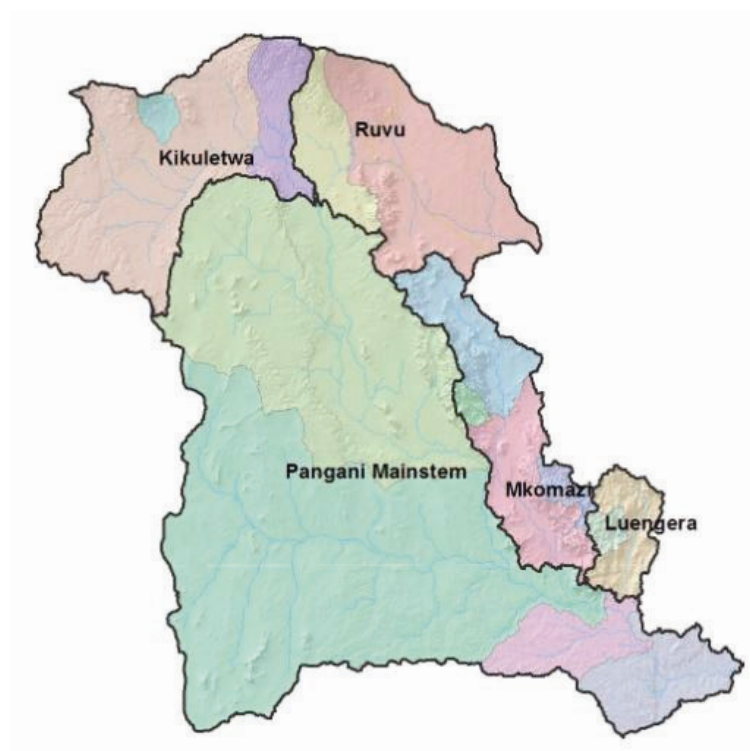


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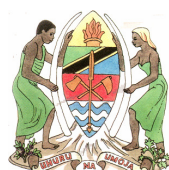


PANGANI RIVER BASIN FLOW ASSESSMENT

Final Project Summary Report

J. King, J. Turpie, C. Brown, B. Clark, H. Beuster and A. Joubert

December 2009



¹ As of 2010, Pangani Basin Water Office is known as Pangani Basin Water Board

Published by: Pangani Basin Water Board (PBWB)
International Union for Conservation of Nature (IUCN)



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Citation: PBWO/IUCN. 2009. Final Project Report. Pangani Basin Water Board, Moshi and IUCN Eastern & Southern Africa Regional Program. 89 pp.

Available from: IUCN - ESARO Publications Service Unit, P. O. Box 68200 - 00200, Nairobi, Kenya; Telephone ++ 254 20 890605-12; Fax ++ 254 20 890615; E-mail: earo@iucn.org

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IUCN WATER AND NATURE INITIATIVE

PANGANI BASIN WATER BOARD

PANGANI RIVER BASIN FLOW ASSESSMENT

Final Project Summary Report



CONTRIBUTORS

J. King	Water Matters
J. Turpie	Anchor Environmental
C. Brown	Southern Waters
B. Clark	Anchor Environmental
H. Beuster	Emzantsi Systems
A. Joubert	Southern Waters

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ACKNOWLEDGEMENTS

The authors wish to extend their thanks to:

- The Pangani Basin Water Office for logistical support.
- The IUCN Nairobi Office for administrative support.

1 INTRODUCTION

1.1 Background

Tanzania's National Water Policy (NAWAPO 2002) provides that water for maintenance of aquatic ecosystems will be accorded second highest priority in allocation, after water for basic human needs. Tanzania has little experience and capacity in environmental flow assessments to support this environmental policy provision. The Pangani River Basin Management Project, supported by the IUCN Water & Nature Initiative, UNDP/GEF and the European Union, has made a commitment to conduct a flow assessment in the Pangani Basin as a means of providing relevant technical information (hydrological, economic, ecological and social) to the Pangani Basin Water Board to support the water-allocation process.

Support to the Pangani Basin Water Office (PBWO) started with a 4-day training course on environmental flows held in Mbeya, in September 2003, organised by the Ministry of Water and Livestock Development (now Ministry of Water and Irrigation) and supported by the World Bank, through its Lower Kihansi Environmental Management Project and River Basin Management Project (with sponsorship from the Bank Netherlands Water Partnership Program), and by IUCN, through its Water and Nature Initiative. A training course in environmental economics, supported by the IUCN Water & Nature Initiative, was convened in October 2003. It focussed on livelihood use of the river and estuary, and valuation of goods and services provided by the freshwater ecosystems in the basin.

Subsequent to these exercises, IUCN and the PBWO initiated discussions with Southern Waters (Southern Waters) and Anchor Environmental Consultants ("Anchor") in October 2004 about conducting a flow assessment in the Pangani River Basin. Initial discussions focussed on conducting a detailed flow assessment using a complex methodology applied in South Africa (the DRIFT Methodology) but key limitations were the amount and nature of supporting hydrological data for the Pangani River Basin, and a limited specialist capacity for conducting flow assessments in Tanzania. Owing to these concerns it was decided that application of a full DRIFT Methodology could be too data- and expert-intensive for what was planned as the first FA application in Tanzania, and that it would in all likelihood fall short on the overriding need of creating capacity for flow assessments within Tanzania. Following this, a series of meetings and visits to key locations in the Pangani River Basin were conducted by representatives from PBWO, IUCN and Southern Waters between 13 and 18 December 2004, and a detailed proposal developed for what was termed a "Pangani capacity-building Flow Assessment". In essence the proposal called for the establishment of a Flow Assessment Team selected from within Tanzania, consisting of specialists in a range of river-related, water-allocation and policy-making disciplines, which could work with international flow-assessment advisors from or working through Southern Waters or Anchor. Together, they would gradually develop an understanding of the hydrology of the Pangani River Basin, the nature and functioning of the river system and the links

between the river and subsistence use of its resources. The two aims of the project were to be hands-on capacity building of the PBWO and the Tanzanian group of specialists (who in the future could act as a nucleus of expertise for other Tanzanian basins), and the provision of technical information and decision support tools to assist the Pangani Basin Water Office and the Pangani Basin Water Board in managing water resources.

1.2 Pangani River Basin Flow Assessment Objectives, Workplan and Deliverables

1.2.1 Project objectives

The objectives of the Pangani Basin Flow Assessment (FA) were to:

- generate baseline data on the condition of rivers, wetlands and the estuary against which the impact of water-related decision-making can be monitored in future;
- enhance the understanding among PBWO and MoW staff of the relationship between flow, river health and the people who use the river;
- create an awareness of the trade-offs to be made between water development and natural-resource protection;
- develop simple tools to help guide water-resource management and water allocations in the Pangani River Basin;
- build capacity that will enable PBWO to act as a nucleus of expertise for FA-related work in other areas;
- support the National Water Policy (NAWAPO 2002) and the National Environmental Management Act (2004).

1.2.2 Work plan

As with many projects, the Pangani River Basin FA project developed and was adjusted through its duration. The project was originally envisaged to span a total period of just over two years – October 2005 to February 2008, but was extended twice: once (“Slow-down I”) to incorporate an additional Training Workshop, and a second time (“Slow-down II”) to incorporate additional scenarios and intensive training on the procedures used to assess those scenarios.

Accordingly, this report addresses three separate phases of the project:

- Phase 1: The project as proposed.
- Phase 2: Slowdown I
- Phase 3: Slowdown II.

A breakdown of timing of these phases is provided in Table 1.1 and Table 1.2, respectively.

1.2.2.1 Phase 1: The project as proposed

The final agreed proposal for the Pangani River Basin FA comprised a total of ten tasks.

Task 1: *Hydrology*: A desktop-exercise that described water-resource developments in the catchment, obtained daily flow records for the basin, simulated daily historical and present-day flow data, developed a simple hydrological system model for the Pangani River Basin, and generated relevant hydrological data for selected scenarios.

Task 2: *Study area delineation and site selection*: The objectives of this task were to divide the river into relatively homogeneous zones in terms of biophysical characteristics (river reach analysis) and land-use, and homogeneous zones across the basin in terms of social factors; to select representative sampling sites in the river zones, in the estuary and in each social zone; and to develop simple (GIS) base maps for use in the following tasks.

Task 2.1: *Scenario identification*: The main objective of this task was to conceptualise the kind of scenarios that would be created and evaluated later in the project, as a guide for appropriate data collection.

Task 3: *Health assessment of the rivers and estuary*: Building on Task 2 and using the sites selected there, this task comprised health assessments of the river system and estuary. The assessments were based on existing information and some data collection.

Task 4: *Baseline socio-economic assessment*: Also building on Task 2 and using the selected sites, this task included completion of a social field survey using participatory methods and household surveys. It described the communities, focussing on their relation to water and water resources, their socio-economic well-being and sensitivity to changes in river flow, and included a baseline assessment of socio-economic conditions in the basin.

Task 5: *Develop an understanding of the ecological and economic systems*: This task identified and evaluated key flow-related changes that have occurred over time in the Pangani River Basin; developed simple conceptual models for the changes that have occurred; identified topics (e.g. climate change; hydropower; vegetation) for more in-depth investigation; and developed Terms of Reference for these in-depth investigations.

Task 6: *Specialist Studies*: In this task, appointed specialists completed research on the priority topics and submitted separate reports. These were initially reviewed by the Project Team and then also by appointed specialist reviewers and IUCN/PBWO.

Table 1.1 Gantt chart showing activities and tasks for the Pangani Basin Flow Assessment, excluding the 'Slowdown Tasks'.

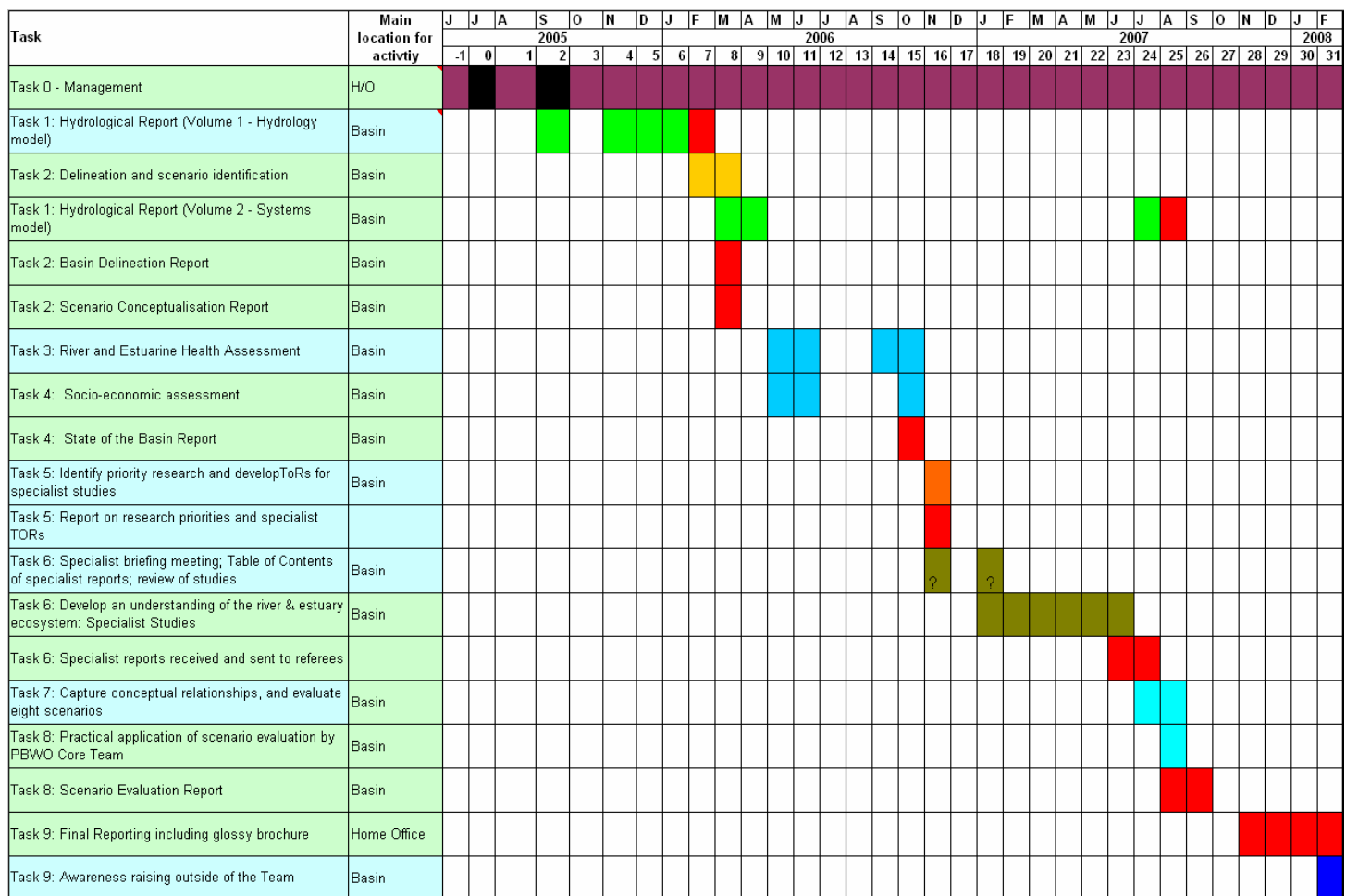
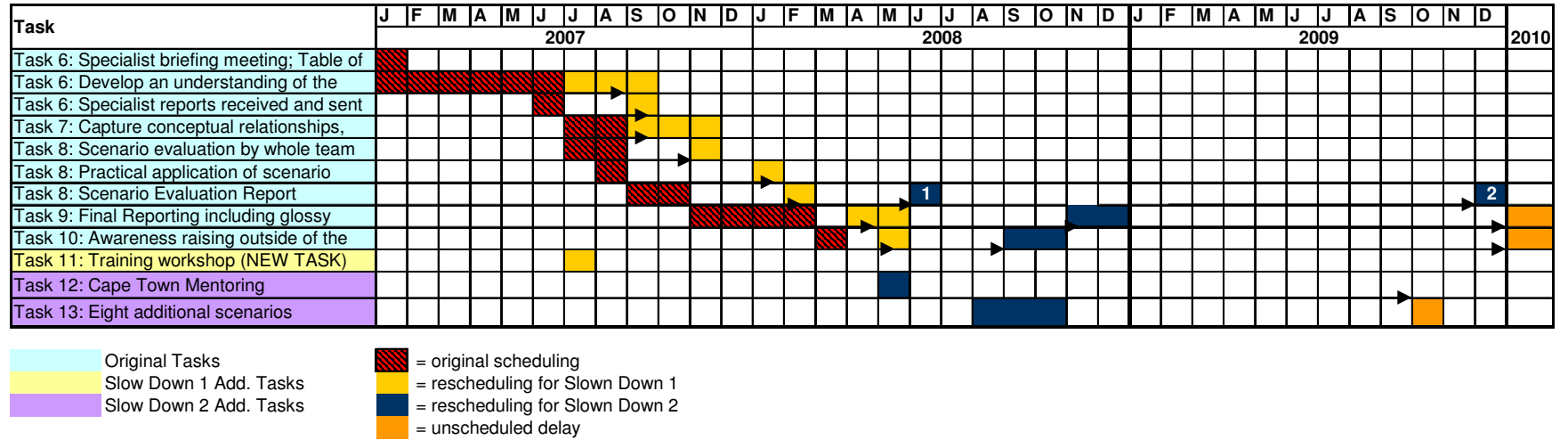


Table 1.2 Gantt chart showing the ‘Slowdown Tasks’, and their effect on the project schedule.



- Task 7: *Develop conceptual relationships, create and evaluate scenarios*: This task included development of conceptual relationships between flows and the river ecosystem, and between flows, river health and livelihoods; development of a simple FA scenario-evaluation tool using the information gathered in previous tasks; population of the scenario-evaluation tool with the conceptual flow-response relationships; training the National Pangani FA Team in the use of the scenario-evaluation tool; and preparation of a manual for operating the FA scenario-evaluation tool.
- Task 8: *Practical application of scenario evaluation by National Pangani FA Team*: This was a capacity-building task wherein the National Pangani FA Team evaluated one additional scenario and evaluated the usefulness of the tool and manual developed in Task 7. This task was eventually augmented by the Slowdown II activities (see Task 12).
- Task 9: *Final Reporting*: This task is the subject of this report, which synthesises information from the previous tasks into a Final Project Report of the Pangani River; and evaluates the extent to which the project has achieved its goals.
- Task 10: *Awareness raising outside the National Pangani FA Team*. This task, not yet completed, comprises presentations to the Pangani Basin Water Board, and the creation of text for two glossy publications (One of these glossy brochures - the State of the Basin Report – was compiled using the results of the river (Section 2.5) and estuary health assessments (Section 2.6) and social state of the basin (Section 2.7) reports; the other will be completed in early 2010.

1.2.2.2 Phase 2: Slowdown I

Slowdown I involved the inclusion, mid-project via Task 11, of a training course for officials from PBWO and the neighbouring Wami-Ruvu Basin.

- Task 11: *Training Course*. This took place on 23-27 July 2007 in Morogoro. The aim was to share information regarding the ongoing project, see what other basins are doing (i.e. Wami Ruvu), and strengthen and develop the community working on Environmental Flow Assessments (EFA) in Tanzania, so that they can continue working in the Pangani and beyond. The first day consisted of background information about rivers and our basic understanding of the physical, chemical and ecological factors that relate to flows. The second day focused on understanding the river and how to use this to guide decision-making on water allocations. The third and fourth days focused on group

meetings to better understand specific issues in the specialist fields.

1.2.2.3 Phase 3: Slowdown II

Slowdown II involved an expansion of work done in Task 8, via Task 12. It consisted of a two-week mentoring session, plus some adjustments to the Pangani FA DSS and the evaluation of an additional eight scenarios.

Task 12: *Two-week mentoring in Cape Town*: Five members of the Tanzanian Core Team travelled to Cape Town for mentoring on the Pangani FA DSS, from the hydrological model WEAP through to the Scenario Interface DSS software, and interpretation of the results. The final three contracted scenarios, plus one other, were run during this visit, whereafter the Southern Waters/Anchor team completed the FIRST DRAFT of the Scenario Report.

Task 13: *Inclusion of additional information in the Pangani Flows DSS*. This task involved incorporation of some economic indicators into the scenario outputs; final edits to the Pangani Flow DSS, protection of key sequences and inclusion of these aspects in the User Manual. Adjustments also included provision for a suite of 18 scenarios in the DSS instead of the previous plan that was to cater for 12 scenarios.

Task 14: *Analysis of eight additional scenarios*: The trained members of the Core Team were responsible for running the hydrological component of these scenarios (i.e., WEAP and DRIFT-Hydro) and the results of these hydrological analyses were checked by the Southern Waters team. The remainder of the scenario analysis' activities were completed at a workshop held from 18-20th August 2009 in Stone Town, Zanzibar, Tanzania. The results from these additional scenarios were incorporated into the Final Scenario Report.

1.2.3 Deliverables

The deliverables for the Pangani Basin FA are listed in Table 1.3. Summaries of each of the reports are also provided in Section 2.

1.3 Layout of this report

This report summarises the above set of reports in Chapter 2, briefly describes the specialist reports in Chapter 3, and assess the achievements of the project in Chapter 4. Chapter 5 concludes the report.

Table 1.3 The deliverables for the Pangani Basin FA, excluding specialist reports

Report #	Title	Tasks addressed	Date first submitted
REPORTS			
1	Hydrology Report Volume 1	Task 1	August 2006
	Hydrology Report Volume 2		August 2009
2	Basin Delineation Report	Task 2	March 2006
3	Scenario Selection Report	Task 2.1	March 2006
4	River Health Assessment	Task 3	October 2006
5	Estuarine Health Assessment	Task 3	October 2006
6	Socio-economic State of the Basin	Task 4	November 2006
7	Task 5 Report	Task 5	November 2006
8	Pangani FA Tool User Manual	Task 7	May 2008
9	Scenario Report	Tasks 7 and 8	June 2008
10	Final Project Report	Task 9	September 2009
OTHER			
-	Pangani FA Tool	Task 7 and 8	May 2008
-	State of the Basin Glossy Report	Task 10	December 2006
-	Summary Report – text for Glossy Report	Task 10	December 2009
-	Powerpoint Presentations	Task 11, 12	As tasks completed

2 SUMMARIES OF PANGANI FA REPORTS

2.1 Hydrology Report (Volume 1)

2.1.1 *Hydrology*

A hydrological model of the Pangani River Basin was configured, calibrated, and used to produce long-term flow sequences at 15 key points in the system. The work to develop and use the models was done in close collaboration with the (then) PBWO Basin Hydrologist, Dr George Lugomela, with assistance from officials working in the regional hydrology offices of the MoW. The Basin was discretised into five main catchments that together comprise 15 sub-catchments. The main catchments have significantly different hydrological characteristics, and it was considered important that successful calibrations be achieved at the outlets of each of the main catchments (the Ruvu, Kikuletwa, Mkomazi, Luengera and Pangani). The main catchments are shown with solid black borders in Figure 2.1. The coloured subdivisions represent the 15 sub-catchments for which long-term flow sequences were developed.

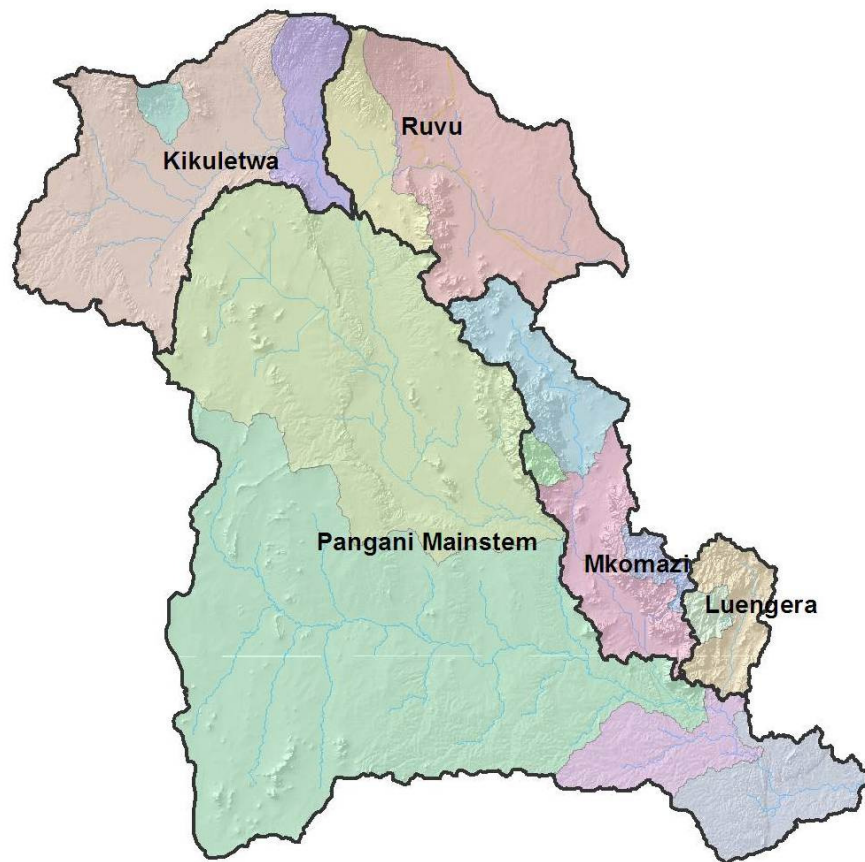


Figure 2.1 Catchment Discretisation

To illustrate the extent to which the water resources of the Basin have been developed, water balances were prepared for five key sites in the Basin. The sites correspond to the downstream outlets of the major catchments, i.e. the Kikuletwa and Ruvu catchments upstream of Nyumba ya Mungu Dam, the Mkomazi and Luengera catchments, and the outlet of the entire Pangani River catchment at the Pangani Estuary. The water balances are shown in Table 2.1.

Table 2.1 Key Point Water Balances

Component			Kikuletwa	Ruvu	Mkomazi	Luengera	Main stem	PANGANI RIVER BASIN
Streamflow reduction by natural forests	Mm ³ /a	A	180	201	35	28	14	458
Natural runoff including endorheic runoff	Mm ³ /a	B	884	928	302	175	830	3 119
Natural upstream inflows	Mm ³ /a	C	0	0	0	0	2020	0
Endorheic runoff	Mm ³ /a	D			212	58	1425	1 695
Cumulative natural runoff	Mm ³ /a	E = B+C-D	884	928	90	117	1425	1 424
Current day upstream inflows	Mm ³ /a	F	0	0	0	0	1691	0
Current day endorheic runoff	Mm ³ /a	G	0	0	82	56	1163	1 302
Consumptive water demand	Mm ³ /a	H	751	276	487	13	74	1 600
Water supplied	Mm ³ /a	I	592	232	240	13	74	1 150
% demand met	%	J	79	84	49	100	100	72
Evaporation	Mm ³ /a	K	0	0	6	0	71	77
Return flows	Mm ³ /a	L	371	183	64	4	15	637
Cumulative current day runoff	Mm ³ /a	M = B + F - G - I - K + L	663	879	38	110	1 227	1 227
Hydropower requirement	Mm ³ /a	N						600
% utilisation	%	(1 - (M-N)/E) x100	25	5	58	6	14	56

The water balances show that the Mkomazi catchment is most developed with about 58% of the catchment's natural runoff utilised, followed by the Kikuletwa catchment where about 25% of the natural runoff is currently utilised. The mass balances are

based on average annual figures, which disguise the fact that most of the utilisation occurs in the dry season, when irrigation requirements are highest.

Figure 2.2 to Figure 2.6 show comparisons of monthly natural and current day runoff at the five key points in the system. The charts provide summary statistics of the 76-year long naturalised and current day runoff sequences, and show 5% (very wet), 50% (median), and 95% (very dry) monthly exceedence volumes.

The hydrology of the Kikuletwa catchment indicates that, in spite of large reductions in dry-season flows, the river is still perennial (Figure 2.2). This is due to the contributions of the springs to surface flows in the middle part of the catchment. Upstream of the springs, some tributaries dry up completely in the dry season, even in years with normal runoff conditions.

The high utilisation of the Mkomazi (Figure 2.3) is illustrated by the fact that this formerly perennial river is now dry for a large percentage of time. A feature of the Mkomazi catchment hydrology, not seen in the other catchments, is the occurrence of large flood events in the short rainy season of November to December. The magnitude of these floods has been reduced by the presence of Kalimawe Dam, in the middle part of the catchment.

Dry season flows in the Ruvu (Figure 2.4) and Luengera (Figure 2.5) catchments have been significantly reduced, but nowhere near the extent seen in the Kikuletwa and Mkomazi catchments.

Current day inflows to the Pangani Estuary (Figure 2.6) show a marked reduction in dry-season high flows and wet-season low flows, mostly due to flood interception at Nyumba ya Mungu and Kalimawe Dams. Dry-season low flows show relatively small reductions, in part due to contributions from the Luengera catchment, but also due to hydropower releases from Nyumba ya Mungu Dam.

Overall utilisation of the water resources of the Basin is estimated to be about 56%, with hydropower accounting for the largest portion of this use. Much of the remaining runoff occurs in the form of floods and is therefore not exploitable. Utilisation is expressed as a percentage of natural runoff, excluding endorheic runoff volumes. The water balance therefore excludes groundwater volumes that can potentially be extracted from aquifers that are not directly connected to the surface water systems.

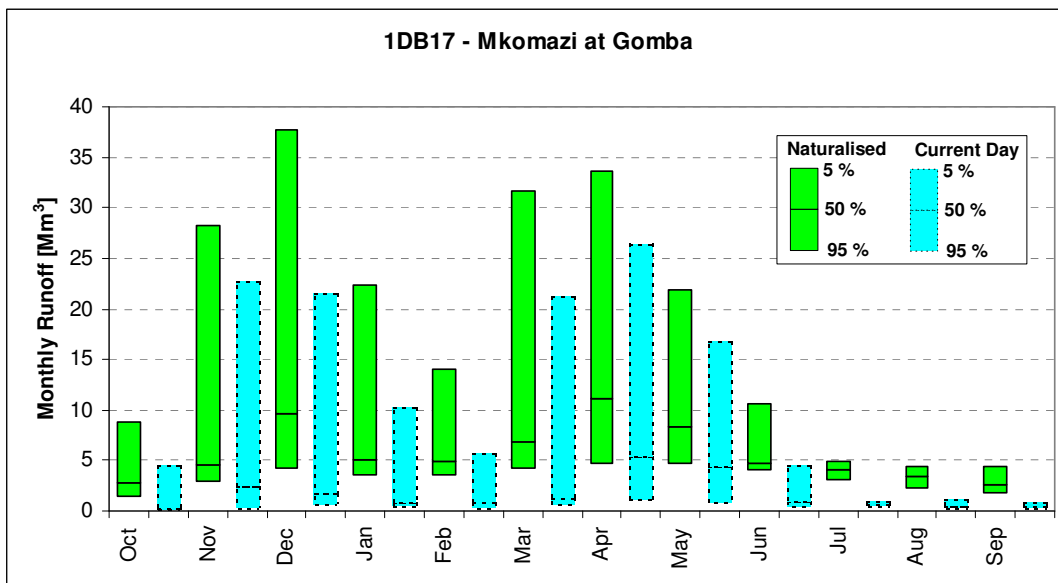


Figure 2.2 Comparison of Naturalised and Current Day Flows – Kikuletwa

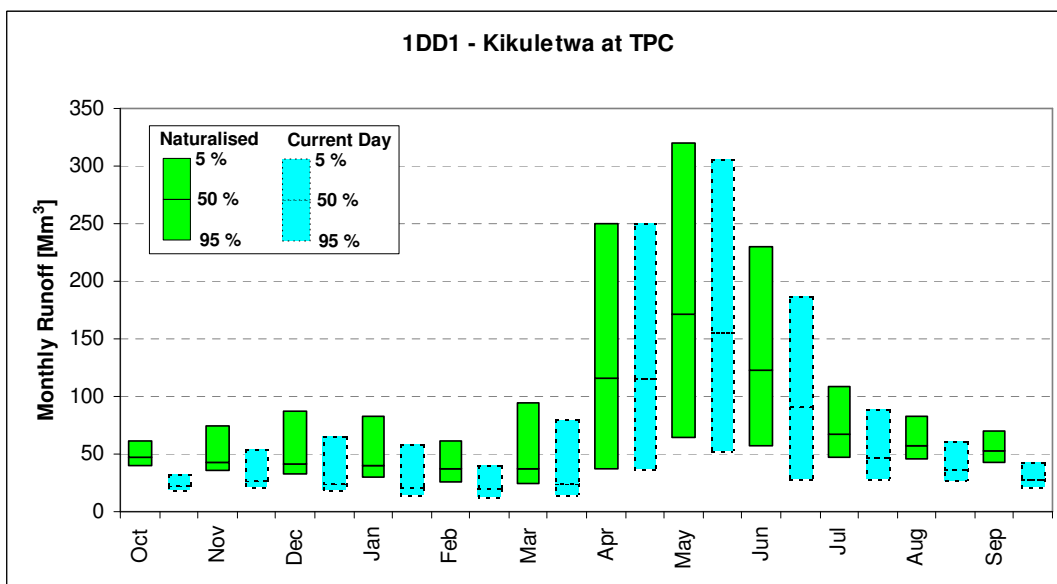


Figure 2.3 Comparison of Naturalised and Current Day Flows - Mkomazi

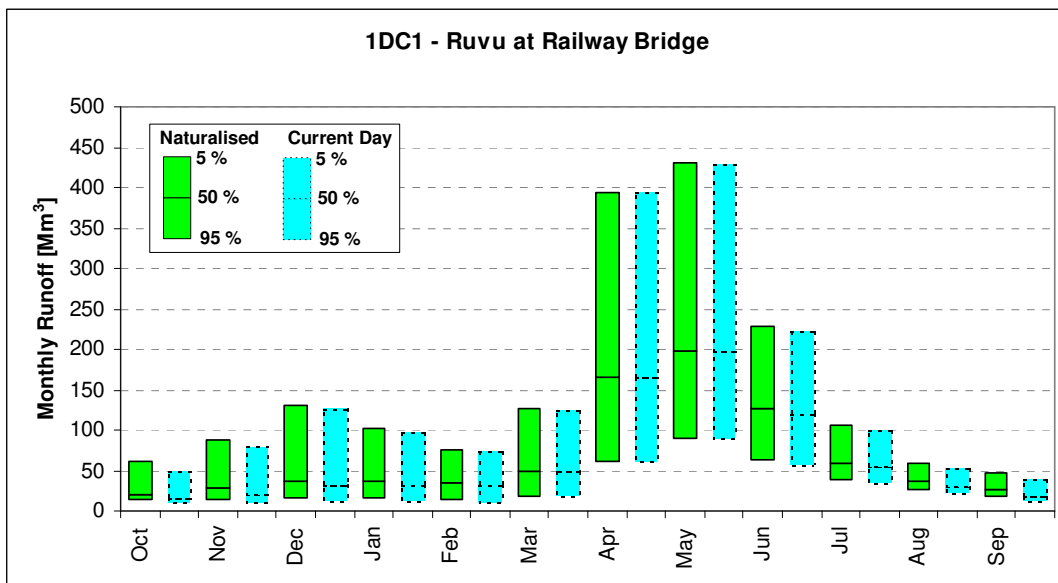


Figure 2.4 Comparison of Naturalised and Current Day Flows – Ruvu

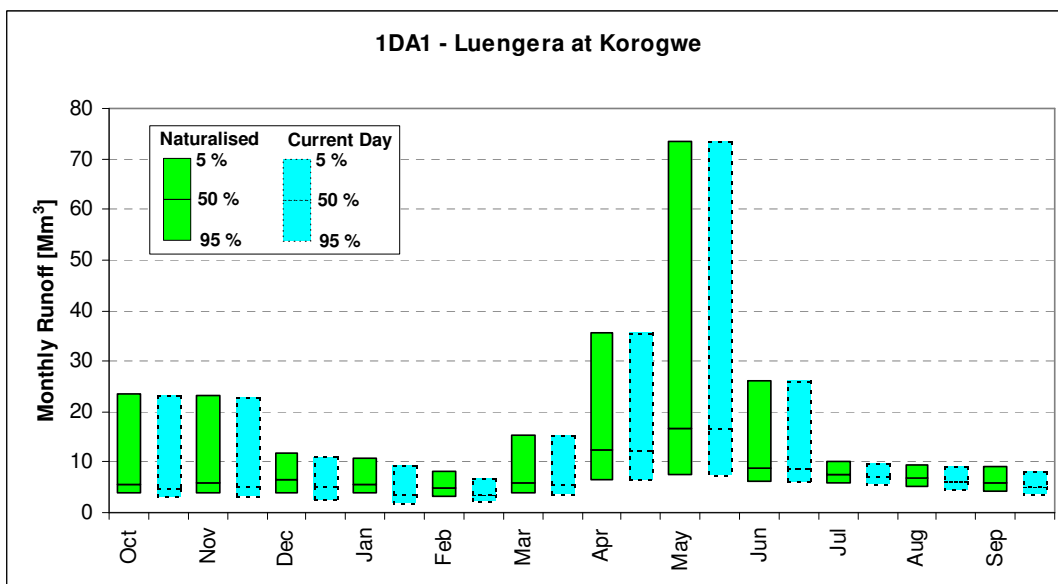


Figure 2.5 Comparison of Naturalised and Current Day Flows – Luengera

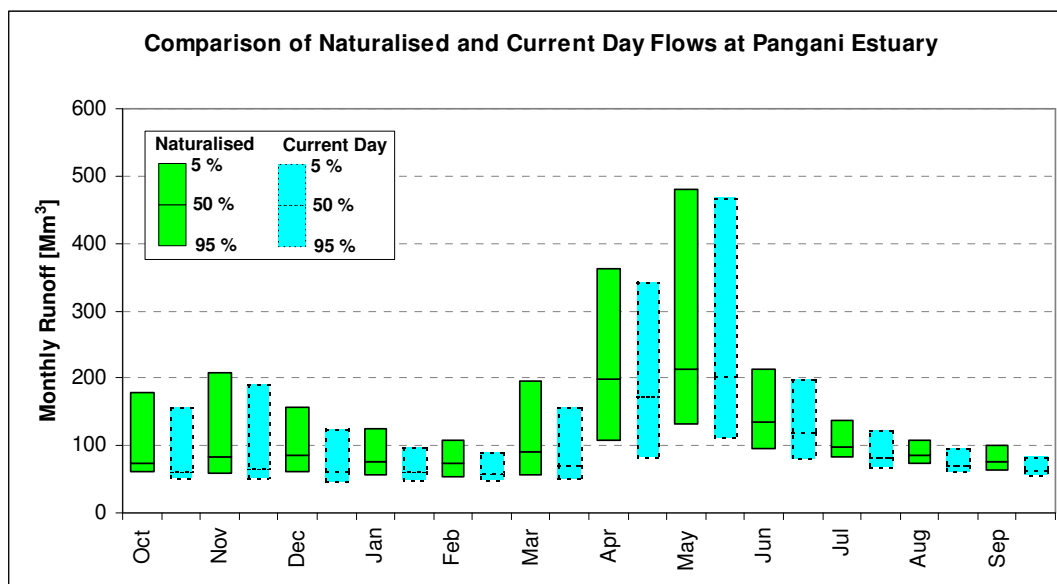


Figure 2.6 Comparison of Naturalised and Current Day Flows – Pangani Estuary

2.1.2 Hydrological Data Management

There is an extensive flow measurement network in the Pangani Basin. The management of data-collection activities and maintenance of the network infrastructure are, however, beset with difficulties that compromise the integrity of the data. These include the management and updating of rainfall and flow records in various copies of a HYDATA database, flow rating curves that do not adequately cover the range of flows that are seen at the measuring stations, infrequent updating of the rating curves, and equipment failures at the measuring stations. Previously, the Ministry was responsible for the collection and management of hydrological (river flow) data through the Regional Offices. This responsibility has now devolved to the Basin Water Office and is done through the Field Offices (formerly regional offices). Taking over the responsibility for data management in the Pangani Basin will probably be one of the more significant challenges that the PBWO will have to address. It will however provide an opportunity to put the necessary quality-assurance procedures in place, and to provide much needed training.

For the purposes of the FA Project, 14 key river-flow measurement stations were identified and the rating curves and data records for these stations were re-worked. The PBWO arranged for Ministry and Field Office officials to participate in the exercise so that data management skills, especially in the Field Offices could be strengthened. The following short-term interventions are recommended:

- At the time of writing this report, the three Regional Offices were maintaining separate copies of the database (in some instances more than one copy in the same office), while the MoW maintains a master copy. To

avoid unnecessary duplication of effort, and to improve overall data quality control, procedures for the synchronisation of the four HYDATA databases should be developed and formalised.

- Some of the data problems that are experienced are due to inadequate training in the use of HYDATA, especially with the management of flow rating curves. It is recommended that refresher training be arranged with the software developers. The HYDATA training should be backed up with general PC (MS Windows) literacy training.
- The HYDATA software has several shortcomings, most notably that the database is essentially a desktop (single user) system, and the inability of the software to allow for variable time-step data recording. It is recommended that multi-user alternatives be investigated. To promote data exchange and pooling of skills, developments in neighbouring countries and SADC should be taken into account.

2.1.3 *Use of the Hydrology in Support of Water Resources Management and Environmental Flow Assessments*

The confidence with which the hydrology report can be used to inform planning decisions is limited by a number of uncertainties, such as the reliability of flow measurement records, the actual extent of irrigated agriculture and volumes of water abstractions in the Basin, complex surface-groundwater interactions in the upper parts of the Basin, and the extent of endorheic runoff in the Mkomazi and Luengera catchments and the Pangani catchment downstream of Nyumba ya Mungu. In spite of these uncertainties, the hydrology provides a clear indication of the extent of water-resource development in the major sub-regions of the Basin and the impact that this has had on flow regimes in the Basin.

This hydrological assessment provided an adequate basis for undertaking the environmental flow assessments of the study, and also for supporting the water allocation process in the long term. The long-term monthly hydrological data were used for scenario planning to describe the effect that possible future demands may have on the water supply to the various water sectors and sub-regions. The systems modelling aspects of this work are discussed in Volume 2 of the Hydrology Report – *Development and Application of a Systems Model for the Pangani River Basin*, and in Section 2.2 of this report. The monthly sequences produced with the systems model do not provide sufficient information to assess impacts on the aquatic ecosystem that may stem from changes in the daily flow regimes. To address this gap in the information, a simple approach was followed to disaggregate the simulated monthly flow sequences into daily flow sequences with the aid of measured daily flow records.

2.2 Hydrology Report (Volume 2)

2.2.1 Purpose

The purpose of the System Analysis component of the Flow Assessment (FA) Initiative of the IUCN/PBWO was to simulate the flow sequences that would result from future development scenarios in order to provide the hydrological information required for assessing the ecological and socio-economic impacts of future development pathways. Current Day flow sequences and the current levels of water use in the Basin provide the Reference scenario against which development scenarios are compared to evaluate their effects on the river system.

2.2.2 Application of the Systems Model for the EF Assessments

To provide the hydrological information required for the EFA, a WEAP systems model was configured to provide current day (baseline) and scenario flow sequences at the EFA sites. WEAP outputs were processed to provide stream flow and inundation information for ecological health assessments at the river, swamp, lake and estuary sites. In addition, information on water supplies to the different water use sectors was provided for the socio and macro-economic assessments.

The modelling sequence and linkages between the processes are shown in Figure 2.7.

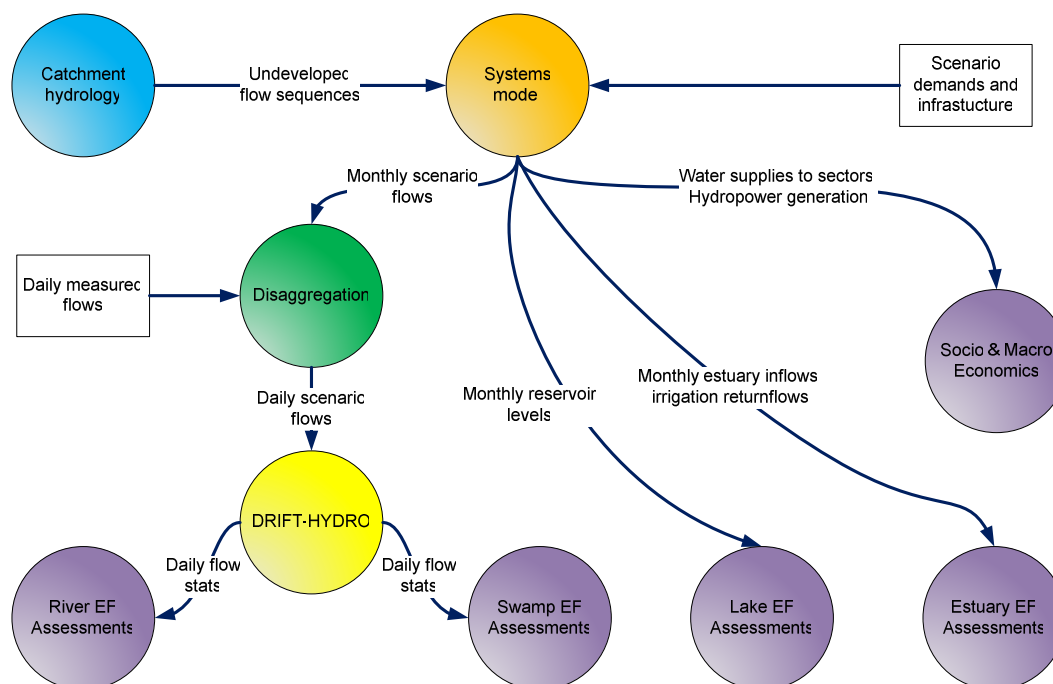


Figure 2.7 Modelling sequence and linkages between the processes

- **Catchment hydrology:** Estimates of naturalised (undeveloped) long-term runoff and present-day water use and infrastructure were obtained from the SHELL Pitman-based catchment model.
- **Systems Model:** The monthly time-step WEAP systems model was used to configure a reference (Present Day), and the future development scenarios. Inputs to the model include the undeveloped runoff sequences for the sub-catchments produced by the catchment model, irrigation scheme and urban abstractions, in-channel dams for irrigation water supply, and run-of-river and storage-based hydropower schemes.
- **Monthly reservoir levels:** Monthly reservoir levels for NyM were exported from WEAP and used in conjunction with the dam's water level – surface area relationship to provide input to the Lake EF assessment.
- **Monthly estuary inflows and irrigation return flows:** These were exported directly from WEAP, and used as input to the Estuary FA tool to assess impacts on the estuary.
- **Water supplies to sectors and hydropower generation:** These were exported directly from WEAP, and used as input to the Socio-Economic FA tool. Volumes of water supplied to irrigation were converted to equivalent areas of irrigation that could be supplied at 75% assurance.
- **Disaggregation:** A custom utility was developed to disaggregate the simulated monthly WEAP flow sequences to daily flow sequences. The use of the utility is described in the Pangani Flows Decision Support System - User Manual (PBWO/IUCN 2006).
- **DRIFT-HYDRO:** The hydrological manipulations required for determining the implications of a daily flow regime on the river ecosystem (represented by a series of river sites) are done using DRIFT-HYDRO. This is a stand-alone software package that forms part of the suite of programmes and databases making up DRIFT. Outputs are summary flow statistics for each site under each scenario that can be interpreted by river and social scientists. Details of the flow analyses are provided in the integrated Scenario Report: The analysis of water-allocation scenarios for the Pangani River Basin (PBWO/IUCN, 2009).

2.2.3 Scenario Identification

The identification and selection of scenarios are discussed in the Scenario Selection Report (PBWO/IUCN, 2006). A summary of the process is given in Section 2.4 of this report. The final list of scenarios are shown here, and repeated in Section 2.4 for ease of reference. Twelve scenarios were initially identified and it was agreed that these be carried forward for further consideration by the FA team. Later, after further consideration of the scenarios, it simulation work began on the six scenarios shown in Table 2.2.

Table 2.2 Initial Selection of Six Scenarios

Name	#	1 st priority	2 nd priority	3 rd priority	4 th priority	Residual	Purpose
Maximise Agriculture	1	Basic Human Needs	Domestic & Industrial	High Agric	Most Likely HEP	Environment	Demonstrates the impact on other sectors if Agriculture expands as much as possible
Maximise HEP	2	Basic Human Needs	Domestic & Industrial	High HEP	Most Likely Agriculture	Environment	Demonstrates the impact on other sectors if HEP production at maximum capacity is always prioritised
Status quo plus Climate Change	3	Basic Human Needs	Domestic & Industrial	Most Likely Agriculture	Most Likely HEP	Environment	Demonstrates the impact on the present situation of climate change
Maximise River Condition + Water Policy	4	Basic Human Needs	Best Possible Environment	Domestic & Industrial	Most Likely Agriculture	HEP	Demonstrates the impacts on other sectors of best possible ecosystem condition given the current infrastructure in the basin. Water Demand Management applied to Domestic and Industrial
Water Policy & Agriculture	5	Basic Human Needs	Moderate Environment	Domestic & Industrial	Most Likely Agriculture	HEP	Demonstrates the most likely projections of implementing NAWAPO and prioritising Agriculture. Water Demand Management applied to Domestic and Industrial
Water Policy & HEP	6	Basic Human Needs	Moderate Environment	Domestic & Industrial	Most Likely HEP	Agric	Demonstrates the most likely projections of implementing NAWAPO and prioritising HEP. Water Demand Management applied to Domestic and Industrial

In November 2008, it was agreed to analyse an additional four scenarios. These were done in May 2008 as part of a Core Team and PBWO training exercise. The additional scenarios were:

7. Maximise Agriculture, less 20% wet season rainfall (Max Agric, less 20%).
8. Maximise Agriculture, less 30% wet season rainfall (Max Agric, less 30%).
9. Maximise HEP, less 20% wet season rainfall (Max HEP, less 20%).
10. Maximise HEP, less 30% wet season rainfall (Max HEP, less 30%).

Subsequent to the May 2008 workshop, a final five scenarios were added to the list. The hydrological analyses for these scenarios were done in July and August 2009, and the biophysical and socio-economic assessments were done by the Core Team at a workshop in Stone Town, Zanzibar in August 2009. The final five scenarios were:

11. Storage upstream of NyM, with Maximise Agriculture.
12. Storage downstream of NyM (Luengera), to compensate HEP.
13. Combination of storage upstream of NyM, with Maximise Agriculture AND storage downstream of NyM (Luengera), to compensate HEP.
14. Mixed benefits, which includes storage upstream and downstream of NyM.
15. Storage upstream of NyM, with Optimised Present Day.

2.2.4 Scenario Results

If existing development trends in the Pangani River Basin prevail into the future, the High Agriculture scenario is the most likely (“Business as Usual”) future for the basin. The scenario was built on a number of assumptions, key of which are that the current crop mix will prevail in the future, the application of the 1975 to 2005 growth rates to project growth of irrigated areas, and that there will be an improvement in the irrigation efficiency (Water Demand Management (WDM) in irrigation). This study has assumed that through various means, the efficiency of water use will improve by 30% by 2025. The effects of this assumption were crucial to the results of the study, in that it allowed expansion in the area under irrigation while water supply to agriculture had to decrease as a result of the expected increase in urban demands. It is important to note that the expansion in agriculture was made possible almost entirely from this increase in efficiency. **This suggests that increasing water-use efficiency should be the top priority of water managers in the basin.** This can be brought about not only through the development of better irrigation infrastructure, but also through water demand management (through pricing and payment collection strategies). The assumptions used in this study did not take the potential impacts of water demand management on urban or rural demands into account. Given the scale of the anticipated growth in urban demand, the outcome of the alternative scenarios might have looked considerably better if greater efficiency in urban use through general demand management had also been assumed.

The foregoing indicates that regardless of the future assumption made, there is actually very little room for expansion of irrigated agriculture under present agricultural practices. The key to agricultural development in the basin lies in unlocking the amount of water tied to irrigation at present. The improvement in irrigation efficiency indicated that actual demand would be lower compared to present demand in some sub-catchments. It therefore means that a high improvement in water-use efficiency would free up a good amount of water for new agricultural expansions and/or other needs. It is therefore recommended that this is the recourse, which the PBWO should promote and work on in order to address shortage of water for irrigation in the Basin.

The hydrological consequences of each scenario were summarised in terms that could be used for social and ecological interpretation. These flow summaries were produced with DRIFT-HYDRO, and are provided in the integrated Scenario Report (PBWO/IUCN 2009). The changes in river flow are summarised in Section 2.9.

The water allocations for urban, industrial, domestic and agriculture, and expected HEP production are provided in Table 2.3.

Table 2.3 Sectoral water allocations

Scenario	Urban, industrial and domestic	Irrigation (@ 75% assurance)	HEP
	Mm ³ a ⁻¹	Mm ³ a ⁻¹	MWh
PRESENT DAY	31.1	1 042	602 647
MAXIMISE AGRICULTURE	54.7	1 032 ²	428 134
MAXIMISE HEP	54.7	634	782 601
OPT PRESENT DAY, AGRIC	53.6	520	612 474
OPT PRESENT DAY, HEP	53.6	435	784 235
HIGH ENVIRONMENT, AGRIC	50.9	497	601 411
MODELLED CLIMATE CHANGE	54.7	1 016 ³	472 371
MAXIMISE AGRICULTURE – LESS 20%	54.7	873	225 815
MAXIMISE AGRICULTURE – LESS 30%	54.7	807	141 347
MAXIMISE HEP – LESS 20%	54.7	286	755 227
MAXIMISE HEP – LESS 30%	54.7	203	614 810
STORAGE U/S NYM WITH MAXIMISE AGRICULTURE	54.7	1 031	420 688
STORAGE D/S NYM WITH MAXIMISE HEP	54.7	934	478 802
COMBINATION OF U/S STORAGE WITH MAXIMISE AGRICULTURE AND D/S STORAGE WITH MAXIMIZE HEP	54.7	950	472 745
MIXED BENEFITS	54.7	932	436 558
STORAGE U/S NYM WITH OPTIMISE PRESENT DAY	53.6	545	610 424

2.2.5 Training Requirements

The Pangani Basin Hydrologist was introduced to the use of the WEAP model and he improved his skills regarding the model during simulation of the suite of development scenarios. No additional specific training may therefore be necessary in respect of this model because it is simple and relatively easy to master. However, the Basin Hydrologist and Hydro-geologist need intensive training on the use of the Mike Basin model because of its complexity. The model will be used for routine operational decision support in the Basin, particularly in the water-allocation process. The base configuration of Mike Basin has been done by the Mentor Hydrologist as part of the FA Study. To fully utilize the Mike Basin operational capabilities, further refinement of the model will be necessary subsequent to this study. As part of the preparation for refining the base configuration, the Basin Hydrologist could apportion the catchment hydrology from sub-catchment to major stream level and the water demands from sub-catchment to water user's association level.

It is further recommended that quotations for a training course in Mike Basin be obtained from DHI of Denmark or RSA and arrangements be made for the Basin

² Note, even though the volume of water allocated to agriculture is less than present day, it is expected to be used to irrigate a greater area as a result of improvements in efficiency of use.

³ Note, even though the volume of water allocated to agriculture is less than Present Day, it is expected to be used to irrigate a greater area as a result of improvements in efficiency of use.

Hydrologist and Hydrogeologist to attend the course. More information about Mike Basin training can be obtained at www.dhigroup.com. It is also possible to invite the trainers to come and provide training in the Basin or any other convenient location in Tanzania. This approach would be particularly useful as more professionals from other Basins and the Ministry of Water and Irrigation could attend. It could also provide room for the course structure to be tailored to Pangani Basin related issues.

2.3 Basin Delineation Report

2.3.1 Introduction

Within a river basin, no study can address ever kilometre of river, or every person living within the area. Thus, it is usual practice to search for representative areas that can together represent the whole study area. These representative areas should be reasonably homogeneous in character, at least in terms of the studies that will be done. A delineation exercise for a river system would search for stretches of river that differ from each other but are internally similar, whilst a social delineation might search for areas that differ in livelihoods or wealth.

Once these homogeneous areas have been identified, one or more representative sites can be chosen in each. These will become the focus of data-collection activities, and the results from each will be extrapolated over the respective area.

For the Pangani, the basin was delineated by first separately delineating relatively homogeneous zones and sub-zones along the river and estuary, and for socio-economic activities in the basin. Thereafter, the resultant delineations were synchronised to produce a scheme for all project work. Within this scheme, representative sites were selected in the sub-zones deemed to be most relevant to the study.

2.3.2 Catchment location and characteristics

The Pangani River Basin is situated in the north-east of Tanzania and covers a total area of some 43 650 km², about 3 900 km² of which is in Kenya (Figure 2.8). Note: The area under the PBWO jurisdiction (referred to as the Pangani Basin) incorporates the Pangani River Basin, plus the Uмба, Zigi-Mkulumuzi Coastal and Msangazi river catchments.

The Pangani River Basin is bordered by Mt Kilimanjaro (5895 masl), Mt Meru (4565 masl) and the Pare and Usambara Mountains to the north and north-east, respectively, and encompasses the Simanjiro and Kitwei plains to the south-west. Lowlands (up to 900 masl) make up about 50% of the basin.

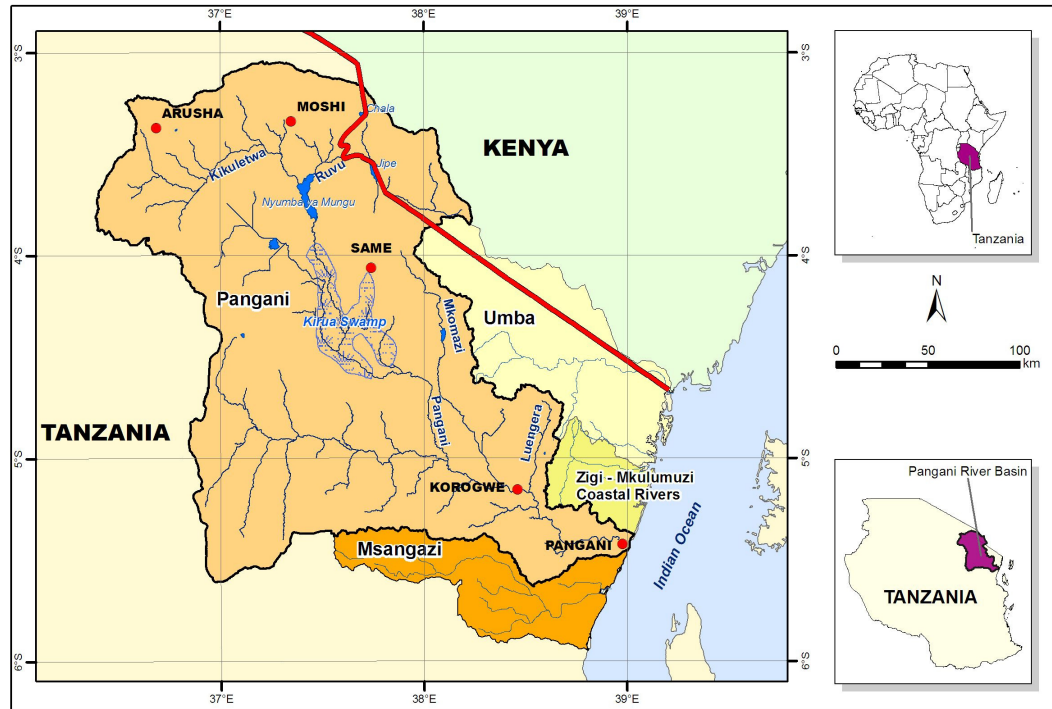


Figure 2.8 River basins administered by the PBWO, including the Pangani River Basin. Source: PBWO/IUCN.

Rainfall patterns are largely related to altitude, with the highlands receiving about 1000-2000 mm annually, and the lowlands receiving 500-600 mm. Rainfall is bimodal, occurring mainly in March-June, with short rains in November-December.

The Pangani River rises as a series of small streams on Mt Kilimanjaro and Mt Meru. The two major rivers created by these streams are the Kikuletwa and Ruvu Rivers, which converge at Nyumba ya Mungu Dam. The Pangani River drains Nyumba ya Mungu Dam and is fed by the Mkomazi and Luengera Rivers before it meets the Indian Ocean at the Pangani estuary, south of Tanga town.

2.3.3 River and estuary zonation

Ten river zones were identified for the study, each of which comprised one or more river reaches (Figure 2.9). The ten zones are Mountain Torrent (>1200 m); Mountain Stream (1000-1200 m); Upper Foothills; Rejuvenated Foothill, Swamps and Lakes; Floodplains (Kirua swamp); Lower Foothills; Rejuvenated Bedrock Cascade, Mature Lower River and Estuary. Within the zones are nested 31 river sub-zones and three estuary sub-zones (Table 2.4).

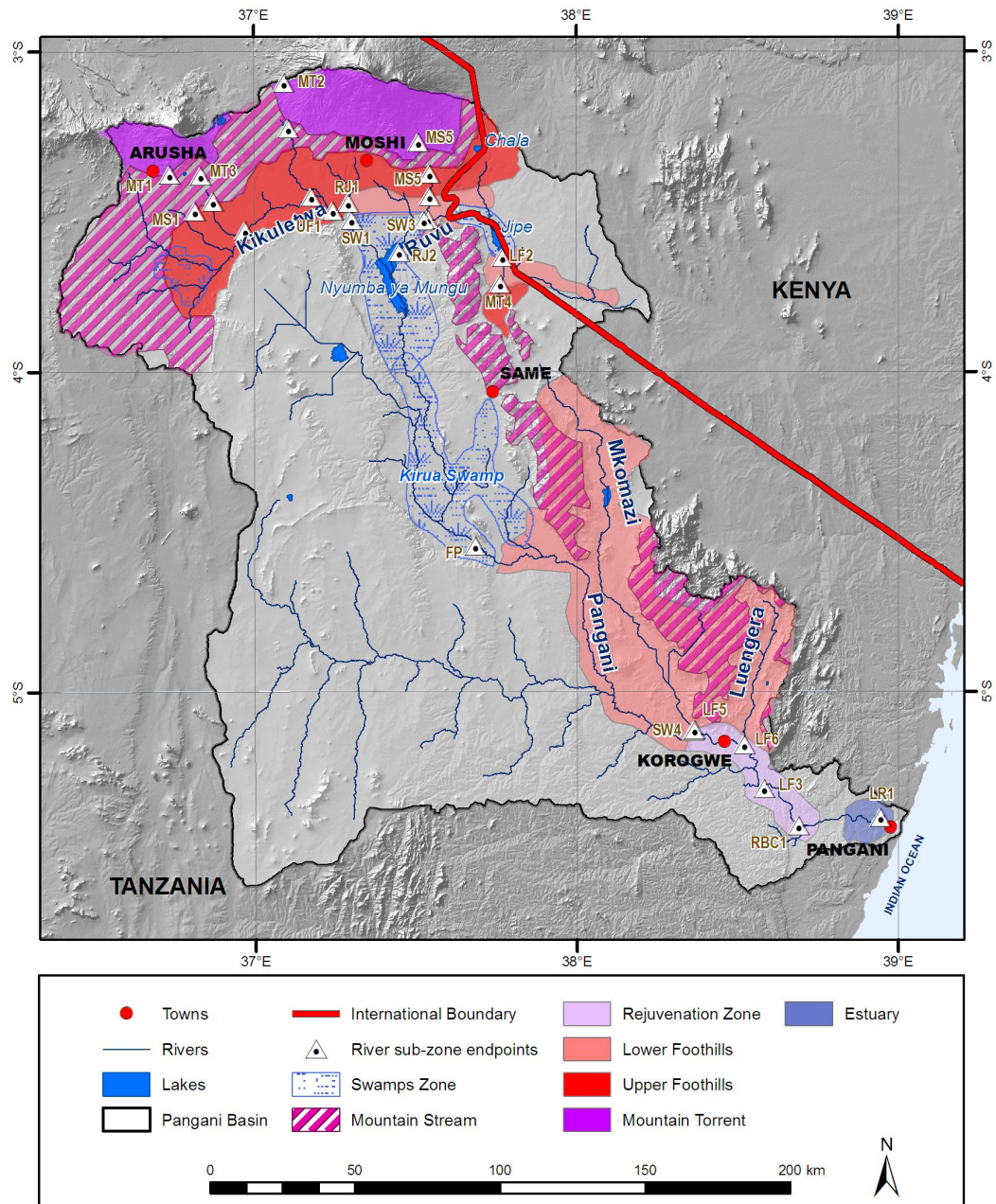


Figure 2.9 River zones. The Rejuvenated Foothill zone is too small to show but is situated in the vicinity of K3 to R7.

Table 2.4 Synchronised ecological and socio-economic zones.

Socio-economic Zone	Socio-economic Sub zone	Harmonized River Zone	River Sub Zones	River
Northern Highlands	Mountain	Mountain Torrent (>1200 m)	MT1	Nduruma River
		Mountain Torrent (>1200 m)	MT2	Sanya River
		Mountain Torrent (>1200 m)	MT3	Tengeru River
		Mountain Torrent (>1200 m)	MT4	Himo River
	Meru/ Kilimanjaro	Mountain Stream (1000-1200 m)	MS5	Himo River
		Mountain Stream (1000-1200 m)	MS1	Nduruma River
		Mountain Stream (1000-1200 m)	MS2	Sanya River
		Mountain Stream (1000-1200 m)	MS3	Tengeru River
		Upper foothills	UF1	Kikuletwa River
		Upper foothills	UF1	Sanya River
		Upper foothills	UF1	Tengeru River
		Rejuvenated foothill	RJ1	Kikuletwa River
		Rejuvenated foothill	RJ2	Ruvu River
		Lower foothills	LF1	Himo River
		Lower foothills	LF1a	Ruvu River
Eastern Highlands	Pare	Mountain Stream (1000-1200 m)	MS5	North and South Pare Mountains
		Upper foothills	UF1	Muraini River
		Lower foothills	LF2	Muraini River
		Lower foothills	LF5	Mkomazi River
	Usambara	Mountain Stream (1000-1200 m)	MS6	Usambara Mountains
Swamps and Lakes	Shambalai	Swamps and Lakes	SW5	Shambalai Swamp
	Lake Jipe	Swamps and Lakes	SW3	Ruvu River
		Swamps and Lakes	SW2	Lake Jipe
	Nyumba ya Mungu Dam	Swamps and Lakes	SW1	U/s of Nyumba ya Mungu Dam
		Swamps and Lakes	SW4	Nyumba ya Mungu Dam
Pangani/Kirua	Kirua Swamp	Floodplain	FP	Kirua Swamp
		Lower foothills	LF3	Downstream of swamp to Mswahe
Mesic Lowlands	Pangani	Lower foothills	LF4	Mswahe to downstream of Mkomazi Confluence
		Rejuvenated Bedrock Cascade	RBC1	From LF4 to d/s Pangani Falls
	Luengera	Lower foothills	LF6	Luengera River
Coastal	Coast	Mature lower river	LR1	Pangani Fall to estuary
	Estuary	Estuary	E1	Upper estuary
		Estuary	E2	Middle estuary
		Estuary	E3	Lower estuary

2.3.4 Socio-economic zonation

The basin was delineated into six relatively homogenous socio-economic zones on the basis of land use and relationships to aquatic ecosystems (Figure 2.10). The six zones are Northern Highlands, Eastern Highlands, Swamps and Lakes, Pangani-Kirua Swamp, Mesic Lowlands and Coast. Within the zones are nested 12 sub-

zones (Table 2.4). The arid western areas were not included because of relatively low population density and distance from the Pangani River and tributaries.

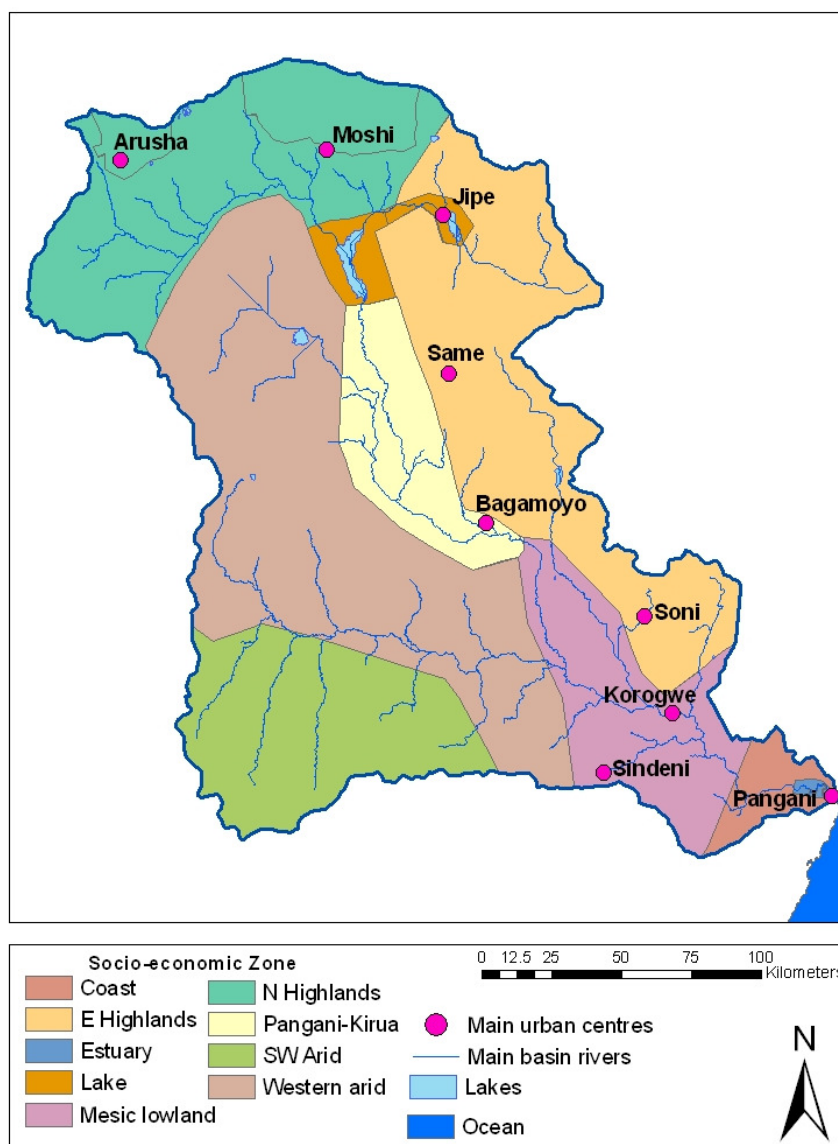


Figure 2.10 Socio-economic zones within the Pangani River Basin, in relation to rivers, major dams and lakes, and villages and towns.

2.3.5 *Synchronisation of the socio-economic and ecological zones*

The zones and sub-zones identified for the river/estuary and socio-economic activities correspond at the sub-zonal level (Table 2.4). They were the units at which representative study sites were chosen.

2.3.6 Study sites

Study sites for river and wetland health assessments were selected in 13 of the river sub-zones (Table 2.5). They were selected on the basis of representivity of a river zone and on accessibility of the sites.

Table 2.5 Study sites selected for the river health assessment.

Site No.	River system	River name at reach	Coordinates	Location Description	River Sub-zone
Riv 1 (MS1)	Kikuletwa R.	Nduruma R.	3°22'24.24"S 36°44'51.06"E	U/S of Nduruma chini	Mountain Stream
Riv 2 (UF1)		Kikuletwa R.	3°33'28.17"S 36°58'05.61"E	Wahoga chini (gauging station)	Upper Foothill
Riv 3 (SW1)		Kikuletwa R.	3°38'23.62"S 37°18'16.72"E	Upstream Nyumba ya Mungu - Along Kikuletwa R.	Swamp
Riv 4 (MS5)	Ruvu R.	Ona R.	3°18'36.51"S 37°30'04.37"E	Samangai - Kimatoloni bridge	Mountain Stream
Riv 5 (UF4)		Himo R.	3°23'29.55"S 37°30'14.94"E	At Himo town, upper bridge (gauging station)	Upper Foothill
Riv 6 (LF1)		Ruvu R.	3°31'08.98"S 37°34'03.63"E	Kifaru, upstream of the bridge	Lower Foothill
Riv 7 (LF2)	Muraini R.	Muraini R.	3°41'09.24"S 37°47'16.74"E	Upstream Jipe (At bridge)	Lower Foothill
Riv 8 (FP)	Pangani R.	Pangani R.	3°54'57.67"S 37°28'01.5"E	Kirua swamp	Swamp
Riv 9 (LF4)		Pangani R.	4°59'02.02"S 38°06'47.91"E	Mkalamo village (at the bridge)	Lower Foothill
Riv 10 (RBC)		Pangani R.	5°18'05.22"S 38°36'26.68"E	Mwakinyumbi (Hale town downstream)	Rejuvenation Zone
Riv 11 (MLR)		Pangani R.	5°21'53.31"S 38°39'57.74"E	Jambe village	Mature Lower River
Riv 12 (LF5)	Mkomazi R.	Mkomazi R.	4°30'07.83"S 38°04'53.31"E	Downstream Kalimawe dam (bridge after Mgandu school)	Lower Foothill
Riv 13 (LF6)	Luengera R.	Luengera R.	5°06'02.03"S 38°31'25.07"E	Kwamndolwa - near Kivira hill	Lower Foothill

In addition, for the estuarine health survey, 12 sites were distributed among three estuarine sub-zones (Figure 2.11). Sites were selected with the aim of obtaining representative coverage of the physico-chemical conditions and biota in the estuary, within the time available during the two estuary surveys. These sites were visited for data collection during the 2006 wet and dry seasons.

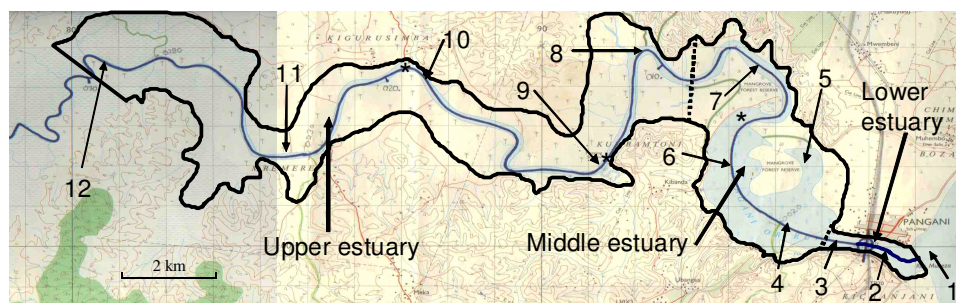


Figure 2.11 Map of the Pangani estuary showing the upper, lower and lateral boundaries (solid lines), division into Upper, Middle and Lower Zones (dotted lines)⁴ and the study sites.

2.4 Scenario Selection Report

2.4.1 Introduction

Within the Pangani River Basin, trade-offs between benefits provided by the aquatic ecosystems and the benefits provided through off-stream water use such as irrigation and hydropower will need to be decided by the stakeholders. The trade-offs may be analysed by examining the potential consequences of a range of scenarios that describe different development pathways into the future. Government and other stakeholders can assess these, leading to identification of a preferred pathway and a strategy to achieve it.

Task 2.1 of the Pangani River Basin Flow Assessment considered the main issues and trends in the basin in order to develop a feasible set of scenarios for analysis. The task began with a Stakeholder Workshop on 6 March 2006 to discuss the main water-related issues and trends in the basin. The outputs of the workshop are outlined below, followed by the preliminary set of scenarios chosen for analysis.

2.4.2 Water-related issues in Pangani River Basin

The Pangani River Basin is a water-stressed basin. Water supply is being reduced by catchment degradation and possibly by climate change, while demand is increasing due to population and economic growth, including land-use change. Water quality is also being affected by effluent and solid-waste pollution. Partly due to lack of information on the availability and use of water in the basin, water is over-allocated, creating conflict among water users. Water shortages are felt in all the economic sectors. This results in a depressed economic output during droughts. Over-allocation of water has led to the drying up of perennial rivers and wetlands, and intrusion of salt water into the estuary. The above problems are exacerbated by

⁴ The solid blue line marks the centre of the estuary. Proposed sampling sites for physico-chemical parameters, phytoplankton, invertebrates and fish are numbered from 1-12. Historic water quality sampling sites are marked with asterisks.

uncoordinated development planning that does not take water requirements into account, as well as by poverty, which constrains people from investing in more efficient technologies. In addition, there is a general lack of awareness about catchment and water conservation issues among basin inhabitants, and a lack of enforcement of legislation pertaining to water use and wastewater treatment.

2.4.3 *Expected trends for different sectors in the Pangani River Basin*

Stakeholders identified trends for different sectors in the different socioeconomic zones of the Pangani River Basin (Figure 2.10). In the hydropower sector, there is a general shortage of water for power production in the basin. Nevertheless, there is a focus on increasing the capacity and generation in the basin, with planned HEP developments in the Northern and Eastern Highlands as well as on the lower Pangani River. There is a general trend of loss of agricultural production or limits to its increase due to water shortages throughout the basin, with the affected crops differing from area to area. An increasing population is putting pressure on domestic water supplies, with shortages expected throughout the basin. It is expected that people will start to rely more on groundwater and the domestic use of rainwater tanks. Loss of biodiversity due to loss of aquatic ecosystem health is occurring throughout the basin.

2.4.4 *Development of scenarios for consideration in the Flow Assessment*

Several relevant factors were identified that could vary in different ways in the future:

Supply variables:

- climate change;
- catchment management actions that affect quantity and quality of water:
 - deforestation vs. afforestation,
 - pollution-control measures,
 - erosion-control measures;

Demand variables:

- water allocation to each sector:
 - hydropower,
 - agriculture,
 - domestic and industry,
 - mining,
 - aquatic ecosystems;
- water-resource development:
 - groundwater use,
 - storage options;
- efficiency of use
 - improved efficiency due to water-demand management (e.g. higher water prices),

- improved efficiency due to investment in better irrigation systems or crop varieties;
- population growth.

2.4.5 Selection and range of variables

It was necessary to limit this list in order to be able to generate a manageable number of scenarios. The factors to be varied in the scenario analysis were selected based on anticipated modelling capacity and available information (Table 2.6). Preliminary estimates were then made of the upper boundary, lower boundary, and most likely values of each of the selected parameters in the year 2025 in order to ascertain the range of conditions that the scenarios should cover.

Table 2.6 System variables and the possible envelope of their characteristics in 2025, including a 'most likely' description

System variable	Low extreme	Most likely 2025	High extreme
Climate change	Zero change (1 scenario)	Best estimate of change (all scenarios but one)	-
Domestic	-	Based on best estimate of population growth	-
Industry	-	Linked to Tanzanian economic growth	-
Afforestation/deforestation	10% reforestation – outcome of payment for ecological services	Status quo – forest lost to charcoal, but new forests being planted	Deforestation follows present trend but may fall off due to government protection, to not >10% additional loss of original forest area
Irrigation	10% reduction in water demand due to increasing efficiency of use, followed by a period of constant demand	Growth at lower than 1995-2005 rate, using groundwater	Small and large storage dams plus groundwater leads to growth at present rate but capped by water availability
Hydropower	Up to 25% reduction in water supply at NyM, Hale and Pangani Falls	Restoring supplies to existing stations including canalising Pangani through Kirua swamps and construction of Mandera HEP station	Restoring supply to existing stations; refurbish Kikuletwa; construct Mandera and mini-hydro stations
Environment	Two condition levels to be determined		

2.4.6 Spatial and temporal resolution

The spatial resolution of the scenario modelling was on the basis of the WEAP hydrological model outputs generated for 16 points in the catchment. The scenarios were considered on a 20-year time horizon to 2025, the base year being 2005.

2.4.7 Scenarios identified

A preliminary list of 12 scenarios was identified for further discussion.

Table 2.7 The 12 scenarios identified for further discussion

Scenario	Supply variables		Demand variables				
	Climate change	Afforest/De-forestation	Basic Human Needs	Domestic Industrial	Irrigation	Hydro-power	Aquatic eco-systems
1a. High agriculture, high HEP	Best estimate	Best estimate	1 st	2 nd (most likely)	3 rd (High extreme)	4 th (High extreme)	Residual
1b. As for 1a but aquatic ecosystems 2 nd priority	Best estimate	Best estimate	1 st	3 rd (most likely)	4 th (High extreme)	Residual	2 nd (Level 1)
2. High agriculture, HEP @ most likely	Best estimate	Best estimate	1 st	2 nd (most likely)	3 rd (High extreme)	4 th (Most likely)	Residual
3a. High HEP, agriculture as close to HE as possible	Best estimate	Best estimate	1 st	2 nd (most likely)	4 (High extreme)	3 rd (High extreme)	Residual
3b. As for 3a but aquatic ecosystem 2 nd priority	Best estimate	Best estimate	1 st	3 rd (most likely)	Residual	4 th (High extreme)	2 nd (Level 1)
4. High HEP + low agric	Best estimate	Best estimate	1 st	2 nd (most likely)	4 th (Low extreme)	3 rd (High extreme)	Residual
5a. Status quo (best estimate for all)	Best estimate	Best estimate	1 st	2 nd (most likely)	Most likely	Most likely	Residual
5b. Ditto with ecosystem 2 nd priority (health at Level 1)	Best estimate	Best estimate	1 st	3 rd (most likely)	4 th (shared residual)	4 th (shared residual)	2 nd (Level 1)
5c. As for 5a but with ecosystem 2 nd priority (health Level 2)	Best estimate	Best estimate	1 st	3 rd (most likely)	4 th (shared residual)	4 th (shared residual)	2 nd (Level 2)
6. Status quo without climate change	None	Best estimate	1 st	2 nd (most likely)	Most likely	Most likely	Residual
7. Low extreme for all	Best estimate	Maximum afforestation	1 st	2 nd (most likely)	Low extreme	Low extreme	Residual
8. As for 1 but afforestation @ maximum	Best estimate	Maximum afforestation	1 st	2 nd (most likely)	3 rd (High extreme)	4 th (High extreme)	Residual

The numbers in the 'demand variables' columns indicate the priority of water allocation. The descriptions in brackets refer to the previous table, indicating which level of water demand would be included in the scenario modelling exercise.

This list was revisited through the course of the project and nine scenarios were eventually chosen for assessment within Tasks 7 and 8.

2.5 River Health Assessment Report

2.5.1 Introduction

The health assessment of the river was based on site visits (with some data collection) during the wet and dry seasons (2006), together with existing PBWO water-quality data collected at key points along the river. Thirteen study sites (Figure 2.12) were selected to represent a range of zones (Mountain Stream; Upper Foothill; Lower Foothill; Mature Lower River and Rejuvenated Bedrock Cascade).

The methods used for the assessment were based on those developed in the River Health Programme of the National Aquatic Ecosystem Health Biomonitoring Programme of South Africa. The method involved the collection of information necessary to characterise a site, to provide an indication of catchment condition and land-use, together with relevant abiotic (water quantity and quality) and biotic (invertebrates, fish, riparian vegetation) information. Each of these biotic components provided information of the health of the instream or riparian zone of the river. A field manual and associated datasheets were compiled for use in the IUCN-Pangani Basin River Health assessment.

The report section provides a description of the characteristics of each site, including a description of channel classification and stream dimensions, and a photographic record for each site during the wet and dry seasons.

2.5.2 Overview of results

In terms of water quantity, discharges were generally higher at sites in the wet season compared to the dry season, with the exception of two lower foothill sites (R8 and R9), both below NYM dam. Sites R2, on the Kikuletwa River, and R7, on the Muraini River, dried up during the dry season; the latter due to the seasonal nature of the river. The site on the mature Lower River (R11) had highly variable flow within a 24-hour period in the dry season due to storage and releases from the Pangani Falls Hydropower station.

Water quality varied from site to site - in response to both position in the catchment, i.e. upper versus lower reaches, and to changing water quality due to anthropogenic activities. Turbidity was higher than expected in the Upper Foothill Zone of the Kikuletwa River (R2), and PBWO monitoring data indicated that levels were also high in the Themí and Kware Rivers. The pH values showed no or very slight variation

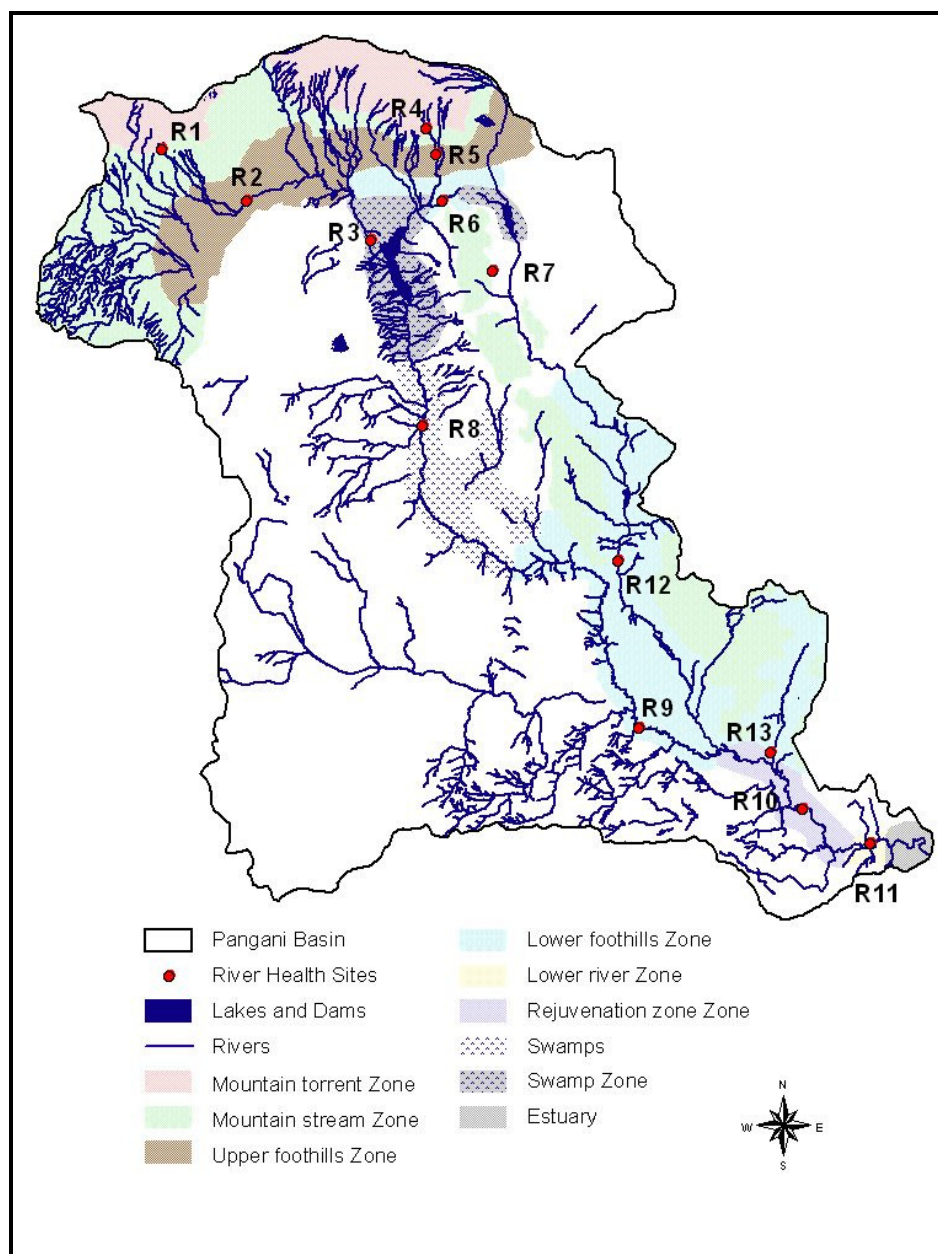


Figure 2.12 Sites within the Pangani River Basin assessed for river health. Zones are indicated.

among the sites and were mostly close to neutral. They were within the range of 6.61 to 8.42 in the wet season and generally increased slightly to a range of 7.14 to 8.93 in the dry season. Conductivity was lowest in the Mountain Stream and Upper Foothill zones (6.7 to 14.0 mSm^{-1}), except for R2 in the wet season, where it was higher than expected (23.9 mSm^{-1}). Conductivity increased markedly at two sites (R3 - Kikuletwa River and R12 - Mkomazi River) from wet to dry seasons. PBWO monitoring data also indicate that high conductivity was measured on the Kware and Kikuletwa Rivers, as well as the Thembi and Maji ya Chai Rivers downstream of the

Arusha-Moshi road. Dissolved oxygen (DO) concentrations ranged from 5.5 - 8.9 mg l⁻¹ in the wet season and were generally lower in the dry season (5.0 - 7.8 mg l⁻¹). One site, R6, had extremely low levels of dissolved oxygen (< 0.6 mg l⁻¹). In terms of nutrients, the concentration of total nitrogen (TN) was elevated at a two sites in the wet season, while total phosphorous (TP) was low at most sites.

This changed in the dry season with TP increasing at most sites resulting in a shift in trophic status from the wet to dry seasons. Algae were present at more sites in the dry season. The concentration of bicarbonates increased below NYM (R8) and from wet to dry season at R3 - Kikuletwa River. Organic enrichment (Biological Oxygen Demand and faecal coliforms), as determined from the PBWO water quality monitoring data, was elevated at sites near Arusha and Moshi. High BOD values were recorded on the Themí River downstream of Arusha and high faecal coliform counts were observed on the Kikuletwa, Themí, Tenguru, Ngarenaro and Njoro Rivers and Lake Jipe at Makuyuni.

A total of 54 aquatic invertebrate taxa (mostly family-level), 23 fish species and 233 plant species were recorded during the surveys. The status of the following abiotic and biotic components – water quality; Index of habitat integrity (instream and riparian); invertebrates, fish and riparian vegetation - was ascertained from the data using common categories to indicate the level of modification from an expected natural or baseline condition (A - Natural, unmodified system; B - Largely natural, slightly modified system; C - Moderately modified system; D - Largely modified system; E* - Only for IHI - Seriously modified system; and F* - Only for IHI - Critically modified system).

In summary, river health varied from site to site, in response to both natural changes within the catchment and anthropogenic impacts that had modified the water quantity and/or quality of the river system.

2.5.3 R1 - Nduruma River (Zone: Mountain Stream)

Discharge	Water Quality	IHI Instream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
C	B	B	F	B	B	C

- **Discharge:** <40% of water was abstracted in the wet season and >80% in the dry season. The dry season flows were reduced and the duration of these dry season flows was extended, with less water in the river generally.
- **Water quality:** DO concentrations decreased and TP increased in the dry season. Trophic status shifted from mesotrophic to eutrophic in the dry season.
- **IHI Instream:** Moderately modified because of water abstraction and flow modification.

- **IHI Riparian:** Critically modified because of the decrease of indigenous vegetation from the riparian zone, exotic vegetation encroachment and bank erosion.
- **Invertebrates:** There was a reasonable diversity of invertebrates in both the wet and dry seasons, with all three biotopes present. A total of 23 taxa was recorded, including four families of mayflies, as well as dragonflies, caddisflies, beetles and flies.
- **Fish:** Habitat was limited to fast flowing, shallow areas and deeper runs. One fish species was caught, *Garra dembeensis*, which is adapted to living in fast flowing streams.
- **Riparian Vegetation:** The riparian width was 30 m on the right hand bank and 5 m on the left hand bank. Trees, shrubs, sedges and grasses were represented. Encroachment by exotic vegetation was widespread and smaller areas were invaded by terrestrial plants.

2.5.4 R2 - Kikuletwa River (Zone: Upper Foothill)

Discharge	Water Quality	IHI Instream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
D	D	D	F	D	D	D

- **Discharge:** The river at this site was no longer perennial and in the dry season it dries up. Floods were smaller but the number of floods has remained the same when compared to historical events.
- **Water quality:** High turbidity value for an Upper Foothill site - most likely due to removal of riparian vegetation and extensive livestock farming.
- **IHI Instream:** Largely modified because of water abstraction and flow modification.
- **IHI Riparian:** Critically modified because of the decrease of indigenous vegetation from the riparian zone, exotic vegetation encroachment and bank erosion.
- **Invertebrates:** This site showed indications of a loss of invertebrates, with lower SASS5 Scores in comparison to the other Upper Foothill sites. A total of 15 taxa was recorded in the wet season - the site was dry during the dry season.
- **Fish:** In the wet season, habitat was limited to fast deep areas, with some overhanging vegetation, undercut banks, gravel substrate and water column. One species was recorded, *Clarius gariepinus*, although fisherman indicated that two additional species of *Tilapia* also occur.
- **Riparian Vegetation:** The riparian zone at the sampling point was almost bare due to removal of riparian vegetation and livestock watering. Downstream of the site, the riparian width was 40 m on the right hand bank and 30 m on the left hand bank. Trees, shrubs, sedges and grasses were represented. Encroachment by exotic vegetation and terrestrial plants was limited.

2.5.5 R3 - Kikuletwa River (Zone: Lower Foothill)

Discharge	Water Quality	IHI Instream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
C/D	B/C	D	E	B	C	C

- **Discharge:** The river at this site had substantially less water during the dry season compared to the wet season. The floods have not changed significantly in terms of size or frequency. Dry-season flows were extended beyond the expected dry season and the river was perennial because it is sustained by the Chemka Springs upstream.
- **Water quality:** Conductivity, carbonates/bicarbonates, magnesium and TP increased in the dry season.
- **IHI Instream:** Largely modified because of water abstraction, flow modification and water quality.
- **IHI Riparian:** Seriously modified because of the decrease of indigenous vegetation from the riparian zone and bank erosion.
- **Invertebrates:** The number of taxa and SASS Scores decreased from the wet to the dry season. A total of 25 taxa was recorded. The fauna included worms, crabs, water-mites, mayflies, dragon- and damselflies, bugs, caddisflies, beetles and flies. Of note was the only record of the caddisfly family, Ecnomidae, in the wet-season survey. Lack of vegetation in the dry season resulted in fewer taxa being recorded.
- **Fish:** In the wet season, habitat was limited to fast, deep areas and in the dry season to fast and slow, shallow areas. There was overhanging vegetation, undercut banks, gravel and rocky substratum and water column. Five species were recorded, although fisherman indicated that two additional species were present.
- **Riparian Vegetation:** The riparian zone was divided into riparian and floodplain, with widths 50 m, 50 m on the right hand bank and 40 m, 90 m on the left hand bank for riparian and floodplain respectively. Trees, shrubs, reeds, sedges and grasses were represented. There was no encroachment by exotic vegetation, reeds or terrestrial plants.

2.5.6 R4 - Ona River (Zone: Mountain Stream)

Discharge	Water Quality	IHI Instream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
B/C	A/B	B	C	A	A/B	B

- **Discharge:** The river at this site was perennial, although flows were lower in the dry season compared to the wet season. There was abstraction for local farming.
- **Water quality:** There were no apparent changes from wet to dry season.

- **IHI Instream:** Largely natural with few modifications - water abstraction.
- **IHI Riparian:** Moderately modified because of exotic vegetation encroachment.
- **Invertebrates:** This site only had stones biotope for sampling - nonetheless, it had the highest SASS5 Score for this biotope (in both seasons) compared to all other sites assessed. Flatworms, crabs and water-mites, four families of mayflies, as well as dragonflies, bugs, caddisflies, beetles (including Elmidae and Psephenidae) and flies. A total of 16 taxa was recorded.
- **Fish:** Habitat was largely limited to fast, deep and fast, shallow areas. There were large amounts of overhanging vegetation (trees), few undercut banks, rocky substrate and water column. Two species were recorded, although fisherman indicated that an additional species was present.
- **Riparian Vegetation:** The riparian width was 70 m on the right hand bank and 80 m on the left hand bank. Trees, shrubs and grasses were represented. There was no encroachment by exotic vegetation.

R5 - Himo River (Zone: Upper Foothill)

Discharge	Water Quality	IHI Instream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
C	C	D	C	C	C	C

- **Discharge:** The river at this site was perennial, although flows were substantially lower in the dry season compared to the wet season and the dry period was extended beyond the expected dry season. There was water abstraction (Himo town nearby).
- **Water quality:** Temperature increased with lower flows and silt was deposited on stones. Sources of water quality impairment result from localized use of the river by people from the town of Himo, e.g. washing cars, clothes, bathing. Bacterial contamination (faecal coliforms) was likely to be a problem - this may impact upon human health.
- **IHI Instream:** Moderately modified because of water abstraction, flow modifications and water quality. Gravel, cobble and sand were extracted upstream.
- **IHI Riparian:** Moderately modified because of exotic vegetation encroachment and bank erosion.
- **Invertebrates:** There was a drop in the number of taxa and scores from wet to dry season. Stones were covered in silt in the dry season and the quality of the stones and vegetation biotope was decreased. The total number of taxa recorded was 23. The limpet, Ancyliidae, was only recorded at this site (dry season).
- **Fish:** Habitat was largely limited to fast, deep in the wet season, and slow, deep and slow, shallow in the dry season. There was overhanging vegetation, undercut banks, rocky and sandy substrate and water column. Three species of fish were recorded.

- **Riparian Vegetation:** The impact on the riparian vegetation was localized. Downstream of the site the riparian width was 10 m on the right hand bank and 10 m on the left hand bank. Trees and shrubs dominated with a few sedges and grasses present. There was very limited encroachment by exotic vegetation.

2.5.7 R6 - Ruvu River (Zone: Lower Foothill)

Discharge	Water Quality	IHI Instream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
B/C	D	D	D	D	D	C

- **Discharge:** The river at this site was perennial, although flows were lower in the dry season compared to the wet season, and the dry period was extended beyond the expected dry season. Annual flooding occurs and the low flows were sustained by outflow from Lake Jipe. There was a wetland upstream of the site although information on this was limited. Lake Jipe has experienced a decline in water levels over the last decade.
- **Water quality:** Critically low dissolved oxygen levels during the wet and dry seasons - extensive decaying material, low-gradient river downstream of Lake Jipe. TP increased during the dry season. Aquatic macrophytes were recorded in the dry season, indicating that TN was limited (*Azolla pinnata* has nitrogen fixing bacteria associated with it).
- **IHI Instream:** Largely modified because of water quality impairment (DO) and exotic macrophytes).
- **IHI Riparian:** Largely modified because of a decrease in indigenous vegetation and bank erosion.
- **Invertebrates:** Biotopes were limited to vegetation and mud in the wet season with gravel/cobble also available in the dry season. The scores dropped from wet to dry season, although two more taxa were recorded in the dry season. Total number of taxa was 16. Dominant invertebrates were air breathers (e.g. several bug taxa) and those adapted to living in waters with low dissolved oxygen e.g. *Chironomus* spp. and oligochaetes.
- **Fish:** Habitat was largely limited to fast, deep in the wet season, and slow, deep in the dry season. There was overhanging vegetation (sedges and trees), few undercut banks, macrophytes; rock, gravel and sand substratum and water column. Five species were recorded in the wet season - possibly migrating upstream to the swamp area for spawning. Two additional species were recorded in the dry season. Fish were observed gulping for air, indicating stress resulting from low DO concentrations.
- **Riparian Vegetation:** The riparian width was 10 m on the right hand bank and 18 m on the left hand bank. Trees, shrubs, reeds, sedges and grasses were represented. There was very limited encroachment by exotic vegetation.

2.5.8 R7 - Muraini (Mvuleni) River (Zone: Upper Foothill)

Discharge	Water Quality	IHI Instream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
D	B/C	C	C	B/C	-	A

- **Discharge:** The river at this site was seasonal and it naturally ceases to flow in the dry season. Water abstraction in the wet season was estimated at >60%. It was likely that the dry season was extended beyond the expected dry season because of the abstraction during the wet season. No information was available on floods.
- **Water quality:** Turbidity and TSS were higher than expected for an Upper Foothill site - this may be a consequence of the rain that preceded the assessment.
- **IHI Instream:** Moderately modified because of water abstraction, flow modifications and water quality.
- **IHI Riparian:** Moderately modified because of bank erosion.
- **Invertebrates:** The stones biotope was limited to a small, shallow, cobble riffle. No marginal vegetation was available for sampling. A total of 13 taxa was recorded. It was one of two sites in the survey where butterfly larvae, Crambiidae, were recorded.
- **Fish:** Habitat was limited to slow, shallow pool areas. There was overhanging vegetation, undercut banks in the pool area and gravel substratum. The water column provided little cover. No fish were caught, although they were known to occur downstream in the rainy season.
- **Riparian Vegetation:** The riparian width was 150 m on the right hand bank and 200 m on the left hand bank. Trees, shrubs and grasses were represented. There was very limited encroachment by exotic vegetation. The riparian vegetation has a closed canopy with minimal undergrowth herbaceous plants. The dominant plants were the fig trees (*Ficus* spp.), which are adapted to surviving in dry areas due to their ability to reserve/store water.

2.5.9 R8 - Pangani River (Zone: Lower Foothill)

Discharge	Water Quality	IHI Instream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
D	C	C	C	C	A/B	B

- **Discharge:** Flow was highly regulated by NYM dam and there was no significant inflow between the dam and the site. Floods were held back at the dam, high flows were irregular and flows were constant. Dry-season base flows were higher than wet-season base flows. Flooding of Kirua swamps no longer occurs.

Depth of the river at this site has increased, perhaps due to trapping of sediment by the dam.

- **Water quality:** TP increased in the dry season - causing a shift in trophic status from mesotrophic to eutrophic. The NYM dam upstream is located on calcareous soils - very high levels of carbonates and bicarbonates were released from the dam. The elevated levels continue into the Mature Lower River.
- **IHI Instream:** Moderately modified because of water abstraction, flow modifications and water quality.
- **IHI Riparian:** Moderately modified because of a decrease in indigenous vegetation, and bank erosion.
- **Invertebrates:** Only marginal vegetation was available for sampling. Fifteen taxa were recorded, including mayflies, damselflies, bugs, caddisflies, beetles and flies.
- **Fish:** Habitat was limited to fast, deep areas. There was overhanging vegetation, emergent macrophytes, gravel/sand/mud substratum and water column. Ten species of fish were recorded. Migratory fish species were recorded, but the fishing weir upstream may affect their availability and distribution.
- **Riparian Vegetation:** The riparian width was 10 m on the right hand bank and 15 m on the left hand bank. Trees, shrubs, reeds, sedges and grasses were all well represented. There was no encroachment by exotic vegetation.

2.5.10 R9 - Pangani River (Zone: Lower Foothill)

Discharge	Water Quality	IHI Instream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
D	C	C	D	B	B	B

- **Discharge:** NyM Dam regulates the flow and there was no significant inflow between the dam and the site. Floods were held back at the dam, high flows were irregular and flows were constant. Dry-season base flows were higher than wet-season base flows.
- **Water quality:** Higher nitrogen concentrations and chlorophyll *a* levels in the wet season indicated that the system was modified in terms of water quality. TP increased in the dry season causing a shift in trophic status from mesotrophic to eutrophic. Upstream of the site there were extensive sisal plantations, cattle ranches and localized agriculture in the riparian zone.
- **IHI Instream:** Moderately modified because of water abstraction, flow modifications and water quality.
- **IHI Riparian:** Largely modified because of a decrease in indigenous vegetation.
- **Invertebrates:** There was a decrease in the number of taxa and SASS5 Score from wet to dry season. This may have been a reflection of the difficulty in sampling the biotopes under the higher dry-season flows. The total number of taxa recorded was 17. The fauna included crabs, water-mites, mayflies, butterfly larvae, dragon- and damselflies, bugs, caddisflies, beetles, flies and snails. Of

note were the five different types of cased-caddisfly in the family Leptoceridae in the wet season.

- **Fish:** Habitat included fast, deep and fast, shallow (bedrock rapids) areas. There was overhanging vegetation, rocky and sandy substrata and water column. Four species of fish were recorded. There was a fishing weir across the river and discussions with local fishermen indicated that seven species have been caught at this site.
- **Riparian Vegetation:** The riparian width was 10 m on the right hand bank and 5 m on the left hand bank. Trees, shrubs, reeds, sedges and grasses were all represented. There was no encroachment by exotic vegetation.

2.5.11 *R10 - Pangani River (Zone: Rejuvenated Bedrock Cascade)*

Discharge	Water Quality	IHI Instream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
D	D	D	E	D	C/D	D

- **Discharge:** Flow was regulated by NYM dam and there was an additional pool (head pond) for storing water before entering the Hale Hydropower station. There were several rivers joining the Pangani River upstream of this site, which contributed to inflows. Floods seem to have the normal pattern. In the dry seasons, the river below the HEP sometimes dries out due to the entire river water being abstracted to generate HEP.
- **Water quality:** Conductivity, nitrites and TP increased in the dry season. The system shifted from mesotrophic to hypertrophic. DO decreased especially in the slower flowing areas of the river. Bacterial contamination (faecal coliforms) may potentially be impacting human health at this site. Rubbish dumping occurred within the riparian zone.
- **IHI Instream:** Largely modified because of water abstraction, flow modifications, water quality, bank modifications and presence of solid wastes.
- **IHI Riparian:** Seriously modified because of decrease of indigenous vegetation, exotic vegetation encroachment and bank erosion.
- **Invertebrates:** More taxa were recorded in the dry season (19 taxa) compared to the wet season (13 taxa), although most of them were ones that were able to tolerate reduced water quality (e.g. the worms Oligochaeta and water bugs Corixidae and Notonectidae). Three taxa were recorded on the stones in the wet season, including leeches (Hirudinea), while 12 taxa were recorded on stones in the dry season (greater accessibility due to the lower water levels). The total number of taxa recorded was 22.
- **Fish:** Habitat included fast, deep and fast, shallow (bedrock rapids) areas in the wet season, but changed to slow, shallow areas in the dry season. There were sparse undercut banks, rocky substrata and water column (decrease from wet to dry season). Ten species of fish were recorded in the wet season, but no fish were recorded in the dry season. This may be a reflection of the reduction in

water quality and quantity (backwater habitat not available in the dry season), although problems with the electroshocker may also have contributed to this.

- **Riparian Vegetation:** The riparian width was 5 m on the right hand bank and 5 m on the left hand bank. Trees, shrubs, sedges and grasses were represented. There was limited encroachment by exotic vegetation. The riparian vegetation was severely exploited and the impact from rural development was high.

2.5.12 R11 - Pangani River (Zone: Mature Lowland River)

Discharge	Water Quality	IHI Instream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
D	C	D	E	C	C	B

- **Discharge:** Flow was regulated by NYM dam and there were two additional pools (head ponds) for storing water before entering the Pangani Falls Hydropower station. Several rivers join the Pangani River upstream of this site, which contribute to inflows. Flows below the intake depend on releases from the HEP dam and were intermittent in the dry season. The river below dries up for approximately 8 hours in every 24 hours.
- **Water quality:** Turbidity was elevated downstream of the HEP station due to releases from the station. Nitrite increased in the dry season. The sub-site R11A, which was on the natural river above the confluence with the outflow, had higher TP in the dry season, which caused a shift in trophic status from mesotrophic to hypertrophic.
- **IHI Instream:** Largely modified because of water abstraction, flow modifications and water quality.
- **IHI Riparian:** Seriously modified because of decrease of indigenous vegetation and exotic vegetation encroachment.
- **Invertebrates:** Three taxa were recorded in the wet season, including the shrimp (Atyidae). A total of seven taxa was recorded. More taxa (6) were recorded in the dry season, although these included highly tolerant worms, Oligochaeta, air-breathing Corixidae, Notonectidae and Dytiscidae (beetles). Prawns were recorded at R11A, on the natural river upstream of the confluence with the outflow.
- **Fish:** Habitat included fast, deep areas in the wet season. In the dry season, habitat was severely compromised through the drying up of the river. There was overhanging vegetation (trees), macrophytes, gravel substrata and water column in the wet season. Seven species of fish were recorded in the wet season, but no fish were recorded in the dry season. Some of these were estuarine species. Site R11A also had bedrock and overhanging vegetation was shrubs. Three species of fish were caught at R11A in the dry season, including an eel, which is a migratory species that matures in the river and then migrates to the ocean to spawn.

- **Riparian Vegetation:** The riparian width was 70 m on the right bank and 5 m on the left bank. Trees, shrubs, sedges and grasses were represented. There was limited encroachment by exotic vegetation.

2.5.13 R12 - Mkomazi River (Zone: Lower Foothill)

Discharge	Water Quality	IHI Instream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
D	C/D	D	F	C/D	C/D	D

- **Discharge:** Dry-season flows were extended beyond the expected dry season and the river may dry up at the end of the dry season. Floods occur but the size has been reduced due to the presence of the Kalimawe Dam upstream. The floodplain was not inundated to the extent that it used to be.
- **Water quality:** Conductivity and sulphate concentration were high in the wet and dry season. Conductivity, sulphate and TP increased in the dry season and trophic status changed from mesotrophic to eutrophic. DO decreased in the dry season. There was extensive agriculture upstream of the site including sisal production and maize and the entire floodplain was cultivated.
- **IHI Instream:** Largely modified because of water abstraction, flow modifications and water quality.
- **IHI Riparian:** Critically modified because of the decrease of indigenous vegetation. Cultivation of crops occurs within the floodplain.
- **Invertebrates:** Vegetation and mud were available for sampling. A total of 17 taxa were recorded: nine in the wet season and 14 in the dry season, although most of them were relatively tolerant ones. Taxa including worms, mayflies, damsel- and dragonflies, caddisflies, beetles, flies and snails.
- **Fish:** Habitat was largely slow, shallow areas. There was overhanging vegetation (reeds, shrubs), gravel and sand substrata and water column was limited. Overhanging vegetation provides important habitat at this site. Seven species of fish were recorded: six in the wet and one in the dry season. *Clarius gariepinus* (air-breathers) were present - they were tolerant of harsh conditions such as extremely low flows (and drying up).
- **Riparian Vegetation:** The riparian width was 45 m on the right hand bank and 105 m on the left hand bank. Reeds and sedges dominated. There was extensive encroachment by exotic vegetation, in addition to some terrestrial plants.

2.5.14 R13 - Luengera River (Zone: Lower Foothill)

Discharge	Water Quality	IHI In stream	IHI Riparian	Invertebrates	Fish	Riparian vegetation
C	C	C	C	C/D	C	B

- **Discharge:** Dry season flows were extended beyond the expected dry season (due to water abstraction for agriculture) and the river dried up in 2004. Floods occur but the size has been reduced in the past 15 years. There was an extensive floodplain area that still appears to flood annually - wetlands were filled with water in the adjacent floodplain.
- **Water quality:** TN was high in the wet season, possibly as a result of agriculture (sisal, maize, rice) in the surrounding area. TP increased in the dry season and trophic status changed from mesotrophic to eutrophic.
- **IHI Instream:** Moderately modified because of water abstraction, flow modifications and water quality.
- **IHI Riparian:** Moderately modified because of decrease of indigenous vegetation.
- **Invertebrates:** This site had a relatively high SASS5 Score and ASPT in the wet season compared to other Lower Foothill sites that only had vegetation and mud for sampling. A total of 18 taxa was recorded: 13 in the wet season, including crabs, mayflies, damsel- and dragonflies, bugs, caddisflies, beetles and snails. Fewer taxa were recorded in the dry season and scores were lower. Leeches were recorded in the dry season.
- **Fish:** Habitat was largely slow, shallow areas. There was overhanging vegetation (reeds and trees), mud substratum and water column. Five species of fish were recorded. Local fishermen indicated that an additional three species were recorded in this site.
- **Riparian Vegetation:** The riparian zone was divided into riparian and floodplain, with widths 2 m, 120 m on the right hand bank and 5 m, 100 m on the left hand bank for riparian and floodplain respectively. Trees, shrubs, reeds, sedges and grasses were represented. There was no encroachment by exotic vegetation, reeds or terrestrial plants.

2.6 Estuarine Health Assessment Report

2.6.1 Introduction

The Pangani estuary located at 05°26'S; 38°59'E is a moderately large estuary on the East African coastline, with a total length of approximately 22 km. The health assessment of the estuary was based on two physico-chemical, fauna and floral surveys conducted during the high (May 2006) and low (September 2006) flow seasons, and provided a preliminary assessment of the health of the estuary. Information from this component of the study was used as the basis for predicting potential changes in the health of the Pangani estuary under various flow regimes.

2.6.2 Survey results

2.6.2.1 Site selection

Ten primary sampling stations were identified along the length of the estuary at which all the physico-chemical and biotic parameters were surveyed. These stations were more or less evenly spaced along the estuary at a distance of 2-3 km apart, spanning a total distance of 22.4 km. Certain parameters were also sampled at up to ten intermediate stations along the estuary.

2.6.2.2 Geomorphology

A number of historic aerial photographs of the estuary was acquired and examined for changes in channel morphology and mouth state. Photographs covered the years 1977, 1982 and 1988, and indicated no obvious changes had taken place in channel morphology or mouth state during the intervening ten-year period.

2.6.2.3 Temperature, salinity, oxygen

A range of water quality parameters (temperature, salinity, oxygen, pH, and turbidity) were measured over spring high and spring low tides at the surface and at 1 m depth intervals to the bottom at 20 stations up the length of the Pangani estuary during the high and low flow seasons. Data on these parameters indicated that water exchange between the estuary and the sea over a spring high-low tide cycle is enormous owing to the large riverine input and the huge tidal range at the mouth (>3 m). Virtually the entire volume of the estuary is exchanged on each tidal cycle. The estuary is very well mixed as a result of this, and oscillates between a river-dominated system at spring low tide and a marine dominated system at high tide. At spring low tide under high flow conditions, the estuary was highly compressed with strong outflow of river water ensuring that the salinity averaged through the water column did not exceed 28 PSU, even at the mouth, from where it declined rapidly to 1.2 PSU at a position 7 km upstream from the mouth. At spring high tide under high flow conditions, the sea water pushed somewhat further up the estuary with salinities of up to 30 PSU recorded as far as 9 km upstream, but declined rapidly to less than 2 PSU beyond this point. At spring low tide under low flow conditions, salinities started off relatively high at the mouth (34 PSU) but declined linearly from this point to a position 14 km upstream where the water was almost completely fresh (2.4 PSU). At spring high tide under low flow conditions the estuary was almost completely filled with seawater with salinities remaining above 30 PSU for the first 14 km upstream of the mouth, from where it declined rapidly to 4 PSU at the head (top) of the estuary (22 km upstream). Little or no vertical stratification was evident in the water column during either of the two sampling excursions. Oxygen concentrations in the estuary were particularly low during the high flow season – mostly <3 mg l⁻¹ (40% saturation), dropping to <2.5 mg l⁻¹ at the head of the estuary - but were somewhat higher in the high flow season – 3.5-5.0 mg.l⁻¹ (45-65% saturation). Temperatures were similar between the high and low flow seasons and varied over a very narrow range

between spring high and spring low tide on each occasion (high flow: 27.1-28.1 °C, low flow: 27.1-27.5 °C). Turbidity was generally very high in the system, especially during the high flow season, a function of high suspended silt loads and high phytoplankton production.

Low oxygen levels in the estuary are cause for concern and are probably a function of high organic loading of the influent river water that is derived from land drainage and possibly industrial and domestic effluent discharged to the system. Organic material tends to settle out within the estuary for various reasons (mainly reduction in flow rate and an increase in salinity) where it decomposes, using up available oxygen. Low oxygen levels are likely to severely limit abundance, and affect the composition of, fish and invertebrates within the system.

2.6.2.4 Nutrients

Historically, estuaries were mostly oligotrophic (nutrient poor) systems, with nitrogen (N) and phosphorus (P) being the primary limiting nutrients that controlled primary production in these systems. Mobilisation of N and P through land clearing, application of fertilizer, discharge of human wastes, animal production, and combustion of fossil fuels has fundamentally changed this situation, with the result that eutrophication is now a worldwide problem affecting estuaries. The Pangani estuary is certainly no exception; with nutrient data collected during the high and low flow surveys indicating that the system is highly eutrophic (particularly problematic during the high flow season). Nitrate concentration (NO_3^-) averaged across the whole estuary ranged between 2652 $\mu\text{g l}^{-1}$ (low flow season) and 4 041.3 $\mu\text{g l}^{-1}$ (high flow season), phosphate (PO_4^-) between 283 $\mu\text{g l}^{-1}$ (high flow season) and 355 $\mu\text{g l}^{-1}$ (low flow season), while ammonia averaged 2 650 $\mu\text{g l}^{-1}$ in the low flow season (not measured in the high flow season). These values are well above the generally accepted levels at which these nutrients cease to become limiting (28 $\mu\text{g l}^{-1}$ for nitrogen and 0.5 $\mu\text{g l}^{-1}$ for phosphorus). These values are also high compared with nutrient concentrations in a range of other tropical and subtropical estuaries around the world, and are mostly in the range of those that are considered to be severely polluted.

2.6.2.5 Sediments

Coastal erosion is reported as being a significant problem in the area to the north of the Pangani river mouth, as well as in the estuary mouth itself. Various reports suggest that the shoreline has been retreating at a rate of up to 7.5-20 m per annum since the 1960s. The mouth of the estuary is also reported to have deepened substantially. This has been attributed to the impact of the various dams on the estuary, particularly Nyumba ya Mungu, which is reported to trap up to 50% of the sediments eroded from the catchment upstream of this point. While little hard evidence was collected to support or reject these ideas during the field surveys, extensive bank erosion evident in the middle and upper reaches of the estuary where

the river banks are undercut in many areas to the extent that trees are falling into the river at numerous sites, does lend some support to these ideas. The banks of the estuary from the mouth right up to the head of the estuary are also very steep and inter-tidal areas very limited (possibly having been eroded away). If reports on the deepening of the estuary mouth and widening of the channel are indeed true (which seems likely), such a change in depth and sediment input must have had a profound influence on the dynamics of the estuary. Water exchange between the estuary and the sea would have increased considerably, for example, as would the tidal range within the estuary and the upstream penetration of seawater.

Of contrasting concern are reports on the increase in amount of fine silt and mud flowing down the rivers in the Tanga district, arising from soil erosion on agricultural lands. The water flowing into the Pangani estuary during the high and low flow surveys was noted to be highly turbid (Secchi depth = 19-24 cm) which supports these observations. The high levels of organic matter in the sediments of the estuary (8.2% in the intertidal and 5.2% in the sub-tidal sediments) also lend support to these observations.

2.6.2.6 Chlorophyll a

Chlorophyll a concentrations in the Pangani estuary were measured by taking water samples from the surface and bottom at ten stations along the estuary, filtering these to extract the chlorophyll, which was then measured spectrophotometrically in the laboratory. Chlorophyll a concentrations were mostly very high – the average for the entire estuary in the high-flow season was $23.4 \mu\text{g l}^{-1}$ (peak $69.3 \mu\text{g l}^{-1}$) and $4.3 \mu\text{g l}^{-1}$ (peak at $13.3 \mu\text{g l}^{-1}$) in the low flow season. Comparing chlorophyll a concentrations in the Pangani estuary with other tropical and sub-tropical systems from around the world indicates that those in the Pangani estuary, particularly in the high flow season, are anomalously high, exceeded by only one highly polluted estuary in South Africa. These high phytoplankton concentrations are most likely linked with high nutrient concentrations in the system, and confirm that the Pangani estuary is severely eutrophic.

2.6.2.7 Vegetation

A survey of the vegetation of the Pangani estuary conducted in the dry season indicated that vegetation changes dramatically along the estuary, these changes being linked with changes in the salt concentration of the water. The lower reaches of the estuary are dominated by mangroves of various species, but have largely been replaced with coconut palms in the middle reaches of the estuary. Above the original upper extent of the mangroves (approximately 14 km upstream from the mouth), the plant communities on the banks of the estuary change abruptly to ones dominated by reeds, grasses, and various shrubs and trees. Few of the hardwood trees that would originally have dominated in the upper reaches of the estuary are still in evidence.

2.6.2.8 *Zooplankton*

Zooplankton communities in the Pangani estuary were surveyed at ten sites over spring high tide at night using a 300 μm plankton net. The net sampled between 6 and 14 m^3 of water at each site. Zooplankton collected in these samples were identified to the level of major taxon only (e.g. Isopoda, Amphipoda, Brachyura). Average zooplankton density across all sites was much higher in the low flow season (average density: 1,571.6 ind. m^{-3}) than in the high flow season (336.6 ind. m^{-3}). Zooplankton communities were overwhelmingly dominated by Copepoda in the high flow season, but this switched to a community dominated by Brachyura (crabs) in the low flow season. Factors considered important in controlling composition and abundance of zooplankton in the Pangani estuary include oxygen, salinity, turbidity, rate of water exchange with the sea, and food supply (phytoplankton abundance). Abundance of zooplankton in the Pangani estuary falls within the range reported for other tropical and subtropical estuaries around the world, albeit on the upper end of this range.

2.6.2.9 *Benthic invertebrates*

Intertidal invertebrate communities were sampled at ten stations up the length of the Pangani estuary using a benthic corer (179 mm diameter, 400 mm in length). The same instrument was used to collect benthic sub-tidal samples in the high flow season (operated by a diver) while a small Van Veen grab was used for collection of these samples in the low-flow season, owing to the presence of crocodiles in the estuary during the latter survey. Three replicate samples were taken from the intertidal and sub-tidal regions at each site. These were sieved through 1 mm mesh bags, the infauna extracted and identified to the level of major taxon only (e.g. Isopoda, Amphipoda, Polychaeta). Abundance of intertidal invertebrates was low during both the high (average: 126 individuals. m^{-2}) and low flow sampling excursions (205 individuals. m^{-2}). Abundance of sub-tidal invertebrates was similarly low, averaging 208 and 156 ind. m^{-2} in the high and low flow field excursions respectively. Community composition for these two groups varied up the length of the estuary, with polychaete worms, amphipods and brachyura (crabs) being the most abundant groups in both habitats. The abundance of both intertidal and sub-tidal benthic invertebrates in the Pangani estuary falls within the range reported for tropical estuaries generally, but in both cases lies at the lower end of the range of values reported. This is probably a function of the limited amount of intertidal area available, the high proportion of very fine silt and mud in the Pangani estuary that does not allow for a great diversity of fauna to colonise the sediments, and the large tidal prism, which ensures that sediments in the estuary are highly mobile.

2.6.2.10 *Fish*

Beach-seine and gill-net fishing methods were used to sample the Pangani estuarine fish community at ten sites distributed along the 23 km length of the estuary. A total of 3,572 fish (20.19 kg) representing 26 families and 53 species was captured in the

39 beach seine hauls and 20 gill net sets that were conducted during the high (May 2006) and low (September 2006) flow seasons. Fish abundance was considerably higher during the high-flow season (total catch 2,578 individuals) compared with the low-flow survey (881 individuals) despite the total area sampled being smaller during the former survey (3,120 versus 4 700 m²). Overall, species from the families Leiognathidae, Clupeidae, Engraulidae, Ambassidae Gerreidae, and Mugilidae dominated the fish community, contributing 93% numerically and 76% by mass to the total catch. Although less numerous, four larger species, *Caranx sexfasciatus*, *Lutjanus argentimaculatus* and *Epinephelus suillus* contributed significantly (12%) to the total mass caught. Community composition was similar in the high and low flow seasons in spite of the huge change in abundance and biomass, with only slightly fewer species recorded in the low flow survey (36 versus 32). All fish caught were small, ranging between 3-35 cm TL, comprising either species that do not attain large sizes or juveniles of marine species.

The fish species richness and biomass within the Pangani was found in these preliminary surveys to be low compared with other tropical or temperate estuaries. The 53 species recorded during this study is considerably less than that reported for many similar sized, tropical and subtropical estuaries around the world. The species count for the Pangani estuary is similar to the range reported for the suite of mostly subtropical estuaries from South Africa (20-55) rather than the other tropical estuaries in Africa (73-153) or elsewhere in the world (59-195). The average biomass of fish within the Pangani estuary is also low relative to values reported for other large tropical estuaries around the world, except for some of the smaller systems that are reported as being moderately or highly polluted. Given that the Indo-Pacific region is widely accepted to have the most diverse fish fauna globally, the Pangani estuary, based on this preliminary survey, appears to have relatively low species richness, abundance and biomass. This is most likely a function of the relatively poor state of health in which the system currently resides.

2.6.2.11 Birds

Bird counts were undertaken opportunistically during the two field surveys, in amongst the other surveys work. A total of only 13 species of birds was observed during two partial and one full count of the Pangani estuary in the high-flow season and a much increased total of 29 species in four partial and two full counts of the estuary in the low-flow season. Actual numbers of birds counted were also low with a maximum count of 113 individuals in the high-flow season and 288 in the low-flow season. Avifauna on the estuary appears to be dominated by piscivorous species (90% of the number of species recorded in the high-flow season, and 67% in the low-flow season). One species of migratory wader was observed in the high-flow season, and only eight observed in the low-flow season. This is very depauperate in comparison with other subtropical and tropical estuaries where the number of bird species recorded is mostly in the range of 40-70 (rising to over 100 in some large systems) and the numbers of individuals present typically number in their thousands.

The range of trophic groups present on the Pangani estuary can also be considered very low. The depauperate nature of the avifauna of the Pangani estuary is most likely a function of limited habitat diversity (e.g. limited intertidal and shallow water habitat, and a lack of submerged or emergent vegetation in the estuary), although other factors may also play a role.

2.6.3 *Estuarine Health Assessment*

The health of the Pangani estuary was assessed following the methods of the Department of Water Affairs and Forestry (DWAF) (2004). This entailed assigning a score to each of a selection of habitat and biotic parameters associated with the estuary based on their perceived change from the natural or reference condition – i.e. percentage of natural characteristics retained - and secondly combining these scores into a **Habitat Health Score** and a **Biotic Health Score**, and finally into an overall **Estuarine Health Score**. Habitat parameters included hydrology, hydrodynamics and mouth condition, water quality and physical habitat alteration, while biotic parameters included micro-algae, macrophytes, invertebrates, fish and birds. Each of the individual habitat and biotic parameters was weighted equally within the two assessment categories (habitat and biota) that in turn were weighed equally to derive an overall estuarine health score. Scores derived for each of the parameters and component, together with the overall health score for the Pangani estuary, are presented in Table 2.8.

Table 2.8 Estuarine Health Score results for the Present State of the Pangani Estuary

Variable	Score	Weight	Weighted Score
Hydrology	86	25	22
Hydrodynamics and mouth condition	40	25	10
Water quality	53	25	13
Physical habitat alteration	72	25	18
Habitat Health Score	63	50	21
Microalgae	40	20	8
Macrophytes	65	20	13
Invertebrates	60	20	12
Fish	50	20	10
Birds	40	20	8
Biotic Health Score	51	50	26
Estuarine Health Score			57

The overall all health score assigned to the Pangani estuary was 57, which places it into the category of “largely modified” as per DWAF (2004). As far as the habitat health scores were concerned, those parameters that were identified as being most severely modified included hydrodynamics and mouth condition (mostly due to the state of the mouth which is considered to be highly modified) and water quality (due to the high nutrient loading and extremely low oxygen levels). Most of the

parameters relating to biotic health were moderately to severely affected by anthropogenic activities, particularly the micro-algal (owing to very high phytoplankton biomass in the system), avifaunal (extremely low diversity and abundance), fish (low diversity and abundance) and invertebrate (low abundance) components. Key abiotic and biotic changes in the present day condition of the estuary from the reference (natural) condition are depicted in Figure 2.13.

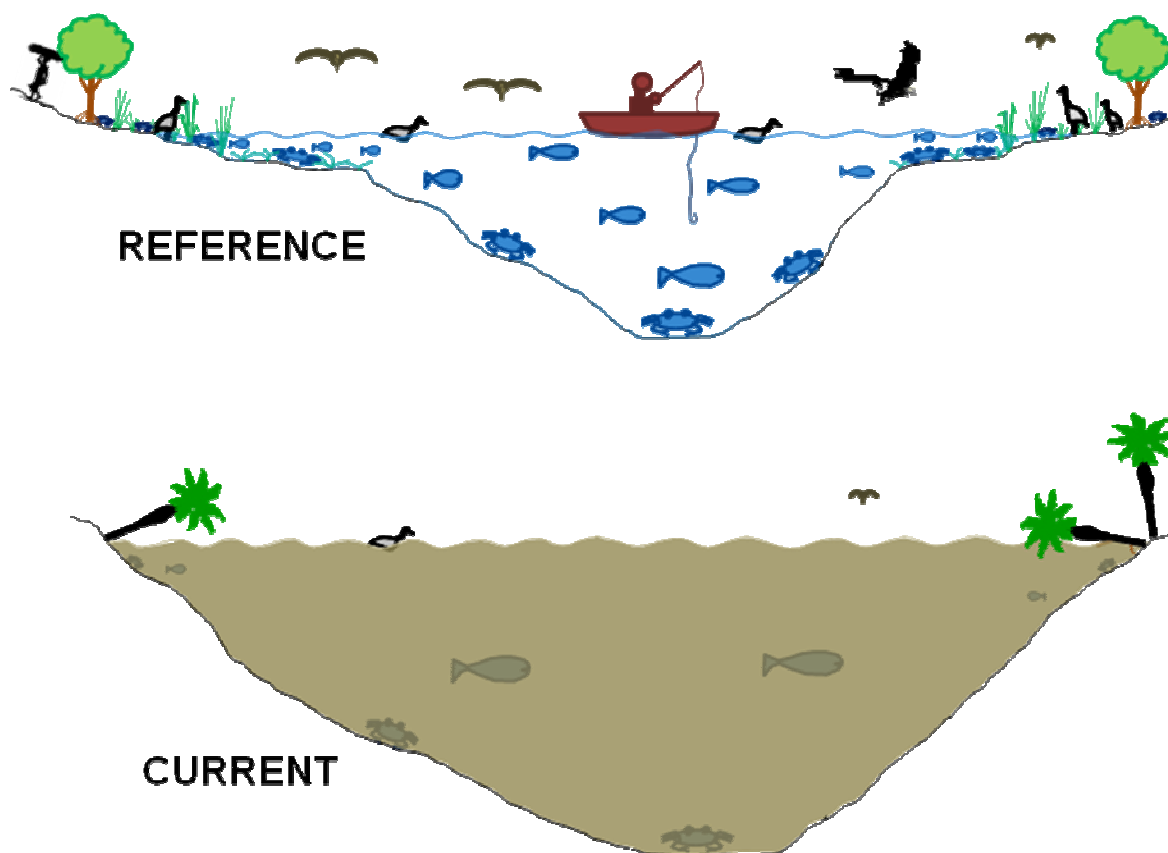


Figure 2.13 Simple graphic showing the hypothesised reference (natural) and present day status of the Pangani estuary. Note changes in channel profile, depth and width, water clarity, and abundance of fauna and flora.

2.7 Socio-economic State of the Basin Report

2.7.1 Introduction

The aims of the socio-economic baseline assessment were:

- to provide an overview of the basin and its economy
- to provide a description of the livelihoods of people living in proximity to rivers in the basin, and
- to estimate the contribution that aquatic ecosystem resources make to people's livelihoods.

2.7.2 Study area and zonation

The administrative Pangani Basin has an estimated population of about 3.4 million, with about 2.6 million within the Pangani River Basin. Population density is highest in the northern and eastern highlands, and is relatively sparse throughout most of the rest of the basin area.

Land use is governed primarily by rainfall, with agriculture being concentrated in the highlands and foothills. There is considerable large-scale/commercial cultivation of coffee, sugar and flowers, as well as small-scale agriculture, mostly irrigated. The latter concentrates on coffee, bananas and vegetables and dairy production in the higher areas, and a wide variety of crops, including rice, on the foothills. Lower areas include extensive commercial plantations, such as sisal, as well as small-scale agriculture. Towards the coastal lowlands, the latter includes coconut, sweet and Irish potatoes, pumpkins, cassava, okra, sisal and fruits. Although livestock are important throughout the basin, pastoralism is particularly important in the arid regions of the basin, with herds of cattle and goats being relatively large in these areas.

The economy is typical of a developing country, with a low GDP per capita (Tshs 384,000 – 445,000 for the Regions in the basin). While agriculture contributes about 46% to national income, it is relatively more important for the basin regions, apart from Arusha, for which other sectors such as tourism make a substantial contribution. Most of the population is dependent on agriculture for subsistence and employment. Within the agricultural sector, forestry, wildlife and fisheries are relatively minor within the basin in terms of their economic contribution, but fisheries are an important source of income and food locally. Of the other sectors, mining and hydropower production are important outputs of the basin, but other sectors, such as industry make a relatively small, although growing, contribution.

Irrigated agriculture is the biggest user of surface water in the basin, but urban and industrial uses and hydropower are also major users. Water that remains in the environment generates aquatic ecosystem goods and services. Households living near aquatic ecosystems harvest a variety of resources, the most important being fish.

The basin was delineated into six relatively homogenous socio-economic zones on the basis of land use and relationships to aquatic ecosystems (Figure 2.1). The six zones are Northern Highlands, Eastern Highlands, Lakes, Pangani-Kirua, Mesic Lowlands and Coast.

2.7.3 Approach used

This project builds on a preliminary study of the use and value of water and aquatic ecosystem resource use in selected areas of the basin conducted in 2003. While aquatic ecosystems generate various types of value, this study concentrated only on

the value of water and aquatic natural resources to rural households in the basin. We examine this from a household perspective only.

The study commenced with an initial review of existing published and unpublished information and a two week-long visit to the basin in which information on the study area was collated, the study area was delineated into sampling areas and the sampling frame was designed. A total of 659 rural households were interviewed throughout the study area and various focus group discussions were held to inform different aspects of the study. Data were standardised and analysed to estimate the value of natural resource use as well as agricultural production by rural households. Values were related to the aquatic habitats of the study area as far as possible.

The study had a capacity-building component and involved a Tanzanian resource economist working under the guidance of a South African mentor and in conjunction with staff of the Pangani Basin Water Office. Several others also benefited from the study in terms of experience gained, including senior staff at the Pangani Basin Water Office and eight graduates of the University of Dar es Salaam and Sokoine University of Agriculture who participated as enumerators in the study.

2.7.4 Findings

Households in the Pangani River Basin are characterised by considerable ethnic diversity, with dominant groups changing throughout the basin. Households are typically large, with an average of over 6.5 people in most areas. Average income from employment and business not related to own agricultural or natural resource production is in the order of only Tshs 10,000 – 48,000 per month. Almost all household heads are farmers, having both crops and livestock. The main exceptions are in the lakes zone and at the estuary, where only 71 – 74% are farmers, but where fishing is more important. A high proportion of households collect a variety of natural resources.

2.7.4.1 Agriculture

Small-scale farming is practiced throughout the basin, with much of the smallholder farming area being irrigated, particularly in the higher-lying areas of the basin. There is almost no crop rotation, reportedly due to acute shortages of arable land area. The dominant crops are maize, beans, bananas and vegetables. In addition, coffee is common in the northern highlands, rice in the eastern highlands, fiwi beans in the lowland areas and cassava and coconuts are common around the estuary. Some 40–60% of farmers in the highland areas irrigate their fields, compared with much lower proportions around the lakes and mesic lowland areas, and almost none in the Pangani-Kirua and estuary zones. However, a large proportion of irrigation farmers in the highlands felt that they did not have access to enough water. Income from dryland farming is about Tshs 200,000 – 300,000 per household apart from the northern highlands, where an average of over Tshs 600,000 was recorded. Irrigation

more than doubles the gross income generated by farming per unit area and irrigation farmers tend to have slightly larger fields than others.

Most rural households in the Pangani Basin keep livestock, apart from in the estuary, where the sample included an urban area, and only 61% had livestock. The most common types of livestock are chickens, cattle, goats and sheep. Other animals include donkeys, pigs, ducks and guinea fowl. Income from livestock is significant, ranging from about Tshs 100,000 – 300,000 throughout most of the basin, apart from the highlands, where dairy in particular contributes to a livestock income of over Tshs 500,000 on average, and in Pangani-Kirua, where livestock generate an average of over Tshs 700,000 per household.

2.7.4.2 Water for domestic consumption

Household consumption ranged from about 90-120 litres per household per day, apart from the northern highlands, where consumption was closer to 190 litres per day, partly due to consumption by zero-grazing cattle. Over half of rural households in the survey area had access to municipal water (taps), and 16% had access to wells or boreholes. However, there is still considerable reliance on natural and semi-natural (dams, canals) systems for water, with nearly half of households obtaining water from these sources. The degree of reliance on natural or semi-natural sources of water varies from 25% at the estuary to 92% in the Lakes zone.

2.7.4.3 River systems for cultural, religious and recreational use

Respondents indicated that river systems contributed significantly to religious and recreational activities as well as for washing clothes.

2.7.4.4 Natural resources

Food and medicinal plants are harvested by about a third of households throughout the basin, generating income of Tshs 12,000-52,000 per household. This is more important in the more remote areas. Grasses, sedges, bulrushes and reeds are used for thatching, fencing and making doors, with the use of different species varying across the basin according to their availability. About a third of households harvest these resources in any one year, generating income of Tshs 1500 at the estuary to 128,000 in the northern highlands. Palm leaves, mainly *Hyphaene* in the upper basin and *Phoenix* toward the coast, are also an important resource, used for producing a variety of goods such as baskets and mats. These resources generate up to Tshs 198,000 per year to user households.

Timber is only harvested by a few households, particularly in the uplands, and a few households engage in the production of wood products such as furniture. Those that do so earn substantial incomes. At least a third of households harvest poles in any one year, and firewood is harvested by the majority of households throughout the

basin. Very little of this comes from aquatic ecosystems apart from at the estuary, where about 10% reportedly comes from mangroves. These resources only generate modest income, but are vital for construction and cooking. Charcoal production tends to be done by only a small proportion of households, but can generate substantial income.

Hunting is undertaken by a small proportion of households throughout the basin, but the information on the amount of hunting is considered to be underestimated due to the illegal nature of most activities. Waterbirds are reportedly an important component of hunting.

Fishing is carried out throughout the basin. Fishing effort is greatest in the lakes zone (at Nyumba ya Mungu Dam and Lake Jipe), with over half of the households involved, and at the estuary (25%), but is relatively minor in the highlands apart from the activity at Kalimawe Dam (eastern highlands). Freshwater catches are dominated by tilapia and catfish, whereas estuary catches are far more diverse and include crabs and prawns as an important component. Fish catches everywhere are correlated with flow or water level, apart from crabs, which are caught in the low flow period.

On average, households derive incomes of between Tshs 140,000 and 630,000 from the use of natural resources. Income from aquatic ecosystem resources ranges from under Tshs 15,000 in the northern highlands, to Tshs 560,000 in the lakes area. Fisheries are the major source of income from aquatic resources, as can be seen from the relatively large contribution of aquatic resources in the lakes, estuary and eastern highland zones. The value of plants such as reeds and sedges are small, but this belies the degree to which they are used. Their low value is due to their relative abundance. The value of mangroves and waterfowl hunting is probably underestimated because of the legality of use.

Households generally perceived crops and livestock to be their most important sources of income. This was borne out to some extent in the estimation of income, but varied between areas. According to the estimated values, river systems (including fish) provide 0.5-6% of income in the highlands and 3-6% of income in the lowlands. They provide about 35% and 13% of income, in the lake and estuary zones, respectively. Households perceived the contribution of aquatic resources to be somewhat higher than these estimates, possibly due to the fact that the market value of natural resources does not always reflect their importance or their replacement cost.

A total of 75% of rural households in the basin are within 10 km of major rivers, and 47% are within 5 km. The total value of aquatic ecosystem resources harvested in the basin was estimated to be between Tshs 8.1 billion and 11.9 billion per year (US\$ 6.5 – 9.5 million). Over 60% of this value (Tshs 5.0 billion – 7.3 billion) was attributed to fishing.

2.7.5 Conclusions

This study provides an estimate of the value of aquatic ecosystems to rural households living within a few kilometres of the Pangani River system. Sample sizes are modest but considered adequate for input into a broadscale analysis of livelihood impacts. The study was limited to estimates of average gross incomes from different activities, and analysis of trade-offs will require estimation of marginal net incomes based on reasonable assumptions regarding costs and the impact of water availability and environmental quality on activities and outputs.

Rural households in the Pangani River Basin are highly dependent on agriculture. It is clear from this study that the irrigation water provided by the river system adds significant value to the agricultural income generated by small-scale farmers, with gross incomes from irrigated fields being more than double that of dryland fields.

Aquatic ecosystems in the Pangani River Basin are a valuable asset to households living in their proximity, and the more important fishery resources attract households from considerable distances. The contribution of these resources to household livelihoods is modest but significant. The relative gross income of these resources compared with other activities does not take into account their value as a safety net or in terms of spreading risk in poor households. Natural resources, particularly fisheries, act as a safety net by providing a means of survival for households that have suffered shocks such as loss of employment or death of a breadwinner. Thus these systems perform a service that the state might otherwise have to perform. Natural resources also help to spread risk for poor households that are vulnerable to crop failures due to rainfall variation, or other risks such as famine before the main harvests. It is interesting to note that the income provided by aquatic ecosystems exceeds the social welfare that is received in the form of pensions.

The total direct consumptive use value of the basin's aquatic ecosystem resources was estimated to be between Tshs 8.1 billion and 11.9 billion per year. However, it is evident that the value provided by aquatic resources has already been substantially eroded. Rivers in the highlands are no longer perennial, and fish have reportedly disappeared from these. The Kirua swamp has been reduced to a fraction of its former size due to cessation of flooding, and with it has been lost a valuable fishery, leaving households in the area even more vulnerable and poor than they were before. Fishers at the Pangani estuary report that catches there have declined, and some believe this is due to reduction in freshwater inputs. Even at Nyumba ya Mungu Dam, which largely replaced a natural wetland, fisheries have reportedly declined due to low water levels as well as over-fishing. At Lake Jipe, the fishery was all but exterminated by anthropogenically increased nutrient levels leading to encroachment of the lake by emergent vegetation. Thus the capacity of the aquatic systems in the basin to provide value to households has been compromised. It follows that restoration of these habitats would provide a significant social service to poor rural households in the basin.

Finally, it is important to note that this study concentrated entirely on the direct consumptive use value of the basin's aquatic ecosystems. Although direct consumptive use value is likely to be the most important component of value in this case, these systems also provide non-consumptive use value in the form of recreation and tourism, and indirect use value in the form of ecosystem services such as dilution of wastes, all of which contribute to economic production. The aquatic ecosystems also have option and existence value, which affect the present and future well being of society generally.

2.8 Task 5 Report: Understanding flow-ecosystem-user relationships

2.8.1 Introduction

The aim of the Task 5 Report was to create an awareness of the links between flow, the river ecosystem and its users, and the trade-offs to be made between water development and natural-resource protection. Part of this task included developing an understanding of the water-related ecological and economic systems of the Pangani Basin based on work completed on the project to date (Tasks 1-4), identification of gaps in this understanding, and developing the Terms of Reference for specialist studies to address these gaps.

The main activities related to this task were completed at the PBWO in Moshi, Tanzania, from 6 to 10 November 2006, involving all members of the FA team.

2.8.2 Key flow-related changes that have occurred in the Pangani Basin

Key flow-related changes that are evident in the river system were identified as follows:

- modified channel and habitats, particularly in the Kikuletwa river (dries up in dry season) and in the mainstem downstream of NYM dam (loss of floods and swamps);
- reduction in water quality (sediment accumulation upstream of NYM dam, pollution);
- decrease in fish abundance and diversity, particularly in Lake Jipe (due to extensive growth of macrophytes and a drop in lake level), the Kirua swamp (due to flood attenuation by NYM dam) and downstream of Pangani HEP station (due to intermittent releases);
- fishery created in NYM reservoir but this is now also declining in response to increased abstractions upstream of the dam that result in lower water levels in the reservoir;
- loss of floodplain vegetation in the Kirua swamp (flood attenuation) and invasion of exotic plants into the riparian zones (due to decrease in flow);
- substantial loss of goods and services historically provided by the river.

Changes associated with the estuary were:

- reduction in mean annual runoff entering the estuary, changes in the seasonality of freshwater flows, and a reduction in flood frequency;
- reduction in coarse sediment carried down by the river, with concomitant impacts on the state of the mouth and channel form;
- an increase in fine sediment (silt) carried down by the river, resulting in an increase in muddiness and anoxic sediment conditions;
- a reduction in water quality, principally a reduction in oxygen concentrations and an increase in the concentration of various inorganic nutrients;
- a reduction in the abundance and diversity of estuarine fauna and flora and in goods and services delivered by the estuary (e.g. fish and agricultural production).

Changes associated with the socio-economic conditions in the basin were:

- erosion of value provided by aquatic resources (e.g. fish) particularly at the Kirua swamps, the estuary, Lake Jipe, and Nyumba ya Mungu Dam;
- erosion of benefits provided by aquatic resources, thus reducing the ability of households to spread risk and to use the river as a safety net after shocks such as loss of employment or death of a breadwinner.

2.8.3 Conceptual frameworks

A conceptual framework (Figure 2.14) was developed that would aid planning at a basin level. This outlines the context of the Pangani Basin Flow Assessment within integrated flow management of the basin.

The process starts with the selection of a range of possible development or other water-management scenarios known or contemplated for the Pangani Basin, for which flows are simulated using the basin hydrology models. Responding to this and using a number of purpose-built tools, the effects of flow changes on ecosystem health and the delivery of ecosystem good and services can be predicted, as can the effects on peoples' livelihoods and national and local economies. Using these predictions, trade-offs between development and protection of the river system's resources can then be considered by decision-makers and other stakeholders in the search for an optimal water-allocation solution. This optimal trade-off, finally decided upon by the decision-makers, could be defined as the foundation of a Basin Development Plan, against which individual proposed developments could then be assessed.

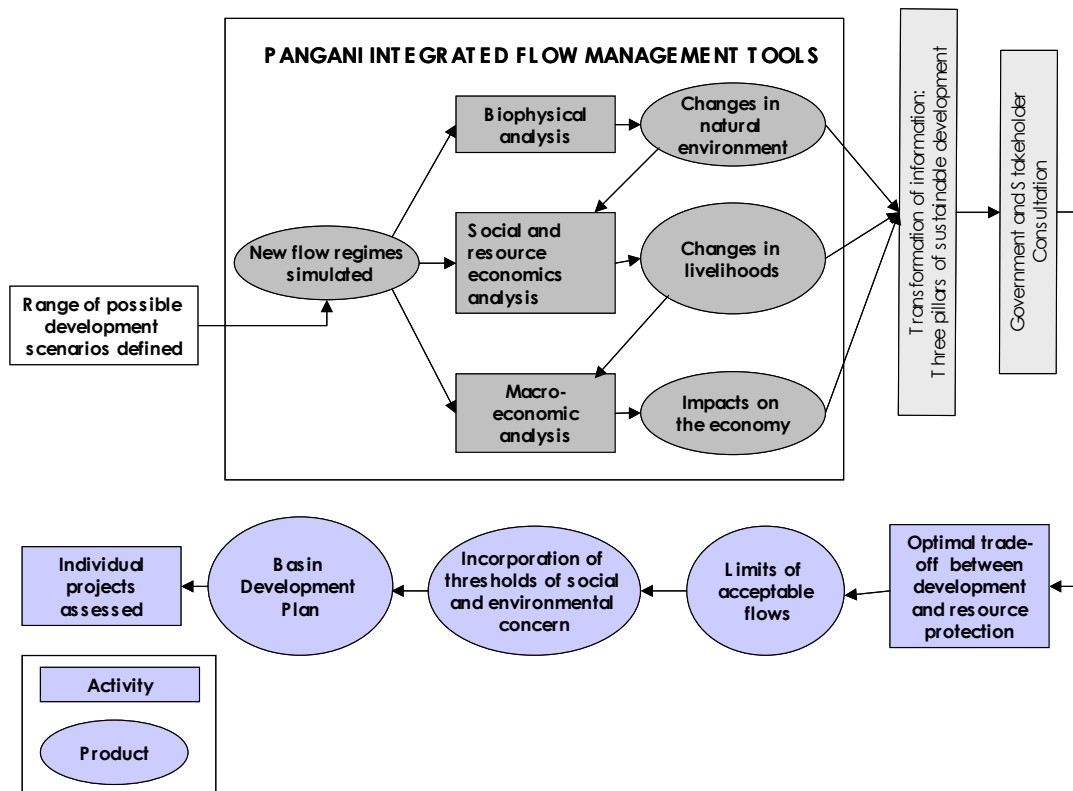


Figure 2.14 Conceptual framework for planning at the basin level

2.8.4 Development and population of FA tools

The Pangani Basin was divided into a series of hydrologically-discrete zones, for which the purpose-built Flow Assessment (FA) tools (or models) were developed. Each described the relationship between flow or water levels and a particular water-related aspect of the basin:

- River ecosystem FA Tool;
- Kirua Floodplain FA Tool;
- Lake ecosystem FA Tool;
- Estuary FA Tool;
- People's livelihoods FA Tool;
- Hydropower FA Tool;
- Macro-economics FA Tool.

The FA tools aid analysis of the development scenarios, providing predictions of ecological, economic or social change linked to each, for decision-makers to consider. Defined steps for the flow of data into and out of each tool were developed, and team members responsible for each were identified.

2.8.5 Identification of specialist studies for Task 6

Members of the project team compiled a list of all specialist studies they felt were necessary to provide a better understanding of the Pangani system and its users, and which were possible within the time limits of the project. Nineteen specialist studies were identified as important. As available funds for specialist studies were limited, these were prioritised for funding in terms of how urgently the knowledge was needed, and their importance to this flow assessment and to Integrated Water Resources Management (IWRM) generally in the Pangani Basin. Other issues considered in the prioritisation process included whether or not it would be possible to derive good value from a desktop study only, the estimated number of person days required to complete each study, the total duration of the project, and whether capacity to do the study was available in Tanzania or would have to be sought elsewhere. A final priority list of eight projects was created:

1. A macroeconomics study that can provide a detailed overview of the water-related economy of the Pangani River Basin, and the contribution that this area makes to the national economy.
2. Hydraulic assessment of the water levels (or depth) and inundated areas in Lake Jipe, Nyumba ya Mungu, and the Kirua swamps associated with different antecedent river flows and seasonal variations in aspects such as evaporation.
3. Assessment of the relationships between water level and/or flow and fishery production for the major fisheries of the Pangani River Basin.
4. Assessment of the links between flow and distribution, biology and life history of key fish and invertebrate species of economic or subsistence value in the Pangani River system.
5. Assessment of the links between flow and the distribution, biology and life history of key plant species of economic or subsistence value in the Pangani River system.
6. A basin-wide assessment of past and present water quality of the Pangani system
7. Assessment of the likely impacts of climate change on the hydrology of the Pangani Basin.
8. Enhanced understanding of the variation in hydropower generated under different flow scenarios.

Funding from Pangani Basin Flow Assessment resources was available for seven priority studies. Topic 7 above, on water quality, was deemed to require a more in-depth study than was possible in this project and was put aside for the present. For the remaining seven topics, PBWO and IUCN published advertisements for specialists in the Tanzanian press, referring interested readers to a website with detailed Terms of Reference, and inviting proposals from interested consultant researchers. An evaluation committee consisting of PBWO and IUCN staff evaluated the proposals and the selected consultants were subsequently contracted to conduct the studies (see Chapter 3).

2.9 Scenario Report

2.9.1 Background

The Pangani Basin Flow Assessment was an initiative of the International Union of Conservation of Nature (IUCN) and the Pangani Basin Water Office (PBWO). Running from August 2005 until 2009, it brought together a core team of Tanzanian specialists in a range of disciplines related to rivers - biophysical, social, economics, water management and policy making - and an international team of flow-assessment specialists from Southern Waters Ecological Research and Consulting and Anchor Environmental Consultants. Their task was to develop an understanding of the hydrology of the Pangani River Basin, the flow-related nature and functioning of the river system and the links between the river and the social and economic value of the river's resources. They then had to create scenarios of possible basin management/ development pathways into the future for consideration by the water authorities and other stakeholders.

In summary, the objectives of the project were to:

- generate baseline data of the condition of the Pangani River system against which the impact of water-related decision-making can be monitored in future;
- enhance the understanding among PBWO and Ministry of Water (MoW) staff of the relationship between flow, river health and the people who use the river;
- create an awareness of the trade-offs to be made between water development and natural-resource protection through consideration of a number of scenarios;
- develop tools to help guide flow management and water allocations in the Pangani Basin;
- build capacity that will enable PBWO to act as a nucleus of expertise for FA related work in other areas;
- support the National Water Policy (NAWAPO 2002) and the National Environmental Management Act (EMA 2004).

During the project, ten major project reports, and six specialist reports, were produced. This is Report No 10 of the project reports: the Scenario Report. It contains technical information on the Present Day (PD) situation in the catchment, the process used for scenario creation, and details of the scenarios analysis and comparison.

2.9.2 The scenarios

Standard allocations of water as at 2025 and other assumptions were made in order to reduce the number of variables contributing to differences between scenarios. These were:

- Urban and industrial allocations:
 - Arusha $39.0 \text{ Mm}^3\text{a}^{-1}$
 - Moshi $15.7 \text{ Mm}^3\text{a}^{-1}$
- Agriculture:
 - future growth based on historical growth rates
 - areas capped where all agriculture potential is already used

- a 30% improvement in the efficiency of water use
 - largest increase in use in Kikuletwa and Mkomazi
- HEP operating ranges
 - NyM 9.8 - 35.0 m³s⁻¹
 - Hale 8.5 - 45.0 m³s⁻¹
 - Pangani 9.0 - 45.0 m³s⁻¹
- Climate change
 - applicable/not applicable
- River ecosystem
 - applicable/not applicable

Fifteen scenarios were selected for analysis:

1. Maximise Agriculture.
2. Maximise hydroelectric power (HEP).
3. Optimise PD flows for ecosystem support, with agriculture (Optimise PD (Agric)).
4. Optimise PD flows for ecosystem support, with HEP (Optimise PD (HEP)).
5. High water allocation for ecosystem support (High Env.).
6. PD flows, with Climate Change (Climate Change from specialist report).
7. Maximise Agriculture, less 20% wet season rainfall (Max Agric, less 20%).
8. Maximise Agriculture, less 30% wet season rainfall (Max Agric, less 30%).
9. Maximise HEP, less 20% wet season rainfall (Max HEP, less 20%).
10. Maximise HEP, less 30% wet season rainfall (Max HEP, less 30%).
11. Storage upstream of NyM, with Maximise Agriculture.
12. Storage downstream of NyM (Luengera), with Maximise HEP.
13. Combination of storage upstream of NyM, with Maximise Agriculture AND storage downstream of NyM (Luengera), with Maximise HEP.
14. Mixed benefits, which include storage upstream and downstream of NyM.
15. Optimise PD flows, with Agriculture and storage in the upper catchment (Optimise PD (Agric with storage)).

The scenarios all included water allocations for Basic Human Needs (BHN), Domestic and Industrial, Agriculture and HEP. For the scenarios where the environment received more than residual water, pre-estimated environmental water allocations (for the rivers, NYM Dam, Kirua Swamp and the Pangani Estuary) were included. Scenarios differed from one another in respect of the order in which the different demands are met from the available water supply, that is, the priority of water allocation. Priorities are summarised in Table 2.9: thus, for example, Scenario 1 (Maximise Agriculture) consisted of maximising the irrigated area for agriculture after allocating water for BHN and urban and industrial use.

Predictions were made regarding the likely consequences of changes in flow using existing biophysical and socio-economic information, supplemented by specialist understanding and local knowledge. The various streams of information and predictions were organised within a custom-built Decision Support System (DSS). Ultimately, each scenario – or development pathway - could be described in terms of the predicted consequences to hydrology, river condition, the economics of the

natural resources of the river, HEP generation, irrigated agriculture, and social impacts.

Table 2.9 Water supply priorities used in the hydrological model WEAP. PD = Present Day.

Scenario	Basic Human Needs	Urban	Agriculture	HEP	Environment	Climate change
1. Maximise agriculture	1	2	3	4	Residual	n/a
2. Maximise HEP	1	2	4	3	Residual	n/a
3. Optimise PD (Agric)	1	3	4	Residual	2	n/a
4. Optimise PD (HEP)	1	3	Residual	4	2	n/a
5. High Environment (Agric)	1	3	4	Residual	2	n/a
6. PD with Climate Change (Agric)	2	3	4	5	Residual	1
7. Max Agric, less 20%	2	3	4	5	Residual	1
8. Max Agric, less 30%	2	3	4	5	Residual	1
9. Max HEP, less 20%	2	3	5	4	Residual	1
10. Max HEP, less 30%	2	3	5	4	Residual	1
11. Storage upstream of NyM, with Maximise Agriculture.	1	2	3	4	Residual	n/a
12. Storage downstream of NyM (Luengera), with Maximise HEP	1	2	Upper: 3	Upper: 4	Residual	n/a
			Lower: 4	Lower: 3		
13. Combination of storage u/s of NyM, with Max Agric AND storage d/s of NyM, with Max HEP.	1	2	Upper: 3	Upper: 4	Residual	n/a
			Lower: 4	Lower: 3		
14. Mixed benefits, include storage upstream and downstream of NyM	1	2	Upper: 3	Upper: 4	Residual	n/a
			Lower: residual	Lower: 4	3	
15. Optimise PD (Agric with storage)	1	3	4	Residual	2	n/a

Some scenarios (Scenarios 6 to 10) also included projections of how flows would be affected by global climate change. Climate change modeling was originally undertaken by experts from the University of Dar es Salaam in order to assess how climate change could affect the basin and the results incorporated into Scenario 6, while Scenarios 7 to 10 included a range of reduced rainfall scenarios. International review by UNDP and University of Cape Town (UCT) climate specialists revealed that the climate-change modelling results had a high degree of uncertainty. More investigations are presently being done by UCT. The scenarios in this report are based on the original climate-change modeling and, because of the uncertainties, the results from the climate-change scenarios should not be considered as the likely climate future. For completeness, they remain in this report, but if the results from the UCT climate-change modeling are significantly different to those of the initial modeling exercise, then additional water-allocation scenarios will be run using the new information.

2.9.2.1 *Predicted changes in flow regime*

The hydrological consequences of each scenario were summarised in terms of river flow:

1. Maximise Agriculture
 - severe decrease in low flows in the dry season, in the Kikuletwa and Ruvu Rivers and the Mkomazi
 - reduced variability at the Pangani River at Kirua, due to lower inflows to NyM and thus storage of floods
2. Maximise HEP
 - Slight decrease in low flows in the dry season in the Kikuletwa
 - significant increase in flows greater than $25 \text{ m}^3\text{s}^{-1}$ in the Pangani at Kirua and thus greater inundation of Kirua swamp
 - slight increase in dry-season low flows in the Mkomazi and Lower Pangani
3. Optimum Present-Day flows with Agriculture
 - low flows partially re-instated, particularly in the dry season and in the Kikuletwa, Ruvu and Mkomazi Rivers
 - Intra-annual floods reinstated downstream of NyM
 - Increases inundation of Kirua Swamps
4. Optimum Present-Day flows with HEP
 - as for 3
5. High Environment with Agriculture
 - dry-season flows partially re-instated, particularly in the Kikuletwa, Ruvu and Mkomazi Rivers
 - a more natural seasonal pattern of flows re-instated in the lower catchment with increased wet-season flows and decreased dry-season flows
 - floods re-instated downstream of NyM to a greater extent than in Scenarios 3 and 4
6. Climate Change
 - drastically reduced low flows, mainly in the dry season, in the Kikuletwa, Ruvu and Mkomazi Rivers
 - a slight increase in intra-annual floods in the middle catchment
 - big floods significantly higher in frequency
7. Maximise Agriculture with 20% Less Rainfall
 - as for Scenario 1 but more severe
8. Maximise Agriculture with 30% Less Rainfall
 - as for Scenarios 1 and 7 but more severe
9. Maximise HEP with 20% Less Rainfall
 - reduced flow at all sites
 - some increased intra-annual flood variation
 - loss of inter-annual floods
10. Maximise HEP with 30% Less Rainfall
 - As for Scenario 9
11. Storage u/s NyM with Maximise Agriculture
 - severe decrease in low flows in the dry season, in the Kikuletwa and Ruvu Rivers and the Mkomazi

- reduced variability at the Pangani River at Kirua, due to lower inflows to NyM and thus storage of floods
12. Storage d/s NyM with Maximise HEP
 - severe decrease in low flows in the dry season, in the Kikuletwa and Ruvu Rivers and the Mkomazi
 - increased dry season lowflows in the Luengera
 - increased inundation of Kirua
 13. Combination of u/s storage with Maximise Agriculture and d/s storage with Maximise HEP
 - as for Scenario 12
 14. Mixed benefits
 - severe decrease in low flows in the dry season, in the Kikuletwa and Ruvu Rivers and the Mkomazi
 - increased dry season lowflows in the Luengera
 - significant increase in inundation of Kirua
 15. Storage upstream of NyM, Optimise PD
 - low flows partially re-instated, particularly in the dry season and in the Kikuletwa, Ruvu and Mkomazi Rivers
 - intra-annual floods reinstated downstream of NyM
 - increased inundation of Kirua Swamps

(Note: The differences in the predictions for large floods in Scenario 6 (Climate Change -CC) and Scenarios 9 and 10 (Max HEP with 20% or 30% less rainfall) are a result of the two different approaches used in hydrological simulation. The CC scenario reflects results from the CC modelling exercise, which included increases as well as decreases in rainfall in various areas, whilst the two Max HEP/Rainfall scenarios simply take away rainfall.)

2.9.3 *Predicted response of the river ecosystem*

2.9.3.1 *River*

The four scenarios that redistribute river flow (Scenarios 3-5 and 15) and, for Scenario 5, increase its volume, resulted in a low to moderate improvement in river condition throughout the system compared to PD (Table 2.10) apart from a very slight decrease at site 3 for Scenario 15.

The scenarios that include climate change (Scenarios 6-10) show an almost basin-wide decline in river condition. Scenarios 7 and 8 (Max Agriculture with 20% or 30% less rainfall) are predicted to result overall in the most severe decline.

Most scenarios indicate a low to moderate improvement in condition in the Kirua area (site 6). This is so not only for the four scenarios aimed at improving river condition, but also for those prioritising HEP as they leave more water in the river than do the ones prioritising agriculture.

Of the scenarios that were not specifically designed to improve river condition, Scenario 2 (Maximise HEP) caused least degradation to the river and actually brought about some improvement to the lower reaches.

Table 2.10 Colour coding to illustrate shift in condition from Present Day at the FA river sites for the fifteen scenarios. pink: low decline in condition; orange: moderate decline; red: severe decline; pale blue: low improvement; dark blue: moderate improvement.

Scenario	Site 1	Site 2	Site 3	Site 4	Site 6	Site 7	Site 8	Site 9
1. Max Agric	-0.193	-0.221	-0.107	-0.061	0.024	-0.971	0.000	-0.049
2. Max HEP	-0.025	-0.007	-0.072	-0.013	0.186	-0.474	0.017	0.068
3. Opt PD (Agric)	0.000	0.055	0.000	0.010	0.319	0.050	0.036	0.000
4. Opt PD (HEP)	0.000	0.055	0.000	0.010	0.319	0.050	0.036	0.000
5. High Enviro	0.072	0.055	0.000	0.010	0.515	0.204	0.036	0.000
6. Climate change	-0.149	-0.227	-0.131	-0.055	0.047	-0.583	-0.095	-0.044
7. Max Agric less 20%	-0.587	-0.558	-0.155	-0.274	-0.204	-1.124	-0.509	-0.200
8. Max Agric less 30%	-0.726	-0.610	-0.412	-0.289	-0.377	-1.143	-0.663	-0.388
9. Max HEP less 20%	-0.383	-0.266	-0.205	-0.239	0.165	-0.311	-0.467	0.059
10. Max HEP less 30%	-0.470	-0.337	-0.275	-0.276	0.056	-0.148	-0.500	-0.009
11. Storage u/s NyM Max Agric	-0.138	-0.227	-0.132	-0.053	0.014	-0.971	-0.169	-0.061
12. Storage d/s NyM Max HEP	-0.132	-0.227	-0.141	-0.027	-0.043	-0.990	-0.266	-0.044
13. Combo11&12	-0.138	-0.227	-0.132	-0.041	0.014	-0.915	-0.245	-0.040
14. Mixed Benefits	-0.121	-0.227	-0.132	-0.067	0.115	-0.915	-0.215	-0.044
15. Add Store Opt PD	0.056	0.088	-0.023	0.016	0.235	0.006	0.017	0.097

The last group of scenarios mostly show a basin-wide decline in river condition, although all but Scenarios 7, 8 and 12 do also improve the condition at Site 6 (Kirua Swamp). Scenario 15 (Optimise PD and add storage in upper basin) allows a mild improvement in river condition except at Site 3 (Upper Ruvu) where storage of flood flows causes a mild decline.

2.9.3.2 Estuary

The estuary is predicted to show a similar decline in health under all scenarios except those that optimise flows for ecosystem maintenance. The one exception to this is again Scenario 2 (Maximise HEP), which also brings improvement to the estuary.

Maximising agricultural production in the Pangani catchment (Scenario 1, 7, 8, 11 and 13) is projected to come at a cost in terms of changes in estuary health, especially if this is coupled with reductions in rainfall (Table 2.11). Projected changes in rainfall associated with the modelled climate change scenario (Scenario 6) are also expected to have a negative impact on estuary health.

On the other hand, maximising HEP under the PD rainfall is likely to enhance estuary health significantly (Scenario 2), but this effect is likely to be largely negated by projected reductions in rainfall under the two rainfall reduction scenarios (Scenarios 9 and 10).

Table 2.11 Change in estuarine health for the 15 scenarios (PD = Present Day).

Scenarios	Health score (%)	Integrity score
PD	57	0
1. Max Agric	46	-0.348
2. Max HEP	65	0.201
3. Opt PD (Agric)	61	0.161
4. Opt PD (HEP)	70	0.436
5. High Enviro	62	0.234
6. Climate change	51	-0.200
7. Max Agric less 20%	34	-0.853
8. Max Agric less 30%	31	-0.931
9. Max HEP less 20%	58	-0.020
10. Max HEP less 30%	57	-0.059
11. U/s storage, Max Agric	46	-0.373
12. D/s storage, Max HEP	48	-0.300
13. Combo 11 & 12	48	-0.319
14. Mixed Benefits	49	-0.266
15. Opt PD with storage	58	0.045

Redistribution of flow within the catchment (Scenarios 3 to 5 and 15) is expected to have a low to modest positive impact on estuary health.

2.9.3.3 *Nyumba ya Mungu*

The average lake area decreases under all scenarios (Table 2.12).

Table 2.12 Change in area of NyM, fish catch and reed area for the 15 scenarios.

Scenarios	Mean lake level	Mean lake area	%change lake area	% incr./ decr. in variability	%change in total fish catch	%change Reed area
current	16	104	0	0	0	0
1. Max Agric	12	66	-37	30%	-28	79
2. Max HEP	11	60	-42	10%	-32	90
3. Opt PD (Agric)	12	68	-35	49%	-26	40
4. Opt PD (HEP)	11	58	-44	9%	-34	28
5. High Enviro	12	64	-38	51%	-29	59
6. Climate change	13	73	-30	34%	-22	92
7. Max Agric less 20%	10	51	-51	-45%	-41	21
8. Max Agric less 30%	10	48	-54	-65%	-43	26
9. Max HEP less 20%	10	49	-53	-71%	-42	-20
10. Max HEP less 30%	9	47	-54	-91%	-43	-38

Scenarios	Mean lake level	Mean lake area	%change lake area	% incr./ decr. in variability	%change in total fish catch	%change Reed area
11. U/s storage, Max Agric	11	64	-38	23%	-29	70
12. D/s storage, Max HEP	11	60	-42	10%	-32	91
13. Combo 11 & 12	11	59	-43	4%	-33	82
14. Mixed Benefits	10	55	-47	-10%	-36	69
15. Opt PD with storage	12	70	-33	69%	-24	83

Lake level becomes more variable under most scenarios apart from the reduced rainfall scenarios (Scenarios 7 to 10) and the Mixed benefits scenario (Scenario 14). Fish catches are predicted to decrease for all scenarios, while the reed area will increase. The decrease in NyM area generally coincides with an increase in inundation of Kirua swamp.

2.9.3.4 Kirua swamp

The maximising HEP and Opt PD scenarios all (except for Max HEP less 30% rain) increase the inundation area of Kirua Swamp relative to PD, but never to anything close to the estimated natural area of 90 000 ha. Consequently, fish and vegetation abundance both also increase for these scenarios. The maximising agriculture scenarios all decrease the inundated area of the swamp and consequently fish and vegetation abundance (Table 2.13).

Table 2.13 Change in area of Kirua swamp, fish and vegetation abundance area for the 15 scenarios.

Scenarios	Area of Kirua swamp	% of PD : fish abundance	% of PD : swamp and vegetation area
PD	4 488	100	100
1. Max Agric	1 745	40	39
2. Max HEP	13 629	294	304
3. Opt PD (Agric)	21 524	458	480
4. Opt PD (HEP)	21 524	458	480
5. High Enviro	22 853	485	509
6. Climate change	2 742	62	61
7. Max Agric less 20%	748	18	17
8. Max Agric less 30%	499	12	11
9. Max HEP less 20%	6 814	150	152
10. Max HEP less 30%	3 823	86	85
11. U/s storage, Max Agric	997	23	22
12. D/s storage, Max HEP	11 634	252	259
13. Combo 11 & 12	8 892	194	198
14. Mixed Benefits	22 853	485	509
15. Opt PD with storage	15 457	332	344

2.9.3.5 Societal well-being

Impacts on livelihoods, measured in terms of impact on household income and on intangible (recreational and spiritual) values, were aggregated into a prediction of the percentage change from PD in societal well-being. Apart from Scenario 6, there are no scenarios that improve well-being anywhere in the highlands and lakes areas, which together contain most of the basin population. Scenario 1 (Maximise Agriculture) and the storage Scenarios 11 to 14 are the ones that decline least from the present levels of social well-being in these areas and the basin as a whole under the increased demand for water in 2025. Societal well-being in the Pangani-Kirua, Mesic Lowlands and Estuary areas improves under some scenarios, mainly those associated with optimising or maximising environmental flows and HEP.

In terms of percentage changes, the biggest losses in societal well-being were associated with the Lakes area for all scenarios and the Pangani Kirua area under the Maximise Agriculture with Less Rainfall scenarios (Figure 2.15). These percentage losses come from a very low base level, as income in these two zones is already very low under the PD scenario.

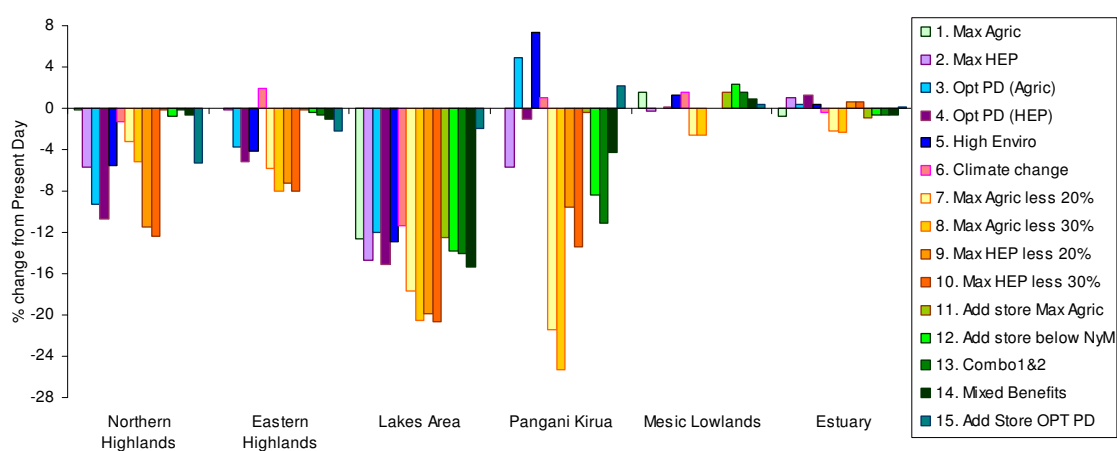


Figure 2.15 Impacts on societal well-being for the 15 scenarios.

2.9.4 Basin-wide summaries

Direct economic implications were measured in terms of impacts due to changes in natural resources, ecosystem services, commercial agriculture and HEP production. When measured as percentage changes in value relative to PD the largest increases in value are for ecosystem services, occurring under the scenarios aimed to improve ecosystem condition. HEP values tend to improve slightly under the same scenarios. The values of both ecosystem services and HEP decline under the scenarios that prioritise agriculture and those that incorporate Climate Change, whilst gains from agriculture are minimal if any. Conversely, agricultural values decline under all scenarios where HEP and the ecosystem are prioritised. Changes in natural

resource values are extremely small relative to PD for all scenarios. However, when viewed in terms of absolute changes in Tsh, those for HEP completely overshadow the others (Figure 2.16; Table 2.14).

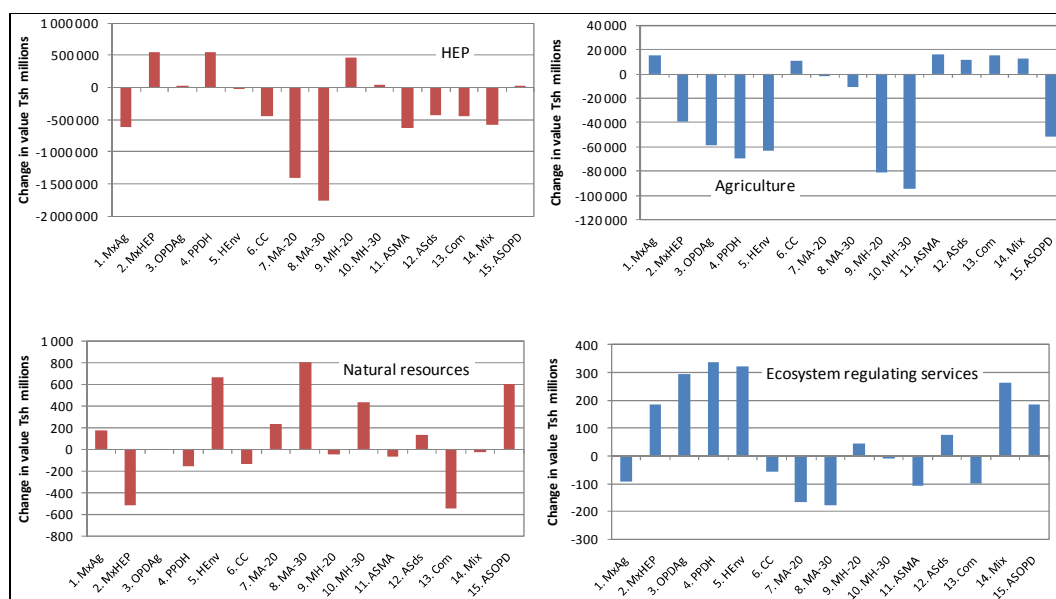


Figure 2.16 Changes relative to Present Day in million Tsh for the economic values showing the relatively large impacts of hydroelectric power and agriculture relative to natural resources and ecosystem services.

Table 2.14 Summarised economic impacts of the fifteen scenarios in terms of changes in Tsh millions from Present Day (DSS software Sept 2009)

SCENARIO	Hydroelectric Power	Agriculture	Natural Resources	Ecosystem services	Total	% change
<i>Present Day</i>	2 380 642	202 391	34 809	327	2 618 170	
1. Max Agric	-606 842	15 540	175	-91	-591 218	-22.58
2. Max HEP	547 991	-38 871	-516	183	508 788	19.43
3. Opt PD (Agric)	31 962	-59 008	-1	296	-26 752	-1.02
4. Opt PD (HEP)	552 606	-69 370	-157	338	483 417	18.46
5. High Enviro	-4 037	-62 798	661	322	-65 852	-2.52
6. Climate change	-445 989	10 933	-136	-56	-435 248	-16.62
7. Max Agric less 20%	-1 403 326	-1 420	230	-164	-1 404 680	-53.65
8. Max Agric less 30%	-1 765 391	-10 500	806	-178	-1 775 263	-67.81
9. Max HEP less 20%	469 726	-80 879	-48	44	388 843	14.85
10. Max HEP less 30%	39 527	-94 457	430	-10	-54 509	-2.08
11. Add store Max Agric	-634 385	16 576	-62	-106	-617 977	-23.60
12. Add store below NyM	-423 001	11 743	136	78	-411 045	-15.70
13. Combo 11&12	-444 648	14 909	-542	-98	-430 379	-16.44
14. Mixed Benefits	-575 842	12 225	-23	265	-563 376	-21.52
15. Add Store OPT PD	25 315	-51 365	605	184	-25 262	-0.96

The maximise HEP scenarios go hand in hand with increased inundation of Kirua swamp (although the swamp is not inundated to the same extent as for the Opt PD and High Enviro scenarios) (Table 2.15). The positive economic effects of increasing HEP production therefore coincide with the positive environmental effects of some degree of restoration of Kirua swamp and consequent increased fish catches and reed area. To some extent this is at the 'expense' of the lake levels, which are reduced in all scenarios, as are fish catches. The river as a whole is only expected to experience better than PD conditions under the optimising PD and high environment scenarios.

Table 2.15 The status of key descriptors under each scenario

Scenario	Urban Industrial & Domestic	Irrigation area as % of PD	Irrigation (@75% assurance)	Hydro-power	Kirua inundation	Fish catch @ Kirua	River condition
	Mm ³ a ⁻¹	% of PD	Mm ³ a ⁻¹	MWH	% of natural	t	% change from PD
<i>Present Day</i>	<i>31.1</i>	<i>-</i>	<i>1 042</i>	<i>602 647</i>	<i>5</i>	<i>133</i>	<i>0</i>
1. Max Agric	54.7	124	1 032	428 134	2	53	-4.3
2. Max HEP	54.7	81	634	782 601	15	389	-0.3
3. Opt PD (Agric)	53.6	64	520	612 474	24	606	1.4
4. Opt PD (HEP)	53.6	55	435	784 235	24	606	2.0
5. High Enviro	50.9	61	497	601 411	25	643	2.5
6. Climate change	54.7	122	1 016	472 371	3	82	-3.2
7. Max Agric less 20%	54.7	109	873	225 815	1	23	-9.9
8. Max Agric less 30%	54.7	101	807	141 347	1	16	-12.3
9. Max HEP less 20%	54.7	40	286	755 227	8	199	-3.7
10. Max HEP less 30%	54.7	28	203	614 810	4	113	-4.5
11. Storage u/s NyM with Max Agric	54.7	125	1 031	420 688	1	31	-4.7
12. Storage d/s NyM with Max HEP	54.7	118	934	478 802	13	334	-4.8
13. Combination of u/s storage with Max Agric and d/s storage with Max HEP	54.7	120	950	472 745	10	257	-4.5
14. Mixed benefits	54.7	118	932	436 558	25	643	-4.1
15. Opt. PD-Agric & storage	53.6	69	545	610 424	17	440	1.2

A basin-wide summary in terms of the three pillars of sustainable development shows that for both river and estuary scenarios that maximise agriculture have the greatest negative ecosystem impact, whilst those that boost HEP generation may help improve river condition (Figure 2.17). Socially, all scenarios have a negative impact on overall well-being in the upper zones and variable but smaller impacts in the lower zones. Overall, the effects are negligible, but they are strongest in the Maximum HEP scenario and Scenario 15. Economically, scenarios that improve river condition also tend to increase HEP values. Ecosystem services and HEP both decline in

value under the scenarios that prioritise agriculture. Conversely, agricultural values decline under all scenarios where HEP and the ecosystem are prioritised.

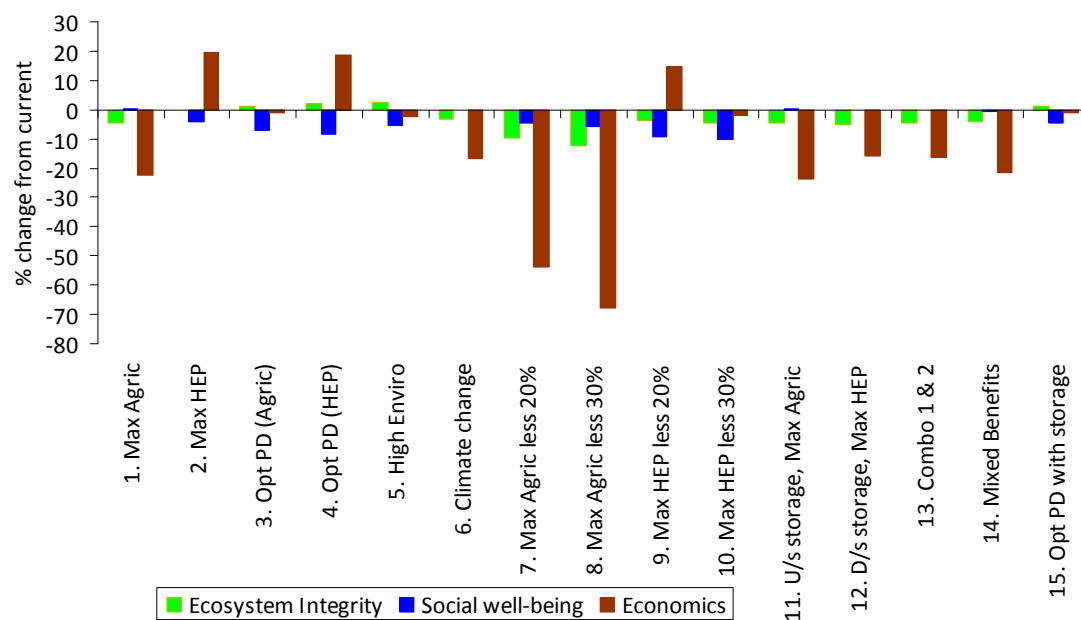


Figure 2.17 Percentage change from present day in terms of ecosystem integrity, social well-being and economic values.

3 SUMMARIES OF EXTERNAL SPECIALIST REPORTS

Terms of reference (TOR) for the specialist studies were written by IUCN, PBWO and the project mentors and amended if necessary after assessment by the international reviewers appointed for each study. The appointed specialists submitted a suggested Table of Contents for approval and then completed the studies during 2007. One specialist team wrote a combined report on two topics: fish and invertebrate life cycles and fishers, making six specialist reports in total. The studies, specialists and reviewers are shown in (Table 3.1). First drafts were subject to an internal review by project leaders and final drafts by the international reviewers. The final versions were not reviewed again.

Table 3.1 Specialist topics, authors and reviewers

Study topic	Specialist(s)	Reviewer(s)
Development of climate change scenarios (2008)	H. Mkhandi, P. Valimba, & T. Kimaro	Hans Beuster, Emzantsi Systems, RSA; Mark Tadross, University of Cape Town, RSA. Jessica Troni, UNDP
Macro-economic model of the Pangani River Basin	G. Kahyarara. University of Dar es Salaam	Glenn-Marie Lange, Centre for Economy, Environment and Society, New York, USA
Fish and invertebrate life histories and important fisheries of the Pangani River Basin	O. Hamerlynck, M.D. Richmond, A, Mohammed, & S.R. Mwaitega. Samaki Consultants	Denis Tweddle, South African Institute for Aquatic Biodiversity, RSA
Hydroelectric power modelling study	K.P. Luteganya & S. Kizzy	Hans Beuster, Emzantsi Systems, RSA
Hydraulic study of Lake Jipe, Nyumba ya Mungu reservoir and Kirua Swamp	T.A. Kimaro, S.H. Mkhandi,, J. Nobert, P.M. Ndomba, P. Valimba & F..W. Mtalo	Hans Beuster, Emzantsi Systems, RSA
The vegetation of the Pangani River Basin and its association with flow regimes	P.K.T. Munishi & A. Chikiti, Sokoine University of Agriculture, Morogoro	Fred Ellery, University of Kwa-Zulu, Natal, RSA

The executive summaries are provided below.

3.1 Climate change scenarios

The Terms of Reference for this study were to provide modified rainfall and evaporation series for each of the selected 16 catchments in the Pangani River Basin under scenarios of climate change. Statistical downscaling was used to establish

multiple linear regression (MLR) models between observed monthly rainfall and NCEP/NCAR re-analyses for the period 1961-2001. Established models gave moderately good to better efficiencies for majority of catchments although rainfall in some months could not be better predicted. However, downscaled monthly rainfall using HadCM3 were poorly predicted and the use of GFDL CM2.1 improved significantly rainfall prediction with no predictions of negative rainfalls. The resulting downscaled rainfall indicated significant changes will be experienced during the months October to January leading to declining predominantly orographic rainfall in these months. An increase of rainfall is predicted during the long rains particularly in April and May and the dry season (June-September) particularly in June suggesting a protrusion of long rains into the dry season. Calibration of MLR models for evaporation could not be achieved due to lack of time series of evaporation and more time is required to establish the scarce available information from hardcopies. However, the highest ratio of 1.368 temperature predictions of between December-February (DJF) and June-August (JJA) and annual evaporation rise of 20% by the year 2100 were used to modify available average monthly evaporation to provide evaporation scenarios for 2020s, 2050s and 2080s.

3.1.1 Comment

Concerns over the techniques and findings of this study led to further review by a climate-change specialist at the Climate System Analysis Group (CSAG), University of Cape Town. The conclusions were:

- The CSAG review identified the same concern that was previously raised by Jessica Troni (UN Regional Advisor: Climate Change Adaptation), namely that the uncertainty in the results may be attributed in part to the reliability of the statistical downscaling techniques that were employed. A relatively simple, unproved regression technique was used.
- The CSAG furthermore pointed out that climate change modeling that formed the basis of the Fourth Assessment Report of the IPCC indicate a general (strong) wetting trend in central-east Africa. In contrast, the Pangani specialist study indicated a drier wet season, and a combination of wetter and drier months in the dry season.

Because of uncertainty regarding the very important likely effects of climate change, this component of the project was terminated at this point, and will be followed up in separate climate-change investigations.

3.2 Macroeconomics

This project has undertaken macro-economics study in the Pangani River Basin to facilitate design of a user friendly macroeconomic model for estimating economic effects of changes in water allocation. In order to map the social, economic and ecological linkages of water supply based on different scenarios the study has developed a simple macro-economic model. The model allows economic and hydrological linkage that can provide a convincing measure for comparing economic

implications of alternative scenarios with the goal of reaching an optimal solution economic feasibility of optimal water allocation. In particular the study i) assessed the economic contribution of the Basin, ii) provided the general assessment of systems of water allocation and management and iii) undertook the basin flow assessment. In the course of study implementation a detailed overview of the economy of the Pangani River Basin, and the contribution that this area makes to the national economy was provided. Furthermore, quantification of the relationships between water supply and sectoral outputs at a micro and macro-scale was conducted. Then using a developed model the economic consequences of changes in water allocation, which would take the form of changes in agricultural, hydropower and fisheries production into account, as well as any other important water user sectors were assessed. The model estimated here is very simple and does not require a specialization in economics to run it. The software needed is very simple and the model is based on a simple Excel spread sheet.

The macroeconomic model designed by this study divides the Pangani economy into production sectors, together producing eight unique goods. These sectors are: (1) Key sector--fishery sector that provides inputs (goods) to the different sectors such as manufacturing and households; (2) a production sector producing agricultural goods, industrial goods and services; (3) an energy sector providing electricity services; (4) an household sector providing labour (employment) and market for the other sectors of the economy. The culmination of the modelling exercise begins with evaluation of economic consequences of different possible future scenarios with regard to the allocation of water among different water user sectors and the environment. In particular, the model provides baseline information on the economy of the Pangani Basin and the means to evaluate the impacts of alternative water allocation scenarios.

Estimates of the model for a scenario with are presented in this report. This scenario considers a 25% increase in water allocation for irrigation and a 19% reduction of water used for electric generation. The estimation results suggest that the macroeconomic effect of the first scenario is to increase GDP by US dollars 9millions and create 7400 jobs In estimating the macroeconomic model six scenarios are considered. In this report we have results for the first scenario, while the rest will follow later. The results for the scenario 1 presented show high agricultural priority and reduction in hydroelectric power production as the major objective of the Basin.

3.2.1 *Comment*

Effectively, a useable model that predicted the effects on the nation's economy was not built and so economic predictions within the project were confined to local/regional resource-economic issues.

3.3 Fish, fisheries and invertebrates

This report is the product of two, short, desk-based Specialist Studies of the Pangani River Basin Flow Assessment (PRBFA) Initiative. Based on published literature, information from the Internet and from a five-day field visit in June 2007, the report describes the main aquatic biotopes of the Pangani River Basin, an area of over 43,000 km².

The relatively high conductivity within the largely volcanic basin is confirmed and a description is given of the fish and invertebrates that reside in the different water bodies - mountain streams, crater lakes, rivers, man-made reservoirs, floodplains and the mangrove fringed estuary.

Finfish and invertebrates (in this case, crustaceans) of commercial importance are further described, particularly in relation to their life histories and response to changes in river flow variables. Included is an updated list of freshwater fish in the Pangani system.

The fishery of Nyumba ya Mungu and of estuaries comparable to the Pangani are described with data from various sources. Hydrological data are used to discern linkages in fisheries output and water levels (river flow or surface area) and conceptual relationships are developed, highlighting probable links between the timing and magnitude of freshwater flows in the Pangani system and the flow-related requirements and life-history characteristics of each species.

It should be kept in mind that 2006 and 2007 were exceptional years with regard to rainfall, water levels and flows and that the findings of several field studies conducted during that period probably do not reflect the average situation in the Pangani Basin. For example, the conductivity situation as recorded in this study, which was comparable to the early post-impoundment studies in Nyumba ya Mungu as reported in Bailey (1996) needs close monitoring over extended time periods across the entire Basin before conclusions can be drawn on the potential impacts of (increasing) conductivity on the fish, invertebrates and fisheries.

The Pangani Basin as whole has a comparatively high fish biodiversity, probably a reflection of the wide range of available habitats. Still, some of the most characteristic species of African rivers and floodplains seem to be absent from the Pangani (*Citharinus*, *Distochodus*, *Alestes*, *Hydrocynus*). Various Cichlidae and the catfish *Clarias gariepinus* dominate the catches but virtually all species present are harvested in any life stage accessible to fishing gears. Invertebrate biodiversity is high in the Basin but knowledge is still incomplete. Harvesting is almost entirely restricted to estuarine crustaceans (prawns and crabs).

The mountain-stream habitat was not directly assessed in this study. Its importance for fisheries is marginal. Important biodiversity values may still be discovered in

these habitats for both fish (e.g. Kneriidae) and invertebrates. Maintaining forest cover and instream flows seems essential for their survival and/or restoration.

In the foothills of Mt. Kilimanjaro Lake Chala is still pristine but highly vulnerable, including its endemic fish. The Lake Jipe catchment has been plagued by water quality and quantity problems for several decades now. Its fisheries have collapsed and its endemic species has declined. Though the expansion of the vegetated marshes in Lake Jipe and on the Ruvu River creates access problems for the fishers, these natural habitats play a vital role as filters and thus protect the downstream areas such as Nyumba ya Mungu from an overspill of the Jipe problems.

The main Pangani River, characterized by a high conductivity, has been strongly modified by the creation of the Nyumba ya Mungu Reservoir. As far as the available data are reliable, its fishery seems to be on a downward trend with catches over the past ten years an order of magnitude lower than those in the 1970s. There are indications that the fisheries react favourably to higher water levels and/or increased reservoir surface area above a threshold of 687 masl and 110 km² respectively. In the absence of reliable monthly catch data, the analyses have been necessarily crude. A standardized long-term monitoring programme independent from the fishery such as the one in Lake Kariba (operated by the power company) could provide highly valuable data. Bottom siltation has been mentioned as a possible cause in the decline of some species.

The Kirua swamps have basically lost their fisheries and the other ecosystem services they provided when they were functional floodplains. The remaining Pangani River bed is intensively fished through a series of weirs, which form barriers to the migration of large individuals.

The Mkomazi River, though fed with high quality runoff, has become largely intermittent and its water quality is low, except in proximity to the various fresh mountain streams that supply it. The fisheries in Kalimawe Reservoir, Lake Karamba and Lake Manga are important for local livelihoods but are sensitive to the declining water supply as are their biodiversity values.

The fisheries of the Pangani estuary are not well described but seem to be in decline. The coastline is eroding and, in the absence of important (peak) flows; the estuary may come to resemble a marine bay with a low contribution to coastal fisheries.

A small number of species with different life history characteristics were chosen as models for what could happen under future flow scenarios: the fishes *Oreochromis esculentus*, *Clarias gariepinus*, *Barbus* sp. and *Hilsa kelee* (as a possible model for estuarine clupeids or engraulids), the crab *Scylla serrata* and the prawn *Fenneropenaeus indicus*. The response curves of flow-species relationships drawn for each of these species under both pulsed flow and non-pulsed flow scenarios are expected to be valid for a guild of associated species. Important break points such as flow interruption, flows that reach river bank vegetation, flows that create

additional river channels and flows that result in significant floodplain or mangrove inundation are identified. All main fish and invertebrate guilds would benefit from increased flows, especially if these are pulsed to be in accordance with natural flood peaks and if they achieve significant inundation of floodplains or mangrove systems.

3.4 Hydroelectric power

The study team developed a simple but effective model to simulate power generation under various water-allocation scenarios in the Pangani Basin. The model uses scenario flow sequences generated by the hydrological models as input, and produces estimates of long-term energy production as output. The model is a valuable addition to the suite of decision support tools that have been made available to the water managers of the Basin.

The report provides a description of the methodology that was used to develop the hydropower model, and presents the results of the scenario simulations in an appendix.

3.5 Hydraulic study

Within the Pangani River Basin, trade-offs between benefits provided by the aquatic ecosystems and the benefits provided through off-stream water use such as irrigation and hydropower need to be decided by the stakeholders. The trade-offs are to be analysed by examining the potential consequences of a range of scenarios regarding the future management of the catchment and its water resources. As part of these trade-offs the impacts on the fisheries and plants associated with the various dams, lakes and flood plains in the basin will be considered. For these resources, the primary determinant of abundance is the water level (or depth) and inundated area in Lake Jipe, Nyumba ya Mungu Reservoir and Kirua swamps associated with different inflow regimes. For the swamps, the primary determinant of fish and plant abundance is also affected by the timing of inundation. This study is aimed at providing predictive tools that can be used to determine the extent of inundation at Lake Jipe, Nyumba ya Mungu Reservoir and Kirua swamps for given inflow and outflow scenarios.

During the study Area/elevation and storage/elevation curves for Lake Jipe and Kirua swamps were developed. These relationships were derived from calibrated NASA Shuttle Radar Topographic Mission (SRTM) Digital Elevation Models (DEM). The STRM DEM is available at 90 m resolution. The DEM was projected to cartesian UTM coordinate system before being used to map the ground surface at the study area. The topographic sheets (73/2, 73/4, 74/1 and 74/3) at 1:50,000 scale, sourced from Surveys and Mapping Division of the Ministry of Land were used to calibrate and validate the DEM. The data was processed using Geographical Information System (GIS) software Arc-view 3.2® with tools for filling pits, stream flow generation and delineation of water sheds.

It was established that the planimetric surface area of Lake Jipe varies from 21.7 km² at elevation of 699.6 m.a.s.l. to 31.2 km² at elevation of 702.0 m.a.s.l.. In the same range of elevations storage of the lake varies between 3.0 to 63.0 Mm³.

Analysis of the cross-sectional data and developed storage/elevation/surface area relationship of Kirua swamps indicated that the swamps geometry is comprised of three main parts, namely:

- a defined river channel;
- extensive floodplains, and;
- a free board.

The channel terminates at an elevation of 620.0 m.a.s.l. This point is located 10.0 m above the general altitude of the Kirua swamps outlet. Above this point, a unit increase in elevation increases the inundated area by more than 22 times, and the storage increases by more than 2 times.

Characterization of groundwater/surface water interaction was done using qualitative and quantitative tools. The approach entailed activities such as correlations between water levels in Lake Jipe and daily rainfall amounts for gauging stations located within the sub-catchments, Lumi River water levels, and the flow discharges at the Outlet. Besides, a water-balance analysis on annual time scale and over a longer time scale was done to complement the regression analysis. The hydro-meteorological data were sourced from the Ministry of Water and Water Resources Engineering Department database, University of Dar es Salaam and Water Development Division in Kenya.

The hydraulic study of Lake Jipe found that there is a strong positive correlation (0.971) between water levels of Lake Jipe and water levels of Lumi River at Lumi gauging station. The results of the correlation analysis showed that rainfall is weakly correlated to base flow into Lake Jipe suggesting that catchment rainfall alone does not account for groundwater flow into the lake. The analysis suggests that the main source of inflow to Lake Jipe is the Lumi sub-catchment.

This study has successfully used an hydraulic modelling approach to map inundation in Kirua swamps. At the middle section of the swamp, the river bank gets overtopped by a 2 year-flood. At the inlet to the swamp overtopping of the river bank can be caused by a 5-year flood. A floodplain inundation model relating inflows to surface area/storage for entire Kirua Swamps was developed using a fully fledged hydraulic model. As an example case, a flood of 50.0 m³ s⁻¹ was simulated to inundate about fifty percent (50 %) of the floodplain.

An inundation model relating inflows and outflows to surface area for Nyumba ya Mungu reservoir was developed using a simple water-balance model that generates storage and converts it to elevation and area using storage-elevation and area-elevation curves. The performance of this model is dependent on the accuracy of the

water-balance model, which also reflects the accuracy of outflow measurement, and inflow modelling. Reasonable results were obtained in estimation of areas based on the balance inflows and outflows.

The Consultant has four major recommendations to improve the hydraulic modelling results of Lake Jipe and the Kirua Swamps. For the case of Lake Jipe, the Consultant recommends a bathymetric survey or spot measurements of bed elevation of Lake Jipe to be done. Besides, water-level monitoring in Lake Chala and Jipe should be continued and extended. The Consultant also recommends further monitoring and modeling of groundwater and surface water interactions in lake Jipe to study the role of groundwater recharge to the lake.

A proper water balance for Nyumba ya Mungu reservoir is important for mapping the inundated area associated with different inflow and outflow scenarios. A comprehensive study involving monitoring of inflows and outflows is recommended to establish the proper model. In this case the outflows, evaporation, bypass flows and inflows need to be monitored to give a proper account of water in the reservoir. The current records have errors that complicate the development of a proper inundation model, which depends heavily on accuracy of water balance.

3.6 Vegetation

The objectives of this vegetation study were to:

- describe the relationships between the timing and magnitude of freshwater flows in the Pangani system and the biology and life-history characteristics of its key plant species;
- use these relationships to infer what the historic abundance levels and distribution patterns were for these species in the Pangani catchment (where such information is lacking);
- predict how abundance and distribution patterns may change in the future under altered flow patterns.

The study used existing vegetation data of the Pangani River Basin (IUCN 2006, Kamugisha *et al.*, 2007) to first describe the longitudinal distribution of the riverine species within the vegetation communities, categorizing them into terrestrial and aquatic, then describe the longitudinal and lateral distribution of the species within vegetation communities in five longitudinal zones of the basin i.e. mountain stream, upper foothill, lower foothill, lower mature river/rejuvenated bedrock cascade and the estuary. Later, the drivers of change in this system were identified as well as the ecologically and socio-economically important plant species.

Conceptual Models were then developed that showed how different species in the different zones of the Pangani River basin are predicted to respond to different flow regimes in different flow seasons i.e. median flow during the dry and short rain seasons, 7-day minimum flow during the dry season and the short rain seasons and duration of flow, median flow and small flood peaks during the long rains.

The Pangani river system has been classified into five zones, namely mountain stream, upper foothill, lower foothill, rejuvenating bedrock cascade, mature lowland river and the estuary (IUCN 2006). Each of these zones represents specific characteristics of the system and has different vegetation species and community composition and distribution.

The estuary's principle vegetation types are sedges, palms and Mangroves. Sedges and lilies are dominant in the upper reaches, while the middle and lower reaches are dominated by palms and mangroves respectively. There is a strong zonation in these communities up the length of the estuary, presumably a function of the salinity distribution in the system. Of these zones, the lower foothill zone was the most species rich in terms of total numbers and aquatic plant species, while the upper foothill was the most species-rich in terms of terrestrial plant species.

The different zones of the basin show changes from natural vegetation cover to modified vegetation especially along the riparian zones. Most of these changes seem to be human induced resulting from degradation of natural vegetation giving the exotics a more competitive ability. Exotic species therefore exclude natural vegetation due to vigorous growth at a rate higher than the indigenous vegetation. Some areas were observed to be critically modified as a result of encroachment by exotic species resulting from removal of natural regeneration and bank erosion.

The ecologically important plant species that were identified in the basin included 33 indicator species, 18 keystone species and 11 ecosystem engineers. Socio-economically important plant species include 33 species used as a source of food, 30 species used for medicinal purposes and 15 species used for construction material.

Response curves were created that depicted the relationships to flow of representative species could in general terms be grouped according to species growth forms and their lateral distribution on the river cross-section, giving three growth forms (trees, shrubs and herbs) and three laterals/cross-sectional zones (aquatic, wet bank and dry bank). Each of the three growth forms and their representative species for each zone seem to respond differently depending on their position on the river cross-section. The curves were used as input into the DSS.

Different flow regimes will influence the survival of plants differently depending on the characteristics of the plant species. Further studies should focus on determining the environmental correlates of different plant species distribution to be able to filter out the impacts of different water regimes from other environmental factors. Clear determination of the plant representative species in the four lateral sections of the river i.e. water column, wet bank and dry bank is necessary for more clear understanding of the different responses by different species.

4 PROJECT GOAL MONITORING AND EVALUATION

4.1 Goal monitoring

The goals of the Pangani FA were as follows:

- generate baseline data on the condition of rivers, wetlands and the estuary against which the impact of water-related decision-making can be monitored in future;
- enhance the understanding among PBWO and MoW staff of the relationship between flow, river health and the people who use the river;
- create an awareness of the trade-offs to be made between water development and natural-resource protection;
- develop simple tools to help guide water-resource management and water allocations in the Pangani River Basin;
- build capacity that will enable PBWO to act as a nucleus of expertise for FA-related work in other areas;
- support the National Water Policy (NAWAPO 2002) and the National Environmental Management Act (2004).

The efforts made to meet each of these goals and the activities linked to each are discussed below.

4.1.1 *Baseline data on the condition of rivers, wetlands and the estuary against which the impact of water-related decision-making can be monitored*

Considerable effort went into the development of a monthly current-day hydrology for the basin. The hydrological model that was configured and calibrated for the basin is at a spatial resolution (i.e. number of sub-catchments and sizes of these) that is as detailed as the availability of measured rainfall and streamflow records allows. The model provides 82-year synthetic runoff sequences at key points in the basin, and should provide a good basis for water-resource planning for the medium-term future. The timing for a future update of the hydrology will be determined by the length of new flow and rainfall measurement records (5-10 years of additional records may allow improvements to the calibrations), significant land use changes, and/or drought or wet conditions that are more extreme than those in the existing history. The EFA methodology requires at least approximations of daily flow regimes at the EF sites. This was accomplished by disaggregation of the monthly hydrology by using the distributions of measured daily records. This method has shortcomings, as the measured records include the effects of current water abstraction and dam operating rules, and is an area where there is room for improvement.

The health assessment survey for the Pangani estuary represents the first detailed study of the biota of any estuary in Tanzania, and one of the first in the East Africa region. As such it provides invaluable data on the biota of estuaries in this country and region. It also serves as an invaluable baseline against which the health and importance of other estuaries in the country and the broader region can be assessed, and against which future changes in this particular estuary can be benchmarked. Data from this study also provide important insights into the links between freshwater flow, water quality and the biota of estuaries in the region. The importance of estuarine resources to local communities and the national economy was also highlighted through this study.

Data on the baseline condition of rivers were sparse compared to what was produced for the estuary because of the much greater areas covered. For instance, no information was available on the lakes or Kirua Swamps. Descriptions of river health and the response curves drawn up of flow-ecosystem relationships should be seen as preliminary and tentative. Nevertheless, the river health assessment produced some valid insights as to which parts of the basin are most impacted and the likely causes of this. This provides a useful baseline set of data for assessing future condition and monitoring management actions.

4.1.2 *Enhanced understanding among PBWO and MoW staff of the relationship between flow, river health and the people who use the river*

Learning by doing is an important and widely recognised way of building capacity. In this project, all team members – national and international – learnt by working together in close association. Tasks 5, 11 and 12 were directly designed to enhance understanding of the flow-ecosystem-people relationships and it is to their credit that PBWO-IUCN inserted the ‘slow-down’ phases to ensure that the complete team kept on track together.

Staff from the PBWO and MoW participated in every phase of this study from the initial planning stages, through the field data collection, model development, to the final reporting, providing them with an opportunity to fully appreciate and understand the complex links between flow, river health and social and economic well-being. Managers and scientists rarely have the opportunity to be exposed to these issues first hand or in such detail and hence seldom have the depth of understanding that will have been gained by the team in this study. Few of the staff that participated directly in the river and estuary components of the study had had any previous experience in such surveys or in the assessment of estuary and river health or importance. Their understanding of ecosystem functioning, health and importance has thus been greatly enhanced through participation in this study.

In terms of the social component of the project, Pangani staff were involved in the development of a household questionnaire prior to this project and also acted as

enumerators in the survey. We used the same questionnaire in this project, with local specialists guiding the survey. The act of doing the interviews is the best way of understanding the way in which people use and perceive the river.

4.1.3 *Awareness of the trade-offs to be made between water development and natural-resource protection*

Scenarios analysed in this study explicitly examined trade-offs between water allocation to different economic sectors (agriculture and hydropower) and the environment, and the socio-economic implications of these tradeoffs. This made explicit the fact that allocating additional water to one sector has implications for other sectors, and has important socio-economic consequences at local, regional and national levels. By prioritising hydropower production for example, it was evident that significant economic benefits accrued at a national level while at the same time the health of the river and estuary improved and hence was able to contribute more to local livelihoods and well-being, but came at the expense of economic benefits within the basin due to reduced agricultural production. Prioritising agriculture, on the other hand, maximised socio-economic benefits within the basin but these came at the expense of national economic benefits (associated with reduced hydropower), river health (due to reduced quantity and quality water in the river), and local livelihoods and social well being (due to reduced ecosystem health, water quality and quantity in the river).

It would have been useful to have more time to discuss the trade-offs that were illustrated by the scenarios, and articulate the probable impacts that people would experience.

4.1.4 *Simple tools to help guide water-resource management and water allocations in the Pangani River Basin*

We developed a tool which is simple in its assumptions and theoretical construct but which is not particularly simple in its construction and operation. This is inevitable because we are trying to evaluate the probable impacts of different water-allocation strategies within a large, important and complex river basin.

Preparation of the hydrological data required for input into any new scenario is a complex part of the process and requires a high level of expertise. Preparation of the response curves of flow-ecosystem and ecosystem-people relationships is also complex and requires specialist skills. At this stage of knowledge the curves were built using a mixture of a generic understanding of these relationships, local data and local wisdom. The Decisions Support System (DSS) that combined all these inputs is complex and needs to be set up by experienced flow-assessment practitioners. Once populated and running, the DSS produces straightforward outputs and communicate them in a way that is relatively easy to interpret and use in broad-level policy decisions.

4.1.5 Capacity building

The basin hydrology was developed as a collaborative effort between the international hydrologist and the PBWO Basin Hydrologist. The process started with a hydrological data collection exercise by the PBWO hydrologist (at the time this was Dr George Lugomela), followed by a four-week long visit by the international hydrologist during which the bulk of the model configuration and calibration work was completed. The initial systems model configuration was done during a subsequent two-week long visit by the international hydrologist. Shortly after this exercise, Dr Lugomela was transferred to the MoW, and Mr Philipo Patrick was appointed as the PBWO Basin Hydrologist. Dr Lugomela spent some time transferring his knowledge of the basin hydrology to Mr Patrick, followed by a training workshop in Cape Town in May 2008, during which the international hydrologist and Mr Patrick configured and simulated a number of scenarios with the systems model. This training was continued in 2009, with the simulation of the final set of scenarios. This time the exercise was carried out in parallel, with Mr Patrick preparing the scenarios in Moshi, Tanzania, and the international hydrologist repeating the exercise in Cape Town. The intensive interaction between the international hydrologist and the two basin hydrologists ensured that the basin hydrologists had a thorough grounding in the basin hydrology and models. In retrospect, the presence of the international hydrologist at the PBWO for an extended period of time presented an opportunity to involve one or two other hydrologists from the MoW and/or other PBWO staff, but this was not considered at the time and therefore was not fully exploited.

The ecological and social specialists within the Tanzanian team similarly participated in a two-way learning exercise with their international colleagues. The national team members participated in all parts of the project - data collection, literature reviews, report writing – and ultimately led some of the analytical work. There is never enough time in projects such as this to follow the necessary long-term capacity building needed when implementing new concepts, but a careful programme of training and awareness raising did allow all phases of the work to be done in a national-international collaborative environment. With more time, it would have been useful to have the national team write up all the reports, but as it was, the contractual deadlines for delivering reports meant that sometimes the international team had to complete reports in South Africa for later review by the Tanzanian team rather than writing them together in Tanzania.

The project as a whole spanned a long period of time (6 years). There is a continuing problem with long-term projects that team members may disappear to other tasks, or be replaced meeting by meeting with new members in order to maximise exposure to the activities. In the Pangani project, we were very fortunate that there was a high level of continuity in respect of the staff members from the PBWO and MoW who participated. Those that were able to participate through the entire process seemed to benefit the most as they were able to build up a holistic

understanding of the entire flow assessment process. Those that joined the process along the way may have found this more difficult to achieve. The capacity certainly now exists within the PBWO and MoW to evaluate future scenarios for the Pangani Basin and, with limited external assistance, to undertake a similar assessment for one of the other large river basins in Tanzania.

4.1.6 *Support of the National Water Policy (NAWAPO 2002) and the National Environmental Management Act (2004).*

The tools and understanding developed during the project speak directly to the requirements of the water policy and NEMA. One scenario analysed in this study prioritised the environment above other water-use sectors (agriculture and hydropower) by explicitly allocating water to maintain the river ecosystem at a high level of health, as required in terms of NAWAPO. Optimising the distribution of existing flows to improve the existing river condition was also evaluated in further scenarios. Through these scenarios, water volumes and water-quality requirements to support healthy river, wetland and the estuarine ecosystems were clearly articulated, and the costs and benefits of allocating water to the environment were also made clear.

One area that needs further attention is that of national level versus basin level trade-offs – that is, between contribution to the national economy (and its need to alleviate poverty) and the welfare of people in the basin. This is a policy issue that we did not, and should not, address, as it is a political issue.

4.2 Evaluation

To be provided by IUCN, as per arrangement.

4.3 Lessons learnt

Because of the delays caused by attempting to obtain acceptable climate-change and other data, the project extended over several years with some large gaps between activities. Such a project loses momentum, risks losing both international and national team members, wastes time because old ground has to be re-covered when activities start again, extends even further than planned because of the difficulty of re-establishing timetables with project members now working elsewhere, and risks losing the interest of stakeholders such as the PBWO and its Board and Ministry. A sequence of shorter projects with well-defined end points would have been preferable.

The specialist studies (Task 6) were designed to fill major gaps in knowledge identified earlier in the project. The national team members did not do any of the studies, as these were all outsourced. Their results were, to various extents, more or less helpful in terms of the larger project goals. This may have been largely because they were done on very small budgets by teams who did not well understand the

flows-assessment process or what data it required from them. In future similar projects it would be advantageous to choose national team members who would also take part in some way in any specialist studies, even if only as advisors.

One of the specialist studies was on the development of a national macro-economic tool for assessing the economic implications of the scenarios. This is usually done outside the flow assessment and linked in at a later stage. Such a plan was unsuccessful in producing what was needed and, again, including this as part of the flow assessment would have allowed the team members and the macro-economic specialist to better liaise and produce the required product.

A stakeholder workshop was held early in the project to assess stakeholder concerns (Scenario Selection Report; Table 1.3). Thereafter all discussions regarding the scenarios to be considered in the project were with the PBWO and its Board. Further consultation with a wider array of stakeholders might have revealed further scenarios of interest to the wider basin population.

The process following scenario production remains undeveloped. The PBWO has the opportunity to become a leader in how this work could proceed in terms of awareness raising; stakeholder consultation; a transparent political decision-making process; design and implementation of a basin water-resource management plan; and monitoring and adaptive management.

5 CONCLUSIONS

Integrated Water Resource Management (IWRM) may be defined as ‘a process that promotes the coordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems’ (Global Water Partnership 2000). It is a relatively new concept that promotes sustainable use of water, encouraging people to move away from traditional project-driven ways of operating and toward a larger-scale basin or regional approach that takes into account the overall distribution and scarcity of water resources and the needs of other potential water users (King and Brown in press). In essence IWRM is:

- a political procedure, that aims for sustainability of use;
- a process of balancing all water demands and supplies, including those for environmental maintenance;
- an iterative approach, that recognizes the need for adaptive management;
- a way of life.

The technical outputs of the Pangani FA project, such as long-term current-day hydrological data, baseline data on the condition of rivers, wetlands and the estuary, and the EF assessments for a wide range of future development pathways, are a step toward IWRM, providing invaluable decision support for water-resource planning decisions in the basin. The next step could be to integrate the findings into a cohesive IWRM basin management plan.

Full development and implementation of IWRM basin plans go far beyond simply allocating water to one or more water-use sectors. Implementation, in terms of truly moving to manage for sustainability, is much wider and more complex (Table 5.1), occurring over a considerable time-span (King and Brown 2009).

The time line of implementation as outlined in Table 5.1 may well be one to two decades, even where the political will, funds and technical skills exist.

Moving toward that goal, the project has evaluated and highlighted the trade-offs that need to be made, and indeed are implicitly already being made, in allocation of water within the Pangani Basin and more broadly within the country. A basin IWRM plan would need to address institutional issues, identify a preferred scenario i.e. a preferred development pathway, and map out the water allocation decisions to be made in order to place the basin onto this path.

A nucleus of expertise has been developed in Tanzania that can be used to help put this in place for the Pangani basin and ultimately for other catchments around the country. This project is just the beginning, however, and needs to be built on. Tanzania can seek to enhance its capacity in this field by implementing environmental flow assessments in other basins in the country as soon as possible,

with assistance as required. If this is not done, the national expertise and experience gained will begin to dissipate and in all likelihood will be lost within a short space of time.

Table 5.1 Sustainable use of rivers: key attributes of implementation (King and Brown in press)

No.	Attribute
1	Development of appropriate policy, legislation and basin agreements
2	Structured and continual engagement with stakeholders
3	Development of holistic flow-assessment methods
4	Re-organisation of institutions to meet new laws
5	Design of new kinds of infrastructure and operating rules to deliver and monitor environmental flows
6	Development of regional regulatory mechanisms for licensing or re-licensing
7	Creation of awareness among governments and other stakeholders
8	Continual investment in research and capacity building
9	Delivery of the environmental flow
10	Monitoring and adaptive management

6 References

- Global Water Partnership (GWP). 2003. Poverty reduction and IWRM. GWP Technical Committee Background Paper 8, prepared for the Water and Poverty Initiative. GWP, Stockholm, 16 January 2003.
- King J.M. and Brown C.A. 2009. Integrated basin flow assessments: concepts and method development in Africa and South-east Asia. *Freshwater Biology* 55 (1): 127-146.