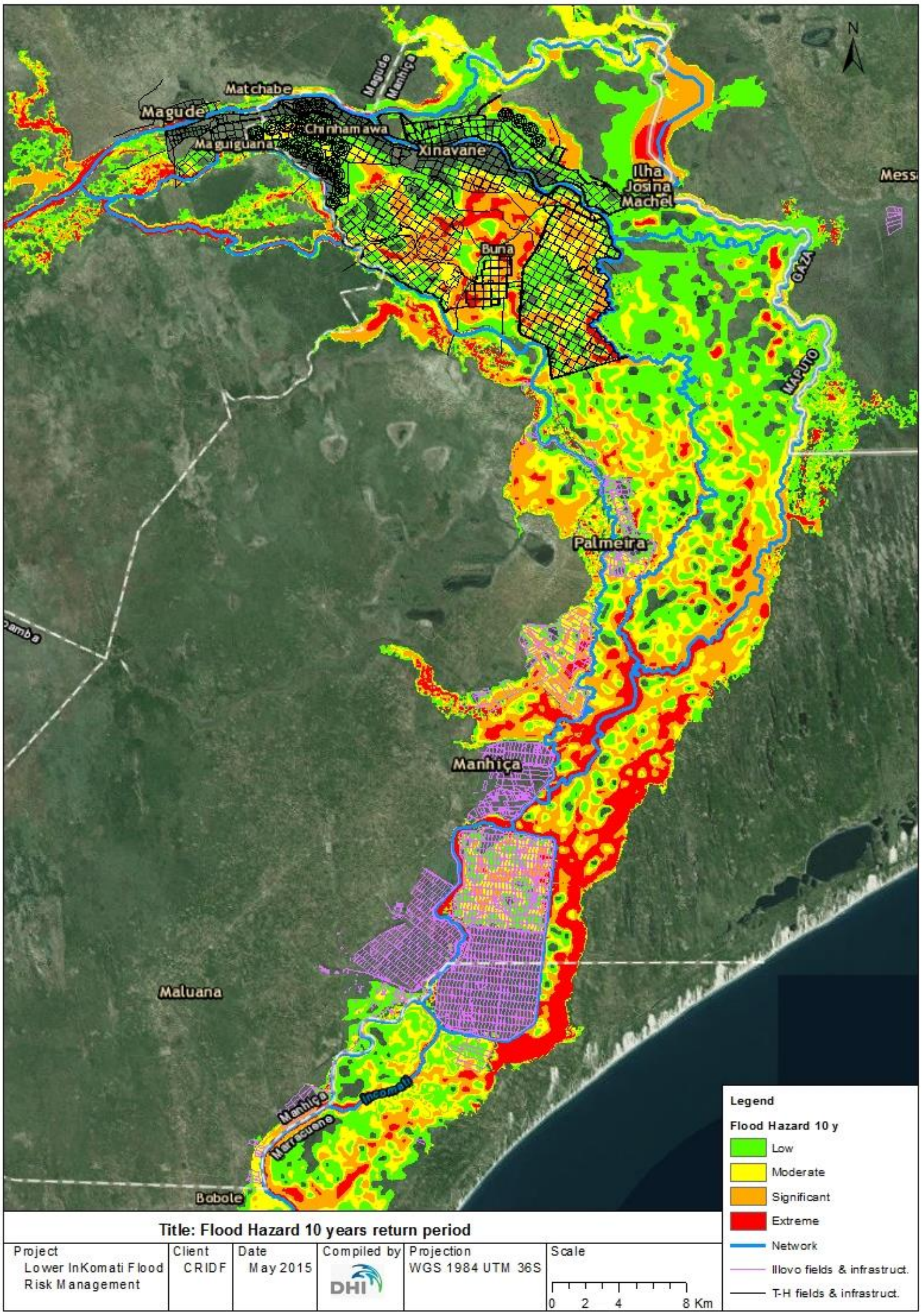


Figure 6-3 Flood hazard estimation for the 1 in 10 year return period.

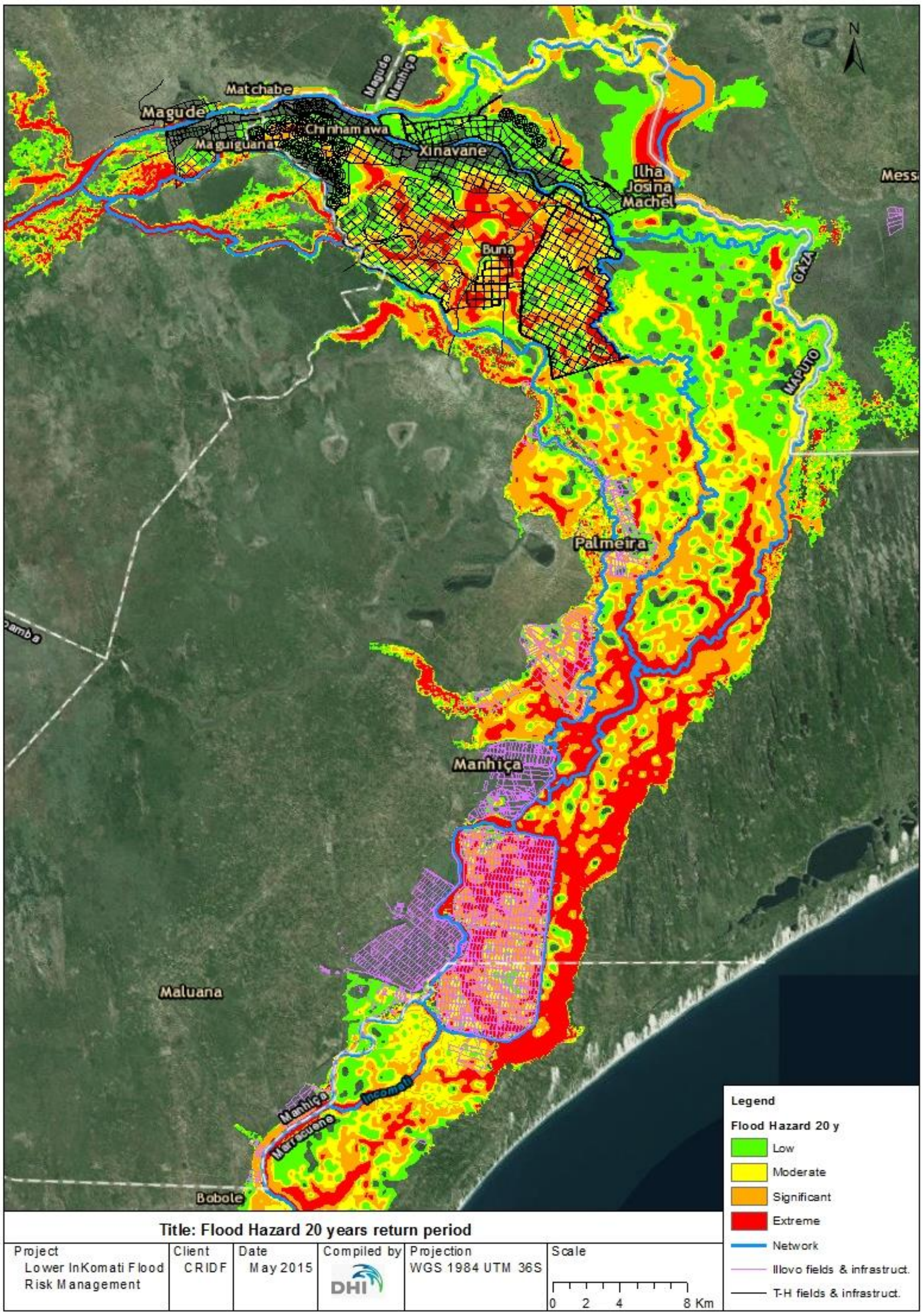


Figure 6-4 Flood hazard estimation for the 1 in 20 year return period.

A clear difference in the significance of impact can be observed from the 1 in 5 year flood event to the 1 in 10 and 20 years flood events where the amount of areas of Significant to Extreme hazard to people increase and affect areas where current and future outgrower developments occur.

Namely, the outgrower areas of Tongaat Hulett located at Low and Moderate hazard during a 1 in 5 year event are respectively: 1 farmer, protected by old road 50ha, 3 de Fevereiro D, 3 de Fevereiro E; and

Associaçao agricola Maria da Luz Guebuza, Associaçao dos camponeses Hoyo Hoyo, Associacao dos Buna, Facazissa Association, Graça Machel, Heróis Moçambicanos.

Regarding Illovo's outgrower areas located at different levels of flood hazard during a 1 in 5 year event are shown in the tables below.

Table 6-1 Illovo outgrower areas located at low hazard zones for the 1 in 5 year flood event

Name				
289001	Adriano Vasco Joao Cossa	Carlos Fabiao Vilanculo	Hanifa Mussa	Maria Do Rosario T. G. Camejo
289002	Agro Qatro Lda	Carmila Sofia Jose Norberto Come	Inacio De Sousa	Maria Simao
289003	Antonio Alberto Mahanuque 1	Custodio Francisco Matlula 2	Isalia Ismael	Mario Manuel Xerinda
289004	Antonio Alberto Mahanuque 6	De Sousa	Izak Cornelis Holtzhausen	Maristas Claasen
289005	Antonio Alberto Mahanuque 7	Domingos Joao Timane	Izak Cornelis Holtzhausen Pvt	Martins Valente Nhambi
289009	Antonio Fabiao Gungulo 1	Emidio Edgar Matlombe	Joaquim Alexandre Moiana	Maximiano Fanuel Mandlate
289010	Antonio Fabiao Gungulo 2	Ernesto Fernando Cossa	Joaquim Manuel Guilundo	Msarl
292011	Antonio Nhocane Cossa	Ernesto Fernando Machava	Jose Fernando Macaneta	308016
297006	Antonio Zibuto Mugade	Eu Area 1 Munguine Outgrower	Jose Nhamene Chavango	Paulo Verde
297007	Armando Da Costa Magalhaes	Eu Area 2 Martins Outgrower	Josue Matsinhe	Pedro Simao Monteiro
297008	Armando Euzane Cheuana	Eu Area Palmeira South 2 Outgrowers	Jr Investments Lda	R Marchant
297009	Armindo Fernando Tete	Euclides David	Judite Lazaro Mauelele	Samuel Timane
297010	Associacao Bloco 1	Felizarda Monica Manhiyé¼A	Juliao Mario Matsinhe	Sinbiri Madeira Investimento, Lda
308010	Associacao Bloco 2	Fernanda Elizabete Matos Fazenda	Laura Natalio Mutombene Nhantumbo 2	Sofia Nazimo Mussa
308011	Bento Xavier Magule	Fernanda Elizabete Matos Fezenda 2	Laura Natalio Mutombene Nhantumbo 3	Zulmiro Ferreira De Oliveira
308012	Bernardo Jacinto Mimbirre	Fernando Chivumana Timana	Madelena Miguel Macie	Zulmiro Oliveira
308013	Bindzu - Agrobusiness & Cons Lda	Fernando Setefano Mandlate 2	Magalhaes	Manuel Alberto Macuacua

308014	Bischoff Private	Filimone Comutimae Sitoe	Mamede De Deus Verde	Manuel Joao Mucusse - Boavida
308015	Bisschoff Agricultura S. Unipessoa	Francisco Filimone Muianga	Francisco Martins Nhambi	Boavida F. Zandamela

Table 6-2 Illovo outgrower areas located at moderate hazard zones for the 1 in 5 year flood event.

Name				
212001	Eu Area 2 Munguine Outgrower	Bernardino Andelo Antonio - Machubo	Samuel Joao Chemana	Fernando Carlos Chopo
302011	Eu Area Palmeira South 1 Outgrowers	Bischoff Plan B2	Sofia Jose - Machubo	Fernando Filipe Armando Changule 1
302012	Ezequias Aurelio Matlava 2 - 183	Bishoff Plan B1	Eu Area 1 Martins Outgrower	Fernando Filipe Armando Changule 2
308017	Gilda Mosse Tune	Amelia Narciso Matos Sumbana	Antonio Fabiao Ngungulo - 473	Mauro Alberto Cossa - 099
308018	Jose Antonio Manhica 096	Amelia Sumbane	Arlindo Julio Melembe	Rodriques Dimane
Agro Quatro Lda	Jose Mazino Manhique	Anita Samuel Uache	Arlindo Vasco Chauque	Salomao Azael Moiane
Armando Aurelio Matlava	Samuel Alfredo Xerinda	Domingos Mario Cossa		

Table 6-3 Illovo outgrower areas located at significant hazard zones for the 1 in 5 year flood event.

Name				
Armando Francisco Cossa	Nazimo Goncalves Manhica	Ezequias Aurelio Matlava 1 - 183	Rosa Santos Ngovo	Pedro Jose Mondlane
Armindo Jose Tsucana 338	Neloito Xavier Novela 1	Fernando Alfredo Manhica	SAM CHERINDA	Pedro Moises Novela 1
Armindo Lazao Machava 1	Neloito Xavier Novela 2	Humberto Pedro Chioze	Sergio Andre Manhica	Pedro Moises Novela 2

Armindo Lazao Machava 2	Ngualane Homo Chitlongo	Juma Almeida Mazive	Tomas Joao Ngovo	Pedro Jose Mondlane
Armindo Lazao Machava 3	Odete Antonio Matlava	Marcos Pinto Mussana	Mario Gaspar Samunoene Banda	Dionildo Alexandre Vilanculo 1
Celina Hunguana	Dionildo Alexandre Vilanculo 2			

Finally, only one plot is located in an extreme flood hazard zone for the 1 in 5 year event: Leonivo luis Cossa.

6.3 Flood Vulnerability Estimation

The results from the vulnerability indicators and MCDA process applied shows that the areas where outgrowers' fields are situated are the most vulnerable to floods (Figure 6-5). This is mainly attributed to the outgrowers' harvest being a significant source of income for a largely permanently unemployed community. Furthermore, in the event of a flood destroying the outgrowers' crops, they are likely to take the longest to recover financially from such a loss due to insufficient insurance cover.

The large scale MCP areas are at a much lower risk than outgrowers. The reasons for this are attributed to permanent employment status, insurance cover (in the case of a flood destroying fields),access to potable water, electricity and credit.

All of the formal residential areas (including low, medium and high density) came out with the lowest flood vulnerability (Figure 6-5). This is particularly due to these areas being in close proximity to necessary infrastructure, along with having access to potable water and electricity. These go with the assumption of people living in formal areas having permanent employment status and access to credit and banks if needs be. In addition, most of the outgrowers do not actually reside in the floodplain area, this population commutes to the fields and back to the areas where they have their residences.

Areas with high vulnerability status include all of the informal areas, with both low and medium house density. Reasons for this are due to the distance away from infrastructure and good roads, limited potable water and electricity supply, along with bank and credit access assumed to be limited.

The vulnerability analysis results with more detail are presented as a collection of maps in Appendix C.

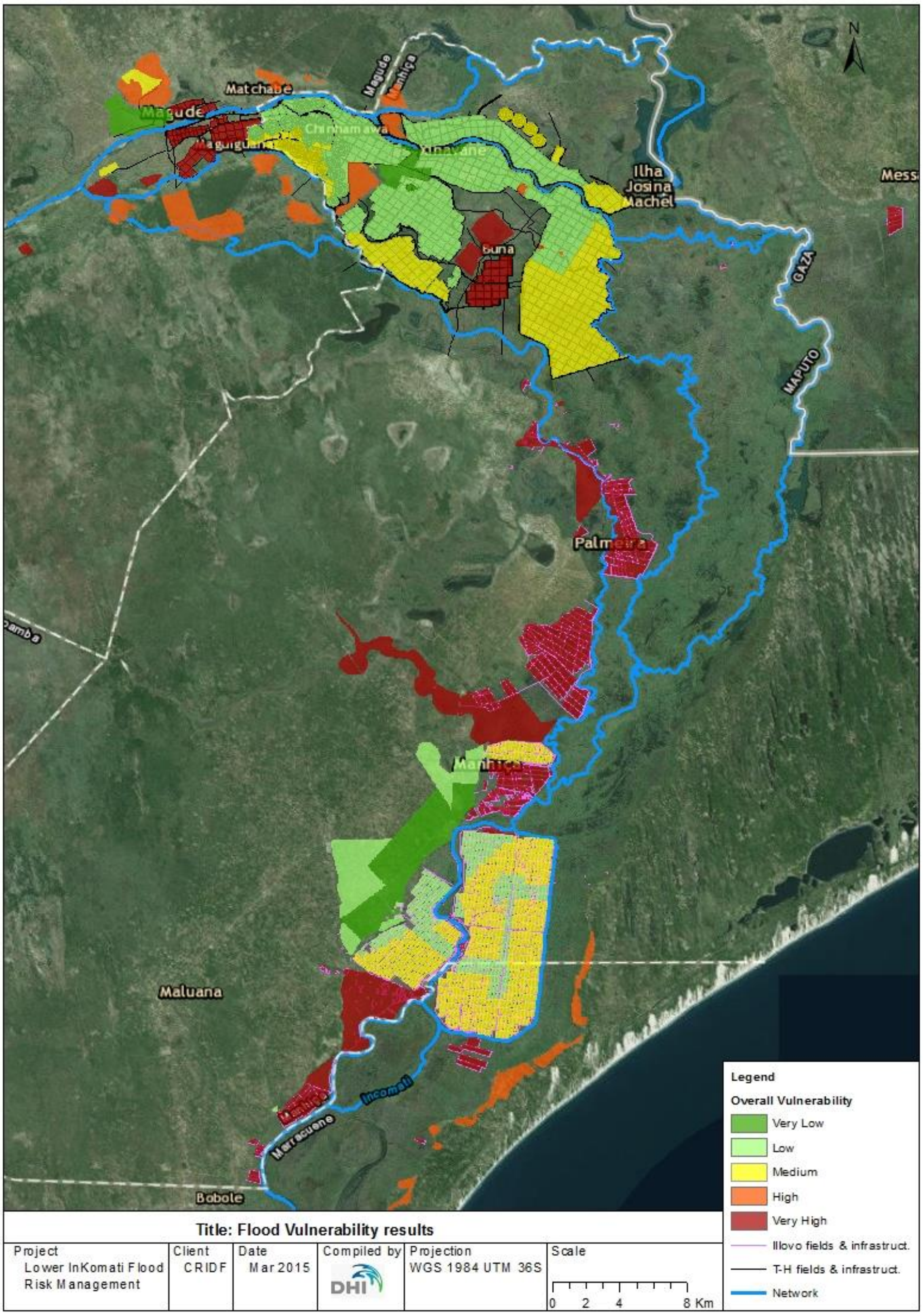


Figure 6-5 Flood vulnerability estimation for the Lower Incomati, based upon MCDA.

6.4 Flood Risk Assessment

Flood risk was determined by the weighted sum of two different layers, namely the overall flood hazard estimate, obtained by a weighted sum of the flood hazard of each of the three return periods considered, and the vulnerability estimate. From the equal weighted intersection of these two parameters, a corresponding risk category was determined.

From this analysis, more areas in the northern region are expected to be at risk around the town of Xinavane, than the southern region, Manhiça. From both of these regions, the 'outgrowers' is the only land use type with extreme risk of flood inundation. This is principally due to the very high vulnerability status of these areas as discussed in section 6.3 above as well as the fact that these areas are not completely protected by dyke walls. The 'large scale' category which relates to the MCP growers, meaning the Milling company's own fields, ranges between moderate and significant flood risk, with a larger total area at risk than 'outgrowers' (Figure 6-6).

The outgrowers at higher flood risk, from significant to extreme, in the Xinavane area are the following: Associaçao agricola Maria da Luz Guebuza, Associaçao dos camponeses Hoyo Hoyo, Associacao dos Buna, Facazissa Association, Graça Machel. The outgrowers at higher flood risk in the Maragra area are presented in the table below.

Table 6-4 Illovo outgrower areas located at significant to extreme risk zones for the 1 in 5 year flood event.

Name				
212001	Adriano Vasco Joao Cossa	Armindo Jose Tsucana 338	Ernesto Fernando Machava	Mauro Alberto Cossa - 099
289001	Agro Quatro Lda	Armindo Lazao Machava 1	Eu Area 1 Martins Outgrower	Maximiano Fanuel Mandlate
289002	Amelia Narciso Matos Sumbana	Armindo Lazao Machava 2	Eu Area 2 Martins Outgrower	Msarl
289003	Amelia Sumbane	Armindo Lazao Machava 3	Eu Area 2 Munguine Outgrower	Nazimo Goncalves Manhica
289009	Anita Samuel Uache	Associacao Bloco 1	Eu Area Palmeira South 1 Outgrowers	Odete Antonio Matlava
289010	Antonio Alberto Mahanuque 1	Associacao Bloco 2	Euclides David	Sergio Andre Manhica
292011	Antonio Alberto Mahanuque 6	Bernardo Jacinto Mimbirre	Ezequias Aurelio Matlava 1 - 183	Sofia Jose - Machubo
302011	Antonio Alberto Mahanuque 7	Bischoff Plan B2	Ezequias Aurelio Matlava 2 - 183	Sofia Nazimo Mussa
302012	Antonio Fabiao Gungulo 1	Bischoff Private	Felizarda Monica Manhiyé¼A	Tomas Joao Ngovo
308010	Antonio Fabiao Gungulo 2	Bishoff Plan B1	Fernanda Elizabete Matos Fazenda	Marcos Pinto Mussana
308011	Antonio Fabiao Ngungulo - 473	Boavida F. Zandamela	Fernanda Elizabete Matos Fezenda 2	Maria Do Rosario T. G. Camejo
308012	Antonio Zibuto Mugade	Carlos Fabiao Vilanculo	Fernando Alfredo Manhica	Maria Simao
308013	Arlindo Julio Melembe	Celina Hunguana	Fernando Chivumana Timana	Mario Gaspar Samunoene Banda

308014	Arlindo Vasco Chauque	De Sousa	Fernando Filipe Armando Changule 1	Mario Manuel Xerinda
308015	Armando Aurelio Matlava	Domingos Mario Cossa	Francisco Martins Nhambi	Samuel Alfredo Xerinda
308017	Armando Da Costa Magalhaes	Emidio Edgar Matlombe	Gilda Mosse Tune	Samuel Joao Chemana
Hanifa Mussa	Judite Lazaro Mauelele	Manuel Alberto Macuacua	Maristas Claasen	Samuel Timane
Humberto Pedro Chioze	Juliao Mario Matsinhe	Manuel Joao Mucusse - Boavida	Martins Valente Nhambi	Rodriques Dimane
Inacio De Sousa	Juma Almeida Mazive	Pedro Moises Novela 1	Sam Cherinda	Mamede De Deus Verde
Isalia Ismael	Laura Natalio Mutombene Nhantumbo 2	Pedro Jose Mondlane	Rosa Santos Ngovo	Paulo Verde
Joaquim Alexandre Moiana	Madelena Miguel Macie	Josue Matsinhe	Joaquim Manuel Guilundo	Magalhaes

Neither formal nor informal residential areas are expected to be at risk of flooding given the return period of the flood events considered in this study. This is encouraging, perhaps based on past flood experiences forcing communities to live out of harm’s way. However, crops are nevertheless still grown in the flood plain area due to nutrient-rich and moist soils perfect for sugar cane. In addition, in the case of the outgrowers, the agricultural activities are many times a source of income but also subsistence.

The risk assessment analyses for each return period with more detail are presented as a collection of maps in Appendix D.

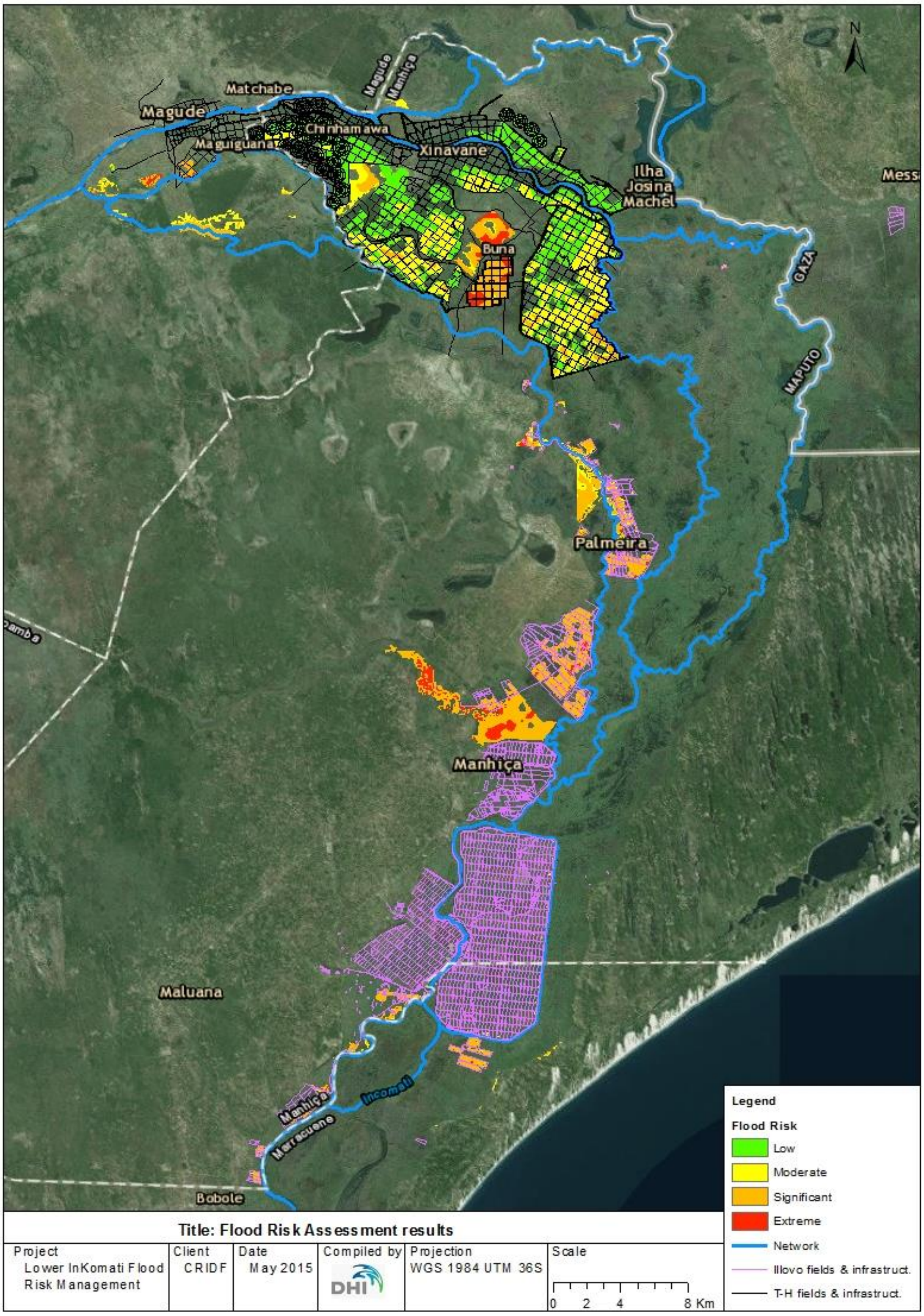


Figure 6-6 Flood risk assessment for the Lower Incomati area.

7 Risk Management Strategies

During several stakeholder workshops presided by ARA-Sul with CRIDF and the Sugar Estates, a number of modelling scenario options were discussed and agreed upon. The purpose was to determine a list of structural interventions which could lead to a more effective management of the flood events in the study area. In order to do this, both sugar estates were asked to provide a list of their preferred planned structural flood alleviation interventions, and these were implemented in the 1D and 2D hydraulic models. In this chapter, the flood risk management structural options are compared to the baseline simulation results presented in the previous chapters. Table 7-1 and Figure 7-1 present the list of scenarios and simulation characteristics.

Table 7-1 List of modelling scenarios of structural interventions for improved flood management in the study area.

Ref	Scenario Description	Model Type	Return Period
S1	Additional protection wall around the 1,000ha developed in close proximity to existing Maragra, new protection Taninga and Martins dykes.	2D	1 in 5y and 1 in 10y
S2	Impact of dredging a section of the Incomati River from the river diversion upstream of the factory to about 5 km beyond Taninga on flooding risk for downstream areas.	1D	1 in 10y
S3	Impact of the new dyke being installed along the Tsatsimbe or Cuenga River for flood protection by Xinavane.	2D	1 in 10y
S1S3	Combination of the additional Maragra protection dykes and the new Xinavane protection dyke.	2D	1 in 10y
S4	Testing of different configurations for the hydraulic structure at Tsatsimbe River bifurcation, such as reduction of number of culverts and raising the river embankment crest level.	1D	1 in 10y
S4E	Testing of one of the proposed configurations for the hydraulic structure at Tsatsimbe River bifurcation.	2D	1 in 5y
S4F	Testing of a scenario with the hydraulic structure at Tsatsimbe River bifurcation removed.	2D	1 in 5y

S4G	Testing of a scenario with the hydraulic structure at Tsatsimbe River bifurcation removed and an additional dyke upstream of Magude town.	2D	1 in 5y

The CRIDF project team agreed with the stakeholders during the 8th May 2015 stakeholder event that the flood risk management strategies would be analysed for the 1 in 10 year event. This is the same as stating that the most viable solution will be investigated which can improve flood management at this level. The decision was based on the fact that farmers risk strategy should allow them to manage at least the 1 in 10 year flood risk as it is believed the 1 in 20 year flood risk and higher would likely be economically unviable. Additional model simulations for the 1 in 5 year flood event were run in order to have another measure of the impact of some of the flood management options.

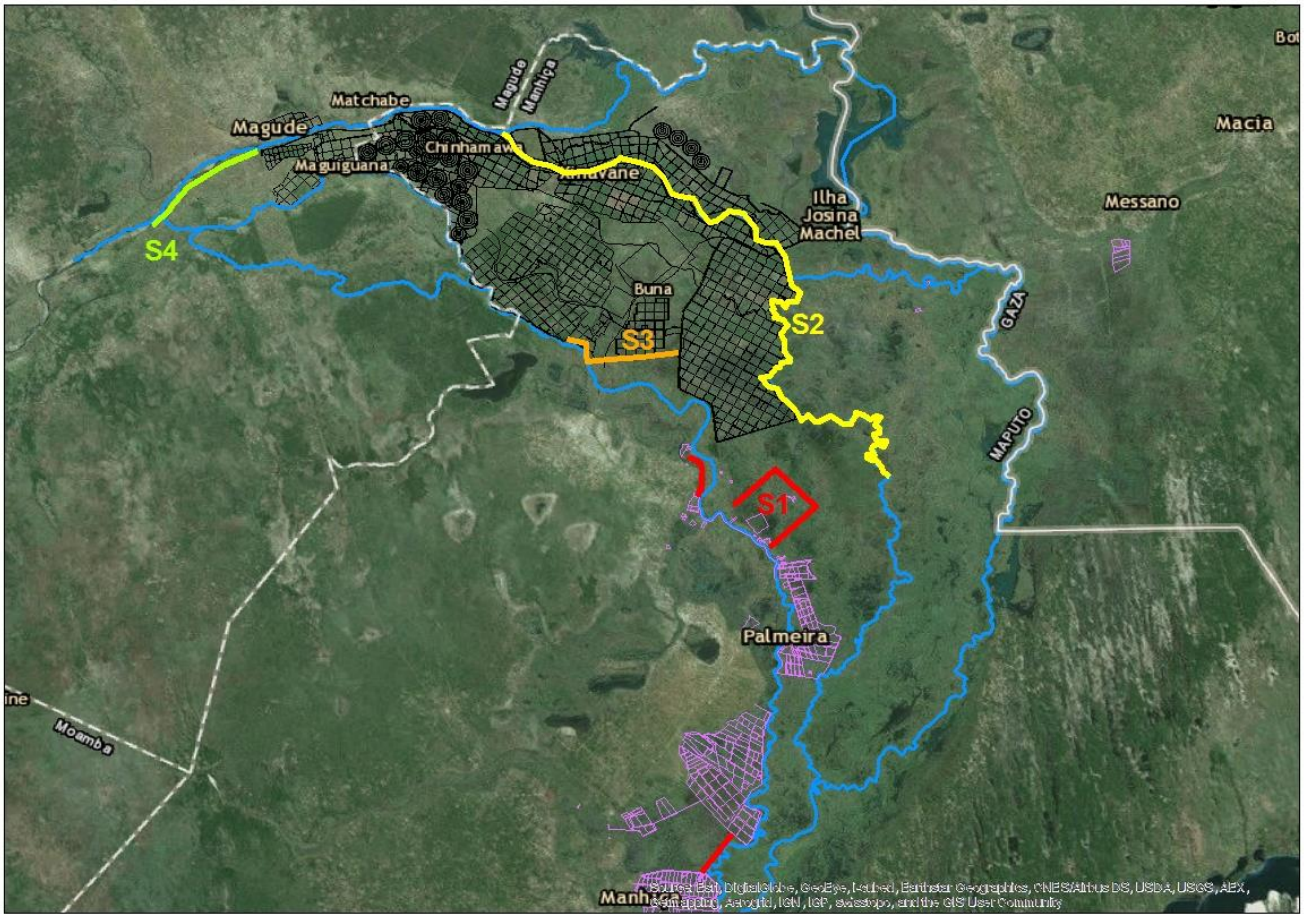


Figure 7-1 Structural Intervention Modelling Scenario Locations

7.1 Scenario Results and Discussion

7.1.1 S1: New Maragra Protection Dykes

The first scenario for the 2D model consists of adding new protection dykes for the Illovo outgrowers south of Sector F as shown in Figure 7-3, as well as a squared dyke around a potential development, and a new dyke at Taninga north of Sector F. The exact location of the dykes to be potentially built is shown in red around the Maragra outgrowers in the figure above.

The new dykes were added to the 2D model topography using the data provided by Illovo, and the 1 in 10 year return period flood event simulation was run. Figure 7-2 presents a comparison of the baseline simulation and the S1 model results for the 1 in 10 year flood event. Another simulation for the 1 in 5 year event was carried out, in order to examine the impact of the new dyke walls with a smaller volume of incoming flood water and this is presented in Figure 7-3.

Note on topography update

During the Flood Risk Assessment stakeholder workshop a discrepancy was noted between two of the topographical surveys of the Maragra dykes in terms of the datums used. The flood risk management scenario models used an updated version of the existing topography where a correction was made which consisted of an elevation reduction of 1.155 m of the dyke crest levels surrounding the Illovo MCP fields and sector D. All scenario comparisons in this report are made to this updated baseline 1 in 10 year flood event simulation.

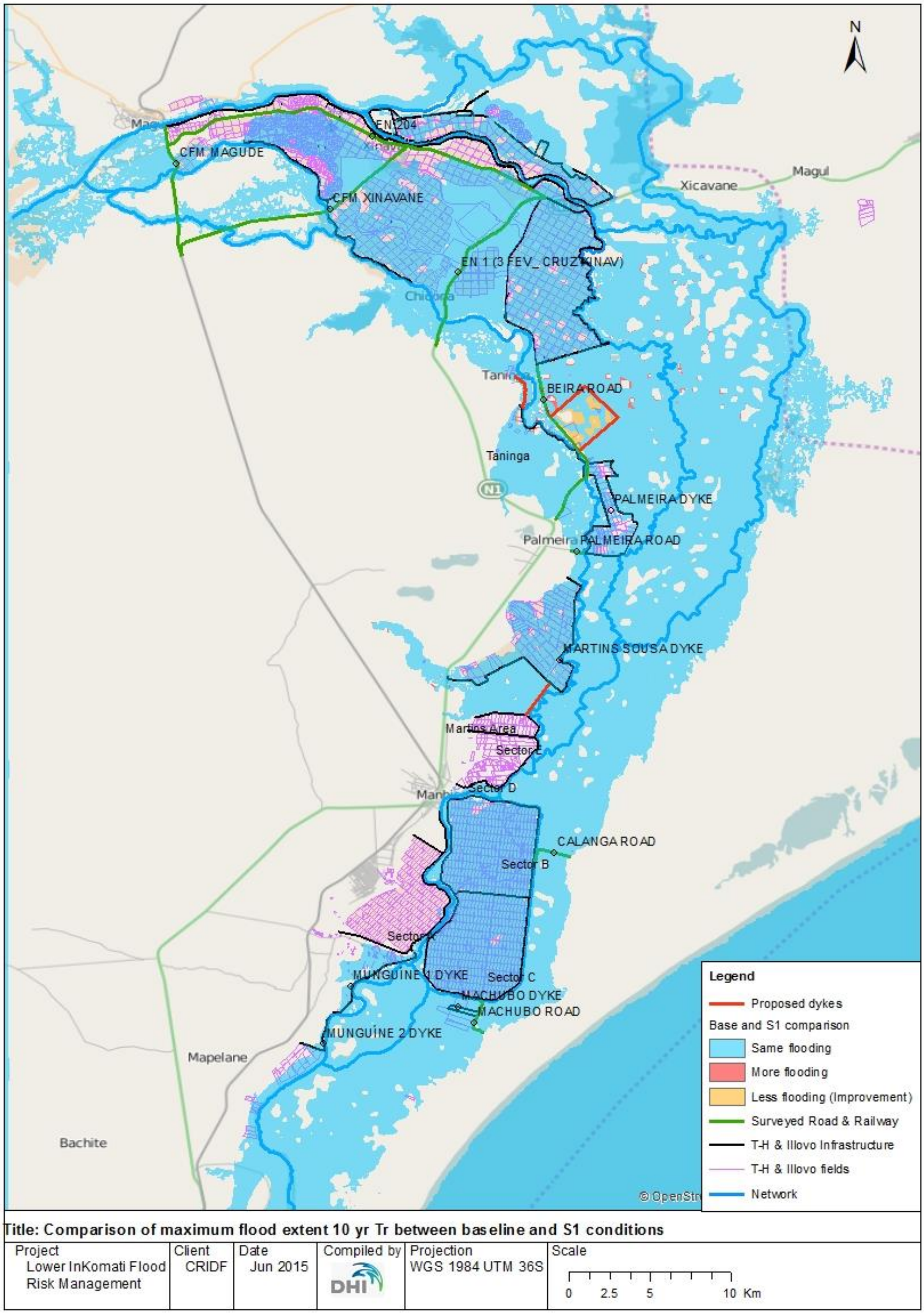
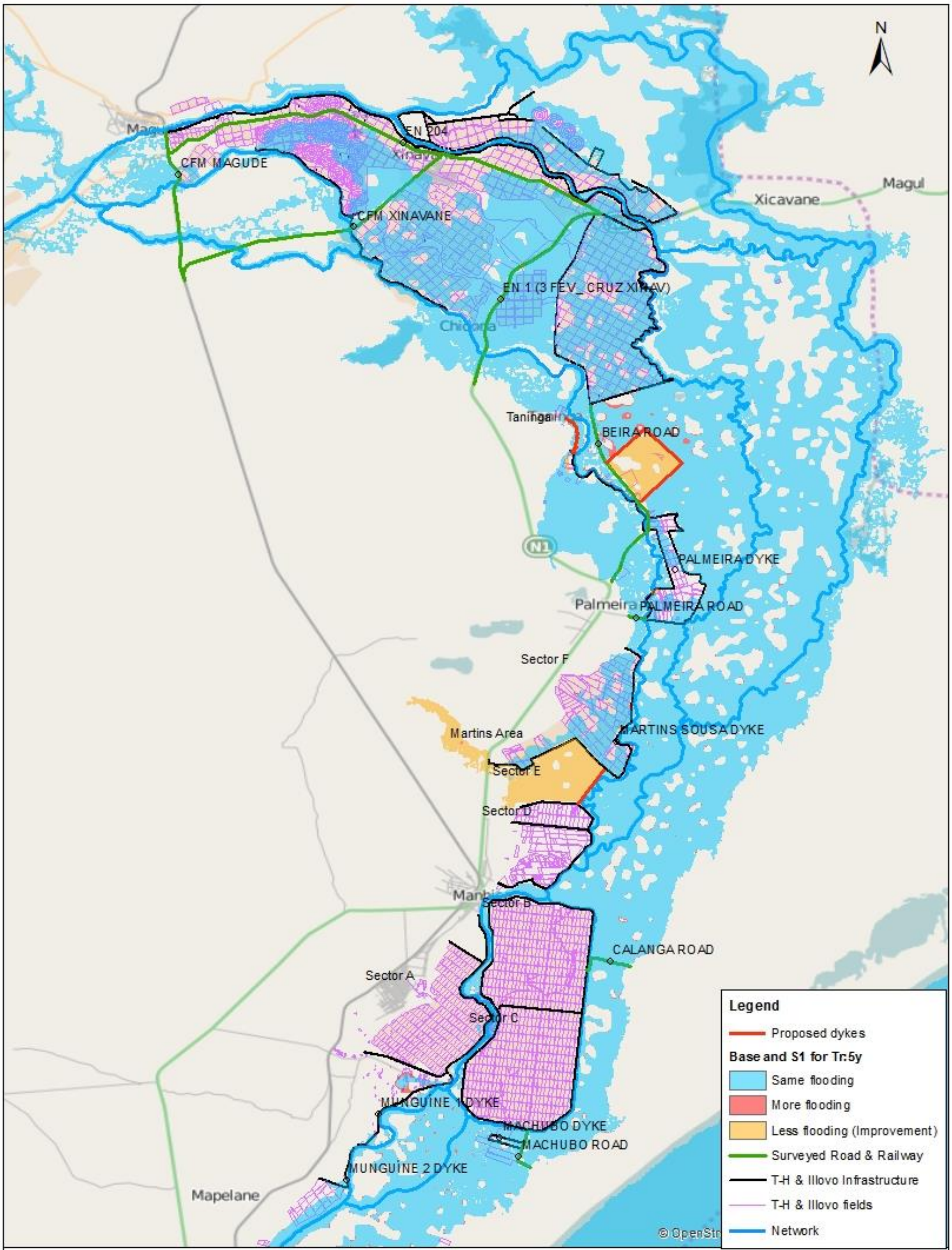


Figure 7-2 Maximum 1 in 10 Year Flood Extent Comparison between the Baseline and S1 Scenario.



Title: Comparison of maximum flood extent 5 yr Tr between baseline and S1 conditions

Project	Client	Date	Compiled by	Projection	Scale
Lower InKomati Flood Risk Management	CRIDF	Jun 2015	DHI	WGS 1984 UTM 36S	0 2.25 4.5 9 Km

Figure 7-3 Maximum 1 in 5 Year Flood Extent Comparison between the Baseline and S1 Scenario

As can be observed from Figure 7-2 and Figure 7-3, the impact of the new protection dykes is clearly seen by comparing the impacts of the 1 in 5 and 1 in 10 year flood event simulations. The only dyke structure which withstands both events is the new Taninga dyke. The square shaped dyke is efficient regarding the impacts of the 5 year event however it fails with regards to the 1 in 10 year event.

Figure 7-5 presents the 1 in 5 year flood event peak flood extents for the baseline condition assuming no dykes are in place and Figure 7-4 presents the 1 in 5 year flood event with the dykes constructed. The results of the hydraulic modelling shows the proposed dyke is designed to protect the Martins area during the 1 in 5 year event with minor flooding. As shown in Figure 7-2 with the proposed dyke at Martin's area fails during the 1 in 10 year flood event.

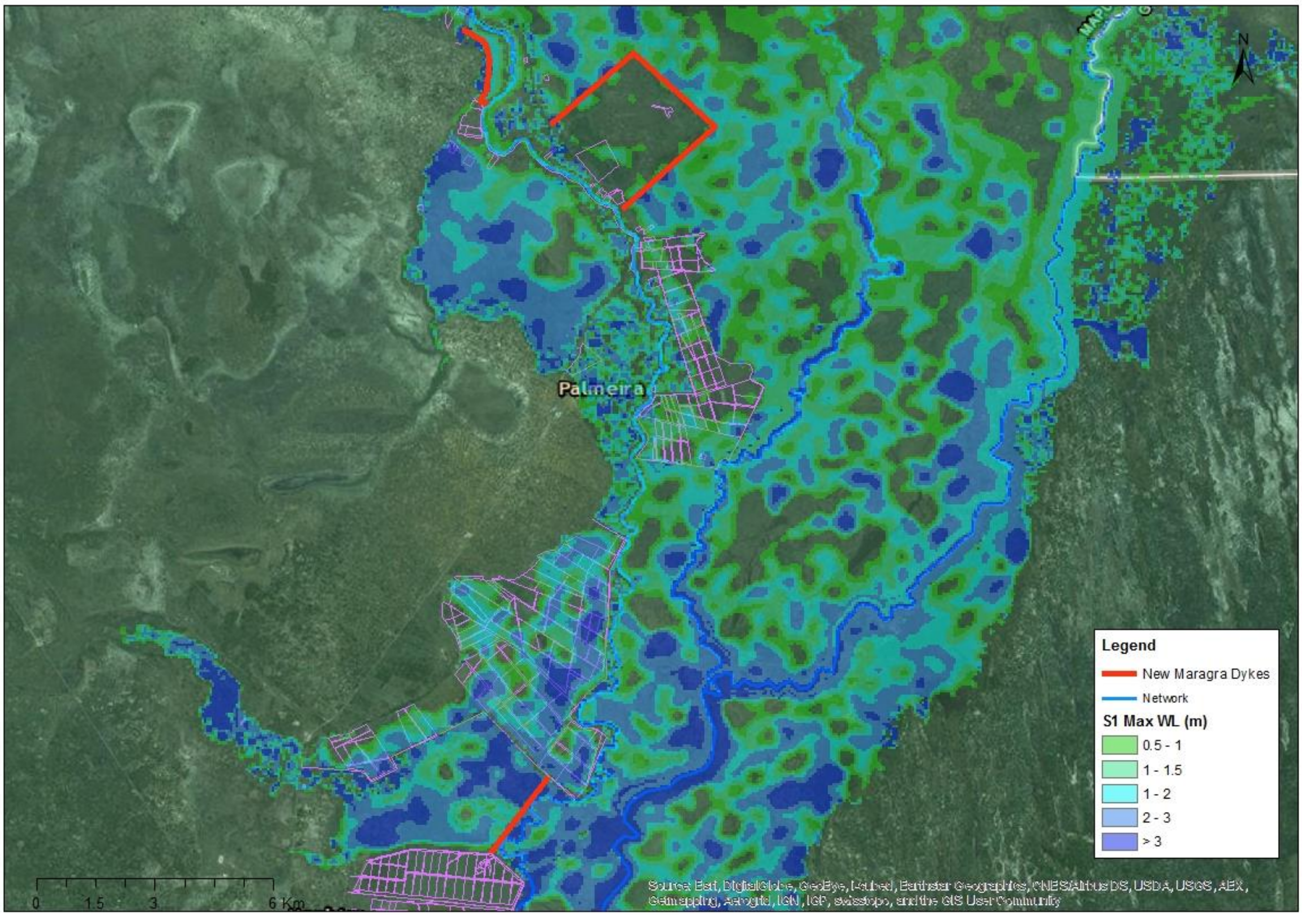


Figure 7-4 Maximum 1 in 5 year Flood Extent with Depth for the Scenario S1.

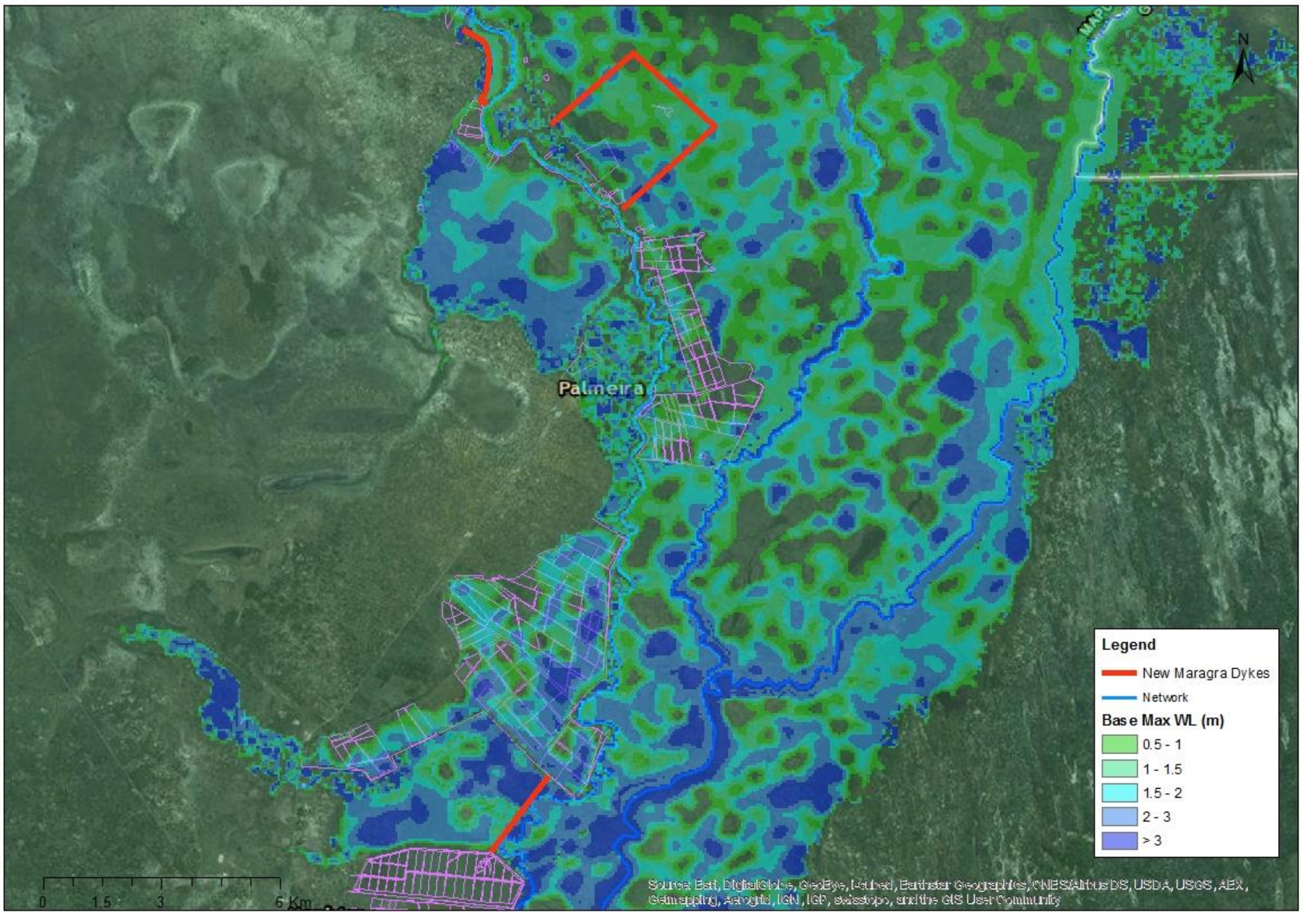


Figure 7-5 Maximum 1 in 5 Year Flood Extent with Depth for the baseline

7.1.2 S2: Dredging Works at Incomati River by Xinavane

Tongaat Hulett is proposing carrying out dredging works along the Incomati main channel as displayed in Figure 7-1 (following the yellow line indicated as S2). The dredging works consist of the removal of sediment to a depth of approximately 3 m and 20 to 30 m channel width.

After the necessary adjustments were carried out in the cross-sectional database of the MIKE 11 model, the latter was executed for the 1 in 10 year return period event, and the results compared to the baseline non-dredged conditions. Effectively, the cross-sections were deepened for the stretch of the Incomati river channel running from chainage 24,196 m to chainage 67,809 m referenced in the hydraulic model. The results are presented in the Figure 7-6 below.

Figure 7-6 presents the longitudinal plot where the cross-sectional adjustments and 1D model configuration differences can be observed. The vertical axis shows topographical elevation in meters and the horizontal axis shows distance in meters along the channel stretch. The difference between the black and purple lines represent the impact of dredging as these represent the bottom of the river bed for the baseline and S2 simulations respectively.

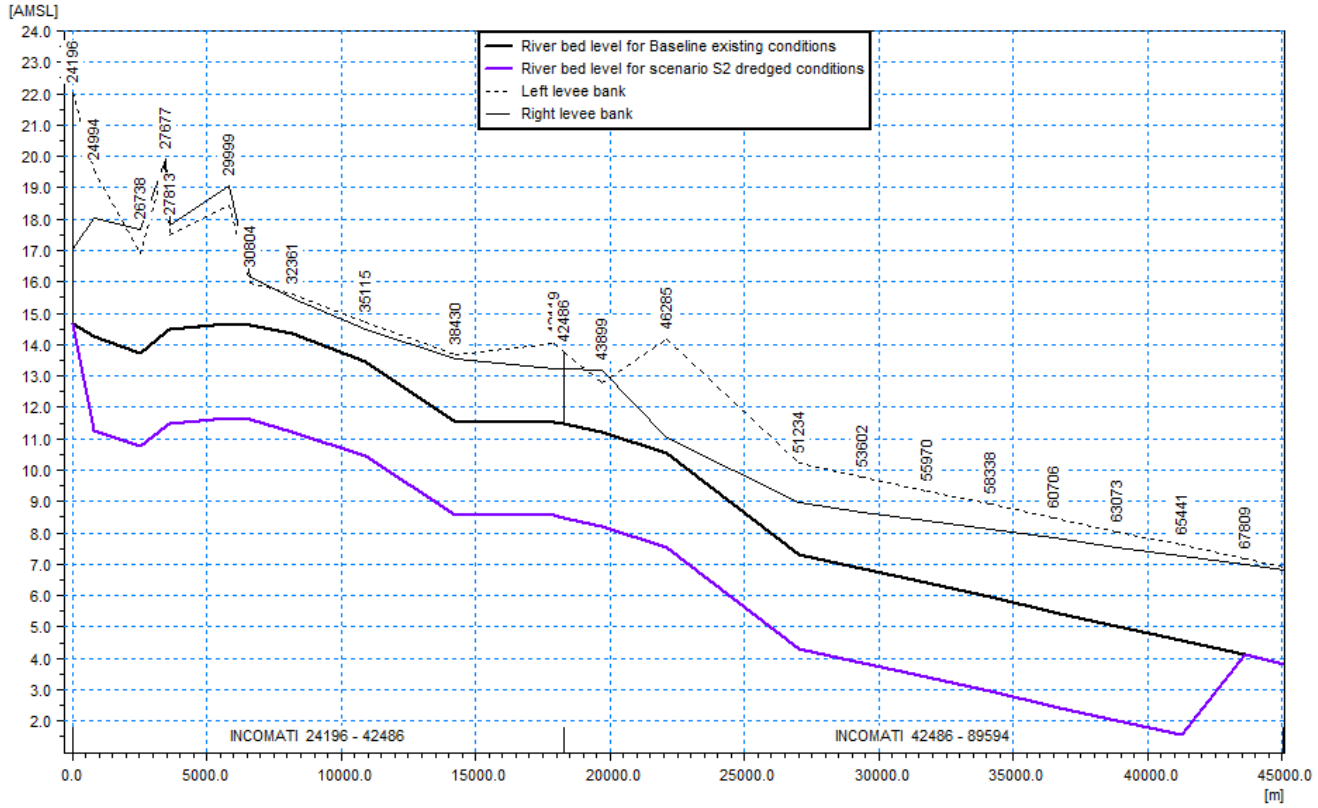


Figure 7-6 Longitudinal profile with River Bed Levels Pre and Post Dredging (scenario S3).

When comparing the simulated discharge for the 1 in 10 year event after the bifurcation of the Incomati which leads to the lake area, at the Incomati and Incoluane (this section is also known as Munhuana) channels, it is possible to see the clear impact of the dredging works on the flow partition. This observation showcases the preferred flow path the dredging has created in the Incomati channel as opposed to the Incoluane as shown in Figure 7-7 overleaf.

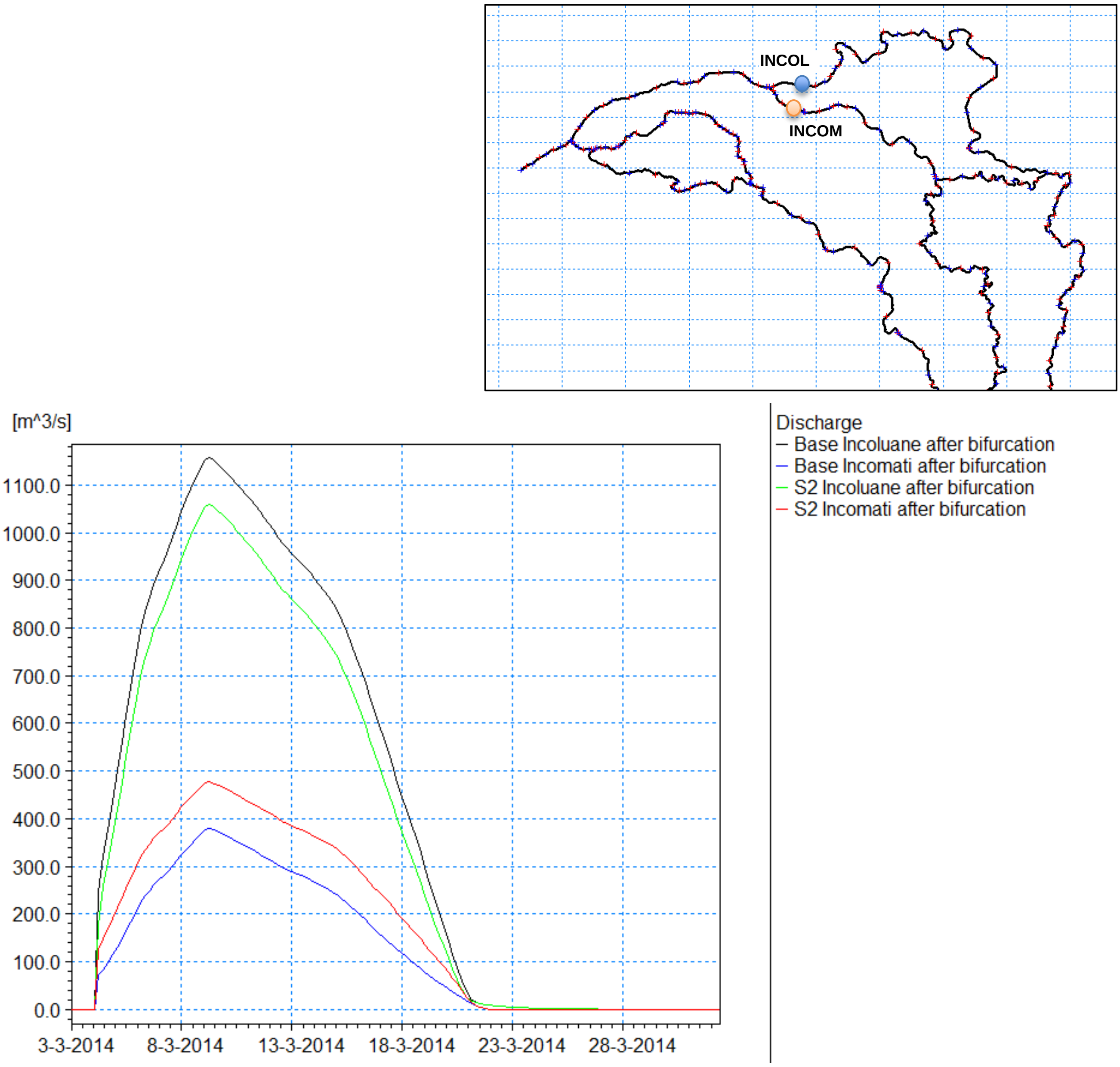


Figure 7-7 Flow Comparison Downstream of the Incomati and Incoluane (Munhuana) Bifurcation for the 1 in 10 Year Flood Event Baseline and S2 Scenarios

In addition, along the Incomati there is a weir used by Tongaat Hulett close to the sugar mill as shown in Figure 7-8 overleaf. It can be observed that with the dredging works Scenario (S2) as represented in the blue plot in Figure 7-8, shows more water is flowing over the weir when compared with the baseline situation.

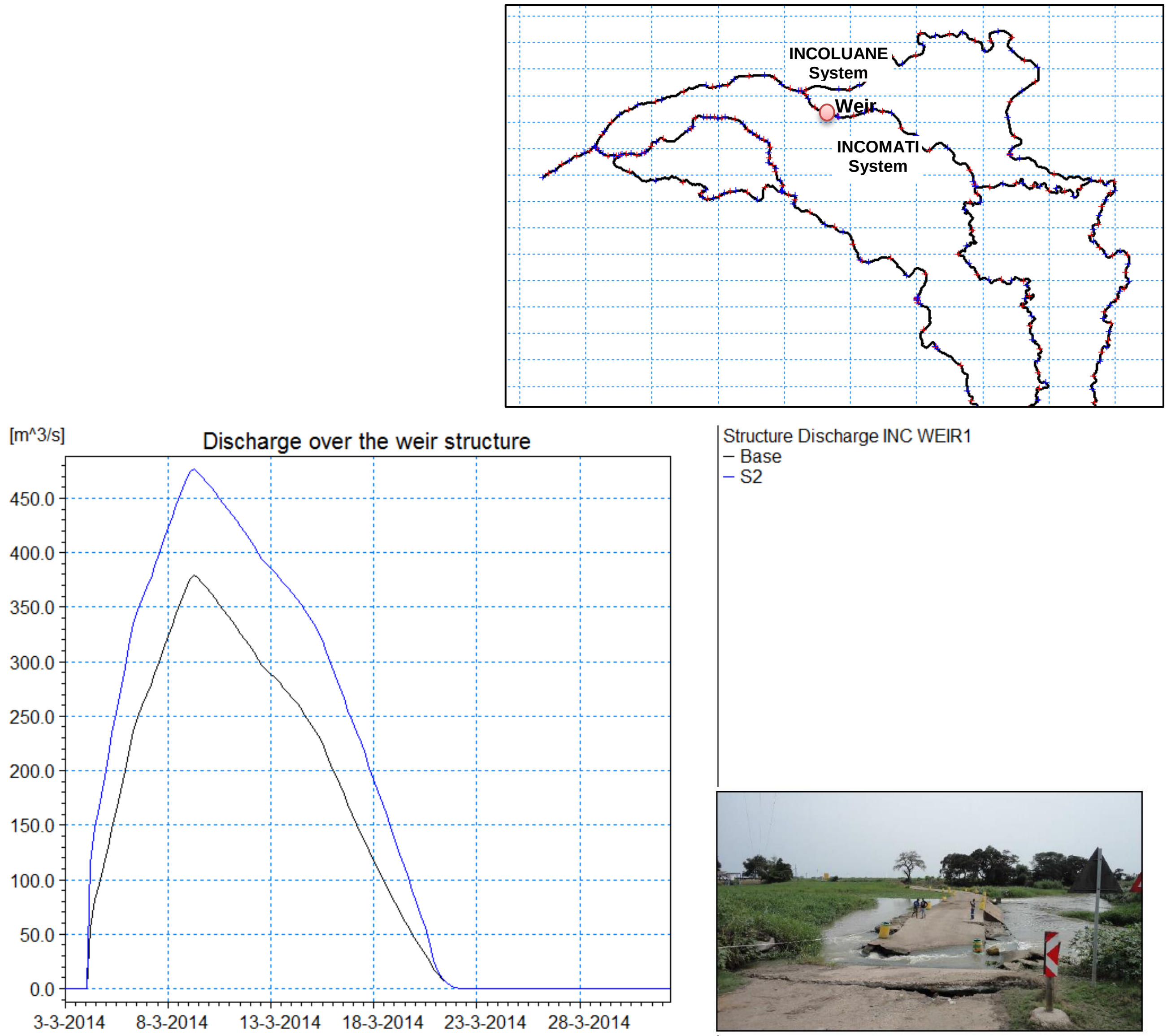


Figure 7-8 Flow Comparison over the Weir by Xinavane Mill for the 1 in 10 Year Flood Event, the photograph was taken during the CRIDF topographical survey.

The dredging impact on peak water depth along the Incomati is presented by comparing the 1 in 10 year flood event maximum water level for the baseline and S2 scenarios. There is a point in the network where the Incomati connects to a smaller channel at chainage 42,486 m as shown in the plan in Figure 7-9. The hydraulic modelling results show that the S2 scenario has an increase in peak flood level compared to the baseline; the reason for this is that after the dredging the connection between the river beds at that point is affected and conveyance into the smaller channel is decreased.

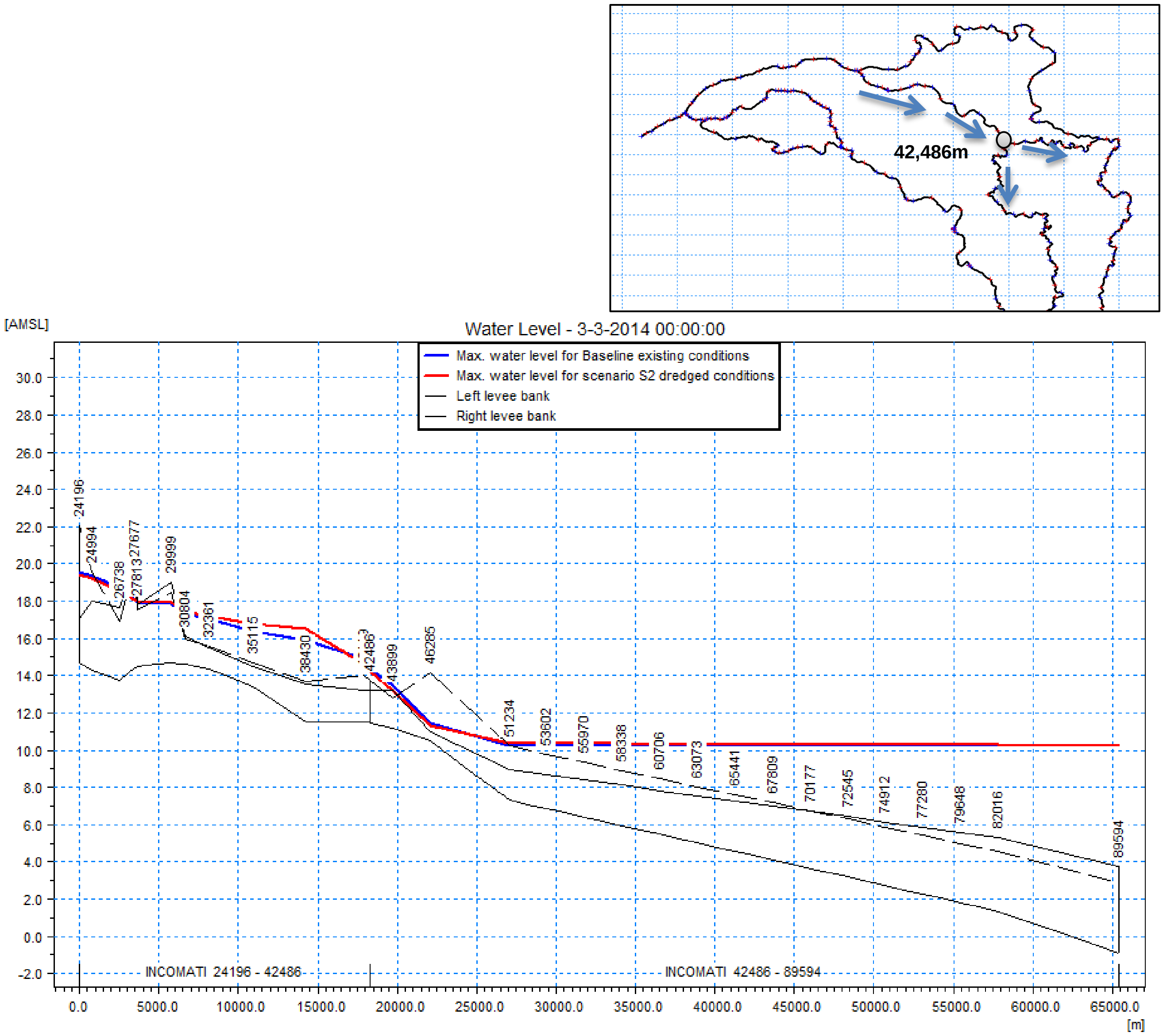


Figure 7-9 Longitudinal Profile of the Maximum River Water Levels before and After Dredging.

The dredging works are not intended as a flood protection measure but rather as part of Tongaat Hulett's operations for irrigation management. However, as shown by the tests carried out in this scenario, for flood events of such magnitude the impact of dredging does not contribute to flood protection.

7.1.3 S3: New Xinavane protection dyke

This scenario consists in revising the baseline topography with the new protection dyke Xinavane is planning for construction. This dyke aims at protecting the outgrower fields of Buna / Hoyo Hoyo and continues through an approximate straight line from EN1 national road to the Taninga dyke. Following Tongaat Hulett's instructions this new dyke is proposed to have a crest level (top embankment level) in line with the current national road level at 14.5 m (AMSL). Figure 7-10 presents a comparison of the simulation results for the 1 in 10 year flood event for the baseline and the S3 scenario.

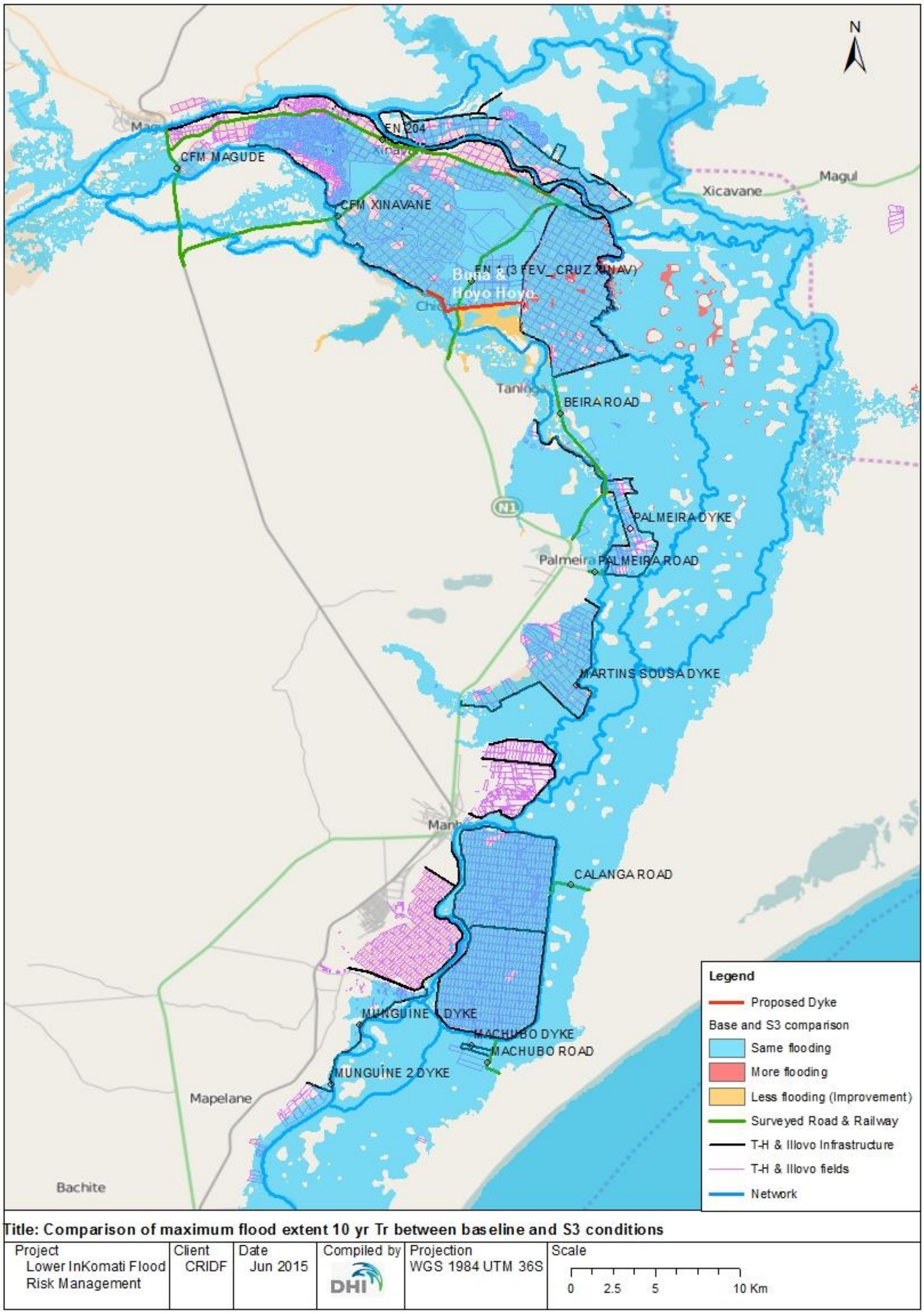


Figure 7-10 Maximum 1 in 10 Year Flood Extent Comparison between Baseline and S3 Scenario

The hydraulic modelling results show that water accumulates behind the dyke wall and attenuates the drainage of flood waters. From the results this shows there is increased flooding for the Buna and Hoyo Hoyo area. Figure 7-11 and Figure 7-12 below illustrate further the effect of the S3 dyke scenario for the 1 in 10 year flood event.

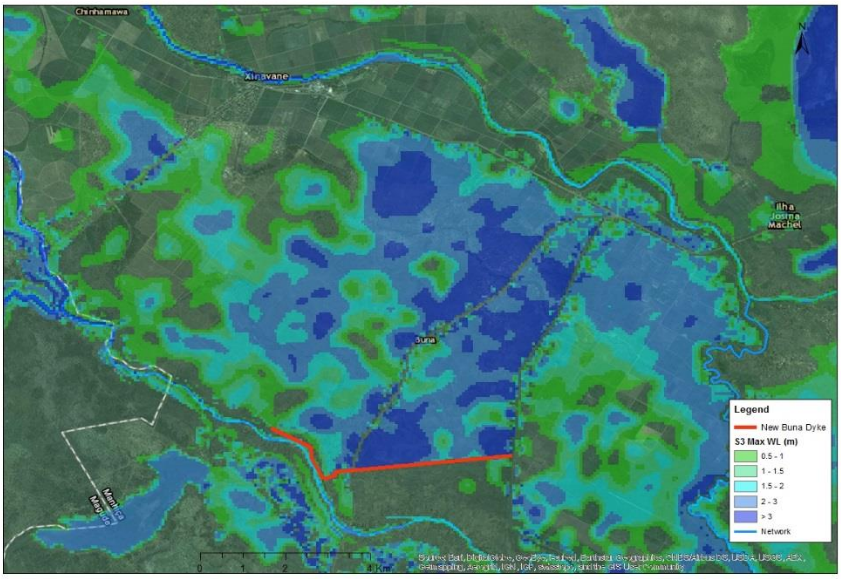


Figure 7-11 Maximum 1 in 10 Year Flood Extent with Depth for S3 Dyke Option at Buna

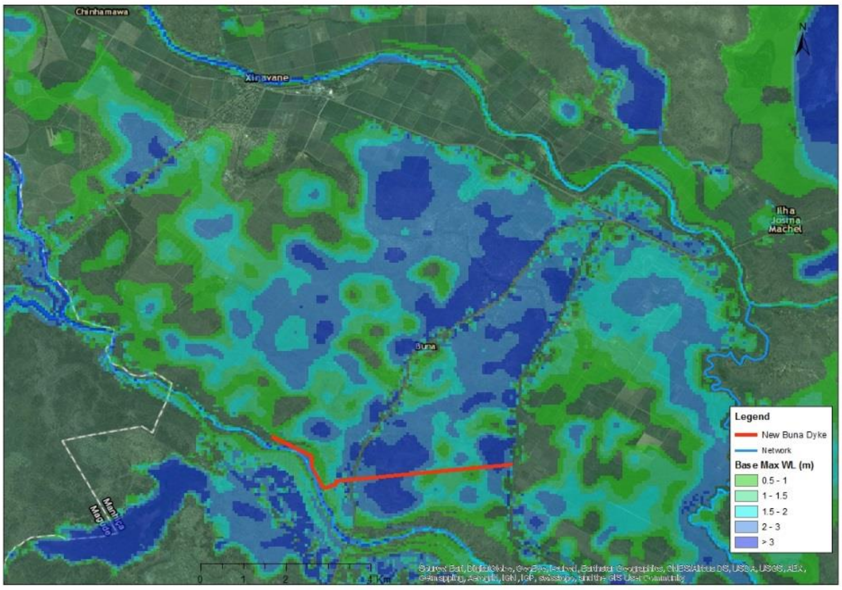


Figure 7-12 Maximum 1 in 10 Year Flood Extent with Depth for Baseline Condition.

7.1.4 S1S3: Combination of all New Protection Dykes

This scenario investigates how the local hydraulic behaviour of flood water impacts maximum flood extent for the 1 in 10 year flood event, assuming that both sugar estates construct all the proposed flood protection dykes.

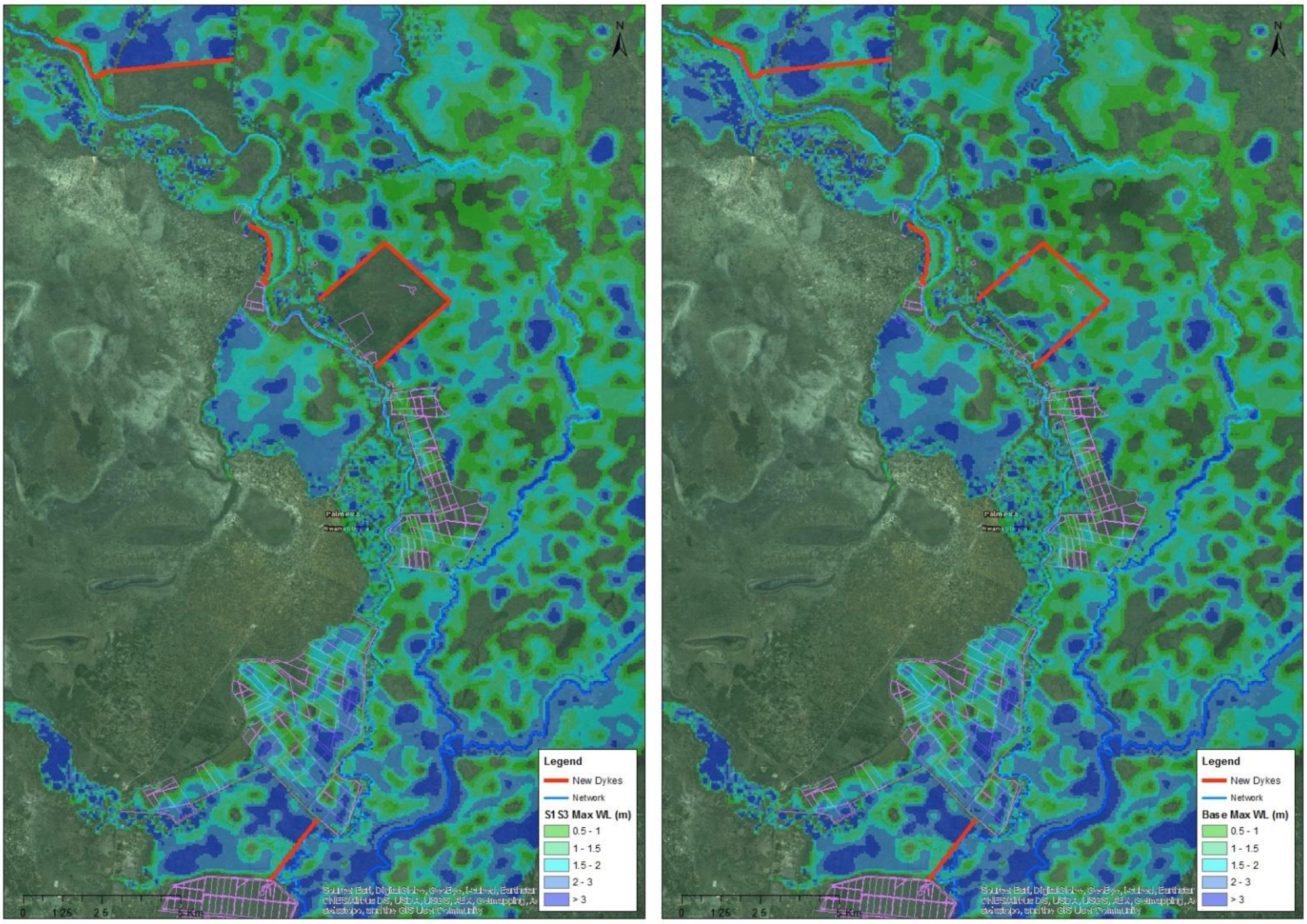


Figure 7-13 Maximum Simulated Water Level for the 1 in 10 year Flood Event Comparison between S1S3 scenario on the left and the Baseline Scenario on the Right.

The simulation results for this scenario show that in the case both sugar estates proceed with the construction of all planned protection dykes, for the 1 in 10 year flood event, there is an increase in water level and reduction in flood extent, however they do not affect outgrower fields negatively as shown in Figure 7-14.. Particularly, the presence of the Illovo dyke surrounding the additional 1,000 m^2 and the Tongaat Hulett dyke next to the Buna/Hoyo Hoyo outgrower areas do not impact negatively each other, generating higher water levels in areas which are not currently being developed.

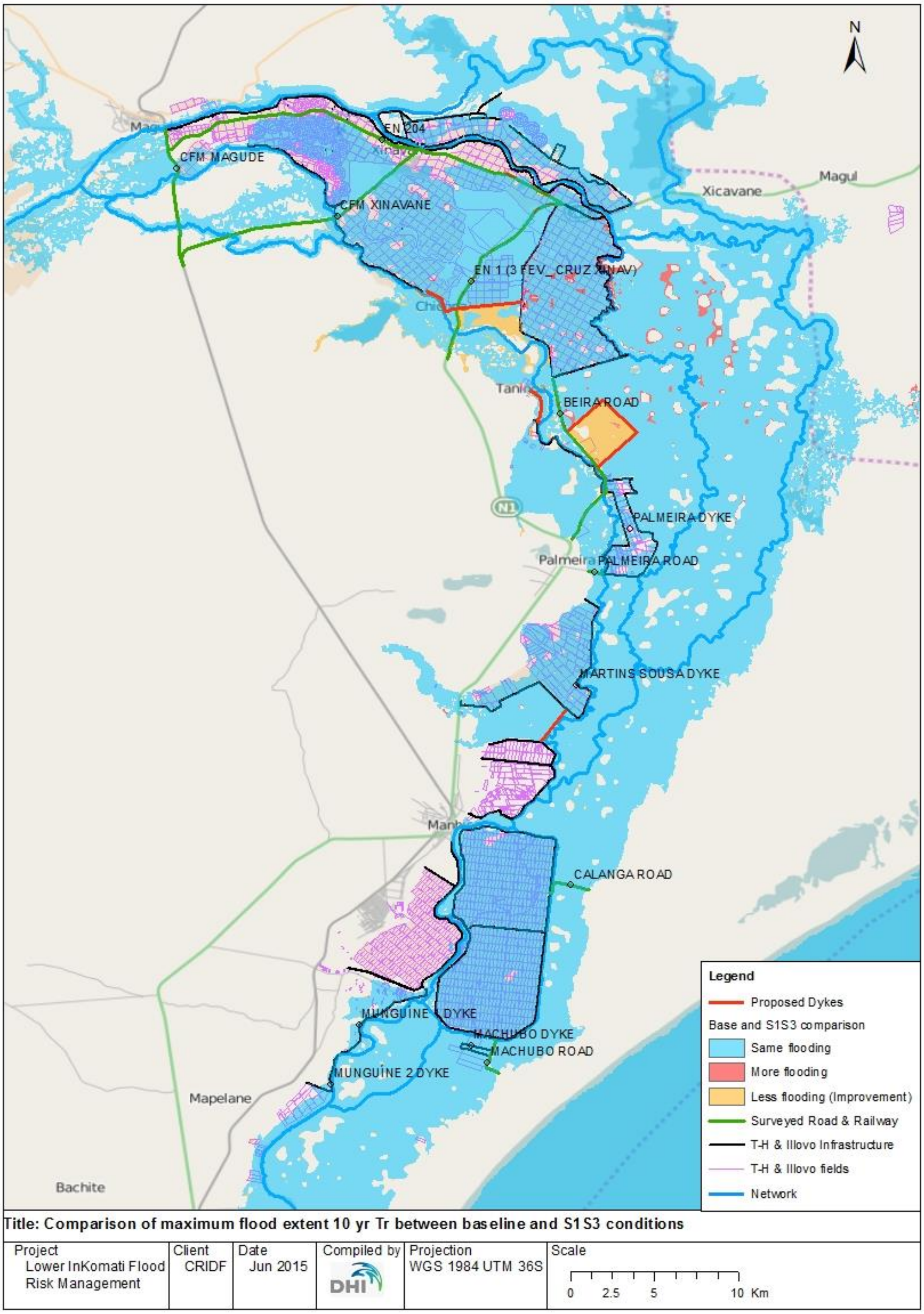


Figure 7-14 Maximum 1 in 10 Year Flood Extent Comparison between the Baseline and S1S3 Scenario.

7.1.5 S4: Tsatsimbe River Bifurcation

At the Tsatsimbe River bifurcation, in 2014, a road crossing was constructed/ rehabilitated as shown in **Error! Reference source not found.** and displayed again in Figure 7-15. Along the 134 m length of concrete structure with a top deck level of 26.4 m (AMSL), there are 64 culverts which are 2 m wide and 1.9 m high.

It has been reported by both sugar estates that since these culverts were introduced by ANE (the national road authority), there has been an increase in flood and flood damage to the downstream areas along the Tsatsimbe/Cuenga system under development, mostly occupied by outgrower fields. Before the culverts were built, the river embankment crest at this location would force routing of peak flood flow down the main channel of the Incomati River which has higher conveyance and this resulted in less damage to the sugar cane fields in the case of a flood event. All project stakeholders agree that although some culverts should be maintained to allow low flows to be routed down the Tsatsimbe/Cuenga system, larger flows and flood events should not be able to enter the system and should enter the main Incomati system.

Figure 7-15 Photograph and Schematic of the Road and Culvert Structure after the Bifurcation from the Incomati River at the Tsatsimbe /Cuenga System.

Therefore, a series of tests were carried out by altering the conveyance and deck level of the road bridge structure while maintaining the dimensions of each culvert (2.0 m x1.9 m). The following tests were run:

- S4A: Current 26.4 m AMSL deck level and all 64 culverts
- Current 26.4 m AMSL deck level
- S4B: half the number of culverts;
- S4C: one third of the number of culverts;
- Restoration of the original embankment level at 28.14 m (AMSL)
- S4D: half the number of culverts available for conveyance of flows;
- S4E: one third of the number of culverts available for conveyance of flows;

The results at key points of interest are presented in Table 7-2 and Figure 7-16 and Figure 7-17.

Table 7-2 Peak Simulated Flows of the Scenario S4 (m3/s)

ID	Incomati after bifurcation (8,863 m)	Tsatsimbe after bifurcation (1,164 m)	Xinavane Mill at Incomati (30,401 m)	3 de Fevereiro bridge at Cuenga (31,793m)	Maragra fields at Incomati (112,347 m)
S4A	1205	948	276	809	926
S4B	1371	788	322	672	908
S4C	1452	698	348	580	913
S4D	1571	584	387	505	911
S4E	1732	425	447	320	927

Note: The locations in Table 7-2 are shown graphically in the plans of Figure 7-16 and Figure 7-17.

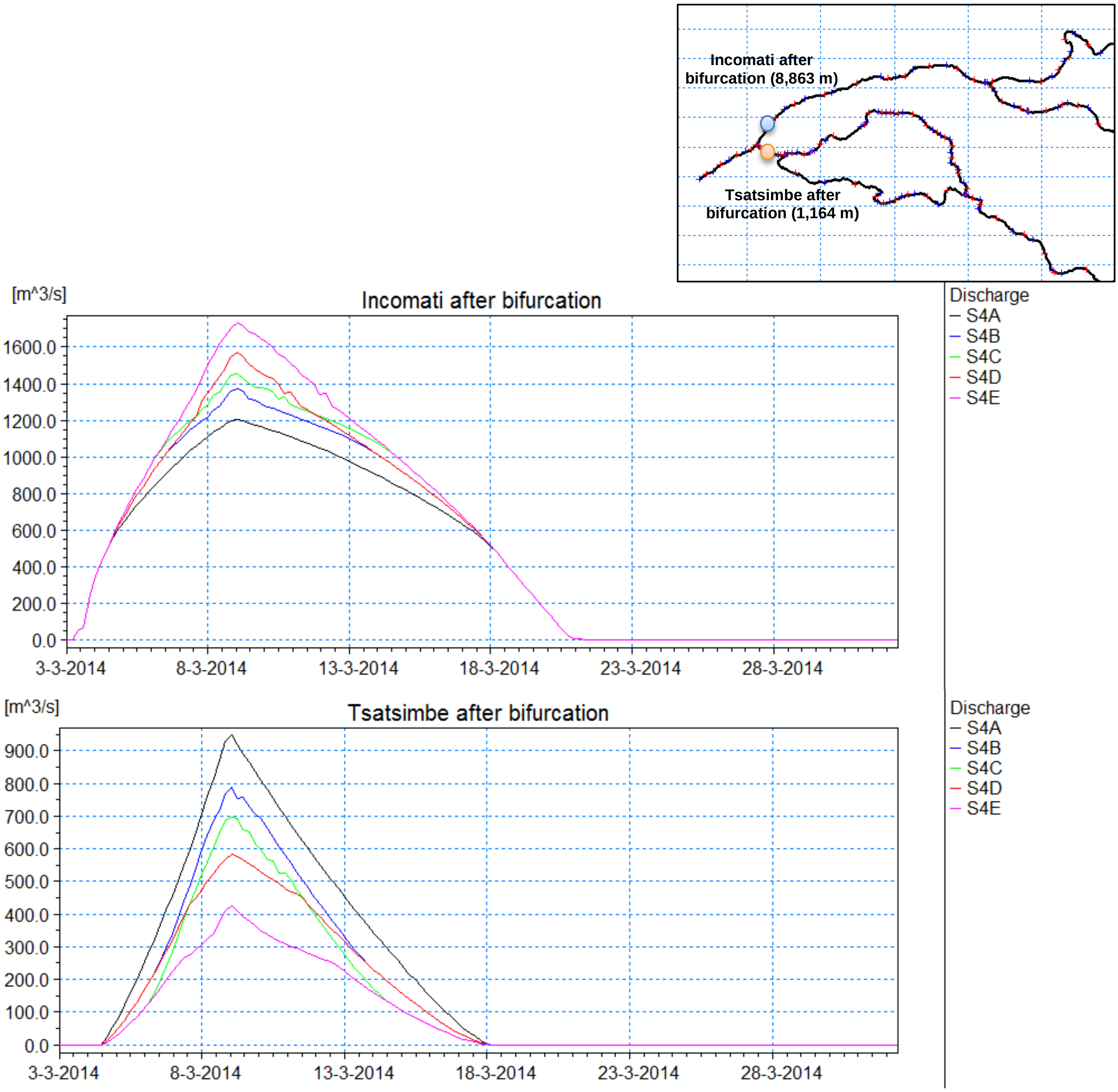


Figure 7-16 Flow Comparison of the 1D Model Scenario 4 Simulations for the 1 in 10 Year Flood Event Return Period

The peak flow results after the Tsatsimbe bifurcation of the Incomati main channel, best displays the flow partition that occurs as a direct effect of the hydraulic structure in place at that location. There is a clear link between the number of culverts and height of the embankment level, and the percentage of flow which is allowed to flow down the Tsatsimbe/Cuenga river channel as shown in Figure 7-16.

Table 7-3 Flow Partition Patterns According to the Different Hydraulic Structure Configurations for the 1 in 10 Year Flood Event

Ref.	%V_{INC}	%V_{TSA}	Simulated V_{INC} (m^3)	Simulated V_{TSA} (m^3)
S4A	70%	30%	1,157,023,840	497,429,002
S4B	77%	23%	1,266,787,902	387,560,855
S4C	80%	20%	1,326,291,981	327,636,736
S4D	80%	20%	1,323,654,946	331,990,783
S4E	86%	14%	1,431,701,026	223,485,837

Note: V_{INC} refers to flood volume on the Incomati;
$V_{TSA\ refers}$ to flood volume on the Tsatsimbe

From Table 7-3 the difference between scenarios S4C and S4D is very small and almost negligible given an event of this magnitude and shows that if the embankment crest level is raised to its original height, and the number of culverts is reduced to one third, the amount of flood waters heading down the Tsatsimbe/Cuenga channel is reduced to half compared to the baseline (S4A) scenario.

From Figure 7-17 near the Xinavane plant location, the S4E scenario results in a larger partition of flow along the main Incomati river resulting in the highest flow peak at this location of 447 m^3/s versus 276 m^3/s for the current conditions (S4A).

As shown in Figure 7-17 at approximately “3 de Fevereiro” area, between the Buna and Hoyo Hoyo Xinavane dykes and the new Taninga Maragra dyke, a very large difference in the 1 in 10 year flow peaks is obtained. For the current situation S4A, 64 culverts with top deck invert level of 26.4 m (AMSL), the simulated flow peak for the 1 in 10 year flood event is 809 m^3/s versus 312 m^3/s for S4E, which consists of 18 culverts with embankment level restored to its original height of 28.2 m (AMSL).

Finally, as expected downstream of the system at the Maragra fields, little change in flow peaks takes place, due to the fact that at this point the cumulative effect of the flows converge.

In addition to the above 1D results, a 2D simulation for the 1 in 5 year event was run for both baseline conditions and scenario S4E. Figure 7-18 and Figure 7-19 show the results.

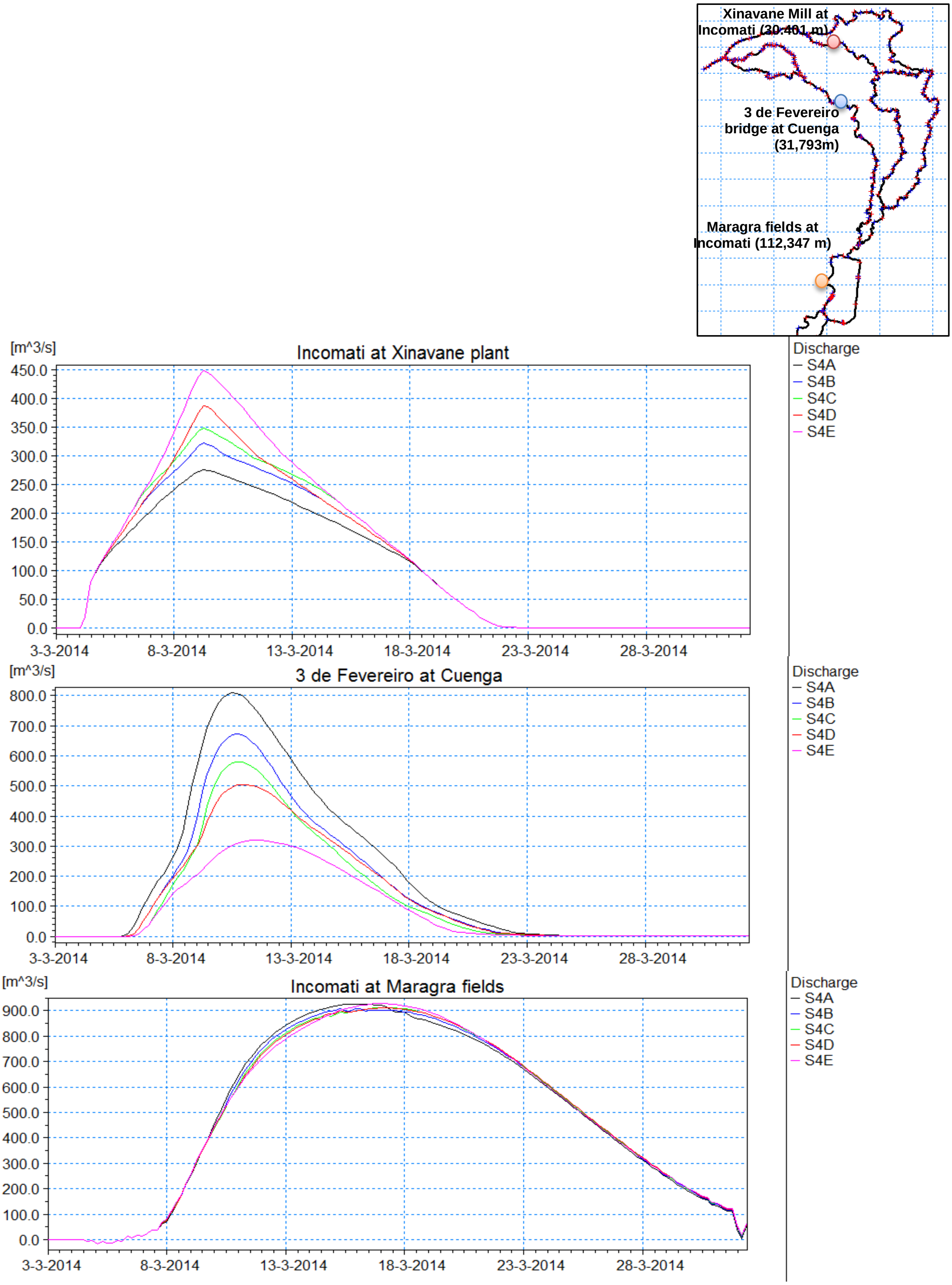


Figure 7-17 Flow Comparison of the 1D Model Scenario 4 Simulations for the 1 in 10 Year Flood Event Return Period

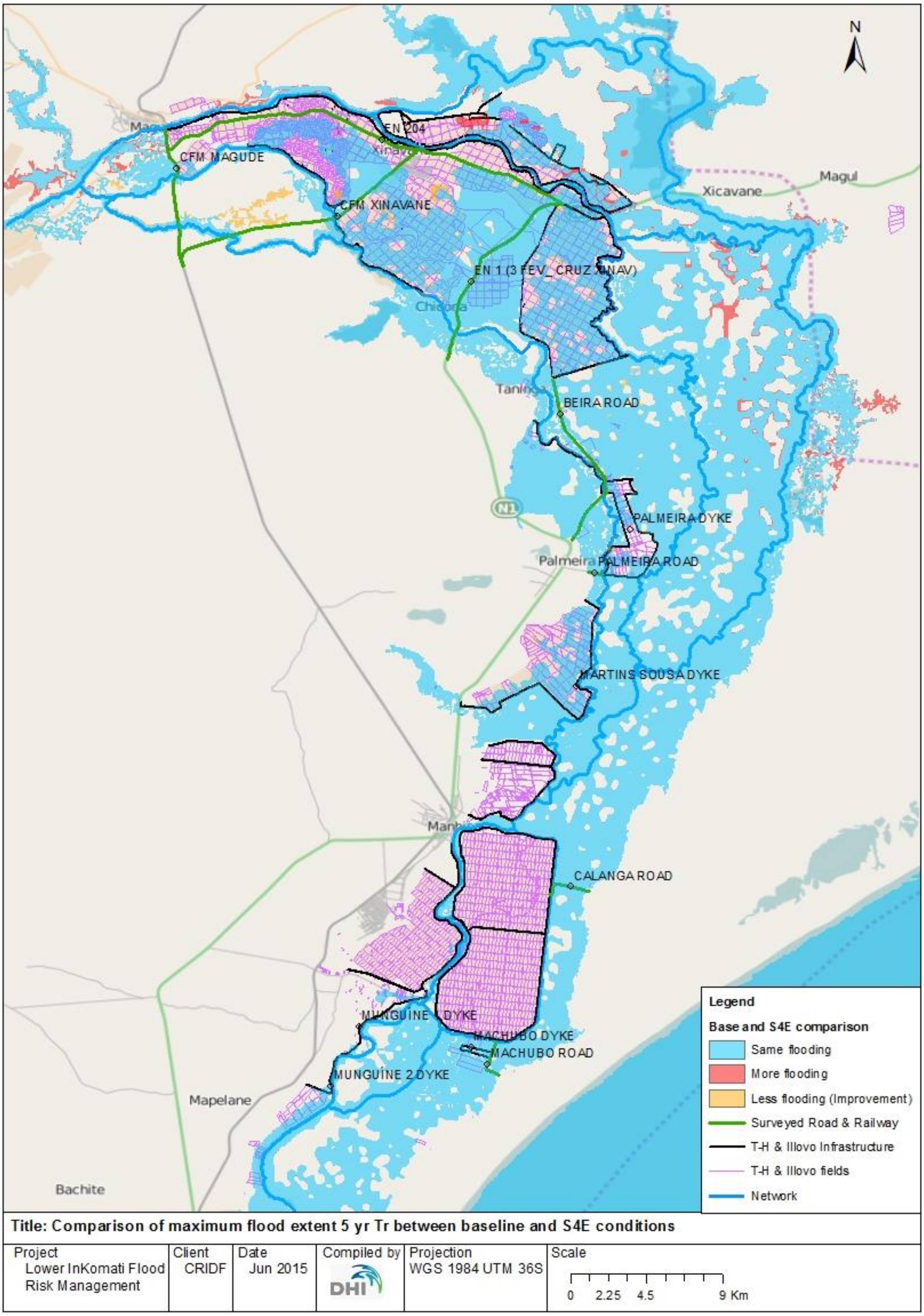


Figure 7-18 Maximum 1 in 5 Year Flood Extent Comparison between the Baseline and S4E Scenario.

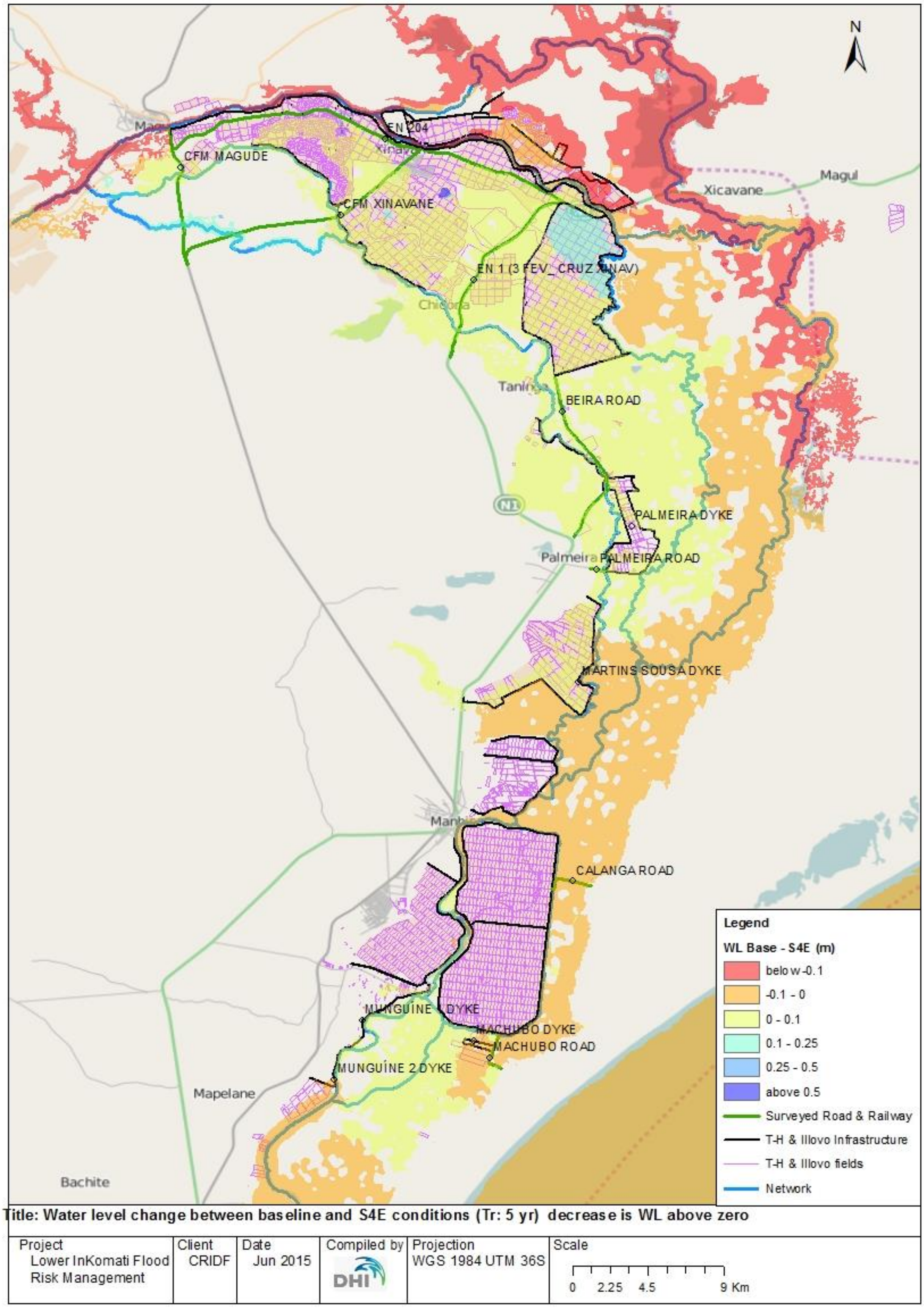


Figure 7-19 Maximum 1 in 5 Year Water Level Difference between the Baseline and S4E Scenario

The 1 in 5 year S4a and baseline comparison results show a slight reduction in flood extent, as there is only a portion of the inundated area within Tongaat's fields shown in orange in Figure 7-18, which does not get flooded when S4E conditions are in place. Main improvements can be detected when subtracting the maximum water level for the scenario S4E conditions from the baseline current conditions, shown in Figure 7-19. All areas in red as expected now have suffered an increase of up to 2 m of water level whereas in the Tsatsimbe/Cuenga stretch after the culverts undergoes a reduction of almost 1 m in water level, corresponding to the areas shown in blue. The inundated areas shown in orange affecting most of the Tongaat and Illovo affected areas also display a reduction in water level of 0.1 m which corresponds to a more significant decrease in overall volume when considering the flood extent area. While this scenario does appear to provide some relief for the situation a more radical management measure may potentially reduce flooding significantly in the key areas of the Lower Incomati.

A further scenario was examined and the 2D model run where the embankment crest level was kept at S4E level, yet the culvert structure was completely removed (Scenario S4F). The results are shown in Figure 7-20,

As can be seen there is a significant water level change in the Tsatsimbe/Cuenga system. This leads to the conclusion that in case of an incoming flood event of the magnitude of the 1 in 5 year probability, less flooding will take place if the culvert structure is fully closed and construction works to raise the embankment crest level have been carried out. However, there is still flood water entering the Xinavane fields which then eventually enters the Tsatsimbe/Cuenga system due to an embankment failure upstream of the Magude town as indicated in Figure 7-21.

An additional model simulation was established where a dyke structure 3m high was additionally build into the Scenario S4F hydraulic model as shown in Figure 7-22, which is Scenario S4G. As presented in Figure 7-22, if a 1 in 5 year flood event occurs, provided the culverts are closed and the embankment crest level has been raised, with the additional dyke structure upstream of Magude town, flood extents are reduced considerably in the Outgrower areas as denoted by the orange areas shown in Figure 7-22.

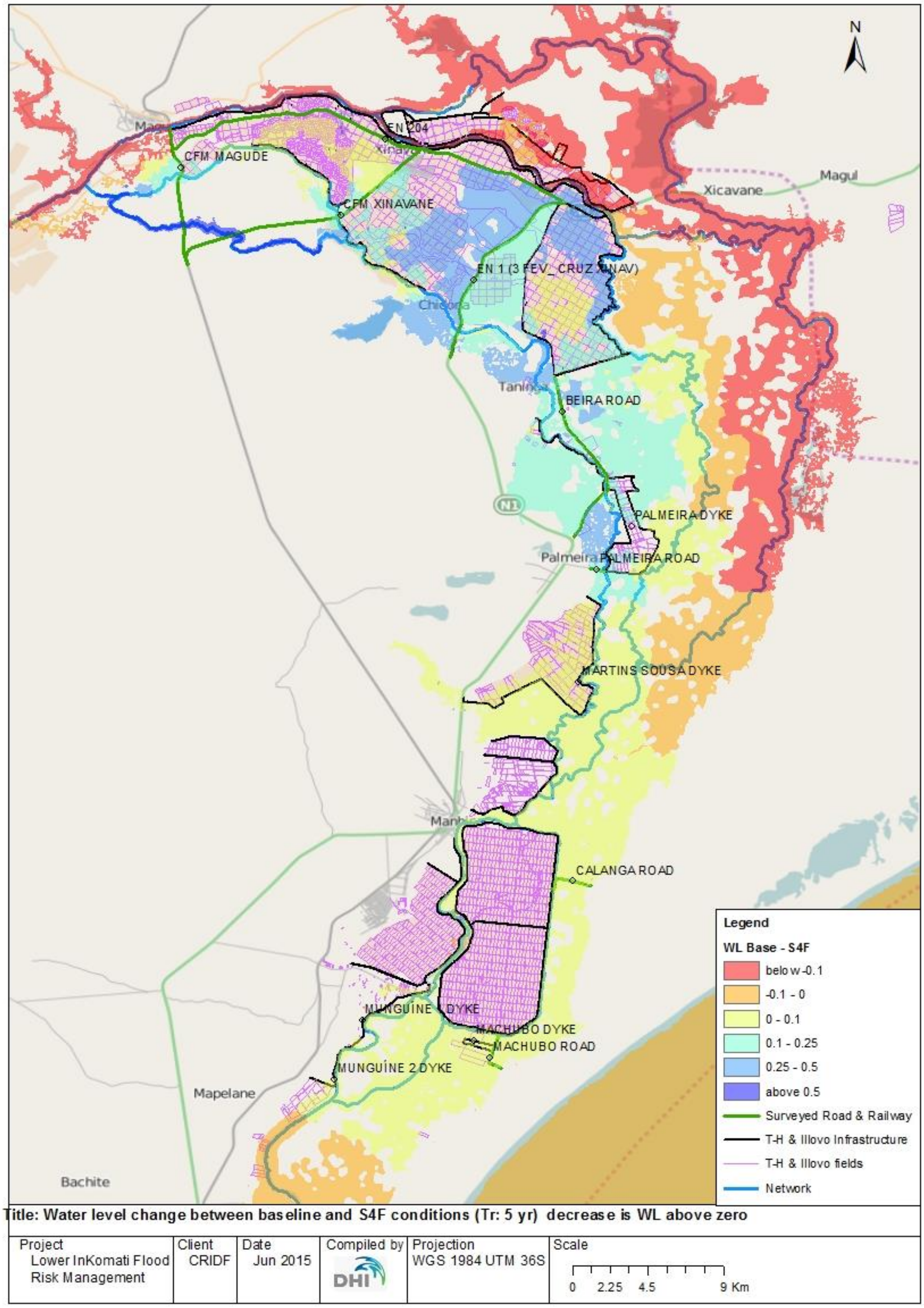


Figure 7-20 Maximum 1 in 5 Year Water Level Difference between the Baseline and S4F Scenario corresponding to conditions without culverts in place.

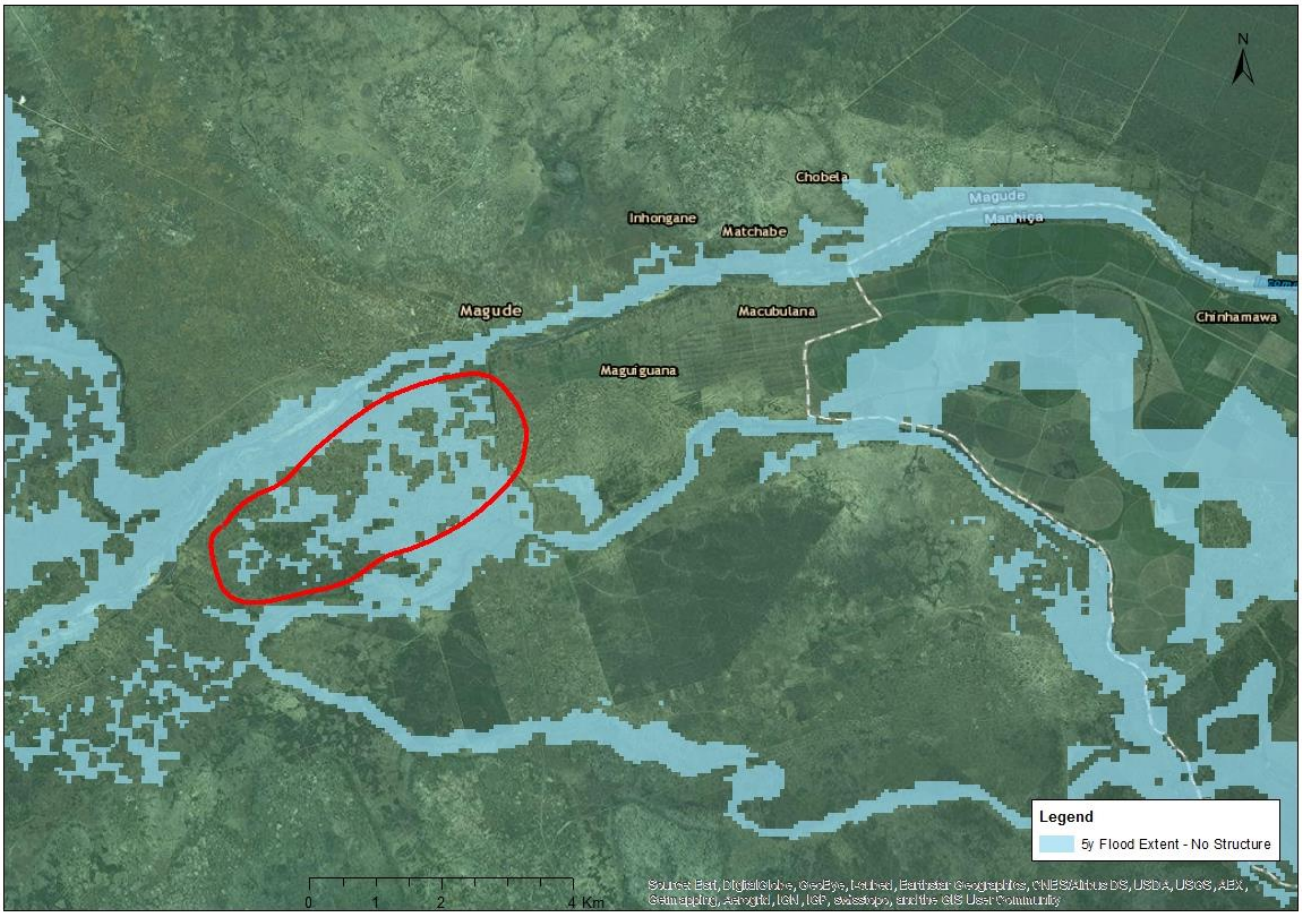


Figure 7-21 Maximum 1 in 5 Year Flood Extent for the S4F scenario and location of embankment failure.

The further testing of embankment behaviour at the Incomati - Tsatsimbe bifurcation carried out by removing the culvert structure altogether combined with the implementation of a dyke upstream of Magude town was found to have the highest reduction of flood impact on outgrower areas.

Finally, regarding the hydraulic structure at Incomati - Tsatsimbe bifurcation, it is suggested that for improved flood risk management, an option where an operational structure (valves, gates) which would allow for complete interruption of flow through the structure, in the event a flood of the 1 in 5 year magnitude is forecasted, should be investigated in detail. This should be carried out at a later stage since it is outside the scope of this pre-feasibility study.

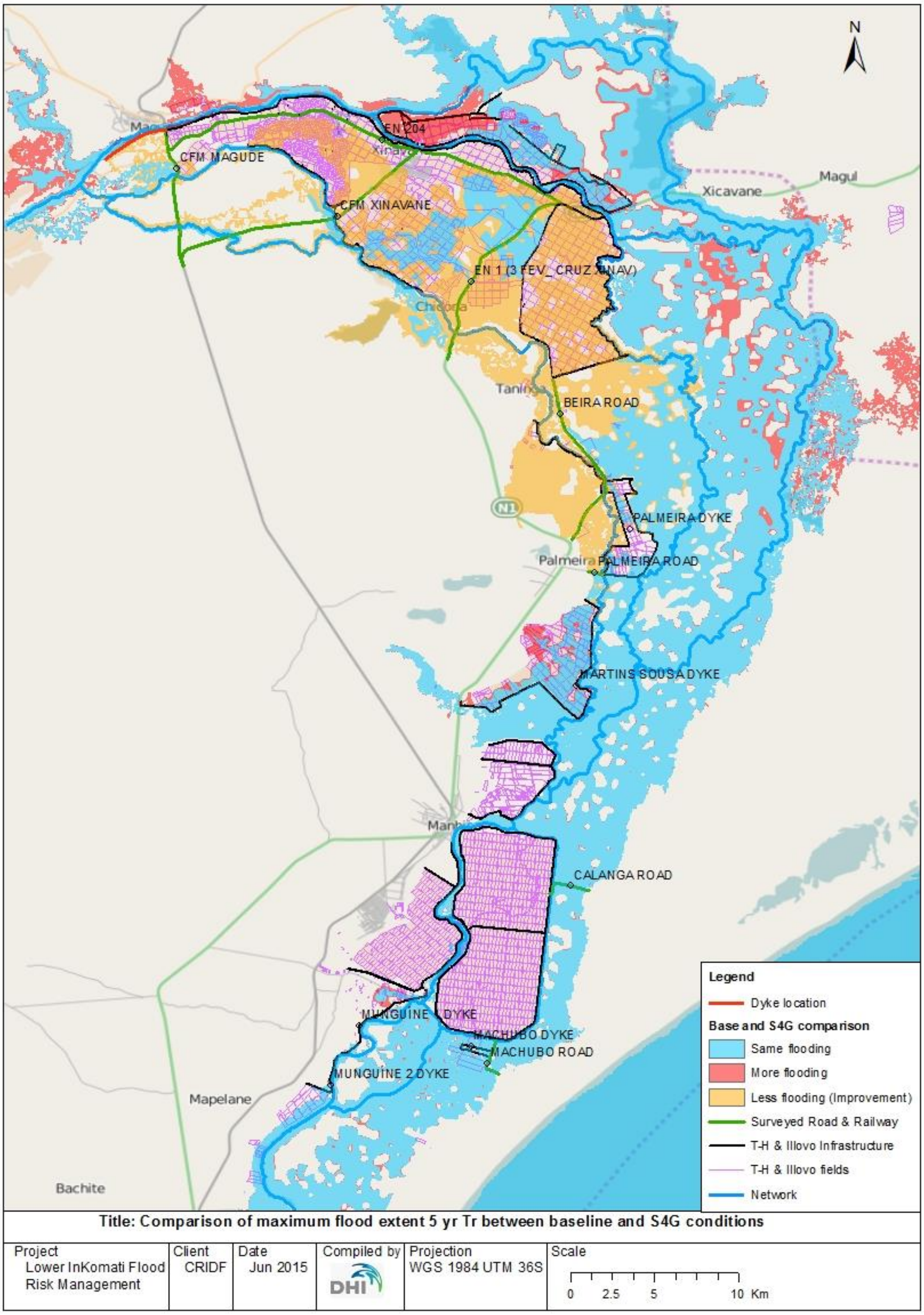


Figure 7-22 Maximum 1 in 5 Year Flood Extent Comparison between the Baseline and S4G Scenario without culverts in place and with an additional protection dyke

8 Flood Modelling Conclusions and Recommendations

The specific objectives of the first deliverable of Phase 1 consisted in the production of the following outcomes: of a flood risk assessment by using a suitable 2-dimensional flood model to determine the degrees of exposure of the floodplain area to flood hazard corresponding to 1 in 5, 10 and 20 years return periods; conducting a vulnerability assessment of the communities and different economic activities in the study area, and producing a flood risk map based on these analyses. In addition, different flood risk management scenarios were investigated. It is considered that the objectives have been fulfilled and the following paragraphs summarise the main conclusions reached.

The estimated flood extent for the 1 in 5, 10 and 20 year return periods was determined and detailed maps are presented in Appendix A. It is concluded that particularly regarding the flood protection dykes, it has been found that Tongaat Hulett's existing dykes are likely to fail for a 1 in 5 year flood event. The existing Illovo protection dykes for the Maragra MCP areas show they are protected from flooding up to the 1 in 5 year flood event with sectors C and B being flooded for the 1 in 10 year event. The location of the failing dykes for both sugar estates and for each return period can be seen in detail as a collection of maps in Appendix A.

Regarding flood hazard, the detailed maps in Appendix B present which areas are affected particularly by Significant and Extreme flood hazard which incur in the worst damage and higher socio-economic impacts. Particular attention has been given to identifying and listing the outgrowers of each sugar estate which are expected to be affected.

Regarding flood vulnerability, the areas where outgrowers' fields are situated are the most vulnerable mainly due to the fact that the outgrowers' harvest being a significant source of income for a largely permanently unemployed community without insurance. The MCP large scale areas are at a much lower risk than outgrowers, due to permanent employment status, insurance cover, and access to potable water, electricity and credit. In addition MCP large scale areas are better protected by flood protection dykes.

As with any modelling work, the results are only as accurate as the data provided and used. For such a flood model, the elevation data of the area used to route the flood waters is the most sensitive. It must be noted that in the applied 60 m DEM for this project, there are still inaccuracies, particularly in the low-lying flood plain region, even after all the considerable improvement made using the MIKE 11 cross-sections, relative dyke elevations, roads, railways and hydraulic structural information collected. This needs to be taken into consideration. Additionally, the topographic information provided is adequate to provide only a first level initial assessment. The relative levels of specific topographic information might be inaccurate which will present problems in any detailed analysis. Essentially this study can be used to prioritise options which could be taken into more detailed planning and implementation processes, but not for detailed infrastructure design.

Given the focus and target community of this project, from the results of the flood risk assessment, although measures have been taken to reduce the impact of floods on crops situated in the flood plains particularly flood levees around the large scale MCP fields and some outgrower areas, it is expected that many of the outgrowers are not in such a fortunate position to afford such infrastructure, and are located in the most hazardous and high risk areas.

A number of different modelling scenarios were agreed upon with the stakeholders, which consisted of different structural intervention measures directed towards an improved management of the risk of flooding in the study area. The models were adjusted to test each of the options which are:

- Additional protection wall around the 1,000ha developed in close proximity to existing Maragra, and new dykes at Martins and Taninga;
- Impact of dredging a section of the Incomati River from the river diversion upstream of the factory to about 5 km beyond Taninga on flooding risk for downstream areas;
- Impact of the new dyke being installed along the Tsatsimbe or Cuenga River for flood protection by Xinavane;
- Combination of the additional Maragra protection dykes and the new Xinavane protection dyke; and
- Testing of different configurations for the hydraulic structure at Tsatsimbe River bifurcation, such as reduction of number of culverts and raising the embankment crest level.

Based on the modelling results, it has been found that the proposed new dyke walls by both sugar estates do not have a negative mutual impact and in the surrounding floodplain areas. However, from the hydraulic modelling results their degree of effectiveness varies as follows:

- The Tongaat proposed Buna dyke with a height of 14.5 m AMSL has negative impacts on the outgrower fields it is trying to protect as it creates a barrier to the flood waters which would previously freely drain downstream of the floodplain. Unless this option is accompanied by raising the dykes which are currently failing the hydraulic modelling shows this will not solve flooding for this area.
- The Illovo proposed Taninga dyke with a height of 9.5 m AMSL has proved to be potentially very effective in preventing flooding for a 1 in 10 year flood event.
- When the protection dyke for the planned Illovo additional 1,000 m^2 development heighten embankment crest level of 9.1 m AMSL, and the Xinavane Buna dyke are constructed, both can potentially withstand an event of 1 in 10 year flood event probability.
- The Illovo Martins dyke with its current embankment crest level of 6.4 m AMSL fails for the 1 in 10 year event; therefore it is recommended this is revised.
- Dredging of the Incomati River adjacent to the Xinavane Mill and fields, will cause an increase of flow along the main Incomati channel which results in higher water levels and potentially increased flooding for a 1 in 10 year flood event; however this measure was never intended as a flood protection intervention.
- Different structure configurations were tested for the culverts placed at the Tsatsimbe bifurcation of the Incomati. It has been found that by decreasing the number of culverts and increasing the embankment crest level the volume flowing down the Tsatsimbe/Cuenga system will decrease by half when compared to the current conditions. It is expected that this

reduces flooding and will result in an improved management of flood risk particularly for events of higher probability of occurrence.

- Further testing of embankment behaviour at the Incomati - Tsatsimbe bifurcation carried out by raising the embankment crest level and removing the culvert structure altogether was found to have the highest reduction of flood impact on outgrower areas. A further scenario combined the latter with the implementation of a dyke upstream of Magude town and the 2D model results showed this added protection structure would reduce flood impacts in the outgrower areas.
- Finally, regarding the hydraulic structure at Incomati - Tsatsimbe bifurcation, it is suggested that for improved flood risk management, an option where an operational structure (valves, gates) which would allow for complete interruption of flow through the structure should be investigated in detail outside the current pre-feasibility study.

It should be noted that the scenarios S1 and S4 related to potential structural interventions reduced flooding in the highest risk areas and greatly improved the situation for the outgrowers who are at the highest risk and most vulnerable. From the hydraulic modelling the S2 and S3 options did not improve the flood risk management situation in any marked way for the outgrowers. Scenario S1 which targeted specific outgrower areas up until the 1 in 5 year flood event, and Scenario S4, which presented the most promise in resolving the problem extensively by carrying out structural interventions at the Tsatsimbe bifurcation, could reduce a major area of flooding for Tongaat Hulett areas as well as the downstream Illovo areas. However, there are other areas where vulnerable communities are located which can be negatively affected by these interventions such as the inhabitants of the Josina Machel area surrounding the Lagoa Chuali, and also areas upstream of the model domain where Tongaat-Hulett currently established other outgrower fields which have not been examined under the scope of this project.

Finally, it is important to note that all conclusions are being drawn regarding the magnitude of the 1 in 10 year flood event and in some cases 1 in 5 year event, which was considered to be a useful measure of initial testing for investment in structural interventions by the sugar estates and farmers.

It should once again be noted that current 2D hydraulic model used for this project utilises a coarse Digital Elevation Model (DEM) with GPS survey blended into this to improve the accuracy. The hydraulic model has been used to find out the relative effects of comparing scenarios, and which flood options are effective to help inform flood risk management decision making. The current hydraulic model does not have the level of DEM accuracy to determine flood embankment crest levels for detail design or construction purposes.

8.1 Outlook for Future Project Phases

Flood risk management includes not only structural interventions but also a very important monitoring side which is carried out by CRIDF's client on this project which is ARA-Sul. Key to the success of the project to date is the stakeholder facilitation and the collaboration between the private sector (Sugar Estates) and the public sector organisations including the signing of the MoU between parties. As the project progresses the aim is to increase the steering group representatives which will provide further influence in improving flood risk management for the local poorer communities in the Lower Incomati.

In addition, testing of specific scenarios relating to flood mitigation would require more detailed interventions. This would also require more accurate and detailed data such as LiDAR topographic information.

It is recommended that the link between early warning and prevention and preparedness is made by effectively engaging the INGC as a participant in workshops. However, it is hereby recommended that ARA-Sul is maintained as the key recipient of the project's outcomes and focus, as it this is considered to be the right institution which should be targeted by a technical project of this nature and of this scope.

Finally, it is recommended that in the next phases of the project, a much higher focus and budget is placed on meeting, training and assessing in detail the needs of this institution in particular, within the scope of this project and thus regarding their monitoring and emergency flood operations.

9 Economic Analysis

9.1 Economic Analysis Purpose

This consists of a comprehensive economic analysis of the project, the purpose of which is two-fold. Firstly, a high-level socio-economic assessment of the project area and intervention is required to inform CRIDF and DFID on whether further investment in the project is justified from the perspective of promoting pro-poor, climate resilient water infrastructure that promotes better management of shared resources.

Secondly, corresponding to The Flood Model, an economic analysis aims to provide an understanding of the total economic cost[2] of flooding on the Lower Incomati Basin, as well as the economic implications of flood management interventions to support the consideration of flood management investment alternatives.

The remainder of this report consists of:

- An outline of the Lower Incomati Basin in terms of demographics, economy, and climate in order to clearly define the project context and parameters in which to assess flood management and investment decisions.
- An outline of the previous economic impact of flooding on the Mozambican economy and in the Lower Incomati Basin in particular, in order to add to the contextual understanding of required flood investments.
- Development of a quantitative analysis that estimates the cost and benefits of flooding in the Lower Incomati, as well as the costs and benefits of two proposed flood protection investments.
- Conclusions and recommendations to both CRIDF/DFID and basin stakeholders based on the above sections and economic analysis.

[2] The economic cost is inclusive of the financial, socio-economic, and environmental impacts across the study area, as far as possible.

10 Economic Analysis Context

10.1 The Lower Incomati Basin

10.1.1 Geography

The Incomati Basin, shown in Figure 10-1, comprises of approximately 46,000km^2 spanning South Africa (62%), Swaziland (5%) and Mozambique (33%).[3] The Mozambican portion – the Lower Incomati – is downstream, with 85% of average annual runoff generated in its upstream neighbours. Mozambique is therefore reliant on the behaviour and good management of the resource by upstream countries, particularly for consistent and adequate flows in dry periods, and early warning in flood events.

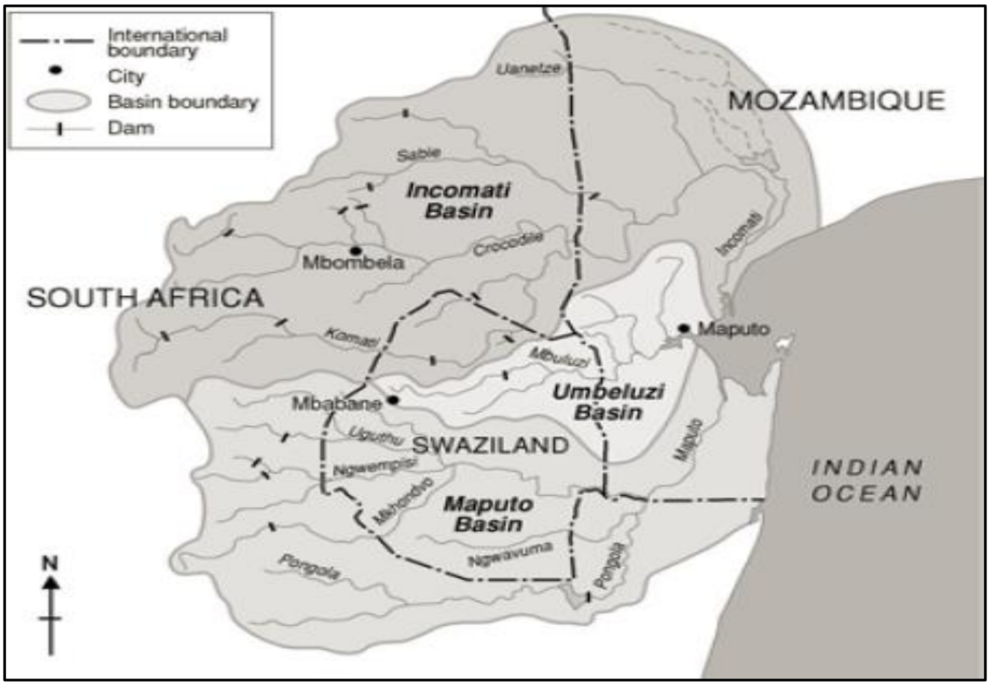


Figure 10-1 The Incomati Basin

Source: IESE Carderno 12E (2013)

[3] Leestemaker, J.H. (2000) "The domino effect, a downstream perspective in water management in Southern Africa", Green Cross Int. 2000, Water for Peace in the Middle East and Southern Africa, 2nd World Water Conference, The Hague

Within Mozambique, the Lower Incomati catchment, covering **14,900km^2**, falls in Maputo Province in the south of the country[4]. Within Maputo Province the basin predominantly falls in the Districts of Magude, Manhiça, Moambe, and Marracuene, as indicated in Figure 10-2.

Currently the Flood Model is limited to the area in the basin immediately adjacent to the River where the major sugar plantations are located (shown in red and in the last map of 0). This study area covers an area of **4,500km^2**, falling primarily in Manhiça District although spilling over slightly into Magude District to include Magude town.

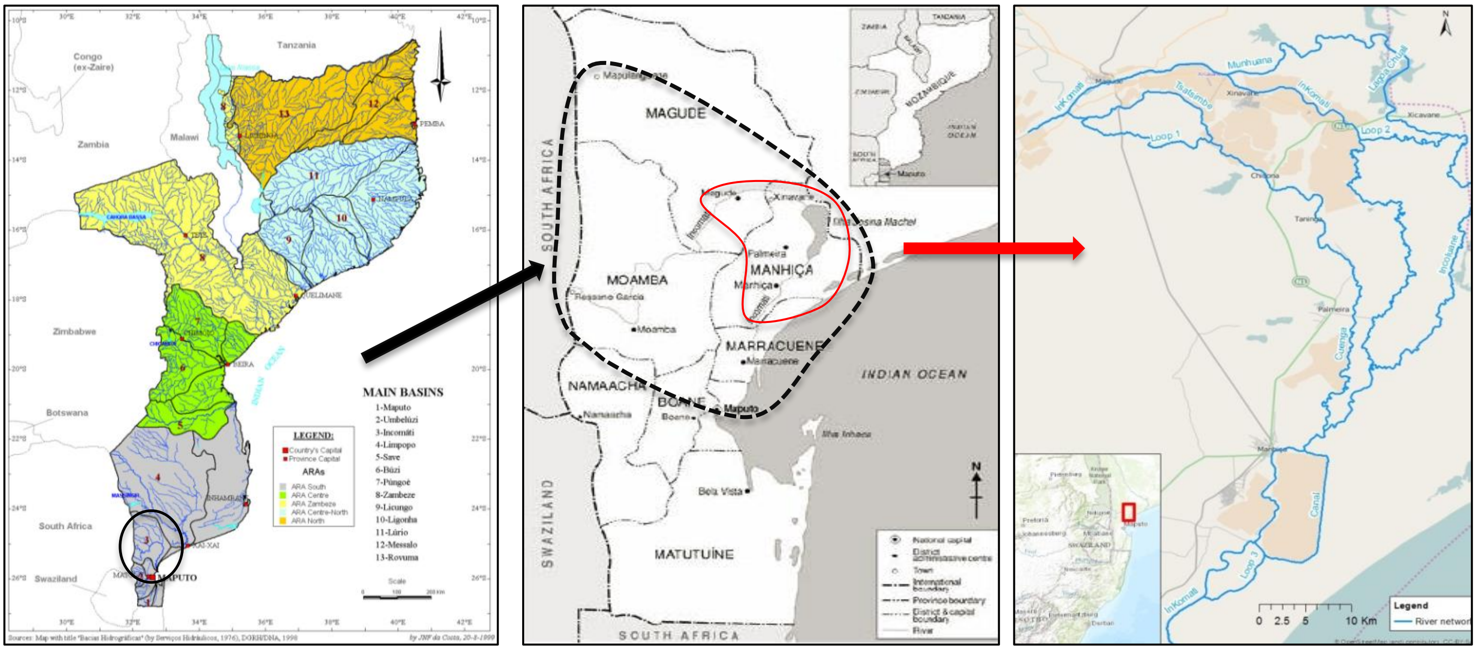


Figure 10-2 The Lower Incomati Basin and the Flood Model Study Area

Sources: DNA (1998); IESE Carderno 12E (2013); CRIDF (2014)

10.1.2 Demographics

Population

Population: Lower Incomati Basin

The total population in the Lower Incomati Basin in Mozambique as recorded in the 1997 census was 258,122. Based on an average population growth rate of 2.5%[5], the current (2015) population of the Lower

[4] Leestemaker, J.H. (2000) "The domino effect, a downstream perspective in water management in Southern Africa", Green Cross Int. 2000, Water for Peace in the Middle East and Southern Africa, 2nd World Water Conference, The Hague

Incomati is estimated to be closer to **402,582**. This is viewed as a conservative estimate given that Maputo Province is one of the fastest growing regions in the country, with populations increasing by 49.5% between 1997 and 2007[6].

More recent population statistics[7] for the four relevant districts located in the Basin find that the 2012 population totalled an estimated 457,009. Assuming the average growth rate of 2.5%, the 2015 population across the four relevant districts shown in Table 10-1 is estimated at **492,149**.

For the purposes of this analysis therefore, the total population for the Lower Incomati Basin is estimated to be 492,149.

Table 10-1 Population by District

District	2012 population	2015 population (projected)
Magude	59,162	63,711
Manhiça	214,751	231,263
Moambe	64,147	69,079
Marracuene	118,949	128,095
Total	457,009	**492,149**

Source: Humanitarian Response (2013)

Population: Flood Model Study Area Only

For the *Flood Model study area* within the Lower Incomati Basin, the population of Manhiça district (231,263) **coupled with that of Magude Town** (13,650 as shown in Table 10-2 below) **is assumed to most relevant – totalling 244,913.**

Error! Reference source not found. indicates population estimates for three of the six administrative posts within Manhiça district; as well as that for the main towns in the study area of Magude, Manhiça, and Xinavane. Figure 10-3 indicates the number of smaller villages across all the administrative posts within Manhiça district.

This kind of disaggregated information becomes important in trying to understand the population urbanisation and density across the rural areas which might be flooded. Moreover, O'Laughlin et.al. (2013)[8] find that in the period since 1997, the central areas – i.e. towns and localities involved in outgrower associations and centres

[5] published by the UN for Mozambique 2011-2015, http://data.un.org/CountryProfile.aspx?crName=mozambique

[6] From 806,179 in 1997 to 1,205,709 in 2007 (http://www.geohive.com/cntry/mozambique.aspx)

[7] http://www.humanitarianresponse.info/en/operations/mozambique/document/mozambique-population-data2007-census2012-projection

[8] O'Laughlin, B. & Ibraimo, Y. (2013) "The Expansion of Sugar Production and the Well-Being of Agricultural Workers and Rural Communities in Xinavane and Magude", IESE Carderno 12E

of labour recruitment – have populations which have grown, whereas in areas that are dominated by subsistence and smallholder agriculture, population has declined.

Table 10-2 Flood Model Study Area Population Breakdown

Towns	2007 population	Projected 2015 population (3.1%)*
Magude town	10,692	13,650
Manhiça town	56,165	71,703
Xinavane town	9930	12,677
Total	76,787	**98,030**
Administrative posts	2007 population	Projected 2015 population (1.9%)*
Xinavane (including 25 de Setembro, and excluding Xinavane town)	14,072	16,359
3 de Fevereiro	40,208	46,742
Ilha Josina Machel	9,346	10,865
Total for the three administrative posts above	63,626	**73,965**

Source: IESE Carderno 12E (2013) & http://www.citypopulation.de/Mocambique.html

*Mozambique 2011-2015 population growth rates for urban areas: 3.1%; and for rural areas: 1.9%[9]

Figure 10-3 Administrative Posts and Villages, Manhiça District

[9] http://data.un.org/CountryProfile.aspx?crName=mozambique

Source: AraSUL (2012)

Assuming the population of the Flood Model study area is that of the Manhiça District, including the three main towns, it can be assumed that approximately **146,884**[10] (60% of the Flood Model study area population) people are located in smaller villages or settlements. Based on estimates of the population in the three administrative posts of Manhiça District for which data is available, 50% of this 'rural' population (74,000 people out approximately 147,000), appears to be in the more northern and central administrative posts; implying the 'rural' population may be fairly evenly spread across the administrations. This is supported by Figure 10-3 showing that the number of smaller villages in the District (totalling 71) are spread fairly equally across the administrative.

Gender

Across the administrative posts of Xinavane, 3 de Fevereiro, Ilha Josina Machel, and Magude, O'Laughlin et.al. (2013)[11] found that the proportion of women headed households had decreased slightly from 1997 to 2007, but remained high at an average of **49%** (ranging from 38% in Xinavane to 58% in 3 de Fevereiro). Further south, community surveys recently carried out under the EU Maragra Smallholder Sugarcane Development Project (MSSDP) in Palmeira North and Munguine, indicated similar statistics showing that **44%** of the female respondents also indicated that they were the household head. This can be compared to an estimated national average of 35.6%.[12]

10.1.3 Economy

Socio Economic Context

The macro economy of Mozambique continues to retain growth rates of around 7%. GNI per capita, published by the World Bank, is estimated at USD 630 (2014), having risen from USD 460 (2010).[13] Eighty-two per cent of the Mozambican population, however, still lives below the poverty line of USD 2 per day.[14] The national poverty line in Mozambique (of about USD 0.50/day) shows a relative high incidence of poverty in Maputo Province at approximately 67.5% (compared to a national rural poverty incidence of 56.9%).[15] National (23%), and youth unemployment (39%), rates also remain high despite growth in the economy.[16]

[10] This is the Manhiça district 2015 population less the 2015 population of Manhiça Town and Xinavane Town.
[11] O'Laughlin, B. & Ibraimo, Y. (2013) "The Expansion of Sugar Production and the Well-Being of Agricultural Worlkers and Rural Communities in Xinavane and Magude", IESE Carderno 12E
[12] http://data.worldbank.org/indicator/SP.HOU.FEMA.ZS
[13] http://data.worldbank.org/country/mozambique
[14] Corporate Citizenship (2015)
[15] IMF (2011) Republic of Mozambique: Poverty Reduction Strategy Paper", IMF Country Report No. 11/132
[16] http://databank.worldbank.org/data//reports.aspx?source=2&country=MOZ&series=&period=

At a local level, the EU MSSDP community surveys provide insights that may be indicative of the larger basin population, showing:

- 90% of respondents were unemployed, 5% informally employed, and 5% formally employed
- 30% of respondents had no annual salary; 46% did not know their annual salary, and the remaining vast majority of respondents (20%) had an annual salary in the range of MZN 30,000-60,000 (approximately USD 760 – USD 1,500)[17]
- In terms of income sources, 14% indicated they had no income; otherwise the main source of income was farming (49%), followed by other-non-farming (20%), and salaries and wages (10%). The remainder relied predominantly on remittances and pensions/grants
- While respondents indicated that almost everyone in their households was involved in farming activities, they also indicated that all household members were also involved in some non-farming income generating activities
- The vast majority of respondents (over 80%) indicated that they grow at least 70-100% of their crops for food; and 64% of respondents indicated that they produce at least 50-100% of the food that they consume

Economic Activity

The primary (formal) economic activity in the Lower Incomati is commercial sugarcane farming and sugar production. The two sugar estates each with their own mill are Maragra (owned by Illovo Sugar) and Xinavane (owned by Tongaat Hulett).

Together the estate's own plantations comprise of approximately 18,000Ha of cane crops; additionally 9000ha (current and under development) of sugarcane are under outgrowers (which sell their crops under their outgrower arrangements to the Estates for processing). The majority of outgrowers are smallholders; cultivating areas of land smaller than 20Ha (the average land size for Xinavane outgrowers is 1.4Ha)[18]. Moreover, for reasons relating to risk and land availability, the future strategy of both estates is to expand through outgrower sugarcane production rather than Miller Cum Planter (MCP) plantations.[19]

At a macroeconomic level, the Incomati Basin produces about 80% of the sugar in Mozambique, resulting in a significant contribution to national GDP and exports. The sugar estates in Mozambique have "duty- and quota-free" access into the EU, which will remain in place beyond 2017. However, Mozambique has also seen a 66% increase in domestic sugar consumption over the past 10 years, and the country's per capita

[17] http://www.oanda.com/currency/converter/ (14.07.15)
[18] O'Laughlin, B. & Ibraimo, Y. (2013) "The Expansion of Sugar Production and the Well-Being of Agricultural Workers and Rural Communities in Xinavane and Magude", IESE Carderno 12E
[19] Xinavane and Maragra field visit interviews, 2014-2015

consumption is still well below that of other countries in the region, implying that this growth is likely to continue.[20]

McCarthy (2008) estimates a national multiplier for the sugar industry in South Africa of 3.2, implying that for every R1.00 increase in output from sugarcane farming, milling and refined combination; national GDP will grow by R3.20 (as a result of the direct, indirect and induced impacts throughout all the sectors of the economy).[21] Such a multiplier can be seen as applicable to Mozambique given the relative contextual similarities of the two countries.

At a more local level too, the economic importance of sugar is significant, by providing a secure and stable market for cane producing smallholders, and through employment generation, both of which increase the monetary income of the basin population. The conversion of land from food and cattle to sugar has been typically met by enthusiasm from individual farmers and government officials based on the income earned by some outgrower associations. [22]

The total number of sugarcane outgrowers is roughly 6,300. Assuming an average household size of 4.45, outgrowing activities support about 28,000 people in the basin. The employment created by the sugar estates (for the MCP and outgrower land) amount to roughly 14,278 jobs (5,772 permanent, and 8,506 seasonal)[23], hence directly supporting about 63,537 people based on average household size.

The knock-on effects of sugar related monetary incomes on the local economy (multiplier effects[24]) have been evident in towns (and areas close to hostels where cane cutters are lodged such as Taninga and Timanguene) where there has been a proliferation of 'end of month trading businesses' which pop up when workers are paid and want to buy monthly rations.[25] In more rural settlements where workers live, economic spin-offs into local trade have also been noted: Manhiça has a long standing artisanal ceramics industry; however there are now brick-burning furnaces, with operators selling to local clients as well as to builders in town, and brick houses are gradually driving out the older traditional circular reed houses.[26] O'Laughlin et.al. (2013) argue, however, that, given the wage level, these multiplier effects have been limited, which is apparent through the continuation of very low saving rates among the population.[27]

Corporate citizenship (2015) estimates that the employment multiplier related to Maragra's operations is between 0.6 and 1.4 (that is, for every direct job at Maragra, between 0.6 and 1.4 additional jobs are

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[20] Tongaat Mozambique operation (AR 2014)
[21] Conningarth Economists (2013) "Growing the Sugar Industry in South Africa", Conningarth
[22] O'Laughlin, B. & Ibraimo, Y. (2013) "The Expansion of Sugar Production and the Well-Being of Agricultural Worlkers and Rural Communities in Xinavane and Magude", IESE Carderno 12E
[23] O'Laughlin, B. & Ibraimo, Y. (2013) "The Expansion of Sugar Production and the Well-Being of Agricultural Workers and Rural Communities in Xinavane and Magude", IESE Carderno 12E and Corporate Citizenship (2015) "Illovo Sugar Mozambique Socio-Economic Impact Assessment Report", Internal Management Report"
[24] Multipier effects are the indirect and induced impacts of income and spending, through both employees and local supply chains, which in turn generate additional rounds of spending in the economy, and lead to further employment opportunities.
[25] O'Laughlin, B. & Ibraimo, Y. (2013) "The Expansion of Sugar Production and the Well-Being of Agricultural Worlkers and Rural Communities in Xinavane and Magude", IESE Carderno 12E
[26] Ibid
[27] Ibid

supported in the economy). [28] If we assume this multiplier estimate is applicable to the entire sugar industry in the Lower Incomati, then is can be assumed that the 14,278 direct jobs that are generated by the estates support an additional 8,567 –19,989 indirect and induced jobs in the economy. Based on an average household size of 4.45, **the sugar estates therefore supports an *additional* 38,123 – 88,951 people** (including dependents) though indirect, and induced employment.

Sugar has not taken over the whole of the Incomati valley however; there remain small areas with alluvial soils which are more difficult to access, such as Ilha Josina. These have remained centres of smallholder fruit and vegetable production.[29] In the past, bananas have also been seen as an important cash crop in the area, and there is a rice mill in Manhiça town implying previous investment in rice in the area.

Additionally, a large portion of the population in Mozambique (some 70%) remains outside of the monetary economy, relying on subsistence agriculture for their livelihoods. Moreover, about one third of the national population is estimated to be chronically food insecure, with conditions particularly fragile in the semi-arid south and central regions.[30]

Based on the EU MSSDP community surveys, as well as team field visits, it appears that the population in the Lower Incomati may increasingly operate in both the formal economy (through links to the sugar industry) and informal economy, cultivating very small areas of land on a subsistence scale for own consumption.

In terms of food and nutritional security in the area, the UN WFP assessment in 2000 found that households in Maputo Province as a whole are more dependent on the market for food than other provinces in Mozambique; linked to the proliferation of drought and flood in the area. The growing importance of purchased food and hence wage income is clear.[31] This WFP assessment was, however, made at the end of winter when stocks from own production were likely exhausted, and focused on staples leaving aside fruit and vegetables that contribute to consumption. Overall, while food security remains a serious issue in the area, it does appear that there have been definitive improvements: the district director of health in Manhiça argued that child nutrition has improved to such an extent that they were considering stopping school-feeding programmes.[32]

10.1.4 Climate

The prevalence of flooding in Mozambique is a result of two factors. Firstly, the climatic conditions of Mozambique are such that the country is subject to tropical depressions in the Indian Ocean and cold fronts from the south, which result in cyclones and ultimately flooding.[33] Secondly, Mozambique is a 'downstream state', through which nine major international river systems drain vast areas of south eastern Africa and enter

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[28] Corporate Citizenship (2015) "Illovo Sugar Mozambique Socio-Economic Impact Assessment Report", Internal Management Report"

[29] O'Laughlin, B. & Ibraimo, Y. (2013) "The Expansion of Sugar Production and the Well-Being of Agricultural Workers and Rural Communities in Xinavane and Magude", IESE Carderno 12E

[30] The World Bank (2007) "Mozambique Country Water Resources Assistance Strategy" AFTWR

[31] O'Laughlin, B. & Ibraimo, Y. (2013) "The Expansion of Sugar Production and the Well-Being of Agricultural Workers and Rural Communities in Xinavane and Magude", IESE Carderno 12E

[32] Ibid.

[33] Carmo Vaz, A. (2000) "Coping with floods – the experience of Mozambique", Consultec, 1st WARFSA/WaterNet Symposium: Sustainable Use of Water Resources, Maputo

the ocean. This means that the severity of flooding in the Lower Incomati for example is decided not only by the rainfall in the Mozambique, but dependant on that in other catchment areas outside of the country.[34]

Being a downstream state also means that Mozambique suffers reduced flows during the dry period and increased flows during the wet period (at the mercy of the water management of upstream neighbours).[35]Local communities are hence faced with prolonged drought periods coupled with irregular flooding.[36] These climatic conditions, together with the social complexities of transboundary resources, make flood management in the Lower Incomati, and in Mozambique generally, particularly challenging.

In addition, Mozambique is recognised as being among the African countries most vulnerable to climate change. A recent study conducted on the 'Impacts of Climate Change on Disaster Risk in Mozambique' looked at the extent to which Mozambique's current vulnerability and exposure to natural disasters might alter with projected climate change, taking into consideration both the climatic conditions and expected socio-economic developments.[37] Overall, indications are that the current challenges in the Lower Incomati – of lower flows in dry periods, and higher flows in wet periods – will intensify. The National Meteorology Institute (INAM) asserts that the intervals between extreme rainfall events are shortening and the intensity of rainfall in these events is increasing due to climate change.

Flooding in the Lower Incomati Basin

In the Lower Incomati Basin specifically, it has been recorded that since 1975 at least three major flood events (1976, 1984, 2000), and five smaller events (1985, 1996, 2012, 2013, 2014) have occurred. Over the last 40 years therefore, a flood event has occurred on average about once every five years.

The major events (1976, 1984, and 2000) have typically resulted in severe infrastructure damage - to the EN1 national highway, railway and various access roads - suspending connectivity; to the Incoluane weir Moamba Bridge and Moamba's water supply system; and to various sugar plantation dykes. Important economic damages from such events have included the complete destruction of large areas of banana and sugar plantations, with the inundation of low lying agricultural areas. In addition, large numbers of the population were displaced and suffered personal losses.[38]

The smaller events (of 1986, 1996) resulted in some inundation of agricultural areas, and more minor damages to infrastructure.[39] The 2012, 2013 and 2014 events are assumed to also be smaller (one-in-five year) events, based on the Flood Model, and are hence assumed comparable to those of 1985 and 1996.

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[34] CDS Case Study Mozambique: Flood Management in Mozambique, Adapted from "Climate Risk Management in Africa: Learning From Practice" (2007), International Research Institute for Climate & Society

[35] Leestemaker, J.H. (2000) "The domino effect, a downstream perspective in water management in Southern Africa", Green Cross Int. 2000, Water for Peace in the Middle East and Southern Africa, 2nd World Water Conference, The Hague

[36] Van Ogtrop, F., Hoekstra, A. & van der Meulen, F. (2005) "Flood Management in the Lower Incomati Basin, Mozambique: Two Alternatives", JAWRA paper no. 03145

[37] INGC (2009) "Study on the impact of climate change on disaster risk in Mozambique, Synthesis Report – First Draft", National Institute for Disaster Management

[38] Carmo Vaz, A. (2000) "Coping with floods – the experience of Mozambique", Consultec, 1st WARFSA/WaterNet Symposium: Sustainable Use of Water Resources, Maputo

[39] Ibid.

Xinavane Sugar has reported losses from flooding in the last 3-4 years due to standing water in both MCP and some outgrower plantations.[40] The flood loss to Maragra outgrowers (small, medium and large) in 2014 was also substantial, totalling roughly 900ha across the main estate, Palmeira and South Growers areas.[41]

Flood Response Strategies in the Lower Incomati

Flood mitigation infrastructure in the Lower Incomati Basin is very limited, consisting only of the large Corumana Dam and a series of dykes that protect the sugar plantations (as well as several small villages and towns). In general people have learnt to live with the floods: Van Ogtrop (2005)[42] argues that the inhabitants of the Lower Incomati occupy the floodplains in the drier times of the year in lightweight huts that can be dissembled, and move to more permanent huts on higher grounds during flood times. Community flood response strategies have also traditionally included game hunting, the sale of firewood & charcoal, livestock and home-made beverages, casual agricultural wage employment, and temporary labour migration to neighbouring districts and regions.

Such strategies have however largely been exhausted given the cumulative impact of consecutive floods in recent years; and there is a general drive to further develop the region and corresponding flood infrastructure, of which the construction of the Moamba major dam is an example.[43]

The Incomati Basin is seen as relatively undeveloped in terms of flood infrastructure, where flood management interventions that have been implemented over the last few decades have been those of the sugar estates. They have primarily involved the construction and heightening of dykes and diversion of water. By interfering with the natural run of the river, and without an overall understanding of the hydro-dynamics of the floodplain system, these interventions may have increased the risk of flooding in certain surrounding areas, increased inundation periods, and compromised the natural function of wetland systems.

In the past, there has been some conflict between communities and the sugar estates based on perceptions that some dykes implemented by the sugar estates worsened the flood impact for surrounding communities. In the past, rural communities around Ilha Josina Machel referred to the ‘new’ floods in the Marilaphuvo and Xissavanine areas as those caused by the Xinavane Sugar Estate (then owned by the Incomati Sugar Company). These occurred between June-August as the maize is ripening.[44]In his observations on the behaviour of the River in the 1984 floods, Van-Ogtrop (2005) found that the Maragra Sugar Company dikes created a backwater effect, increasing the lag time of the flood downstream but in doing so causing problems for upstream communities.[45]

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[40] Field visit interviews, February 2015

[41] Maragra Agriculture OPCO Presentation: Floods, March 2014

[42] Van Ogtrop, F., Hoekstra, A. & van der Meulen, F. (2005) “Flood Management in the Lower Incomati Basin, Mozambique: Two Alternatives”, JAWRA paper no. 03145

[43] Ibid

[44] Leestemaker, J.H. (2000) “The domino effect, a downstream perspective in water management in Southern Africa”, Green Cross Int. 2000, Water for Peace in the Middle East and Southern Africa, 2nd World Water Conference, The Hague

[45] Van Ogtrop, F., Hoekstra, A. & van der Meulen, F. (2005) “Flood Management in the Lower Incomati Basin, Mozambique: Two Alternatives”, JAWRA paper no. 03145

There is on-going tension between Xinavane and its surrounding communities that arise around flooding, as there is a strong perception that the company is responsible for flooding, or at least exacerbates flooding. One perception is that because Xinavane no longer dredges the river as in the past, flooding has worsened. Another community around Taninga destroyed a Xinavane dyke based on the belief that it was the cause of the flooding in their area.

10.2 The Economic Impact of Flooding

The following section provides an overview of how to understand the economic implication of water shocks on an area or country/region.

10.2.1 The Direct Economic Cost of a Flood Event

The most obvious cost of a flood on the economy is the immediate emergency response required and necessary reconstruction. Economic costs, however, extend beyond these costs to include lost production; intermediate product costs; purchasing power reductions; and disincentives to investment at all levels.

Additionally, water shocks also have potential implications for budgetary and trade balances, and can require changes in monetary and fiscal policies to respond to shock-induced inflation, increased expenditure on relief and reconstruction, pressures to increase subsidies, and diminished revenues and taxes due to lower than projected growth.[46]

In order to capture all of these economic costs, the World Bank defines three categories of costs: direct, indirect (or flow-effects), and relief costs.

- **Direct costs** – comprise of the physical damage to assets and inventories, which can be valued at the 'same-standard' replacement costs (i.e. the cost of restoring assets to the standard that existed before).
- **Flow-effects** – comprise of the output losses and foregone earning (typically as a result of damaged assets).
- **Relief costs** – include the provision of emergency life-supporting services to affected populations (food aid, health care, safe water and sanitation), as well as the support required to enable them to resume their livelihoods.

Based on these cost categories, the World Bank estimates that the 2000 flood event had a total economic cost (including direct, flow and relief costs) of about USD 550million.[47] Based on the previous impact of floods in Mozambique between 1980 and 2003 (about once every four years), the World Bank argues that it is reasonable to assume that **every one-in-four year flood will be 40% as severe as the 2000 event**. This

[46] World Bank (2005) " The Role of Water in the Mozambique Economy – Identifying Vulnerability and Constraints to Growth" Memorandum
[47] World Bank (2000) "A Preliminary Assessment of Damage form the Flood and Cyclone Emergency of February-March 2000

means that, on average, Mozambique experiences floods that cost about USD 240million (in 2000 prices)[48] every four years.

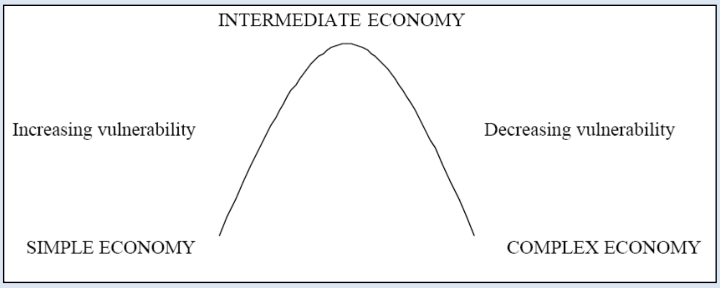
10.2.2 The Secondary Economic Cost of a Flood Event and Macroeconomic Impact

The above costs should not be confused with the ‘knock-on’ or ‘multiplier’ effects in the economy, which are referred to as indirect and induced impacts in other sectors of the economy. In this sense, the above flood-costs (direct, flow and relief) are all ‘direct’ or ‘first round’ impacts. When these secondary knock-on effects are taken into consideration, the World Bank estimates that Mozambique’s GDP is cut by 5.6% on average when a major water shock (flood/drought) occurs (indeed, the 2000 floods corresponded with an abrupt fall in GDP growth to 1.5% from an average of 7.5% between 1994 and 2003). Based on the assumption of a water shock once every five years, this translates into an annual reduction in Mozambique’s GDP by 1.1%. Based on these estimates, the future cost to the national economy of Mozambique from water shocks if no mitigation measures are taken, assuming a 5% annual GDP growth rate, will amount to USD 3 billion by 2030.[49]

A simple assessment of the sensitivity of Mozambique’s economy to water shocks (measuring fluctuations in GDP and the growth rate of agricultural and non-agricultural sectors), showed that almost all major volatilities between 1984 and 2002 in the still largely agricultural economy were linked to major flood and drought events. The text box below provides an explanation of the sensitivity of national GDP to climatic shocks based on the development of a country’s economy.

Box 1: **The Sensitivity of an Economy to Climatic Shocks**

Various studies based on multi-country comparisons and historical observations demonstrate that a country’s economic sensitivity to climatic shocks is highly dependent on a country’s state of economic development; the relationship following an inverted U is shown graphically below and elaborated on in the text that follows.



In simple economies, the prominence of the agricultural sector and weak inter-sectoral linkages to the rest of the economy, mean that the impact of climatic shocks is typically confined to the agricultural sector, with the remainder of the economy less affected. (Although the monetary impacts may be less in simple economies, more people are likely to be directly and catastrophically impacted given their dependence on agriculture and subsistence). As an economy develops, resulting in increased manufacturing and stronger overall economic integration, the impacts of water shocks become more dispersed and extensive throughout the economy. In the long term however, the relative vulnerability is expected to again decrease as the economy moves from an ‘intermediate’ to ‘complex’ stage of development where there are few dependence on the agricultural sector and the population is more financially resilient to shocks.

This theory implies that Mozambique’s economic sensitivity to climatic shocks is likely to become more pronounced before decreasing, as the country develops and diversifies.

[48] World Bank (2005) “ The Role of Water in the Mozambique Economy – Identifying Vulnerability and Constraints to Growth” Memorandum

[49] Ibid.

Source: World Bank (2005)

10.2.3 Response: Investment in Flood Management in Mozambique

Despite the significant cost of flood events, Mozambique remains among the countries in southern Africa with the least developed water infrastructure and storage capacity, and the water resources sector continues to be chronically underfinanced and below annual planned expenditure.[50]

A provisional Cost-Benefit Analysis was conducted on proposed investments in the water resources sector amounting to USD 1.063 billion[51]. These investments aimed to mitigate the estimated annual loss due to floods by 75%.[52] The CBA found that the investment was economically viable (considering the mitigation of 75% of the 1.1% annual loss in GDP) at a discount rate of up to 12%. The analysis also indicated that the annual investment required to implement the proposed investment strategy is USD 80 million to USD 90 million; and the annual cost of not investing (the 'do nothing' scenario) is about USD 120 million due to water shocks alone, excluding foregone growth as a result of under-investment in water infrastructure.

[50] As set out in the revised PARPA (2002-2004), World Bank (2005) " The Role of Water in the Mozambique Economy – Identifying Vulnerability and Constraints to Growth" Memorandum

[51] Based on proposed public investments in water in water management infrastructure 2005-2025, in the Government Water Infrastructure Development Strategy (2004)

[52] World Bank (2005) "The Role of Water in the Mozambique Economy – Identifying Vulnerability and Constraints to Growth" Memorandum

11 Quantitative Analysis

11.1 Purpose

The objective of a quantitative analysis of proposed flood management investments by the sugar estates is to:

- Provide stakeholders with a comprehensive and holistic understanding of the nature and relative scale of the socio-economic costs of a flood in the Lower Incomati (Flood Model study area).
- Provide stakeholders with a framework with which flood management investment alternatives can be assessed in a manner that takes into consideration all socio-economic impacts (costs and benefits) of the interventions on society.
- Provide stakeholders with an indicative analysis of the financial and economic viability of the proposed flood prevention investments, using the above mentioned framework and based on available data.

11.2 Approach

The costs of floods to the rural poor are often largely hidden as they remain outside of the monetary economy, and are hence unrecorded in assessments of the cost of floods at a national level. This segment of the population in Mozambique is significant, as some 70% of the population are dependent on rain-fed subsistence agriculture. Moreover, the cumulative effect of consecutive water shocks has exhausted traditional coping mechanisms such as game hunting, the sale of firewood, charcoal, home-made beverages, and livestock, casual agricultural wage employment and temporary labour migration to neighbouring districts and regions.[53]

Moreover, reducing the impact of water shocks on the rural poor will provide the greatest benefit to the largest number of people, even if the benefits are not discernible from a macro-economic perspective.[54]

A quantitative analysis, which can explicitly take into account these 'hidden' costs, is therefore required to inform considered flood management investment decisions.

11.2.1 Cost-Benefit Analysis

Cost-Benefit Analysis (CBA) is a methodology for assessing the net economic value of a proposed investment. The analysis is made from a microeconomic perspective and weighs up all relevant impacts (financial, socio-economic, environmental, etc.) as far as possible, by using money as a common unit of analysis.

[53] World Bank (2005) "The Role of Water in the Mozambique Economy – Identifying Vulnerability and Constraints to Growth" Memorandum
[54] World Bank (2005) "The Role of Water in the Mozambique Economy – Identifying Vulnerability and Constraints to Growth" Memorandum

Valuation techniques are used to assign monetary values to impacts for which there is no financial price determined by a market. The monetary value assigned should reflect the real value of the impact to society.

CBA also looks at investments over a long time frame, and discounts expected future impacts (costs and benefits) to the present day in order to inform current decision making.

In applying the CBA methodology to flood management alternatives, the status quo – that is the 'do-nothing' scenario, is first assessed. The incremental improvement from this 'base scenario', due to the proposed investments, is then considered against the investment cost, to determine the economic viability of the investment.

11.2.2 Flood Model

The 2D Hydraulic Flood Model produced is an essential source of information in understanding the impact of a flood on the Lower Incomati (study area). Specifically, flood hazard maps indicating where and to what degree flooding occurs in the basin, coupled with a land-use map, provides a basis for assessing the scale of expected damages across the study area and economic value of such damages. Given the incompleteness of the land-use map however, and in the absence of a comprehensive land-use survey of the area, various additional sources of information have been used to complete the picture of what land-uses, population densities, and economic activities are across the entire basin.

Source: CRIDF (2015)

Figure 11-1 Maximum1 in 5 year Flood Hazard and Land Use in the Study Area

The quantification and monetisation (valuation) of flood impacts is based on the degree of hazard and the degree of damage experienced in comparable flood events in the past.

As additional information on the social and economic impacts of flooding in the Lower Incomati is most readily available for the experiences in 2012 and 2014; Hydrological analysis indicates that these events are synonymous to a one-in-five year flood (**Error! Reference source not found.**), the quantitative analysis is conducted on a one-in-five year event (the flood hazard of which is shown in 0). (**Error! Reference source not found.** shows the hydrological analysis for the one-in-five year flood in light green, and the actual 2012, 2013, and 2014 floods in yellow, blue and orange. It is clear that the three actual flood events are very similar to the Flood Model project one-in-five year event.)

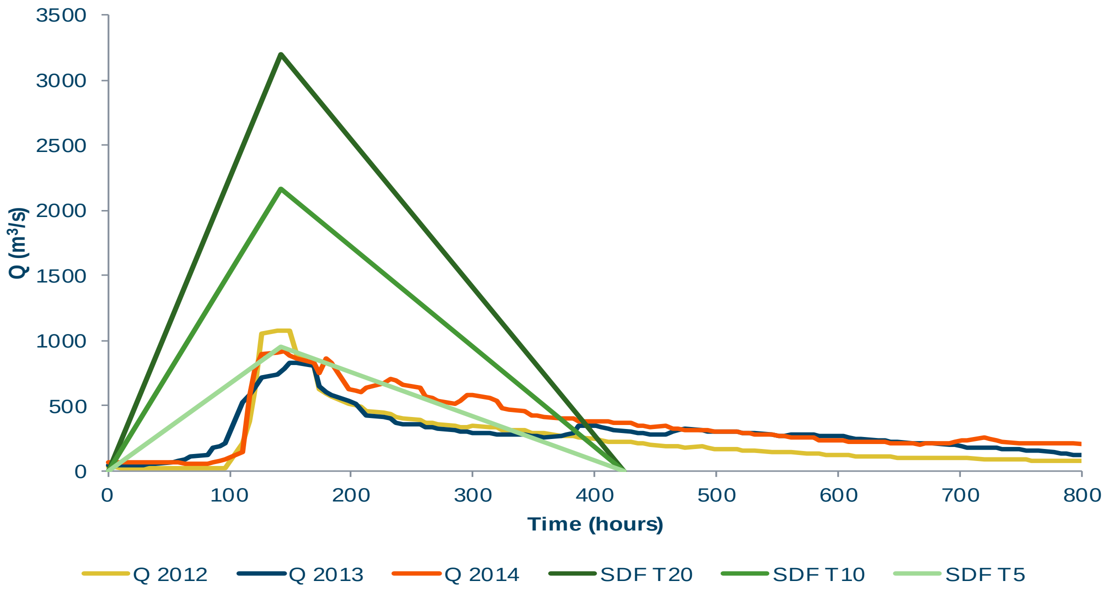


Figure 11-2 Comparison of recent historical flood hydrographs and Return Period Design Events

Note: Standard Design Flows (SDF)

Source: CRIDF (2015)

11.2.3 Assumptions

The following assumptions have been made in the quantitative analysis:

- As the one-in-five year event is the subject of the analysis, this event is therefore assessed in isolation of other possible simultaneous (1 in 10 year or 1 in 20 year flood) events.
- The CBAs are conducted using a 20 year period from 2016 to 2035, with one-in-five year flood events occurring in 2019; 2024; 2029; and 2034. This was based on the assumption that the last one-in-five year flood occurred in 2014.

- All prices are constant to 2015; the GDP deflator for Mozambique (annual %) (I.e. inflation) published by the World Bank has been used to convert 2000 prices to current 2015 prices[55].
- Discount rates used in the CBAs are 6.75%, 10%, and 3.5%. The rate of 6.5% is based on the standard used for Mozambique by Tongaat Hulett[56]; and the latter two discount rates are based on CRIDF standard rates for economic analyses specified in the CRIDF CBA Guidelines.

11.3 Framework

The first step in the quantitative analysis is the identification of impacts – that is the financial, social, economic and environmental costs and benefits. Using the categories of flood costs (direct, flow, relief) outlined by the World Bank as a basis, the framework below (**Error! Reference source not found.**) sets out all the economic costs expected to be relevant to the Lower Incomati Basin.

As some direct, indirect (flow effects) and relief costs may overlap to varying degrees, it is important to be mindful of potential double counting when valuing all the costs categories in the framework.

[55] http://data.worldbank.org/indicator/NY.GDP.DEFL.KD.ZG
[56] Tongaat Hulett (2014), Annual Report

Table 11-1 Framework: Identification and Definition of Flood Costs

	Direct	Flow effects	Relief
Social sectors			
Health	Damage to infrastructure (hospitals, clinics, dispensaries), equipment and supplies	Lost productivity due to increased prevalence of disease and illness as a result of the flood event & the associated cost of treatment	Emergency supply of medical services to the injured and/or infected population
Education	Damage to infrastructure (schools), equipment and supplies	Lost school days to the youth	Provision of temporary structures for classes
Housing & private property	Damage to houses and personal possessions	n/a	Provision of temporary housing for displaced persons, and/or emergency provision of basic household items
Government property	Damage to government (administration) buildings	Lost productivity	Provision of temporary structures
Infrastructure			
Water and sanitation	Damage to WASH infrastructure – boreholes, pumps, wells, small treatment and distribution systems	Lost productivity due to negative impacts on health, and additional time and resources spent on accessing alternative sources	Provision of emergency supply of clean water and temporary sanitation solutions
Energy	Damage to production and distribution infrastructure	Lost production due to interruptions / cost of temporary alternatives	Emergency supply of alternative energy sources to local populations (paraffin etc.)
Transport	Damage to roads, bridges, railways	Cost of delays or suspension of connectivity on productive sectors and populations	Emergency transportation of people and supplies

Disaster prevention	Damage to flood protection infrastructure – dykes, berms, dams etc.	n/a	n/a
Productive sectors			
Agriculture – sugar	Damage to crops, irrigation infrastructure, and farming equipment	Lost production, forgone output	Replanting costs to resume the same level/standard of production
Agriculture – other (non-sugar smallholders / subsistence farmers)	Damage to crops and farming equipment	Lost production, forgone output	Emergency food aid to affected subsistence and non-sugar smallholder farmers (& broader populations if relevant); and the support required to enable the affected to resume their livelihoods
Industry	Damage to infrastructure – sugar mills	Lost production, forgone output	n/a
Trade	Damage to goods	Lost sales - forgone income	n/a
Environment			
Ecosystem services		Loss / increase in productive capacity due to ecosystem services based on flooding: erosion; alluvial soil deposits; freshwater intrusion etc. (May be a net negative cost, i.e. benefit)	n/a

11.4 Base Scenario: Cost of a 1 in 5 year Flood Event on the Lower Incomati Basin

Based on the above framework (Table 11-1), each cost category and class is quantified and monetised based on a one-in-five year event. Where it is not possible or practical to quantify/monetise certain costs, these are considered qualitatively in as much detail as possible. Overall this informs an estimate of the total economic cost of a one-in-five year event on the Lower Incomati, and defines the 'base scenario'.

Appendix 1 provides a detailed breakdown of the 'base scenario' providing a description and the calculation of the costs of a one-in-five year event for each sector and cost category as set out in the framework. Table 11-2 below provides a summary of all the quantified cost estimations.

Based on this preliminary analysis, a one-in-five year flood event costs the Lower Incomati Basin approximately USD 24.6 million. This number should be considered as a coarse estimate, with the understanding that:

- Many impacts could not be quantified and valued and hence excluded from the quantitative estimate, but discussed qualitatively;
- The quantitative estimates are based on uncertain assumptions and questionable data, and should be seen as indicative at best.

At a high level, **Error! Reference source not found.** also provides an indication of the level of investment that may be justified to mitigate flood impacts per sector, and whether direct, indirect (flow effects) or relief costs are most costly.

To understand the financial and economic viability of specific proposed flood management interventions, it is, however, necessary to understand the level to which an intervention will mitigate the impacts outlined in this base scenario. The CBAs contained in the following section assess two flood mitigation interventions proposed by Basin stakeholders.

Table 11-2 Base Scenario Flood Costs (Benefits) Summary Table

Costs	Direct	Flow	Relief	Total
Social				
Health	USD 575,912	Qualitative	USD 123,485	USD 699,396
Education	USD 210,008	Qualitative	Qualitative	USD 210,008
Private property	USD 104,410	n/a	Qualitative	USD 104,410
Government property	none	Qualitative	none	-
Subtotal (quantitative)	*USD 890,329*	-	*USD 123,485*	***USD 1,013,814***
Infrastructure				
Water and Sanitation	USD 958,480	Quantitative	Quantitative	USD 958,480
Transport	Qualitative	Qualitative	Qualitative	-
Energy	4,234,388	45,534	Qualitative	USD 4,279,922
Disaster prevention	Qualitative	n/a	n/a	-
Subtotal (quantitative)	*USD 5,192,868*	*USD 45,534*	-	***USD 5,238,402***
Productive sectors				
Agriculture (sugar)	USD 6,339,962	USD 11,181,110	Qualitative	USD 17,521,072
Agriculture (other)	USD 801,856	Qualitative	USD 8,500	USD 810,355
Industry	None	None	n/a	-
Trade	Qualitative	Qualitative	n/a	-
Subtotal (quantitative)	*USD 7,141,818*	*USD 11,181,110*	*USD 8,500*	***USD 18,331,427***
Environment				
Eco-system services	Qualitative	Qualitative	n/a	-
Subtotal (quantitative)	-	-	-	-
Grand Total (quantitative)	**USD 13,225,015**	**USD 11,226,644**	**USD 131,984**	**USD 24,583,644**

11.5 Investment Scenarios – Cost Benefit Analysis

11.5.1 Methodology

The following CBAs assess the costs and benefits of two proposed investments versus the alternative of a 'do-nothing' scenario. The costs and benefits included in each analysis are therefore incremental to what is expected to happen if the investments do not take place.

The base scenario developed in the previous sub-section provides an indication of this 'do-nothing' scenario, concluding that every five years on average the Lower Incomati will incur economic damages from a flood event of approximately USD 24 million. This quantitative estimate includes – as far as possible – the direct, flow, and relief costs to the entire local economy (looking at impacts on social, infrastructure, and productive sectors, as well as the environment).

Included in each CBA therefore, are only the expected positive and negative changes in these cost categories, due to the proposed investment.

The costs included in the CBAs are therefore:

- The capital investment of the proposed flood management infrastructure
- Annual maintenance costs related of the proposed flood management infrastructure
- Refurbishment costs for proposed flood management infrastructure

The benefits included in the CBAs are therefore:

- The expected change in the economic flood impacts from the base scenario. (Should any of these changes be negative (i.e. the proposed flood management infrastructure results in a negative impact in one of the categories, then it is included as a 'negative benefit' i.e. a cost). The benefits can therefore be understood as the avoided future cost of not doing anything.

11.5.2 S1: New Maragra Protection Dykes

The S1 investment scenario consists of adding new protection dykes for the Illovo outgrowers south of Sector F; a squared dyke around a potential development; and a new dyke at Taninga north of Sector F.

The estimated capital cost of this investment is **USD 994,820**. This rough estimate is based on per unit cost provided by the sugar estates as per **Error! Reference source not found.**.

Table 11-3 Capital Cost Estimate

Description	Unit	Taninga	Martins	1000ha block	Total
Structure height	m	1.1	3	3	
Structure length	m	2,336	2,369	8,233	

Design and build	Cost/m (ZAR)	160	630	630	
Design and build	Cost (ZAR)	373,760	1,492,470	5,186,790	7,053,020
Contingency	20% (ZAR)	74,752	298,494	1,037,358	1,410,604
Total	(ZAR)	448,512	1,790,964	6,224,148	8,463,624
Optimism Bias	30% (ZAR)	134,554	537,289	1,867,244	2,539,087
Grand total	(ZAR)	583,066	2,328,253	8,091,392	11,002,711
Grand total	(USD)				**994,820**

Annual maintenance costs are estimated to be 5% of the capital cost, and account for site investigations, topographic surveys, additional materials to ensure the bank height is maintained, and any small reconstruction required. Additionally a contingency for potential rehabilitation equal to 10% of capital costs once every 10 years is included.

The expected benefits include the change in flood impact - this change (outlined in

Table 11-4) is ascertained from analysis of the Flood Model output shown graphically in Figure 11-3. This Figure shows in blue all the areas that experience the same level as flooding as in the base scenario; in orange all the area that experience less flooding than in the base scenario; and in red all the areas that experience more flooding than in the base scenario.

Table 11-4 High Level Expected Change in Flood Costs per Sector under the S1 Scenario

Sector	Expected change
Social	No change – the dykes are not expected to further protect or aggravate flooding, to any social sector infrastructure
Infrastructure	No change – the dykes are not expected to protect or aggravate flooding, to any significant infrastructure
Productive sectors	Agriculture-sugar – decrease in MCP and outgrower hectares flooded Agriculture other – decrease in hectares flooded (EU MSSDP Martins expansion includes 240ha allocated for food crop production); the dykes are not expected to aggravate flooding to any of the surrounding land
Environment	No change – the dykes are not expected to change the flow of the river significantly from the base scenario

Source: CRIDF (2015)

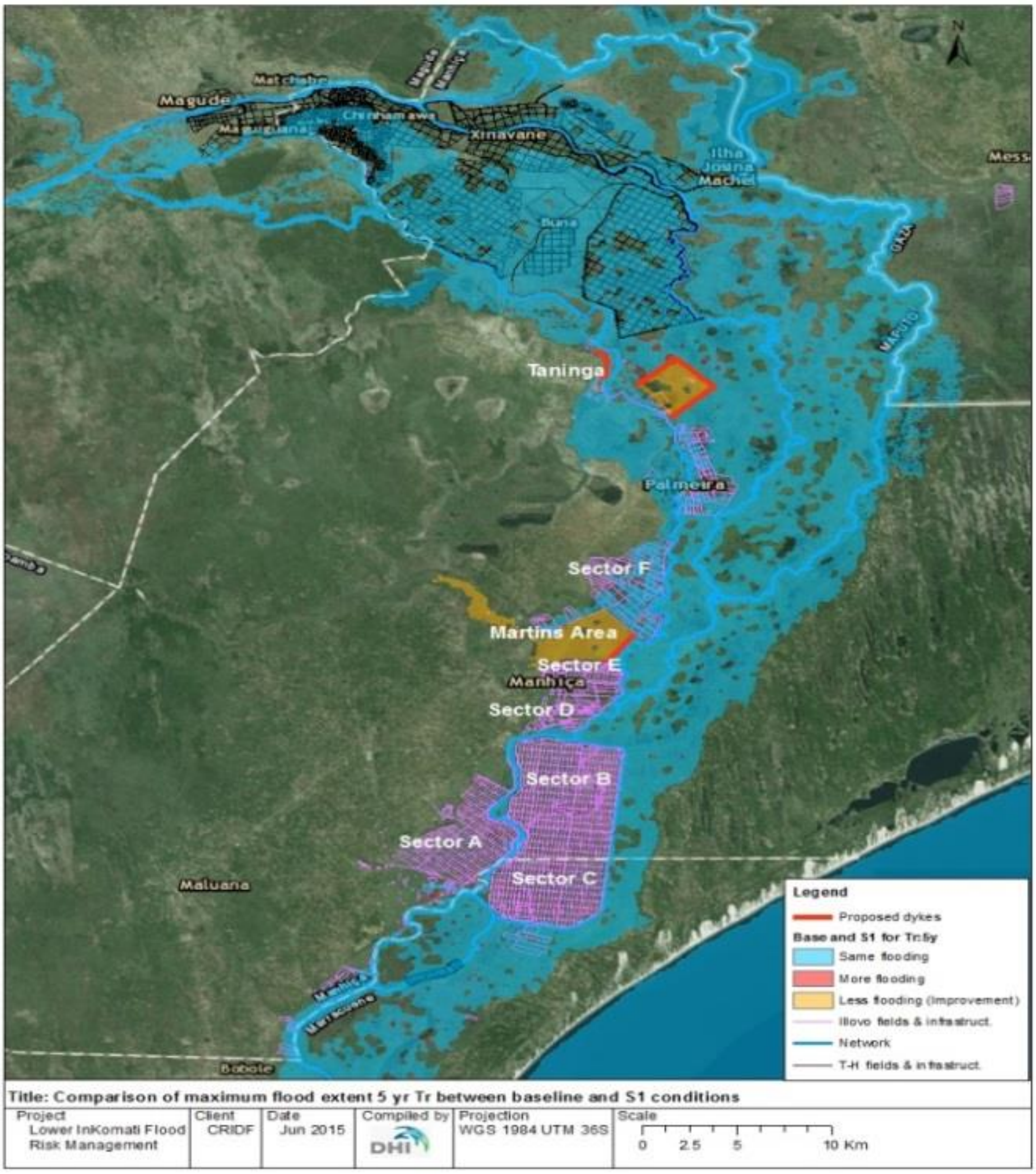


Figure 11-3 1 in 5 year Flood Extent Comparison between the Base and S1 Scenarios

Based on the Flood Model, the S1 investment is expected to result in a decrease of flooding to a total of 1,164 hectares (orange areas in Figure 11-3). Figure 11-4 below shows that of this area:

- the net decrease of flooding on outgrower crops amounts to **1164.72Ha**
- the net decrease of flooding on MCP crops amounts to **-0.65Ha** (i.e. an additional 0.65Ha of MCP crops are actually flooded)

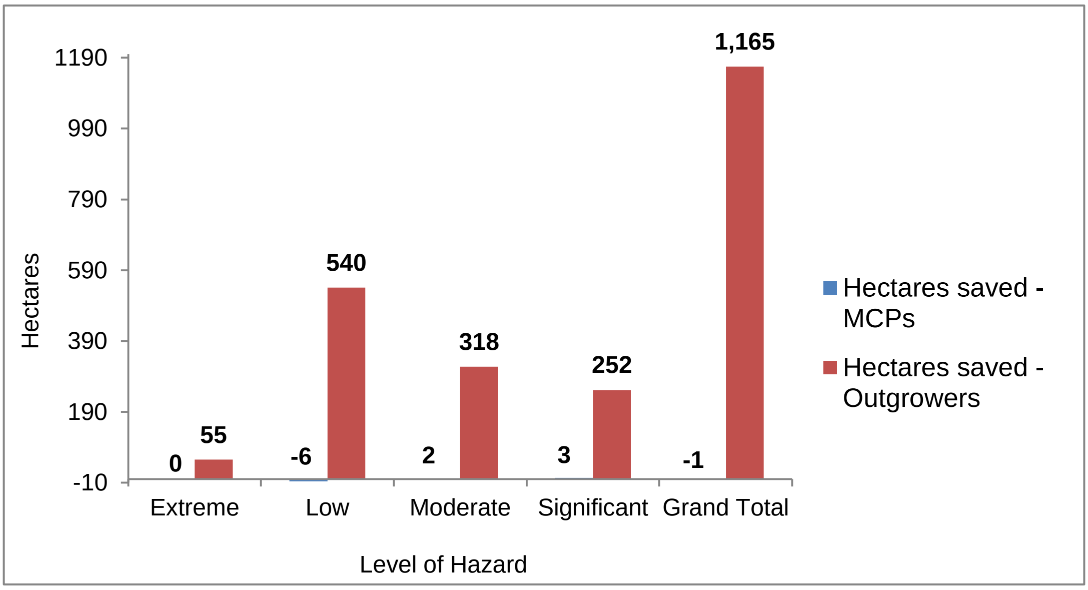


Figure 11-4 S1 Scenario - Avoided Flooding by Hazard Rating: Sugarcane (Ha)

The value of this avoided flooding is estimated to be **USD 2,428,661** (estimated through the same methodology as that in the base scenario for sugar shown in Appendix 1), of which:

- USD 918,704 will be to outgrowers (the direct flood cost savings on outgrower hectares), and
- USD 1,509,957 will be to MCPs (the direct flood cost savings on MCP hectares; all flow cost savings)

It is also expected that the S1 investment will protect other food crops from flood damage relative to the base scenario. Specifically, it is clear that the S1 investment will protect the Martins Area; within the Martins Area, the EU MSSDP outgrower expansion includes 240Ha reserved for food crops. The value of avoided flooding to these crops (estimated through the same methodology as that in the base scenario for non-sugar agriculture shown in Appendix 1) is approximately **USD 53,462** in avoided direct costs and relief costs.

S1: CBA Results

The CBA shows that the S1 investment is economically viable over 20 years. At a 10% discount rate, the Net Present Value (NPV) of the investment is positive, at USD 2million; the Benefit Cost Ratio (BCR) is greater than one, at 2.49; and the Economic Rate of Return (ERR) of 33%, exceeds the assumed discount rate.

Table 11-5 Summary of CBA Results for the S1 Investment Scenario

Performance indicator	3.5% discount rate	6.75% discount rate	10% discount rate
NPV	USD 4,447,924	USD 2,997,373	USD 2,054,096
BCR	2.88	2.49	2.49
ERR	33%	33%	33%

11.5.3 S4e: Tsatsimbe River Bifurcation

In 2014 a road crossing was constructed/ rehabilitated at the Tsatsimbe River bifurcation to consist of 134 m of concrete structure with a top deck level of 26.4 meters, and 64 culverts (each 2 meters wide and 1.9 meters high). It has however been reported by both sugar estates that since these culverts were introduced by the national road authority (ANE), there has been an increase in flood and flood damage to the downstream areas along the Tsatsimbe/Cuenga system, mostly occupied by outgrower fields.

The S4e investment scenario therefore involves restoring the embankment at a road crossing to its original height of 28.14m, and decreasing the number of culverts to one third of those currently available to still allow for necessary conveyance flows.

The estimated capital cost of this investment is **USD 357,220**. This rough estimate is based on per unit cost as per 0.

Table 11-6 S4e Capital Cost Estimate

Description	Unit	Total
Structure height	m	3.74
Structure length	m	134
Design and build	Cost/m (ZAR)	18,900
Design and build	Cost (ZAR)	2,532,600
Contingency	20% (ZAR)	506,520
Total	(ZAR)	3,039,120
Optimism Bias	30% (ZAR)	911,736
Grand total	(ZAR)	3,950,856
Grand total	(USD)	**357,220**

Annual maintenance costs are estimated to be 5% of the capital cost, and potential rehabilitation requirements once every ten years equal to 10% of capital costs.

The expected benefits include the change in flood impact - this change (outlined in Table 11-7) is ascertained from analysis of the Flood Model output shown graphically in Figure 11-5. This Figure shows in blue all the areas that experience the same level of flooding as in the base scenario; in orange all the areas that experience less flooding than those in the base scenario; and in red all the areas that experience more flooding than in the base scenario.

Table 11-7 High Level Expected Change in Flood Impact per Sector under the S4e Scenario

Sector	Expected change
Social	No change – the dykes are not expected to protect or aggravate flooding, to any social sector infrastructure
Infrastructure	The S4e intervention is not expected to protect or aggravate flooding to any significant infrastructure based on 0; however the road crossing maintenance costs currently incurred by ANE may be avoided under the investment scenario. This benefit (avoided cost) has however not been quantified in this preliminary analysis
Productive sectors	Agriculture-sugar – decrease in hectares flooded shown in orange, increase in hectares flooded shown in red (0) Agriculture other – patches of more flooding south east of Ilha Josina Machel; patches of less flooding south of Magude (in 0)
Environment	No change – the dykes are not expected to change the flow of the river significantly

Source: CRIDF (2015)

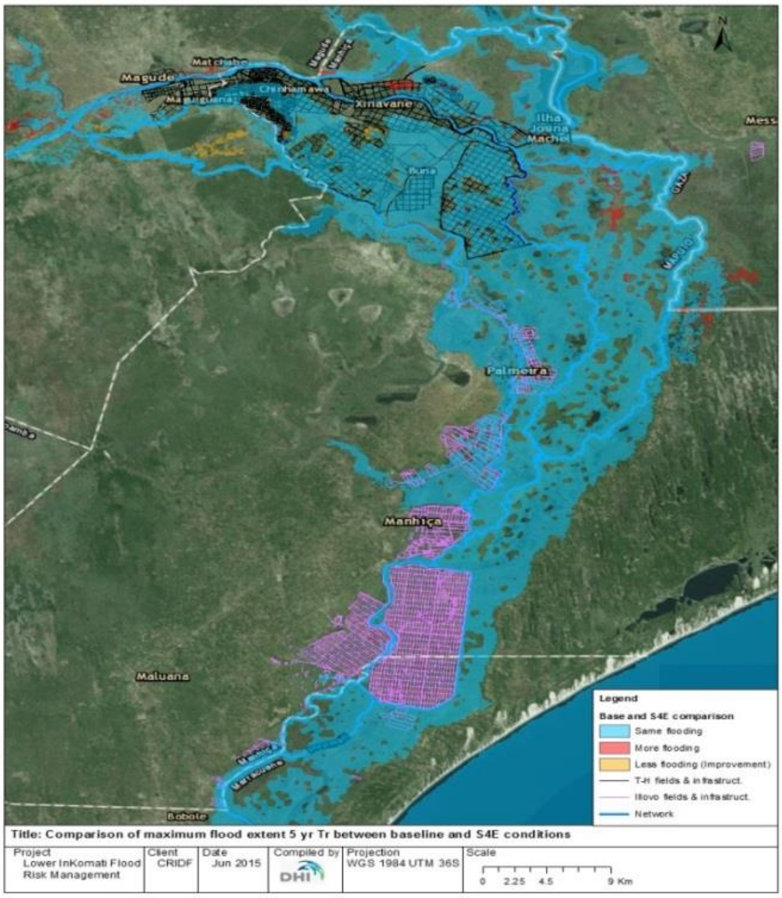


Figure 11-5 1 in 5 year Flood Extent Comparison between the Base and S4e Scenarios

Based on the Flood Model, the S4e investment is expected to result in a decrease of flooding to a total of **197 hectares** (**Error! Reference source not found.**). Of this:

- the net decrease of flooding on outgrower crops amounts to **151 Ha**
- the net decrease of flooding on MCP crops amounts to **46 Ha** (interestingly the MCP hectares flooded at a low hazard increases by 160ha, but hectares flooded by moderate, significant, and extreme levels of hazard decrease by 3ha, 108ha, and 95ha respectively)

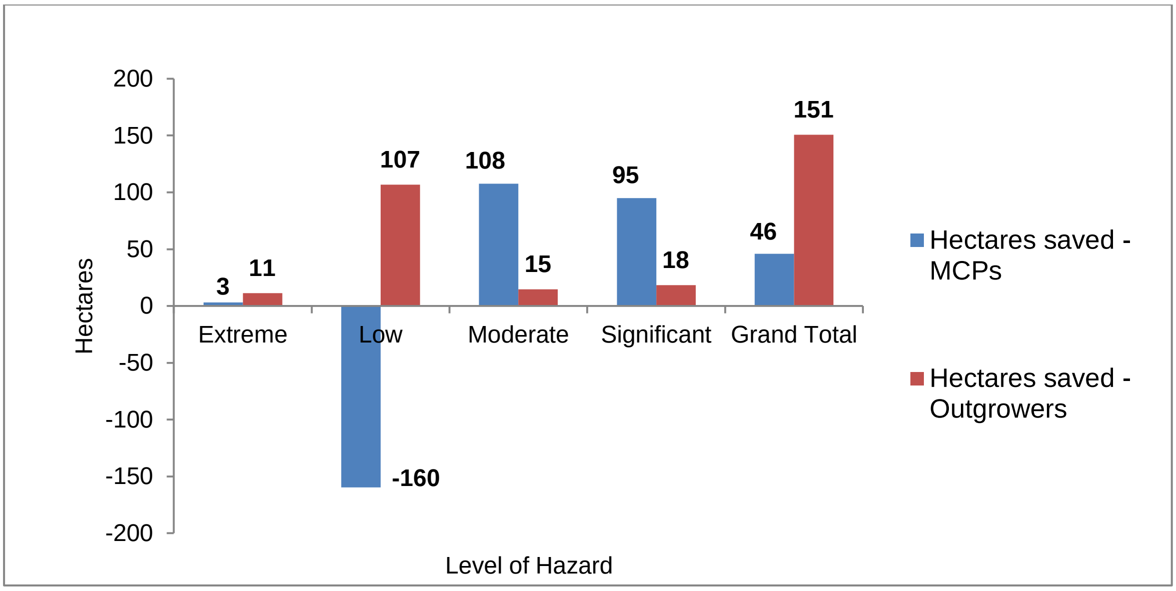


Figure 11-6 S4e Scenario - Avoided Flooding by Hazard Rating: Sugarcane (Ha)

The value of this avoided flooding in a one-in-five year event is estimated to be **USD 1,163,782**, of which:

- USD 81,354 will be to outgrowers (the direct flood cost savings on outgrower hectares), and
- USD 1,082,428 will be to MCPs (the direct flood cost savings on MCP hectares; all flow cost savings)

Based on the Flood Model results, in the S4e scenario there are expected to be patches of more flooding in the area south east of Ilha Josina Machel (shown in red in Figure 11-5) and less flooding in the area south of Magude (shown in orange in 0) relative to the base scenario. The cost of this additional flooding and benefit of the avoided flooding depends of the land-use characteristics and population in those specifics areas.

Erring of the side of caution, it is assumed that the patches of land now flooded (totalling an assumed 300ha) consist of non-sugar smallholders/subsistence farmers. The cost to the economy of this additional flooding is in included in the CBA, estimated through the same methodology as that in the base scenario, at approximately USD 66,126 in direct and relief costs.

Similarly it is assumed that those areas with less flooding (also totalling approximately 300Ha) also consist of non-sugar smallholders/subsistence farmers. The benefit to the economy of this avoided flooding is included in the CBA, estimated through the same methodology as that in the base scenario, at approximately USD 66,126 in avoided direct and relief costs.

S4e: CBA Results

The CBA shows that the S4e investment is economically viable over 20 years. At a 10% discount rate, the NPV of the investment is positive (USD 1,155,587); the BCR of 2.84 is greater than one; and the ERR of 45% exceeds the assumed discount rate.

Table 11-8 Summary of CBA Results for the S4e Investment Scenario

Performance indicator	3.5% discount rate	6.75% discount rate	10% discount rate
NPV	USD 2,344,660	USD 1,625,488	USD 1,155,587
BCR	3.77	3.26	2.84
ERR	45%	45%	45%

Further Considerations of the S4e Investment

The four maps shown below in 0 respectively show:

1. The change in **flood extent** between the **base and S4e scenario** (in a one-in-five year flood)
2. The **flood hazard** in a one-in-five year flood **base scenario**
3. The **flood hazard** in a one-in-five year flood under the **S4e scenario**
4. The change in **water levels** between the **base and S4e scenario** (in a one-in-five year flood) – where areas in red have higher flood water levels relative to the base scenario, and areas in orange and green have lower flood water levels relative to the base scenario.

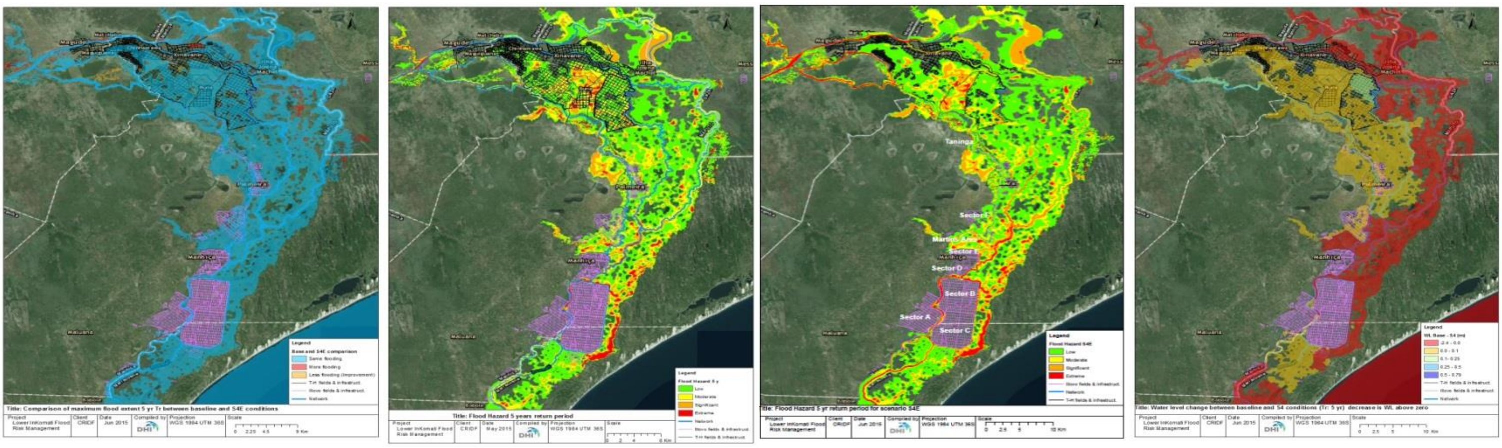


Figure 11-7 Additional S4 Considerations

Source: CRIDF (2015)

Together these maps show that the extent of flooding does not change significantly under the S4e scenario; moreover, the change in flood hazard between the base and S4e scenarios also does not appear significant. There is however a widespread change in water levels, with an increase in water levels across large parts area in the north east of the study, and decrease in large parts of the Xinavane estate and more central western area. This is expected given that water is being diverted into the channel up and around Xinavane.

These changes in water levels are not significant enough to change the hazard ratings of the flood; therefore (given that the damages assumed in the CBA are based on *flood hazard),* the value of the damages considered in the S4e CBA does not change much from the base scenario. Should S4e be considered a preferred investment solution, it may be necessary to assess whether the change in water levels are in fact relevant to overall flood damage, and should be used as the basis against which damages are estimated in a more comprehensive CBA rather than hazard ratings.

Moving from the S4e to S4g Investment Scenario

Given the water level effect achieved by the S4e investment described above (whereby large areas under sugarcane are flooded at a lower water level), an additional investment scenario (S4g) was considered by the Flood Model. The S4g investment scenario extends the S4e intervention to closure of all culverts plus an additional protection dyke upstream of the road crossing where the river is expected to breach.

The impact of the S4g scenario is shown in **Error! Reference source not found.**-8 below. It can be seen that the desired effect of the S4e investment is even more pronounced as intended. That is, water is diverted up and around Xinavane to the east and all the sugarcane areas (Xinavane and Maragra) experience less flooding in the 1 in 5 year flood event (shown in orange). Under S4g however, there are significant areas that do receive more flooding (shown in red).

Should S4g be seen as a preferred investment option given the significant positive impact on the sugar estate and outgrower areas, it is recommended that the negative impacts – that is, the economic costs – to the areas that will be flooded more be carefully considered. Targeted data collection on population and land use in those specific areas affected positively and negatively (shown in orange and red in **Error! Reference source not found.**) should be undertaken so that the all flood impacts (as outlined in the flood cost framework) can be accurately accounted for relative to the base scenario.

Given the expected positive impact on sugarcane areas, S4g is likely to be economically desirable overall (weighing up costs and benefits). A more detailed CBA will still however have value in highlighting the nature and scale of the negative impacts (costs), as well as which Basin stakeholders will incur them. This will inform the necessity for possible compensation mechanisms or additional targeted mitigation measures to be put in place in correspondence with the S4g investment.

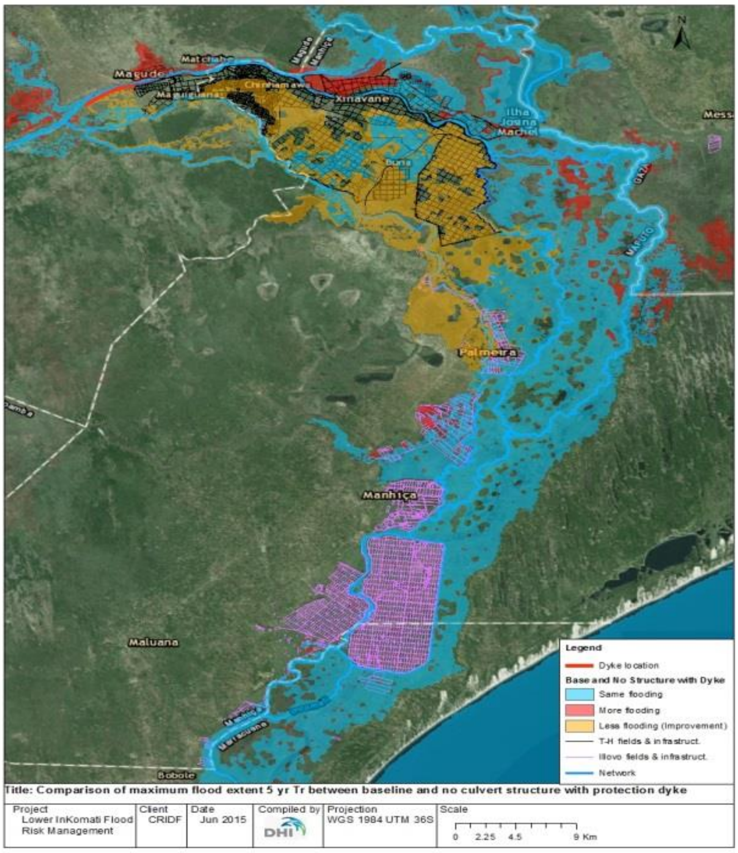


Figure 11-8 S4g Investment Scenario – Flood Extent Change

Source: CRIDF (2015)

11.5.4 Sensitivity Analysis of CBAs

The results of the two CBAs above are based on various assumptions and inputs, the value of which in uncertain, particularly when looking into the future. A sensitivity analysis is therefore conducted to see how sensitive the results of the CBAs are to changes in the variables and assumptions used in the analysis.

The following variations were tested for both the S1 and S4ed investment scenarios given the uncertainty around their values (the full results of which can be found in Appendix 3):

- A decrease in the assumed sugar price of USD 285 to USD 260 (9% decreased) and USD 200 (30% decrease)
- Inclusion of the indirect/flow benefits only – that is the avoided production losses from the base scenario (i.e. excluding avoided direct and relief losses)
- Exclusion of the benefit to subsistence/non-sugar smallholders as a result of the S1 scenario (i.e. the avoided losses to 240ha of food crops relative to the base scenario); and to the S4e scenario (i.e. the assumed 300ha of subsistence/non-sugar smallholders with less flooding)
- A decrease of 25% in the hectares assumed to no longer be flooded under the S1 and S4e scenarios based on the Flood Model results (relative to the base scenario)

- An increase of 25% in capital costs (and hence maintenance and refurbishments costs)
- A decrease in capital costs (and hence maintenance and refurbishments costs) of 30% (i.e. exclusion of the optimism bias included in the cost estimates for both investments)
- Exclusion of the refurbishment costs assumed to be required once every 10 years (i.e. in every second one-in-five year flood)

The results of the above sensitivity scenarios showed that the viability of both the S1 and S4e investments are robust, and resilient to such changes. The CBA results for both the S1 and S4e investments remain positive in all cases.

The variables which the S1 and S4e investments are most sensitive to are investment costs, the hectares of sugarcane saved by the investment, and the sugar price. Even significant negative changes in these variables, do not, however, impact the overall viability of either investment.

The inclusion/exclusion of potential increased/decreased flooding to surrounding areas such as non-sugar smallholders/subsistence farmers has a negligible effect of the overall results. This result should be viewed with caution as it may either be due to the fact that these affected areas are relatively small, or that they have not adequately been valued currently given data challenges. In other investment scenarios (such as S4g possibly) the impacts on other sectors outlined in the flood cost framework may become more significant.

11.5.5 Investment Prioritisation

Both investments will result in a positive impact on the Lower Incomati Basin and are hence both economically viable. In other words, the cost to society of not implementing each of the investments is higher than the cost of implementing them.

However should the resources of stakeholders be limited to the degree that only one investment can be implemented immediately, the CBA results can inform the prioritisation of investments.

Error! Reference source not found. indicates that in terms of NPV, the S1 investment is preferable to the S4e investment. This preference is, however, due to the fact that S1 is a significantly larger investment. The BCR and ERR performance indicators are independent of investment size, showing the relative ‘bang for buck’ of the investments. Based on the BCR and ERR indicators, **Error! Reference source not found.** shows that the S4e investment is preferable.

This result fluctuates however as the CBA assumptions are varied, implying that one investment is not clearly preferable over the other. Moreover, it is recognised that these two particular investments are independent unrelated interventions and are not mutually-exclusive.

Table 11-9 The S1 versus S4e CBA Performance Indicators

Performance indicator	S1 (10%)	S4e (10%)	Comparison
NPV	USD 1,972,909	USD 1,155,587	S1 > S4e
BCR	2.13	2.84	S4e > S1
ERR	33%	45%	S4e > S1

It is also useful to compare the investment prioritisation indicated by the CBA results to the final Flood Risk maps which take into account vulnerability with flood hazard.

The CBA methodology tries to adequately value and price the flood impact on vulnerable populations and areas, even when these are not included in the formal monetary economy (there is also the option of weighting the impacts on particular populations and areas within CBA). There remains a risk, however, that these impacts are not adequately accounted for due to the inherent challenges and subjectivity in valuation techniques.

A comparison between the prioritisation of investments indicated by the CBA results and final Flood Risk maps will serve to highlight any conflicting recommendations, and prompt examination into why this may be case. In instances where an investment has particularly high economic returns, but excludes or worsens the situation for the most vulnerable, compensation or additional mitigations strategies can be identified.

The CBA prioritisation in this case does not appear to contradict the results shown in the Flood Risk map (0), which shows the greatest risk to the Martins and Buna areas.

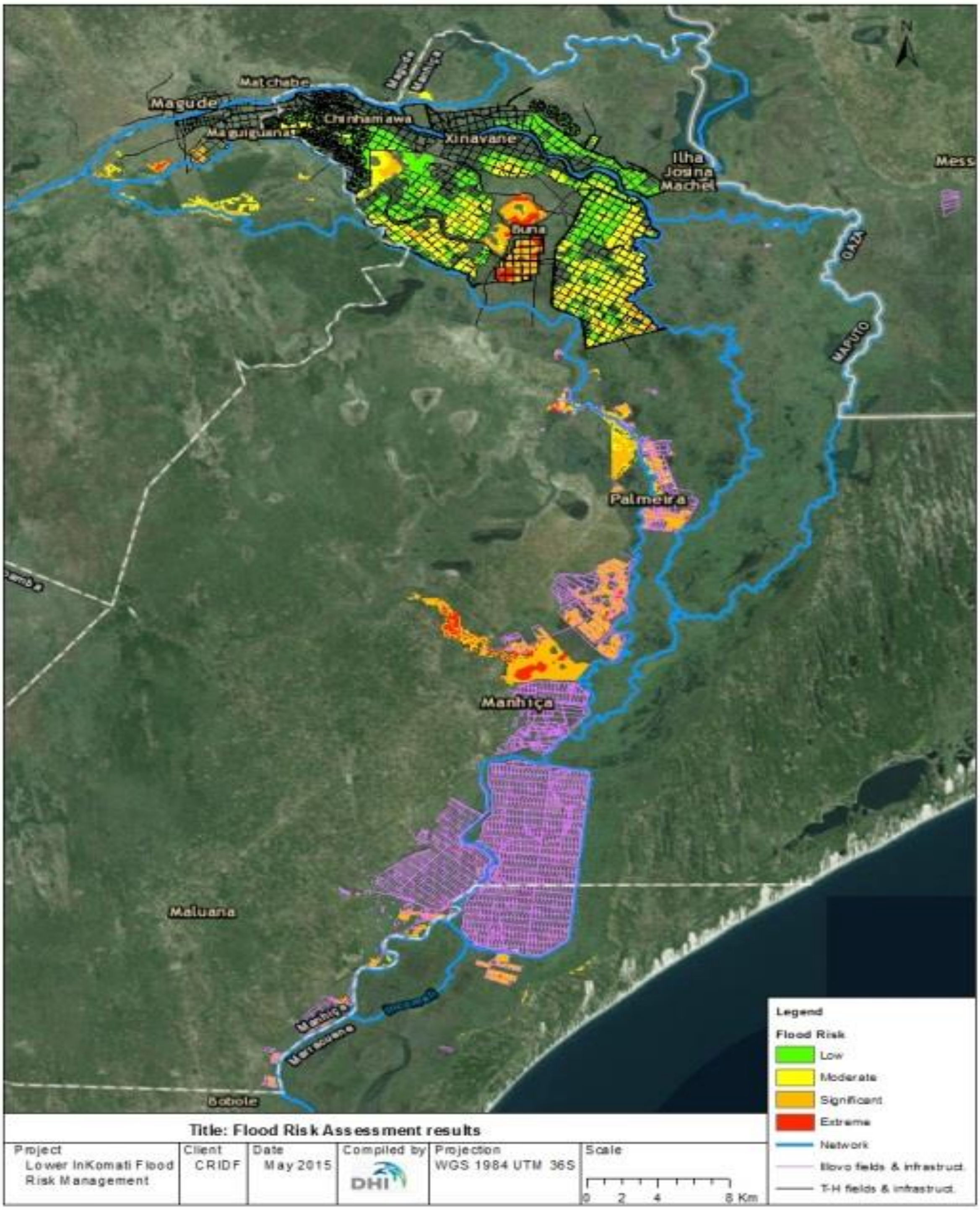


Figure 11-9 Flood Risk in the Lower Incomati Basin

Source: CRIDF (2015)

12 Economic Analysis Conclusions

The framework developed in this report (**Error! Reference source not found.**) identifies and defines all of the flood impacts (costs) relevant to the Lower Incomati Basin. As such, the framework provides a basis from which to holistically assess flood management options by taking into consideration all of their resultant costs and benefits on the local economy and population.

The indicative CBAs, based on this framework and conducted on the proposed S1 and S4e flood mitigation investments, indicate that both investments are economic viable in response to a one-in-five year flood versus the 'do nothing' scenario.

12.1 Recommendations for Further Economic Analysis

The analysis conducted in this report provides a basis from which further, increasingly useful analyses can be conducted. Suggestions of some next steps include:

- Improve the assumptions and accuracy of values used in the quantitative analysis through feedback from stakeholders, and hence the overall accuracy and meaningfulness of the CBAs;
- Update the assumptions and inputs used in CBAs as more data on the Lower Incomati becomes available, and as the model is extended and improved;
- Use the framework to assess other investment options (infrastructure and management, or mix of each) for different flood events (or for all flood events, based on the probability of each occurring);
- Conduct a more detailed analysis on preferred investments – such as S4g – through targeted land use and population data collection on those areas that are expected to experience more flooding under the scenario;
- Included different climate change scenarios in the Flood Model, and ultimately the CBA of different investment options;
- Conduct a detailed distribution analysis as part of the CBAs, looking at how the costs and benefits within the Lower Incomati Basin are distributed amongst basin stakeholders. Such an analysis will indicate the need for compensation to some stakeholders.
- Depending on the objective of an investment or perspective of investor, the CBA can include weights on the costs and benefits incurred by certain stakeholder (e.g. the most vulnerable) to ensure the investment speaks to the ultimate objective (e.g. decreasing vulnerability; increasing equality, etc.)
- Link the CBAs to a macro level analysis to assess the eventual impact on the national economy by looking at the multiplier/knock-on impacts on the larger economy (that is, the indirect and induced effects through other sectors)

12.2 Importance and Relevance to CRIDF

The Lower Incomati Basin is a sub-basin which is particularly vulnerable to both climate change and the transboundary consideration of upstream countries. The majority of the Lower Incomati population are also poor communities largely reliant on subsistence for food security, and particularly vulnerable to the increasing occurrence of water shocks.

The Flood Model developed under this project provides a critical basis against which stakeholders can base a flood risk management strategy. The use of socio-economic CBA, based on the Flood Model and proposed flood risk management strategies, assists in ensuring that private sector investments, which dominate the area in terms of flood prevention infrastructure, are aligned to the CRIDF principles of climate resilience and pro-poor development. It also serves to ensure that an investment will result in a net positive impact on society as a whole, and highlight where the distribution of impacts is an issue and compensation mechanisms required.

Lastly, in line with CRIDF's objective to leverage private sector investment in water resource management, the analysis contained in this report, and its extension to further suggested analyses, can provide a means for CRIDF and private sector stakeholders to align objectives and share risk.

13 Next Project Phases

CRIDF has discussed initial ideas with ARA-Sul, Illovo and Tongaat Sugar Estates and other stakeholders for inclusion in Phase 2 of the project. A summary of the key aspects is presented below

A. Transboundary

The aim is to have an early flood warning system encompassing South Africa, Swaziland and Mozambique to enable additional time for key stakeholders to plan and mitigate against impending flood events

With a rainfall runoff model of the Incomati basin and a 1D hydro dynamic river model, working with ARA-Sul this will enable a clear understanding of the rainfall runoff responses in catchments. This will also enable reservoir operation scenarios to be tested for the existing situation and future dam developments to optimise storage of flood water within the dams to reduce flooding downstream.

It should be noted that setting up a transboundary early flood warning system should not be underestimated given the complexity.

From discussions with Department of International Rivers within Mozambique that this project is within the Tripartite Permanent Technical Committee (TPTC) priority plans so would be very welcomed.

B. Climate Resilience

The future impacts of potential climate change scenarios must be included within the flood risk management options and flood hydrographs be factored accordingly.

C. Evolution of the Stakeholder Influence

With the current steering group gaining influence the next steps would be to potentially expand this from Sugar Estates, ARA-Sul and ANE to include Disaster Management (INGC), Agricultural Dept, and other country departments, Inkomati Catchment Management Agency (ICMA), DWS etc. This stakeholder influence could be coordinated via forums thereby still enabling decisive decision making within the smaller steering group.

D. Infrastructure Development

Through the flood warning system and flood risk management options will be developed with the focus on infrastructure development to enable the construction of critical infrastructure.

In order to enable items A to D to be achieved the LiDAR survey of the existing project planned to be flown in August and processed in September 2015 area must be incorporated into the existing hydraulic model. The added detail from the LiDAR will improve the accuracy of the hydraulic model to influence detailed design of the Flood Risk Management options. As part of this work the model should be extended further upstream to the border with South Africa. It should be noted that the ARA-Sul Director General and Management Team are also keen to extend the hydraulic model further upstream also for a more fuller understanding of other potential flood risk management options. With the Hydrological flood modelling (Rainfall runoff) of catchments of the Incomati being produced as part of the early warning flood system, further inflow hydrographs are anticipated to be added to the hydraulic model, enabling a more accurate understand of the impacts of flooding from other tributaries.

The likely timeframe for Phase 2 would be approximately 12 to 15 months.

A potential idea for Phase 3 of the project is to have a Hydrologic-Agronomic-Economic Model. The reason for this are as follows:

- From a water resource perspective developments in the next 10 years will contribute significantly to increased agricultural production
- Climate change scenarios may impact on crop production
- Understanding is needed on the water stresses on irrigation and other abstractions in the future for the Incomati basin
- Improving irrigation water management particularly in the dry season when stress on resources is greatest.

Water resources management key for the future is key to agricultural production and understanding the issues for competing water Phase 2 could start looking at the building blocks to commence this in Phase 3.

Note: CRIDF funding for Phases 2 and 3 is not guaranteed and requires further discussion with DFID in the near future to determine whether budget be made available.

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Appendices

The following Appendices are produced separately to this main report.

Appendix A – Flood Extent Maps

Appendix B – Flood Hazard Maps

Appendix C – Flood Vulnerability Maps

Appendix D – Flood Risk Maps

Appendix E – Stakeholder Event Meeting Notes

Appendix F – Economic Analysis

Appendix G – Hydraulic Model Configuration

Appendix H- Flood Vulnerability Detailed Analysis

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