PAPER 6

SUSTAINABILITY OF FLOOD STUDIES: FROM INUNDATION MAPPING TO HOLISTIC RISK MANAGEMENT IN PROSPECTON, DURBAN

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ABSTRACT
Often, when flood studies are conducted, the main focus is on delineating the inundation area exposed to flooding and establishing flood levels. This information is important for legal requirements and for designing infrastructure to mitigate flooding. However, these studies have much more to offer and assist in making better informed and more sustainable decisions to manage flood risks. Instead of solely focusing on flood levels, the potential economic impact can also be understood, and this information can be used to plan better ways to protect communities and infrastructure.

This paper shares a real-world example from Prospecton, Durban, where different parties – from private sector (Toyota South Africa Motors (TSAM)) to public sector (eThekwini Municipality) and even international partners (Dutch Disaster Risk Reduction and Surge programme (DRRS)) – collaborated to use flood analysis in a more sustainable manner. Initial flood studies conducted by AECOM between 2019 and 2023 helped everyone understand the complex flood dynamics and exposure factors in the region. Subsequently, Atana (Pty) Ltd and Royal HaskoningDHV partnered with the eThekwini Municipality in 2024 to undertake a detailed economic flood risk assessment. This progressive approach moved beyond simply identifying flood extents to quantifying potential damages and evaluating the financial viability of various mitigation interventions, aiming to optimise the overall flood mitigation strategy.

This example highlights the value of a continuous and adaptive methodology in flood studies. By building upon the initial flood level assessments to incorporate consequence analysis, a more holistic and sustainable understanding of flood risk emerges. This facilitates more informed decision-making regarding resource allocation for flood mitigation, leading to more resilient infrastructure and safer communities in the long term.

Finally, this paper will offer some practical steps and key considerations for municipal engineers and decision-makers who want to adopt this more sustainable approach to flood risk assessment within their own contexts. By embracing a flexible and ongoing methodology for flood studies, more effective and lasting solutions can be developed to protect towns and cities from the increasing threat of floods.

1. INTRODUCTION
Flooding remains one of the most significant natural hazards in South Africa, frequently causing widespread damage to infrastructure, displacement of communities, and loss of life. The country's increasing exposure to flood risk is driven by rapid urbanisation, inadequate capacity and maintenance of drainage infrastructure, and uncertainty associated with climate patterns. As a result, robust floodline (or flood risk) studies have become essential tools for understanding, managing, and mitigating these risks.

These studies typically rely on hydrological and hydraulic modelling to delineate flood extents and determine flood levels for various annual exceedance probabilities (also known as return periods). However, to ensure long-term sustainability and resilience, floodline studies must extend beyond the regulatory compliance typically associated with flood extent mapping. There is growing recognition of the value in leveraging these models for broader applications, including damage estimation, cost-benefit evaluations of mitigation strategies, and integration with spatial planning and climate adaptation strategies.

To showcase the evolving role of floodline studies in South Africa and demonstrate how they can contribute to more sustainable, equitable, and climate-resilient flood risk management, the work undertaken by various private consultants will be used as a case study. This case study will examine various flood studies conducted in Prospecton, Durban, following significant extreme flood events, specifically those of 2017, 2019, and 2022.

2. UNDERSTANDING "FLOOD RISK"
To effectively address escalating flood challenges, a clear and precise understanding of what constitutes flood risk is paramount. Flood risk can be comprehensively defined as a combination of the probability of a flood event occurring and the consequences of that specific event. These consequences can be far-reaching, encompassing impacts on people, critical infrastructure, the natural environment, and the economy. The United Nations Office for Disaster Risk Reduction (UNDRR) defines flood risk as a function of three primary, interconnected components, as illustrated in Figure 1 (UNDRR, 2017):

FIGURE 1: *Defining flood risk*

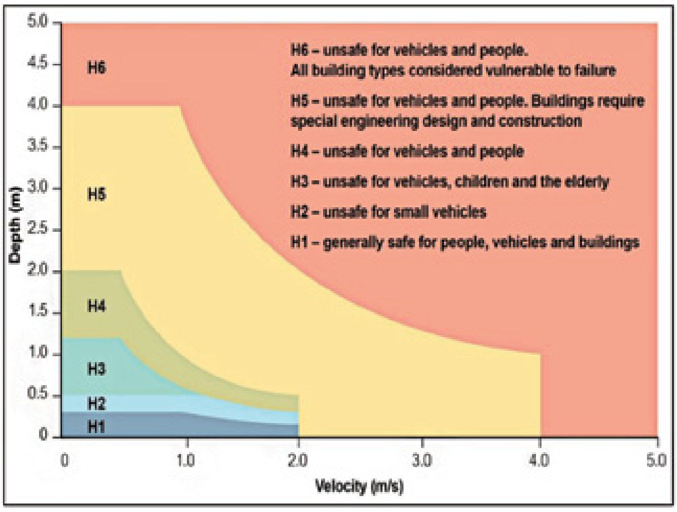

FIGURE 2: *Australian Institute for Disaster Resilience Guidelines flood hazard vulnerability curves (AIDR, 2017)*

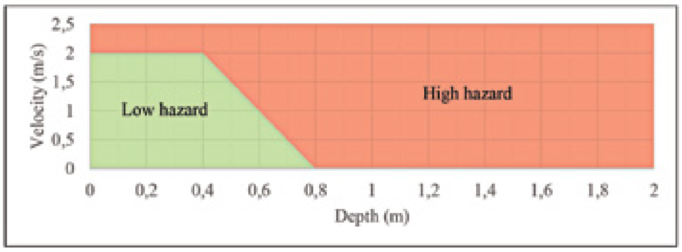

FIGURE 3: *City of Cape Town Floodplain and Stormwater Corridor Management Policy flood hazard vulnerability curves (2009)*

- **Hazard:** *What are the chances of this happening?*

This component refers to the physical flood event itself, characterised by its frequency or probability of occurrence and its inherent potential to cause harm. For instance, deep or fast-flowing floodwaters inherently possess a high potential to cause severe harm, whereas slower-moving, shallow floodwaters generally present a lower hazard.

- **Exposure:** *Who will be affect by the event?*

This refers to all elements situated within the flood-prone area that could be affected by the event. These typically include people, buildings, infrastructure networks such as roads and utilities, and critical facilities. Exposure is primarily determined by the spatial distribution of these assets and population density, often informed by detailed land-use maps.

- **Vulnerability:** *What is their capability to cope, adapt or recover?*

This component describes the susceptibility of exposed elements to harm or damage from a flood event. It is typically influenced by a range of socio-economic factors (e.g. poverty, access to resources), physical characteristics (e.g. building materials, structural integrity), and adaptive capacities (e.g. early warning systems, emergency response capabilities) that determine their ability to cope, adapt, or recover.

3. FLOOD HAZARD MAPPING

Understanding flood risk, particularly the hazard component, is significantly enhanced by the results derived from advanced hydrological and hydraulic models. Advances in computational capabilities and modelling approaches have considerably improved the ability to simulate flood events and process the resulting model outputs. However, as stated in the IMESA *A Best Practice Guideline for Design Flood Estimation in Municipal Areas in South Africa* (Brooker *et al.*,2023), "floodlines are usually presented as a simple line on a plan. While this may comply with National Water Act (Act No 36 of 1998) (NWA) requirements, it provides little information on risk." This highlights a critical gap: even though these "simple lines on a plan" meet NWA requirements, the Guideline itself refers to numerous legislative documents that collectively emphasise the broader responsibility to ensure public safety.

A more advanced method, increasingly adopted internationally, involves reporting flood hazard as a function of both flood depths and velocities. For example, the Australian Institute for Disaster Resilience (AIDR) developed six hazard categories that considered the impact various velocity and depth combinations could have on people, vehicles, and buildings, as shown in Figure 2. This type of detailed hazard reporting is especially beneficial when considering multi-purpose flood attenuation facilities, such as recreational parks or sports fields. These facilities are designed to be inundated during extreme flood events, thereby serving as vital flood attenuation infrastructure. Notably, a simplified version of flood hazard categories based on flood depth and velocity combinations has already been successfully adopted by the City of Cape Town, as shown in Figure 3 (CCT, 2009).

With ongoing advancements in modelling software and post-processing capabilities, the inclusion of other crucial flood characteristics can further enhance hazard mapping. Parameters such as the rate of flood level rise, duration of inundation, or even debris potential can be considered to more comprehensively determine flood hazards and identify and map potentially unsafe areas.

4. DEVELOPING FLOOD MITIGATION STRATEGIES

The overall flood risk can be mitigated by reducing either (or a combination of) the hazard, exposure, or vulnerability. These risk reduction strategies typically comprise a combination of mitigation measures, including structural and non-structural interventions. Structural mitigation interventions involve physical changes to the built environment or landscape to directly alter flood pathways, reduce flood depths, or manage water flow. They are typically engineered solutions designed to control water, with a specific design return period in mind. The result is that damages would be reduced up to a certain return period (or probability), but damages could increase during more extreme events, as shown in Figure 4(a). Non-structural interventions reduce flood impacts by influencing how people interact with flood-prone areas, improving preparedness, and enhancing awareness. These measures often complement structural solutions, creating a more comprehensive flood risk management strategy (UNDRR, 2017). Unlike structural measures, non-structural measures are not necessarily designed with a specific return period in mind and could typically reduce damages across all return periods, as shown in Figure 4(b).

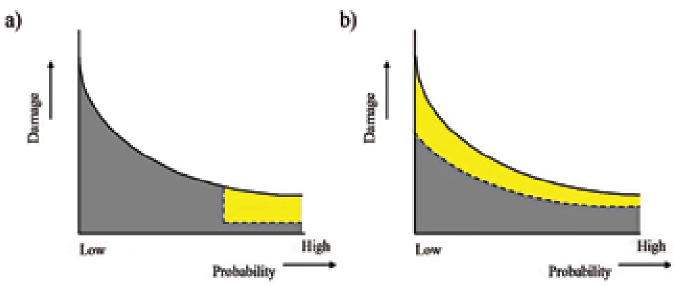

FIGURE 4: *Typical impact of (a) structural and (b) non-structural mitigation interventions on damage probability curves.*

FIGURE 5: *Schematic of multi-layer flood mitigation approach (Gersonius et al., 2014)*

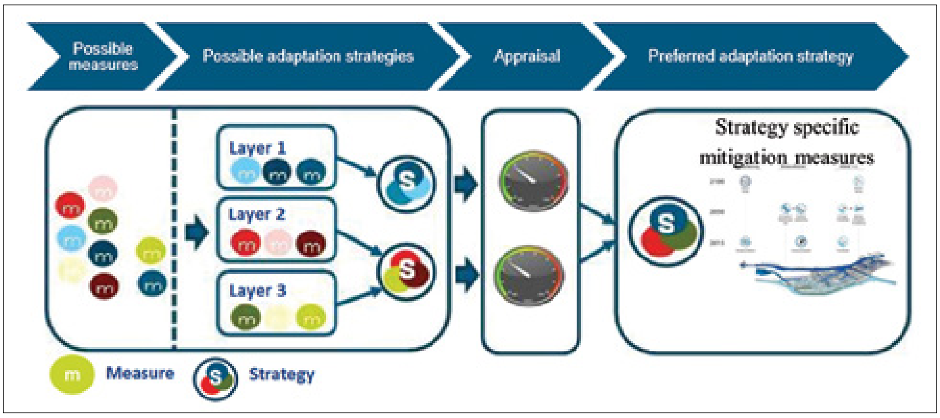

FIGURE 6: *Workflow for adaptation strategies (RHDHV, 2024)*

When developing flood mitigation interventions, a combination of structural and non-structural measures should be considered. This approach typically comprises various layers of mitigation, including prevention, preparedness, and response, key components of the disaster risk management cycle. Figure 5 shows a typical example where a structural measure, such as a levee, would form part of the first layer of flood protection - prevention. The second layer, preparedness, can be informed by spatial planning of the town, and the third layer would involve emergency response or evacuation plans. This example illustrates how multiple measures can form part of the various phases of the disaster risk management cycle, resulting in a multi-layer flood mitigation approach.

The various mitigation options identified as part of the multi-layer flood mitigation approach can then be combined to develop potential adaptation strategies for flood mitigation, as shown in the workflow schematic in Figure 6. An appraisal of these strategies can then be conducted based on a multi-criteria assessment. The appraisal could include cost-benefit analyses, environmental and socio-economic impacts, potential risk transfer to other properties, and the technical feasibility of the measures. This appraisal would depend on case-specific requirements, from which the preferred adaptation strategy can be identified for implementation.

5. THE CASE STUDY: PROSPECTON, DURBAN

5.1 Background

To showcase how floodline studies can significantly add value to understanding a flood regime and its consequences, a recent collaborative effort in the Prospecton area of Durban is presented as a case study. This area has unfortunately been subject to various extreme flood events in recent years. This case study, therefore, aims to demonstrate how understanding the flood hazard, specifically flood depths emanating from advanced modelling, can provide insights into the April 2022 floods and inform the economic impact assessment of proposed mitigation measures.

During the 1960s, the Isipingo and Mlazi Rivers were strategically diverted away from the Isipingo Estuary. This significant intervention aimed to unlock the large, flat floodplain, now known as Prospecton, for extensive development. Flow from the approximately 40km^2 Isipingo River catchment was rerouted in a southerly direction towards the Mbokodweni River. Concurrently, the Mlazi River, which has a considerably larger catchment area of approximately 951km^2, was canalised and redirected in a westerly direction towards a new sea outfall, as indicated in Figure 7. These alterations resulted in a substantial reduction of natural flow towards the Isipingo Estuary.

Over the past decade, the Prospecton area has experienced a number of extreme flood events with devastating consequences. These impacts include extensive damage to infrastructure, significant business disruption, severe environmental degradation, and tragic loss of life. The most significant of these events occurred in October 2017, April 2019, and April 2022.

The former two events (October 2017 and April 2019) were primarily characterised by intense downpours within the local catchments that drain directly to the Isipingo Estuary. Rainfall associated with the October 2017 event, specifically for 60- to 120-minute storm durations, exceeded the design rainfall depths for a 1-in-200-year event. This resulted in severe flooding experienced in smaller, local catchments, particularly affecting bulk drainage systems from Isipingo Hills and Prospecton. The rainfall associated with the April 2019 event, on the other hand, exceeded the 1-in-20-year design rainfall depth for storm durations in the order of 12 hours, leading to flooding typically experienced in larger catchments (AECOM, 2019).

The April 2022 event proved to be the most extreme of the three. Rainfall stations along the coast recorded rainfall depths between the 20- and 50-year return periods for storm durations of 2 to 3 days. However, inland

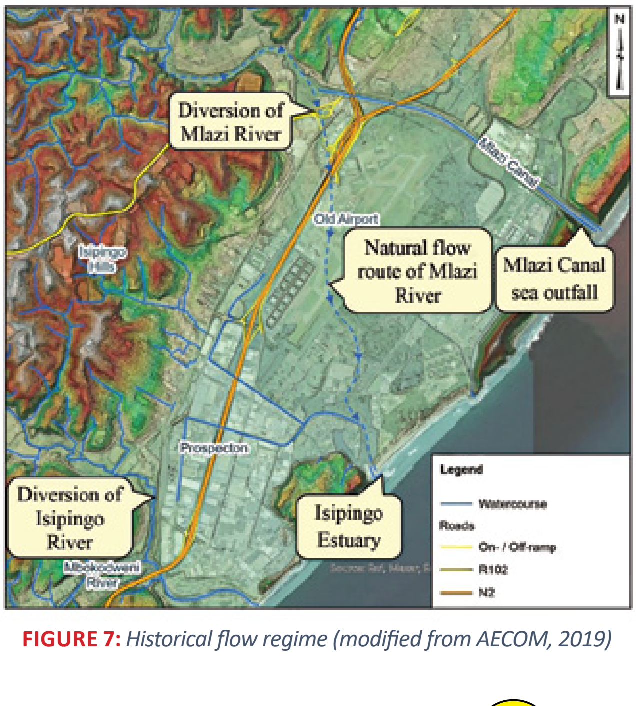

FIGURE 7: *Historical flow regime (modified from AECOM, 2019)*

TABLE 1: *Highest discharge flow at Shongweni dam since the construction of the Mlazi Canal (AECOM, 2024)*

Year	Estimated peak flow rate (m^3/s)	Approximate design return period (years)
1959	1400	100 - 200
1987	1420	100 – 200
2022	2000 - 2400	> 200

stations recorded significantly higher rainfall depths, between the 100- and 200-year events, for storm durations ranging from 16 hours to 2 days. The resulting flow in the Mlazi River far exceeded the capacity of the Mlazi diversion berm (referred to as the R102 diversion berm) and canal, leading to overtopping and multiple breaches. Crucially, floodwaters discharged at these breaches followed the natural, historical path of the Mlazi River towards the Isipingo Estuary, directly resulting in the widespread flooding observed in Prospecton. It is important to note that apart from the 2022 breach, the Mlazi Canal has overtopped during only two other flood events since its construction in the mid-1950s: the first being in 1959 and again in 1987. Flow records at the Shongweni Dam, situated along the Mlazi River approximately 43km upstream of the Mlazi River diversion and Mlazi Canal, are summarised in Table 1.

These recent catastrophic flood events triggered significant investment from various parties, including private, public and international stakeholders. This investment was aimed at gaining a better understanding of the complex flood regime in the Prospecton area and, critically, to better inform future flood mitigation interventions. Table 2 presents a clear timeline of the extreme flood events since 2017, and the associated studies conducted by the collaboration partners for the Prospecton area.

5.2 Flood modelling approach

Over the period shown in Table 2, several hydrological and hydraulic models were developed to better understand Prospecton's complex flood regime. The hydrological models, developed using PCSWMM modelling software specifically designed by the Computational Hydraulics International (CHI) for personal computer-based (PC) stormwater management modelling (SWMM), aimed to determine flood magnitudes, such as peak runoff rates and hydrographs, for various flood probabilities or return periods. This data directly informed the hazard component of the risk assessment. The hydraulic models, on the other hand, focused on understanding specific flood characteristics like depth and velocity, which are crucial for both the hazard and exposure components of the risk assessment. These were developed using a combination of PCSWMM for the local catchment and HEC-RAS for simulating the overtopping and breaching of the Mlazi Canal system.

The model developed during the 2019 study was based on the local authority's existing catchment management model. During this study, the

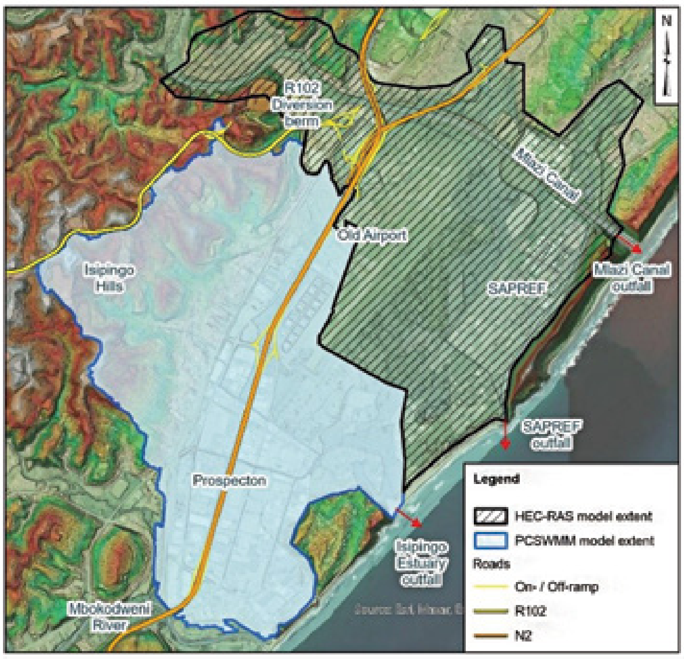

FIGURE 8: *Model extent for the Local Catchment model*

catchment management model was further enhanced to include a two-dimensional (2D) modelling component specifically for the Prospecton area. 2D modelling offers significant advantages: it better represents lateral flow in flat areas (showing both flow direction and spread) and allows for the determination of flow paths as part of the simulation process. This capability enabled a more detailed representation of the complex flow regime associated with Prospecton's flat topography. Furthermore, a 'Rain-on-Grid' (also known as 'Direct Rainfall') modelling approach was adopted specifically for the Prospecton area.

This approach simulates rainfall directly onto a 2D modelling domain, eliminating the need for separate hydrological and hydraulic modelling stages. Initially, this model's extent only considered the catchment area draining towards the Isipingo Estuary, which notably excluded the old airport site and industrial developments that drained to an additional outfall located north of the Isipingo Estuary, as illustrated in Figure 8. During the 2024 economic risk assessment study, the model was updated to include these previously excluded areas, as well as a developed area north of the Mlazi Canal that drains towards it. The final updated extent was similar to the 2022 Mlazi Canal flood study model's extent, illustrated in Figure 9. This ensured the economic risk assessment covered the same geographical areas, considering the two different drivers of recent flood events.

During the 2022 study, a PCSWMM model was developed for the Mlazi River catchment to generate hydrographs for various return periods. This PCSWMM model not only generated runoff hydrographs for the different

TABLE 2: *Timeline of extreme flood events and studies conducted for Prospecton, Durban*

Year	Flood event	Study conducted	Purpose of the study
2017	October 2017		
2019	April 2019	Flood level assessment of Prospecton (AECOM, 2019)	Conducted for Toyota South Africa Motors (TSAM) and in collaboration with eThekwini Municipality.
2022	April 2022	Investigation of Flood Risk Mitigation Measures at TSAM Durban Plant (AECOM, 2024)	Conducted for TSAM in collaboration with eThekwini Municipality.
2023	-	Desktop study for the Dutch Disaster Risk Reduction and Surge Support (DRRS) programme (RHDHV, 2023)	To assess the relevance of a request for support to eThekwini Municipality.
2024	-	Economic flood risk assessment (RHDHV, 2024)	Conducted for the DRRS programme and eThekwini Municipality.

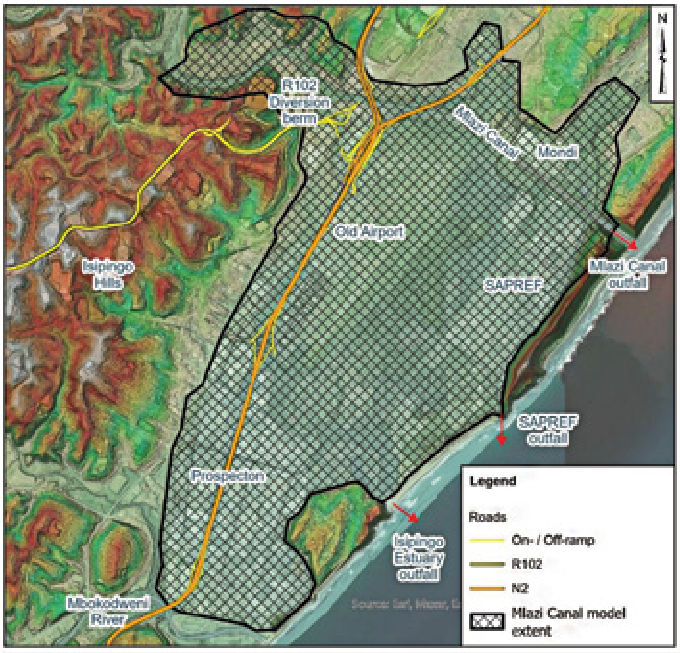

FIGURE 9: *Model extent for the Mlazi River model*

return periods but also investigated the impact of the Shongweni Dam on the flood hydrographs at the Mlazi Canal. A 2D HEC-RAS model was specifically developed to simulate the breaches associated with the Mlazi diversion berm and along the Mlazi Canal, with inflow flood hydrographs based on the results from the PCSWMM model. Various scenarios associated with the breaching of the diversion berm and canal were considered, as shown in Figure 10, to investigate the potential hazards and areas exposed to flooding. Furthermore, these scenarios also quantified the reduction in hazards and exposure expected once the reinstatement works have been completed.

Simulated results for the October 2017 and April 2019 events were compared to the local catchment model results, and the April 2022 event to the Mlazi Canal breach model results, to improve the confidence in the modelling results and associated scenarios investigated.

5.3 Local catchment modelling results

The hydraulic model results directly inform the hazard and exposure associated with flood events in the Prospecton area. A range of different recurrence interval events were simulated to determine the flood properties for various return periods. One of the challenges inherent in the modelling approach, specifically the 'Rain-on-Grid' method, is that each modelling cell receives rainfall input, which can initially result in shallow flood depths across the entire model extent. As a result, flood depths less than 50 mm were excluded from the risk assessment to focus on significant

Scenario	Description	R102 Berm		Mlazi Canal	
A	April 2022 event	Breaching		Breaching	
B	Current Conditions	Reinstated		At breached level	
C	Reinstated R102 and Mlazi canal	Reinstated		Reinstated	

FIGURE 10: *Breaching scenarios (modified form AECOM, 2024)*

FIGURE 11: *Local catchment 1 in 100-year flood depths*

inundation. Figure 11 presents the 1-in-100-year flood depths associated with the local catchment hydraulic model.

From the model results presented in Figure 11, it is evident that during extreme flood events, the bulk drainage system overtops, resulting in flooding of adjacent properties. Furthermore, the low-lying, flat nature of the topography in Prospecton poses a challenge to drain the developed areas once the bulk drainage system has reached its capacity, resulting in large areas being inundated with only a small increase in flood level.

5.4 Mlazi River modelling results

Another significant source of flooding, as experienced during the April 2022 event, is the overtopping of the Mlazi River diversion system, which includes the R102 diversion berm at the and the Mlazi Canal. During the April 2022 event, the diversion system not only overtopped, but the excess flow also resulted in scouring and failure of the flood protection system.

Since the April 2022 flood event, the breach of the R102 river diversion berm, as shown in Scenario A in Figure 10, has been reinstated. However, this scenario provides an understanding of the damages experienced during the April 2022 event and shows the relative impact of the breach on the flood depths when compared to the current condition of the diversion system. To better understand the importance of reinstating the Mlazi Canal breaches, four extreme flood events were simulated for Scenarios B and C in Figure 10. These included the 1-in-100- and 1-in-200-year events, as well as peak flow rates of 2 200m^3/s (approximately 1 in 275-year event) and 2 400m^3/s (approximately 1 in 375-year event). The latter two flows were derived from the tipping of the Shongweni Dam fuse gates which occurred during the April 2022 flood event.

a) Scenario A: April 2022 flood depths with R102 berm and Mlazi Canal breach	b) Scenario B: 2 200m³/s with R102 berm reinstated and Mlazi Canal breach	c) Scenario C: 2 200m³/s with R102 berm and Mlazi Canal reinstated

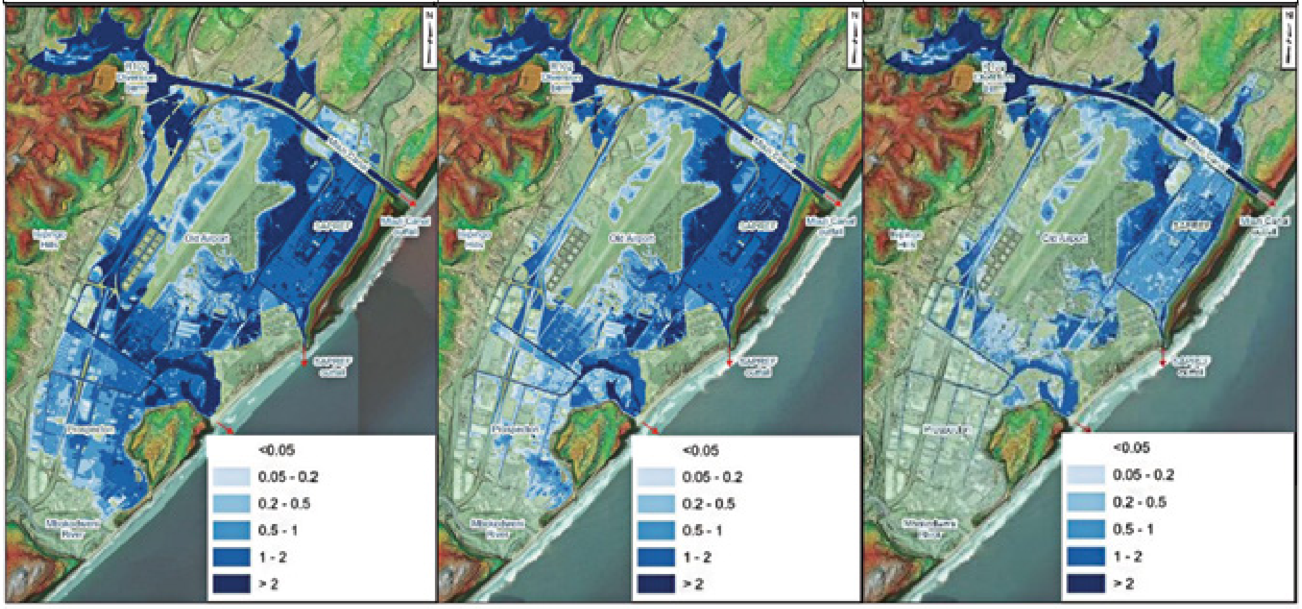

FIGURE 12: *Mlazi Canal model results for (a) Scenario A during the April 2022 event, (b) Scenario B and (c) Scenario C during the 2 200m^3/s event*

Figure 12(a) presents the hydraulic modelling results for the April 2022 event based on Scenario A in Figure 10, where the R102 diversion berm and Mlazi Canal have breached. As mentioned previously, the April 2022 event is considered greater than the 1 in 200-year event and is therefore compared to the 2 200m^3/s flood model results for Scenario B and C, shown in Figures 12(b) and (c) respectively, during this case study.

From the model results, it is clear that the overtopping and breach of the R102 diversion berm had a more significant impact on the flood depths in Prospecton, whereas the Mlazi Canal overtopping and breach would be more severe for the properties between the Mlazi Canal and the Isipingo Estuary.

5.5 Understanding the impact of mitigation strategies

As defined earlier in this paper, flood risk comprises hazard, exposure, and vulnerability. The previous section showcased the hazard and exposure components of the risk assessment. To better understand the vulnerability component of the flood risk, flood depth-damage relationships and maximum damage values were derived for each land-use type. The maximum damage values, presented as a cost per area, are not only a representation of replacement value but also indirect costs associated with a loss in revenue. These total damages (capital and operational losses) were scaled based on depth-damage curves derived from international sources, such as the Rijkswaterstaat (2004) and then modified based on stakeholder interviews.

This assessment indicated a total loss of approximately 4.1 billion USD as a result of the April 2022 floods, with the largest portion of the loss attributed to industrial land-uses and the associated business disruption (RHDHV, 2024). Since these curves were calibrated for the overtopping and breaching of the Mlazi Canal, modifications had to be made for the assessment of local catchment flood events.

At the time of the 2024 Economic Flood Risk Assessment study, several structural flood mitigation interventions have been planned (or partially implemented) by various stakeholders. Some of these mitigation measures were compared to a baseline model to evaluate their estimated economic impact.

Table 3 presents the interventions included in each of the models.

The impact of these mitigation strategies on the estimated total damage for various return periods is presented in Figure 13.

The flood mitigation interventions presented for the local catchment model had a localised impact on flood levels. This resulted in no significant change in the estimated total damage for all return periods up to the 1-in-200-year event experienced in Prospecton, as shown in Figure 13(a). However, the upgrading and scour protection interventions proposed for the Mlazi River model had a significant reduction in flood depths and extent, significantly reducing the estimated total damage in the Prospecton area for the extreme flood events.

TABLE 3: *Flood mitigation interventions included in each model*

Scenario \ Model	Local Catchment	Mlazi River
Baseline	Represents conditions prior to the implementation of the proposed flood mitigation interventions.	Assumes the R102 diversion berm and Mlazi Canal are reinstated to pre-flood conditions without scour protection measures, assuming a breach when overtopping.
Mitigated	• Additional sea outfall at Clark Road • Upgrading of the Prospecton Road Canal • Attenuation facilities in Isipingo Hills • N2 Relief Culvert and Canal system	• R102 diversion berm and Mlazi Canal upgraded to 1 in 200-year flood protection • Scour protection measures preventing a breach. • Spillway along the southern berm of the Mlazi Canal near SAPREF • Upgrading of the bulk drainage system and outfall near SAPREF

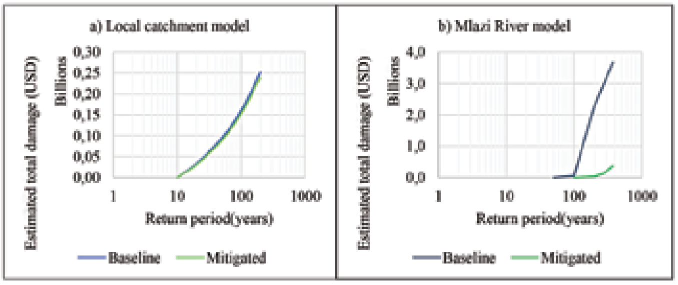

FIGURE 13: *Damage probability curves for the (a) local catchment and (b) Mlazi River models*

6. CONCLUSIONS AND RECOMMENDATIONS

This case study presented a condensed summary of specific parts of the studies conducted between 2019 and 2024. Its aim was to showcase the benefits of assessing all three components of flood risk: hazard, exposure, and vulnerability. Beyond the work presented in this paper, the reduction in flood damages was also compared to investment costs to further optimise the design and development of these flood mitigation strategies and inform the appraisal of mitigation strategies.

A key consideration for ensuring the sustainability of floodline studies—or more broadly, flood hazard assessments – is to move beyond the "simple line on a plan" approach. Instead, the scope of these assessments should include more detailed flood characteristics, such as depth and velocity combinations (to identify various hazard classifications), rate of flood level rise and duration of inundation. These richer flood characteristics can then be used for more than just identifying potential areas exposed to flooding, but also assist in disaster management, as well as determining potential damages. They can, in fact, facilitate a multi-layer approach to flood mitigation strategies. Ultimately, these strategies can then be optimised and appraised to better inform robust flood adaptation strategies. Unlocking this full potential of flood level assessments, however, truly necessitates moving beyond the basic "line on a plan" approach.

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