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IUCN WATER AND NATURE INITIATIVE

PANGANI BASIN WATER BOARD[1]

PANGANI RIVER BASIN FLOW ASSESSMENT

Scenario Selection Report

Water-related issues and trends in the Pangani River Basin and the selection of preliminary scenarios for analysis

Final Report

J. King, C. Brown, J. Turpie, B. Clark, G. Lugomela, H. Sadiki, Eng. I.I. Nkuba, B. L. Benno, A. Hepelwa, L. T Kaaya, D Salum, L. Lukambuzi, E. Materu, Felix Peter, S. Kamugisha, K. West and H. Beuster

September 2006

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

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EXECUTIVE SUMMARY

Introduction

The Pangani River Basin Flow Assessment is an IUCN-Pangani Basin Water Office (PBWO) initiative that brings together a Flow Assessment Group selected from within Tanzania, consisting of specialists in a range of river-related, water-allocation and policy-making disciplines. These specialists will work together with advisors from South Africa to 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 the social and economic value of its resources.

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. These can be assessed by government and other stakeholders, leading to identification of a preferred pathway and a strategy to achieve it.

Task 2.1 of the Pangani River Basin Flow Assessment aimed to consider the main issues and trends in the basin and 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.

Water-related issues in Pangani River Basin

The Pangani River Basin is a water-stressed basin. Water supply is being reduced by climate change and catchment degradation, 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 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.

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 E.I). 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.

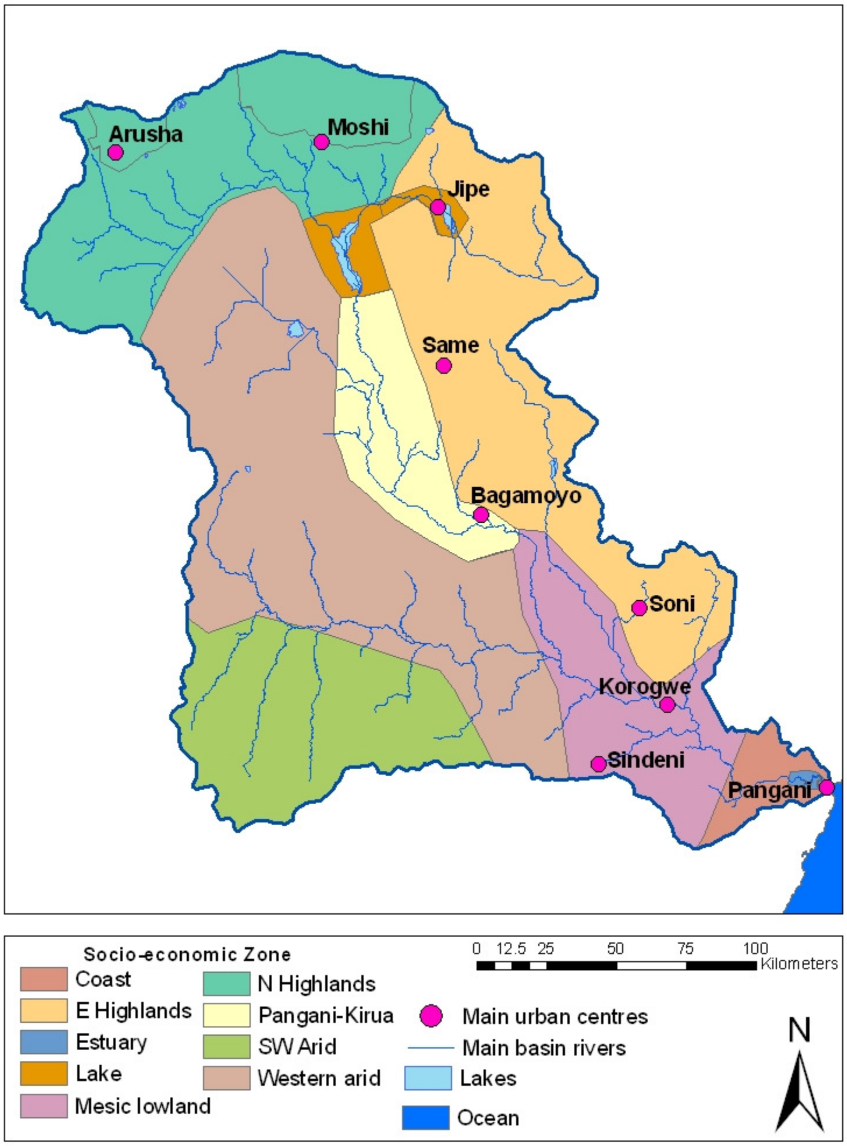

Figure E.I. Socio-economic zones of the Pangani River Basin

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.

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. 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:

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 canalizing 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		

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

Scenarios identified

A preliminary list of 12 scenarios was identified, to be taken forward for further discussion:

	Supply variables		Demand variables				
Scenario	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	1st	2nd (most likely)	3rd (High extreme)	4th (High extreme)	Residual
1b. As for 1a but aquatic ecosystems 2nd priority	Best estimate	Best estimate	1st	3rd (most likely)	4th (High extreme)	Residual	2nd (Level 1)
2. High agriculture, HEP @ most likely	Best estimate	Best estimate	1st	2nd (most likely)	3rd (High extreme)	4th (Most likely)	Residual
3a. High HEP, agriculture as close to HE as possible	Best estimate	Best estimate	1st	2nd (most likely)	4 (High extreme)	3rd (High extreme)	Residual
3b. .As for 3a but aquatic ecosystem 2nd priority	Best estimate	Best estimate	1st	3rd (most likely)	Residual	4th (High extreme)	2nd (Level 1)
4. High HEP + low agric	Best estimate	Best estimate	1st	2nd (most likely)	4th (Low extreme)	3rd (High extreme)	Residual
5a. Status quo (best estimate for all)	Best estimate	Best estimate	1st	2nd (most likely)	Most likely	Most likely	Residual
5b. Ditto with ecosystem 2nd priority (health at Level 1)	Best estimate	Best estimate	1st	3rd (most likely)	4th (shared residual)	4th (shared residual)	2nd (Level 1)
5c. As for 5a but with ecosystem 2nd priority (health Level 2)	Best estimate)	Best estimate	1st	3rd (most likely)	4th (shared residual)	4th (shared residual)	2nd (Level 2)
6. Status quo without climate change	None	Best estimate	1st	2nd (most likely)	Most likely	Most likely	Residual
7. Low extreme for all	Best estimate	Maximum Af-forestation	1st	2nd (most likely)	Low extreme	Low extreme	Residual
8. As for 1 but afforestation @ maximum	Best estimate	Maximum Af-forestation	1st	2nd (most likely)	3rd (High extreme)	4th (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 will be revisited through the course of the project and nine scenarios eventually chosen for assessment within Tasks 7 and 8.

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ACKNOWLEDGEMENTS

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1 INTRODUCTION

1.1 Introduction

Large water-resource developments or excessive water abstraction affects the flow regimes, water chemistry, sediment and temperature regimes of aquatic ecosystems, and, as a knock-on effect, their fauna and flora. These changes also affect the people dependent on the rivers. Impacts can be reduced by manipulation of flow releases from impoundments for maintenance of the downstream river, or by regulation of water abstractions, or both (Brown and King 2000).

Aquatic ecosystems can be managed to be at different levels of condition, from pristine, through various stages of change from pristine, to seriously degraded (King 2004). The functioning and characteristics of a system change with a change in condition, as does its socio-economic value. With water-resource development and concomitant changes in flow, for instance, fish may start to disappear, and problem plants invade the water.

Within the Pangani River Basin, trade-offs between the natural benefits such as fish provided by the aquatic ecosystems in the catchment and the benefits provided through off-stream water use such as irrigation and hydropower will need to be decided by the government's representatives, ideally in consultation with stakeholders in the catchment. These trade-offs may be different for sub-catchments. For each sub-catchment, the level of ecosystem condition that is decided on, with its corresponding flow allocation, will become the Environmental Flow for the aquatic ecosystems in that sub-catchment.

The trade-offs are described through a range of scenarios regarding the future management of the catchment and its water resources. These describe the consequences of different possible management actions, and by doing so offer options for the future for consideration by decision-makers. No recommendations are made by the technical team on what the allocation of water per sector should be, although the team members remain available to provide interpretation to the decision-makers.

The Pangani River Basin Flow Assessment (FA) is a World Conservation Union (IUCN)-Pangani Basin Water Office (PBWO) initiative that brings together a national team of specialists in a range of river-related, water-allocation and policy-making disciplines and an international team of flow-assessment specialists from Southern Waters Ecological Research and Consulting and Anchor Environmental Consultants, to 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 the social and economic value of its resources (see Basin Delineation Report for details). The project commenced in August 2005.

1.2 Project aims

The objectives of the Flow Assessment are 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 though consideration of a number of scenarios;
- develop simple tools to help guide flow management and water allocations in the Pangani Basin;
- build capacity that will enable PWBO 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).

1.3 Project tasks

The project is divided into ten tasks, as follows:

Task 1:	Hydrology.
Task 2:	Study area delineation and site selection
Task 2.1	Scenario Identification
Task 3:	Health assessment of the river and estuary.
Task 4:	Baseline socio-economic assessment.
Task 5:	Synthesis of understanding of the river systems and its economies and identify major gaps.
Task 6:	Specialist Studies.
Task 7:	Creation and evaluation of scenarios.
Task 8:	Practical application of scenario evaluation by National Pangani FA Team.
Task 9:	Final Reporting.
Task 10:	Awareness raising outside the National Pangani FA Team.

This report addresses Task 2.1.

1.4 Task 2.1: Scenario identification

Scenarios, in the context of this project, are descriptions of possible future water-use pathways in the basin, with their ecological, social and economic benefits and costs. None of these scenarios is certain to happen. Rather, they are our best predictions of possible development paths, which planners and decision-makers can consider in order to identify a preferred path and strategise to achieve it.

The scenarios thus outline options for the future, and do not make recommendations of which should be chosen. This choice is a value judgement to be made by the Tanzanian government, in consultation with the stakeholders of the basin.

Tasks 3-6 are a series of activities aimed at increasing our understanding of the Pangani ecosystem and its users, as a precursor to creating the predictions of change (i.e. the scenarios). Tasks 7 and 8 then address scenario development and evaluation. The early attention to scenarios, here in Task 2.1, is designed to ensure that stakeholder concerns are identified so that they can be included within the description of each scenario. The information offered by stakeholders will be used to guide the data-collection exercise and design scenarios that address their concerns.

Task 2.1 encompasses the following:

1. collation of relevant information on development plans, options, major issues and concerns through liaison with stakeholders;
2. development of criteria for scenario selection;
3. justification of scenarios selected;
4. identification of general envelope of issues to be represented by the scenarios;
5. agreement on the number of scenarios to be developed;
6. identification of scenario components/consequences;
7. development of criteria for evaluation of scenarios.

The list of possible scenarios developed in Task 2.1 will be re-visited through the life of the project by the team and stakeholders, leading to a final set of scenarios to be addressed in Tasks 7 and 8.

All sub-tasks except 5 and 7 are reported below. These remaining sub-tasks will be completed later in the project in collaboration with the PBWO and other stakeholders.

1.5 Approach for Task 2.1

The main activities related to Task 2.1 were completed at the PBWO in Moshi, Tanzania, from 6 to 10 March 2006. The week was divided into several work sessions as follows:

Day 1:	Stakeholder Workshop, where a wide range of stakeholders (Section 1.7), identified water-related issues within the basin.
Days 2 and 3:	International and national team work session, in which a short list of possible scenario configurations for the basin was drawn up.
Days 3 and 4:	Report writing.
Day 5	Planning for Tasks 3 and 4.

1.6 Participants at the Stakeholder Workshop

Thirty-eight delegates attended the Stakeholder Workshop (Table 1.1). Joining the national and international FA teams was a range of stakeholders with interests in water use in the basin. They ranged from national planners, through water managers and representatives for energy production, irrigation, communities and the aquatic ecosystems. The agenda for the Stakeholder Workshop is given in Appendix 1.

Table 1.1 Delegates at the Stakeholder Workshop on 6 March 2006

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2 WATER-RELATED ISSUES IN PANGANI RIVER BASIN

2.1 The PBWO perspective

The following is based on a presentation by Mr Hamza Sadiki, Water Officer, PBWO.

The Pangani Basin is a water-stressed basin (demand > supply)

- Demand is increasing due to population growth
- Flow is being reduced by climate change
- Demand is also increasing due to change in land use e.g. coffee to vegetables and flowers, sisal to rice paddy
- There are 1000 registered water users plus 1800 traditional abstractions
- Water is over-allocated
- Watershed degradation due to forestry, cultivation on hilly slopes and mining sand in river beds is leading to reductions in flow and sedimentation of reservoirs
- Water quality is being negatively affected by:
    - Municipal discharges and industrial effluents
    - Solid-waste dumping sites close to rivers
    - Village water-supply sources polluted from sisal decortications, especially in Tanga region.

Environmental issues include the following:

- Drying up of perennial rivers
- Natural-resource based activities: mining, agriculture, pastoralism, timber – all depend on water – the whole economy relies on water and economic output will have decreased in response to current drought
- Salt-water intrusion
- Water shortages compromise water supply to Pangani town, impacts on agriculture and fisheries
- Water-related conflicts particularly in the Arumeru and Hai districts
- Large vs. small scale farmers
- Upstream vs. downstream communities
- Resource tenure and access
- Uncoordinated development
- Agricultural investments that lack water to sustain them
- Population migration from high to lowlands that lack water resources
- Poverty
- Financial constraints prevent people from improving irrigation efficiency or using groundwater

Management of the basin's water management issues, in particular water allocation, is by the Pangani Basin Water Office, with supervision by the Basin Board. The Board has ten members from different stakeholder groups, appointed by the Minister responsible for water.

2.2 Water-related issues in Pangani Basin: the stakeholder perspective

In the March 2006 workshop, stakeholders were asked to think about the main issues and concerns regarding water in the Pangani River Basin. Issues were written down on cards and these were grouped into seven categories. In addition to issues or problems, several of the cards also identified future needs or gave suggestions (Table 2.1).

Table 2.1 Problems and suggestions relating to water in the Pangani Basin raised by stakeholders

	Problems	**Suggestions**
Water availability	• Shortage of water due to climate change • Population growth has increased water demand • Shortage of clean and safe water for drinking • Not enough water for domestic use (rural and urban) • Insufficient water for livestock • Insufficient water for crop production, especially in lowlands • Lack of water for new agricultural investments • Land use change and increase in production causes unsustainable water use • Dependence on hydropower is a problem for resource management	• Provide more water for production of electricity all year round • Provide adequate water for users downstream of Nyumba ya Mungu • Increase water for agriculture • Increase water for irrigation to reduce national food shortage • Provide more water for subsistence food production
Natural resources	• Deforestation due to increased use of forest resources results in floods, sedimentation and changes in river courses • Drying up of water sources • River pollution • Pollution may be having negative impact e.g. on fish • Encroachment into river banks by agriculture and sand mining • Drying of rivers and severe reduction in flows • Livelihood activities along catchment areas negatively affect river flows • Saline water intrusion in estuary	• Environment should be considered in water allocation • Need to protect water sources from surrounding human activities • Need more investment in afforestation in source areas
Pollution	• Untreated waste-water discharge into water sources due to inefficient treatment plants • Industries dumping waste water without meeting standards • Scarcity of potable and safe water for communities	

	Problems	Suggestions
Water management	• Conflicting water rights • Lack of co-ordination between sectors in water management resulting in conflict between users (marginalised users) • Achievement of equitable water allocation is difficult because of competing demands • Conflict between upstream and downstream users • Frequent water conflicts for irrigation due to drought	• Basin Office needs to control unofficial abstraction • Need to streamline water management to avoid duplication of responsibilities among organisations • Help PBWB make good decisions on water allocation and conflict management
Water demand management and conservation	• Inefficient irrigation methods	• We need to improve irrigation systems to increase efficiency • More investment needed in efficient irrigation systems. • Encourage growing of crops with less water demand. • Enhance water conservation measures
Data needs	• There is a lack of data on water flows, availability and use and on the aquatic ecosystems in general	• Traditional abstractions should be documented and quantified
Planning	• Development is expanding without considering water availability • Lack of political commitment to rainwater harvesting • Promotion of irrigation agriculture without looking for new water sources	• Promote groundwater irrigation • Construct a series of dams for storages and regulation • Promote drip irrigation
Awareness and participation	• Lack of awareness and education about water • Lack of opportunity for marginalised groups to participate in water management	• Creation of awareness among water users • Awareness raising to politicians on Integrated Water Resources Management issues • Management of the resource at the lowest level (community level responsibility) • Increase of water flows to maintain a healthy river ecosystem and maintain biodiversity • Create awareness on environmental rehabilitation among the community
Policy and legislation	• Sectoral linkages are not co-ordinated	• Establish applicable and binding by-laws at every level in the basin • Effective enforcement of water legislation

3 EXPECTED TRENDS FOR DIFFERENT SECTORS IN THE PANGANI RIVER BASIN

3.1 Expected sectoral trends and possible targets for different areas of the basin

Stakeholders were arranged into five groups and each group was asked to describe the expected trends and targets for a particular water-user sector. They were asked to be geographically explicit as far as possible, using the Socio-economic Zones (Figure 3.1). The outputs of the different groups are summarised by sector in Table 3.1 and by area in Table 3.2. Detailed stakeholder outputs are provided in Appendix 2.

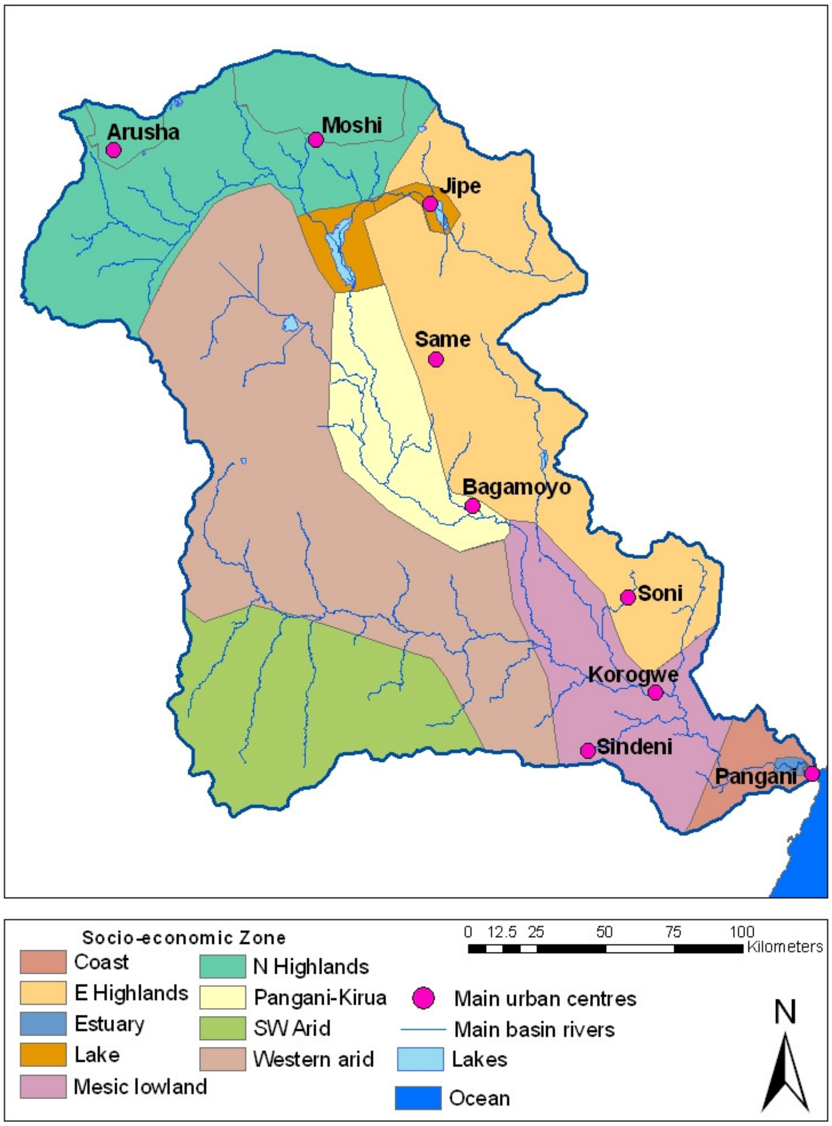

Figure 3.1 Socio-economic Zones.

Table 3.1 Expected and desired trends of different sectors in the Pangani River Basin, as presented by the stakeholder groups.

Sector	Area	Expected	Targets
Power	Whole basin	Decreased power generation due to less flow into dams	Refurbish and expand HEP capacity
	Northern Highlands		Refurbish Kikuletwa Power Station (1MW)
	Lakes		Restore NyM to installed capacity of 8MW
	Eastern Highlands	Development of new HEP plants	Expand HEP capacity
Agriculture	Northern Highlands	Yield decline due to water shortage (coffee and banana)	Improved irrigation efficiency
	Pangani-Kirua	Yield decline due to water shortage (paddy, sugar, maize, beans, vegetables)	Crop varieties with lower water demand; improved irrigation efficiency
	Mesic Lowlands	Yield decline due to water shortage (paddy, maize)	Improved irrigation efficiency, water storage
	Coast	Yield decline due to water shortage (banana)	Improved irrigation efficiency
	Eastern Highlands	Yield decline due to water shortage (coffee, banana vegetables)	Improved irrigation efficiency, water storage
Water management	Whole catchment	Reduction in runoff due to climate change; increase demand due to population increase; increased water user conflicts; management compromised by too many institutions	need improved water use efficiency
	Northern & Eastern Highlands	Drying up and degradation of water resources	
	Lakes	Problems of alien invasion; pollution and sedimentation	Eradicate aliens, have pollution control measures and improve land use practices
	Estuary	Salt water intrusion	
Environment and natural resources	Northern	Decline in agriculture due to water shortage	Reduce production
		Decreased livestock production due to water shortage	Reduce stocking rate to carrying capacity
		Increased demand and pollution due to tanzanite mining	Better practices
		Increased pollution from industry	Enforce treatment regulations
		More floods and decreased dry season flows due to deforestation (e.g. for timber, charcoal)	Reduce harvesting, increase afforestation
	Lakes	Intensive livestock keeping – decline in productivity	Reduce stocking rate
		Decline fish production due to over-fishing	Enforce regulations

Sector	Area	Expected	Targets
	Mesic Lowlands	Sisal production reduces water quality	Wastewater treatment
	Coast	Decline in fisheries	Enforce fishing regulations
		Pollution from domestic sewage	
	Estuary	Decline in fisheries and mangroves due to over harvesting	Enforce regulations
		Salt water intrusion	Need to restore flows
	Whole basin	Loss of biodiversity due to change in water quality and flow	
Rural and urban water supply	Whole basin	Expect decrease in water availability for domestic use due to population increase and decreased flows	Recycling; water meters, afforestation, customary laws
	Whole basin	Expect 30% increase in use of rainwater	Built into house construction by law
	Lowland areas	15% increase in groundwater use	15% increase in number of boreholes
	Whole basin	Improved awareness and participation	50% of water stakeholders have better knowledge

3.2 Summary of trends for different areas of the basin

Many of the trends identified were applicable to the whole basin, while some were identified as specific to a particular area (Table 3.2). In particular, it was felt that agricultural production in all areas is declining due to water shortages, with the main differences between areas simply being the types of crops that were affected (Table 3.2). It should be noted however, that the proportion of crops that are irrigated might vary from area to area. The main solutions are perceived to be improved irrigation efficiency (including water-efficient crop varieties) and improved water storage. However, it was also pointed out in the discussions that (a) the lining of 2000 irrigation canals in order to improve water efficiency was a major undertaking and possibly unrealistic, and (b) increased water storage would only be viable on a small scale, due to the cumulative effects of small dams on river flows.

In the power sector, developments in different parts of the basin may have far reaching effects in the basin, affecting water availability for considerable distances upstream and downstream of the power stations. Where there are trends specific to different areas, these are highlighted separately in the table below.

Aquatic ecosystem biodiversity has been negatively affected throughout the basin, fisheries are alleged to be in decline in the lakes and estuary, and mangroves are believed to be over-harvested in the estuary. While better enforcement was suggested as a possible way forward, this is one of several possible approaches to improved natural resource management. Deforestation in the highland areas is reducing the availability of water in the basin as a whole, although the actual impact on flows and the rate of deforestation are not well understood.

Table 3.2 Trends of different water-user sectors in different socio-economic zones of the Pangani River Basin, based on stakeholder inputs.

Area	Main sectoral trends	Possible ways forward
Whole catchment	**Power**: General shortage of water for power production	The main focus is on increasing capacity and generation in the basin
	Agriculture: General trend in loss of production due to water shortages	More efficient systems and more dams.
	Domestic: Expect shortages throughout basin due to increased population and decreased flows. Expect a 30% increase in the use of rainwater and 15% increase in the use of groundwater	Recycling, better monitoring of users and afforestation; increased use of rainwater and groundwater
	Natural resources: Loss of biodiversity due to change in water quality and flow	Restore flows
	Water resources: Water availability reduced by climate change and demand increased due to population increase, leading to conflict; management compromised by too many institutions	Equitable allocation, rationalized and strengthened institutions; demand management and improved efficiency
Northern Highlands	**Power**: Plans to refurbish the defunct Kikuletwa Power Station (1MW)	
	Agriculture: Coffee and banana production will decline due to water shortage	Increased irrigation efficiency
	Natural resources: Flow changes due to deforestation; Water pollution problems due to mining and industry, soil erosion due to livestock	More regulation, afforestation
	Water resources: Drying up and degradation of water resources	Conservation measures
Lakes	**Power**: Power generation not at full capacity due to water shortages	Restored to full capacity (8MW)
	Natural resources: Fisheries in decline due to over harvesting	Enforce regulations
	Water resources: Problems of alien species invasion, pollution and sedimentation	Eradicate aliens, pollution control measures and improved land use practices
Pangani - Kirua	**Power**: Proposed Mandera power station (20MW)	
	Agriculture: Agric production is declining due to water shortage (Paddy, sugar, maize, beans, vegetables)	Crop varieties with lower water demand, improved irrigation efficiency
	Natural resources: Drying up of the Kirua swamp	
Eastern Highlands	**Power**: There are grants to install mini power stations on the Mkomazi, Soni and Luengera Rivers – to provide local needs (ease grid)	
	Agriculture: Yield decline due to water shortage (coffee, banana, vegetables)	Increased irrigation efficiency and dam construction
	Water resources: Similar to Northern Highlands: Drying up and degradation of water resources	Conservation measures, afforestation
Mesic lowlands	**Agric**: Yield decline due to water shortage (paddy, maize)	Improved irrigation efficiency, rainwater harvesting (dams)
	Natural resources: Water quality affected by sisal production; deforestation and soil erosion	Better wastewater treatment plants
	Water resources: Increased water scarcity	
Coast	**Agriculture**: Banana production will decline due to water shortage	Improved irrigation efficiency
	Natural resources: Marine fisheries declining; pollution from domestic sewage	
	Water resources: Problem of water quality for domestic and irrigation use	
Estuary	**Natural resources**: Decline in fisheries and mangroves due to over harvesting	Better enforcement of regulations, restored flows
	Water resources: increasing salt water intrusion; sedimentation may have changed due to upstream dams, lack of flushing; also reduced water level for transportation	Restored flows

4 DEVELOPMENT OF SCENARIOS FOR CONSIDERATION IN THE FLOW ASSESSMENT

4.1 Selection of variables to be included in the scenario analysis

From the issues identified by the stakeholders and expected trends in key water related sectors in the Pangani Basin, the Pangani Flow Assessment team identified a number of key factors, split into supply variables (those that affect water supply to or within the basin) and demand variables (those that affect water abstraction from the catchment), that could be varied for the scenario analysis:

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,
  - industry,
  - mining,
  - aquatic ecosystems;
- Water resource development:
  - groundwater use,
  - storage options;
- Efficiency of use
  - Improved efficiency due to water demand management (higher water prices),
  - Improved efficiency due to investment in better irrigation systems or crop varieties; and
- Population growth.

It would not be feasible to generate scenarios in which all of the above were varied independently, as this would yield an unmanageable number of scenarios. It was thus necessary to refine the list to a smaller set of variables that would be changed in a scenario, while others would be held constant. It was also recognized that some of the variables were subsidiary drivers of others and hence would not directly affect water availability in the catchment, and that others would co-vary and could hence be eliminated as they would be represented on this basis. Taking this into account, input variables were dealt with as follows.

1. All variables that could not feasibly be modeled using the WEAP water-resource model were excluded[2]. The resulting scenarios, and their evaluation, will thus be constrained by the variables included in the model and the resolution at which they are modeled.

[2] The reasons for the selection of the WEAP Model are provided in PBWO/IUCN (2006).

The model currently has the capacity to model:

- water allocation per sector
- changes in flow due to climate change;
- changes in groundwater use;
- changes in amount of storage; and
- changes in the relative contribution by agricultural return flows .

At present, it does not have the capacity to model:

- changes in water quality due to pollution control
- changes in sedimentation due to erosion control
- changes in hydrology due to changes in forest cover

Nevertheless, it was agreed that deforestation is a sufficiently important issue that it would be considered as a possible parameter for scenario analysis, pending future data availability.

2. Basic human needs and domestic consumption change with population growth. We worked with the best estimate of population growth as a constant throughout all the scenarios.
3. Allocation to the industrial and mining sectors will be fixed in the model, since water use by these sectors in the Pangani Basin is relatively small. Mining is more reliant on groundwater than surface water supplies.
4. Irrigation efficiency was not identified as a variable. Thus a single level of irrigation efficiency (the most likely level) will be used in all of the scenarios. Investment in irrigation efficiency will not be varied *a priori*, but can be varied in the analysis of economic outputs

4.2 Defining the value boundaries of variables

From the above considerations, six variables were selected as inputs that could be changed in the hydrological systems model to represent different water outcomes. Each permutation of these six would produce a different flow regime in the river and thus could become a different scenario.

For each of the variables the range of conditions that could occur needed to be identified, so that the scenarios could encompass this. Preliminary estimates were thus made of the upper boundary, lower boundary, and most likely values of most of the selected variables over the period to 2025 (Table 4.1). Exceptions were:

- Climate change, where the level of model development does not warrant distinguishing between medium and high levels of change, and so only the Most Likely option has been used;
- Domestic and Industry, which use relatively little water and so only the Most Likely option was deemed necessary.

For domestic, industry and climate change, it is envisaged that these estimates will be refined as more information becomes available.

4.3 Spatial and temporal resolution of the scenario analysis

The scenarios will be described for different areas over set time spans. This spatial and temporal resolution will be determined by the hydrological modeling capacity and by factors such as national planning horizons, as follows.

Table 4.1 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 canalizing 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		

4.3.1 Spatial resolution

The hydrological sub-catchments and their characteristics are described in the Hydrology Report (PBWO/IUCN 2006). The Pangani River Basin was delineated into five main catchments (see Hydrology Report), which together comprise sixteen sub-catchments (Table 4.2).

Table 4.2 Sixteen hydrological sub-catchments

Main catchments	Subcatchments
Kikuletwa	Kikuletwa at Katangai (1DD55)
	Kikuletwa at old Power Station (1DD54)
	Kikuletwa at TPC (1DD1)
Ruvu	Ruvu River at Tanga Bridge (1DC2A)
	Ruvu River at Railway Bridge (1DC1)
Pangani	Nyumba ya Mungu Dam wall
	Pangani River at Buiko (1D10)
	Pangani at Korogwe (1D14)
	Pangani River at Hale (1D17)
	Pangani River at Estuary (1D17)
Mkomazi	Saseni River at Gulutu (1DB2A)
	Mkomazi River Upstream of Kalemawe
	Soni River at Soni (1DB19)
	Mkomazi River at Gomba (1DB17)
Luengera	Luengera River at Magoma (1DA3)
	Luengera River at Korogwe (1DA1)

Model outputs will be provided at the outflow points for the 16 sub-catchments (Table 4.2).

4.3.2 Temporal resolution

The WEAP model incorporates hydrological data at a monthly resolution. This means that, for the most part, scenarios will be built using monthly data. The single exception to this is the water that remains in the river/estuary, where the monthly volumes provided by WEAP will be disaggregated into daily distributions using appropriate observed data in order to facilitate interpretation by the aquatic ecologists.

4.3.3 The base year for scenario analysis

The base year (i.e., the starting point for scenarios), which is called the "current accounts year" in WEAP terminology, is taken as 2005. This is because hydrological data for the project are available up to 2005.

4.3.4 Planning horizons

Discussion was held on whether the scenarios should be static or non-static. Static scenarios represent the situation that would be encountered at some selected time in the future, illustrating how that would change through dry and wet climatic phases. Non-static scenarios illustrate how the situation would gradually change from year to year. Based largely on concerns of data availability, the static-scenario option was chosen. Again, considerable discussion took place as to what the selected time in the future should be. The hydrologists preferred to work with a short time horizon of 5-10 years, which they could most accurately simulate hydrological data for, whilst the water managers and ecologists preferred a longer time. The decision was to use the year 2025, which accords with Tanzania's national planning horizon, that is, a 20-year horizon.

4.4 Identification of possible scenarios for analysis

A preliminary list of 12 scenarios (Table 4.3) was identified to be taken forward for further discussion. The scenarios were identified by changing different sectoral use demands through the three different levels identified in Table 4.1.

For simplicity, and to ensure that the overall number of scenarios to be analysed was kept within manageable limits, variables affecting water supply (i.e. climate change and afforestation/deforestation) were kept constant for most of the scenarios. These were generally set at the best available estimate for the variable in question. The effect of climate change was set at the best available estimate for all scenarios except one (Scenario 6) where it was set to zero (no climate change). Similarly, deforestation/afforestation was set at the best estimate for all scenarios except one (Scenario 7), which was included simply to examine the effects of maximum achievable afforestation on water supply in the catchment.

Water allocation to the water demand sectors was then set at one of the preset levels for each (low extreme, best estimate, high extreme) and then allocated a priority from 1st to 4th with the final remaining variable being allocated the residual water supply.

Table 4.3 Provisional list of scenarios to be taken forward for further consideration by the FA team and other stakeholders. Some may not be significantly different hydrologically because of constraints in model resolution.

	Supply variables		**Demand variables**				
Scenario	**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	1st	2nd (most likely)	3rd (High extreme)	4th (High extreme)	Residual
1b. As for 1a but aquatic ecosystems 2nd priority	Best estimate	Best estimate	1st	3rd (most likely)	4th (High extreme)	Residual	2nd (Level 1)
2. High agriculture, HEP @ most likely	Best estimate	Best estimate	1st	2nd (most likely)	3rd (High extreme)	4th (Most likely)	Residual
3a. High HEP, agriculture as close to HE as possible	Best estimate	Best estimate	1st	2nd (most likely)	4 (High extreme)	3rd (High extreme)	Residual
3b. .As for 3a but aquatic ecosystem 2nd priority	Best estimate	Best estimate	1st	3rd (most likely)	Residual	4th (High extreme)	2nd (Level 1)
4. High HEP + low agric	Best estimate	Best estimate	1st	2nd (most likely)	4th (Low extreme)	3rd (High extreme)	Residual
5a. Status quo (best estimate for all)	Best estimate	Best estimate	1st	2nd (most likely)	Most likely	Most likely	Residual
5b. Ditto with ecosystem 2nd priority (health at Level 1)	Best estimate	Best estimate	1st	3rd (most likely)	4th (shared residual)	4th (shared residual)	2nd (Level 1)
5c. As for 5a but with ecosystem 2nd priority (health Level 2)	Best estimate)	Best estimate	1st	3rd (most likely)	4th (shared residual)	4th (shared residual)	2nd (Level 2)
6. Status quo without climate change	None	Best estimate	1st	2nd (most likely)	Most likely	Most likely	Residual
7. Low extreme for all	Best estimate	Maximum Af-forestation	1st	2nd (most likely)	Low extreme	Low extreme	Residual
8. As for 1 but afforestation @ maximum	Best estimate	Maximum Af-forestation	1st	2nd (most likely)	3rd (High extreme)	4th (High extreme)	Residual

The Tanzania water policy stipulates that the provision of water required for basic human needs should always be accorded highest priority when water allocation is considered. This sector was thus allocated 1st priority in all scenarios. In allocating water to the remaining sectors it was recognised that it would not be possible to provide the full amount of water required for the pre-selected level of a particular demand sector in any particular scenario (e.g. it is unlikely that it will be possible to satisfy both the high extreme irrigation demand and the high extreme HEP demand as required for Scenario 1). Under these conditions, it was agreed that the lower-ranked sector would receive a supply as close to that required for the preset level as possible. Any assumptions made in allocation of water to such a sector would be clearly articulated in the scenario description. Similarly, where two water-demand sectors were ranked equally, it was decided that these would share the available supply and any assumption made in this respect would be clearly articulated.

The range of scenarios available for consideration included some cases where levels of irrigation and/or hydroelectric power (HEP) demands were assumed to be at the high extreme level, others where demand from one or both of these sectors was set at the most likely or low extreme levels, and finally where one or both of these sectors was allocated whatever residual water was left in the system after other demand sectors had been allocated their shares. In all cases, supply to the domestic and industrial sectors was allocated 2nd and 3rd priority, respectively, both because this was considered the most probable situation and because demand by this sector was small relative to the other sectors. In most cases each development scenario was run for two different ecosystems demands:

1. with aquatic ecosystems receiving the residual water;
2. with the environmental flow requirements for aquatic ecosystems receiving a second-priority allocation.

5 SELECTION OF FLOW ASSESSMENT SITES

When the scenarios are developed (Tasks 7 and 8), each will be described as conditions at a selected number of points along the system. These points are chosen with due consideration of the points at which simulated data can be created by the WEAP hydrological model. This is because the hydrological simulation of change is the starting point of any scenario, with the remainder of the scenario (river change, social change, economic change) being built onto that.

A short-list of eleven preliminary Flow Assessment reaches is identified below. Six final Flow Assessment reaches will eventually be chosen from these.

The preliminary Flow Assessment reaches are:

1. Upper Kikuletwa River (incorporating the Mountain Stream and Upper Foothill Zones).
2. Lower Ruvu River (incorporating the Lower Foothill Zone).
3. Lake Jipe.
4. The swamp area upstream of Nyumbu ya Mungu Dam.
5. Nyumbu ya Mungu Dam.
6. Kirua Swamps (incorporating the Floodplain Zones).
7. Pangani River from Kirua Swamps to the confluence with the Mkomazi River (incorporating the Lower Foothill Zone).
8. Pangani River from Korogwe to Pangani Falls (incorporating the Bedrock Cascade Rejuvenation Zone)
9. Lower Mkomazi River (incorporating the Lower Foothill Zone).
10. Lower Luengera River (incorporating the Lower Foothill Zone).
11. Lower Pangani River (incorporating Mature Lower River Zone).

6 REFERENCE

PBWO/IUCN. 2006. Hydrology and system analysis. Volume 1 of 2. The hydrology of the Pangani River Basin. Report 1: Pangani River Basin Flow Assessment, Moshi, 62 pp.

APPENDIX 1 Workshop Agenda

PANGANI RIVER BASIN FLOW ASSESSMENT

Scenario Planning Workshop
Pangani Basin Water Office, Moshi, Tanzania
Monday 6 March 2006

AGENDA

0900 - 0910	Welcome		Hamza Sadiki
0910 – 0925	A Basin perspective on water management		Hamza Sadiki
0925 – 0945	Introduction to the IUCN-PBWO Pangani Basin Flow Assessment Initiative		Sylvand Kamugisha
	The concept of scenarios		Jackie King
0945 – 1000	Questions and discussion	Chair:	Sylvand Kamugisha
1000 – 1030	Tea		
1030 – 1130	Identification of water issues		Jackie King Cate Brown Kelly West
1130 – 1230	Sector Groups identify future trends and targets related to water use		
1230 – 1330	Lunch		
1330 – 1500	Presentations from Sector Groups	Chair:	Hamza Sadiki
1500 – 1530	Tea		
1530 – 1700	Developing a Pangani Basin picture of issues to be included in the scenarios		Barry Clark Jane Turpie Hans Beuster

APPENDIX 2. Trends identified by stakeholders

Sector	Social zone	Water related issue	Expected trend in next 20 years	Future target
Energy	Northern highlands	Kikuletwa power station	Refurbishment of the plant (1MW)	Refurbishment of the plant and development of additional power plant
		Nyumba ya Mungu power station	Less and less power generation due to decreasing inflow into the dam	Generate power at the installed capacity (8MW)
	Entire catchment except the estuary	Hale power station Pangani Falls power station	Less power generated due to decreasing release from Nyumba ya Mungu and inflows from Mkomazi and Luengera rivers	Generate power at installed capacities (21 MW and 66 MW)
		Proposed Mandera power station (20 MW)	Construction of the new plant	Enough flow to operate at full capacity
	Eastern Highlands	Proposed mini – hydro power stations in Mkomazi, Soni and Luengera rivers	Development of mini – hydro power plants in the Mkomazi, Soni and Luengera rivers	Water available for full operation of the mini plants to supplement the power from the main plants in the Pangani basin
Rural and Urban water supply	All seven zones	Supply of clean, adequate and safe water for domestic use	Decline of water quantity due to increase of population	Minimize water use for domestic purposes, Conserve water sources, Establish recycling of water
		Rainwater harvesting for domestic use	Increase of 30 % in the use of rainwater for domestic use	Establish laws for rainwater harvesting for house constructors
		Develop and improve ground water use	15 % increase of ground water use in lowland areas	Increase of number of bore holes by 15 %

Sector	Social zone	Water related issue	Expected trend in next 20 years	Future target
		Protection of existing water surfaces	Decline of quantity of water from surface sources	Sustain existing surface sources by customary laws, Encourage tree planting to conserve catchment areas
		Awareness and participation	Better knowledge on proper us of domestic water	Provide training on water management to 50 % stake holders
Agriculture	Northern Highlands	Coffee and banana production	Crop production will decline due to water shortages	Increase production by introducing efficient irrigation systems (drip irrigation)
	Eastern highlands	Coffee, banana, beans and vegetables	As above	As above
	Lake zone	No agricultural activities		
	Pangani - Kirua	Paddy, sugarcane, maize, beans and vegetables	Yield decline due to water shortage	Stabilize production by introducing rice varieties (species) which have less water demands , Improve irrigation systems efficiency
	Mesic Lowlands	Paddy and maize	As above	Increase water supply for irrigation, Rainwater harvesting. Modernize existing irrigation systems
	Coastal zones	Banana	Yield decline due to water shortage	Modernize traditional irrigation systems (introduction of drip irrigation)
Environmental and Natural	Northern Highlands	Agriculture	Increase in water pollution due to excess fertilizers and pesticides	Use of Organic fertilizers and biological pest control

Sector	Social zone	Water related issue	Expected trend in next 20 years	Future target
Resources		Mining (Tanzanite)	Water pollution, increase water scarcity and decrease of aquatic biodiversity	Adoption of better mining practices, enforcement of mining regulations and water standards
		Biodiversity Protection	Loss of species due to decline in both water flows and quality	Maintain biodiversity at present level, Relocate rare species to other places
		Industries	Increase in water pollution	Enforcement in water treatment plants and regulations
		Livestock keeping	Increase in soil erosion and siltation	Reduce livestock levels to carrying capacity
		Deforestation	Increase in water shortage and floods (seasonal perspective), Increase in soil erosion, Decrease in wood and charcoal fuel	Reduce harvesting and promote afforestation
	Lake Zone	Livestock Keeping	Increase in soil erosion and siltation	Reduce livestock levels to carrying capacity
		Fishing	Decline in fish production	Enforce fishing regulation
		Hydro electric power	Decline in fish production especially migratory fish spp., Trapping of sediments and nutrients in the dam and production is reduced downstream, Decrease in mangrove forests downstream	Construction of fish bypass, Occasional dam water release
		Decline in water level	Decrease in habitats for fish and other aquatic organisms	Protection of critical microhabitats for aquatic organisms
	Mesic Lowlands	Sisal plantations	Reduction of water quality	Establish waste water treatment for effluents

Sector	Social zone	Water related issue	Expected trend in next 20 years	Future target
		Hydro electric power production	Decline in fish production especially migratory fish spp., Trapping of sediments and nutrients in the dam and production is reduced downstream, Decrease in mangrove forests downstream	Construction of fish bypass, Occasional dam water release
		Deforestation	Increase in water shortage and floods (seasonal perspective), Increase in soil erosion, Decrease in wood and charcoal fuel	Reduce harvesting and promote afforestation
	Coastal Zone	Intensive fishing	Decline in fish production	Enforcement of fishing regulations
		Domestic sewage	Reduction in water quality, Diseases outbreaks	Establish domestic wastewater treatment plants and sanitation systems, Enforcement of wastewater standards
	Estuary	Mangrove Harvesting	Decline in mangrove forest and fish production	Enforce regulations on mangrove forest management
		Salt water intrusion	Extension of the estuary upstream and change in biodiversity	Maintain current flow level in the river system