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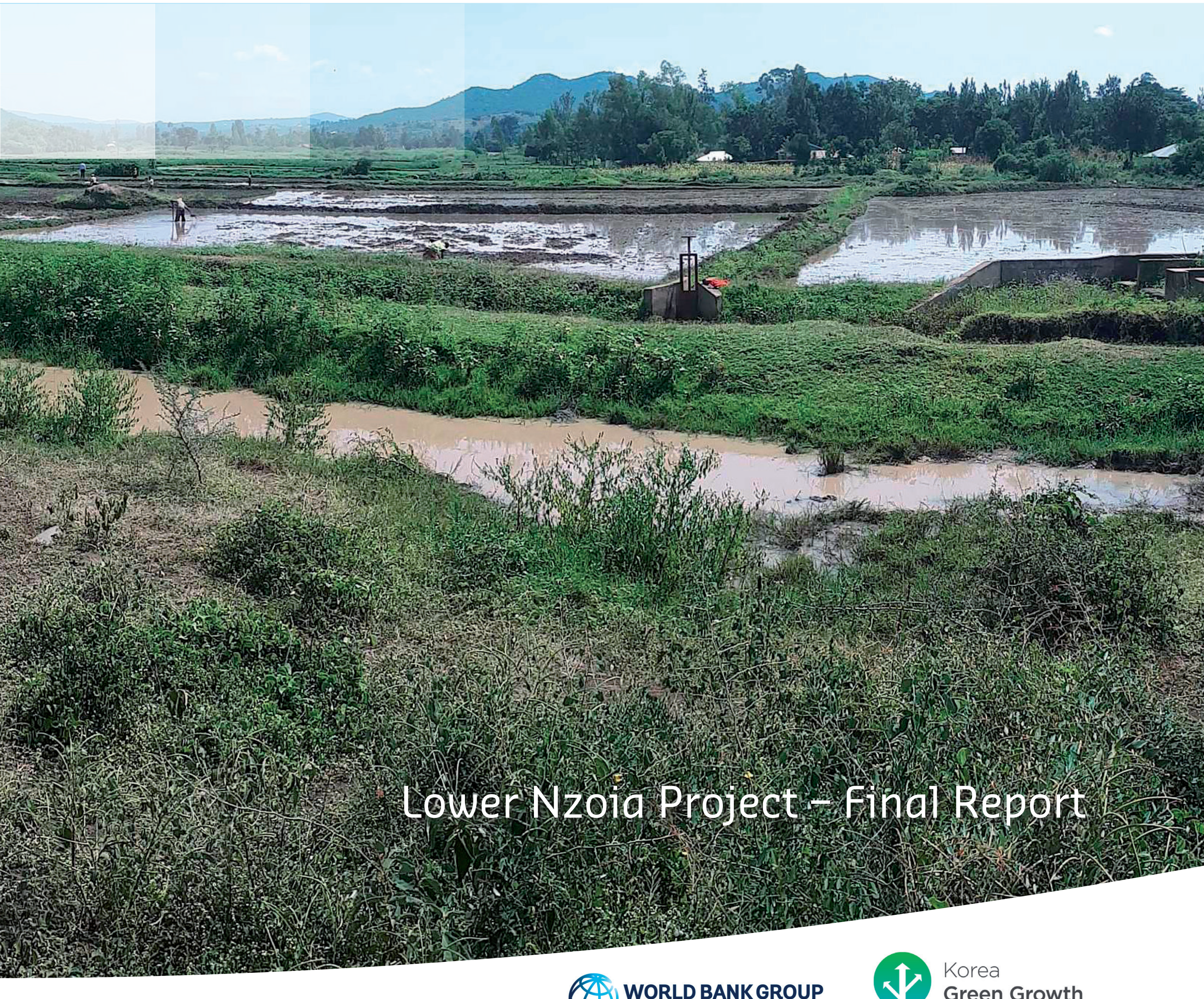

Lower Nzoia Project – Final Report

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Climate Change Risk Analysis for Projects in Kenya and Nepal

Lower Nzoia Project – Final Report

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Summary
This is the Final Report for the Nzoia case study of the World Bank assignment number 7187313, *Climate Change Risk Analysis for Projects in Kenya and Nepal*, financed by the Korean Green Growth Trustfund. The case study concerns the application of the Decision Tree Framework (DTF) to assess the climate change risk for the project to increase the irrigated area and to improve flood protection in the Lower Nzoia region. The Lower Nzoia project is supported by the World Bank under the Kenya Water Security and Climate Resilience Program.

This report describes the DTF and the Lower Nzoia irrigation extension and flood protection project. The DTF consists of four phases:

1. Project Screening Phase;
2. Initial Analysis Phase;
3. Climate Stress Test Phase; and
4. Climate Risk Management Phase.

This Final Report is an update of the Second Interim Report and describes the results of all four phases. Compared to the Second Interim Report, the findings and stakeholder feedback collected during the visit in May 2019 to Kenya and comments of the World Bank and stakeholders have been incorporated in the text of the report. Furthermore, results of some additional analyses have been included.

References
Vat, M.P. van der, Hunink, J.E. and Stuparu, D., 2019. Lower Nzoia Project – Final Report, Climate Change Risk Analysis for projects in Kenya and Nepal. Deltares, FutureWater and University of Cincinnati for the World Bank.

The work behind this report has been supported by several technical staff of Deltares, FutureWater and University of Cincinnati, namely Peter Droogers, Patrick Ray, Asphota Wasti, Marjolijn Haasnoot, Ümit Taner. This report and previous versions have been reviewed by Ad Jeuken, Deltares.

Status
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0 Executive Summary

0.1 Introduction

A quantitative assessment of the climate change risk vis-à-vis other identified risks unrelated to such change has been carried out for the Lower Nzoia investment project using the Decision Tree Framework methodology (DTF, Ray and Brown, 2015). The DTF involves a stepwise approach that guarantees that the depth of the analysis is coherent with the sensitivity of the project to climate change risks versus other non-climate change related risks. Furthermore, the DTF is a bottom-up approach focusing on the performance of the project under a range of future climate change realizations, instead of focussing the analysis on a limited number of climate change scenarios derived from results of Global Circulation Models (GCMs).

The Lower Nzoia investment project concerns the extension of the irrigated area and improvement of flood protection along the Lower Nzoia in West Kenya (Figure 0.1). The project is part of the Kenya Water Security and Climate Resilience Program (KWSCRP). A Final Design Report including an analysis of the economic feasibility of the project has been prepared in 2017 (Lahmeyer, 2017). This Final Design has been used as the basis for the climate change risk analysis.

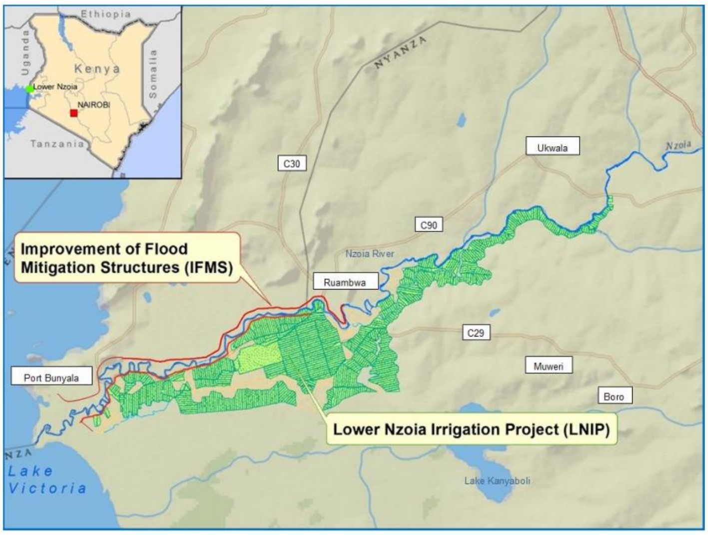

Figure 0.1 Location of the Lower Nzoia investment project in West Kenya (source: Lahmeyer, 2017). The dark green colours indicate the newly irrigated areas of LNIP1, light green the existing Bunyala irrigation scheme, the red lines the new embankments

0.2 Results climate change risk analysis

The results of the climate change risk assessment show that the Lower Nzoia investment project is sensitive to climate change, but that the design performs well under the current climate as well as under most of the future climate projections. Several performance indicators have been assessed:

- The project Economic Internal Rate of Return (EIRR) with a threshold value of 12%, the same as in the Final Design report;

- Economic robustness defined as the fraction of the GCM projections for which the project EIRR exceeds the threshold value;
- Reliability of the flood protection defined as the fraction of time that the flood protection succeeds to prevent flooding. The design safety level is 1/30 year, so the design reliability equals 29/30=0.97 1/year;
- Reliability of the irrigation water supply defined as the fraction of the time that irrigation water demand can be supplied;
- Vulnerability is a measure of the maximum damage to the project by floods or droughts. The maximum damage due to flooding could not be assessed due to lack of data on the damage of floods with low probability. For water supply the vulnerability is expressed as the maximum percentage of the demand that cannot be supplied, since this is directly related to crop damage; and
- Resilience is a measure of the capacity of the system to bounce back after failure. Here it is defined as the inverse of the average length of a flood event or shortage event. The socio-economic aspects of resilience, such as the time needed to recover after the event, are not included due to lack of data.

Analysis of historic trends and GCM results has informed the selection of a range of future climate change of -50% to +100% for precipitation and an increase of 0 ºC to +6 ºC for temperature. For the hydrological analysis the latter translates in an increase in potential evapotranspiration (PET) of 0% to 15%. For these ranges of future climate change time series of river discharges have been simulated using a weather generator and a hydrological model. These discharge time series have been used as input to calculate the project benefits of improved flood protection and extended irrigation following a similar approach as in the Final Design Report.

The results of the climate change risk analysis are presented in different ways in the two figures below. Figure 0.2 shows a climate response map indicating failure or success of the project, defined by EIRR threshold of 12%. The dots in the figure represent the actual climate and the GCM projections from different climate models and for different emission scenarios and time horizons. The result shows that the project performances well under the current climate and with an increase of precipitation of not more than 25%. Further increase of precipitation reduces project benefits due to increased flood damage, while a decrease in precipitation reduces the benefits from the extended irrigation area due to water shortage. 70% of the GCM projections result in a project EIRR of 12% or more, therefore the economic robustness of the project is assessed as 70%. It can furthermore be observed that the project is much more sensitive to the selected range in precipitation than the range in PET and temperature. Similar response maps have also been prepared for the reliability, vulnerability and resilience of the flood protection and irrigation systems.

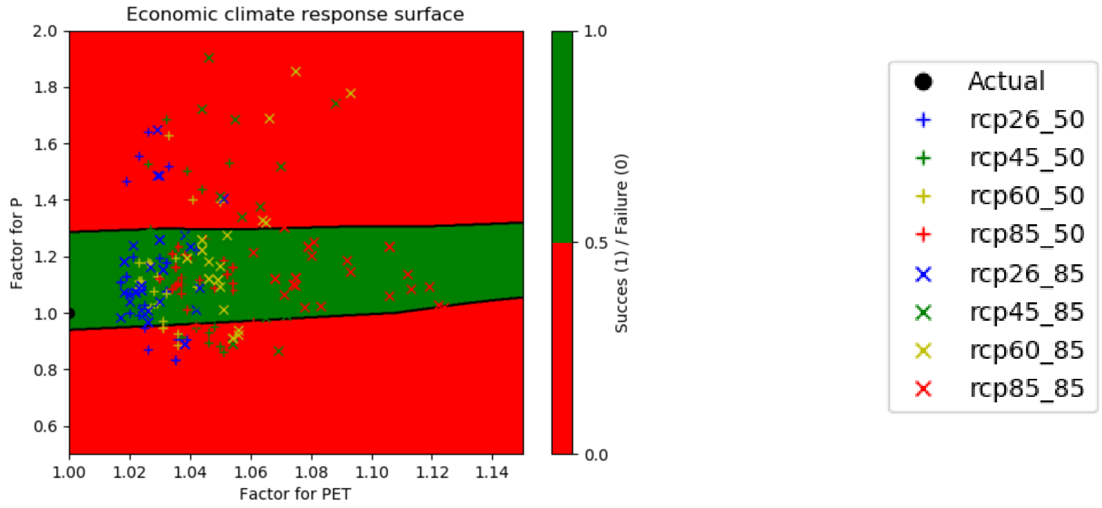

Figure 0.2 Climate response map with on the Y axis the factor of change in precipitation and on the X axis the factor of change in PET; the colours show the success (green) and failure (red) of the project to provide a 12% or higher EIRR and the dots show the location of the actual climate and the GCM results for the different emission scenarios RCP2.6, RCP4.5, RCP6.0 and RCP8.5 and for the time horizons 2035-2065 (indicated by _50) and 2070-2100 (indicated by _85)

Given the reduced sensitivity to temperature changes compared to rainfall changes, the previous figure can be simplified, focusing the results as in Figure 0.3 for the change in precipitation only. This figure shows that most GCM projections predict an increase in precipitation by less than 25%. The avoided flood damage increases with increasing precipitation to a maximum value of nearly 250 MKES/year for a 25% increase in precipitation. The supply reliability for the irrigation system decreases sharply with decreasing precipitation. This results overall in a maximum value of the project EIRR of around 13% for annual average precipitation ranging between the actual value and an increase by 25%. A decrease of precipitation or an increase by more than 25% will reduce the EIRR below the 12% threshold value. The frequency distribution of the GCM results show that 70% of the results are in the range between 0% and +25%, indicating an economic robustness of the project to climate change of 70%. 20% of the projections result in a below threshold performance of the project due to limited water availability as does another 10% due to increased flood damage. Please note that however that there is an ongoing debate in the climate modelling community on the performance of GCMs in the East-African region, thus, these likelihoods should be taken with caution.

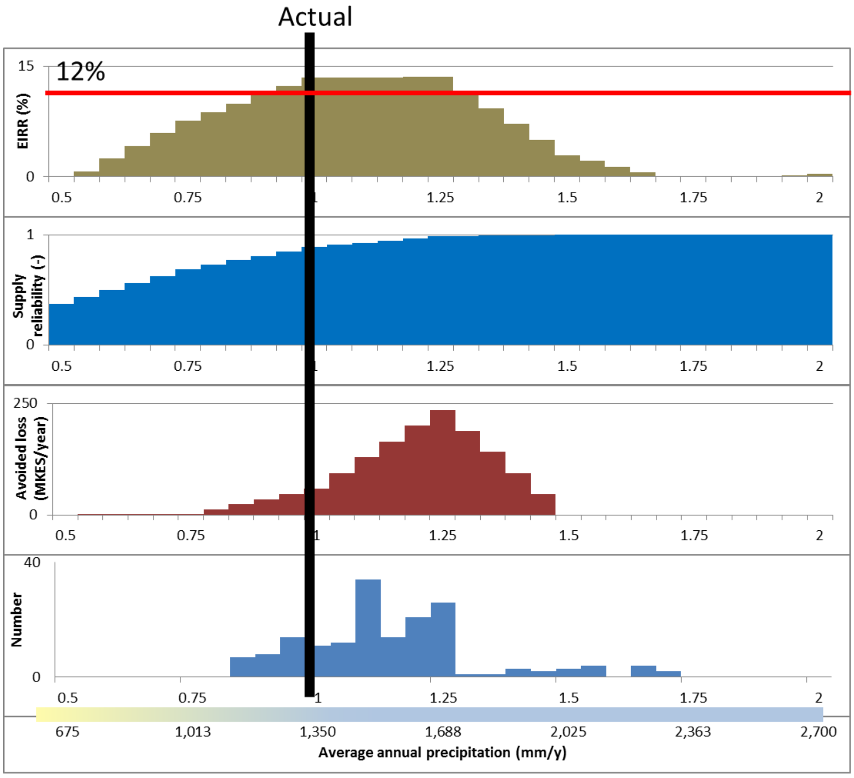

Figure 0.3 Results of the climate stress test showing (from bottom to top) for the range of future change in average annual precipitation of -50% to +100%: a) the frequency distribution for the GCM projections; b) the avoided flood damage; c) the supply reliability for the irrigation system; and d) the EIRR of the project.

For the flood protection, the design safety level of 1/30 years results in a reliability for the current climate of 1-1/30 = 0.96667. This will only happen in the current climate and with lower precipitation, which covers 20% of the climate futures. In all other climate futures, the precipitation increases and the reliability decreases.

In the current climate the average length of a flood event is 1.25 days, so the resilience equals 1/1.25 = 0.8 1/day. The likelihood over all climate futures of a resilience of more than 0.5 1/day is 56%.

For the irrigation scheme, the reliability performance indicator was analysed and shows that the typical 80% value that is often used for irrigation scheme design is reached in most of the climate futures (91%). The drought vulnerability indicator as defined in this study is related to the fraction of the demand that is not met with supply. The analysis shows that the system is already slightly vulnerable under climate change, with 59% likelihood that the vulnerability is 0.2 or lower. The drought resilience indicator is related to drought duration and shows that droughts will take likely two to three months in the future. Overall the analysis suggests that the performance indicators for the irrigation scheme are acceptable as farmers typically adapt their operations and practices to short periods of under-supply, and the project design considers this. More importantly: the analysis shows that further water resources developments upstream will likely have an impact on water availability to the project, which were also assessed (see hereafter).

A sensitivity analysis has been performed to assess the trade-off between the threshold EIRR value and the economic robustness of the project to climate change, since there is an ongoing debate about the right threshold value for climate adaptation investments. Often, as is also the case here, impacts of climate change and adaptation measures occur principally in the second half of project lifetime. These impacts get little weight with a relatively high threshold value like 12%. For this project, it appears that reduction of the threshold EIRR from 12% to 5% would increase the robustness of the project to climate change from 70% to 90%.

The impact of an alternative design with a flood protection level of 1/100 year has been analysed. The costs for this have been assumed to equal the costs to raise the protection level from the actual 1/10 year to 1/30 year as in the Final Design. The higher flood protection level increases the reliability and resilience of the flood protection as well under the current climate as for all climate futures analysed. However, the EIRR for the actual climate reduces from 13.4% to 12.2% and the economic robustness, the likelihood over the GCM projections of the EIRR to exceed 12%, decreases from 69% to 57%. This shows that for the actual climate as well as for most projections the avoided flood loss does not outweigh the extra costs of the increased protection level. This also indicates a trade-off between resilience and reliability on the one hand and economic robustness on the other hand.

0.3 Adaptation measures

Given the fact that the performance indicators (reliability, vulnerability, resilience and EIRR) show acceptable values for most of the climate futures, is it not considered necessary to modify the current design. However hereafter, several recommendations are done based on the non-climate change risks that require immediate attention.

Also, it should not be disregarded that 20% of GCM projections result in project failure due to limited water availability and 10% result in failure due to flood damage. As the future direction of climate change, especially in this region, is highly uncertain, it is recommended to apply the Dynamic Adaptive Policy Pathways approach (Haasnoot et al., 2013) to manage this risk. This approach is based on trigger points in future climate where the current design would no longer result in an acceptable project performance. Adaptations should be implemented to improve project performance if a trigger point is reached. The advantage of this approach is that costs for investment in climate change adaptations can be postponed till there is an actual need for adaptation.

Figure 0.4 presents pathways and trigger points for the Lower Nzoia project for both water availability and flood risk. For water availability the trigger point is a reduction of average annual precipitation below the current level, while for flooding the trigger point occurs at an increase of average annual precipitation by 25%. The pathways in Figure 0.4 indicate the adaptation measures that have been identified to adapt to a drier or a much wetter climate.

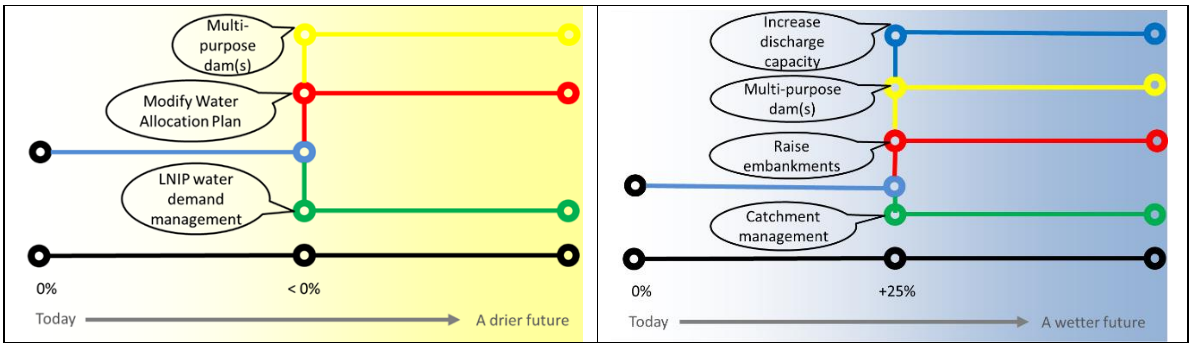

Figure 0.4 Dynamic Adaptation Policy Pathways for water availability (left) and flood risk management (right) for the Lower Nzoia project depending on the future development of the annual average precipitation under climate change, with 0% representing the actual situation and trigger points at a decrease in precipitation below the actual level (left) and an increase of 25% (right).

Figure 0.4 shows that it is recommended to start selection and design of adaptation measures if a decreasing trend is observed in precipitation and discharge or if a strongly increasing trend is observed. Therefore, it is essential to monitor as accurately as possible precipitation and discharge and to perform an annual trend analysis on the monitoring results. Also it is recommended to keep updated on the latest knowledge on climate trends in the East-African region and new insights in climate science, by collaborating with the research community and national experts in this matter.

0.4 Non-climate change related risks

The analysis has also shown that in addition to the climate change risks there are several non-climate change related risks to the project performance that have an impact in the same order of magnitude as climate change.

The most important non-climate change risk is the questionable quality of the discharge time series of the two stations used in the Final Design as well as for the hydrological model used in this analysis. This is no new finding. The Final Design and other earlier studies have identified this issue as well. The reason for the questionable quality appears to be the dynamics of the cross sections at the measurement locations due to siltation and sand mining. The risk is that water availability might be overestimated, or flood discharges might be underestimated. It is not possible to quantify this risk since no reliable discharge data are available, but most likely the range of uncertainty is smaller than the range of the impact of climate change. It is recommended to establish new discharge measurement stations upstream and downstream of the newly constructed intake weir as well as in the main intake canals and to monitor the development of the cross sections regularly.

A second non-climate change related risk is the lack of adequate operation, maintenance and enforcement. Based on local experience, it is estimated that this would lead to a reduction of the lifetime of the improved flood protection from 30 to 5 years. This would substantially impact project performance, but the EIRR would still be above 12%. It is recommended to ensure that institutional safeguards are in place to ensure adequate operation, maintenance and enforcement of the irrigation system and the embankments. These arrangements should consist of mechanisms to ensure adequate funding as well as sufficient oversight by stakeholders of the way in which the funding is used.

Cost recovery of at least a part of the operation and maintenance costs could provide funding as well as ensure commitment of the stakeholders. Enforcement and maintenance with respect to the improved flood protection could be strengthened by granting the WRUAs and the IWUAs a formal role, which they apparently currently do not have.

Furthermore, sand mining activities could be converted from a threat to an opportunity if activities would be regulated and coordinated to prevent damage to the flood protection system and to increase the discharge capacity of the river. It is recommended to prepare this regulation jointly by the counties Busia and Siaya in cooperation with WRA. A hydraulic modelling study is recommended to be included in the preparation of the regulation to assess the impact of changes in the riverbed on its discharge capacity.

A third non-climate risk that was identified and assessed is related to upstream water resources developments that compromise the water availability downstream. The analysis showed that it is very likely (91%) that the development of water resources as planned in the National Water Master Plan 2030 will lead to a basin that surpasses the sustainable use limit and to a moderately water-stressed basin. This indicates that there will be a considerable risk for water conflicts among users. A more phased and carefully planned water resources development strategy is recommended, possibly with reduced irrigation development, especially of the major schemes. An Integrated Water Resources Management (IWRM) approach is key to harmonize and coordinate developments across the basin and among stakeholders, especially given the fact that the basin covers several regions together with the regionalized political system the country has adopted recently.

Contents

Appendices

1 Introduction

1.1 Context and objectives of the project

Climate change is one of the major issues our society faces nowadays and directly affects most of our current and future activities. However, within the World Bank Group and other water resources organizations, there is no accepted general methodology or work process for assessing the significance of climate risks relative to all other risks to water resources projects. To overcome this, the World Bank Group has actively supported the development of a set of practical guidelines for practitioners, which has resulted in the publishing of the book '*Confronting Climate Uncertainty in Water Resources Planning and Project Design: The Decision Tree Framework'* (Ray and Brown, 2015). Since its release, the Decision Tree Framework, further referred to as DTF, has been applied to six pilot projects covering multiple water related functions: hydropower, water supply, and irrigation. The methodology is currently also being piloted in a river basin planning study in the Chancay-Lambayeque basin, Peru.

The World Bank has assigned Deltares, FutureWater and the University of Cincinnati to carry out two pilot applications of the DTF under the contract number 7187313, *Climate Change Risk Analysis for Projects in Kenya and Nepal (CCRA)*, financed by the Korean Green Growth Trust fund. This Final Report concerns the application concerning flood protection and irrigation developments in the Lower Nzoia River basin in Kenya. Figure 1.1 presents a map with the location of the Nzoia Basin in West-Kenya. The project is located in the south-west of the basin just before the river flows into Lake Victoria. As specified in the terms of reference, '*the overall objective of the project is to quantitatively assess the climate change risk vis-à-vis other identified risks unrelated to such change, followed by guidelines for a phased adaptation leading to increased resilience of the integrated Nzoia River Flood Program and irrigated expansion using the Decision Tree Framework*".

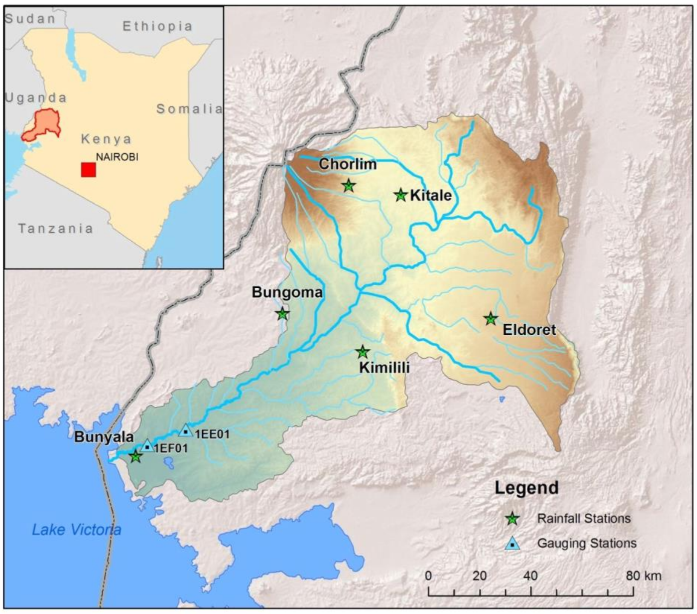

Figure 1.1 The Nzoia river catchment

The focus of the project has two dimensions: irrigation developments and future flood protection within the Lower Nzoia basin. The main application of the analysis regards two investment projects concerning on one hand, the implementation of an irrigation scheme in Lower Nzoia and, on the other hand, the Lower Nzoia Flood Protection scheme.
These two investments are connected: the flood protection works are in part designated to safeguard the investments in the development of the irrigated crop area. The proposed investments have multiple objectives, such as the development and revitalization of the Lower Nzoia area, more acceptable flood risk levels and prevention of further deterioration of levees.

The aim of the bottom-up vulnerability assessment using the Decision Tree Framework is to assess whether the objectives mentioned above can be reached and maintained under a range of plausible future conditions. If necessary, we will propose modifications to the design of the investment projects to enhance their resilience for climate change.

The analysis is based as much as possible on the existing data and models used for the Final Design of the flood protection and irrigation projects (Lahmeyer, 2017). Missing data and models have been replaced in the analysis. The approach and implementation of the analysis in the Final Design has been reviewed and where necessary adapted.

1.2 Scope and objectives of this Final Report

This report is the Final Report for the Nzoia case study of the Decision Tree Framework as mentioned in the ToR and is an update of the Second Interim Report with new text describing the progress of the project. The DTF consists of four phases:

1 Project Screening Phase;
2 Initial Analysis Phase;
3 Climate Stress Test Phase; and
4 Climate Risk Management Phase.

This Final Report is an update of the Second Interim Report and describes the results of all four phases of the DTF. Compared to the Second Interim Report, the findings and stakeholder feedback collected during the visit in May 2019 to Kenya and comments of the World Bank and stakeholders have been incorporated in the text of the report. Furthermore, results of some additional analyses have been included. Table 1.1 presents a description of the content of the different chapters.

Table 1.1 Content of the different chapters of this report

Chapter 2	Description of the DTF methodology and its application to the Nzoia river basin
Chapter 3	Description of the Lower Nzoia projects based on the previous studies, together with the findings from the inception visit. Results of the data collection process, including findings on data availability and our strategy on how to adapt to the limitations of the available data;
Chapter 4	Results of Project Screening Phase in the form of the Climate Screening Worksheet
Chapter 5	Results of the Initial Analysis Phase, including results of the data analysis
Chapter 6	Results of the Climate Stress Test Phase, including the hydrological model development and calibration and the hydrological risk assessment
Chapter 7	Results of the Climate Risk Management Phase
Chapter 8	Conclusions and recommendations

2 The Decision Tree Framework

The Decision Tree Framework has been developed by Ray and Brown (2015) and proposes a robustness-based, bottom-up approach to climate risk assessment. The framework is structured in four phases, illustrated in Figure 2.1.

The first phase is entitled '*Project screening'* and begins with an analysis of the system, with focus on the relevant elements that should be considered for decision making. The input of stakeholders is taken into account from this phase, in order to understand and identify both climate and non-climate system vulnerabilities. At this step, climate vulnerabilities are explored, to understand how the system could be impacted by changes in climate. Historical events and results of Global Circulation Models (GCMs) for different emission scenarios might be used to define the climate conditions that may pose a concern to the system. The result of this phase is an assessment whether the project is potentially sensitive for climate change risks.

The second phase, '*Initial analysis*', is only executed if the results of the first phase indicate that the project under consideration is potentially sensitive for climate change risks. The second phase consists of a rapid scoping exercise, using a simplified water resources model which relates climate conditions to impacts or performance indicators of the system. In this phase, simple statistical models may be employed, or existing and trusted models of the stakeholders, if available. This phase aims to estimate the sensitivity of the project to climate change risks relative to other risks and the result indicates whether a more in depth climate change risk assessment is required.

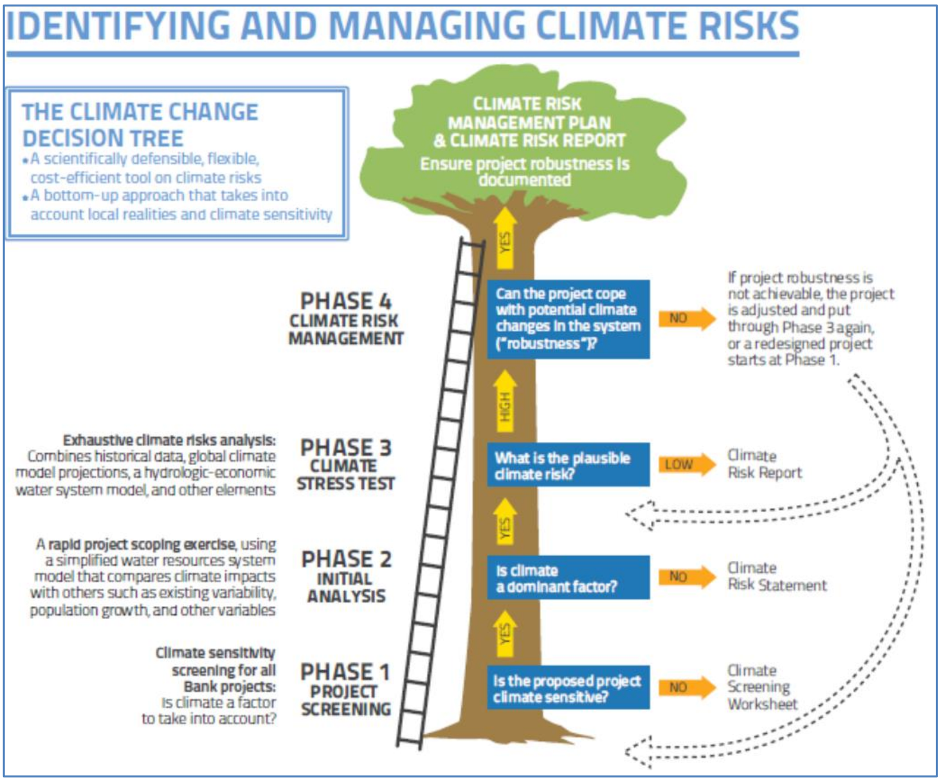

Figure 2.1 The Decision Tree framework (Ray and Brown, 2015)

The third phase of the DTF is entitled the '*Climate Stress Test'* and is only executed if the results of the second phase indicate that the climate change risks of the project are considerable and exceed the non-climate change risks. In this phase, a full system model is developed, in order to assess the climate sensitivity of the system in quantitative terms: robustness analysis. If significant and credible risks are identified in the robustness analysis, the phase 4, *'Climate risk management'* is executed to mitigate those risks.

Within phase 4, climate vulnerabilities are reduced through design modifications (or, in the extreme, the abandonment of the original design) using tools for decision making under uncertainty.

Phases 1, 2, and 3 include points for exit from the decision tree, to be used when the climate change risk is deemed limited relative to other relevant risks.

Traditional decision analysis in water systems planning is often performed using climate scenarios derived from the GCMs, which are downscaled to regional applications. The output of the GCM models (for example average daily temperature and precipitation) is then translated into projections of future stream flow using a hydrological model and then related to impacts. However, this approach heavily relies on the selected GCM models and may not consider the entire future range that is relevant for the area. Furthermore, the GCM models have a limited capacity in capturing climate extremes (Olsen and Gilroy (2012)), which are very important for assessing flood events and the impacts of droughts.

In a decision scaling approach such as part of the DTF, the performance of the system is tested across a wide range of potential futures, often beyond the range within the GCM models. In this way, the vulnerability of the water system is estimated, facilitating the identification of future scenarios in which the system has a lower performance. Figure 2.2 presents a schematic comparison between the traditional approach and decision scaling.

We note the previous application of the DTF in Kenya for the Mwache dam in 2016. The Mwache dam intends to provide domestic water use in the greater Mombasa area and irrigation use in the adjacent Kwale County. The purpose of the DTF application was to assess the risks to the Mwache Dam design due to climatic and demographic changes, and to evaluate dam adaptation and risk management options from a water supply perspective. Among the conclusions of the study, it was found that larger dam design sizes offered minimal benefits in terms of average yield; however, the larger design capacities may significantly increase system resilience to drought conditions by decreasing the duration of deficit events. Although the current study has a different purpose than the application for the Mwache dam, the Mwache study report offers useful insights on how the DTF was successfully applied.

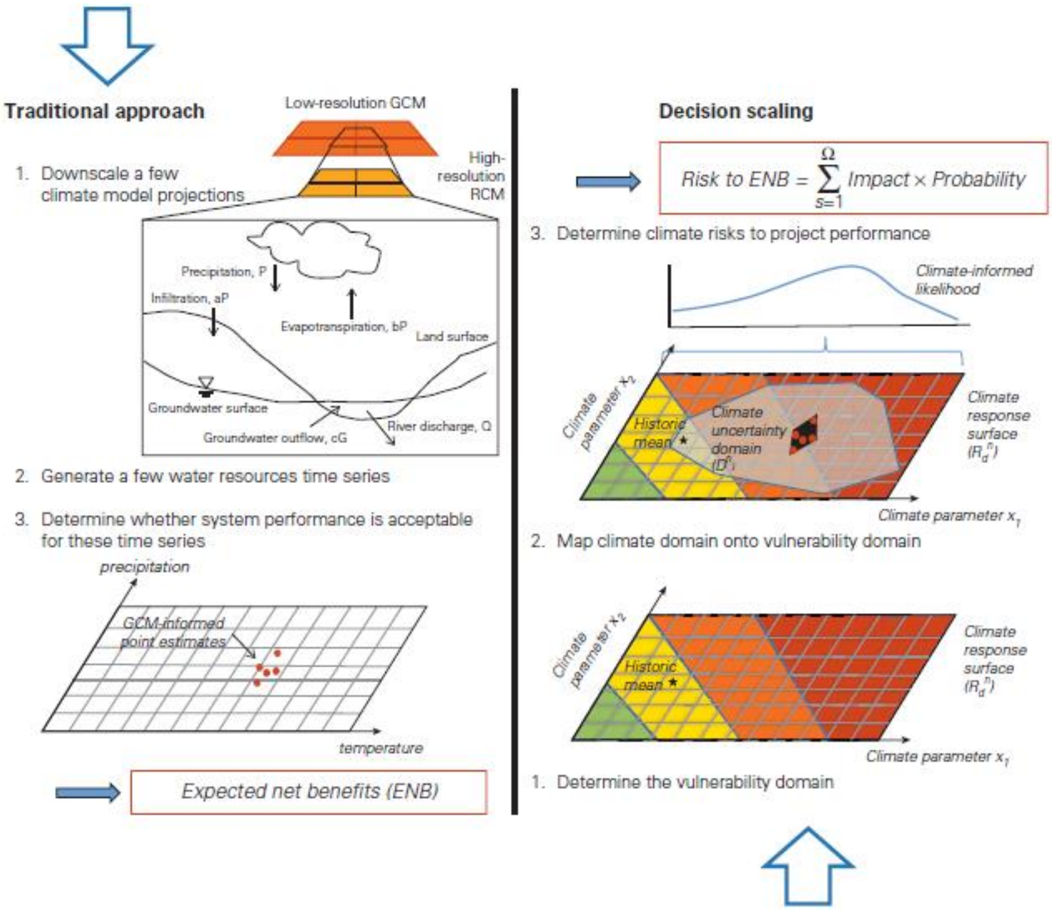

Figure 2.2 Schematic comparison of the traditional approach to climate change risk assessment (left) with decision scaling (right) (GCM = Global Circulation Model; RCM = Regional Climate Model) (Ray and Brown, 2015)

3 Description of the Lower Nzoia projects

The description of the Lower Nzoia projects presented in this Chapter is based on the Final Design Report (Lahmeyer, 2017) unless stated otherwise.

3.1 Description of the Lower Nzoia Irrigation Project – Phase 1 (LNIP-1)

The Lower Nzoia Irrigation Project (LNIP) is located in the Lower Nzoia Basin (see Figure 3.1) and is situated in 3 districts (Ugunja, Siaya and Bunyala). It will involve the construction of new water abstraction, conveyance, distribution and drainage structures. The Lower Nzoia Irrigation Project Phase I should contribute toward addressing the aspirations of agricultural development policies in Kenya, as envisioned in the Agricultural Sector Development Strategy and Kenya's Vision 2030. The project is financed by the World Bank and KfW (Kreditanstalt für Wiederaufbau (German Reconstruction Credit Institute), with a contribution from the beneficiaries and the Government of Kenya.

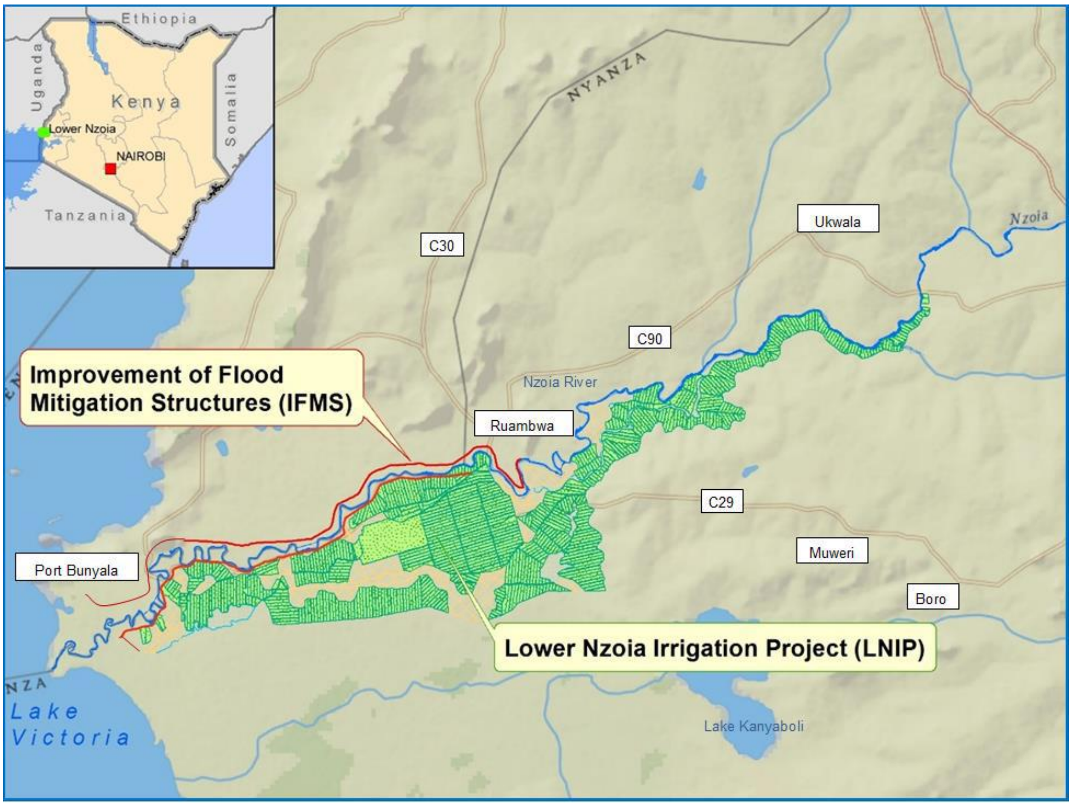

Figure 3.1 Project location (IFMS and LNIP-1) (Lahmeyer, 2017) LNIP-2 is located north of the River Nzoia. The dark green colours indicate the irrigated areas, light green the existing Bunyala irrigation scheme, the red lines the new embankments

The Lower Nzoia Irrigation Scheme should improve agricultural production through the rehabilitation of the already existing Bunyala irrigation scheme (which covers 705 ha) and expansion of the irrigated area. The Irrigation Scheme Phase I is located on the left bank (to the south) of the lower Nzoia River. It will have a gross command area of about 6,469 ha.

The diversion weir with intake structure, which supplies the irrigation areas, is located on the Nzoia River some 3 km upstream of the Old Nzoia Bridge. From this point, water is fed into the Headworks Canal via a Covered Connecting Channel (length 145 m) from the intake.
At the end of the Headworks Canal, the Head Regulator structure controls water releases into the (Left Bank) Main Canal (Figure 3.2).

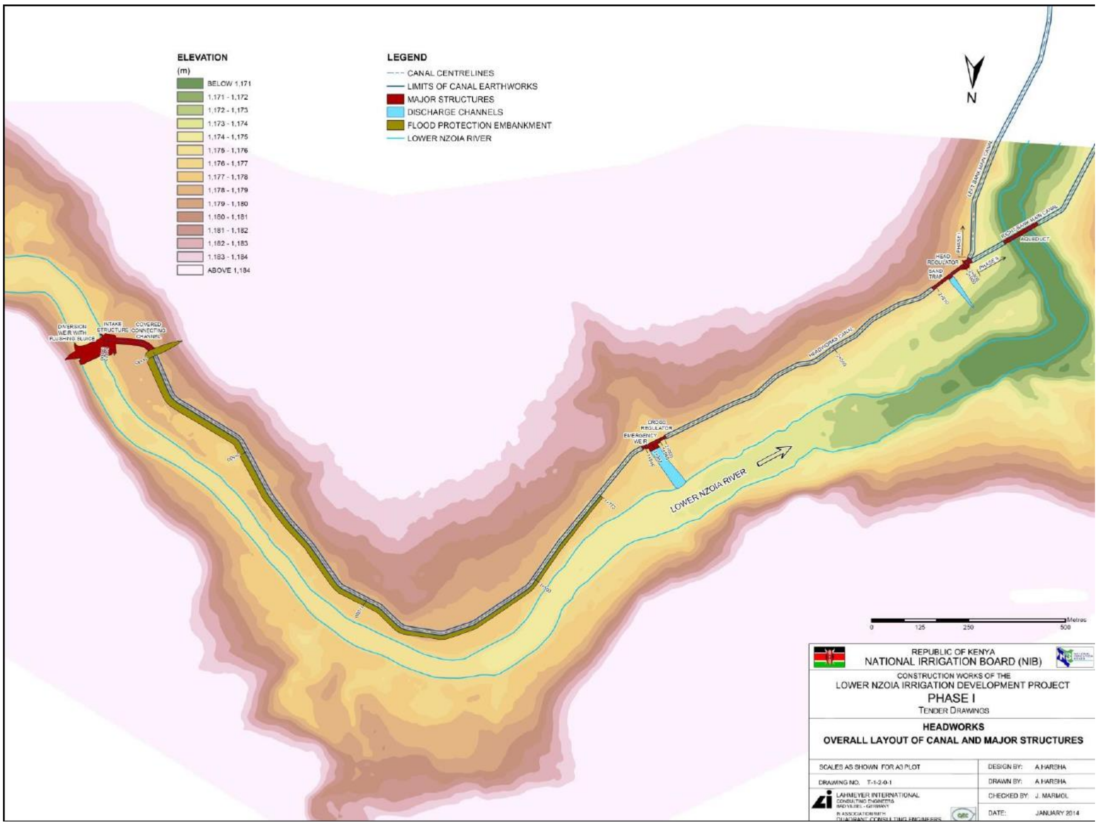

Figure 3.2 Headworks – Overall layout of canal and major structures (Lahmeyer, 2017)

The scheme is located in the lower part of the left bank of the River Nzoia and will benefit about 2,100 small farmers' households who will have an average of around 2 ha of net irrigable area. In total, the irrigated area will be 4,020 ha for Phase 1. During our field visit, stakeholders in the Bunyala irrigation scheme were extremely positive about the project as they believe it will provide more guaranteed and cheaper water in the future.

The Final Design has been elaborated by the engineering firm Lahmeyer, which will also perform the construction works. Preparation works for the construction of the diversion weir have already been started and have been visited during the inception visit (see Figure 3.3).

Figure 3.3 Construction works for the diversion weir for LNIP (picture taken July 2018 during the inception visit)

Overall, stakeholders consulted during the inception visited highlighted the following benefits related to the irrigation scheme:

- Improved food production / food security / enhanced nutrition (first priority);
- High value crops;
- Employment;
- Reduction of water use conflicts;
- Improvement of infrastructure within irrigation scheme;
- Evacuation centres with clean water;
- Increase education level;
- Improved livelihoods and increased income.

3.2 Description of the Lower Nzoia Irrigation Project – Phase 2 (LNIP-2)

The Phase II project covers the Ugunja and Bunyala districts and has a gross area of about 4,958 ha. The settled areas are located on the slightly higher, better-drained land than Phase I, with villages or homestead areas having farmhouses encircled by hedges, together with woodlots and roads in the same areas. The cropping area is the transition zone between the higher ridges into the depressions, which therefore has better drainage than the depressions themselves and allows the growing of rainfed crops, mainly for food.

The Phase II area includes the already existing Rwambwa-Mudembi Irrigation Scheme on the north bank. In total, the Phase II area will lead to an additional 3,622 ha on the right bank of the Lower Nzoia.

LNIP-2 is expected to start in 2019. No detailed design study has been carried out so far. Abstraction of water from the Nzoia River will take place using the same headworks as for LNIP-1 (see Figure 3.2 and Figure 3.3).

3.3 Description of the Implementation of Flood Mitigation Structures Project (IFMS)

The final design of the Implementation of Flood Mitigation Structures Project (IFMS) was carried out by Lahmeyer, based on previous work by Atkins. The objective is to reduce the flood risk from the Lower Nzoia between Rwambwa Bridge and Lake Victoria.

The works include improvements to the existing dykes, including measures to improve stability and control seepage during flood conditions. In some locations new dykes will be constructed, particularly where there is a need to set back the alignment where erosion by the river channel is a concern. Other key works include erosion protection measures on river meanders that threaten the integrity of the dykes and gated culvert structures

The dyke crest levels, due to the lack of reliable hydrological data and rating curves, were decided to be designed to withstand the highest observed flood on 10 May 2013, estimated at around 800 m^3/s, where the water level reaches Ruambwa bridge. A dyke level calculated for a discharge of 750m^3/s and including 750 mm freeboard is expected to give a satisfactory protection for this extreme flood event. Thus, a discharge level of 750m^3/s was used for the design of the crest levels in the final design report.

During the inception visit several stakeholders confirmed that a current risk is sand mining practices, which cause damage to the dikes, and undermines flood protection. In the future situation that these sand mining locations would disappear this may have an impact on the livelihood of the people depending on it. Also some stakeholders had the impression that the project could reduce the risk for flooding from so-called “back flow” from Lake Victoria, probably due to deposition of sediment carried by the Nzoia River near the inlet to the Lake. The project aims to reduce the sediment load of the river by its catchment management component, consisting of tree planting and improving agricultural practices.

Overall, stakeholders consulted during the inception visited highlighted the following benefits:

- Reduce flood risk by raising / improving dykes;
- Safe lives from flooding and avoid displacement and damage;
- Reduce incidence of water-borne deceases related to flooding;
- Less encroachment of riparian area;
- Reduced flooding from back flow.

3.4 Economic and financial analysis of the joint projects

The final design reports include a cost-benefit analysis of Phase I and Phase II of the LNIP, as well as of the IFMS. The performance indicator evaluated is the EIRR, the Economic Internal Rate of Return on the investment. The Final Design report presents an overall EIRR for the project of 14.1% per year.

The Phase I project is expected to transform an area of 3,837 net irrigable hectares from its current rain fed, flood prone subsistence cropping regime (with an annual cash benefit of about US$ 400 per net cropped ha) to an improved irrigated cropping pattern with an annual cash benefit of around US$ 4,000 per net cropped ha.

An estimate has been made of the LNIDP Phase I construction works investment costs: excluding the costs of agro-processing, the total project investment costs are estimated to be KES 6,603.6 million (US$ 77.7 million), of which 87% represents the construction works (KES 5,616 million, including 5% technical contingencies).

The cost benefit analysis (CBA) assumes that the water charges are collected in full (KES 2.1 per m^3 or KES 15,200 per net irrigated ha). This provides annual revenue at full development of KES 61.6 million to meet operation and maintenance costs. At full project development, water charges would be about 15% of farm costs, equivalent to about 5-8% of annual farm cash flow.

The cost-benefit analysis has shown that agro-processing will be very important to achieve financial and economic profitability of the project. Because of the very high volumes of paddy produced under either of the alternative cropping patterns, rice milling is the most cost-effective processing facility, even though it only doubles the value of paddy.

Project risk was examined through a sensitivity analyses on the financial and economic input parameters of the cost-benefit analysis. Project economic indicators were found to be most sensitive to the price of paddy rice, followed by the cost of the construction works.

The economic impact of including the proposed Phase II of the project on the right bank of the Lower Nzoia is considered favourable. In that case, the costs of the head works are shared between the projects on the two banks, because LNIP-1 and LNIP-2 use the same headworks. Despite this development, costs per unit area are higher on the right bank. However, it is expected that this will be compensated by reduced costs due to increased economic activity and scale of agricultural processing investments. The final design report concludes that the combined Phase I and II project is more economically attractive than Phase I alone.

3.5 Assessment of crop production and crop water demand

The Bunyala Irrigation Scheme weather station has been used to calculate the crop water requirements. The FAO CROPWAT 8.0 program has been used to calculate crop water requirements and net irrigation requirements.

Using CROPWAT 8.0, the net crop water requirements (ETcrop) have been calculated for a range of crops at different planting times. The net irrigation requirement is the crop water requirement less the effective rainfall (and, in the case of rice, percolation losses and water required to retain the correct water depth in the paddy). The results are expressed as the depth of water (mm) per 10-day period.

Applying the crop water requirements to the areas of the irrigation blocks (total 14), the crop water demands per block for Phase1 were calculated and are presented in Table 6-34 of the Final Design Report. The average crop water requirement (l/s x ha) is 0.33, minimum: 0, maximum: 1.39.

In order to estimate the gross water demand, the efficiency of irrigation has to be considered, based on three factors: i) conveyance efficiency (assumed 95%); ii) operation efficiency (assumed 95%) and iii) irrigation efficiency (depending on soil and crop, assumed to be between 50% and 72%). From this, gross irrigation requirements are calculated (table 6.36 in Final Design report).

The Final Design Report then compares (table 6-37) this gross water demand versus water available at the gauging location in the area (EE01) and concludes that over-abstraction can occur over a period of about 20 days at the end of January and the beginning of February.
It stresses though that this analysis is very conservative, and the amount over- abstracted is very limited in terms of flows (15% and 25%), and only lasts for a very short period of time.

The report also stresses that no information was obtained from Water Resources Management Authority (WARMA) for this analysis on possible future abstractions upstream in the Nzoia River that could affect the water availability for LNIP-1 and LNIP-2. During the inception visit it was clear that all visited stakeholders are concerned about the impact of future upstream water development projects on water availability.

3.6 Background information on hydrological modelling

Rainfall-runoff modelling was carried out for the Nzoia catchment using the Australian Water Balance Model (AWBM), which is part of the Rainfall-Runoff Library (RRL) package. The main inputs to this lumped model are observed evaporation, rainfall and river flow measurements. Calculations were done on a daily time step.

The data required to run this model include rainfall, which were derived from several stations within the Nzoia basin, evaporation estimates, discharge measurements for calibration, and catchment area. For this analysis, daily discharge data for station 1EE01 (Ruambwa) covering the period from 2001 – 2013 were used. The results shown in the report indicate good performance of the model.

The AWBM model used for the final design has been requested from NIB for use in the climate change risk assessment, but has not been received.

3.7 Background information on hydraulic and flood damage analysis

The detailed design report of IFMS focuses on the data from gauging station 1EF01, which is located approx. 650 m downstream of Ruambwa Bridge, located within the dyke project (see Figure 3.1). This data has been used earlier by previous studies done by Atkins and RCMRD (The Regional Centre for Mapping of Resources for Development Nairobi), which are related to the IFMS project.

The implementation support consultant has revisited the contemporary records and compared the data with known, verifiable events, such as the most recent significant flood of 10 May 2013, where photographic records are available and included in the body of the report. They identified issues with the rating curve, and contrasted measurements and observations with hydraulic modelling using the HEC-Ras tool.

The report shows several simulations by HEC-Ras, with different dyke levels, and flood discharges of 750m^3/s and 1000 m^3/s. The HEC-Ras model used for the final design has been requested from NIB for use in the climate change risk assessment, but has not been made available.

4 Phase I: Project Screening

This chapter describes the result of the Project Screening Phase for the Lower Nzoia basin in the form of the Climate Screening Worksheet for which a template is provided in Appendix B of Ray and Brown (2015). In this stage of the climate risk assessment, context analysis is performed using the Four C's framework of the DTF (Choices, Consequences, Connections, unCertainties), in order to describe potential climate vulnerabilities relative to potential vulnerabilities of other types. The result of this stage consists of a categorization of the project as either climate sensitive (leading to Phase II) or not climate sensitive (leading to the end of the climate assessment process and exit from Phase I).

4.1 Step 1

The first step of the climate screening worksheet consists of a description of the project context and objectives. For the Lower Nzoia basin, this information is available in chapter 3.

4.2 Step 2

The second step of the worksheet consists of an evaluation whether the development projects may be influenced by changes in climate. The Lower Nzoia development projects analysed in this study are water infrastructure projects, thus highly dependent on climate conditions influencing the water quantity. The irrigation part of the project is most sensitive for the dry season flow that defines the water availability at the time with the highest water demand. The flood protection part of the project is most sensitive for the maximum flow. Some key characteristics of the project are listed in Table 4.1. These underscore the fact that the project is potentially sensitive to climate change.

Table 4.1 Some key characteristics of the Lower Nzoia projects (based on the Final Design Report, Lahmeyer, 2017)

Performance indicator	EIRR (Economic Internal rate of Return of the investment)
Economic lifetime	30 years
Discount rate	12%
Project beneficiaries	Farm households in the project area. A significant part of the adult male population is currently not living on the farms, but working in the cities. It is expected that a lot of these males will return to their farm if irrigation becomes available.
Rehabilitation or expansion	A small part of the irrigation project focuses on rehabilitation of existing schemes, while the largest part is formed by conversion of rain-fed agricultural land to irrigated land. For the flood protection project, the largest part concerns rehabilitation and improvement of existing embankments with a minor extension.
Water intake	The irrigation projects depend completely on the intake of surface water from the Nzoia River.
Flood protection	The project contains a flood protection part
Water demand	The project concerns only irrigation water demand. No domestic water supply component is included.

The World Bank's Climate Change Knowledge Portal (http://sdwebx.worldbank.org/climateportal/index.cfm) provides multiple future projections for Kenya, regarding changes in both temperature and precipitation. Figure 4.1 and Figure 4.2 illustrate estimated changes in monthly temperatures for Kenya for the periods 2020-2039 and 2040-2059. The change in monthly temperature is with respect to the reference period (1986-2005). In general, the value of monthly temperature increase for the period 2020-2059 varies between 0.5 and 2.5 degrees.

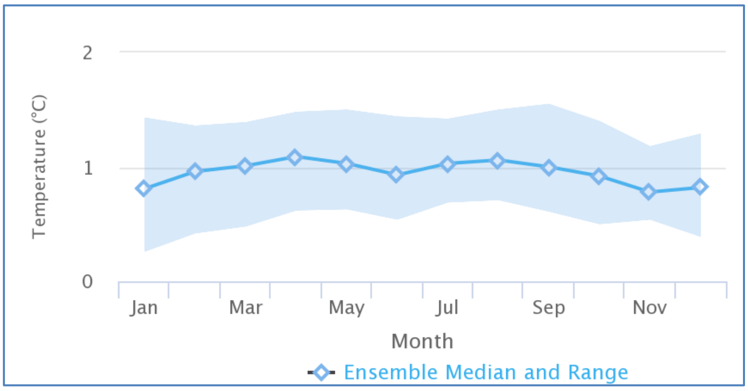

Figure 4.1 Projected Change in Monthly Temperature for Kenya for 2020-2039 showing the range of outcomes for different GCMs and emission scenarios as the shaded area and the median value as the line with the dots (source: World Bank's Climate Change Knowledge Portal)

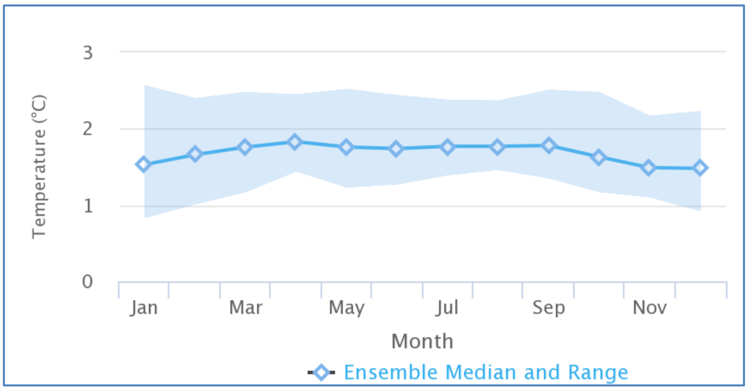

Figure 4.2 Projected Change in Monthly Temperature for Kenya for 2040-2059 showing the range of outcomes for different GCMs and emission scenarios as the shaded area and the median value as the line with the dots (source: World Bank's Climate Change Knowledge Portal)

The model results within the World Bank's Climate Change Knowledge Portal project changes in monthly precipitation ranging from minus 30% to plus 50 % compared to the historical observed monthly precipitation (Figure 4.3 and Figure 4.4). It is remarkable that specifically for the month of July all model results appear to indicate that there will be either no change in precipitation or a decrease. Change in precipitation is likely to have an effect on the existing and future development projects within the Lower Nzoia basin.

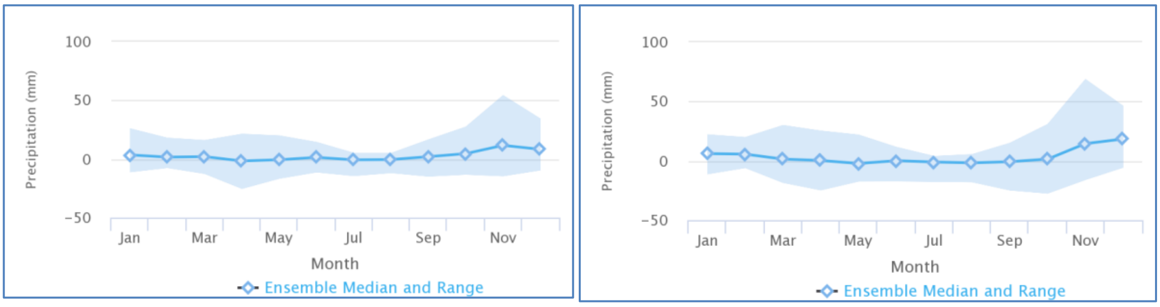

Figure 4.3 Projected Change in Monthly Precipitation for Kenya for 2020-2039 (left) and 2040-2059 (right)

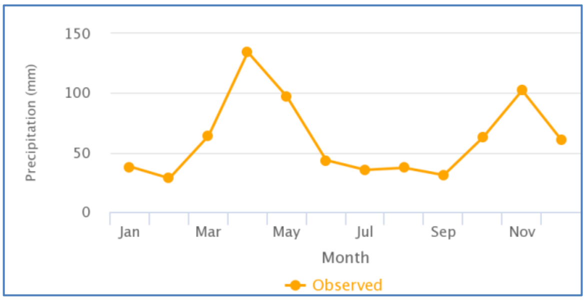

Figure 4.4 Historical Observed Monthly Precipitation for Kenya for 1986-2005

4.3 The Four C's: Choices, Consequences, Connections, unCertainties

The Four C's framework of the DTF aims to support the analysis of the context of the project and evaluates the project Choices (objectives and constraints), Consequences (performance thresholds), Connections and unCertainties.

Choices

The Lower Nzoia project situates itself in a relatively advanced stage of project development: the local authorities have committed to address future developments of the Lower Nzoia basin and have undertaken analysis and design studies for this purpose. The plans for the future developments are divided into different components: LNIP-1, LNIP-2 and IFMS as described in chapter 0 of this report. The design choices made within these components are highly dependent on water quantity, thus also on changes in climate conditions. Although the impact of the changes in climate is not yet quantified, the insights in the project so far suggest that there is more room for design adaptations in LNIP-2 since the detailed design for this phase has not yet been prepared. However, it might also be possible that certain design decisions in LNIP-1 could still be changed, although construction has already started. There appears to be little benefit in delaying implementation of LNIP-1 and IFMS. Delay of implementation of LNIP-2 could be considered.

The major relevant design choices are:

- The area and location of irrigated land;
- The cropping patterns on the irrigated land;
- The level of the embankment.

The findings of the inception visit do not suggest that there is much discussion remaining about the choices made in the Final Design. Complaints of farmers mostly focused on delay in implementation of the project.

Consequences
The findings of the inception visit suggest a high level of support for the Lower Nzoia projects from different stakeholders, who are actively involved in the project developments. However, many stakeholders show unrealistically high expectations regarding the benefits of the project, such as the complete prevention of flooding and the permanent availability of irrigation water. All stakeholders are concerned about the impact of future upstream water development projects on water availability. Furthermore, possible new development plans and limited coordination between different actors may hinder a smooth and successful project implementation.

We have identified both possible benefits of the project and possible negative consequences from stakeholder input during the inception visit. These findings are listed in Table 4.2 and Table 4.3.

Table 4.2 Benefits of the project

	Benefits of the project
1	Improved food production / food security / enhanced nutrition (first priority)
2	High value crops
3	Reduce flood risk by raising / improving dykes
4	Employment
5	Reduction of water use conflicts
6	Improvement of infrastructure within irrigation scheme
7	Safe lives from flooding and avoid displacement and damage
8	Reduce incidence of water-borne deceases related to flooding
9	Evacuation centres with clean water
10	Increase education level
11	Improved livelihoods and increased income
12	Reduced sediments from watershed management reduces costs of dyke maintenances and increase life span of dykes
13	Less encroachment of riparian area
14	Reduced flooding from back flow

Table 4.3 Negative consequences of the project

	Negative consequences of the project
1	Resettlement (5 households)
2	Economic resettlement (losing land)
3	Malaria / bilharzia from stagnant water
4	Less flow through riparian zone of lakes
5	Aquatic ecosystem influenced by sedimentation
6	Higher groundwater level leads to more evapotranspiration and might lead to salinity problems. Should be mitigated by the deeper drainage canals in the design.
7	Loss of sand mining locations → loss of livelihood
8	Migration to the area due to increased economic opportunities, might lead to competition
9	More exposure to pesticides and herbicides which might threaten drinking water supply from wells
10	Reliance on flood protection might increase vulnerability of assets and lives

The project performance indicator used in the Final Design is the EIRR with a threshold value equal to the selected discount rate of 12%. The EIRR captures most of the economic benefits from irrigated agriculture and flood protection (items 1 to 3 in Table 4.2), but does not take into account the listed negative consequences nor the intangible benefits. The use of the EIRR as the project performance indicator in the climate change risk analysis has been discussed in the wrap-up meeting of the inception mission on July 12, 2018. All stakeholders present, World Bank, WRA PIU, MoWS, NIB, KfW, Directorate of Climate Change agreed with the selection of this performance indicator.

Connections

The project results are very directly connected with climate changes due to their reliance on the flow of the Nzoia River. Sufficient water is needed in all years (including dry years) and during all seasons in order to support irrigated agriculture. And the flow should not exceed the design flow more often than foreseen to protect lives, assets and agricultural production from flood damage. For our modelling framework described in Chapters 5 and 6 this means that the climate change should be expressed ideally in parameters directly related to water availability and flooding, such as the dry season precipitation deficit and the maximum monthly precipitation.

A crop growth model will be used to assess the impact of reduced water availability on the crop production, while for flood damage the impact of climate change on the frequency of the design flood event will be evaluated.

The success of the project is closely connected to potential development of new irrigation projects upstream. This is recognized by the project stakeholders, but apparently no coordination has taken place so far and no investigation of the combined impact of the Upper and Lower Nzoia irrigation development projects on water availability has been carried out.

We also mention two ongoing studies that are investigating the combined impact of implementing the upper and lower Nzoia irrigation project. The NIB has appointed a consultant to assess the impact of full implementation of the planned upper scheme on water availability to LNIP-1 and LNIP-2. Separately, the KWSCRP ISC 2.2 ‘Strengthening Water Resources Planning and Management’ have included the upper and lower schemes (and other planned developments) in a maximum development scenario forming part of the analyses feeding into basin planning for the Lake Victoria North Basin.

unCertainties

The Lower Nzoia development projects are subject to multiple non-climate change risks. The plans for water developments upstream have an immediate effect on the water availability in the Lower Nzoia region. The upstream irrigation plans are considered to have the highest consequences in this direction; other plans include domestic developments (due to population growth) and industry related water demand. The prospect of two multi-purpose dams upstream has been mentioned during the inception meeting; however this is currently not politically acceptable and therefore dam developed is currently stalled.

Other not climate related risk is the lack of coordination and integration of developments, policies and operations between the institutions. WRA coordinates with other institutions for regulating water use activities in the catchment; however its authority is not always recognized by the local counties. Also, WRA is only in charge of water aspects, while the planning of developments related to land use and industry are performed by other institutions.

Operation and maintenance of dikes and irrigation installations also influences the successful implementation of the projects.

The facts that the fees may be used for other purposes than maintenance, farmers may not pay the fees, coupled with other governance and institutional issues pose serious threats to the sustainability of the projects.

We further name other possible factors of risk: limited market for the agricultural products, crop diseases, crop reductions due to not sufficient water, less than planned impact of the catchment management part of the project resulting in sedimentation and raising of flood levels and that design is based on relatively high theoretical irrigation efficiency.

4.4 Synthesis

The irrigation and flood risk reduction objectives within the Lower Nzoia projects do highly depend on the water flow of the Nzoia River. Climate related changes that influence the water quantity will therefore have a direct effect on the success of the Lower Nzoia projects. Although other non-climate related factors might pose a threat to the project, a more in-depth quantitative exploration of the project robustness to climate change and the relative importance of climate change and non-climate change related risks is needed. The results of this analysis are presented in Chapters 5 and 6.

5 Phase II: Initial Analysis

5.1 Overall approach

The aim of the Initial Analysis Phase is to determine whether the project performance should be considered sensitive to climate change risks when compared with sensitivities to non-climate factors. This phase normally employs either an existing water systems model (as might have been developed for a prefeasibility study) or a simple water balance analysis.

The basis for the initial analysis is the cost-benefit analysis as presented in the Final Design Report (Lahmeyer, 2017). At some points in the analysis the results presented in this report deviate from those in the Final Design Report. This is further discussed in Appendix D. The project performance indicator presented in the Final Design Report is the EIRR of the investment. However, it is too complicated to assess the project performance in terms of EIRR during the short Initial Analysis Phase. Therefore, the impact is analysed on water availability for irrigation and on flood damage.

This Chapter starts with a presentation on the data availability and continues with an analysis of these. Then the non-climate change risks are presented, followed by the analysis of the sensitivity of the irrigation and flood protection components of the project.

5.2 Data availability

This section presents an overview of the available data relevant for the climate change risk assessment of the planned Lower Nzoia projects. We hereby indicate the data sources we have considered for the analysis. Table 5.1 presents an overview of the available data. For topography, precipitation and evapotranspiration, different sources of data are indicated. The datasets used in the hydrological modelling are highlighted in yellow.

1. **Topographic information.**
   – Three data sets are available for the digital model of the terrain, of resolution ranging from 30 m to 2.2 km. The HydroSHEDS data has been provided by RCMRD, while the SRTM data has been downloaded from the NASA website. In the hydrological modelling, the HydroSHEDS data of resolution 2.2 km has been used. This choice is motivated by the necessity of having a fast hydrological model, needed to simulate many weather perturbations. We note that the Final Design report (Lahmeyer (2017)) mentions the existence of a LIDAR survey topography data (survey by the Western Kenya Community Driven Development and Flood Mitigation project (WKCDD&FMP)). However this dataset was not provided during this project and was therefore not used in the analysis.

2. **Meteo information**
   – Unfortunately, neither measured precipitation nor measured temperature data have been made available for the Lower Nzoia basin. This means that global datasets are needed to analyse the hydrology of the system. Where possible, literature was consulted to validate the global datasets.
   – For precipitation, six datasets are available, of different resolution and timespan. The CHIRPS dataset seems most suitable for the hydrological analysis, based on the data availability and also previous usage by RCMRD in the CREST model.
   – Daily temperature data is available from ECMWF, for the period 1979-2014.

- Potential evapotranspiration data is available from WRR2 (eartH2Observe) and is derived using the Penman – Monteith equations.

3. Hydrological information

- WRA has made available discharge data for stations 1EE01, for the period 1963-1994, and 1EF01 for the period 1974-2018, both datasets including missing data
- Flow discharge records were received from RCMRD for the station 1EF01 (Rwambwa), located close to the Ruambwa Bridge, for the period 1985-2006 and 2010-2016.

4. Water use and demand

- Estimates of present water uses and future water demands are included in the National Water Master Plan 2030 (NWMP 2030). The data behind these estimates (irrigated area, population, livestock, etc) will be used to develop the water resources system model. The most relevant data that will be extracted from this data source are (current and future):
  - Population;
  - Irrigated area (including future projections);
  - Water supply infrastructure;
  - Prioritisation of water allocation;
  - The inception meeting confirmed that new large storage dams in the basin are not feasible (mainly due to political reasons) so the impact of this potential additional storage will not be considered.

Table 5.1 Data sources with in yellow the source used in the hydrological modelling

Parameter	Name	Resolution	Format	Time step	Period	Source	URL/Source
Topographic information							
Topography	HydroSHEDS	2.2 km	GeoTIFF			USGS	Provided by RCMRD
	HydroSHEDS	927 m	ASCII			USGS	Provided by RCMRD
	SRTM	30.9 m	GeoTIFF			Nasa	https://search.earthdata.nasa.gov
Meteo information							
Precipitation	CHIRPS	5.5 km	GeoTIFF	Daily	1981 - 2017	UCSB*	ftp://ftp.chg.ucsb.edu/pub/org/chg/products/CHIRPS-2.0/africa_daily/tifs/p05/
	MSWEP	27.8 km	NetCDF	Daily	1979 - 2014	eartH2Observe	https://wci.earth2observe.eu/thredds/ncss/grid/jrc/mswep-rainf-daily-agg.nc/dataset.html
	ECMWF	111.3 km	ASCII	Daily	1995 - 2014	eartH2Observe	https://wci.earth2observe.eu/thredds/dodsC/ecmwf/met_forcing_v0/rainf_daily.nc.html
	RFE	11.1 km	NetCDF	Daily	2001 - 2017	WATCH	https://wci.earth2observe.eu/thredds/catalog/cnr/rfe2.0/catalog.html
	TRMM V7	27.8 km	BIN	3 hours	2000 - 2017	NASA	ftp://trmmopen.gsfc.nasa.gov/pub/merged/mergeIRMicro/
	TRMM V6	27.8 km	BIF	Daily	2001 - 2004	NASA	Provided by RCMRD
Potential evapotranspiration	PET	27.8 km	BIF	Monthly	--	USGS	https://earlywarning.usgs.gov/
	PET	27.8 km	BIF	Daily	2001 - 2004	USGS	Provided by RCMRD
	WRR2	27.8 km	NetCDF	Daily	1979 - 2014	eartH2Observe	https://wci.earth2observe.eu/thredds/catalog-earth2observe-model.html?dataset=deltares-ref-et-penmanmonteith-wrr2-agg
Temperature	ECMWF	27.8 km	NetCDF	Daily	1979 - 2014	eartH2Observe	https://wci.earth2observe.eu/thredds/ncss/grid/ecmwf/met_forcing_v1/tair_daily.nc/dataset.html
Water use and demand information							
Irrigation Demand		Project			Current	Final Design R.	
Crops and growth seasons		Project			Current	Final Design R.	
Efficiencies		Project			Current	Final Design R.	

Parameter	Name	Resolution	Format	Time step	Period	Source	URL/Source
Population		Basin		Annual	2010; 2030	NWMP 2030	
Irrigated area		Basin		Annual	2010; 2030	NWMP 2030	
Water supply infrastructure		Basin		Annual	2010; 2030	NWMP 2030	
Priorities water allocation		Basin				NWMP 2030	

Note: (*) UCSB = University California Santa Barbara

For the climate change projections, different sources of information have been used:

- The World Bank's Climate Change Knowledge Portal (http://sdwebx.worldbank.org/climateportal/)
- Coupled Model Intercomparison Project (CMIP5) (https://cmip.llnl.gov/cmip5/)
- NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) (https://cds.nccs.nasa.gov/nex-gddp/)
- The IPPC reports (http://www.ipcc.ch/report/ar5/)

The climate change projections are used as an indication of the probability of the problematic climate conditions that have been identified in the climate stress test.

Our overall conclusion with respect to the availability of data is that enough data of sufficient quality are available to carry out the climate change risk analysis, although the data analysis showed some issues with the reliability of the discharge data (see further Section 5.3.3).

5.3 Data analysis

The Nzoia river basin is located in the western part of Kenya. The Nzoia river network runs in the northeast–southwest direction, from the Cherangani Hills to Lake Victoria, where it drains. Its elevation ranges from above 4300 meters above sea level (m.a.s.l.) on Mount Elgon to about 1135 m.a.s.l. near Lake Victoria. The Nzoia main river measures ~334 km and has a catchment area of about 12 950 km^2, which makes it the major Kenyan tributary to Lake Victoria (RCMRD, 2015).

The Nzoia basin presents annual average climatic conditions which vary from tropical humid with 16^{0}C in the highlands to semi-arid with 28^{0}C in lower areas. Due to the inter-tropical convergence zone, the Nzoia watershed experiences four seasons per year:

- Two rainy seasons (short rains from October to December and long rains from March to May).
- Two dry seasons (January to February and June to September).

This section has two objectives: analyse the characteristics of the available precipitation and evapotranspiration data and look for possible evidence of climate change. The data sources can be found in Table 5.1. For precipitation, three gridded datasets data sets were considered: CHIRPS (1981 - 2017), MSWEP (1979 – 2014) and RFE (2001 - 2017). Two other datasets were downloaded (ECMWF, TRMM V7 and TRMM V6) but were not further analysed because of the limited data length and difficulty of assembling the data consistently. For potential evapotranspiration we have considered the WRR2 (1979 - 2014), as this is the longest dataset available.

5.3.1 Precipitation

Figure 5.1 shows the annual cumulative precipitation for the Nzoia basin, from three data sources. We can see that the CHIRPS and the MSWEP datasets gave a good overall agreement, while the RFE dataset has lower annual cumulative precipitation. There is considerable inter-annual variation of the estimated precipitation ranging from 700 mm to almost 2000 mm when considering all three datasets. The CHIRPS data has an overall annual mean cumulative precipitation equal to 1480 mm, MSWEP of 1408 mm and RFE of 1326 mm. We have compared these values with the mean annual rainfall reported by Kizza et al, (2011), using 13 rainfall stations for the period 1970–1988 (Figure 5.2). They report a mean annual rainfall of 1398 mm, which means that all three data sets are quite close to the measured annual average precipitation.

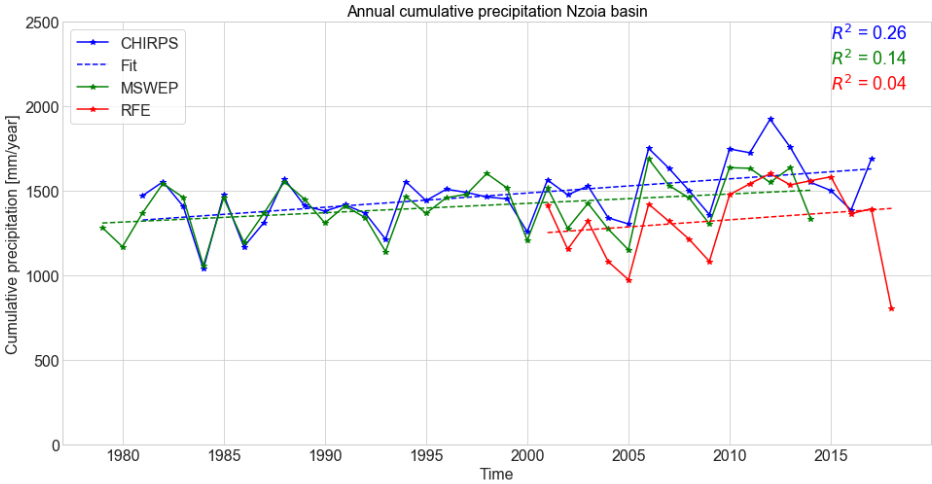

Figure 5.1 Annual cumulative precipitation for the Nzoia basin

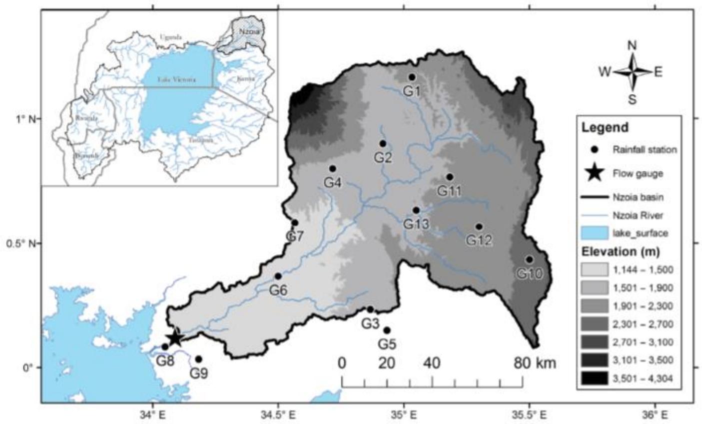

Figure taken from Kizza et al, (2011): Fig. 1 The rainfall stations are labelled G1 to G13, data is covering the period 1970–1988.

Station ID	Mean annual rainfall (mm/year)
G1	952
G2	1263
G3	2135
G4	1482
G5	2050
G6	1995
G7	1517
G8	1063
G9	1124
G10	1198
G11	1033
G12	1025
G13	1334
Average	**1398**

Figure 5.2 Annual average precipitation for the Nzoia basin, based on Kizza et al, (2011)

When applying a simple linear relation to the cumulative annual precipitation, we observe an increasing trend for all three precipitation data sets.

In terms of average monthly distribution, December, January and February are the driest months, while the highest precipitation occurs in April and May (Figure 5.3). We see that the three data sets generally agree with respect to monthly precipitation data, with the CHIRPS data having slightly higher values. Kizza et al, (2011) report a mean monthly rainfall in the catchment for the period 1970–1988 from about 40 mm in December and January to about 185 mm in April, with an additional peak of 145 mm in August (Figure 5.4). This shows that the gridded datasets might slightly overestimate the precipitation when compared to these measurements.

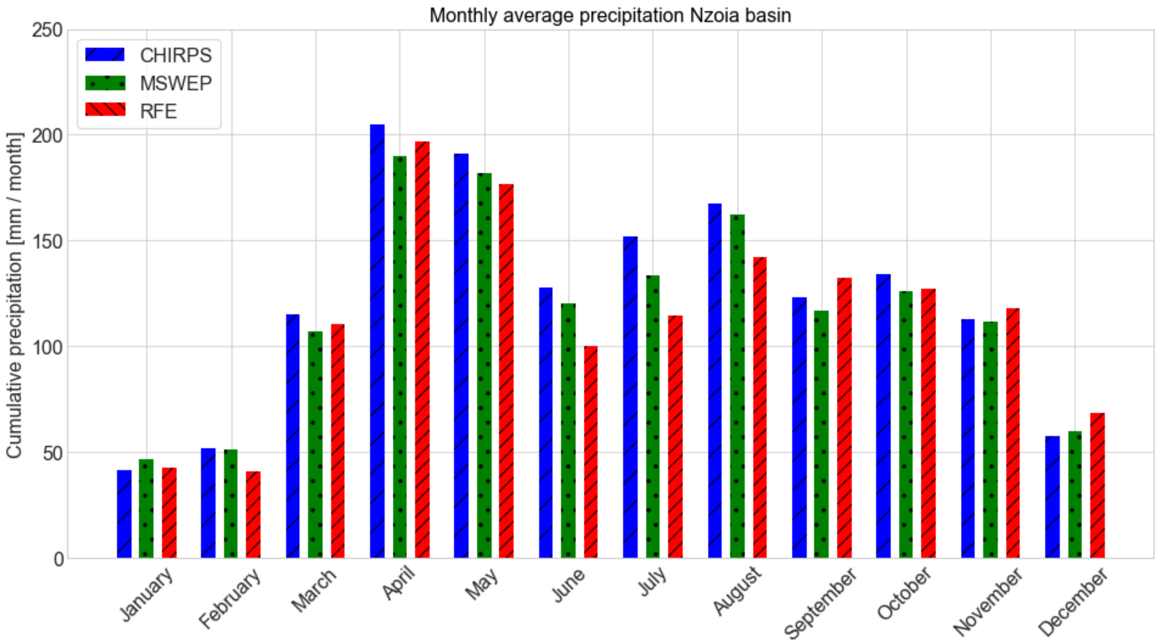

Figure 5.3 Average monthly precipitation distribution for the Nzoia basin

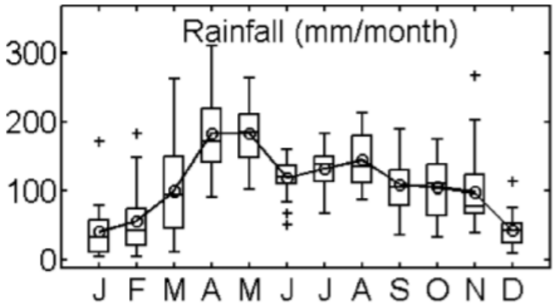

Figure 5.4 Figure taken from Kizza et al, (2011): Fig. 2 Mean monthly values for the stations G1 to G13, period 1970–1988

Le and Pricope (2017) compared the CHIRPS dataset for Kenya to four rain station data provided by the University of California Santa Barbara's Climate Hazard Group, for the period 1990-1995. They report a good correlation between the CHIRPS data and the station data (Figure 5.5), and mention that the CHIRPS data consistently over-predicted rainfall over wetter periods and reported 0 mm of rainfall in months that the in situ station dataset reported anywhere between 13.7 and 57.67 mm of rainfall.

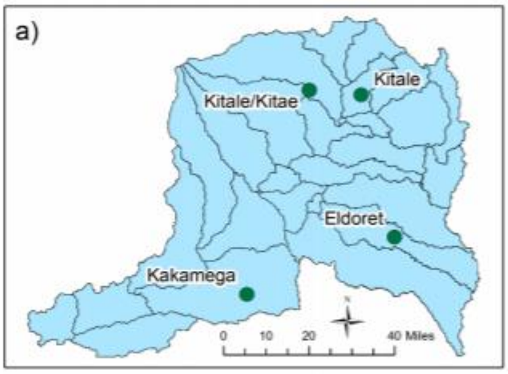

Figure taken from Figure 4., Le and Pricope (2017)

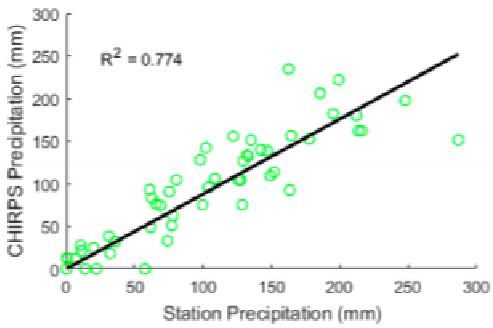

Figure taken from Figure 5., Le and Pricope (2017)
Correlation of CHIRPS precipitation estimation to station precipitation data over the period 1990-1995

Figure 5.5 Comparison between CHIRPS data and station data from Le and Pricope (2017)

The lack of measured rainfall data for long periods of time makes it difficult to assess the performance of gridded climate data in comparison to station precipitation data. We can so far conclude that there is considerable inter-annual variation of the estimated precipitation ranging from 700 to almost 2000 mm, based on the precipitation data from CHIRPS, MSWEP and RFE. All three datasets suggest an increasing trend in annual cumulative precipitation. As the CHIRPS dataset has been previously used in the RCMRD studies, it is known to the local institutions and is relatively close to the other data sets in terms of monthly average values, we have selected this data set for the further hydrology analysis and application of the weather generator in the climate stress test phase. As shown above from the available literature, the CHIRPS data set sometimes does not fit the station data and might overestimate the precipitation by a factor of up to 10%. We estimate that the effects of the inaccuracies in the CHIRPS data are small compared to the natural variability in the region and are compensated by the long-term temporal consistency and good spatial density of the data.

For the CHIRPS data, we have looked into the precipitation patterns within 5 different regions (Figure 5.6) in the Nzoia basin, in order to estimate whether there are regions that have a very different behaviour.

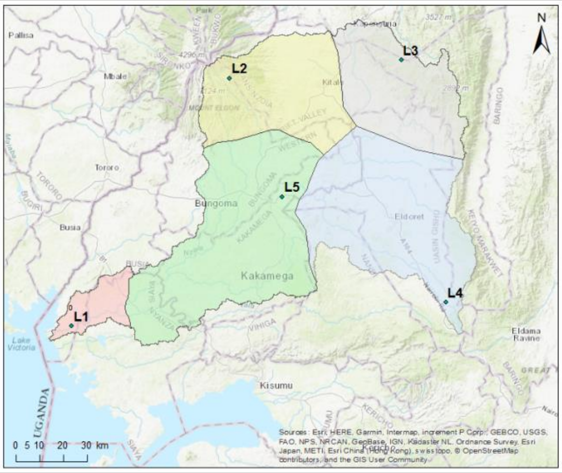

Table 5.2 Location and altitude of selected points within the five regions within the Nzoia basin

Location	Description	Altitude (m)
L1	Outlet and study area	1242
L2	Mt. Elgon	3583
L3	Cherangani Hills	2441
L4	South East	2429
L5	Centre	1653

Figure 5.6 Division of the Nzoia basin in five different regions

Figure 5.7 shows the annual cumulative precipitation for the five regions, using the CHIRPS data. We see that the top three highest precipitation regions are the area around Mount Elgon, followed by the region where the Nzoia river is reaching lake Victoria and the region of Cherangani Hills. The precipitation pattern in time is very similar for the five regions, which is an indication that we may safely use the weather generator only based on overall basin characteristics, and not need to apply it on separate sub-basins.

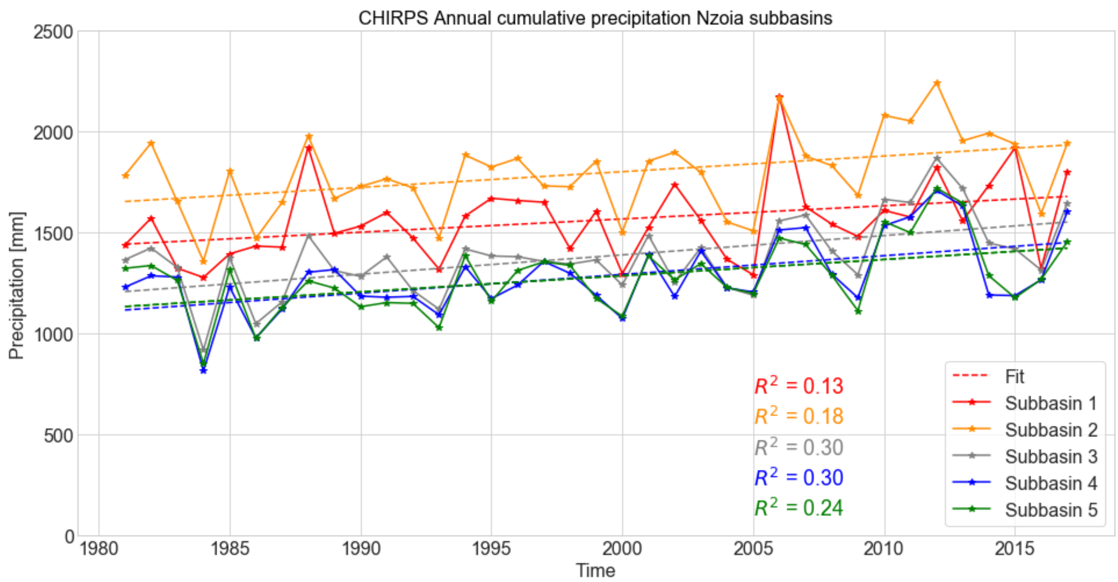

Figure 5.7 Annual cumulative precipitation for the Nzoia basin per subbasin

5.3.2 Potential evapotranspiration

Potential evapotranspiration (PET) is a key hydrologic variable describing the amount of evapotranspiration that would occur if sufficient water would be available. In semiarid areas such as parts of the Nzoia basin, around 90% or more of the annual precipitation can be evapotranspired (Wilcox et al., 2003).

Figure 5.8 shows the annual cumulative PET for the Nzoia basin for the period 1979 – 2014, based on ECMWF data. According to this data, the region records high rates of PET between 1200 mm and 1500 mm per year. A linear fit for the annual cumulative PET shows a slightly decreasing trend.

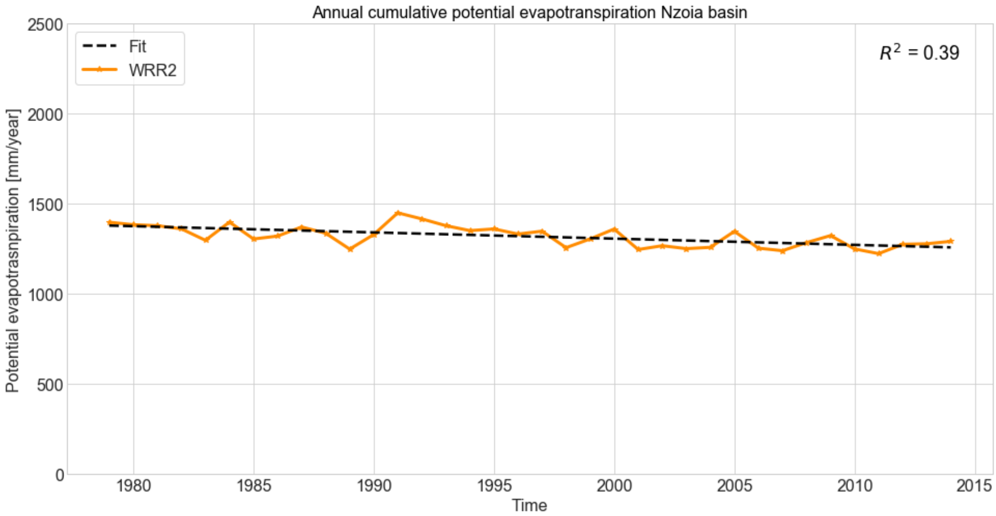

Figure 5.8 Annual cumulative potential evapotranspiration for the Nzoia basin

Figure 5.9 shows the estimated monthly PET together with monthly precipitation data from the CHIRPS data set. In the first dry season (January to February) the PET exceeds rainfall amounts, while in the second dry season (June to September) the WWR2 data set estimates evapotranspiration as lower than precipitation. Unfortunately, no data was available to validate the potential evapotranspiration rates.

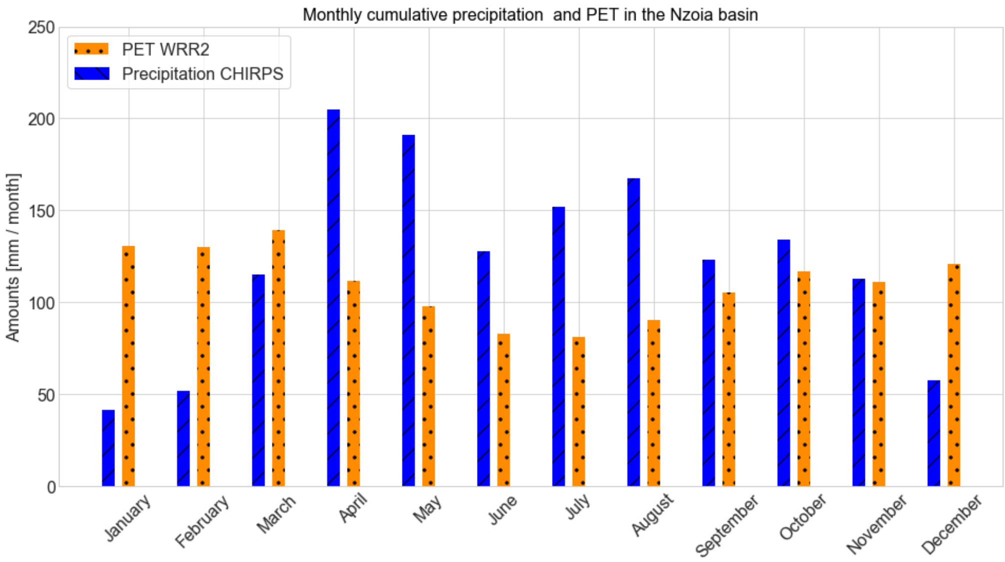

Figure 5.9 Average monthly potential evapotranspiration and precipitation for the Nzoia basin

5.3.3 Discharge measurement data

During the project, two datasets of discharge data became available, from RCMRD and WRA. The records are from two river gauging stations: EE01 (coordinates 0.178 N, 34.225 E), located close to the Old Nzoia Bridge; and EF01 (coordinates 0.124 N, 34.090 E), located close to the Ruambwa Bridge:

- 1EE01 from WRA, from 1963-1994, including missing data;
- 1EF01 from WRA, from 1974-2018, including missing data;
- 1EF01 from RCMRD, from 1985-2016, including missing data.

Figure 5.10 shows the annual maxima for the three data sets. We see that station 1EF01 (in black and grey) has larger annual maxima values compared to 1EE01(in red). According to these datasets, the average annual maximum discharge at 1EE01 is 309m^3/s, while at 1EF01 this is 451m^3/s, which is almost 50% higher than 1EE01. This is a questionable difference, as these two stations are situated only 17 km from each other and the contribution from the catchment area between the two stations is about 6% of the catchment (IFMS page 34).

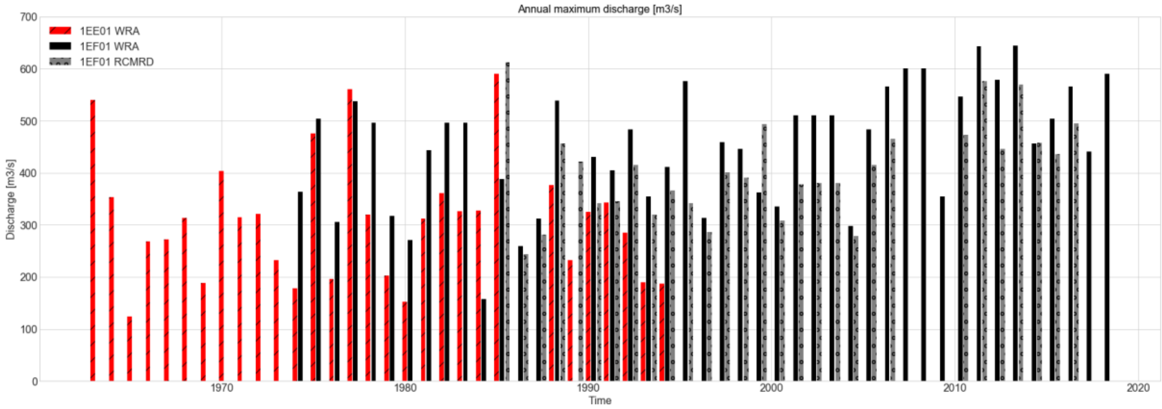

Figure 5.10 Annual maximum discharges at gauges 1EE01 and 1EF01, based on data from WRA and RCMRD

The annual maxima based on 1EE01 WRA data was also compared with the information found in the Final Design report (Figure 5.16). In general we see that the two data sets are in agreement, with the exception of years 1984 and 1985, when the annual maximum discharges in the Final Design report are significantly smaller. The cause of these differences is unclear and therefore it is not possible to assess which of the datasets is more reliable.

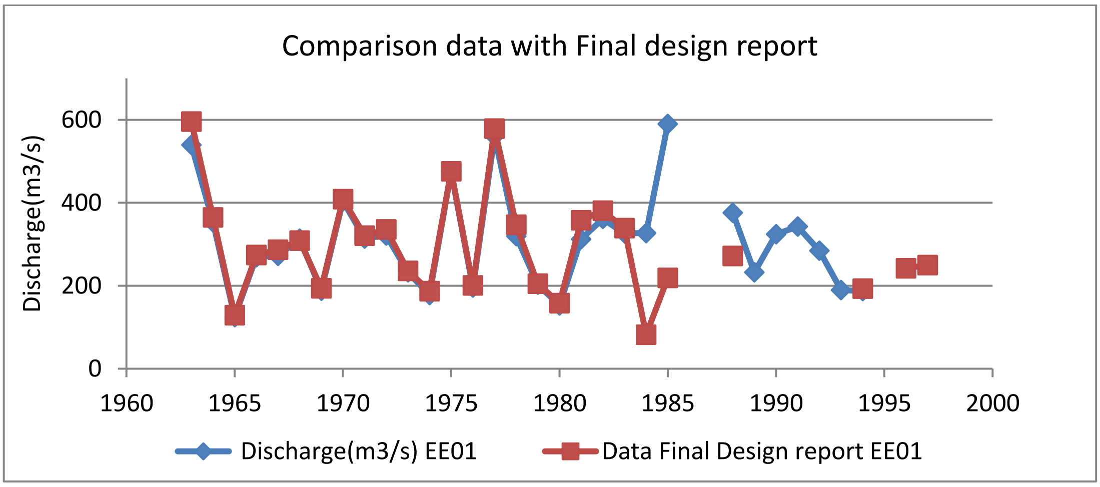

Figure 5.11 Comparison annual maximum discharges at gauge 1EE01, based on data from WRA and the Final design report

Further on, Figure 5.12 shows the monthly average discharge for the two stations. When compared to the data in the Final Design report (Figure 5.13), we can conclude that the seasonal pattern is comparable; however the data from the WRA has on average higher values. We note that the results in the Final Design report are based on a different data set period than the WRA data (see Table 5.3).

Table 5.3 Discharge data sources

	Data Source		
Station	WRA	RCMRD	Final design report
1EE01	1963-1994	-	1974-1999
1EF01	1974-2018	1985-2016	1974-1999

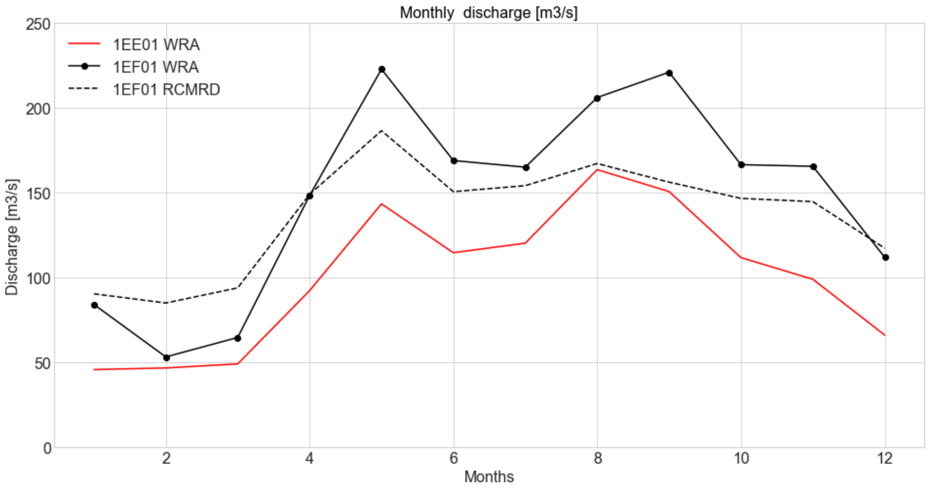

Figure 5.12 Comparison monthly average discharges at gauge 1EE01 and 1EF01 based on data from WRA and RCMRD

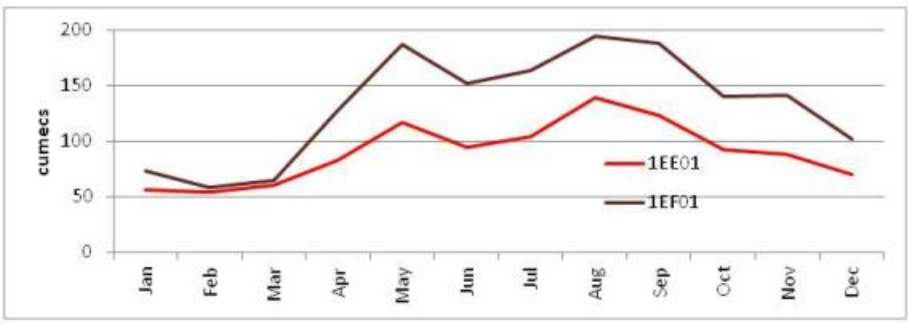

Figure 4-12 Average monthly discharge at 1EF01 and 1EE01 gauging stations

Figure 5.13 Average monthly discharge at 1EF01 and 1EE01, figure identical with Figure 4-12 from the Final design report.

Finally, Figure 5.14 shows the inter-comparison between daily discharges at stations 1EE0 and 1EF01 using the WRA data. Following the approach in the IFMS report (see left figure), the data has been split in two periods: before 1990 and after 1990. Similar to the conclusion of the IFMS report, we obtain that the daily discharges shows no correlation between 1EE01 and 1EF01 during 1990's (see red points in Figure 5.14). The integrity of the data after 1990 is therefore highly questionable. No relation has been found or suggested by other sources between this

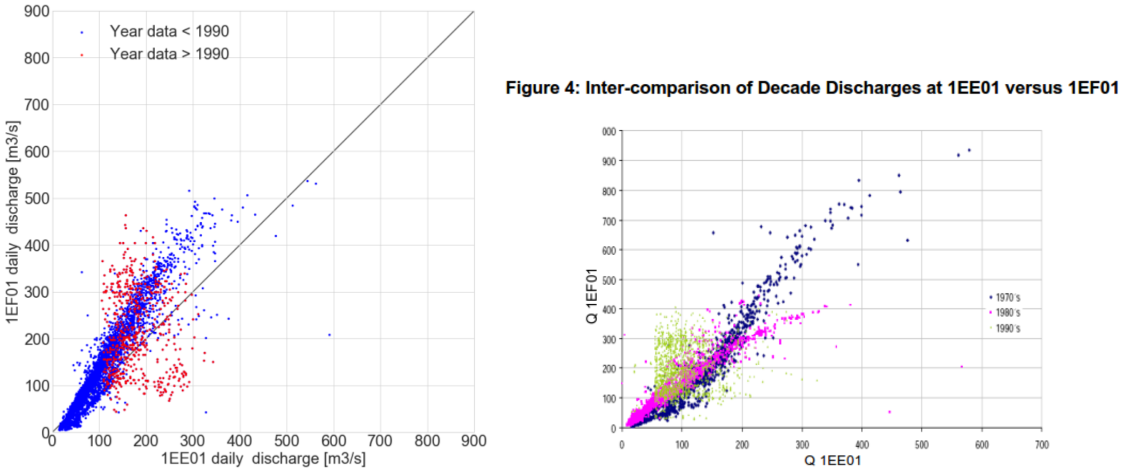

Figure 5.14 Right: inter comparison between daily discharge at 1EF01 and 1EE01 based on WRA data. Left: figure identical with Figure 4 from the IFMS report.

The available discharge data is therefore subject to many inconsistencies, probably originating from the application of inconsistent rate-discharge curves in one or both stations. Similar concerns have been raised by previous consultants and support our conclusion that the available discharge data is highly uncertain. Based on the available data and information it is not possible to judge which of the datasets is most reliable. Therefore, we have followed in the Climate Stress Test Phase (Chapter 6) the Final Design Report and used the station 1EE01 for the calibration and validation of the hydrological model.

This issue has been extensively discussed during the field visit of May 2019. There are apparently issues with the stability of the cross sections of both stations that affect the applicability of the rating curves for the stations. Station 1EE01 has been discontinued by WRA because of siltation and vandalization. The river cross section near station 1EF01 is constantly affected by sand mining in the river bed. This makes the discharge time series for both stations questionable.

5.4 Non-climate change risks

An important part of the Initial Analysis phase is to assess the non-climate change risks. Table 5.4 presents an overview of the risks that have been selected for further analysis based on the review of the Final Design report and discussions with the stakeholders. The table furthermore describes for each risk the way its impact can be assessed. The aim of the Initial Analysis Phase is to compare climate change and non-climate change risks.

Table 5.4 Selected non-climate change risk and, the way to calculate the impact

Non-climate change risk	**Calculation of impact**
Increased upstream water use	Decrease available discharge with the estimated abstractions for a) the Upper Nzoia Irrigation project; and b) all 2030 demands as listed in the National Water Master Plan 2030 (Nippon Koei, 2013)
Inadequate operation, maintenance and enforcement	Reduce the lifetime of improved flood protection from 30 to 5 years
Catchment management fails to reduce the sedimentation	Reduce the lifetime of improved flood protection from 30 to 15 years
Irrigation efficiency	Recalculate the irrigation water demand with an irrigation efficiency reduced from 50% to 30%

A further important risk to the project is the uncertainty in the discharge data that have been used in the Final Design, as discussed in Section 5.3.3. This issue has also been extensively analysed and discussed in previous studies (Lahmeyer, 2017, and RCMRD, 2015). It is difficult to quantify this risk, as no trustworthy discharge data is available to verify the results of the hydrological model. We have selected the 1EE01 station for calibration of the hydrological model (see Section 6.3.1) as this station was used in the Final Design to calculate water availability and since it shows lower discharges which provide a conservative analysis of water availability compared to the other station. For the flood analysis a relative approach has been developed which depends less on the absolute calibration results (see Section 6.3.3).

An additional non-climate risk that was already identified and calculated in the Project Design report is the non-execution of LNIP-2 (second phase of the project). Non-execution could occur for example due to institutional failure, funding problems, or political issues. The Final Design report showed that this would jeopardize the economic effectiveness of the project and yield a negative project outcome.

5.5 Initial analysis of impacts

In this phase of the DTF, an initial analysis was carried out to assess the sensitivities of the system to climate variability and non-climate factors. This was done separately for:

- Stream flow;
- Flood damage of the project site; and
- Irrigation water supply reliability to the project.

5.5.1 Impact on stream flow

As a first step, correlation plots have been created between the average streamflow at a monthly time step and the total precipitation in the previous three months for both stations 1EF01 and 1EE01, as shown in Figure 5.15 and Figure 5.16. The figures show a clear positive correlation between precipitation and streamflow. It is to be noted that this linear relationship is taken only to demonstrate the positive correlation between precipitation and streamflow from which follows that changes in rainfall lead to changes in streamflow. Obviously in reality this is not a linear process so this relationship cannot be considered as a representation of a hydrologic model.

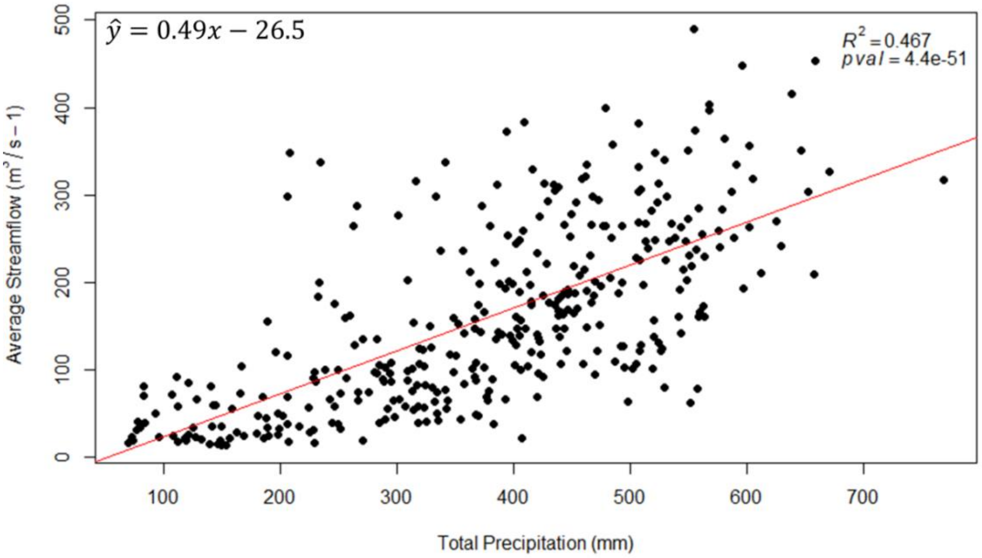

Figure 5.15 Correlation plot between mean monthly streamflow and precipitation in the three previous months for the EF01 station

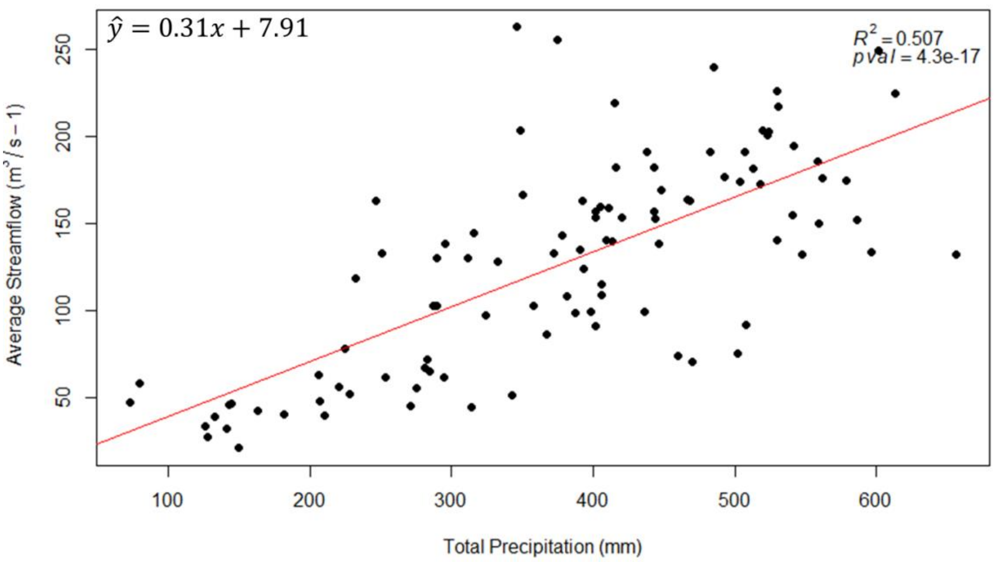

Figure 5.16 Correlation plot between mean monthly streamflow and precipitation in the three previous months for the EE01 station

To this analysis we add a few findings from the previous studies of the Nzoia river. Kite and Waititu (1981) have shown that the Nzoia River is highly sensitive to variations in rainfall input. They used a Sacramento model to investigate the sensitivity of the river flow to varying precipitation and evapotranspiration. According to their analysis (Figure 5.17), a 10% increase in rainfall input would result in a 40% increase in runoff when the PET does not change.

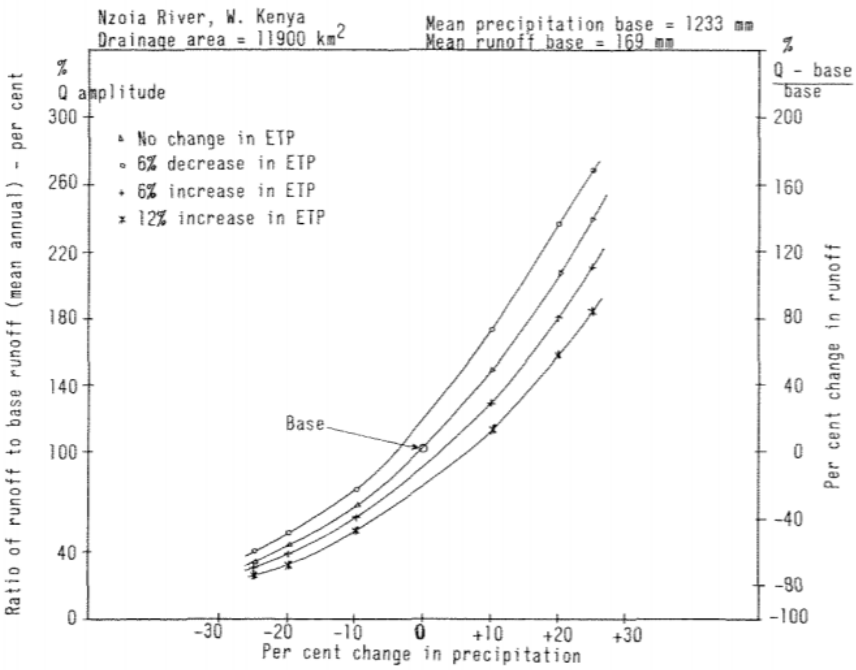

Figure 5.17 Changes in streamflow as a function of changes in precipitation and potential evapotranspiration — Nzoia River, Kite & Waititu (1981)

Furthermore, Joseck et al. (2016) mention that in 2014, 51% of rainfall received converted to surface runoff compared to 44% in year 2000. The study reports that 3.1% forest cover, 2.2% wetland, 15.3% tea, 5.5% sugarcane were destroyed to create space for human settlement, and suggests that the base flow and ground water recharge are decreasing.

Based on the findings presented in this paragraph the range of change in stream flow for the initial analysis phase was selected as -30% to +50% of the actual stream flow.

5.5.2 Impacts on irrigation

For this initial analysis, the sensitivity of irrigation water supply reliability to several factors was considered:

- Climate-induced changes in streamflow;
- Non-climate risk: additional upstream irrigation demand;
- Non-climate risk: reduced irrigation efficiencies.

The project water balance (LNIP1 and LNIP2 together) as presented in the project design report was based on Q80 (flow exceeded in 80% of the recorded data). The water availability is calculated as Q80 - Q95 (e-flow) – current abstraction rights. The calculations in the design report (table 6-37) show that in one particular month of the year (February), the balance is slightly negative. This means that the final reliability of the project as was calculated in the final design report is slightly lower than 80%.

The water balance has been recalculated using the data we received from WRA at station 1EE01. The values used for Q80 and Q95 were thus updated with this *new* data. Q95 based on these data was used for the minimum flow that needs to be left in the river (environmental flow). To assess the sensitivity to climate-induced streamflow changes, the Q80 was altered between -30% and +50%. The rest of the water balance components were left unchanged.

The water balance calculations in the final design report did not consider future abstractions, but only current abstraction rights (7.1 MCM/year). However, the future upstream water demands projected in the National Water Master Plan 2030 (hereafter NWMP2030) are much higher than the abstraction rights (1332 MCM/year). There is thus the risk that the water balance calculations in the design report were too optimistic. As such, upstream irrigation developments were included in this initial analysis to assess how sensitive the supply reliability is to upstream abstractions compared to climate-induced changes.

For this analysis, the projected irrigation demand was used from NWMP2030. The projected irrigation demand for 2030 in this plan is 1332 MCM/year, but part this water returns to the river so comes available again for downstream use. For this initial analysis, an overall efficiency of 60% was assumed. For this initial analysis, this new demand was distributed among the year, the same way the upstream abstraction rights were distributed in the project design report. Obviously this is a first approximation, as upstream demand will depend on the future crop cycles and climate and hydrological regime upstream.

Also, the non-climate risk of reduced irrigation efficiencies was included in this analysis. For this initial analysis, the efficiencies used in the final design report were lowered by an additional 20%.

Figure 5.18 shows the outcome of the Phase II initial analysis for the irrigation water supply reliability. The analysis was done based on the flow statistics calculated for 10-day timesteps, as was done in the project design report (table 6-37). For this initial analysis, the reliability was calculated by counting the number of 10-day timesteps in the year that the water availability (calculated the same way as in the design report: Q80 – Q95 – upstream water demand) becomes negative, divided by the total number of timesteps (36). Please note that due to the fact that this analysis is done based on 10-day statistics, the reliability calculation here is different from the typical reliability calculation that is based on a water balance for a full time-series (so dynamically instead of based on statistics). Reliability was not calculated in the design report. For this initial analysis, given that the water balance was based on Q80, it was assumed that the ¨*baseline*¨ reliability of the project design is 80%.

For the current climate and based on the streamflow data that was made available for this analysis (1EE01), the water balance analysis performed in the same way as in the Final Design Report shows a reliability of 71%. Please note that this is probably a very conservative estimate, as we took 80% as the baseline value. However, for this initial analysis, the relative differences are most important, and less the absolute values.
As mentioned before, for this initial analysis, the Q80 was then altered between -30% and +50%. Figure 5.18 shows that the reliability reduces considerably if streamflows (and Q80) are reduced due to climate change. Increase of Q80 lead to a reliability of 80% or higher. Please note that Q80 was used so nothing can be said about possible higher reliabilities and therefore the +25% and +50% appear as having the same value, while in reality they may have different reliability somewhere between 80% and 100%. For a more accurate calculation of the reliability, the water balance should be calculated for the full timeseries instead of 10-day statistics. Upstream irrigation developments lead to a reliability slightly lower than current: 69%. Reduced efficiencies in the project cause the reliability to go down to 58%.

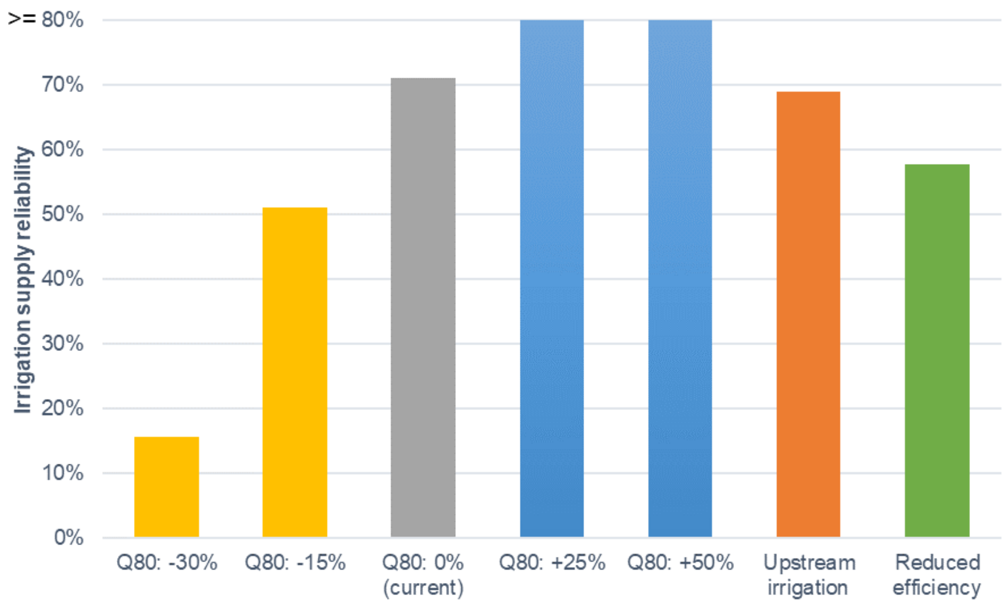

Figure 5.18 Sensitivity of irrigation supply reliability to LNIP1 and LNIP2, with changes in climate change-induced streamflow, and due to upstream irrigation developments and reduced efficiencies of the project.

Overall, it can be concluded that the project is highly sensitive to climate change-induced streamflow changes. Upstream irrigation developments seem to have limited impact on the project water supply reliability. However, this should be further analysed in a model-based analysis (Phase III). Reduced irrigation efficiencies in the project lead to considerable reduced reliability, and thus should be considered in the further analysis as well.

Overall, it can be concluded that a dynamic modelling assessment is required to assess climate change impacts and other non-climate risks on the irrigation project. Climate risk assessment is part of Phase III of the DTF-approach, including key non-climate risks. Water allocation and water resources planning questions are typically dealt with in Phase IV.

From Phase II it is further suggested that factors that need to be considered in Phase III and Phase IV are:

- Previous studies in the basin, and analysis done for this study have shown that streamflow data are of extremely poor quality. Under these data scarce conditions, it is recommendable to use hydrological models that are physically-based, instead of data-based statistic approaches to assess streamflow. This assures that the future simulations for the climate stress test are within the bounds of what is physically feasible and can be expected.
- Part of the allocated water in the Water Allocation Plan is proposed to be extracted from groundwater. Groundwater versus surface water allocation influences the water availability especially during the dry season, as competition during the dry season may become lower, while return flows could potentially have a positive impact. If the Phase III (climate stress test) shows that there is a considerable climate risk for water availability and irrigation, in Phase IV (risk management) more analysis can be done on how groundwater versus surface water allocation can reduce the risk. Impacts on flooding

5.5.3 Impacts on flooding

The Final Design states that the flood protection by the current embankments protects the project area against flood events that do not exceed the flow associated with an event with a probability of 1/10 year. The proposed improvement of the embankments will increase the protection level to a flood with a probability of 1/30 year (Lahmeyer,2017, page 270). The Final Design Report uses the data from station 1EF01 for this frequency analysis.

Fitting of a Gumbel frequency distribution through the annual maximum observed discharge for station 1EF01 (see Figure 5.19) results in estimates for the 1/10 year flood event of 650 m^3/s and for the 1/30 year event of 780 m^3/s.

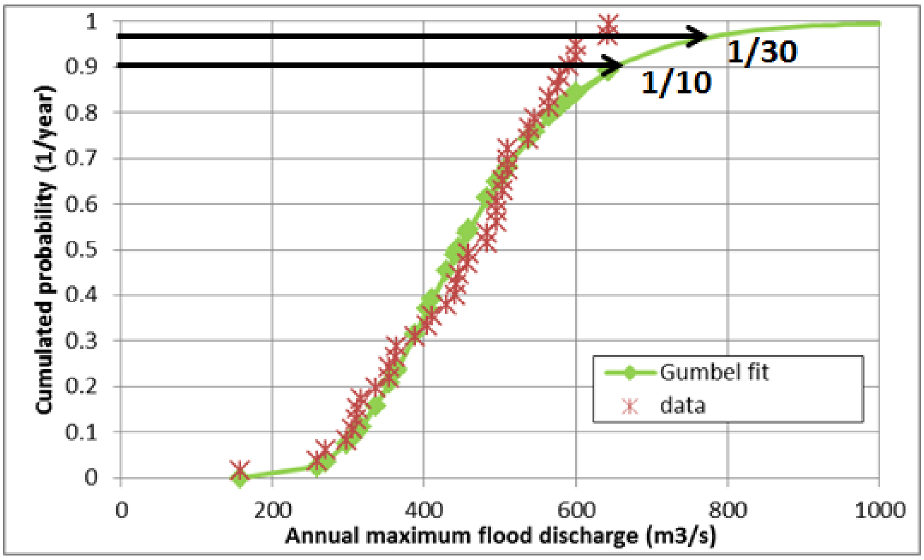

Figure 5.19 Fit of a Gumbel frequency distribution through the annual maximum observed discharges for station 1EF01

For this first analysis the annual maximum discharges have been altered between -30% and +50%. The results are presented in Figure 5.20. A current 1/30 year flood event could change its return period under the different flow regimes between 1/600 years and 1/3.3 years. That would mean that the design flood event could happen from 20 times fewer to 10 times more frequent. Clearly, the flood protection part of the Lower Nzoia project is sensitive to climate change.

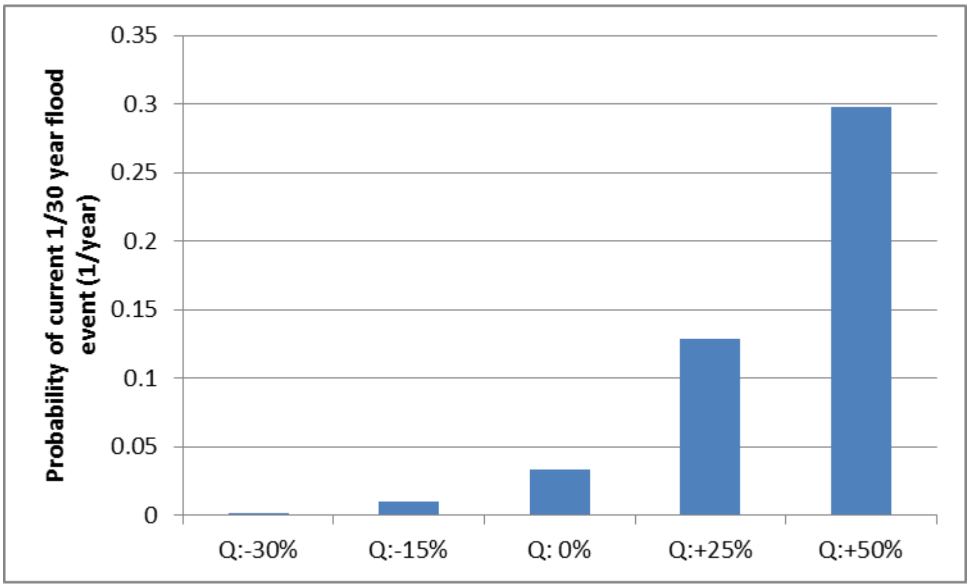

Figure 5.20 Sensitivity of the probability of the design event for flood protection for climate change-induced stream flow variation

The *Project Paper on a Proposed Additional Credit in the Amount of SDR 41.3 Million (US$58 Million Equivalent) and a Proposed Additional Grant from the Korea World Bank Group Partnership Facility in the Amount of US$3.5 Million to the Republic of Kenya for a Kenya Water Security and Climate Resilience Projec*t (World Bank, 2015) contains a subcomponent of the Nzoia project called Nzoia Watershed Management that aims to improve livelihoods through the promotion of sustainable land management practices and to reduce sediment loads in the Lower Nzoia Watershed. The latter aim is quantified as a reduction of the sedimentation rate in the Lower Nzoia from the actual value of 65 mm/year to 25 mm/year. This would increase the carrying capacity of the dyke improvements from 15 years to 30 years (World Bank, 2015, p. 15). This is interpreted as a reduction in the lifetime of the project if the watershed component does not succeed. The Nzoia Watershed Management subcomponent is not mentioned in the Final Design Report (Lahmeyer, 2017), but the PIU of KWSCRP has confirmed that watershed management is still part of the program and will be implemented in a selected number of pilot areas in the Nzoia Basin.

It is not possible to compare the reduction in lifetime directly with the sensitivity of the flood protection for climate change as presented above. However, it is clear that a reduction in lifetime could have an important impact on the internal rate of return and will be included in the analysis during the Climate Stress Test Phase. The same applies for inadequate operation, maintenance and enforcement.

5.6 Conclusions initial analysis

The results presented above regarding the sensitivity of water availability for irrigation and flood damage for climate change clearly show that both components of the Lower Nzoia Project are very sensitive for climate change. Therefore, a climate stress test is required (see Chapter 6).

Regarding the non-climate change risks the following can be concluded:

- Sensitivity of water availability for upstream developments appears limited under the current climate, but could increase if water availability is reduced under future climate circumstances;
- Sensitivity of water availability for the irrigation efficiency appears to be considerable;
- Sensitivity of the flood protection for sedimentation requires an economic analysis and will be carried out during the Climate Stress Test Phase.

The sensitivity of the project for inadequate operation, maintenance and enforcement also requires an economic analysis and is, therefore, also included in the Climate Stress Test Phase.

6 Phase III: Climate stress test

6.1 Overall approach

This chapter describes the approach and results of Phase III of the DTF application: the Climate Stress Test. This phase of the DTF is only executed if the results of the Initial Analysis Phase show that the project climate change risk are important when compared to the non-climate change risks, as presented in Chapter 5. This chapter covers all contents of the Climate Risk Report as described by Ray and Brown (2015). The relevant non climate change risks as identified in the Initial Analysis Phase (see Chapter 5) are also included in the stress test.

The stress test consists of six consecutive analysis steps (Figure 6.1):

1. Climate change projections;
2. Weather generator;
3. Hydrological modelling;
4. Flood damage modelling;
5. Crop water modelling and yield assessment;
6. Economic analysis.

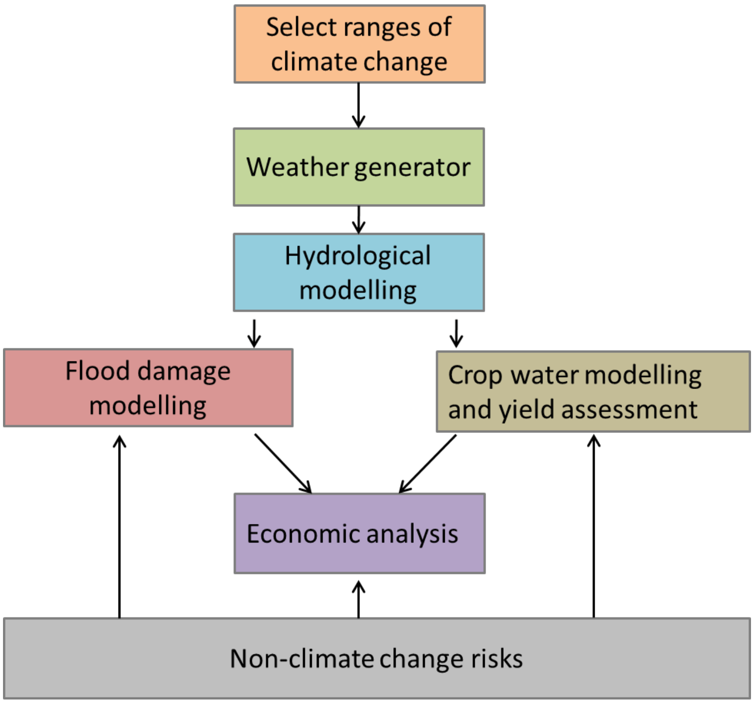

Figure 6.1 Climate stress test steps

Each of these steps is further detailed in the sections below. At some points in the analysis the results presented in this report deviate from those in the Final Design Report. This is further discussed in Appendix D.

6.2 Metrics used in the analysis

The analysis presented in Chapters 5 and 6 is based on the assessment of a number of parameters:

1. Average stream flow;
2. Maximum daily stream flow;
3. Minimum monthly stream flow;
4. Probability of flood events with flows equal to the current 1/10 and 1/30 years flood events;
5. Annual Probability of Loss (APL) with and without project;
6. Avoided APL by implementation of the project;
7. Water demands and unmet demands;
8. Crop yields;
9. Nett Present Value (NPV) of the project; and
10. Economic Internal Rate of Return (EIIR).

The results of the climate stress test in Chapter 6 are presented as so-called climate response surfaces introduced by Ray and Brown (2015) which present the variation of a parameter over different future climate realisations as expressed by changes in precipitation and temperature or evapotranspiration. Then based on the variation of the parameters for different climates, a number of performance metrics have been defined, further described in Table 6.1.

Table 6.1 Performance indicators

Performance indicator	Definition	Notes	Definition in the project
EIRR	Economic Internal Rate of Return on the investment	For the **economic analysis** success means that the EIRR of the project equals or exceeds the threshold of 12%. Failure means that the EIRR is less than 12%. Applies to **individual climate realizations**.	The **EIRR** is a measure for the ratio between costs and benefits and is calculated as the discount rate for which Net Present Values (NPV) becomes equal to zero. It captures all economic costs and benefits but does not take into account intangibles.
Reliability	Describes how often the system succeeds under one specific climate realization.	For **flooding** success is defined as providing a safety level that equals or exceeds the design safety level of 1/30 years. Failure means that the safety level is less than the design safety level. For the **water resources availability analysis**, success means that the demand is met in all months within the year. Failure means a positive water deficit (unmet demand) for a particular month. Applies to **individual climate realizations**.	**Flood reliability** is 1- probability of exceedance of the design protection level for the improved embankments **Supply reliability** is defined as 1 minus the number of months that the water supply is lower than the demand, divided by the total number of months in the full simulation period (30 years: 1985 – 2014).
Vulnerability	Vulnerability describes how significant the likely consequences of failure may be.	**Vulnerability has not been assessed for flood damage**, since no information is available to assess the flood damage for discharges higher than the discharge of a current 1/100 years flood. For the **water resources availability analysis**, it is assumed that the consequences that are felt by the irrigators are related to the unmet water demand, as a water shortage will have a direct impact on the yield, total agricultural production, and their main source of income. Applies **to individual climate realizations.**	**Drought vulnerability** corresponds to the average unmet demand divided by the average total demand.

Performance indicator	Definition	Notes	Definition in the project
Resilience	The inverse of the average time after failure required for the system to return to its normal functioning (Hashimoto et al., 1982).	For **flooding,** the only part of resilience that can be quantified based on the results of the hydrological simulations is the length of the flood event. This does not include the time to recover after the water level recedes, due to a lack of information on the socio-economic aspects of recovery. For the **water resources analysis**, resilience is based on the duration of the drought periods (number of months that supplies are lower than demand). This does not include recovery from the consequences of inadequate supply Climate change impact on resilience can be expected from longer lasting and more damaging floods. Applies to **individual climate realizations**	**Flood resilience** is defined as the inverse of the average length of flood events. **Drought resilience** is defined as the inverse of average drought period length
Robustness	Reflects the behaviour of the performance metrics among the multiple climate projections	For both **flooding** and **water resource analysis**, the fraction of the GCM projections for which the project succeeds, given a certain threshold for one or more performance metrics It is calculated by **integration over all GCM projections.**	**Economic robustness** of the project is expressed as the fraction of the GCM projections where the project provides an EIRR of 12% or more. **Flood robustness** is calculated as the fraction of the GCM projections for which the improved flood protection succeeds to provide the design safety level of 1/30 year. Flood robustness can be regarded as the integration of flood reliability over the GCM projections, while flood reliability is an indicator for individual climate realizations. **Supply robustness** is calculated as the fraction of the GCM projections for which the supply reliability is above 80%.

6.3 Climate change projections

6.3.1 Climate change projections from the GCMs

According to the 2007 Intergovernmental Panel 15 on Climate Change (IPCC) Fourth Assessment Report (AR4), the annual precipitation is likely to increase in East Africa and Kenya. Based on 100-year data, Hulme et al. (2011) suggest a positive rainfall trend of about 10-20% in Kenya and a temperature increase of about 0.5 degrees C. Although the future projections are uncertain, a changing climate will place additional stresses on water resources and flood protection and irrigation plans.

Global Circulation Models (GCMs) can be used to estimate changes in temperature and amounts and distribution of precipitation. However, the GCMs have a coarse resolution, as they seek to model the planetary circulation, which means that less confidence can be assumed for small areas compared to large regions.

Figure 6.2 shows the climate change projections for the Nzoia basin based on the CMIP5 climate models. The climate change projections are expressed as changes in the average annual precipitation and temperature in 2036-2065 and 2066-2100 relative to 1950-2010. There are three outliers showing more than 100% increase in precipitation for the RCP85 2066-2100 scenario. Analysis of the performance for the historical situation shows that these GCMs underestimate the precipitation considerably in the historical period. The GCMs show annual averages in the rage of 80 to 400 mm/year, while the observed average annual precipitation is around 1400 mm/year.

The performance of GCMs in the East-African region is still under debate in the scientific arena. Past data on rainfall trends do not match with GCM projections, also referred to as the East-African Paradox (Rowell and Booth, 2015; Rowell et al., 2015). According to data, the long rains have been declining in recent decades, while droughts have become longer and more intense and their causes are not well understood (Nicholson, 2017). Souverijns et al., (2016) looked at circulation patterns in the East-African region concluded that some areas will become drier and others wetter. The Kenyan part of the Lake Victoria region is predicted to become wetter. A detailed analysis for the Lake Victoria region revealed that pasta data confirms extreme precipitation intensification and comes to the conclusion that this will further increase in the future (Thierry et al., 2016).

Overall, it can be concluded that the absolute estimates of the GCMs for this region cannot be used for this study as they are highly biased. Relative outcomes (relative changes compared to the historic period) however can be indicative for future trends, but must be considered with caution, given the current status of the climate model performance in this area.

Figure 6.2 shows that most GCM results show an increase in precipitation of up to +70%. However, a smaller, but not insignificant number of GCM results show a decrease of up to -20% in precipitation. The projections furthermore indicate an increase in temperature of 1 to 5 degrees Celsius.

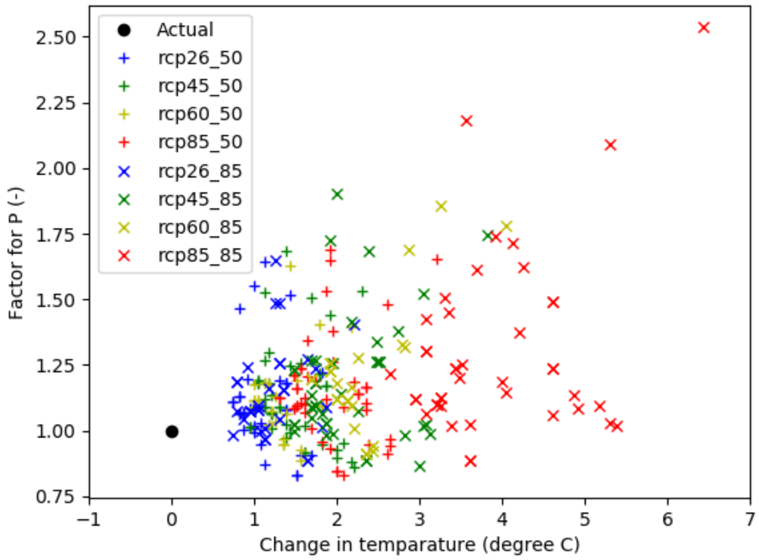

Figure 6.2 Ensemble of CMIP5 GCM projections for the Nzoia Basin (change in average annual precipitation and temperature in 2036-2065 (_50) and 2066-2100 (_85) relative to 1950-2010).

Appendix C presents boxplots of monthly precipitation and temperature change for the periods 2036-2065 and 2066-2100. The highest precipitation increase is foreseen for the short rainy season from October to December. The changes in temperature are relatively uniform along the year; however the range of change is very different from scenario RCP2.6 to scenario RCP8.5.

We note that climate models provide future projections for precipitation and temperature changes. However, the CREST model uses PET as input. Therefore it is necessary to translate the range of temperature projections to a range of PET projections. For this purpose, the well-known Hargreaves equation (Hargreaves et al. (2003)) has been used:

$$PET = 0.0023 * R_e * (T_{max} - T_{min})^{0.5} * (T_{avg} + 17.8)$$

Where R_e is the extra-terrestrial solar radiation, T_{max} , T_{min}, T_{avg} are the maximum, minimum and respectively average daily temperatures. With a range of 9.8 degrees C between T_{min} and T_{max} and an average temperature of 25.8 degrees C, this results in a change in PET of 2.29% per degree C. A temperature increase of 0 to 6.5 degrees C will therefore result in a relative change in PET between 100% and 115%.

The choice for the use of the Hargreaves equation to translate changes in temperature in changes in PET is a pragmatic choice. Recent publications (Lofgren and Rouhana, 2016, Xiaojie Li, 2019) advice the use of physically-based PET equations (Penman-Monteith, Priestly-Taylor) for climate change analyses that also include climate induced changes in humidity, wind and other factors. For the Nzoia basin, the initial results indicate that the relative ranges of change in precipitation are much higher than the relative ranges of change for temperature (thus also PET). Therefore, the response of the hydrology of the system to changes in precipitation is higher than to changes in PET. Based on this reasoning, we have opted for a simplified translation of temperature to PET.

6.3.2 Future projections using the weather generator

The climate stress test was conducted using a stochastic weather generator (Steinschneider and Brown, 2013) for the Nzoia basin. The weather generator uses as input historical climate data and translates them into future projections. The set-up of the weather generator is conditioned on the main characteristics of the historical data, to assure that the climate permutations preserve the variability and spatial correlations of the historical records.

For the Nzoia basin, the weather generator has been applied to both CHIRPS precipitation and potential evapotranspiration WRR2 historical data. The weather generator was applied simultaneously to the time series of all gridded cells such that the spatial correlation between neighbouring areas can be preserved. The stochastic weather generator application can be summarized in four main steps:

1. Step 1. Produce synthetic historical time series for the area of interest. The stochastic time-series generation is performed using a wavelet autoregressive model (WARM) on the annual time series.
   The WARM model aims to identify low-frequency and inter-annual variability. The WARM procedure first decomposes the annual series into significant low-frequency signals and the residual error term (noise). Each low-frequency component and the residual error is then simulated stochastically using best-fit linear autoregressive (AR) models.
   Finally, the simulated low frequency and noise component(s) are aggregated to obtain the simulated representative annual series.
2. Step 2. The simulated annual series from Step 1 are disaggregated in time and space to obtain daily realizations at all grid cells.
3. Step 3. The generated dataset of daily realizations are reduced to a smaller set of realizations. This step is not mandatory in the stochastic weather generation process but is desired to reduce the computational challenges, i.e., due to the need to store and simulate large number of climate realizations in hydrological models.
4. In Step 4, the daily climate realizations are perturbed to simulate a wide range of future climate realizations.

In steps 1 and 2, 34 years of precipitation and potential evapotranspiration daily data was reshuffled into synthetic historical time series while preserving the intra-annual and inter-annual variability to generate 34 years of synthetic data. The wavelet decomposition analysis on the historical annual basin-total precipitation time series has shown no significant inter-annual periodicities (see Figure 6.3 – for a period of 34 years, the black line does not cross the dashed red 90% confidence level line on the right-hand figure; there is a crossing at the end of the period, however this does not suggest a low-frequency signal within the data). The details of the analysis procedure can be found in (Steinschneider and Brown 2013).

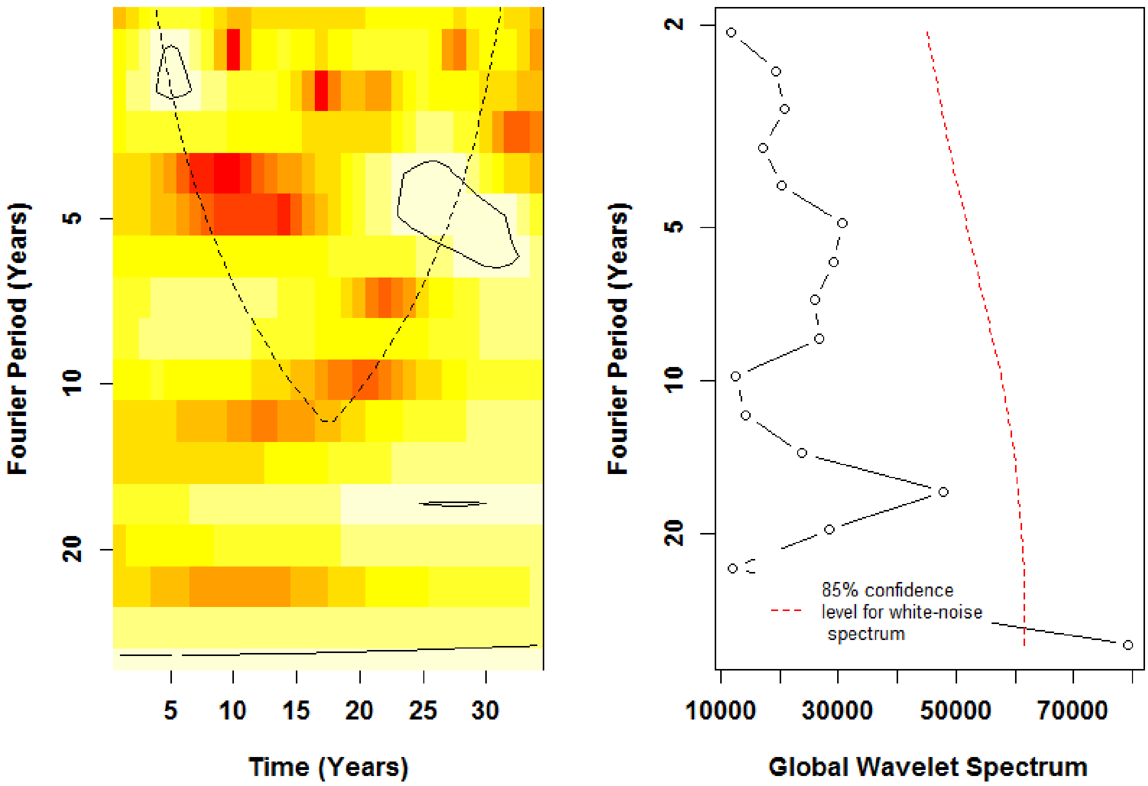

Figure 6.3 Wavelet analysis results for the CHIRPS precipitation data (1981-2014): a) Local wavelet power spectrum plot for annual precipitation, b) Global wavelet spectrum plot for the same precipitation data. The local wavelet spectrum (a) displays the strength of each signal (shown in y-axis) locally around the given time (shown in x-axis). The strength of the signal increases in the color direction of from red to yellow. The black contours show the scales at which power spectra appear greater than 90% confidence for a white-noise process. The cross-hatched regions on either end indicate the "cone of influence," where edge effects become important. The global wavelet plot (b) summarizes the local information by removing the time-dimension. The dashed red line shows the significance level for the global wavelet spectrum.

Steps 3 and 4 apply perturbations to the synthetic historical time series. To limit the computational demand for the subsequent hydrological simulations, five synthetic historical time series were randomly selected for each future climate realization. Figure 6.4 shows the annual cumulative precipitation for the Nzoia basin for the five selected realizations (in color) and the initial CHIRPS precipitation data (in black). The chosen realizations seem to cover well the space of possible climates.

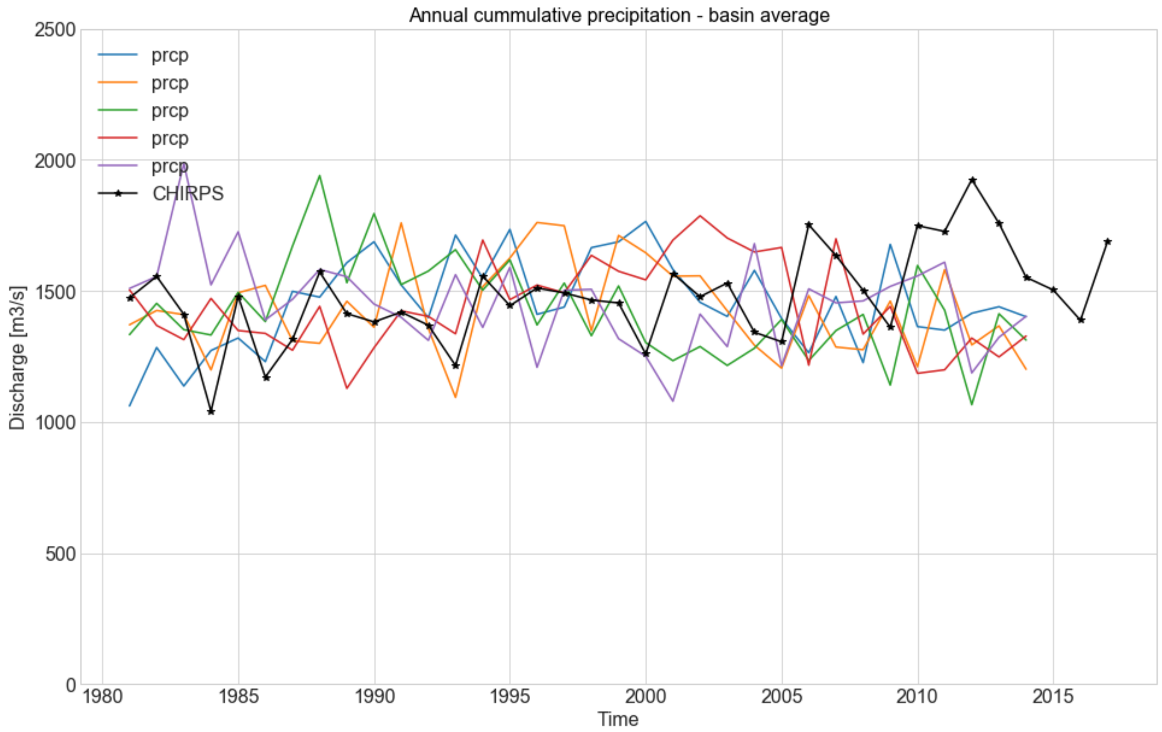

Figure 6.4 Annual cumulative precipitation for five selected climate realizations.

The climate realizations were obtained by applying direct perturbations to all values of the selected synthetic historical time series. Perturbations have been applied uniformly over the year and not differentiated over the seasons. Based on the climate change projections for temperature and precipitation, the range of change for precipitation has been chosen between -50% and 100%, with a step change of 25%. For PET, the projected change in temperature increase of 0 to 6 degrees C resulted in a PET range of change of 0% to 15% increase, with a step change of 3%. As shown in the Table 6.2, this results in total number of 210 climate realizations.

Table 6.2Climate change scenarios

Type of uncertainty	Range of change	Sample size
Natural climate variability	stochastic realizations of the historical climate	5 realizations
Changes in mean annual precipitation (%)	-50% to 100% with 25% increment	7 realizations
Changes in mean annual PET (%)	0% to 15% increase with 3% increment	6 realizations
	Total	210 climate scenarios

6.4 Flood analysis

6.4.1 Hydrological modelling

The AWBM hydrological model used for the Final Design (Lahmeyer, 2017) has not become available to be used in this analysis, although the authorities have requested the consultant to make it available.

The CREST hydrological model application to the Nzoia basin that has been used earlier in the preparation of the design of the improvement of the flood protection (Khan et al, 2011a and 2011b, Wang et al, 2011 and RCMRD, 2015) has been made available by RCMRD. It has therefore been used to evaluate the response of the system to the projected synthetic climate scenarios.
CREST (Couple Routing and Excess Storage) is a distributed hydrological model developed by the University of Oklahoma (http://hydro.ou.edu/) jointly with the NASA SERVIR Project Team (http://www.servir.net/). The CREST model simulates the spatio-temporal variation of water and energy fluxes and storages on distributed grid cells of arbitrary user defined resolution. Figure 6.5 presents a schematic presentation of the modelling of the run-off generating processes in CREST.

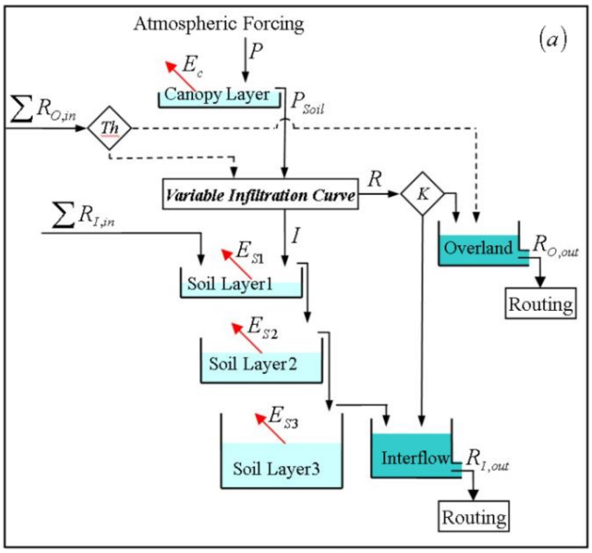

Figure 6.5 Vertical profile of a cell including rainfall-runoff generation, evapotranspiration, sub-grid cell routing and feedbacks from routing; figure identical with Figure 1-1 from the Coupled Routing and Excess STorage User Manual version 2.1 (2015)

The hydrological model is fed with daily precipitation and potential evapotranspiration grids throughout the length of the simulation. For this study, following the practice of RCMRD, the CREST model was used within the Ensemble Framework for Flash Flood Forecasting (EF5). EF5 is a hydrological modelling framework that allows users to monitor and forecast hydrological conditions such as floods and droughts. EF5 is structured into two main sections: water balance and routing. The water balance concerns the water inputs (precipitation, upstream runoff, interflow) and outputs (runoff and interflow) for each model cell. The routing determines how quickly the outputs will travel downstream. For both water balance and routing, multiple model options are available in the EF5 framework.

In this study, we used the CREST model for water balance and the kinematic wave for routing. The water balance CREST parameters adjust the volume of water present in the runoff hydrograph, while the routing parameters adjust the timing and placement of water in the runoff hydrograph.

The CREST model within the EF5 framework can be calibrated using six parameters, further described in Table 6.3. The parameters describing the routing process are presented in Table 6.4.

Table 6.3 CREST water balance calibration parameters

Parameters CREST	Description	Range		
		Min	Max	Units
Wm	Maximum soil water capacity	5	250	mm
B	Exponent of the Volume Infiltration Curve	0.1	20	-
Im	Impervious area ratio	0.01	0.5	-
Ke	Conversion factor from PET to actual ET	0.001	1	-
Fc	Soil saturated hydraulic conductivity	0	150	mm/h
Iwu	Initial volume of soil water, , a % of WM	24.999	25	%

In the following points, the function of these parameters is briefly described:

- ***wm*** is the maximum soil water capacity of the soil layer in the model, in millimetres and represents how much water the soil layer can store. Physically, this is a function of several soil properties. If *wm* increases, that means there's more space in the soil for water, which means less runoff will be produced.
- ***b*** is the exponent of the variable infiltration curve (VIC). The VIC governs how much water enters the soil layer and how much remains at the surface as runoff. If *b* increases, more runoff is produced.
- ***im*** is the impervious area ratio. This parameter can be seen as the percentage area of the modelled domain covered in roofs, concrete, rocky soils, laterite and other impervious materials. If *im* increases, the runoff increases. For example, if 10% of a basin is covered in rocks or concrete, the *im* should be about 0.10.
- ***ke*** is the multiplier to convert the input PET to local actual ET. The *ke* parameter can range from 0.001 (one one-thousandth of the PET grid) to 1.0 (the entire PET grid).
- ***fc*** is the soil saturated hydraulic conductivity (Ksat) in mm/hr. This describes how easily water moves through saturated soil. The higher the value, the more easily water can travel through saturated soils. Higher values tend to decrease runoff.
- ***iwu*** is the initial value of soil water, it is a percentage of *wm*. *iwu* can be safely estimated around 25.0, assuming that the soil is not completely dry (0.0) and not totally saturated either (100.0). The higher the value of *iwu*, the less space for water and therefore the higher the runoff.

wm and *b* are the most important parameters for the accuracy of the simulation.

Table 6.4 CREST routing calibration parameters

Parameters Kinetic wave	Description	Range		
		Min	Max	Units
Under	Interflow flow speed multiplier	0.0001	3	-
Leaki	Amount of water leaked from interflow to reservoir	0.01	1	-
Th	Threshold of No grid cells contributing to a STREAM	1	10	#
Isu	Initial value for the reservoir	0	0.00001	-
Alpha	Coefficient in channel cells: multiplier in Q = a (A) b	0.01	3	-
Beta	Coefficient in channel cells: multiplier in Q = a (A) b	0.01	1	-
alpha0	Coefficient in non-channel cells: multiplier in Q = a (A) b	0.01	5	-

- ***under*** represents the interflow flow speed multiplier. Higher values of this parameter result in water moving faster through the soil layer, which can result in faster peaks in a hydrograph.

- ***leaki*** stands for the amount of water leaked from interflow reservoir in each time step and is expressed as a percentage of the total water in the interflow reservoir. The water that leaks out moves on to the next downstream cell's interflow reservoir. Increasing this parameter will result in faster peaks.
- ***th*** represents the number of grid cells needed to flow into a cell for it to be part of a channel and it is dependent on resolution of the topographical files. As the resolution increases, the value of TH should also increase
- ***isu*** represents the initial value of the interflow reservoir. Setting this parameter to something other than zero will result in an unrealistic peak in the hydrograph at the very beginning of the simulation time.
- ***alpha*** and ***beta*** govern routing and are used in the equation $Q = \alpha * A^{\beta}$
- ***alpha0*** is used for overland cells routing.

The CREST model made available by RCMRD had previously been calibrated using TRMM and CHIRPS precipitation for different time periods. A new calibration has been executed using the CHIRPS dataset for half of the period for which data are available (1982-1984 for station 1EE01). The other half of the observation data in the period 1985-1994 have been used for validation. Calibration was carried out within the EF5 framework using the DREAM (Differential Evolution Adaptive Metropolis) algorithm. This is a global parameter optimization method which uses Multi-Chain Monte Carlo (MCMC) simulations to find the best objective value. The sum of squared errors (SSE) has been selected as the objective function to be minimized within EF5.

Table 6.5 shows the main results of the calibration and validation of the EF5-CREST model. For each of the parameters driving the water balance (Parameters CREST) and routing (Parameters kinetic wave), the table shows the minimum and maximum values used for the automatic calibration, as well as the results of the calibration. The minimum and maximum values of some parameters, such as conductivity, have been adapted compared to Table 6.3 and Table 6.4 by taking into account the characteristics of the Nzoia basin.

The performance of the model has been evaluated using three indices: bias, correlation coefficients and NSCE.

1. The bias is calculated as: $Bias = \frac{\sum_{i=1}^{n} R_{sim,i} - \sum_{i=1}^{n} R_{obs,i}}{\sum_{i=1}^{n} R_{obs,i}} \times 100$, where $\sum_{i=1}^{n} R_{sim,i}$ is the sum of all the simulated streamflow values and $\sum_{i=1}^{n} R_{obs,i}$ is the sum of all the observed streamflow values

2. The correlation coefficient measures the agreement between the simulation and the observation time series
3. The NSCE indicator is calculated as: $NSCE = 1 - \frac{\sum_{i=1}^{n}\left(R_{obs,i} - R_{sim,i}\right)^2}{\sum_{i=1}^{n}\left(R_{obs,i} - \overline{R_{obs}}\right)^2}$, where $\overline{R_{obs}}$ is the average of all the observed discharge values. A very well-calibrated model should have a NSCE of 0.7 or more. This would be necessary for a hydrological model requiring high accuracy, such as for models used in flood forecasting. In climate change analysis other uncertainties are much larger and a lower value is acceptable.

Figure 6.6 and Table 6.5 show the results of the model for the period 1981-2014 as calibrated on the data for the period 1982-1984. The calibration period was chosen by dividing the number of observations after 1982 in half. For station 1EE01 this translates into a calibration period of 1982-1984 and a validation period of 1985-1999.

The source of the ranges of calibration is the CREST model documentation. For parameters im, ke and fc the initial ranges have been adapted to better reflect the local conditions in the Nzoia basin.

The simulated discharges have a good overall resemblance with the observed flows for station 1EE01, with nearly no bias and high values for the correlation coefficient and the NSCE for the calibration period. For the validation period the coefficients are somewhat less favourable, but still acceptable for application in a climate change analysis.

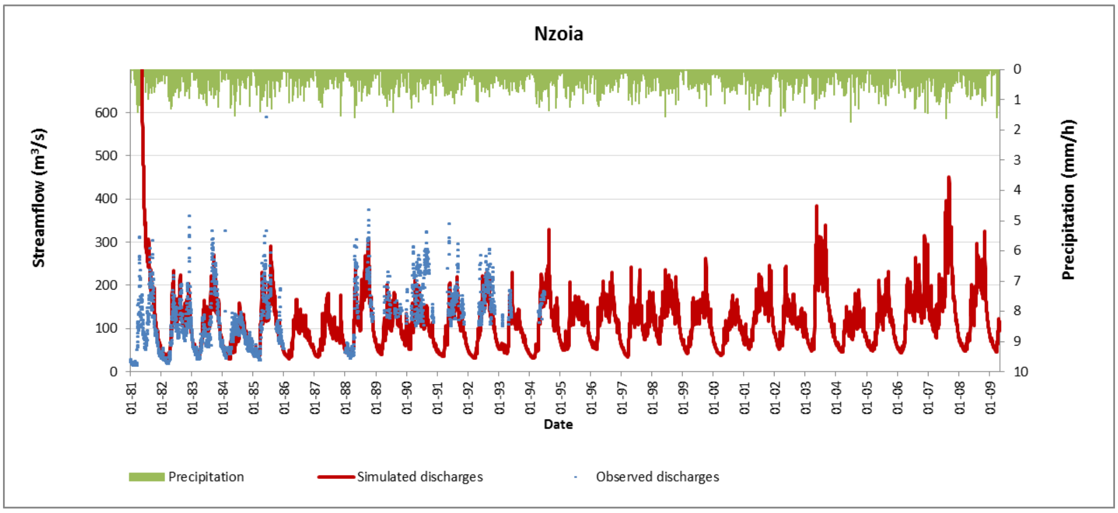

Figure 6.6 Nzoia calibration: Top: estimated precipitation from the CHIRPS data source (in green), Bottom: observed discharges (blue) and simulated runoff (in red) for the Nzoia basin during the calibration period 1981-2014.

Table 6.5 Calibration results of the EF5 model (all: 1982-1994; calibration: 1982-1984; and validation:1985-1994)

	all	calibration	validation
Bias	-10%	2%	-17%
Correlation coeficient	0.818	0.830	0.777
Nash-Sutcliffe	0.631	0.688	0.463

Parameter		Description	Range of calibration			Calibrated value
			Min		Max	1982-1984
Parameters CREST						
wm	[mm]	Maximum soil water capacity	**5**	**-**	**250**	247
b	[-]	Exponent of the Volume Infiltration Curve	**0.1**	**-**	**20**	0.640
im	[-]	Impervious area ratio	**0.01**	**-**	**0.1**	0.075
ke	[-]	Conversion factor: PET to AET	**0.001**	**-**	**1.0**	0.995
fc	[mm/h]	Soil saturated hydraulic conductivity	**0.01**	**-**	**50**	21
iwu	[%]	Initial volume of soil water	**0**	**-**	**100**	25.478
Parameters kinetic wave						
under	[-]	Interflow flow speed multiplier	**0.0001**	**-**	**3**	0.0007
leaki	[-]	Amount of water leaked from interflow to reservoir	**0.01**	**-**	**1**	0.021
th	[km^2]	Threshold of No grid cells	**1**	**-**	**100**	60

Parameter		Description	Range of calibration			Calibrated value
			Min		Max	1982-1984
		contributing to a STREAM				
isu	[-]	Initial value for the reservoir	**0**	**-**	**1**	0.109
alpha	[-]	Coefficient in channel cells: multiplier in Q = a (A) [b]	**0.01**	**-**	**3**	2.445
beta	[-]	Coefficient in channel cells: multiplier in Q = a (A) [b]	**0.01**	**-**	**1**	0.680
alpha 0	[-]	Coefficient in non channel cells: multiplier in Q = a (A) [b]	**0.01**	**-**	**5**	3.564

6.4.2 Impacts on streamflow

The calibrated and validated CREST model introduced in the previous section has been applied to assess the impact of climate change on stream flow. The dots in Figure 6.7 represent the location of the historic climate and the results of different climate change projections in the future climate space. The position of the dots can be used as an indication of the plausible range of the changes in precipitation and PET. The simulated average discharge for the period 1985-2014 for the actual situation is 150 m^3/s. The range of precipitation is much larger than the range for PET. This causes the simulated flow to appear much more sensitive to the change in precipitation than to the change in PET. A reduction of average precipitation by 25% results in a simulated average flow of approximately 100 m^3/s, while an increase of precipitation by 25% results in an average flow of 210 m^3/s and a 100% increase results in 400 m^3/s. An increase of PET by 15% reduces the simulated average flow to approximately 140 m^3/s.

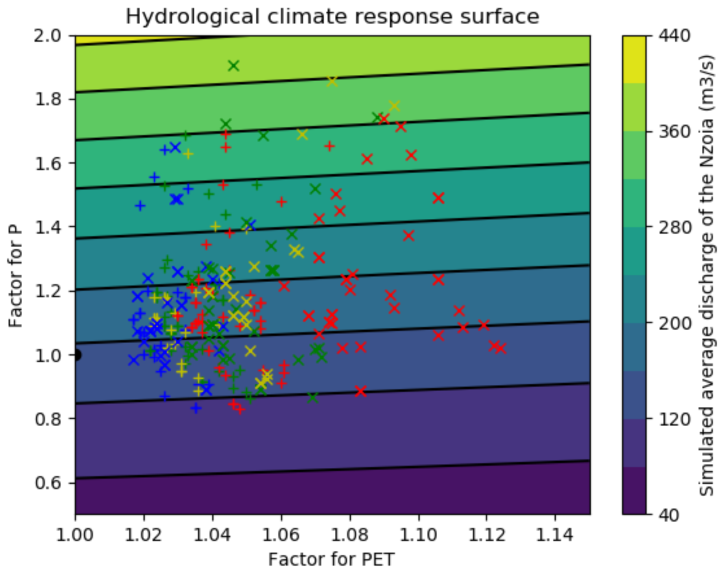

Figure 6.7 Climate response map with on the Y axis the factor of change in precipitation and on the X axis the factor of change in PET; the colours show the simulated average discharge for different rates of change in precipitation and PET and the dots show the location of the GCM results (for the legend of the dots see Figure 6.2)

The results presented in Figure 6.7 show a high sensitivity of discharge to precipitation change but not outside the range presented by Kite & Waititu (1981), see section 5.3.2. An extra sensitivity analysis has been performed with a not calibrated application of Deltares' wflow-hbv model (see https://wflow.readthedocs.io). The model results showed for both increases and decreases of the precipitation similar sensitivities of the simulated discharge as those presented for the CREST model application. This provides an additional validation of the climate sensitivity of the discharges as simulated with CREST, which are used as the basis for the rest of the analysis. However, it should be noted that earlier calibrations of the CREST model showed a higher sensitivity to changes in precipitation. This shows that the sensitivity for precipitation change is influenced strongly by the calibrated set of parameters.

Figure 6.8 shows the effect of variation in precipitation and PET on high discharges, specifically the 95th percentile of the annual maximum daily discharge. The effects of change in precipitation on maximum daily discharge are somewhat higher than on average discharges, with 25% increase in precipitation resulting in an increase of average discharge of some 40% and an increase of maximum discharge of some 45%.

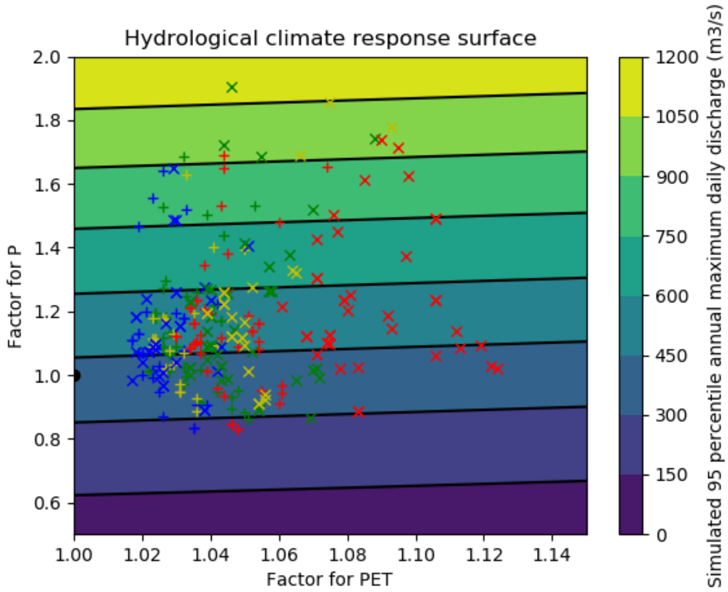

Figure 6.8 Climate response map with on the Y axis the factor of change in precipitation and on the X axis the factor of change in PET; the colours show the simulated 95% annual maxima at the Rwambwa station for different rates of change in precipitation and PET and the dots show the location of the GCM results (for the legend of the dots see Figure 6.2)

Figure 6.9 shows the effect of variation in precipitation and PET on low discharges, specifically the 90th percentile of the annual minimum 30-day discharge. The effects of change in precipitation on the annual minimum 30-day are very close to the effects on average discharges, with 25% increase in precipitation resulting approximately 40% increase in the annual minimum 30-day discharge.

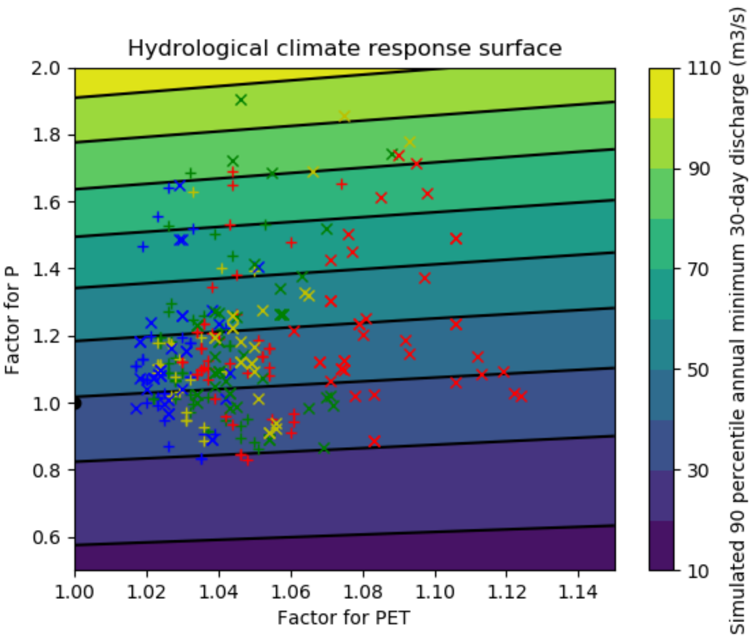

Figure 6.9 Climate response map with on the Y axis the factor of change in precipitation and on the X axis the factor of change in PET; the colours show the simulated 90% annual minimum 30 days discharge for different rates of change in precipitation and PET and the dots show the location of the GCM results (for the legend of the dots see Figure 6.2)

The climate response surfaces presented give an indication of the sensitivity of the simulated discharge of the Nzoia River to changes in precipitation and potential evapotranspiration. Discharges are most sensitive to the selected range of change for precipitation. The expected change in PET has a more limited impact. GCM results indicate that both increase and decrease of precipitation is projected for the future. There are positive and negative changes in precipitation projected for all emission scenarios, depending on the GCM used. The results of the GCMs indicate that more results tend to an increase in precipitation.

We note that further uncertainty in the analysis is introduced by the approximation of the impact of climate change on stream flow using a mathematical model. The calibrated CREST model (see Chapter 6.3.1) provides an adequate description of the flows under the current climate. However, the estimated model parameters and the model concept introduce uncertainty in the results. Further uncertainty is introduced when applying the model with the calibrated parameters to time series representing a climate substantially different from the current climate. However, a separate assessment of the impact of the model uncertainty on the results of the CCRA will have little added value, since the model uncertainty is much smaller than the climate uncertainty as expressed by the range of precipitation (-50% decrease up to 100% increase) change that is evaluated.

6.4.3 Flood damage assessment

The approach for the flood damage assessment follows closely the approach outlined in Section 9.4 of the Final Design Report (Lahmeyer, 2017).

The following steps have been taken:

1. Attempt to reproduce the results in the Design report.
2. Extreme value analysis based on simulated discharges using the CREST model.
3. Calculate the change in probabilities of exceedance due to climate projections.
4. Calculate the Annual Probability of Loss with and without embankments.
5. Estimate the effect on performance indicators.

In should be noted that this is a flood assessment relating flood discharges to damage. No detailed flood modelling, including hydraulic modelling of water level, overbank inundation and inundation depth has been performed.

In the Final Design Report the benefit of the improvement of the embankments is calculated as the difference between the Annual Probability of Loss (APL, in MKES/year) in the situation without and with the improvement of the embankment implemented. The APL is the term used in the Final Design. It is equivalent to what is sometimes also called the expected or average annual damage. Its calculation starts with listing the flood damages for all flood events with return periods for once per year to once per 100 year. The APL is then calculated as the sum overall 1/1 to 1/100 year events of the damage multiplied by the probability.

The Final Design Report states that in the current situation no damage occurs in flood events with a frequency of 1/10 year or more and that after improvement of the embankment no damage will occur in flood events with a frequency of 1/30 year or more. A distinction is made in the final design between crop loss and damage to the irrigation scheme.

Figure 6.10 reproduces the most important tables from the Final Design Report regarding the assessment of the benefit of the extension of the flood protection. Based on this information the benefit of extension of the flood protection is presented in the cost-benefit analysis of the Food Security cropping pattern (Table 9-51 in the Final Design Report) as 36.00 MKES/year for avoided loss of crops and 71.06 MKES/year for avoided damage to the irrigation scheme, resulting in a total benefit of the improved flood protection of 107.06 MKES/year. New calculations based on the same data result in a benefit of 62.37 MKES/year (see Appendix D for details).

Table 9-26 Estimated Loss of Crop Production from Floods of Different Periodicities

Cropping pattern	Estimated loss of value of gross margin, KES m				Without flood scheme gross margin, KES m
	1:5	1:10	1:25	1:50	
Present	-	61.61	269.46	269.46	385.93
Food Security	0	108.89	694.66	694.66	1,406.65
HVC	-	82.85	643.32	643.32	1,560.45

Table 9-27 Estimate of Avoided APL With Improved Embankment Protection

Cropping pattern	APL Crop Loss without embankment, KES m	APL Crop Loss with embankment, KES m	Incremental benefit, KES m
Present	19.69	3.99	15.70
Food security	46.17	10.26	35.91
HVC	43.46	9.74	33.72

Table 9-28 Estimate of Indirect Benefit of Protecting the Irrigation Scheme

Flood return period	1:5	1:10	1:25	1:50	1:100
Cost of making good flood damage	0.0%	15%	30%	40%	50%
Damage incurred, KES m	-	431	862	1,149	1,436
APL without embankment	-	21	57	77	89
APL with embankment	-	-	-	5	18
Avoided APL	-	21	57	71	71

Figure 6.10 Reproduction of the most important tables from the Final Design Report regarding the assessment of the benefit of the extension of the flood protection (Lahmeyer, 2017, pages 270-271)

The calculation of the benefit of embankment improvement for the climate change realizations follows exactly the approach outlined above. The difference is in the time series: while in the initial analysis of impacts (see Section 5.5.3) observed discharges have been used to estimate flow probabilities, in this analysis flows simulated by the CREST model based on the changed climate are used. The benefit of embankment improvement is incorporated in the calculation by changing the probability of the flood events that have a 10 and 30 year return period in the actual situation. As a first step, the discharges of 1/10 and 1/30-year flood events have been determined from the CREST simulated flow time series for 1985-2014 by fitting a Gumbel extreme value distribution through the annual maxima (Figure 6.11). The simulated discharge for a 1/10 year flood event in the current situation is 510 m^3/s and for a 1/30 year event 630 m^3/s.

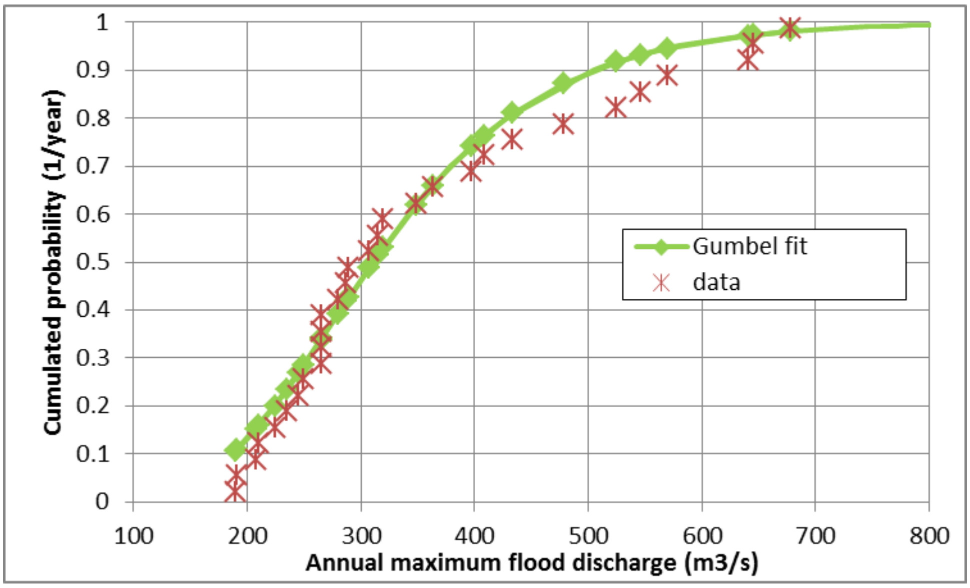

Figure 6.11 Fit of a Gumbel extreme value distribution through the CREST simulated annual maxima for the period 1985-2014

A Gumbel extreme value distribution is also fitted through the CREST simulated flows for the climate change realizations. This is used to calculate the return period of the flows for the 1/10 and 1/30 year events of the current situations. These new return periods are used to calculate the APLs and avoided APLs. The procedure is illustrated with a graphical example in Figure 6.12.

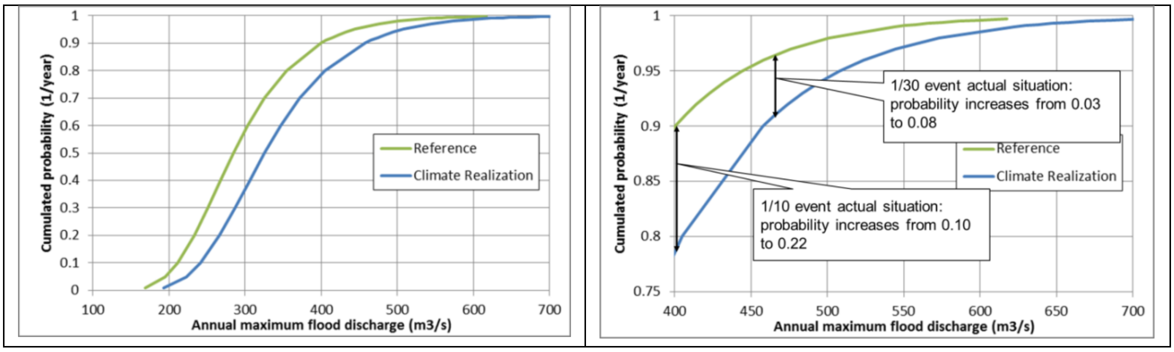

Figure 6.12 Illustration of the calculation procedure of the probability of discharges that have a 1/10 and 1/30 year probability in the actual situation: a Gumbel extreme value distribution is fitted through the CREST simulated 1985-2014 annual maxima for the actual situation and for the considered climate realization; for the climate realization the probabilities of exceedance of the 1/10 and 1/30 discharges in the actual situation are determined; right panel zooms in on the higher discharges as presented in the left panel.

Figure 6.13 shows the impact of climate change on the probabilities of the current 1/10 and 1/30 years flood events. The dot in the left map at precipitation factor 1.0 and PET factor 1.0 shows that for the current situation this probability is 0.1 1/y. With increasing precipitation the probability of occurrence of a current 1/10 year flood discharge increases to 1.0 for an increase of 50% or more. This and the following climate response maps show how future probabilities and risk might change under different climate realizations.

The probabilities of the current 1/10 and 1/30 years flood events are hardly affected by the change in PET. The impact of changes in precipitation on the probabilities is very large: a reduction of 25% in precipitation makes a current 1/10 years event something like a 1/2,000 years event. On the other side, an increase of 25% in precipitation makes a current 1/10 years event a flood that occurs every other year and a current 1/30 years event would occur every 3 years.

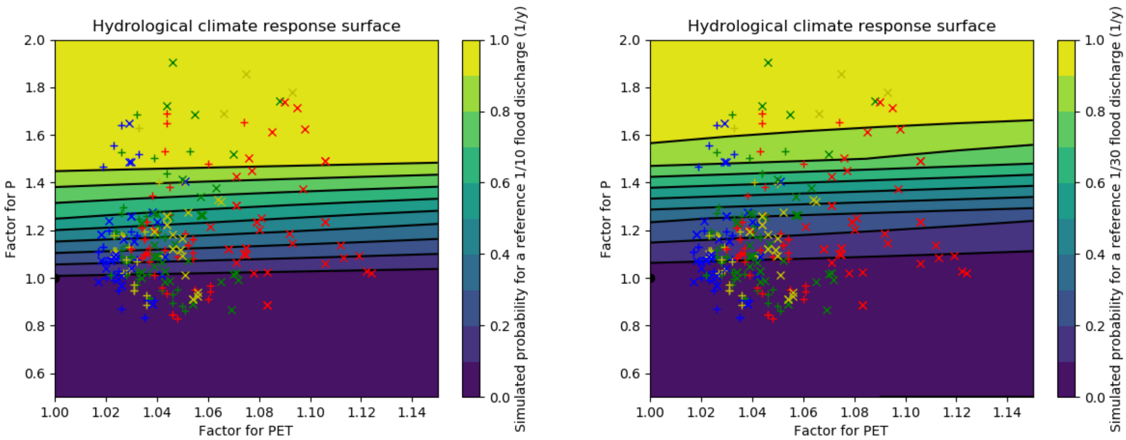

Figure 6.13 Climate response maps with on the Y axis the factor of change in precipitation and on the X axis the factor of change in PET; the colours show the probability of a 1/10 years flood event (left) and 1/30 years flood event (right) for different rates of change in precipitation and PET and the dots show the location of the GCM results (for the legend of the dots see Figure 6.2)

The right-hand side of Figure 6.13 shows the probability of exceedance of the design protection level for the improved embankments, which is the inverse of the reliability.

The improved embankments are designed for a flood event with a return period of 1/30 years. So the reliability under the current climate is 1-1/30=0.9666 1/year. Figure 6.14 presents the climate response surface for the reliability. It shows that the reliability is rapidly decreasing with increasing precipitation. A 50% increase in precipitation, leads to a reliability of 0.13 1/year, since the probability of the actual 1/30 years flood discharge then increases to 0.87 1/year. A 75% increase would reduce the reliability nearly to zero.

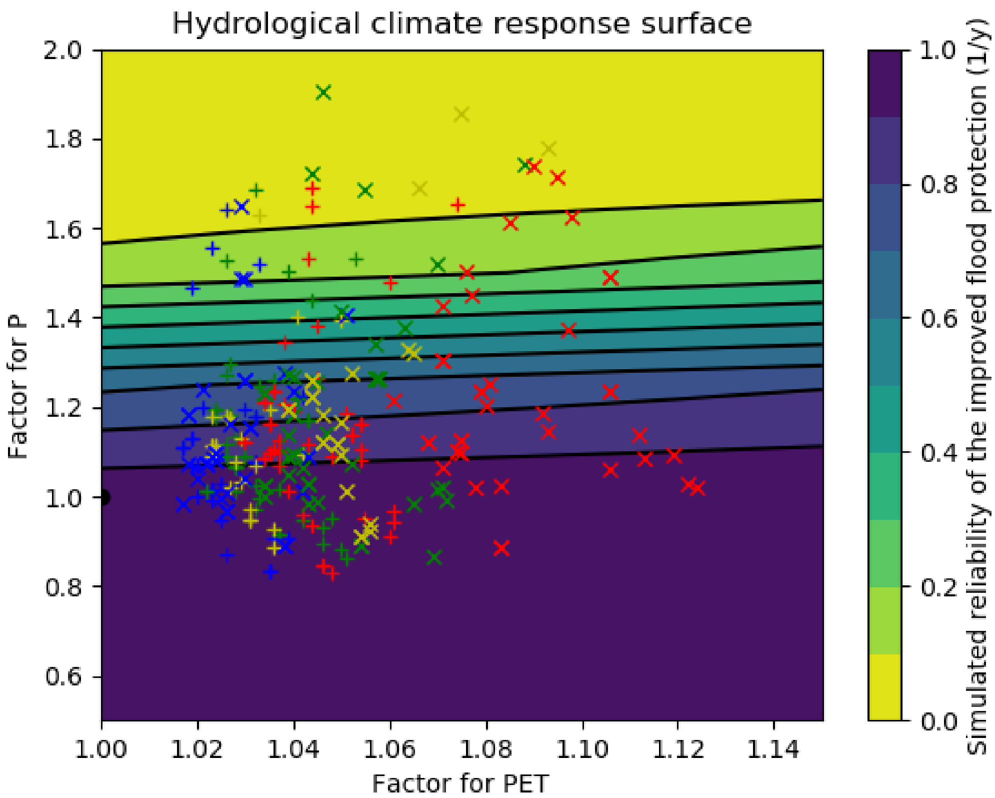

Figure 6.14 Climate response map with on the Y axis the factor of change in precipitation and on the X axis the factor of change in PET; the colours show the reliability of the improved embankments (with a current reliability of 0.9666) and the dots show the location of the GCM results (for the legend of the dots see Figure 6.2)

The climate response map can also be presented as a map of success and failure of the improved flood protection. For this, success can be defined as a safety level equal to or higher than the designed 1/30 years. Figure 6.15 presents the resulting response map, showing the obvious, i.e. that the flood protection fails to deliver the design safety level if the precipitation increases in the future. The robustness of the proposed improvement of the flood protection can be calculated as the fraction of the GCM projections for which the flood protection succeeds to provide the design safety level. This is the case in 56 of 284 GCM projections, so the robustness of the improved flood protection is 0.20.

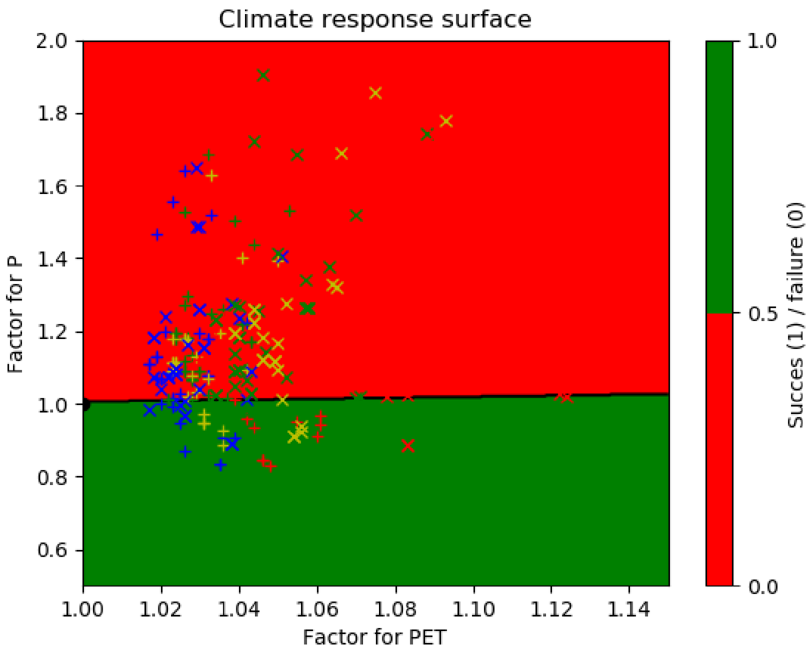

Figure 6.15 Climate response map with on the Y axis the factor of change in precipitation and on the X axis the factor of change in PET; the colours show the success (green) and failure (red) of the improved flood protection to provide the design safety level and the dots show the location of the GCM results (for the legend of the dots see Figure 6.2)

The probabilities as affected by climate change presented in Figure 6.13 are used to calculate the APL for the different climate realizations. The results are presented in Figure 6.16. The results for the APL, both with and without embankments, are very sensitive to the change in precipitation and related change in probabilities of the actual 1/10 years and 1/30 years flood events. The actual flood protection level of 1/10 years is in case of a 25% reduction in precipitation sufficient to reduce the APL to almost zero. On the other side, an increase of precipitation with 25% would increase the APL by a factor 5 to 10.

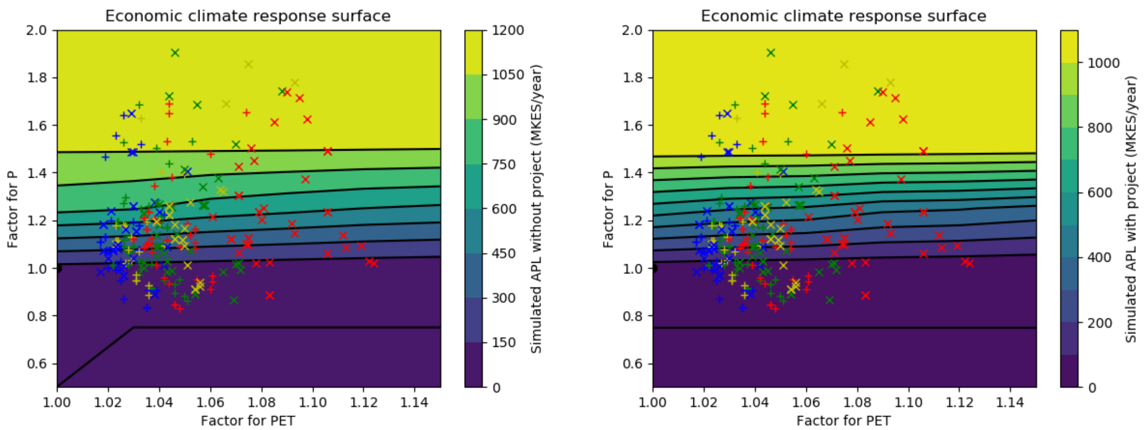

Figure 6.16 Climate response maps with on the Y axis the factor of change in precipitation and on the X axis the factor of change in PET; the colours show the APL (Annual Probability of Loss) without the project (left) and with the project (right) for different rates of change in precipitation and PET and the dots show the location of the GCM results (for the legend of the dots see Figure 6.2)

The benefit of the improvement of the flood protection works is defined as the avoided APL: the difference between the APL with embankment and the APL without embankment. The climate response surface for the avoided APL is presented in Figure 6.17. These results show that the benefit of the flood protection works is most sensitive for the range in future precipitation change. The current situation shows a benefit of some 70 MKES/year. This is reduced to zero if precipitation decreases by 25%, since in that case hardly any flood events will occur that exceed the flood protection level provided by the existing embankments. That would reduce the benefit of improving the embankments to zero.

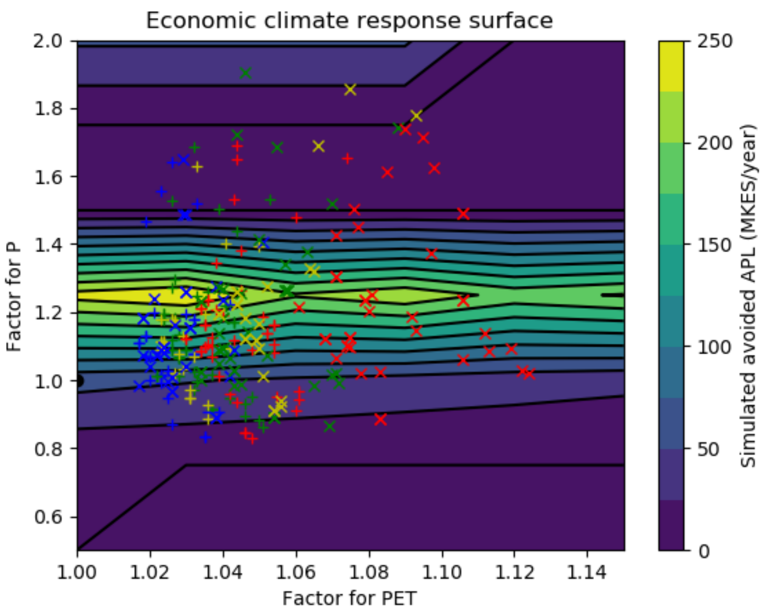

Figure 6.17 Climate response map with on the Y axis the factor of change in precipitation and on the X axis the factor of change in PET; the colours show the avoided APL (Annual Probability of Loss) for different rates of change in precipitation and PET and the dots show the location of the GCM results (for the legend of the dots see Figure 6.2)

The figure shows, on the other hand, that the benefit of improving the embankments will increase if the precipitation increases by 25%. The benefit would than reach a maximum value of some 200-250 MKES/year, because there would be more frequent floods against which the improved embankment would protect, but the current embankment not. A further increase of precipitation would again reduce the benefit of improved flood protection to zero, since the design level of the improved embankments would be exceeded nearly every year by the flood level. The majority of the GCM results project a future climate in the region between the actual situation and the maximum level of the benefit of improved flood protection. However, a not insignificant number of GCM results point to a reduction of these benefits, even to zero, due to possible higher or lower flood discharges.

The sensitivity of project performance for climate change has been assessed in this section for the flow of the Nzoia, the probability of flood events, the reliability and robustness of the design for the improvement of the flood protection and the benefit of the improvement, expressed as the avoided APL. Climate change also affects vulnerability, because the increased flood flows will lead to increased flood depth and flood extent. Therefore, the maximum damage, often used as a measure for vulnerability, will increase with increasing flows. However, data regarding increased impacts above the current design flows are not available.

Therefore, a quantitative analysis of the climate sensitivity of the flood vulnerability is not possible, other than the response surface of the 95 percentile annual maximum flow as presented in Figure 6.8.

Another important metric could be the resilience, often defined as recovery rate or the inverse of the average time after failure required for the system to return to its normal functioning (Hashimoto et al., 1982). Climate change impact on resilience can be expected from longer lasting and more damaging floods. The only part of resilience that can be quantified based on the results of the hydrological simulations is the length of the flood event, which is here defined as the length of the period that the flow exceeds the design flow of the 1/30 years event in the current situation. The resulting response surface for resilience is presented in Figure 6.18. It shows that under the current climate flood events are mostly limited to one day exceedance of the design discharge resulting in a resilience of slightly below 1 1/day. However, an increase of precipitation by 100% would reduce the resilience to below 0.1 1/day indicating an increase in the average duration of flood events to more than 10 days.

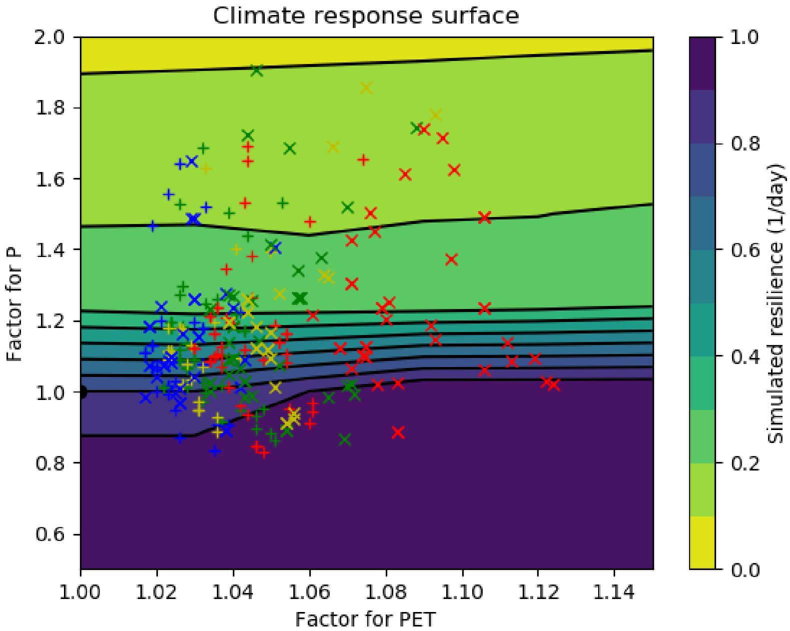

Figure 6.18 Climate response map with on the Y axis the factor of change in precipitation and on the X axis the factor of change in PET; the colours show the resilience defined as the inverse of the average duration of a flood event for different rates of change in precipitation and PET and the dots show the location of the GCM results (for the legend of the dots see Figure 6.2)

6.5 Irrigation analysis

6.5.1 Water resources system model setup

A simplified water resources system model for the Nzoia basin was schematized in the Water Evaluation and Planning (WEAP) modelling software, developed by the Stockholm Environmental Institute (SEI). This software is typically used for river basin-level water allocation studies as well as for impact assessments on water reliability and crop yield response. More information on the WEAP model can be found on http://weap21.org/. The model is often used also in stakeholder consultations to collect inputs, stakeholder preferences and interactively assess outputs. The model outputs are used to calculate performance metrics as reliability, vulnerability and resilience among others.

The model schematic setup for the Nzoia basin is presented in Figure 6.19 below and includes:

- Rainfall and potential evapotranspiration rates as are used in the CREST model for the project site.
- Stream flows at the project intake, simulated by the CREST model.
- A catchment node with an irrigation demand component for the current project Phase I (LNIP1), and future Phase II (LNIP2).
- An environmental demand node for the project. Demand is Q95 of station 1EE01, as used in project design report.
- For the scenario analysis, the following nodes are added:
    - Demand nodes for future demands as projected by NWMP2030, for
        - Domestic,
        - Industrial,
        - Livestock and
        - Fisheries
    - A demand node for the future irrigation developments as planned in NWMP2030 (see more details in chapter 7.2)
    - Groundwater node

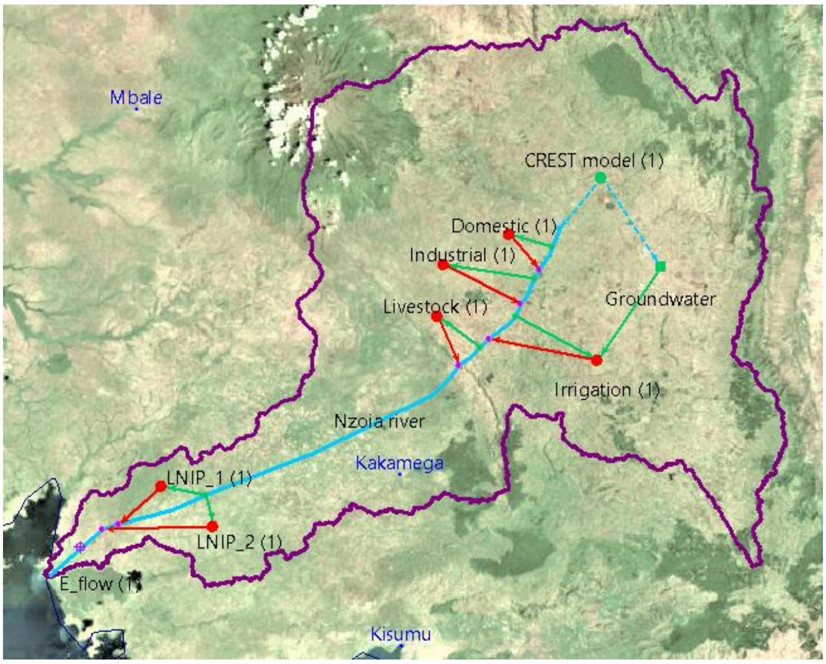

Figure 6.19 Schematic presentation of the water system model WEAP for the Nzoia basin

For Phase III of the DTF, the WEAP model is used to assess the climate-related risks to the water supply and crop yields of the project, under the same assumptions as in the project design report (project design scenario), but also looks at how these climate risks compare with the two most significant non-climate related risks identified in Phase II. Thus, for this phase, the following scenarios are studied in WEAP:

Table 6.6 WEAP scenarios

No	Code	Scenario
1	01_prj	Conditions considered for project design
2	02_full_us_dev	Full upstream development: new water demands as projected in NWMP2030
3	03_red_eff	Reduced irrigation efficiency of LNIP by 20%

Phase III (this chapter) does not include an exploration of possible adaptation options: this is part of Phase IV (next chapter). Phase IV also includes an analysis of the NWMP2030 water allocation plan.

Crop water demand and crop yield is simulated in WEAP and parameterized based on the Food Security Pattern, which is the proposed cropping system in the Final Design Report of LNIP1. This pattern has two principal crop types that were simulated separately in the WEAP model: (1) Maize and legumes, and (2) Paddy rice. For the maize/legumes crop combination, the crop parameters of maize were used as this is the dominant crop. Two cropping seasons were simulated: the long-rainy season (between March and May) and the short-rainy season (between June and November).

For LNIP2, there is no study available yet on proposed cropping patterns, so it was assumed that the same cropping pattern will be implemented in LNIP2.

Table 6.7 shows the cropping parameters that were used for the analysis. These were mostly extracted from the Final Design Report, and if not from standard literature (FAO guidelines). For the monthly variation of the future upstream irrigation demand (scenario 02_full_us_dev, see Table 6.6), the same pattern was used as are available in the Feasibility Report of the Upper Nzoia scheme (2015, commissioned by NIB, executed by GEDO associates).

Table 6.7 Cropping parameters implemented in WEAP for LNIP1 based on the Final Design Report

	Long rains (Mar-May)		Short rains (Jun-Nov)	
	Maize/legumes	**Paddy rice**	**Maize/legumes**	**Paddy rice**
Area LNIP1 (ha)	1639	2361	1867	668
Area LNIP2 (ha)	1476	2126	1681	602
Crop coefficient (kc) init	0.3	1.1	0.3	1.1
kc develop	0.75	1.15	0.75	1.15
kc mid	1.2	1.2	1.2	1.2
kc late	0.35	0.85	0.35	0.85
growth stage (total days)	105	150	1866	669
Potential yield (kg/ha)	4000	6050	4000	6050
Max yield response factor	1.3	1.09	1.3	1.09
Plant date (month no)	3	2	8	9
Harvest date (month no)	8	7	3	2
Plant date (water year start sep)	7	6	1	1
Harvest date (water year start sep)	12	11	7	6

The WEAP model analyses the impact of water shortage on crop yield using the most commonly used FAO's approach (Allen et al, 1998), which describes the yield reduction as a function of the transpiration deficit:

$$Y_{act} = Y_{pot} \times K_Y \times \frac{T_{act}}{T_{pot}}$$

with Y_{act} the actual yield (kg/ha); Y_{pot} the potential yield (kg/ha); K_Y the crop and time specific yield coefficient (-); T_{act} the actual crop transpiration (mm); and T_{pot} the potential crop transpiration (mm). The potential yield values were obtained from the project design report. The efficiency coefficients are those used in the final design report (section 6.5.5) are:

Table 6.8 Efficiency coefficients

Efficiency	Value
Conveyance	95%
Operation efficiency	95%
Field irrigation min	50%
Field irrigation max	72%
Overall min	45%
Overall max	65%
Overall mean	**55%**

For the effective precipitation, the same monthly coefficients were used as in the Final Design Report (table 6-24).

6.5.2 Impacts under project design scenario

The WEAP model outputs for the current climate were compared with calculations in the Final Design report. The WEAP model simulates the crop water demand, considering the reference ET, crop coefficients and effective precipitation. The total simulated demand is approximately 32 MCM, which is very similar to the demand calculated in the final design report (29 MCM). The small difference is likely due to different meteorological inputs, and different approaches in the crop calculations. Even though roughly the same assumptions were used for the cropping systems, there are obviously differences in the approaches which lead to slightly different outcomes.

The simulated irrigation water supply reliability of the 01_prj (conditions as in project design report) is 89%. Reliability is defined as 1 minus the number of months that the water supply is lower than the demand, divided by the total number of months in the full simulation period (30 years: 1985 – 2014). Please note that in the initial analysis phase, a slightly different approach was taken for the reliability calculation, based on flow statistics only, and taken as a baseline value 80%: for this reason the values calculated there were lower. The final design report does not provide a reliability calculation but the water balance calculation in the report did confirm that water availability was very tight (i.e. water availability is very close to water demand under certain conditions and the assumptions in the report). So this reliability simulation based on a dynamic water balance calculation confirms that.

Figure 6.20 shows outputs of the WEAP model for the current climate (in fact: one particular realization from the weather generator with no changes in rainfall and temperature). The above figures shows the inter-annual variability in irrigation water demand, and the below figures shows the mean monthly actual evapotranspiration for the two crop types and two cropping seasons, as they were incorporated in the WEAP model.

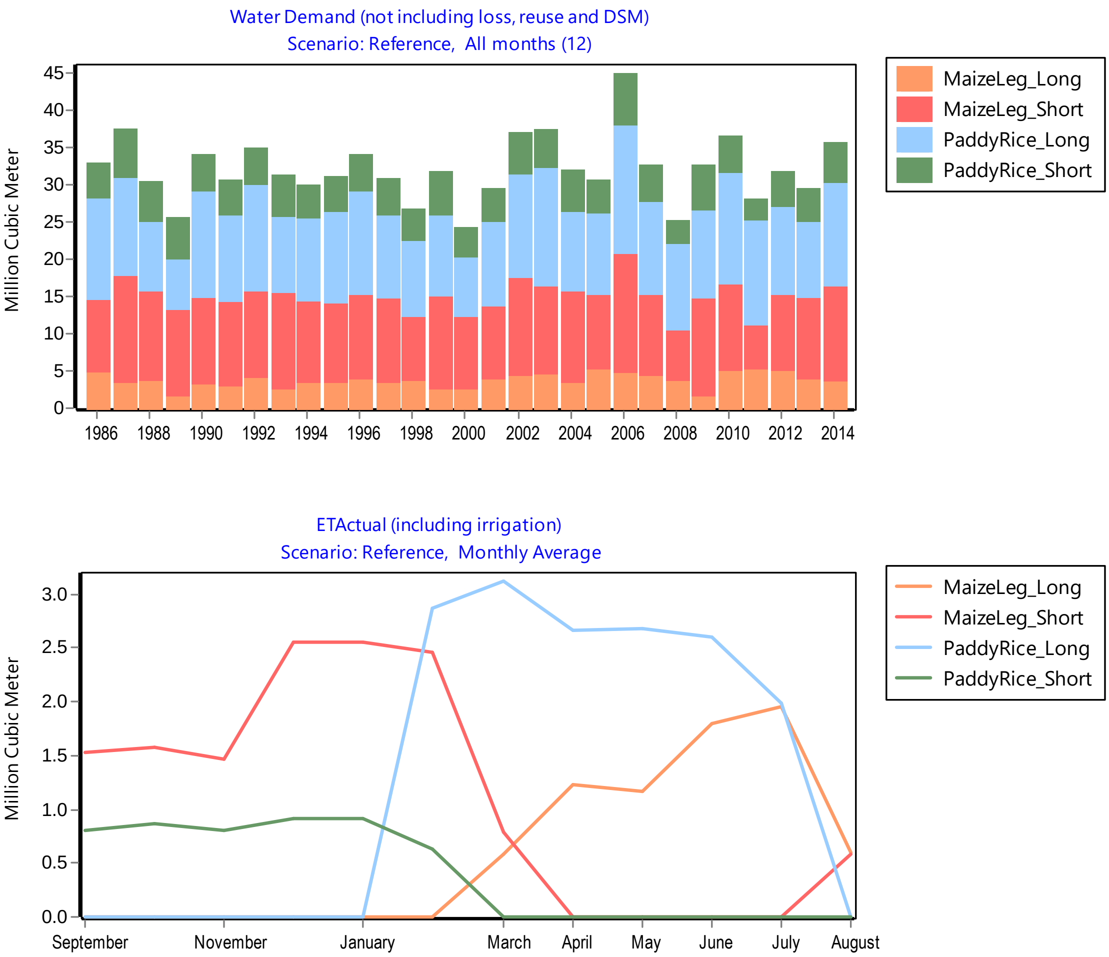

Figure 6.20 Annual water demand and monthly actual evapotranspiration of the two crop types and two cropping seasons, for both LNIP1 and LNIP2.

The irrigation water supply reliability was simulated for all the climate realizations (all dPET and dP values). Figure 6.21 shows the climate response plot of the irrigation supply reliability to LNIP1 and LNIP2. As can be seen, this performance metric is certainly sensitive to PET changes, but changes in rainfall dominate the response surface. Changes in rainfall do have significant influence on the reliability.

If 80% reliability is taken as a critical value, looking at the GCM-based dP and dPET values, it can be seen that most of the points are above this threshold. From this observation, it can be concluded that under the 01_prj scenario (assuming same conditions as in the project design: no development as planned in the water allocation plan and irrigation efficiency as in the design report), climate risks to the project's water supply are relatively low. Figure 6.21 (right) shows also how the threshold chosen for reliability is related to the likelihood to surpass that threshold in the future, based on the GCM projections. The plot shows for example that there is a 91% likelihood that the reliability will be 80% (0.8) or higher under the 01_prj scenario. For a reliability of 90% (0.9) or higher, the likelihood is 59%.

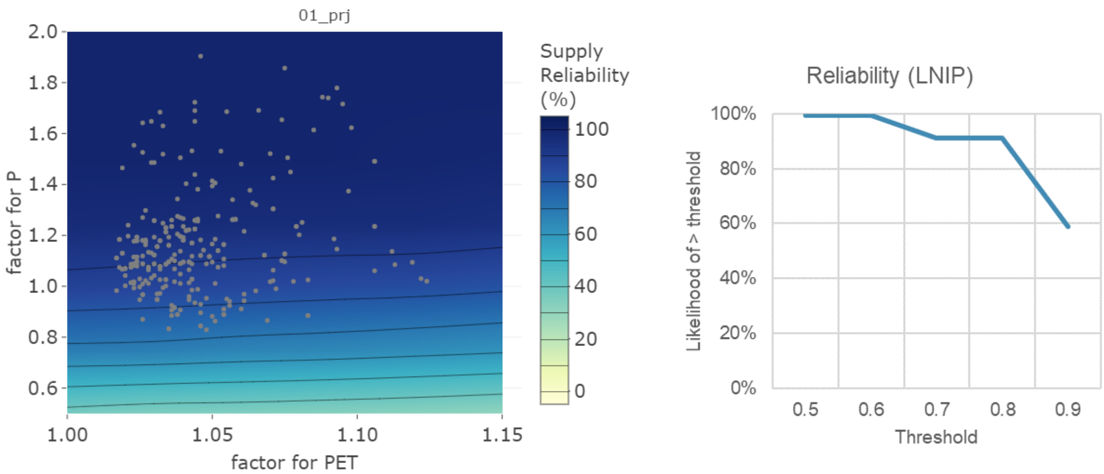

Figure 6.21 Left: climate response plot of the irrigation water supply reliability to LNIP. Right: Right: likelihood to surpass a certain threshold for reliability

Figure 6.22 shows a similar pattern for the Drought Vulnerability performance indicator, defined as the unmet water demand divided by the total water demand of the project (for reference, see Table 6.9 for the demands and unmet demands of the current climate, i.e. when dP and dPET = 1.0). Again this response plot is mainly dominated by rainfall changes. The right figure shows again the likelihood of surpassing a certain threshold for this indicator. The likelihood of a vulnerability of 0.2 in the future or lower is 59%. For a threshold for vulnerability of 0.3, the likelihood is 91%.

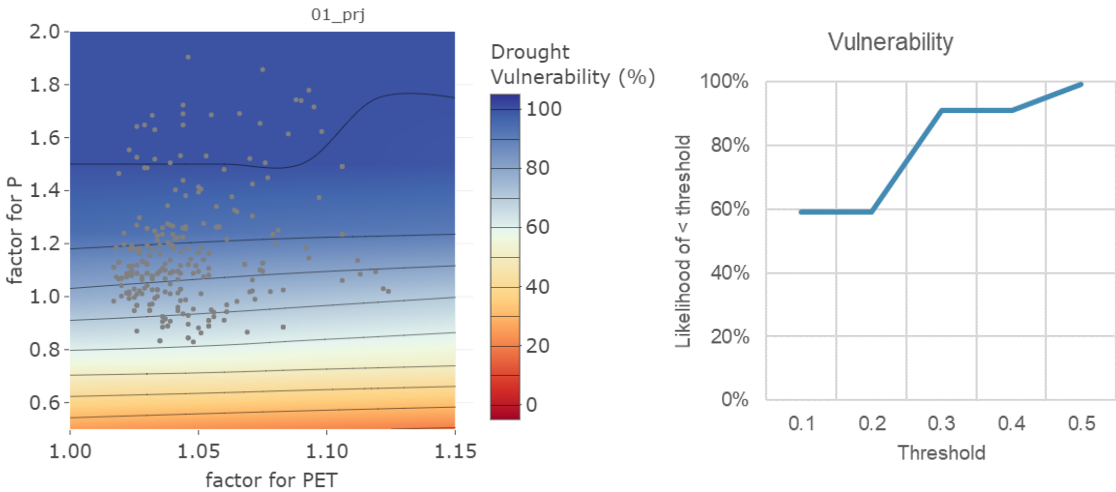

Figure 6.22 Left: climate response plot of the Drought Vulnerability (total unmet demand divided by the total demand). Right: likelihood to surpass a certain threshold for vulnerability

Figure 6.23 shows the climate response plot for the Drought Resilience indicator, here defined as the inverse of drought duration, and a drought being defined as a continuous period in which supply is below demand. A value of 0.5 means that mean drought duration is 2 months (based on the full simulation period). A value of 0.1 means that drought duration is 10 months. The figure shows the likelihood (based on the GCM projections) that a certain threshold is surpassed or not. For example: according to the GCM projections, the likelihood is 100% that the resilience will be higher than 0.1 (in other words, droughts have a duration of less than 10 months). However, for a threshold value of 0.5, the likelihood is only 42% to reach that value or higher.

Overall it can be concluded that under the project design scenario (01_prj) there is generally a reliable irrigation supply under the future climate, as the likelihood that the reliability is high (>80%) is high. Still, the vulnerability performance indicator clearly indicates that the system is already to some extent vulnerable under this scenario (59% likelihood that the vulnerability, or the relative unmet demand will be 0.2 or lower). The resilience indicator also shows that drought duration may increase in the future, and likely even more in case the upstream catchment will be further developed in terms of water resources (see next section)

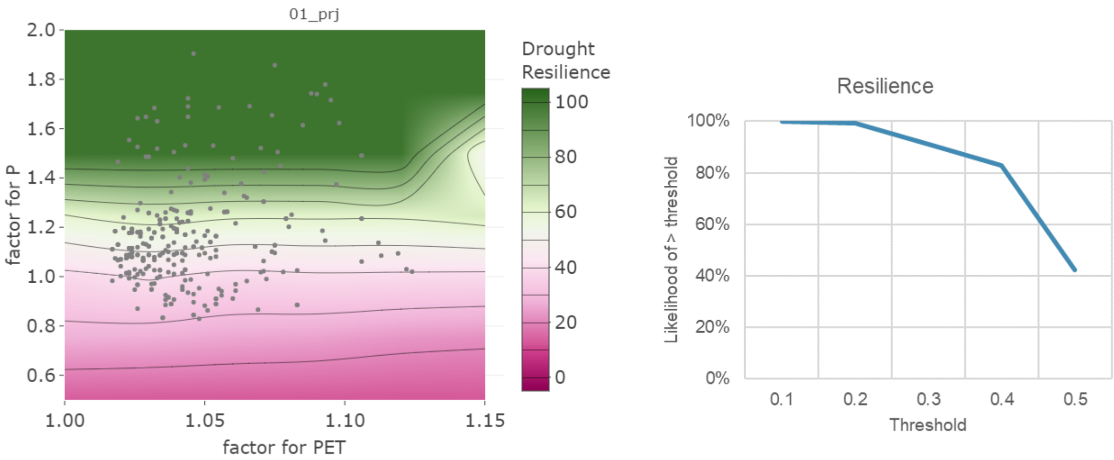

Figure 6.23 Left: climate response plot of the drought resilience (inverse of drought duration). Right: likelihood to surpass a certain threshold for resilience

The WEAP model has also been used to simulate the crop yield impacts, shown in Figure 6.24 of the two crop types. Again, most of the grey dots are in the greenish part of the plot, suggesting that there is a relatively low climate risk to crop yields, under this particular scenario (01_prj). These outputs have been used in the economic analysis (section 6.5) to assess the combined effect of flooding and drought.

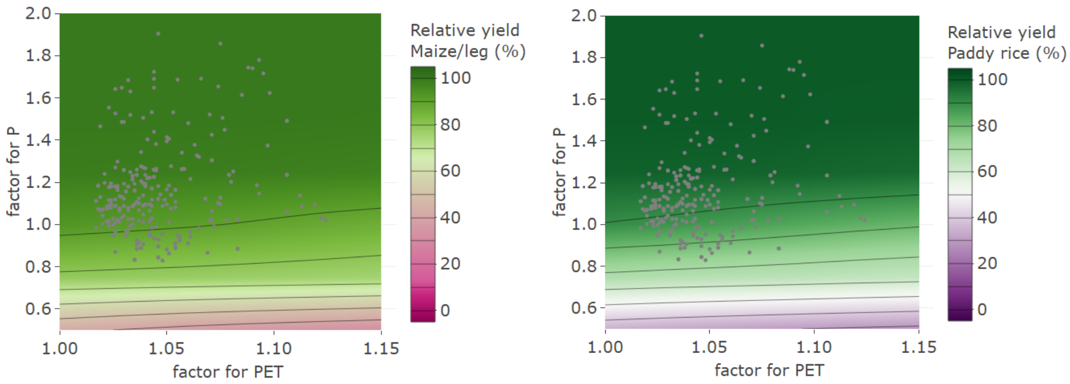

Figure 6.24 Climate response plot of the Crop yield as a percentage of potential yield for maize/legumes and paddy rice

The next section shows the outcomes for the assessed non-climate risks.

6.5.3 Impacts considering key non-climate risks

NWMP2030 projects in total 161,645 hectares in LVNCA region. The Nzoia basin covers 70% of this region. All large-scale irrigation projects are located in the Nzoia region (total 78,370 hectares). For the small-scale and private project irrigation projects, it was assumed that they are equally distributed over LVNCA (so 70% of the area corresponds to Nzoia).

Thus, the total projected newly irrigated area in 2030 in the Nzoia basin was assumed to be 138,000 hectares. Also for the other demands (domestic, industrial, etc), the Nzoia-specific demands were calculated assuming that they correspond to 70% of the total demand in LVNCA.

For this analysis, an overall (conveyance, distribution and application) efficiency of 60% is assumed, as in NWMP2030. The monthly variation in irrigation demand for the upstream irrigation development was assumed to be the same as in LNIP. Please note, that for this analysis, impacts of changes in rainfall and evapotranspiration on upstream irrigation demand were not considered. This would require a more elaborate model on the sub-basin level that is able to consider climate variability across the basin. Also, it can be expected that the relative increases in water demand due to climate change are much smaller than the projected increases in water demand due to the expansion of irrigated areas.

Table 6.9 shows the mean annual demands and unmet demands as were simulated by WEAP for the different scenarios. Table 6.10 shows the main performance metrics for the current climate (dP and dPET = 1.0) shown in this section: reliability, vulnerability, relative yield and water stress index. The water stress index is a proxy for the level of water stress a basin experiences and related to management problems the basin can face, conflicts among users, environmental issues, etc. The index is defined as:

$$Water\ stress\ index = \frac{Total\ withdrawals}{Total\ water\ availability}$$

The reliability numbers shown in Table 6.10 show that the simplified approach taken in the initial analysis phase overestimated the impacts due to various reasons: it was assumed there that the “base” reliability is 80%, while in fact the reliability may be higher as in the wetter months of the year it can be expected that reliability is 100%, and there are differences in the water availability- water demand calculations, performed in a dynamic way instead of based on flow statistics.

Table 6.9 Demands and unmet demands for the three scenarios analysed and for the current climate (dP = 1.0 and dPET = 1.0), US= upstream

		Irrigation US	**Irrigation US**	**LNIP1**	**LNIP1**	**LNIP2**	**LNIP2**
No	**Code**	**Water Demand**	**Unmet Demand**	**Water Demand**	**Unmet Demand**	**Water Demand**	**Unmet Demand**
1	01_prj	0	0	34	6	31	6
2	02_full_us_dev	942	140	34	8	31	7
3	03_red_eff	0	0	43	9	39	8

Table 6.10 Performance metrics for the three scenarios analysed and for the current climate (dP = 1.0 and dPET = 1.0)

No	**Code**	**Supply Reliability LNIP**	**Drought Vulnerability**	**RelYieldMaizeLeg**	**RelYield Rice**	**WaterStress Ratio**
1	01_prj	0.89	0.19	0.93	0.89	0.01
2	02_full_us_dev	0.85	0.25	0.91	0.85	0.28
3	03_red_eff	0.88	0.20	0.93	0.88	0.02

The below climate response plots show how irrigation water supply reliability is influenced under the non-climate risk scenarios (02_full_us_dev and 03_red_eff). For both scenarios, the reliability is slightly lower than the 01_prj scenario, but still most of the response surface shows value of above 90% due to the high predicted rainfall increases. For the Drought Vulnerability, Resilience and relative yields, response surfaces are similar.

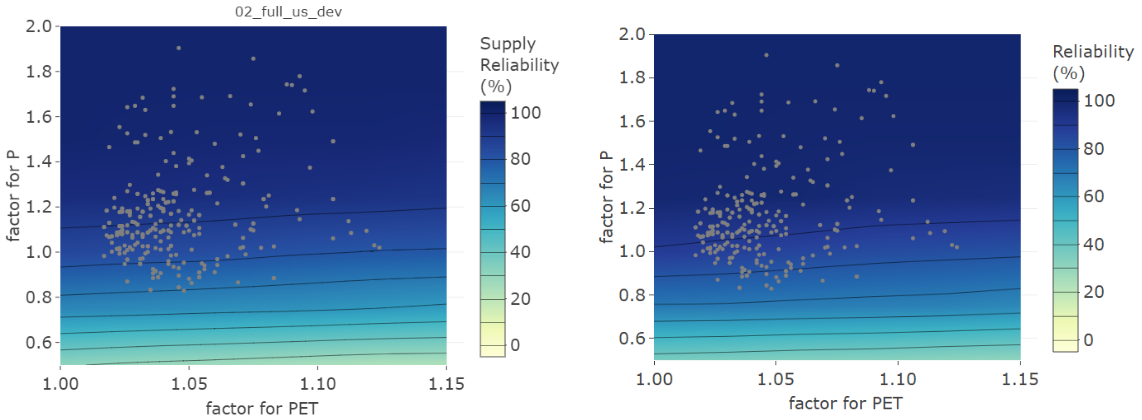

Figure 6.25 Climate response plots of water supply reliability (LNIP) under (left) projected irrigation upstream in 2030 as planned in NWMP2030, (right) reduced irrigation efficiency by 20%

An additional analysis was done, analysing how full water resources development upstream (02_full_us_dev) affects the economic performance of the project. The result is that the robustness of the project is only slightly reduced, from 69%, to 64%. This limited impact because (1) the project robustness is mainly influenced by the flood protection and projections showing an increase in precipitation, and (2) the impact on irrigation supply reliability and other metrics is limited. However, as shown hereafter, on the basin-level there is certainly an impact.

The water stress index was analysed for the 01_prj scenario and the 02_full_us_dev scenario. As can be seen in the below figure, the water stress ratio currently is very low (below 5%), suggesting a high potential to further develop water resources in the basin. The planned upstream developments (02_full_us_dev) will increase the water stress ratio considerably. Similarly as was calculated in the NWMP2030, the water stress ratio will go up to around 32% not considering climate change (see Table 6.10), but could under certain climate future go up to values above 40%. Most of GCM-based projections however are between 20% and 30%.

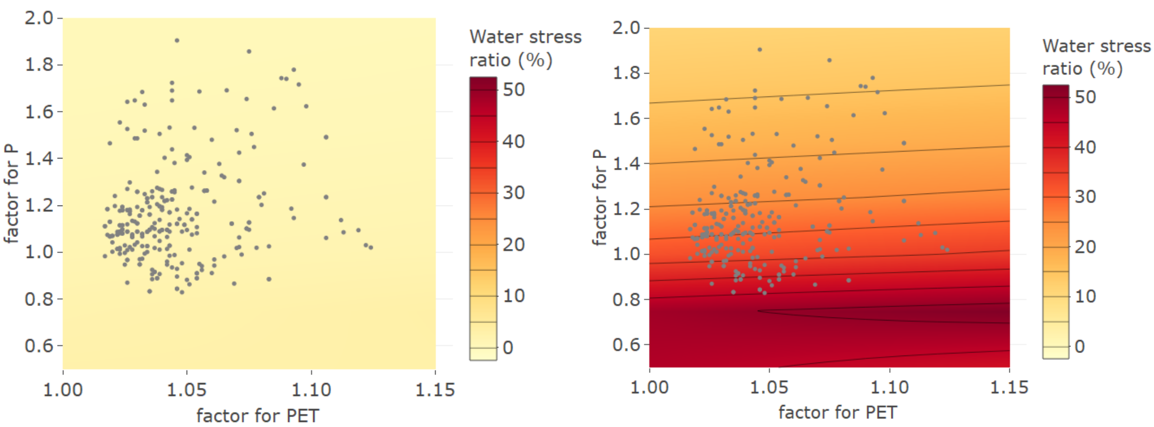

Figure 6.26 Climate response plots of the water stress ratio, under the project design scenario (left) and the upstream irrigation development scenario (right)

The above shows that there is a risk of the water stress ratio to reach levels of severe stress (30 - 40%). Therefore, Phase IV should analyse how the water stress ratio and related sustainable use limit is influenced under various upstream water development scenarios and groundwater allocation scenarios.

6.6 Economic analysis

6.6.1 Methodology for economic analysis

The economic analysis follows the analysis presented in Chapter 9 of the Final Design Report and especially Table 9-51 that presents for the selected project alternative, Food Security Cropping Pattern, the streams of costs and benefits for the years 2017 to 2046 and that is used to calculate the (NPV) Nett Present Value and the EIRR (Economic Internal rate of Return). This table is reproduced in Appendix F. The NPV is calculated in the Final Design Report for this alternative as 1,500 MKES and the EIRR as 14.1%. New calculations based on the same data result in an NPV of 1,000 MKES and an EIRR of 13.4% (for details see Appendix D).

A Python script has been developed to calculate for each climate realization the NPV and the EIRR in line with Table 9-51 of the Final Design Report (see Appendix E for the script). Input for each climate realization consists of the probability of an actual 1/30 years flood event (Figure 6.13), avoided APL (Figure 6.17), the relative yield for maize and legumes and the relative yield of paddy rice (both Figure 6.24).

- The values in the following columns of Table 9-51 of the Final Design Report that contain the benefits of the project have been based on these input parameters:

- Irrigated with-project benefits
  - Model 1: Maize/legumes (original values modified by the relative yield for maize as calculated by WEAP, see Section 6.4.2)
  - Model 3: Paddy (original values modified by the relative yield for paddy rice
  - as calculated by WEAP, see Section 6.4.2)
  - Model 4: Bunyala Project (original values modified by the relative yield for paddy rice as calculated by WEAP, see Section 6.4.2)
  - Rice Mill (original values modified by the relative yield for paddy rice as calculated by WEAP, see Section 6.4.2)
- Flood Management with-project benefits
  - Avoided annual probability of loss of crops (original values replaced by avoided APL calculated as presented in Section 6.3.3)
  - Avoided annual probability of damage to LNIP (original values replaced by avoided APL calculated as presented in Section 6.3.3)
- The values in the following columns have been recalculated with the new values for the inputs:
  - Incremental benefits (summation per year of the benefits of Model 1: Maize/legumes, Model 3: Paddy, Model 4: Bunyala Project, Rice Mill, Avoided APL of crops, Avoided APL of damage to LNIP and Rainfed with project benefits minus Without project benefits) ;
  - Net benefit stream (Incremental benefits minus the Incremental costs).

The NPV has been calculated for each climate realization based on the discount rate of 12% mentioned in the Final Design Report. The EIRR has been determined as the discount rate at which the NPV would be zero.

6.6.2 Results of the economic analysis

Figure 6.27 shows the results of the economic analysis in the form of climate response maps for the NPV and the EIRR of the project. Again, the sensitivity for the evaluated range of change in PET is limited. However, the economic performance of the project appears to be very sensitive to the change in precipitation. Increased precipitation appears to be most likely, based on the GCM results. An increase of precipitation by 25% would lead to an increase of the EIRR to just above 13.5% (from 13.4% for the actual climate). A further increase in precipitation would rapidly decrease the EIRR to values below the threshold of 12% shown as a negative NPV in response map. Current precipitation amounts would lead to an EIRR just over 12% and therefore a positive NPV except for the climate realizations with an increase of PET by 12% or more, corresponding with a temperature increase of more than 5 degrees C. A decrease in precipitation below the actual level would rapidly result in an EIRR below the 12% threshold and therefore a negative NPV.

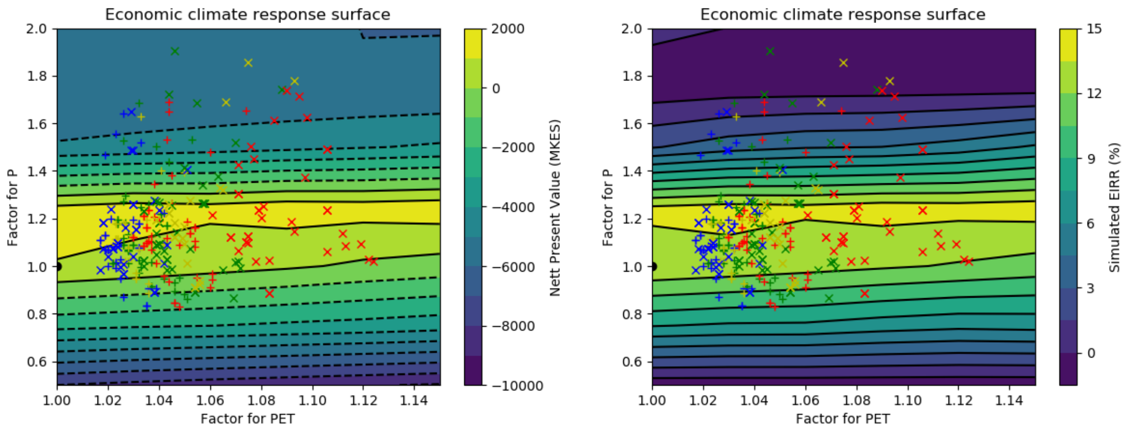

Figure 6.27 Climate response maps with on the Y axis the factor of change in precipitation and on the X axis the factor of change in PET; the colours show the Nett Present Value (left) and the Economic Internal rate of Return (right) for different rates of change in precipitation and PET and the dots show the location of the GCM results (for the legend of the dots see Figure 6.2)

The results can also be presented as a response map of success and failure of the project, where success is defined in accordance with the Final Design as an EIRR of 12% or more. This response map is presented in Figure 6.28. It shows that the project will be successful under the current climate and with a limited increase or decrease of precipitation. Furthermore, a large increase of PET of more than 10%, corresponding to a temperature increase of more than 5 degrees C, will reduce the EIRR below 12% under current precipitation levels.

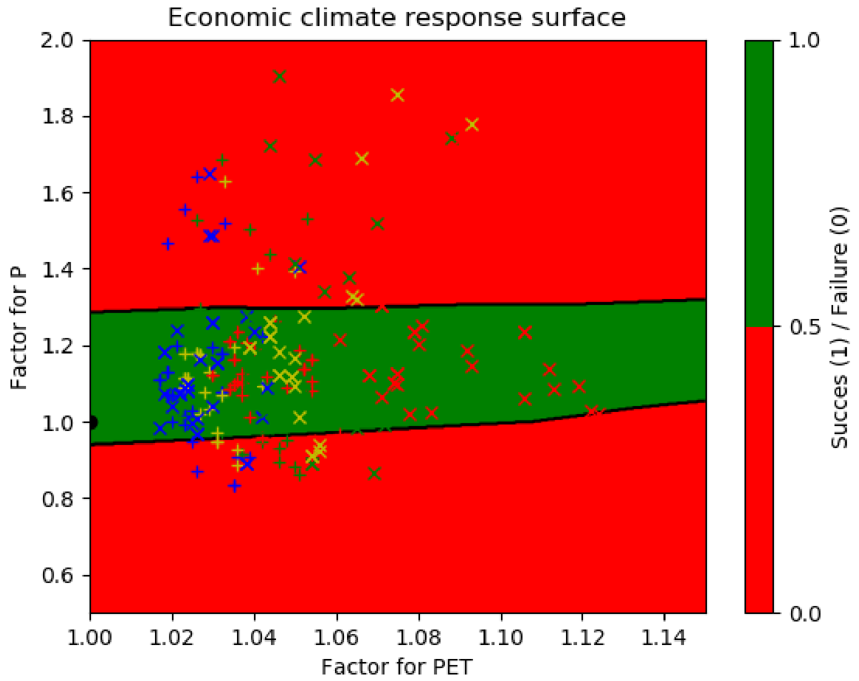

Figure 6.28 Climate response map with on the Y axis the factor of change in precipitation and on the X axis the factor of change in PET; the colours show the success (green) and failure (red) of the project to provide a 12% or higher EIRR and the dots show the location of the GCM results (for the legend of the dots see Figure 6.2)

The robustness of the project can be expressed as the fraction of the GCM projections in the green zone in Figure 6.28, i.e. where the project provides and EIRR of 12% or more. 196 of the total of 284 GCM projections have an EIRR of more than 12% resulting in a robustness of 69%. The robustness has also been calculated separately for the 2050 and 2085 GCM results. The different time horizons appear to have no impact on the calculated robustness with a value of 68% for the 2050 and 70% for the 2085 predictions (70%).

The results as presented and discussed above clearly show that the current project design results in an acceptable performance as expressed by the EIRR and the NPV under the current climate and with 25% increase in precipitation. Further increase in precipitation or a reduction in precipitation would reduce EIRR and NPV to values below the thresholds.

Figure 6.29 shows a one-dimensional presentation of what can be considered the most essential variables in the climate stress test. In this figure, temperature change is not included, as the analysis shows that the project is much more sensitive to the expected range in precipitation than the expected range in temperature and associated potential evapotranspiration. This is mostly caused by the large uncertainty in the development of the precipitation. This allows for a simplified presentation in a one-dimensional graph instead of the two-dimensional maps used above.

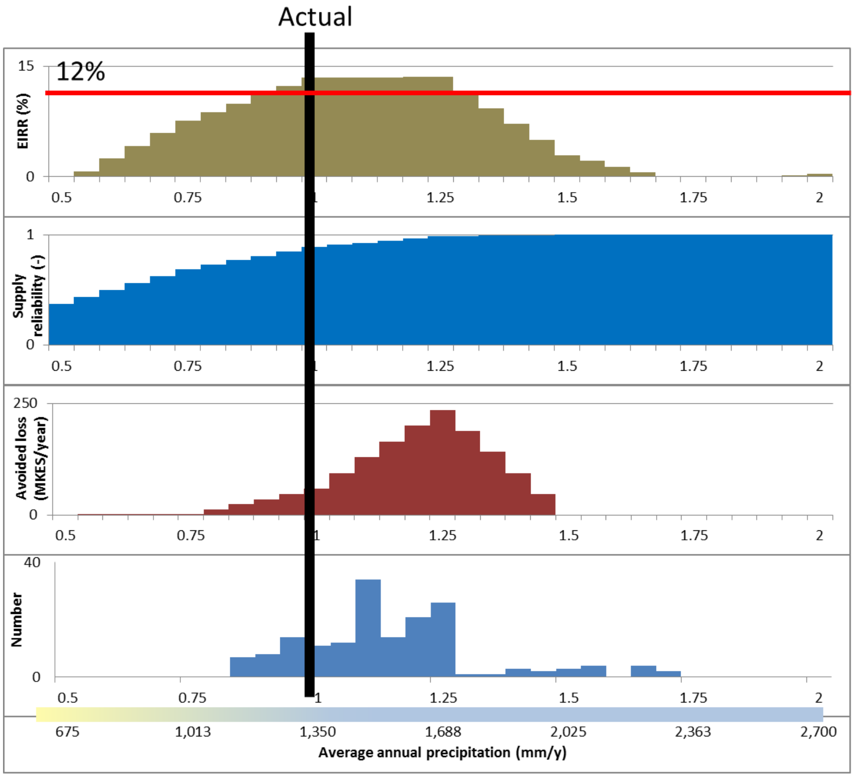

Figure 6.29 One dimensional representation of the results of the climate stress test showing (from bottom to top) for the range of future change in average annual precipitation of -50% to +100%: a) the frequency distribution for the GCM projections; b) the avoided flood damage; c) the supply reliability for the irrigation system; and d) the EIRR of the project.

Figure 6.29 shows that most GCM projections show an increase in precipitation by less than 25%. The avoided flood damage increases with increasing precipitation to a maximum value of nearly 250 MKES/year for a 25% increase in precipitation. The supply reliability for the irrigation system decreases sharply with decreasing precipitation.

This results overall in a maximum value of the project EIRR of around 13% for annual average precipitation ranging between the actual value and an increase by 25%. A decrease of precipitation or an increase by more than 25% will reduce the EIRR below the 12% threshold value. The frequency distribution of the GCM results show that 70% of the results are in the range between 0% and +25%, indicating a robustness of the project to climate change of 70%. 20% of the projections result in a below threshold performance of the project due to limited water availability as does another 10% due to increased flood damage.

6.6.3 Non-climate change risks

Section 5.4 presented two non-climate related risks that require economic analysis to assess their impact. The impact of failure of catchment management to reduce the sedimentation rate and thereby limit the lifetime of the improvement of the flood protection has been evaluated based on the description in World Bank (2015). As described in Section 5.5.3, the life time of the improved flood protection is assumed to decrease from 30 to 15 years due to sedimentation when catchment management fails. This has been implemented in the economic analysis by increasing the probability of flooding from 1/30 years in the 15th year of the project to 1/10 years in the 30th year of the project. This results in a very limited reduction of the project EIRR from 13.4% to 13.3%. For the actual climate the reliability of the flood protection would reduce after 15 year from 0.96667 to 0.9 and the resilience from 0.8 to 0.4.

The reason for this limited reduction in EIRR is that the reduction in benefits takes place only in the second half of the project lifetime and this period contributes little to the NPV and EIRR with discount rates of 12% and higher.

The impact of inadequate operation, maintenance and enforcement has been evaluated by reducing project benefits starting some years after implementation. No data are available to select a reduction percentage and the number of years after project implementation. However, officials with extensive local experience have suggested during the May 2019 field visit that the influence on the irrigation system will be limited, since farmers will operate and enforce the system themselves or will force the governmental agencies to do so, since the direct benefits are very clear to the farmer. The main issue related with inadequate operation, maintenance and enforcement has been suggested to be the deterioration of the embankments due to traffic on and over the embankments and deliberately lowering the embankments to provide lorries access to the floodplain, especially for sand mining activities. Local experience has shown that lack of enforcement and maintenance has led to severe reduction of the safety level within five years after improvements had been implemented.

Based on the above presented local information, the risk of inadequate operation, maintenance and enforcement has been quantified by reducing the lifetime of the improvements of the flood protection from 30 to 5 years. This results in a project EIRR of 12.7% and a NPV of 500 MKES, which is a substantial reduction compared to the EIRR of 13.4% and the NPV of 1,000 MKES with adequate operation and maintenance. The reduction of reliability and resilience after 5 years is the same as presented above for the failure of the watershed management after 15 years, since the safety level is reduced in both cases to 1/10 year.

The results of the assessment of the impact of non-climate change risks are summarized in Table 6.11.

Table 6.11 Selected non-climate change risk and, the way to calculate the impact

Non-climate change risk	Result impact assessment
Increased upstream water use	Limited reduction of water supply reliability, but a substantial increase of the water stress ratio for the basin
Inadequate operation, maintenance and enforcement	Substantial reduction of resilience and reliability after 5 years and project EIRR
Catchment management fails to reduce the sedimentation	Substantial reduction of reliability and resilience after 15 years, but limited reduction of project EIRR
Irrigation efficiency	Limited impact on all indicators

6.7 Conclusions climate stress test

The results of the climate stress test and the evaluation of the non-climate change risks as presented in this Chapter lead to the following conclusions:

Uncertainties in the climate inputs

1. There is a lot of uncertainty in the climate projections for precipitation for the Nzoia basin, resulting in the selection of a range of -50% to +100% for the climate stress test.
2. The uncertainty in the development of the temperature is represented by a selected range of 0 to 6 degrees C warming.
3. The temperature range has been converted to a range of PET using the Hargreaves formula, resulting in a range for PET of 0 % to 15% increase.

4. As can be expected, the simulated flow of the Nzoia is much more responsive to the selected range of precipitation than to the selected range of PET. Therefore, the uncertainty in the range of PET introduced by the use of the Hargreaves formula has no significant impact on the results of the climate stress test.

Climate risks:

5. As can be expected, the frequency of flood events increases with increasing precipitation and decreases with decreasing precipitation. The benefit of the improved flood protection, expressed as the avoided flood damage, has a maximum value of 200-250 MKES/year for a climate with a 25% increase in precipitation. A reduction in precipitation with 25% would reduce the benefit to almost zero, since hardly any flood events would occur. On the other hand, an increase by 50% or more would also eliminate the benefit of the improved flood protection, since the area would be flooded nearly every year due to the higher discharges exceeding the design level.
6. In terms of irrigation supply and crop yields, 25% increases in precipitation raises the supply reliability from 89% to 100%. Precipitation reductions of 25% reduce the reliability to around 65%, and considerable crop damage. Considering the uncertainties in future climate change, the likelihood of having a water supply reliability of >80% (= supply robustness) is high (91%). The vulnerability performance indicator indicates that the system is already to some extent vulnerable: there is 59% likelihood that the indicator will be 0.2 or lower, thus a 41% likelihood that it will be higher than 0.2. The third performance indicator studied for the irrigation scheme: drought resilience shows that drought duration (supply < demand) will in the future most likely be on average two to three months (resilience of 0.4 or less). The likelihood for shorter durations, corresponding to drought resilience of 0.5 or higher, is relatively low (42%).
7. The EIRR as the performance indicator of the project remains above its threshold of 12% for most of the climate realizations with no change in precipitation or an increase below 25%. A higher increase in precipitation would decrease the EIRR below 12%. Also even a minor decrease in precipitation would make the EIRR drop below 12%. Furthermore, a large increase of PET of more than 10%, corresponding to a temperature increase of more than 5 degrees C, will reduce the EIRR below 12% under current precipitation levels, however this can be considered highly unlikely.
8. The economic robustness of the project has been calculated as the fraction of the GCM projections where the project would have an EIRR exceeding the threshold of 12%. The calculated robustness shows that 69% of the GCM projections would results in an EIRR of 12% or higher. This underscores that the project design is well suited for the current climate as well as for most future climate realizations.
9. The design reliability for the actual climate is 0.97 1/year as defined by the design safety level of 1/30 year. In the 80% of the projections with an increase in the precipitation, the reliability is reduced, dropping below 0.1 for an increase of around 60% or more. The calculation of the resilience metric as the inverse of the average flood duration shows that increase in precipitation results in a decrease of resilience. An increase by 50% of the precipitation would reduce the resilience from 0.8 to 0.2 1/day.
10. The patterns of the response maps for reliability and resilience differ substantially. In other words: the reliability and resilience indicators show a different response to climate change. This is also the case for the drought analysis. This highlights the importance of using multiple indicators to assess the system performance under climate change.

    At the same time, it is important to note that the vulnerability and resilience indicators analysed here are only based on the biophysical response of the system: not the socio-economic response. Typically, as also here, no reliable data or model is available on socio-economic consequences of floods and droughts. It is important that this is communicated clearly when presenting outcomes based on these indicators, as the audience may have a broader definition of these terms and may misunderstand the outcomes.

Non climate-risks:

11. The stress test identified lack of adequate enforcement to protect the embankments from damage by traffic as a major non-climate change risk that could undermine the economic effectiveness of the project, specifically by reducing the lifetime of the improved flood protection. According to the calculations, the EIRR would not drop below the threshold value of 12%, indicating that the project would remain economically efficient.
12. Another important non-climate change risk is the uncertainty in the measured stream flow data that have been used to calibrate the hydrological model. This means that this uncertainty is also incorporated in the results of the hydrological model. The impact on relative indicators (such as the flood damage analysis) is limited, but absolute flows, such as used in the analysis of water availability, could contain a systematic error. However, the magnitude of this uncertainty is limited when compared to the range of climate change.
13. For irrigation supply, the non-climate risks that were assessed in this phase: future upstream water resources development and reduced efficiencies have a small impact under the current climate, but in combination with reduced rainfall in the future do exacerbate the impact considerably. The water stress index that was calculated at the basin level shows severe levels for part of the future climates. More in-depth analysis of non-climate risks and performance indicators is done in Phase IV of the DTF.

7 Phase IV: Climate Risk Management

The final phase of the DTF is executed because the climate stress test has shown that there are major climate change risks as well as non-climate change related risks to the project. The aim of this phase is to search for modifications in the design and/or implementation of the project that mitigate the identified climate change risks and that make the project more resilient to climate change. This could entail changes to the final design. Another option is to increase robustness flexibly over time based on the Dynamic Adaptive Policy Pathways approach (Haasnoot et al., 2013) by considering future adaptation of the project when the climate develops in a direction that requires adaptations to be implemented. These future adaptations might require modifications of the current final design.

The non-climate change risk of reduced water availability due to future upstream developments has been included in the risk management regarding water availability (Section 7.2). The other identified substantial non-climate change risk of inadequate operation, maintenance and enforcement applies mainly to flood risk management.

It is recommended to improve the design to ensure that institutional safeguards are in place to ensure adequate operation, maintenance and enforcement of the irrigation system and the embankments. These arrangements should consist of mechanisms to ensure adequate funding as well as sufficient oversight by stakeholders of the way in which the funding is used. Cost recovery of at least a part of the operation and maintenance costs could provide funding as well as ensure commitment of the stakeholders. Enforcement and maintenance with respect to the improved flood protection could be strengthened by granting the WRUAs and the IWUAs a formal role, which they apparently currently do not have.

7.1 Flood risk management options

Figure 6.28 shows that the current project design is quite well suited to the actual climate and that it is quite sensitive for the expected range of future precipitation and not very sensitive to the expected range of future PET, as derived from the expected range in temperature change. The simulations show that the EIRR will drop below the threshold value of 12% if the precipitation increases by 28% or more. This is caused by increased flood damage due to more frequent flood discharges that exceed the design protection level of 1/30 years (as shown in Figure 6.16).

Four promising measures have been identified to reduce the flood risk:

- Increasing the design safety level by raising the embankments;
- Reducing flood discharges by construction of an upstream dam that could also be used to store water for irrigation water supply if carefully operated;
- Reducing flood discharges by catchment management, such as construction of wetlands and additional flood plains that can store flood water; and
- Increasing the discharge capacity of the Lower Nzoia River by a combination of dredging and sand mining and/or by construction of new distributaries.

Only the raising of the embankments is considered possible for the short term. The findings of the inception visit showed that for the short term there is no public and political support to make space available for the measures. A hydraulic modelling analysis should be carried out to assess the impact of dredging and sand mining on the discharge capacity and the flood levels. Since most of the damage is related to the crops and the infrastructure, flood early warning has also little potential to limit the flood damage. The analysis of possible modification of the final design therefore only considers raising of the embankments. The analysis of future adaptations also includes the other measures, since they might become possible in the future.

There are no data available on the costs of increasing the design safety level. For the sake of this analysis, it has been assumed that raising the design safety level from 1/30 to 1/100 years will cost the same as the costs mentioned in Table 9-51 of the Final Design Report (see Appendix F for a reproduction) to increase the safety level from the current 1/10 years to 1/30 years. The complete climate stress test as described in Chapter 6 has been executed with this new safety level and the new costs. The results are presented in Figure 7.1, Figure 7.2 and Figure 7.3 that should be compared with Figure 6.28, Figure 6.18 and Figure 6.14, respectively, for the actual design. Vulnerability to flooding has not been analysed, since there are no data available to assess the flood damage for discharges larger than the current 1/100 year flood.

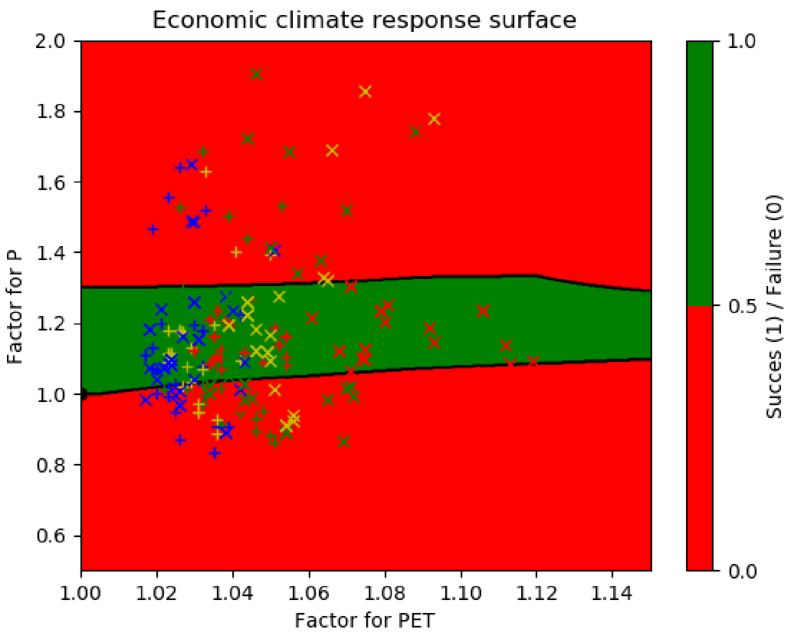

Figure 7.1 Climate response map with on the Y axis the factor of change in precipitation and on the X axis the factor of change in PET; the colours show the success (green) and failure (red) of the project to provide a 12% or higher EIRR for the design alternative with a safety level of 1/100 years; the dots show the location of the GCM results (for the legend of the dots see Figure 6.2)

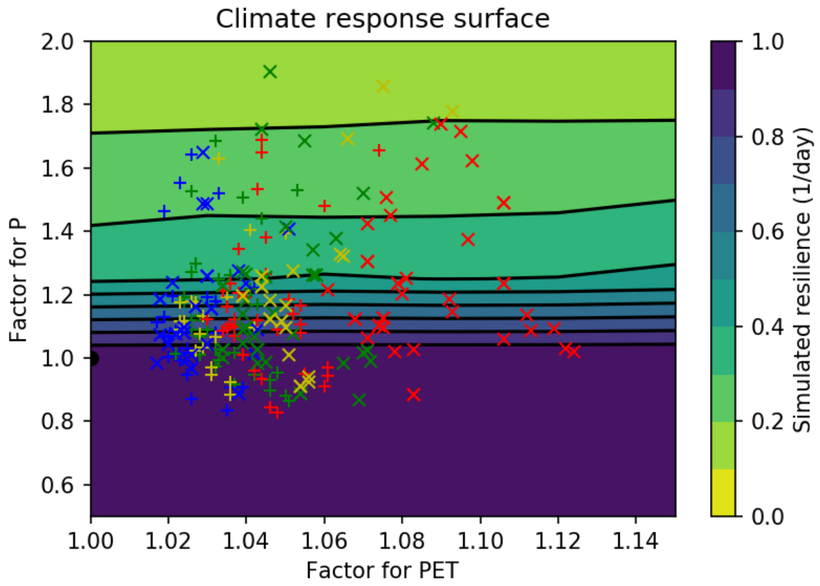

Figure 7.2 Climate response map with on the Y axis the factor of change in precipitation and on the X axis the factor of change in PET; the colours show the resilience defined as the inverse of the average duration of a flood event for the design alternative with a safety level of 1/100 years; the dots show the location of the GCM results (for the legend of the dots see Figure 6.2)

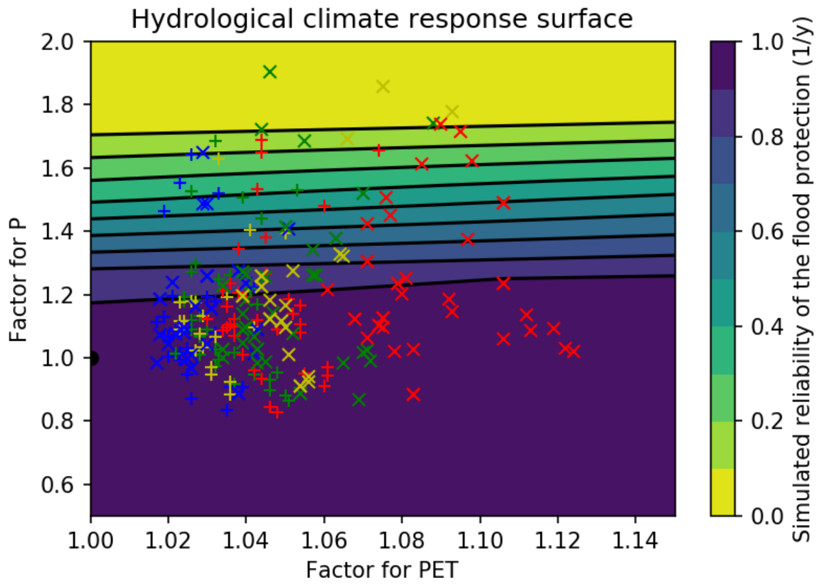

Figure 7.3 Climate response map with on the Y axis the factor of change in precipitation and on the X axis the factor of change in PET; the colours show the reliability of the improved embankments for the design alternative with a safety level of 1/100 years (with a current reliability of 0.99) and the dots show the location of the GCM results (for the legend of the dots see Figure 6.2)

The design alternative with a safety level of 1/100 years instead of 1/30 years reduces the EIRR in the current situation from 13.4% to 12.2% and the NPV from 1012 to 183 MKES. This shows that this alternative design, with the assumed costs, results in no improvement under the actual climate. The window of success in Figure 7.1 is reduced compared to that in Figure 6.28. This is also expressed by the economic robustness, the likelihood over the GCM projections that the EIRR equals or exceeds 12%, that decreases from 69% to 57% (see Figure 7.4).

This shows that the extra investment in embankments in most climate realizations do not yield enough benefits in the form of avoided flood loss to compensate for the increased expenses.

The resilience for the actual climate increases with the higher safety level from 0.8 to 1.0 1/day, indicating a reduction in the average length of the flood events from 1.25 to 1 days. Comparison of Figure 7.2 with Figure 6.18 shows that the resilience is increased for all climate realizations. This also applies to the reliability of the flood protection as shown in Figure 7.3 and Figure 6.14.

Figure 7.4 presents likelihood for the indicators EIRR, reliability and resilience to exceed relevant threshold values. This clearly shows that the economic robustness, the likelihood of the EIRR to exceed 12%, decreases with a higher design safety level, but that the likelihood of the reliability and the resilience to exceed their threshold values increases. This means that a higher design safety level has under most climate realizations a positive impact on the reliability and resilience, but that the extra costs outweigh the extra avoided flood loss in most realizations.

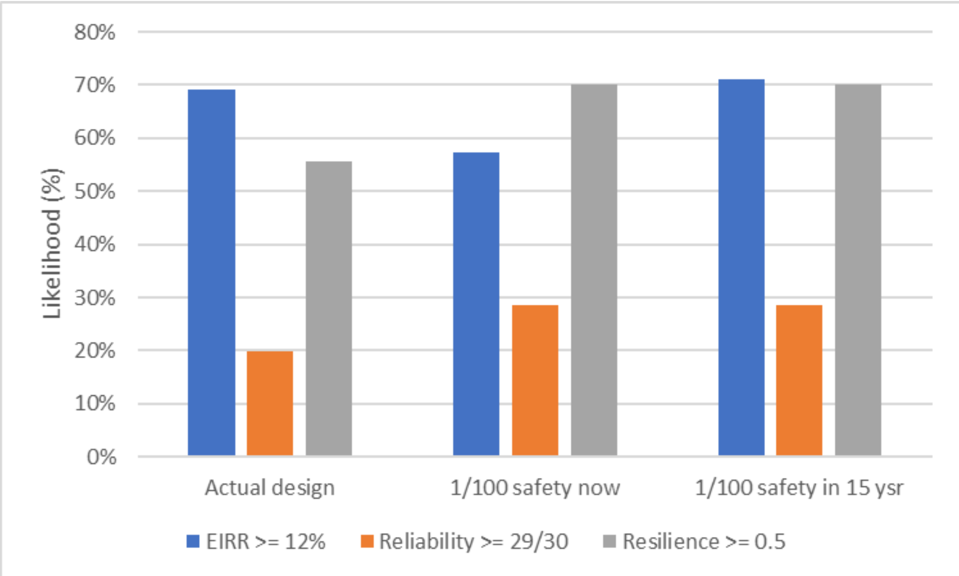

Figure 7.4 Comparison of the likelihood over the GCM projections that EIRR exceeds 12%, flood reliability exceeds 29/30 year and resilience exceeds 0,5for the current design and alternatives with an increased safety level of 1/100 years implemented from the start of the project or after 15 years

However, following the Dynamic Adaptive Policy Pathways approach, it could be a future modification of the project needs to be considered if the increase in discharge and associated flood damage starts harming the project benefits. The results of this analysis indicate that increased flood damage would reduce the EIRR below the 12% threshold if the increase in precipitation exceeds 28%.

Figure 7.5 shows the climate response surface when the increased design safety level would be implemented by raising the embankments over 15 years. The period of 15 years has been selected arbitrarily, because it is half way the time period used for the economic analysis. Earlier or later implementation would slightly alter the results presented below, because costs and benefits would occur at other moments in the economic analysis.

The results for reliability and resilience do not depend on the moment of implementation and are therefore the same as presented above in Figure 7.2 and Figure 7.3.

The delay of the costs increases the range of precipitation for which this pathway would provide an EIRR of 12% or more, since future costs are valued lower than present costs. With delayed implementation, an EIRR exceeding 12% appears to be possible for increases of precipitation up to 33% and the robustness of the design would increase from 69% to 71% (see Figure 7.4).

This seems a very limited benefit from doubling the investment in flood protection. However, this value is very uncertain. First of all, it depends on the estimated costs for increasing the design safety level from 1/30 years to 1/100 years. Lower costs would provide a higher return rate for a future with more increase in precipitation. Furthermore, the climate response analysis is based on steps of 25% in precipitation increase. Results between those steps are derived from interpolation. Therefore, it is recommended to perform a much more detailed analysis of the costs and hydrologic response to precipitation increase once monitoring indicates an increase of precipitation and flood frequency.

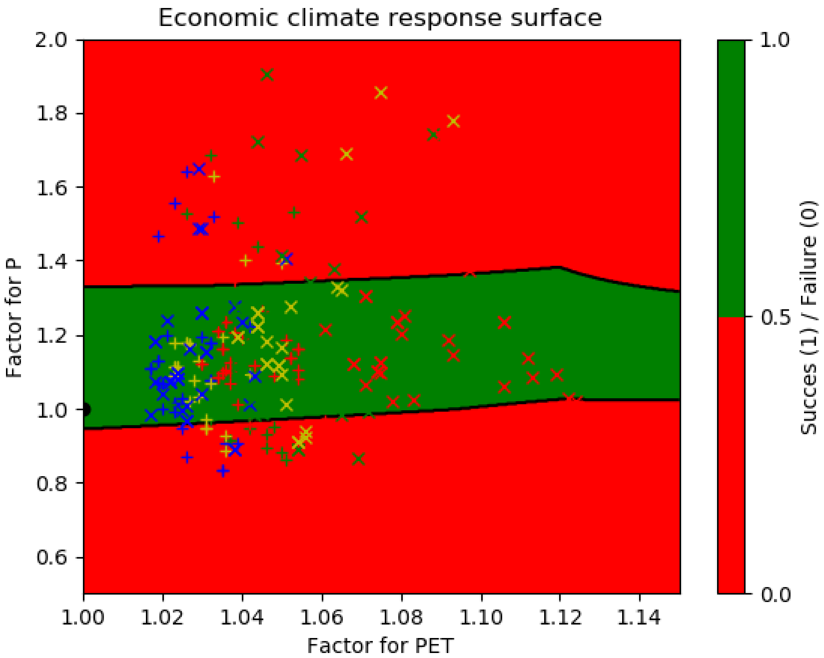

Figure 7.5 Climate response map with on the Y axis the factor of change in precipitation and on the X axis the factor of change in PET; the colours show the success (green) and failure (red) of the project to provide a 12% or higher EIRR for the design alternative with a safety level of 1/100 years implemented over 15 years; the dots show the location of the GCM results (for the legend of the dots see Figure 6.2)

The intervention to increase the design safety level has been included in the Adaptive Policy Pathways presented in Figure 7.6 together with the possible measures to construct an upstream dam, catchment management or increase of discharge capacity. No climate response surfaces have been created for these measures due to lack of data on the impact on the annual streams of costs and benefits of the project. The actual situation is represented in Figure 7.6 on the left-hand side where the precipitation increase is 0%.

The current Final Design can be maintained until the trigger point at an increase of the precipitation of approximately 25%. With further increase of precipitation, action is required to maintain the return on the investment in the project acceptable.

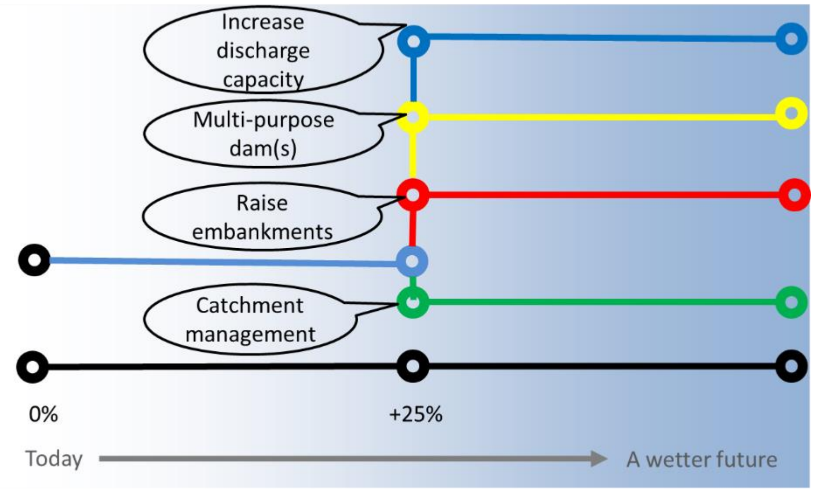

Figure 7.6 Dynamic Policy Adaptation Pathway for flood risk management for the Lower Nzoia projects depending on the future development of the annual average precipitation under climate change, with 0% representing the actual situation and a trigger point at an increase by 25%.

To assess the development of precipitation along the pathway presented in Figure 7.6 it is recommended to closely monitor precipitation and discharge and to analyse the monitoring continuously to detect as early as possible any trend in precipitation, discharge and especially the frequency of the higher discharges. In order to detect trends as early as possible, it might be necessary to include derived and associated parameters, such as maximum 30-day precipitation or other meteorological variables. Monitoring and timely detection of relevant changes it is not a question that can be easily answered. Ideally, a long dataset on precipitation and discharges would be available. When the data is highly variable, it will take longer to detect signals of change because of the strong natural variability effect. To overcome this limitation, an analysis of multiple precipitation or discharge scenarios can be done. Synthetic transient scenarios can be used to describe possible futures, including natural variability and possible trends over time. Another important aspect is how fast can a decision be implemented? When implementation of decisions takes a long time, then even weaker signal may be useful. See Haasnoot et al. (2018) for a description of ways to optimize monitoring with the aim of detecting trends.

It is recommended to execute a study to select the best measure at the moment that the monitoring results show indications of increases in the frequency of discharges that exceed the current design safety level of 1/30 years. Furthermore, it is advised to reserving room within the spatial lay-out of the Final Design to allow for future rising of embankments, which could require more room than the current design includes.

7.2 Water availability and implications for the Water Allocation Plan

7.2.1 Rationale

There is concern from several stakeholders that upstream development together with climate change impacts may cause increased water shortages in the future, and impact negatively the economic returns of the project.

Some stakeholders have highlighted that especially last year (2018) was very dry and that they fear a future in which further developments upstream will lead to more frequent and more intense water shortages. A few stakeholders have expressed during presentation of the preliminary results, that there may be already a downward trend going on in water resources availability.
Other stakeholders did not agree with this notion of a downward trend, although it is clear that 2018 was especially dry. In any case, the data does not confirm a negative trend; in fact the data shows a slightly positive trend in rainfall amounts. Trends in discharge data cannot be reliably analysed given the limitations in these data.

The impact of reduced water availability on the project performance has been analysed in the stress test (Phase III). The results of the economic analysis indicate that reduced crop yields would reduce the EIRR below the 12% threshold if the precipitation decreases by 4% or more.
Approximately 20% of the GCM projections indicate such a decrease, thus it is certainly a possible scenario, also, given the on-going debate on the performance of GCMs in the East-African region and studies that highlight an intensification of droughts (see section 6.2.1).

Following the Dynamic Adaptive Policy Pathways approach, and similar to Figure 7.6, Figure 7.7 shows the three principal pathways that can be followed in case sufficient evidence comes available (through more data and studies in the area) that there is a negative trend in the rainfall the Nzoia basin receives:

1. Enhance storage capacity in the basin is an intervention that could allow for more within-year or over-year storage capacity to be available and utilized, in order to make wet-season surplus water available during the dry season (or wet-year surplus water available during dry years). Increasing storage capacity in the basin can be realized by principally three means (a) multi-purpose storage dams, although these seem not to be an option nowadays given the political situation and concern by the communities; (b) boost the usage of groundwater storage, for example by artificial groundwater recharge measures or currently not-used aquifers or aquifers used below their potential; (c) improved catchment management activities that increase the infiltration, reduce fast runoff, increase usage of natural water retaining features in the landscape (wetlands) etc. On this latter option, please note the remarks in section 7.1 on management mechanisms that could be considered that are based on the Payment for Ecosystem Services paradigm.
2. Pathway two corresponds to the modification of the Water Allocation Plan: coordinated and optimized usage of surface versus groundwater resources, and modify priorities among sectors and users, see further below.
3. The third pathway corresponds to measures at the project level (LNIP) that can reduce the water demand (seasonality, total demand, etc) by increasing efficiencies (conveyance, distribution, application), cropping patterns, promote drought-resistance crops, etc.

   Obviously also a combination of the above pathways can be considered. The climate stress test has indicated that these measures are not necessary today, nor in a wetter climate, but can become necessary if rainfall trends will be negative, or water availability will be severely compromised by upstream water resources developments.

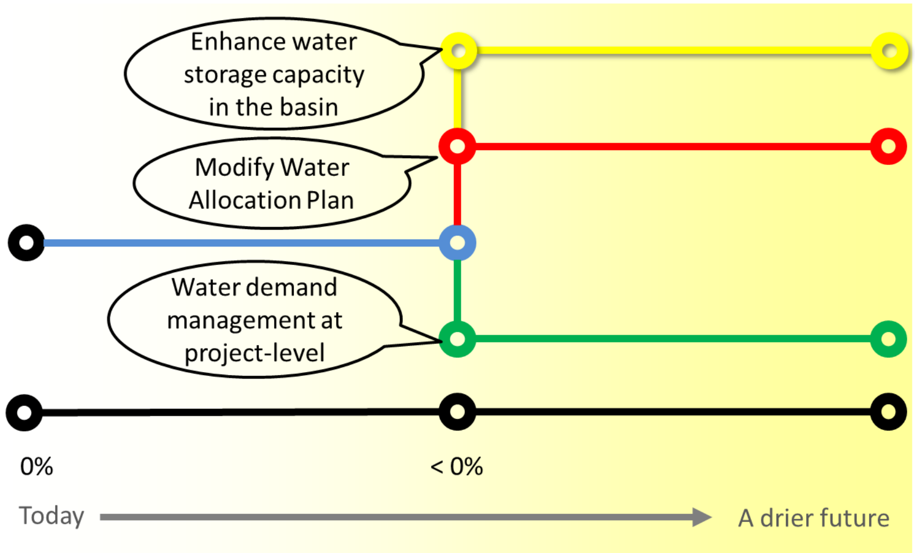

Figure 7.7 Dynamic Policy Adaptation Pathway for water availability for the Lower Nzoia projects depending on the future development of the annual average precipitation under climate change, with 0% representing the actual situation and a trigger point a decrease of precipitation below the actual level.

This section (7.2) dives into pathway 2 (Water Allocation Plan modification) and uses the data and tools for the climate stress test to inform a possible revision of the plan. Several scenarios were analysed for water allocation and upstream developments, to assess how these affect project performance and water use at the basin level, in order to inform decision making on water resources development and water allocation, and extract recommendations to revise the water allocation plan.

7.2.2 Data and methods

The Water Allocation Plan as proposed in the National Water Master Plan 2030 (NWMP2030) lays out the foundation for water resources development for all basins in Kenya up to the year 2030. For the Lake Victoria North Catchment Area (LVNCA) of which the Nzoia Basin forms part (70% of the area), projections and plans are presented on new demands (domestic, irrigation, etc) and irrigation projects.

For this national-level water resources assessment, a simple hydrological model was used to assess water resources availability for current and future conditions, up to 2050. Only multi-annual average water availability was assessed, so no variation between wet and dry years was taken into account and no allocation under drought conditions is elaborated.

Please note that the analysis presented here can be considered a first-order climate stress test of future water resources developments and allocation, as it (1) uses a water resources system model lumped at the basin-level, not considering water balances and allocation at the sub-basin level, and (2) provides a scoping-level analysis of possible development and allocation scenarios using the DTF methodology and tools used for the climate stress test of LNIP.

NWMP2030 projects water demands for 2030 for entire LVNCA. Table 7.1 shows the water allocated to the different sectoral water uses in the LVNCA for this horizon. The NWMP2030 does not provide figures specific to the Nzoia basin. These were calculated for all sub-sectors except irrigation based on areal proportionality and assuming a similar spatial distribution and level of development in both areal extents. For irrigation demand, this was based on the same procedure for the projections on small-scale and private irrigation, but for the projected

irrigation projects based on the actual projected new irrigation projects (ha). An average annual irrigation water requirement (7,000 m3/ha) rate was extracted from NWMP2030.
For this analysis it was assumed that the upstream irrigation demand follows the same monthly water demand pattern as in LNIP. The projected irrigation projects in NWMP2030 are:

- Lower Nzoia Irrigation Project (10,470 ha);
- Lower Sio Irrigation Project (6,600 ha);
- Yala Swamp Drainage & Irrigation Project (4,600 ha);
- Upper Nzoia Dam Irrigation Project (24,000 ha);
- Moi's Bridge Dam Irrigation Project (19,800 ha);
- Kibolo Dam Irrigation Project (11,500 ha);
- Total: 78,370 ha.

The County Integrated Development Plans (CIDP) of Busia County (2018-2022) and Siaya County (2013-2017) have been studied to verify whether the planned developments are beyond NWMP2030. This was not the case; in other words: the foreseen increase in water demand for upstream developments as assessed in NWMP2030 already include the developments in these two CIDPs.

For irrigation, most (98%) of the water is proposed to be supplied from surface water resources and only 2% from groundwater. For domestic use, groundwater allocation is 14%, and for industrial 47%. In total, 15% of the water resources are proposed to be extracted from the groundwater.

Table 7.1 Water demands for the different sub-sectors and surface and groundwater allocation, for the Lake Victoria North Catchment Area (LVNCA) and the Nzoia basin. Source: NWMP2030 (Nippon Koei, 2013, part B, page MB-6) and own calculations based on areal proportionality

	LVNCA			Nzoia basin		
MCM/yr	Water demand	Surface water	Ground water	Water demand	Surface water	Ground water
Irrigation	1359	1332	27	1076	1054	22
Livestock	61	61	0	43	43	0
Domestic	424	363	61	297	254	43
Industrial	19	10	9	13	7	6
Fisheries	16	16	0	11	11	0
Total	459	389	70	321	272	49

To assess the scope for water resources development, NWMP2030 uses a basin-level water stress index (or water stress ratio) that assesses how the water demands relate to the available renewable resources. This water stress index (WSI) is calculated as: total withdrawals (surface and groundwater) divided by total renewable resources.

For all scenarios (see next section), WSI levels are assessed based on the outcomes of the water resources system modelling, forced with the climate-stress test hydrological flows. For the WSI, typically the following thresholds are used (Falkenmark et al 2007):

- No stress: WSI < 20%;
- Moderate stress: WSI = 20% - 40%;
- High stress: WSI = 40% - 70%;
- Extreme stress: WSI > 70%.

For this analysis, the sustainable water use limit is set at the level in which WSI <= 20%, i.e. when water withdrawals are on average 20% of the renewable available water resources.

Table 7.2 shows all the performance metrics that are used in the analysis. The table also shows the thresholds for each metric that were used to assess the probabilities to enter a fail or positive state of the system. For the WSI, two thresholds were studied (corresponding resp. to “no stress” and “no severe stress”).

Table 7.2 Performance metrics used for this analysis and corresponding thresholds to calculate the robustness (probabilities based on climate stress test)

Performance metric	Abbreviation	Threshold
Supply reliability (LNIP)	Rel	0.8
Drought Vulnerability (LNIP)	Vul	0.3
Drought Resilience (LNIP)	Res	0.4
Water Stress Index (Nzoia basin)	WSI	0.2 / 0.4

7.2.3 Scenarios

For analysing the implications of climate change on the water allocation plan, Table 7.3 shows all the scenarios that are analysed for this part of the study. Three groundwater allocation scenarios are studied (02_full_us_dev, 06_no_gw_alloc and 07_high_gw_alloc) and three development scenarios (02_full_us_dev, 04_only_small and 05_med_us_dev).

Future climate change will also influence upstream irrigation water requirements. It is out of scope of this analysis to fully consider these impacts as this requires a parameterization of the upstream projects, cropping schemes and a consideration of the spatial climate variabilities upstream. An additional scenario was however added to this analysis in which the demand is modified using a simple approximation of how the demand is affected, based on simulated outputs that consider rainfall and ET changes of the demand at LNIP.

Table 7.3 Scenarios analysed in the water allocation plan revision analysis

No	Code	Description
2	02_full_us_dev	Full upstream development: new water demands and allocation from groundwater as projected in NWMP2030
4	04_us_dev_up_nz	New upstream domestic, industrial and livestock demands as in NWMP2030. Irrigation: only Upper Nzoia project
5	05_med_us_dev	Medium upstream development: as NWMP2030 but no large irrigation projects, only Upper Nzoia project
6	06_no_gw_alloc	As scenario 2 but without allocation from groundwater
7	07_high_gw_alloc	As scenario 2 but five times currently projected allocation from groundwater
8	08_cc_us	As scenario 2 but including an approximation of climate change (rainfall) impacts on upstream demand

Substituting surface water allocation by groundwater allocation will reduce surface water abstractions but may also reduce groundwater availability and thus baseflow. For this analysis, it will be assumed that the groundwater bodies of the Nzoia basin are 100% connected to the hydrological system of the basin itself, and not external basins. Under that assumption, groundwater abstractions lead to a reduction in baseflow of the same volume. This reduction is possibly favourable compared to the impact surface water abstractions have, as baseflow reduction is smoothed out over the year, while surface water abstractions do have an immediate impact on water availability downstream. WEAP considers this process, as well as the effect return flows have on surface water availability.

The analysis uses the WEAP water resources system model that was used for the Phase III climate stress test (see section 6.4.1).

7.2.4 Results

All scenarios were subject to the climate stress test analysis and were analysed using climate responses maps and the performance metrics. Figure 7.8 shows the climate response maps for the Resilience index (i.e. inverse of average duration of water deficits for LNIP, see Appendix B), for a scenario with no groundwater allocation (06_no_gw_alloc) versus a scenario with relatively high groundwater allocation (five times the level that is proposed in NWMP2030). Again, the dependency on PET change is limited and the metric is mainly influenced by rainfall changes.

As can be seen, groundwater allocation of the upstream demand sectors has a slightly positive effect on the duration of the drought periods (i.e. consecutive months when water supply is lower than water demand) for LNIP. This can be seen from the grey isolines being pushed towards the x-axis, meaning that more grey dots are in the greenish and whitish colour zone. In other words, a higher number of future possible climates give higher resilience values.

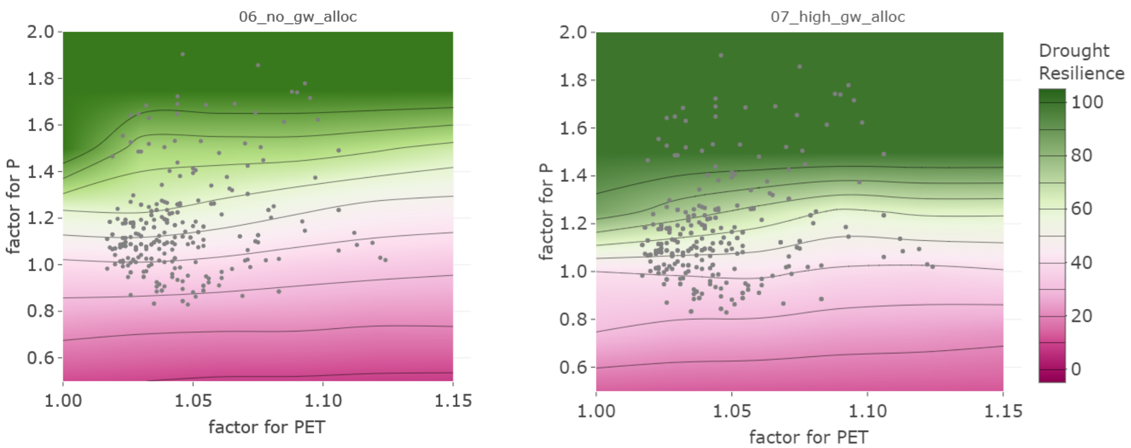

Figure 7.8 Climate response maps of the resilience index for the LNIP project; left: 06_no_gw_alloc scenario (no groundwater allocation); right: five times groundwater allocation (07_high_gw_alloc). The dots show the location of the GCM results.

The number of future climates that generate a positive state of the performance metric can be calculated and expressed as a probability, by dividing it by the total number of future climates. This was done for the three principal performance metrics that were assessed for LNIP: Reliability, Vulnerability and Resilience, with as threshold values those listed in Table 7.2. Figure 7.9 shows these probabilities for the three groundwater allocation scenarios analysed. Please note, that 02_full_us_dev corresponds to a scenario in which groundwater allocation is simulated as is proposed by NWMP2030.

The orange (Resilience) bars in Figure 7.9 confirm the positive trend as was observed in the previous climate response maps. For the reliability metric, the effect is hardly notable: in other words, groundwater allocation will not have a significant impact on the reliability of the project, under full upstream development according to NWMP2030. For the vulnerability metric (related to water deficit volume), interestingly, the 07_high_gw_alloc scenario (five times groundwater allocation as proposed by NWMP2030) gives a much higher probability for being below the threshold of 0.20.

Overall, results suggest that groundwater allocation has a slightly positive effect on the LNIP project performance. This is due to the fact that groundwater abstractions upstream do not compete directly (in the same month or season) with surface water withdrawals downstream. Groundwater abstractions upstream do have an impact on the average water availability for downstream users, but under the assumption that these abstractions substitute surface water withdrawals, the net effect is slightly positive, as especially during the dry season, competition for surface water can be high. Besides, return flows from upstream water sectors (included in this analysis) that originate from groundwater can in fact increase surface water availability during the dry season. Obviously, these are outcomes based on a lumped modelling approach, and should be further investigated with a more detailed water resources system model. Also, it is important to note that this assumes that return flows come available for downstream use, but this is certainly not always the case, for example due to groundwater dynamics and re-use upstream.

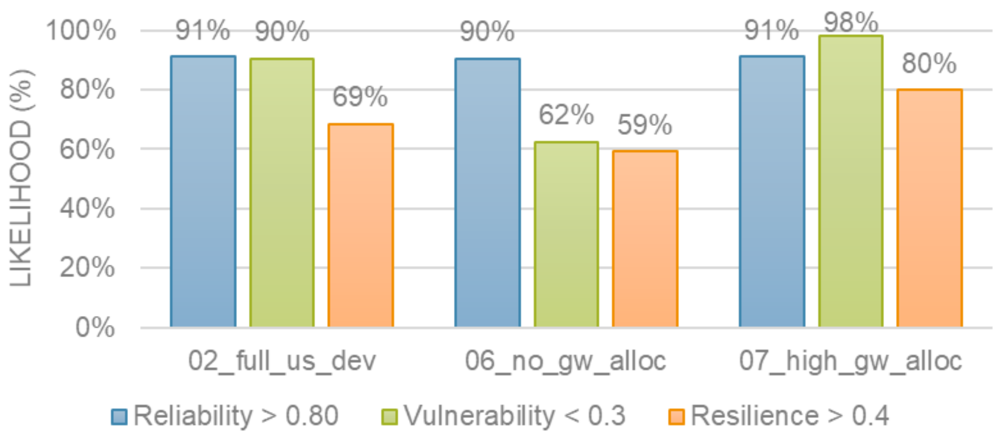

Figure 7.9 Probabilities to surpass the thresholds for three performance metrics (Supply Reliability, Drought Vulnerability and Drought Resilience), calculated for the LNIP project (combination of LNIP1 and LNIP2).

Secondly, the impact of the level of development was investigated on the Water Stress Index, by analysing three scenarios: 04_us_dev_up_nz (l development as in NWMP2030 but for irrigation only Upper Nzoia Irrigation scheme), 05_med_us_dev (medium development of irrigation) and 02_full_us_dev (full development as in the NWMP2030 scenario). Figure 7.10 shows the climate response maps of the low and the full development scenarios. The figures show clearly that the WSI increases considerably when the catchment is further developed, up to values around 40% under the drier climates. The wetter climates show values around 20% for the full development scenario.

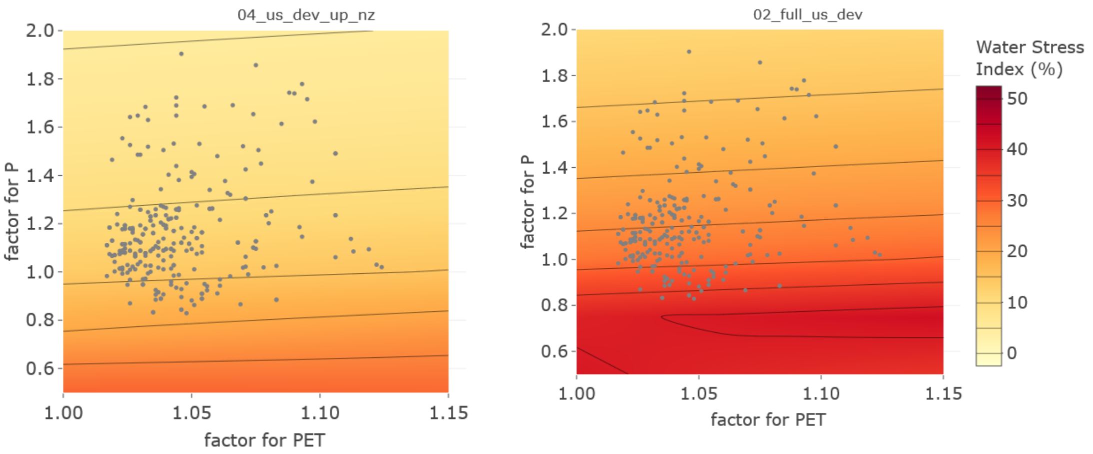

Figure 7.10 Climate response maps of the Water Stress Index for the Nzoia basin; left: 04_only_small scenario; right: the full development scenario (02_full_us_dev). The dots show the location of the GCM results.

Figure 7.10 shows the probabilities for WSI being below a certain level in the future, indicating also the typical stress levels that were listed previously (7.2.2). What can be observed in this figure, is that for the 02_full_us_dev, it is very unlikely (less than 20%) that the basin will be in a No-Stress condition, while it is very likely that it will be in a moderate stress condition. For the 04_us_dev_up_nz scenario (leaving out irrigation developments upstream except Upper Nzoia scheme), this becomes much more favourable, and there is actually a very high likelihood (91%) that the basin will be in a no-stress condition. For the intermediate scenario including other small-scale and private irrigation as planned in NWMP2030, there is a 60% likelihood of remaining in a no-stress status, and thus a 40% chance that the basin enters a moderate stress status.

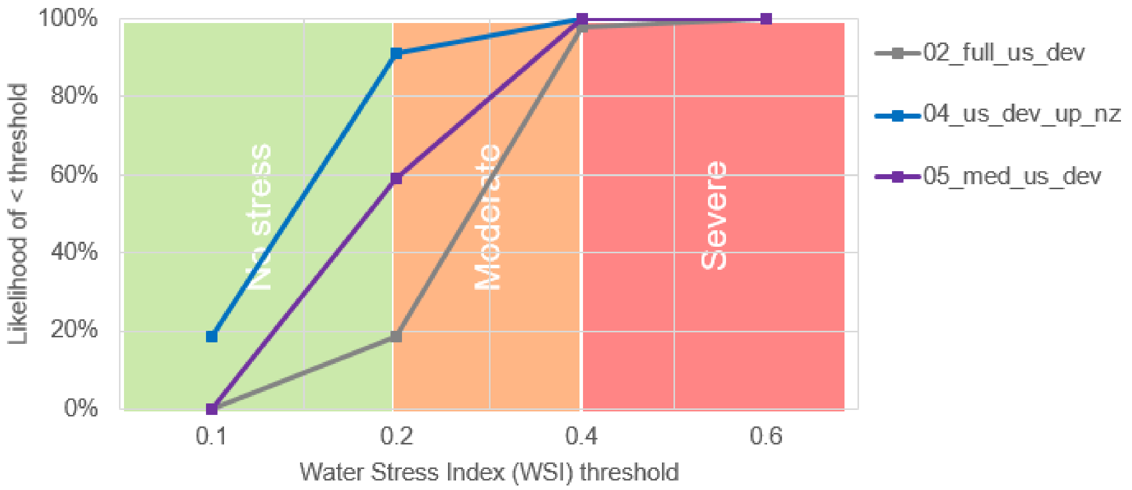

Figure 7.11 Probabilities to surpass the thresholds for WSI (0.2 – no stress and 0.4 – no severe stress) for the three water resources development scenarios

It has to be noted that the absolute values of the WSI and Reliability should be taken with care, as this analysis was based on a lumped approach which is valid only for identifying trends and comparing climate risks versus non-climate risks. A more detailed water resources analysis is recommended to assess the reliabilities and other performance metrics on the sub-basin-, and sectoral level.

Table 7.4 shows the probabilities for all scenarios (so also including scenario 1 and 3 from Phase III climate stress test) analyzed in this study. The table also includes the values that were shown previously in Figure 7.9 and Figure 7.11). The three left columns are representative for LNIP (and thus give insight in how upstream development affects the downstream project), the two right columns are representative for the basin as a whole. The “greener” the row, the more likely it is that this scenario leads to a value indicating a higher performance.

Please note that the probabilities calculated here were based on the full ensemble of GCM outputs analyzed in this study, without making distinction between RCPs and future horizons.

Table 7.4 Probabilities for the performance metrics to surpass the thresholds given the future climate uncertainties, for all water resource scenarios analysed in this study

Scenario	Reliability > 0.80	Vulnerability < 0.3	Resilience > 0.4	WSI: no stress	WSI: no severe stress
01_prj	91%	91%	83%	100%	100%
02_full_us_dev	91%	90%	69%	19%	98%
04_us_dev_up_nz	91%	78%	67%	91%	100%
05_med_us_dev	91%	90%	69%	59%	100%
06_no_gw_alloc	90%	62%	59%	19%	100%
07_high_gw_alloc	91%	98%	80%	19%	91%
08_cc_us	91%	91%	69%	28%	91%

7.2.5 Implications for the Water Allocation Plan

This analysis shows that the developments as planned in the Water Allocation Plan (here referred to as NWMP2030) are likely (likelihood approximately 80%) to lead to a situation in which the basin achieves a moderate stress level. It is highly unlikely that the basin will enter a severe stress level.

The sustainable use limit is set at the water resources usage level that corresponds with a Water Stress Index of 0.2 (i.e. on average, 20% of the renewable available water is withdrawn). From the analysis it follows that:

- A reduced irrigation development scenario (scenario 04) will very likely (91%) lead to a favourable situation in which the sustainable use limit is not surpassed.
- The medium development scenario (scenario 05) could lead to a situation in which the sustainable use limit is surpassed (likelihood 41%).
- The full development as is planned in NWMP2030 will most likely lead to a situation in which the sustainable use limit is surpassed (likelihood 91%). In other words, only in case rainfall amounts will increase majorly in the basin, this limit will not be surpassed

Thus, given the uncertainties in how climate change will affect water resources in the Nzoia basin, it is recommended to target a somewhat lower level of development as is projected in NWMP2030, in order to remain below the sustainable use limit (WSI < 0.2). Only if rainfall increases considerably, basin water resources can be exploited to the potential that is projected in NWMP2030.

The exact scope for development should be investigated in a more in-depth analysis that considers the sub-basin and intersectoral linkages in the Nzoia basin. Currently a detailed water resources assessment is performed within the scope of the same program for the Nzoia basin, using a similar water resources modelling approach but with more detail and scenarios.

The climate change scenario component of this assessment is limited to only one extreme climate change scenario. It is highly recommended to further extend that analysis incorporating more climate dimensions, similar as was done in this study. This will give a more comprehensive understanding of the risks at the the basin and sub-basins level and should make sure that there is a sustainable balance between demands and projected supplies in a wide range of climate futures.

It should be noted that the analysis presented here did not consider any new future water reservoirs that are projected in NWMP2030, as they were marked as highly unlikely by all stakeholders. A more detailed analysis would allow assessing the impact of these dams on the water resources allocation, in combination with flood control, and could provide quantitative arguments in favour or against some of these, considering the future climates. Besides the impact of surface water storage bodies, also the impact of other options to increase upstream water retention and storage can be studied, like conjunctive surface and groundwater management, and catchment management interventions that increase infiltration, recharge aquifers, and reduce fast runoff.

Further exploitation of the potential of groundwater (as an alternative natural reservoir) may have a positive impact on water resources use in the basin, as the analysis suggests: especially during the dry season, competition for surface water may be slightly lower, and return flows could lead to slightly higher water availability during the dry season. Some performance metrics for LNIP were positively influenced when the basin uses more groundwater upstream, due to these processes. However, these results should be interpreted with caution as they assume a 1:1 substitution of surface water withdrawals by groundwater abstractions, meaning that there will be no changes in the demand pattern and demand amounts. In reality, it is often seen that upstream water users tend to optimize the use of their available sources, and that return flows will be (at least partially) consumed upstream, which means that they do not come available for downstream users.

If water resources development will follow the NWMP2030 path, it is thus recommended to carry out a more detailed analysis on the potential to extend groundwater exploitation, which requires more in-depth analysis of aquifers, groundwater recharge and discharge, inter-basin connection of aquifers, river-aquifer connections, and connection with Lake Victoria, among others. The National Groundwater Potential Report, released in 2018 under the KWRCRP program, suggests that there is some potential in the Nzoia basin. However, it also highlights that these are national-level outcomes and that further analysis at the aquifer-level should be done to assess the exact scope for groundwater exploitation.

To conclude, this analysis shows that it is of paramount importance to follow the Integrated Water Resources Management (IWRM) approach to further plan and develop this river basin. Discussions during the missions of this project have clearly revealed that there is discoordination among the county governments and WRA, at various levels (political and technical). In a situation where the basin is likely to be moderately stressed, this discoordination will very likely lead to mismanagement and conflicts among water users. Stakeholder participative processes, transparent decision-making, integrated planning systems and capacity building should be key components of the future water resources planning process in the Nzoia basin.

Finally, stakeholder-driven approaches that are based on the Ecosystem Services approach and that consider the linkage between upstream catchment management and downstream water availability can be considered to improve the sustainability of the basin and collaboration among stakeholders. A successful example of such a management mechanism is implemented elsewhere in Kenya, as the Nairobi Upper Tana Water Fund (Hunink and Droogers, 2015).

7.3 Trade-off between robustness and economic return

The climate change risk assessment and the analysis of risk management options has been based so far on a 12% threshold value of the project EIRR for distinction between failure and success of the project. This value has been taken from the Final Design Report (Lahmeyer, 2017) and is a standard value applied by the World Bank for most investment projects in the water sector. The threshold EIRR value combines the opportunity costs of the investment, the risk of failure and the tendency of society to value current benefits higher than future benefits. It is comparable to the discount rate used to calculate the NPV.

There is a lot of discussion about the threshold value of the EIRR or the discount rate to use to calculate the NPV (see for instance Drupp et al., 2015). A high value will put a high importance on the current costs and benefits at the expense of future costs and benefits. Using a value of 12% will reduce the influence of costs and benefits that will occur in 18 years by 90% when compared to the current costs and benefits. This is especially problematic when analysing the impacts of climate change, since the impact most likely will not be felt now but possibly in 10 or 20 years from now.

An analysis has been carried out to show the trade-off between the threshold value of the EIRR and the robustness of the current Final Design. This provides the answer to the question: what will be the robustness, if another threshold value for the EIRR would be selected? The result is presented in Figure 7.12. It shows the robustness of 69% for the EIRR threshold of 12% that was the result of the analysis in Section 6.5.2. Increasing the threshold value, i.e. putting even more weight to the near future, would quickly reduce the robustness to 0%, meaning that the project would not be economically efficient for the results of all GCM projections. Decreasing the threshold value, i.e. putting more weight to the more distant future, increases the robustness with a value of 90% for a threshold EIRR of 5%. This shows, that robustness for climate change will increase if a lower EIRR of the project would be considered acceptable. If so, the need for adaptive measures would be limited to the more extreme ranges of climate change. In some way, lowering of the EIRR threshold value can therefore also be regarded as a climate change adaptation measure for this project.

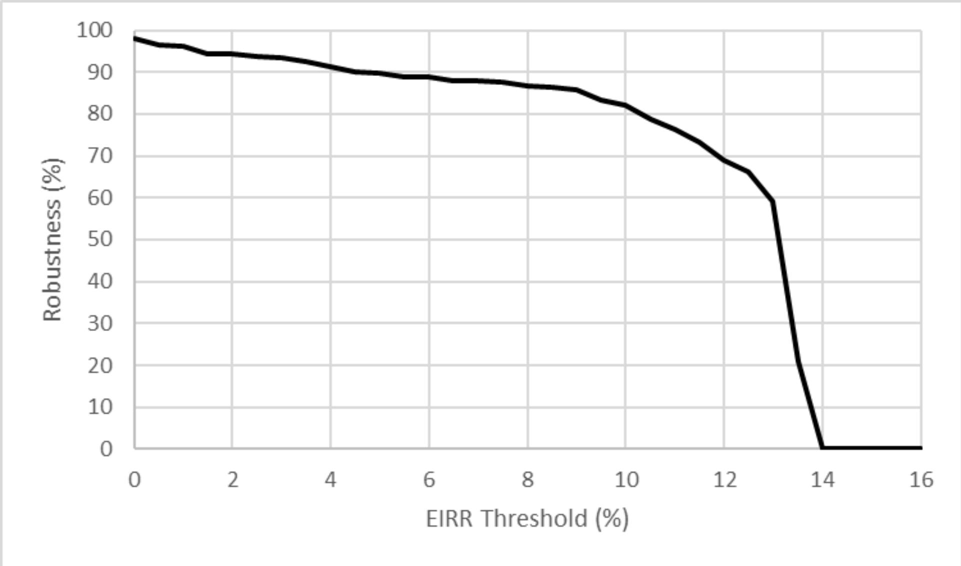

Figure 7.12 Relation between the threshold EIRR and the robustness

As an example, Figure 7.13 shows the success and failure of the project for the future climate realizations comparable to Figure 6.28, but now with a EIRR threshold value of 5%. The success envelop of future climate change is now extended to roughly minus 30% to plus 45% for the precipitation. The figure furthermore shows that no GCM projections show such a decrease of precipitation and only 10% of the GCM projections show such a large increase in precipitation that the EIRR would drop below the 5% threshold value.

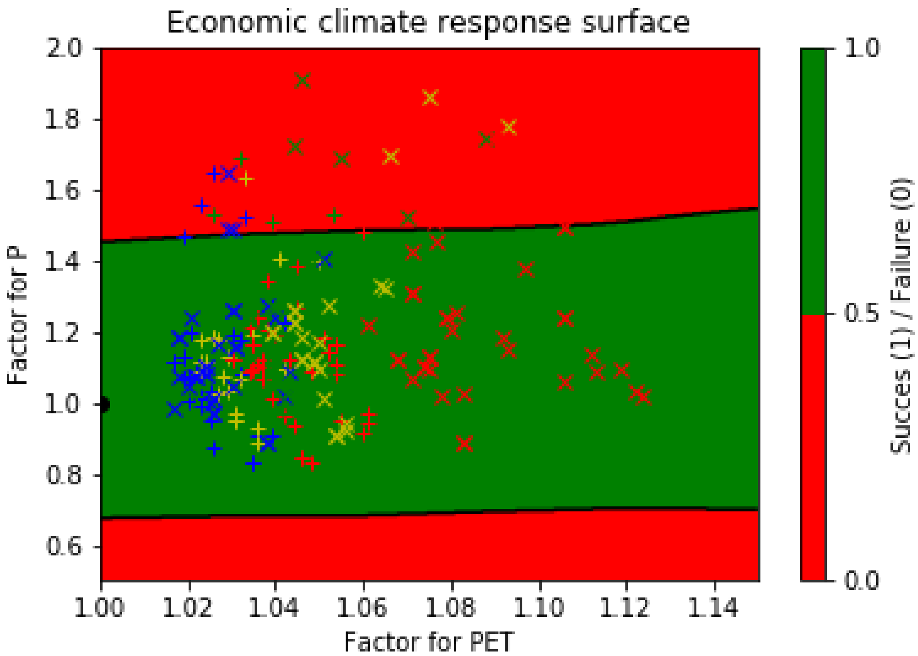

Figure 7.13 Climate response map with on the Y axis the factor of change in precipitation and on the X axis the factor of change in PET; the colours show the success (green) and failure (red) of the project to provide a 5% or higher EIRR and the dots show the location of the GCM results (for the legend of the dots see Figure 6.2)

8 Conclusions and recommendations

This report describes the results of a project that aims to assess whether the objectives of both irrigation and flood protection developments within the Lower Nzoia basin can be reached and maintained under a range of plausible future conditions, using the Decision Tree Framework (DTF) to perform a climate change risk assessment. This Final Report describes the results of all four phases of the DTF.

The following can be concluded:

- As a result of the project screening phase, it was concluded that the irrigation and flood protection development projects in the Lower Nzoia basin are potentially sensitive to climate risks. Although other non-climate related factors such as upstream water use might pose a threat to the project, a more in-depth quantitative exploration of the project robustness to climate change compared to other risks was deemed necessary and has been carried out.
- The observed historic trend and the GCM results suggest that an increase in annual precipitation in the future is more likely than a decrease. 70% of the GCM projections show an increase of precipitation by less than 25%, 10% of the projections show a larger increase and 20% show a decrease of precipitation. There is an ongoing debate in the scientific climate science community (“East-African paradox”) on the performance of the current state-of-art GCMs in this region, which means that the likelihoods derived from the ensemble of projections should be taken with caution.
- Results of the initial analysis phase show that the project is sensitive to climate change. A first analysis of the impact of non-climate change risks indicates that these are in the same order of magnitude of the climate change risks.
- The expected range of climate change for the climate stress test (Phase III) has been selected based on the historic trend and the GCM projections as -25% to +75% for precipitation and 0 ºC to +6 ºC for temperature. The results of the climate stress test show that the expected range of precipitation has a strong impact on low and high discharges and will therefore affect both water availability (relevant for the irrigation part of the project) as well as maximum flows (relevant for the flood protection part of the project).
- The current design has a positive economic performance (EIRR exceeding the threshold value of 12%) under the current climate as well as most of the likely future climate realizations. Based on this performance indicator, the robustness of the project is calculated as approximately 70%, meaning that the EIRR will be above 12% in approximately 70% of the GCM projections. These are projections with no change of precipitation or an increase below 25% in precipitation. A decrease in precipitation (as in 20% of the projections) or an increase by more than 25% (as in 10% of the projections) would reduce the EIRR below the threshold value.
- There is a trade-off between the threshold EIRR value and the robustness of the project to climate change. If the threshold EIRR would be reduced from 12% to 5%, the robustness would increase from 70% to 90%, substantially limiting the necessity for adaptation measures.
- Besides EIRR, the three performance indicators that have been central in this study and were analysed for the flood protection and the irrigation water supply were (1) reliability, (2) vulnerability and (3) resilience.

    - For the flood protection, reliability was defined as providing the design safety level of 1/30 years. This will only happen in the current climate and with lower precipitation, which covers 20% of the climate futures. In all other climate futures the precipitation increases and the reliability decreases. Vulnerability of the flood protection could not be assessed since no data are available for flood damages of events with a larger discharge than the current 1/100 year flood. Due to lack of data, resilience analysis is limited to the hydrological resilience and defined as the inverse of the average length of a flood event. In the current climate the average length of a flood event is 1.25 days, so the resilience equals 0.8 1/day. The likelihood over all climate futures of a resilience of more than 0.5 1/day is 56%.
    - For the irrigation scheme, the reliability performance indicator was analysed and shows that the typical 80% value that is often used for irrigation scheme design is reached in most of the climate futures (91%). The vulnerability indicator shows that the relative unmet demand is most likely at least 30%. Then, the resilience indicator demonstrates that drought duration (supply<demand) will most likely be two to three months in the future. Overall the analysis suggests that the performance indicators for the irrigation scheme are acceptable as farmers typically adapt their operations and practices to short periods of under-supply.
- For the flood and irrigation scheme performance analysis, each of the analysed indicators shows a somewhat different response to climate change. The frequency of flood or droughts events is captured in the concept of reliability, while the intensity of the event, such as flood or drought duration in incorporated in the resilience indicator. This highlights the importance of using multiple indicators to assess the system performance under climate change. It is important to note that the definitions of vulnerability and resilience used for this analysis are narrower than they are used in many other contexts: they are based on the biophysical or hydrological response of the system and do not cover the socio-economic response. Typically, as also here, no reliable data or model is available on socio-economic consequences of floods and droughts. It is important that this is communicated clearly when presenting outcomes based on these indicators, as the audience may have a broader definition of these terms and may misunderstand the outcomes.
- Based on these performance indicators and EIRR, for the current design, it seems likely that the project will perform well enough in the future. The robustness, calculated based on EIRR, is also reasonably high, so it is not considered necessary to modify the design in order to reduce the climate change risk to the project.
- Three non-climate change risks have been identified that could also affect the project performance significantly: lack of reliable discharge data, reduction of water availability by future upstream developments in combination with climate change-induced reduction of flows, and reduction of project benefits due to inadequate operation, maintenance and enforcement. Sand mining activities in the riverbed could jeopardize the improved flood protection in case of inadequate maintenance and enforcement.
- The stakeholders furthermore indicated during the final mission as an additional non-climate risk that LNIP-2, the second phase of the irrigation extension, might not be executed. This has already been described in the Final Design Report and analysis there showed that this would jeopardize the economic performance of the project. Non-execution of LNIP-2 is not likely, but probably cannot be discarded either given the political and institutional situation.

- The impact of an alternative design with a flood protection level of 1/100 year has been analysed. The costs for this have been assumed to equal the costs to raise the protection level from the actual 1/10 year to 1/30 year as in the Final Design.

  The higher flood protection level increases the reliability and resilience of the flood protection as well under the current climate as for all climate futures analysed. However, the EIRR for the actual climate reduces from 13.4% to 12.2% and the economic robustness, the likelihood over the GCM projections of the EIRR to exceed 12%, decreases from 69% to 57%. This shows that for the actual climate as well as for most projections the avoided flood loss does not outweigh the extra costs of the increased protection level. This also indicates a trade-off between resilience and reliability on the one hand and economic robustness on the other hand.
- It is very likely (91%) that the development of water resources as planned in the National Water Master Plan 2030 will lead to a basin that surpasses the sustainable use limit and to a moderately water-stressed basin. This indicates that there will be a considerable risk for water conflicts among users. A more phased and carefully planned water resources development strategy is recommended, possibly with reduced irrigation development, especially of the major schemes. The Upper Nzoia irrigation scheme however is feasible though, if other irrigation expansions are limited. For example, a reduced irrigation development scenario will very likely (91%) lead to a favourable situation in which the sustainable use limit is not surpassed. For a medium development scenario this likelihood reduces to 41%.
- The reliability, vulnerability and resilience indicators for the irrigation scheme were analysed under several scenarios for surface water versus groundwater allocation. The reliability indicator seemed less sensitive to the allocation priorities then the other two performance indicators: vulnerability and resilience. These two indicators improved slightly in case more water is withdrawn from groundwater resources. Obviously this is up to a limit and needs to be further studies in a detailed groundwater potential study.

The following recommendations are made with respect to the Lower Nzoia projects:

- The reliability of the discharge data for the Lower Nzoia should be improved. The locations of the 1EE01 and 1EF01 stations appear to be unsuitable because of constant modifications to the river bed by siltation and sand mining. It is therefore recommended to establish a new measurement station upstream of the new intake weir at a suitable location with a stable cross section. Ideally, also the discharges in the Nzoia River and in the two main intake canals downstream of the weir would be monitored to be able to validate the data based on a simple water balance. Annual detailed surveys of bathymetry of cross sections up to the maximum flood level at the locations of all stations should be executed as well as measurements of discharge using equipment, such as an ADCP (Acoustic Doppler Current Profiler). Rating curves can be best derived by applying a mathematical hydraulic model, such as HEC-RAS and SOBEK, basing the schematization on the survey results and calibrating the model on flow measurements. The improved data set of discharges should be used to check the Final Design and the calibration and validation of the hydrological model. To allow for comparison of data, it is recommended not to discontinue measurement at station 1EF01.

- Adaptive policy pathways have been presented for decreasing and increasing future precipitation.
    - If a decreasing trend is observed for precipitation, a further study is recommended to select one or a combination three proposed interventions: 1) Enhance water storage capacity (multi-purpose storage dams, artificial groundwater recharge, catchment management measures that enhance water retention in soil and wetlands, etc); 2) Adaptation of the Water Allocation Plan (surface versus groundwater usage, re-assess water rights and priorities among demands, etc) and formally agreeing this among different counties and user sectors, and 3) Water demand management for LNIP (increasing efficiencies, modified cropping patterns, more drought-resistant crops among others, but also participatory irrigation management as is already supported by the LNIP/KWSCRP program).
    - If an increasing trend is observed, the measures to select from consists of: 1) Upstream dam(s); 2) Catchment management measures that reduce fast runoff; 3) Raising of embankments; and 4) Increase of discharge capacity of the Lower Nzoia by a combination of dredging and sand mining and/or the construction of new distributaries.
    - Note that both pathways include catchment management as intervention. Clearly this is a recommendable intervention under any future scenario ("no-regret"). Under the KWSCRP program currently a few pilots are being implemented for catchment management that contribute to flood risk mitigation and water resources conservation. It is recommended to upscale these pilot projects to an extent that they can cause a positive impact at the basin level, and reduce fast runoff and erosion, and increase infiltration and groundwater recharge.
- It is advised to consider reserving room within the spatial lay-out of the Final Design to allow for future rising of embankments, which could require more room than the current design includes.
- The presented adaptive policy pathway depends on the future trend in precipitation and discharge, but also on the decision-making structure of regional authorities and duration of implementing actions. It is therefore recommended to analyse annually the monitoring data on precipitation and discharge for trends and to start an iterative process between analysts and stakeholders in order to design a signal monitoring system suitable for the local context. When data availability is an issue, synthetic transient scenarios can be used to describe possible futures. For additional information, we refer to the paper of Haasnoot et al., (2018). It is recommended to prepare feasibility and design studies to select one or more of the adaptations in the pathways if a trend is observed towards one of the two trigger points: a decrease in average precipitation below the current level or an increase of more than 25% in the extremes.
- It is advised to monitor the upstream development of water use and to combine this with the assessment of the trend in water availability. A combination of a reduction in precipitation and increased upstream water use would necessitate a revision of the Water Allocation Plan.
- It is recommended to review the threshold value of 12% for the EIRR that is used to evaluate project performance and to consider using a lower value for projects sensitive to climate change, since climate change impacts and benefits of adaptations measures will mostly appear in the latter half of project lifetime, which gets little weight when using a high threshold value like 12%.

- It is recommended to ensure that institutional safeguards are in place to ensure adequate operation, maintenance and enforcement of the irrigation system and the embankments. These arrangements should consist of mechanisms to ensure adequate funding as well as sufficient oversight by stakeholders of the way in which the funding is used. Cost recovery of at least a part of the operation and maintenance costs could provide funding as well as ensure commitment of the stakeholders. Enforcement and maintenance with respect to the improved flood protection should receive much attention and will require stakeholder engagement activities. This could be included in the foreseen capacity building activities for management entities and user groups but would be further strengthened by granting the WRUAs and the IWUAs a formal role in enforcement, which they currently do not have.
- Sand mining activities could be turned from a threat to improved flood protection to an opportunity if activities would be regulated to prevent damage to the flood protection system and to increase the discharge capacity of the river. It is recommended to prepare this regulation jointly by the counties Busia and Siaya in cooperation with WRA. A hydraulic modelling study is recommended to be included in the preparation of the regulation to assess the impact of changes in the river bed on its discharge capacity.
- An Integrated Water Resources Management (IWRM) approach will be key to harmonize and coordinate developments across the basin and among stakeholders, especially given the fact that the basin covers several regions together with the regionalized political system the country has adopted recently. It is thus recommended to establish a multi-stakeholder basin water resources committee as is in fact mandated by the 2016 Water Act.
- As a final recommendation, stakeholder-driven approaches that link upstream land-users (farmers) with downstream water-users (irrigators, towns) using the Payment for Ecosystem Services paradigm can be considered to strengthen collaboration within the basin (alias the Nairobi Upper Tana Water Fund elsewhere in Kenya).

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A Minutes of stakeholder meetings

A.1 Minutes of Inception Workshop Meeting, July 2018

Time	Activity	Participants	Venue	Input received
Day 1; Kick off Meeting, Monday 9th July				
9.00 - 9.30 am	Introductions Welcoming remarks, PM	WB, WRA PIU, NIB, MoWS, NW&SA, Mission team	PMU BR, ACK Gardens	
9.30-11.00am	Presentation of study Scope and Approach			WB and local counterparts perception on the study objectives. See 1.1
11.00-11.30am	Brief overview of WRA Sub-components in the Study Area	WB, WRA PIU, NIB, MoWS, NW&SA , Mission team	PMU BR, ACK Gardens	Documentation available WRA. See table
11.30am-12.00pm	Brief overview of NIB Sub-components in the Study Area			Documentation available NIB. See table
12.20 – 1.00pm	Plenary /Guided discussions; Distribution of benefits and impacts,	WB, WRA PIU, NIB, MoWS, NW&SA, Mission team	PMU BR, ACK Gardens	Initial list of benefits and impacts, to be complemented with inputs field visits. See table 4.2 and 4.3
2.00pm-3.00pm	Plenary /Guided discussions; Performance indicators and risk thresholds Climate and non-climate risks	WB, WRA PIU, NIB, MoWS, NW&SA, Mission team	PMU BR, ACK Gardens	Long-list of climate versus non-climate risks. See chapter 4.
Day 2; Visit to Project Area, Tuesday 10th July				
9.00-9.30	Brief meeting with ISC-Lahmeyer	All participants	ISC office Ugunja	Detrails on environmental risks considered, final design documents
9.30-10.00am	Visit to the main Intake Site for Lower Nzoia Irrigation Project		Project site	

Visit to the main Intake Site for Lower Nzoia Irrigation Project

11.00am-12.30 noon	Visit the Dykes; Discussions with NIB and NW&SA representative	All participants		Livelihood factors; visit streamflow gauge and issues related to data quality, sedimentation issues

Visit to the Dykes

1.00-2.00pm	Meeting with Irrigation Water User's Association at Bunyala Irrigation Office	All participants	Bunyala Irrigation Office	Expectations of farmers (high), their perception on climate risks (high)
3.00-4.00pm	Meeting with Water Resources Users Association (Safu and Bunyala)	All participants	Siaya WRA Sub region office	

Discussion of project team with farmers of the Bunyala WRUA

Day 3 ; Visit to CoGs Busia & Siaya, Wednesday 11th July

9.00 - 11.00am	Meeting with Busia County CEC Water and Environment	All participants	Busia County Office	Lack of coordination between different political levels. Great interest in project

Meeting with Busia County CEC Water and Environment

2.00-3.30pm	Meeting with Siaya County CEC Water and Environment		Siaya County Office	Political dimension of the project:
Day 4; Wrap up Meeting, Thursday 12th July				
10.00am-12noon	Meeting with Directorate of Climate Change	World Bank, WRA PIU, MoWS, NIB, Directorate of Climate Change (MoEF), Mision team	NHIF Building, 12th fl Rm 1226	Mainly involved in climate mitigation, however still very much interested in this development.
2-4pm	Wrap-up Meeting	World Bank, WRA PIU, MoWS, NIB, KfW, Directorate of Climate Change, Mission team	PMU BR, ACK Gardens	Short-list of benefits, impacts, and climate versus non-climate risks. Presentation by project team
Day 5; Wednesday 13th July; Additional Meetings				
9.00-11.00am	Meeting with Water Resources Planning and Management Project	Aurecon, WRA PIU and mission team	NHIF Building	Working on water system models, but not in time for our project
11.30am – 1.00pm	Meeting with National Water Infrastructure Investment Pipeline project	EGIS, WRA PIU and mission team	EGIS office	Working on water system models, but not in time for our project
2.00-4.00pm	Meeting with RCMRD	RCMRD, WRA PIU and mission team	RCMRD office	Modeling of hydrology and flooding discussed and models made available

A.2 Minutes of the Final Meeting, May 2019

Time	Activity	Particip ants	Venu e	Input received
Day 1; Presentations at RCMRD, Monday 13th May 2019				
9.30 – 10.00 am	- Introductions - Welcoming remarks- RCMRD - Director Technical	WB, WRA PIU, NIB,	RCM RD Offic e,	- First reaction of WB en WRA PIU - Discussion on human behavior - Upstream dams: on the short-term not, but on long-term yes

	Services			
10.00–1.00 pm	Presentation of study result- CCRA Nzoia	MoWS, PMU, NW&SA, Mission team	Kasarani	
				
11.45 am-12 noon	Health Break			
12.00-1.00 pm	Plenary/Feed back			- Maintenance of dike is challenging, poor enforcement, participation key - Sand harvesting key threat
PM	Travel To Kisumu – Mission Team			
Day 2 ; Visit to Project Area, Tuesday 14th May 2019				
8.30 am	Team Departs for Bunyara Irrigation Office	All participants		- Expectations on greenhouses - Recent and historic periods of water scarcity and drought - Terminology (e.g. green infrastructure versus catchment management)
10.00-12.00pm	Meeting with Irrigation Water User's Association at Bunyala Irrigation Office		Bunyala Irrigation Office	

2.00-4.00 pm	Meeting with Busia County CEC Water and Environment	All participants	Siaya WRA Sub region office	- Recent periods of drought and water scarcity. Some people consider things have worsened, others not - Expectations on the investments
4.00 pm	Travel back to Kisumu	Visiting team		
Day 3 ;Visit to CoGs Busia & Siaya, Wednesday 15th May 2019				
7.30 am	Team Departs Kisumu for Busia	All participants		
9.00 - 11.00am	Meeting with Water Resources Users Association (Safu and Bunyala)		Busia County Office	- Importance of maintenance and participation with stakeholders - Importance of capacity building on climate adaptation measures at the irrigation scheme level (efficiency, etc) - Recent droughts

11.0	Transfer to Siaya			

0 am-1pm	County office			
2.00-3.30 pm	Meeting with Siaya County CEC Water and Environment		Siaya County Office	- Increased water pollution: importance of upstream catchment management - New water diversions at Gomre intake - Capacity building is key - IWRM-approach is not at all a reality, but necessary
3.30 pm	Back to Kisumu and travel to Nairobi			
Day 4 ; Wrap up Meeting, Thursday 16th May 2019				
12.00-2.15 pm	- Introductions - Welcoming remarks, PM	WB, WRA PIU, NIB, MoWS, NW&SA, Mission team,DCC	PMU BR, ACK Gardens	- Deforestation and forestry activities: catchment management and linking upstream with downstream by IWRM but maybe also using payment for ecosystem services mechanisms as Water Fund for Nairobi city - Sand mining and the influence on the flow data - Groundwater-related conclusions: highlight that more work needs to be done
2.15-3.30 pm	Presentation of study result and field feed back			
3.30-4.00 pm	Plenary/ Feed back			
4.00-4.30 pm	Tea Break			

B Working definitions for Metrics of Project Performance

Reliability
Reliability describes how often the system succeeds under one specific climate realization. It is defined by Hashimoto et al. (1982) as "the frequency or probability that a system is in a satisfactory state". In this report for flooding success is defined as providing a safety level that equals or exceeds the design safety level of 1/30 years. Failure means that the safety level is less than the design safety level.

The reliability is calculated as follows:

$Reliability\ (\alpha) = P[X_t \in S] \quad = 1 - \frac{\sum Failures}{\sum(Failures + Successes)}$, *where S may be seen as system success and F as system failure*

Vulnerability
Vulnerability describes how significant the likely consequences of failure may be. Hashimoto et al. (1982) use as a metric for vulnerability "the expected maximum severity of a sojourn into the set of unsatisfactory states". Vulnerability does not express the likelihood or duration of a failure event, but its maximum impact. It can be seen as a kind of stress test of the system and provides information how bad impacts can become. Vulnerability can be expressed both for one specific climate realization and as a metric to express the vulnerability over all the climate realizations.

In this report the vulnerability of the flood protection system could not be assessed, since no flood damage information is available for flood events with discharges exceeding the current 1/100 years discharge. The vulnerability of the irrigation component of the project is assessed as the average unmet demand divided by the average total water demand (see Section 6.4).

Resilience
Resilience expresses "how quickly a system is likely to recover or bounce back from failure once failure has occurred" (Hashimoto et al., 1982). It can be calculated as the average probability of a recovery from the failure set in a single time step and equals the inverse of the average duration of a failure event:

$$Resilience\ (\beta) = P[X_{t+1} \in S \mid X_t \in F]$$

Resilience is a characteristic of the whole system with both bio-physical and socio-economic components, since recovery from an event such as flooding depends both on characteristics of the flow as on the time the socio-economic system requires to recover after the flood recedes. Resilience can be expressed both for one specific climate realization and as a metric to express the vulnerability over all the climate realizations.

In this report resilience of the flood protection system is derived from the length of flood events, i.e. the number of days that the simulated discharge exceeds the discharge associated with the design safety level. The socio-economic aspects of recovery, such as planting of new crops and access to markets and credits, are not taken into account due to a lack of data.

Resilience for the water resources analysis is calculated as the inverse of the average drought periods, thus giving a single value for each climate realization.

Robustness

Robustness is used in this report to evaluate project performance over different future climate realizations. For each climate realization the success or failure is determined. For flood protection success is defined as the providing a safety level of 1/30 years as in the design.. For the economic analysis success means that the EIRR of the project equals or exceeds the threshold of 12%. Robustness is then defined as the probability of success over all climate realizations. This provides important insight of the ability of the project to cope with climate change.

$$Robustness\ (\Lambda\,(d,x)) = \begin{cases} 1\,, & x \in S \\ 0\,, & x \in F \end{cases}$$

$$Robustness\ Index\ (RI_d) = \sum \Lambda\,(d,x).\ p(x)$$

The robustness can be assessed as an aggregate metric over all climate change realizations in the climate response surface, so over the whole range of precipitation and PET in the response surfaces, or over all climate change realizations of the GCM results, so for all points on the response surfaces. In this report, the latter method has been selected in order to focus on the most likely climate futures and to disregard the more extreme parts of the response surfaces.

C Climate change projections for precipitation and temperature for the Nzoia basin

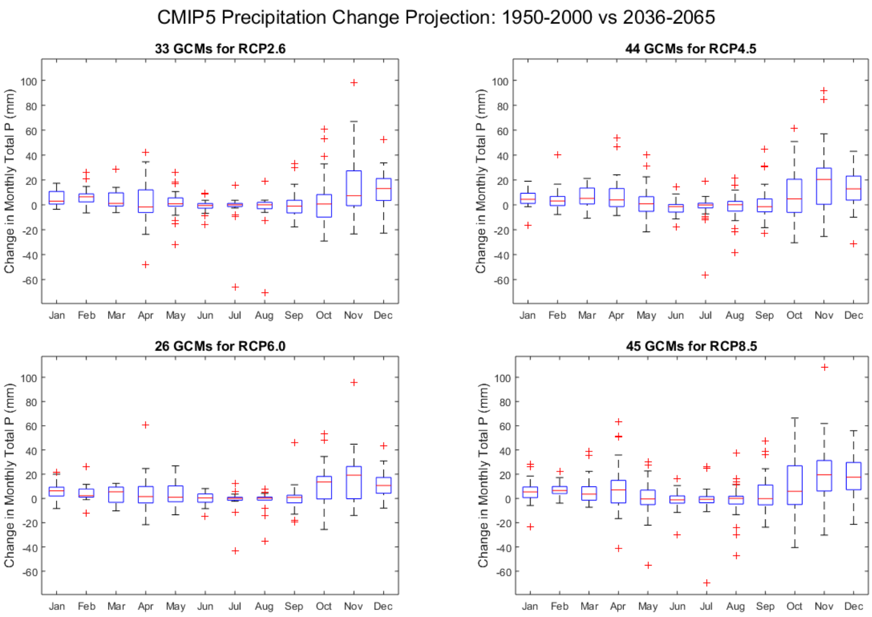

Figure 9.1 Boxplots of monthly precipitation change from Ensemble of CMIP5 GCM projections for the Nzoia Basin (change in average monthly precipitation in 2036-2065 relative to 1950-2010).

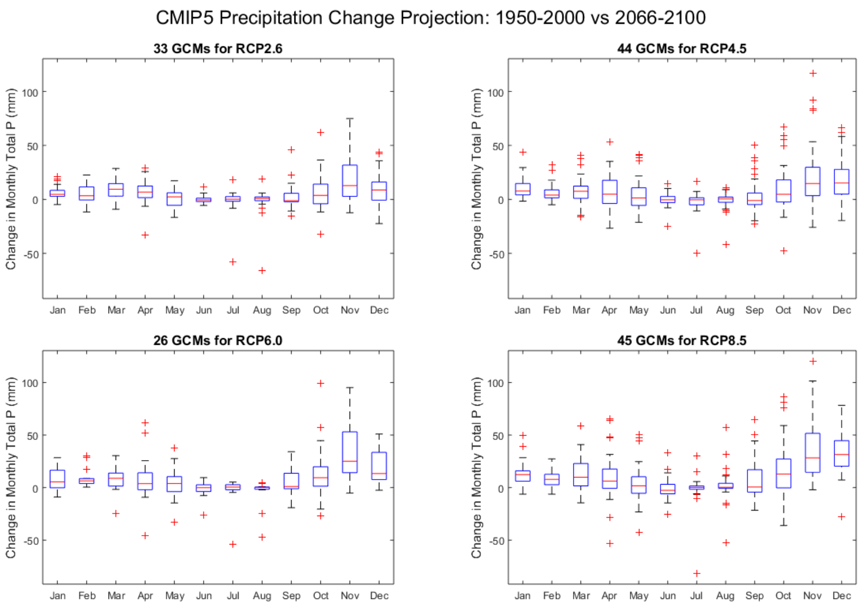

Figure 9.2 Boxplots of monthly precipitation change from Ensemble of CMIP5 GCM projections for the Nzoia Basin (change in average monthly precipitation in 2066-2100 relative to 1950-2010).

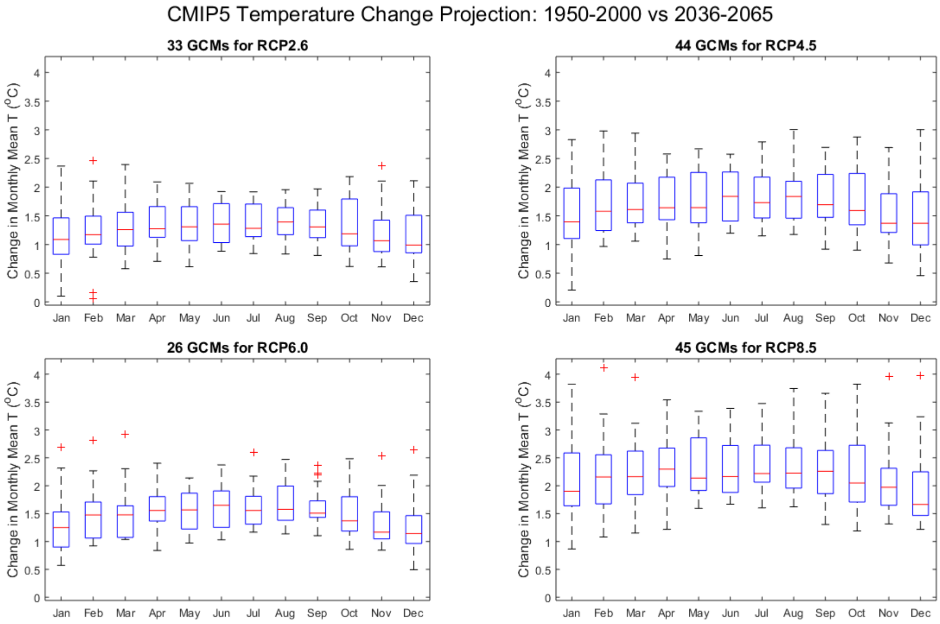

Figure 9.3 Boxplots of monthly temperature change from Ensemble of CMIP5 GCM projections for the Nzoia Basin (change in average monthly precipitation in 2036-2065 relative to 1950-2010).

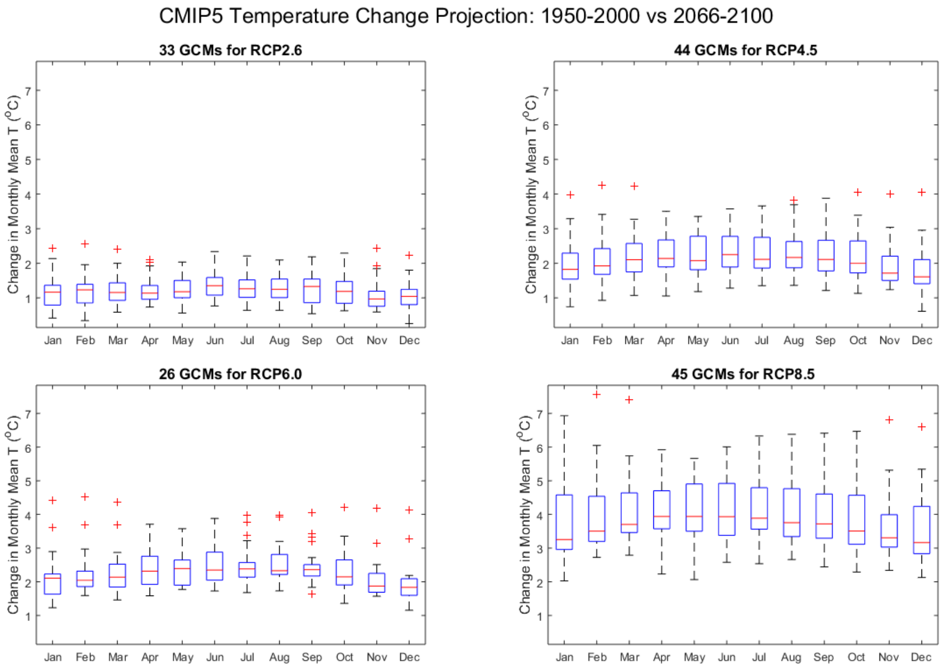

Figure 9.4 Boxplots of monthly temperature change from Ensemble of CMIP5 GCM projections for the Nzoia Basin (change in average monthly precipitation in 2066-2100 relative to 1950-2010).

D Deviations of analysis results from the Final Design

Some results of the analyses presented in Chapters 5 and 6 of the report deviate from the results presented in the Final Design Report (Lahmeyer, 2017). This Appendix provides an inventory of these differences with a reference to the relevant section in the main text.

D.1 Section 5.5.2: Stream flow data used to assess water availability

During the Initial Analysis phase, alarming issues have been discovered with the streamflow data that were used in the final design report. The report states that for the water balance analysis, station 1EE01 is used. However, the Q80 and Q95 values that are reflected in the water balance table do no coincide with values elsewhere in the report, nor with the data that was received from WRA for this study.

Therefore, we decided to recalculate the water balance using the data we received from WRA at station 1EE01. The values used for Q80 and Q95 were thus updated with this *new* data. Q95 based on these data was used for the minimum flow that needs to be left in the river (environmental flow).

D.2 Section 6.3.3: Flood damage assessment

The final result and some of the calculation steps in the flood damage assessment presented in the Final Design Report cannot be reproduced completely. The calculation of the APL of crop loss without embankment based on the data provided in Table 9-26 of the Final Design Report has been carried out as follows:

1. For a list of return periods ranging from 1 to 100 years the accumulated probability is calculated as one divided by the return period;
2. The probability for each individual return period is calculated by subtracting the value of the accumulated probability of the next year from the value for the actual year;
3. The damage for each return period is derived by linear interpolation from the data presented in Table 9-26 of the Final Design Report as reproduced in Figure 6.10 of this report;
4. The contribution to the APL for each return period is obtained by multiplying its probability with the damage; and
5. The APL is obtained by summing the contributions for all years in the list.

This results in a value of 45.53 MKES/year. This slightly deviates from the value of 46.17 MKES/year presented in table 9-27 of the Final Design Report. The difference for the APL with embankment is much larger. A 1/30 year flood yields 694.66 MKES damage. So, the APL is: 694.66 / 30 = 23.16 MKES/year.

The report, however, presents a value of 10.26 MKES/year. From this, the report calculates an avoided APL for crop loss of 35.91 MKES/year, while the calculations presented here result in an avoided APL of 22.37 MKES/year.

A similar problem occurs in calculation of the avoided APL for the damage to the irrigation scheme. It is not clear how the APLs and avoided APL presented in Table 9-28 of the Final Design Report can have been calculated for different return periods, because the APL follows from the integration over all return periods.

Combining the data provided on damage for the different return periods, the without project APL is calculated as 80.37 MKES/year, the with project APL as 40.38 MKES/year and the avoided APL as 39.99 MKES/year. This reduces the overall benefit of the extension of the flood protection from the reported 107.06 MKES/year (Final Design Report, Table 9.51, reproduced in Appendix F) to 62.37 MKES/year. The impact on the overall project performance indicator, the EIRR (Economic Internal Rate of Return) is limited. The presented EIRR of 14.1% reduces to 13.7% due to the reduction of the flood protection benefits.

D.3 Section 6.5.1: Methodology for economic analysis

As discussed in Section D.2, a correction has been applied to the calculation of the flood protection benefits. The calculation of NPV and EIRR as presented in the Final Design furthermore ignores the 1/30 years crop damage due to flooding. The proper inclusion of flood protection benefits and the 1/30 year crop damage due to flooding are necessary to calculate the NPV for the climate realizations. This reduces for the actual climate the NPV to 1,000 MKES and the EIRR to 13.4%.

E Python script used to calculate the NPV and EIRR

```
print("Program efa.py, version 1.0, January 28, 2019")
print("Executes the economic and financial analysis for the Nzoia project")

#input files
cbainpfile='cba.inp'
pqinpfile='PQ_WG.csv'
yieldinpfile='Rel_yields_190312.csv'
#output file
outfile='EFA_WG.csv'
gcmfile='gcm.csv'

#define the ranges for the multiplication factors of P and PET
pmin=0.5
pmax=2.0
petmin=1.0
petmax=1.15
#and the number of steps and drawings per step
npetstep = 6
npstep = 7
ndraw=5
#npstep=3
#npetstep=3
#ndraw=1

import csv as csv
import numpy as np
from scipy.optimize import minimize
from scipy import interpolate
import matplotlib.pyplot as plt

#function to minimize to calculate EIRR
def eirr(x,netben,year):
    year0=year[0]
    discfact=1./(1.+x)**(year-year0)
    npvpy=netben*discfact
    npv=abs(np.sum(npvpy))
    return npv

#function to write a list as a line
def writelist(out,llist):
    sline=''
    for item in llist: sline += '{},'.format(item)
    sline += '\n'
    out.write(sline)
```

```
def
calceirr(avapl,pq30,maisfact,ricefact,benmod1,benmod2,benmod3,benmod4,benmill,benfruit,benrfwp,benwop,costwp,cost
wop,discfact):
    pq30=float(pq30)
    benflood=benwop.copy()
    benflood=0. * benwop
    benflood[3:]=avapl
    incrben=(1-
pq30*0.5)*(maisfact*benmod1+ricefact*(benmod3+benmod4+benmill)+benmod2+benfruit+benrfwp)+benflood-benwop
    incrcost=costwp-costwop
    netben=incrben-incrcost
    npv0=np.sum(netben)
    npvpy=netben*discfact
    npv=np.sum(npvpy)
    #check if npv with 0% discount is positive
    if npv0 < 0:
        valeirr=-1
    else:
        disc=0.12
        bound=list()
        bound.append((0.0,1.0))
        res=minimize(eirr, disc, args = (netben, year), bounds=bound, method ='SLSQP',options={"disp": False})
        valeirr=res.x[0]*100
    return npv, valeirr

#read the cba input file
cbamat=np.loadtxt(cbainpfile,delimiter=',',skiprows=1,)
year=cbamat[:,0]
costwp=cbamat[:,1]
costwop=cbamat[:,2]
benmod1=cbamat[:,3]
benmod2=cbamat[:,4]
benmod3=cbamat[:,5]
benmod4=cbamat[:,6]
benfruit=cbamat[:,7]
benmill=cbamat[:,8]
benrfwp=cbamat[:,9]
benwop=cbamat[:,10]
discfact=1./(1.12)**(year-year[0])

#read the results of the runs from the columns of the PQ_WG input file
pqfile=open(pqinpfile,'rt')
pqinp=csv.reader(pqfile)
runlist=pqinp.__next__()
pq10list=pqinp.__next__()
pq30list=pqinp.__next__()
q10list=pqinp.__next__()
q30list=pqinp.__next__()
apl0list=pqinp.__next__()
apl1list=pqinp.__next__()
avapllist=pqinp.__next__()
```

```
pqfile.close()
#print(runlist)
#print(avapllist)

#read the yield input
yieldinp=csv.reader(open(yieldinpfile,'rt'),delimiter=';')
header=yieldinp.__next__()
yrunlist=list()
maisfacts=list()
ricefacts=list()
for row in yieldinp:
    idum,run,dp,dpet,rel,vul,maisfact,ricefact,dum=row
    maisfact=float(maisfact)
    ricefact=float(ricefact)
    yrunlist.append(run)
    maisfacts.append(maisfact)
    ricefacts.append(ricefact)

#initializa output variables
outavapllist=list()
outpq30list=list()
mfact=list()
rfact=list()
npvlist=list()
eirrlist=list()
reallist=list()
eirrmat=np.zeros((npstep,npetstep))
npvmat=np.zeros((npstep,npetstep))
mfact.append('Maize yield factor')
rfact.append('Rice yield factor')
reallist.append('Realization')
npvlist.append('NPV')
eirrlist.append('EIRR')
outavapllist.append('Avoided APL')
outpq30list.append('PQ30')

#reference
scenario='reference'
irun=runlist.index(scenario)
avapl = avapllist[irun]
#print(scenario,irun,yrun,avapl)
pq30 = pq30list[irun]
reallist.append(scenario)
maisfactref=0.932
ricefactref=0.892
mfact.append(1.)
rfact.append(1.)
npv,valeirr                                                                                    =
calceirr(avapl,pq30,1.,1.,benmod1,benmod2,benmod3,benmod4,benmill,benfruit,benrfwp,benwop,costwp,costwop,discfact
)
print ("Scenario {} NPV {:5.0f} EIRR {:5.2f}%".format(scenario,npv,valeirr))
```

```
npvlist.append(npv)
eirrlist.append(valeirr)
outavapllist.append(avapl)
outpq30list.append(pq30)

#loop over the realizations
#loop over steps in P and PET and run the model
Y=np.zeros(npstep)
X=np.zeros(npetstep)
for pstep in range(npstep):
    pfact=pmin + pstep * (pmax-pmin) / (npstep-1)
    Y[pstep]=pfact
    for petstep in range(npetstep):
        petfact=petmin + petstep * (petmax-petmin) / (npetstep-1)
        X[petstep]=petfact
        run ='P{:5.3f}_PET{:5.3f}'.format(pfact,petfact)
        for draw in range(ndraw):
            scenario='P{:05.3f}_PET{:05.3f}_D{:02d}'.format(pfact,petfact,draw+1)
            yrun=yrunlist.index(scenario)
            irun=runlist.index(scenario)
            avapl = avapllist[irun]
            #print(scenario,irun,yrun,avapl)
            pq30 = pq30list[irun]
            reallist.append(scenario)
            maisfact=(maisfacts[yrun])/maisfactref
            ricefact=(ricefacts[yrun])/ricefactref
            mfact.append(maisfacts[yrun])
            rfact.append(ricefacts[yrun])
            npv,valeirr                                                    =
calceirr(avapl,pq30,maisfact,ricefact,benmod1,benmod2,benmod3,benmod4,benmill,benfruit,benrfwp,benwop,costwp,cost
wop,discfact)
            print ("Scenario {} NPV {:5.0f} EIRR {:5.2f}%".format(scenario,npv,valeirr))
            npvlist.append(npv)
            eirrlist.append(valeirr)
            outavapllist.append(avapl)
            outpq30list.append(pq30)
            eirrmat[pstep,petstep]+=valeirr
            npvmat[pstep,petstep]+=npv

out=open(outfile,'wt')
writelist(out,reallist)
writelist(out,outpq30list)
writelist(out,outavapllist)
writelist(out,mfact)
writelist(out,rfact)
writelist(out,npvlist)
writelist(out,eirrlist)
out.close()

eirrmat=eirrmat / ndraw
npvmat=npvmat / ndraw
```

The input file with the data used to calculate the NPV and EIRR has been derived from Table 9-51 of the Final Design Report (see Appendix F) and is presented below.

Year	Total with project costs	Total without project costs	Model 1: Maize/legumes	Model 2:	Model 3: Paddy	Model 4: Bunyala project	Fruit processing factory	Rice Mill	Rainfed with project benefits	Without project benefits
2017	1349.55	13.21	0	0	0	0	0	0	285.36	285.36
2018	2530.65	13.21	0	0	0	0	0	0	353.82	353.82
2019	2241.92	13.21	-55.57	0	0	0	0	0	278.98	397.03
2020	1449.17	13.21	17.16	0	32.98	3.98	0	0	0	396.65
2021	344.18	13.21	71.33	0	292.59	44.3	0	298.75	0	395.65
2022	437.72	13.21	119.61	0	597.53	96.26	0	627.37	0	395.7
2023	733.12	13.21	152.09	0	789.19	130.16	0	1194.99	0	396.78
2024	859.27	13.21	167.95	0	963.61	162.45	0	1493.74	0	397.17
2025	1032.05	13.21	171.06	0	977.19	164.49	0	1792.49	0	397.13
2026	1111.2	13.21	182.18	0	975.15	164.31	0	1792.49	0	397.17
2027	1032.05	13.21	183.67	0	991.03	166.53	0	1792.49	0	397.17
2028	1032.05	13.21	198.8	0	992.08	166.46	0	1792.49	0	397.17
2029	1032.05	13.21	195.89	0	1014.51	168.89	0	1792.49	0	397.17
2030	1032.05	13.21	195.35	0	1014.28	168.89	0	1792.49	0	397.17
2031	1032.05	13.21	197.9	0	1014.24	168.89	0	1792.49	0	397.17
2032	1111.2	13.21	199.38	0	1013.38	168.89	0	1792.49	0	397.17
2033	1032.05	13.21	199.53	0	1009.53	168.89	0	1792.49	0	397.17
2034	1032.05	13.21	201.26	0	1009.6	168.89	0	1792.49	0	397.17
2035	1032.05	13.21	199.94	0	1012.79	168.89	0	1792.49	0	397.17
2036	1032.05	13.21	199.62	0	1013.12	168.89	0	1792.49	0	397.17
2037	1032.05	13.21	199.62	0	1013.12	168.89	0	1792.49	0	397.17
2038	1032.05	13.21	199.62	0	1013.12	168.89	0	1792.49	0	397.17
2039	1032.05	13.21	199.62	0	1013.12	168.89	0	1792.49	0	397.17
2040	1032.05	13.21	199.62	0	1013.12	168.89	0	1792.49	0	397.17
2041	1032.05	13.21	199.62	0	1013.12	168.89	0	1792.49	0	397.17
2042	1032.05	13.21	199.62	0	1013.12	168.89	0	1792.49	0	397.17
2043	1032.05	13.21	199.62	0	1013.12	168.89	0	1792.49	0	397.17
2044	1032.05	13.21	199.62	0	1013.12	168.89	0	1792.49	0	397.17
2045	1032.05	13.21	199.62	0	1013.12	168.89	0	1792.49	0	397.17
2046	1032.05	13.21	199.62	0	1013.12	168.89	0	1792.49	0	397.17

F Reproduction of table from the Final Design Report to calculate NPV and EIRR

Table 9-51 of the Final Design Report (Lahmeyer, 2017)

Table 9-51 CBA of LNIDP, Food Security Cropping Pattern: Economic Prices, KES million

	A. LNIP Civil Works Component	B. IFMS Civil Works Component	B. Agricultural Support and Value Chain Component		C. Participatory Irrigation Management Component		D. Project Management Component				Fruit Processing Factory		Rice Mill				Irrigated with-project benefits						Flood Management with-project benefits						
Year	Capital costs	Capital costs	Capital costs	Operating Costs	Capital costs	Operating Costs	Capital costs	MOM 1/	Environmental Management Plan	Resettlement Costs	Capital costs	Operational costs	Capital costs	Operational costs	Total with project costs	Without project costs (MOM Bunyala) 2/	Model 1: Maize/legumes	Model 2:	Model 3: Paddy	Model 4: Bunyala Project	Fruit Processing Factory	Rice Mill	Avoided annual probability of loss of crops	Avoided annual probability of damage to LNIP	Rainfed With-project benefits	Without project benefits	Incremental benefits	Incremental costs	Net benefit stream
2017	730.53	305.71	23.61	6.78	29.72	-	18.19	-	11.85	223.14	-	-	-	-	1,349.55	13.21	-	-	-	-	-	-	-	-	285.36	285.36	-	1,336.33	(1,336.33)
2018	1,753.28	687.85	45.80	-	32.54	-	2.80	-	8.39	-	-	-	-	-	2,530.65	13.21	-	-	-	-	-	-	-	-	353.82	353.82	-	2,517.44	(2,517.44)
2019	1,753.28	229.28	82.58	45.92	99.14	13.57	10.80	-	7.35	-	-	-	-	-	2,241.92	13.21	(55.57)	-	-	-	-	-	-	-	278.98	397.03	(173.63)	2,228.71	(2,402.33)
2020	876.64	-	55.57	103.92	111.45	13.57	2.44	-	7.93	-	-	-	277.66	-	1,449.17	13.21	17.16	-	32.98	3.98	-	-	36.00	71.06	-	396.65	(235.48)	1,435.96	(1,671.44)
2021	-	-	43.15	81.19	18.76	13.57	8.63	-	7.35	-	-	-	-	171.52	344.18	13.21	71.33	-	292.59	44.30	-	298.75	36.00	71.06	-	395.65	418.38	330.97	87.42
2022	-	-	35.00	5.09	17.13	13.57	0.78	-	7.93	-	-	-	-	358.22	437.72	13.21	119.61	-	597.53	96.26	-	627.37	36.00	71.06	-	395.70	1,152.13	424.51	727.63
2023	-	-	12.53	1.63	11.55	13.57	-	-	7.35	-	-	-	-	686.50	733.12	13.21	152.09	-	789.19	130.16	-	1,194.99	36.00	71.06	-	396.78	1,976.71	719.91	1,256.81
2024	-	-	-	-	-	-	-	-	-	-	-	-	-	859.27	859.27	13.21	167.95	-	963.61	162.45	-	1,493.74	36.00	71.06	-	397.17	2,497.64	846.06	1,651.58
2025	-	-	-	-	-	-	-	-	-	-	-	-	-	1,032.05	1,032.05	13.21	171.06	-	977.19	164.49	-	1,792.49	36.00	71.06	-	397.13	2,815.17	1,018.84	1,796.33
2026	-	-	-	-	-	-	-	-	-	-	-	-	79.15	1,032.05	1,111.20	13.21	182.18	-	975.15	164.31	-	1,792.49	36.00	71.06	-	397.17	2,824.03	1,097.98	1,726.04
2027	-	-	-	-	-	-	-	-	-	-	-	-	-	1,032.05	1,032.05	13.21	183.67	-	991.03	166.53	-	1,792.49	36.00	71.06	-	397.17	2,843.61	1,018.84	1,824.78
2028	-	-	-	-	-	-	-	-	-	-	-	-	-	1,032.05	1,032.05	13.21	198.80	-	992.08	166.46	-	1,792.49	36.00	71.06	-	397.17	2,859.72	1,018.84	1,840.88
2029	-	-	-	-	-	-	-	-	-	-	-	-	-	1,032.05	1,032.05	13.21	195.89	-	1,014.51	168.89	-	1,792.49	36.00	71.06	-	397.17	2,881.67	1,018.84	1,862.84
2030	-	-	-	-	-	-	-	-	-	-	-	-	-	1,032.05	1,032.05	13.21	195.35	-	1,014.28	168.89	-	1,792.49	36.00	71.06	-	397.17	2,880.90	1,018.84	1,862.07
2031	-	-	-	-	-	-	-	-	-	-	-	-	-	1,032.05	1,032.05	13.21	197.90	-	1,014.24	168.89	-	1,792.49	36.00	71.06	-	397.17	2,883.42	1,018.84	1,864.58
2032	-	-	-	-	-	-	-	-	-	-	-	-	79.15	1,032.05	1,111.20	13.21	199.38	-	1,013.38	168.89	-	1,792.49	36.00	71.06	-	397.17	2,884.03	1,097.98	1,786.05
2033	-	-	-	-	-	-	-	-	-	-	-	-	-	1,032.05	1,032.05	13.21	199.53	-	1,009.53	168.89	-	1,792.49	36.00	71.06	-	397.17	2,880.33	1,018.84	1,861.50
2034	-	-	-	-	-	-	-	-	-	-	-	-	-	1,032.05	1,032.05	13.21	201.26	-	1,009.60	168.89	-	1,792.49	36.00	71.06	-	397.17	2,882.13	1,018.84	1,863.30
2035	-	-	-	-	-	-	-	-	-	-	-	-	-	1,032.05	1,032.05	13.21	199.94	-	1,012.79	168.89	-	1,792.49	36.00	71.06	-	397.17	2,884.01	1,018.84	1,865.17
2036	-	-	-	-	-	-	-	-	-	-	-	-	-	1,032.05	1,032.05	13.21	199.62	-	1,013.12	168.89	-	1,792.49	36.00	71.06	-	397.17	2,884.01	1,018.84	1,865.17
2037	-	-	-	-	-	-	-	-	-	-	-	-	-	1,032.05	1,032.05	13.21	199.62	-	1,013.12	168.89	-	1,792.49	36.00	71.06	-	397.17	2,884.01	1,018.84	1,865.17
2038	-	-	-	-	-	-	-	-	-	-	-	-	-	1,032.05	1,032.05	13.21	199.62	-	1,013.12	168.89	-	1,792.49	36.00	71.06	-	397.17	2,884.01	1,018.84	1,865.17
2039	-	-	-	-	-	-	-	-	-	-	-	-	-	1,032.05	1,032.05	13.21	199.62	-	1,013.12	168.89	-	1,792.49	36.00	71.06	-	397.17	2,884.01	1,018.84	1,865.17
2040	-	-	-	-	-	-	-	-	-	-	-	-	-	1,032.05	1,032.05	13.21	199.62	-	1,013.12	168.89	-	1,792.49	36.00	71.06	-	397.17	2,884.01	1,018.84	1,865.17
2041	-	-	-	-	-	-	-	-	-	-	-	-	-	1,032.05	1,032.05	13.21	199.62	-	1,013.12	168.89	-	1,792.49	36.00	71.06	-	397.17	2,884.01	1,018.84	1,865.17
2042	-	-	-	-	-	-	-	-	-	-	-	-	-	1,032.05	1,032.05	13.21	199.62	-	1,013.12	168.89	-	1,792.49	36.00	71.06	-	397.17	2,884.01	1,018.84	1,865.17
2043	-	-	-	-	-	-	-	-	-	-	-	-	-	1,032.05	1,032.05	13.21	199.62	-	1,013.12	168.89	-	1,792.49	36.00	71.06	-	397.17	2,884.01	1,018.84	1,865.17
2044	-	-	-	-	-	-	-	-	-	-	-	-	-	1,032.05	1,032.05	13.21	199.62	-	1,013.12	168.89	-	1,792.49	36.00	71.06	-	397.17	2,884.01	1,018.84	1,865.17
2045	-	-	-	-	-	-	-	-	-	-	-	-	-	1,032.05	1,032.05	13.21	199.62	-	1,013.12	168.89	-	1,792.49	36.00	71.06	-	397.17	2,884.01	1,018.84	1,865.17
2046	-	-	-	-	-	-	-	-	-	-	-	-	-	1,032.05	1,032.05	13.21	199.62	-	1,013.12	168.89	-	1,792.49	36.00	71.06	-	397.17	2,884.01	1,018.84	1,865.17

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